DE LA RECHERCHE À L'INDUSTRIE

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EMBEDDED HIGH G SHOCK SENSOR BEHAVIOR ANALYSIS FOR SEVERE PERFORATION TESTS

Sérey CHHIM – Aurélien HOTTELET – Don-Pierre ZAPPA – Olivier PIROTAIS – Bernard DEMESURE

CEA DAM, GRAMAT
F-46500 Gramat, France
serey.chhim@cea.fr

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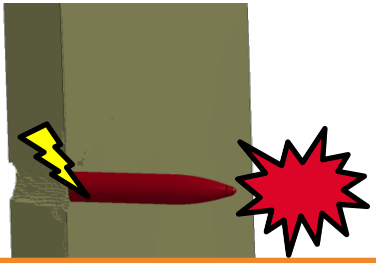
www.cea.fr

OVERVIEW

- CEA Gramat is the French leader in research on the lethality of weapon systems
- One field of investigation deals with fuze mechanical resistance to high-velocity projectile impact (military penetration warhead)

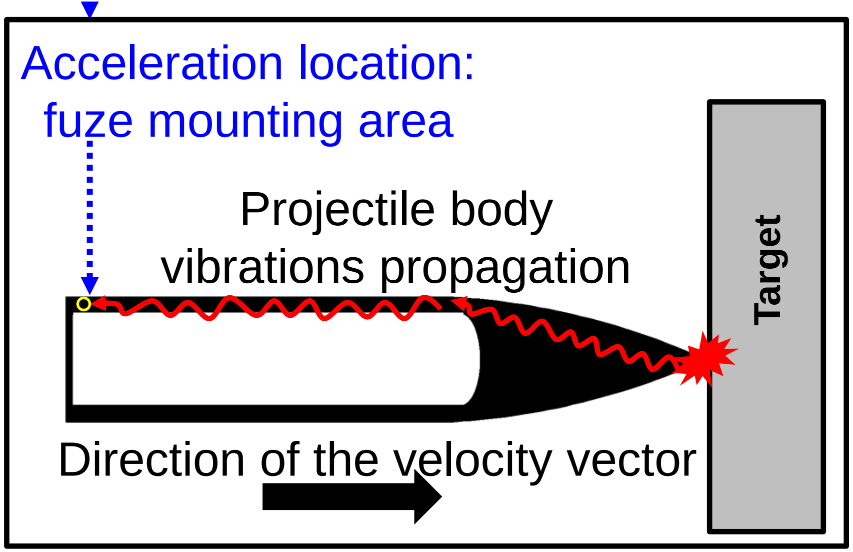


Simulation: perforation of a concrete slab by ammunition

- Objective of CEA Gramat studies: characterize the mechanical shocks that can damage fuzes
  - Mechanical environnement can be used as input for Industry to design fuzes
- In order to characterize the mechanical environment, high-G PCB triaxial accelerometer is used
  - Measurement range of 60 000 g and resonance frequency around 160 000 Hz
    - ► The sensor is limited in maximum range and bandwidth measurement
  - In our applications, we want to measure high acceleration ranges (> 60 000 g) at high frequencies (>160 000 Hz)

ACCELERATION SIGNAL: SENSING PROPERTIES FOR FULL FREQUENCY CONTENT ACQUISITION

GOAL: characterize the mechanical environment transferred from the warhead body to the fuze body

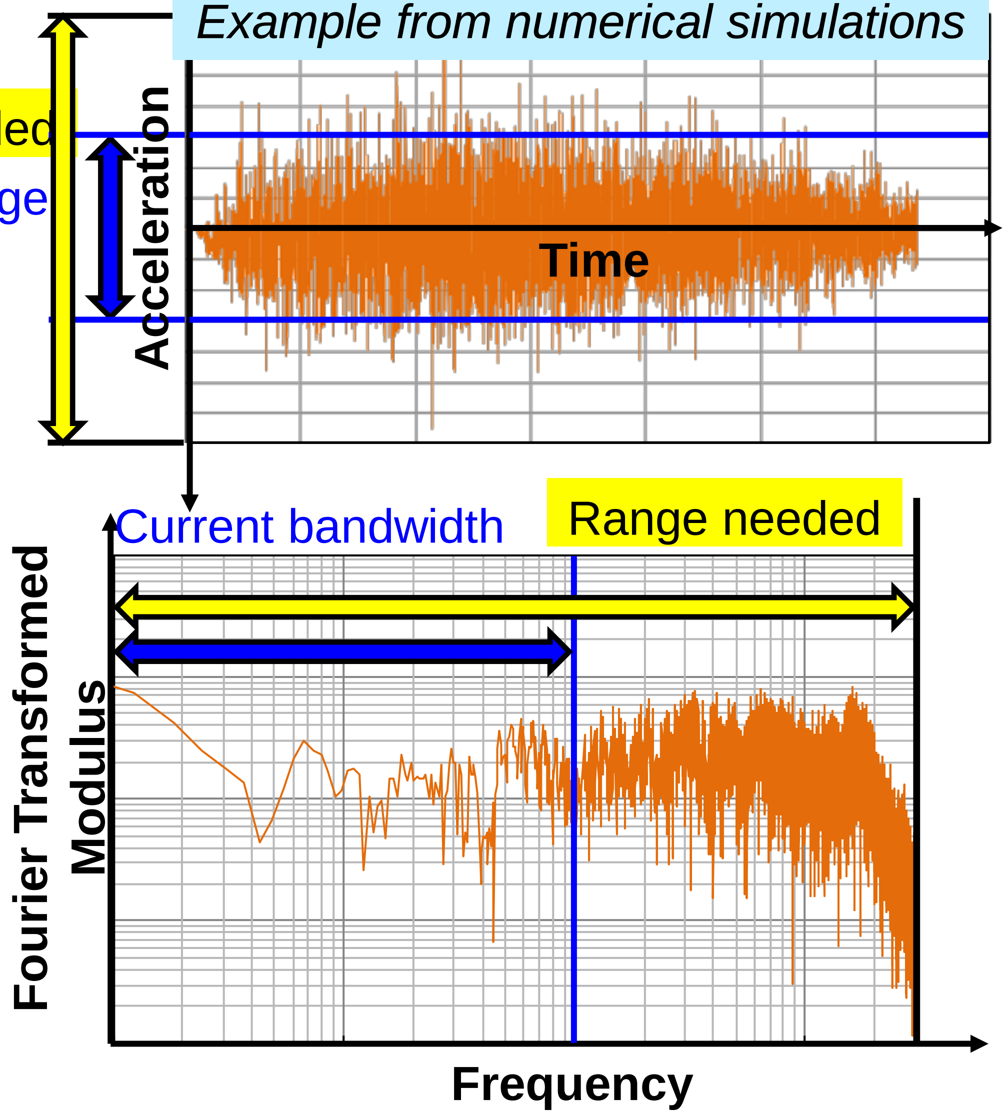


Acceleration location: fuze mounting area

Projectile body vibrations propagation

Direction of the velocity vector

Acceleration versus time history: Example from numerical simulations



Range needed

Current range

Current bandwidth

Range needed

Numerical simulations show that:

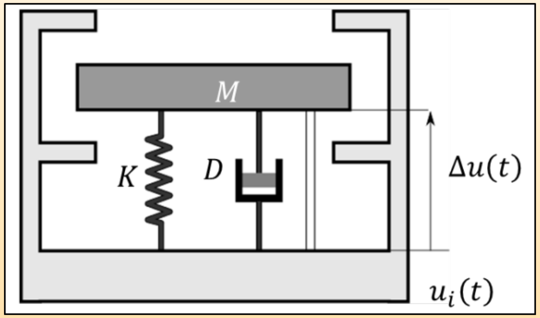
- We need x2 Sensor Maximum Range
- We need x30 Sensor Maximum Bandwidth

SENSOR MODELLING / SIGNAL CONVOLUTION

Physical value
$\left(m.s^{-2}\right)$
$\vec{\gamma}(t)$

Sensor response
$\left(m.s^{-2} \rightarrow pC \text{ or } mV\right)$
$S_{sensor}(t) = G(f) \otimes \gamma(t)$

Acquisition
$(pC \text{ or } mV$-> bits)



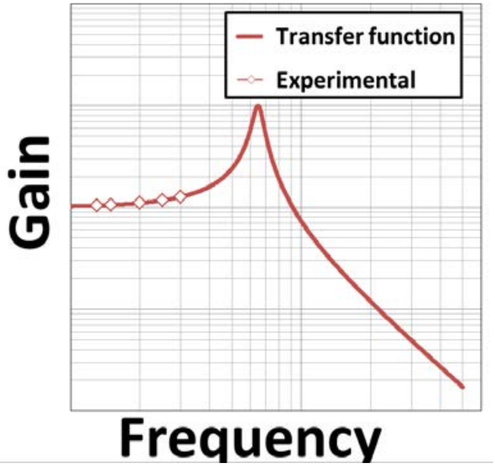
Displacement of M :

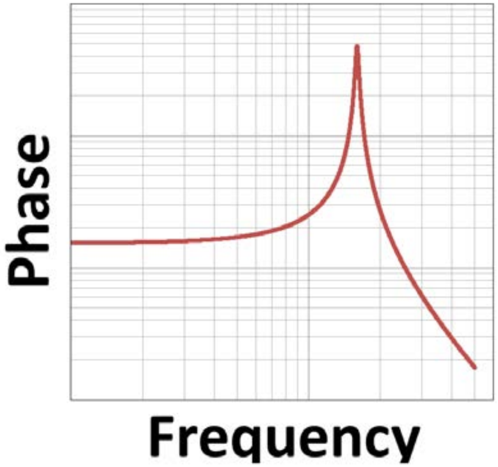
$$\ddot{u} + 2\omega\xi\dot{u} + \omega_0^2 u = \frac{\gamma_i}{m}$$

with $\xi = \frac{D}{2\sqrt{KM}}$ et $\omega_0^2 = \frac{K}{M}$

Transfer function

$$G(f) = \frac{G_0}{\sqrt{\left(1-\left(f/f_0\right)^2\right)^2 + \left(2\left(f/f_0\right)^2\right)^2}} \text{ and } \varphi(f) = -arc\tan\left(2\xi\left(\frac{f}{f_0}\right) \Big/ 1-\left(\frac{f}{f_0}\right)^2\right)$$



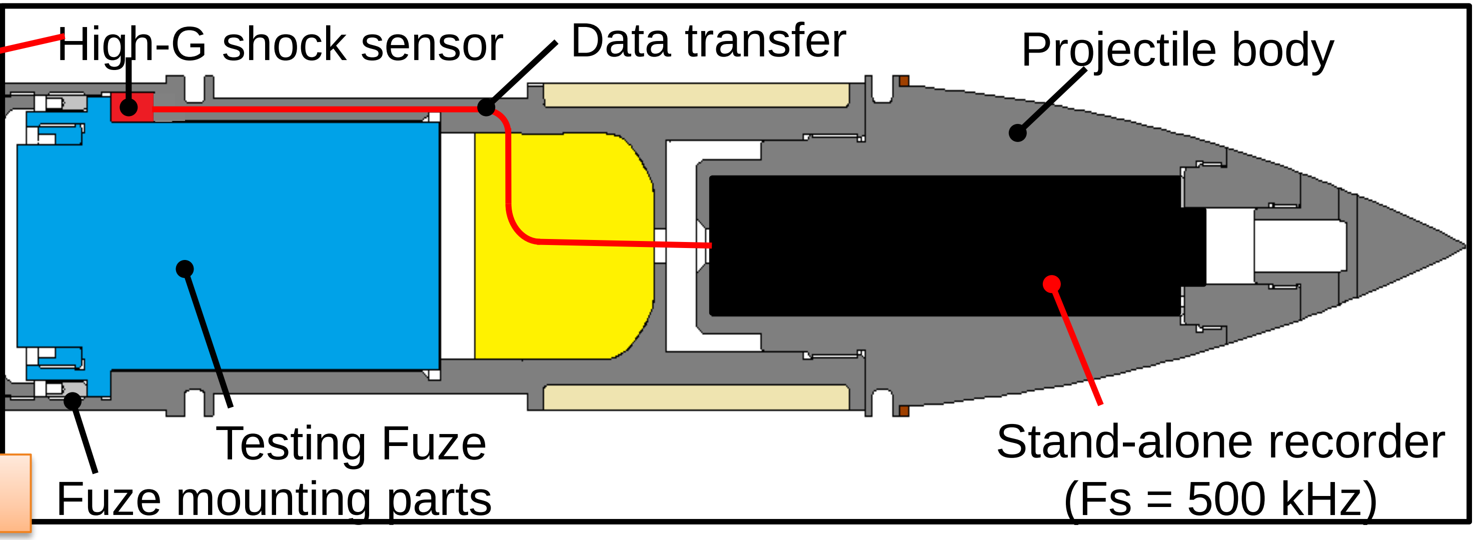


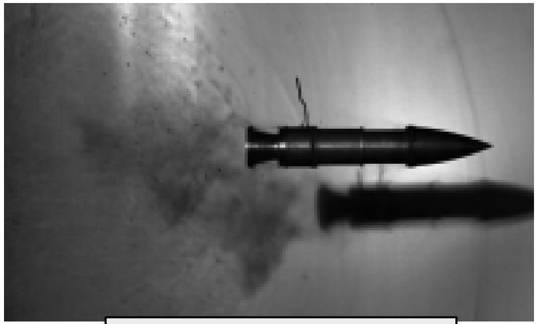
Accelerometric sensors are spring-mass-damper systems

- Physical value is acceleration
- Acceleration is measured through displacement of mass M which modifies piezo-resistive gage resistance
- Mechanical sensor response is given by its transfer function.
- Usable frequency range: where gain is constant and equals to unity
- Knowledge of transfer function allows artificial increase bandwidth by inverse convolution

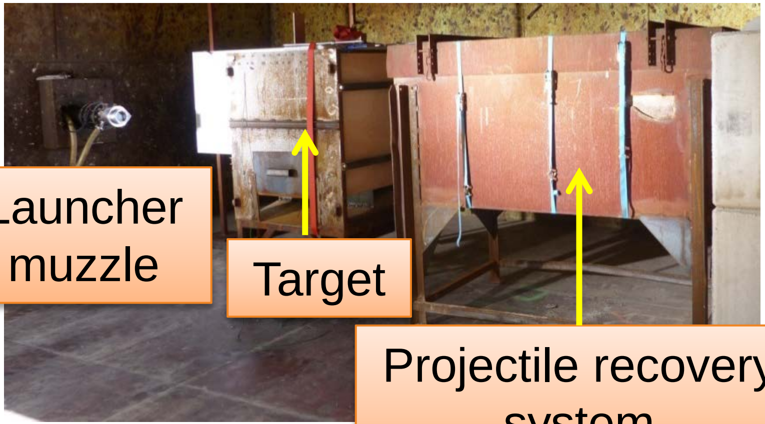
EXPERIMENTAL SETUP – TERMINAL BALLISTICS

Projectile rear view



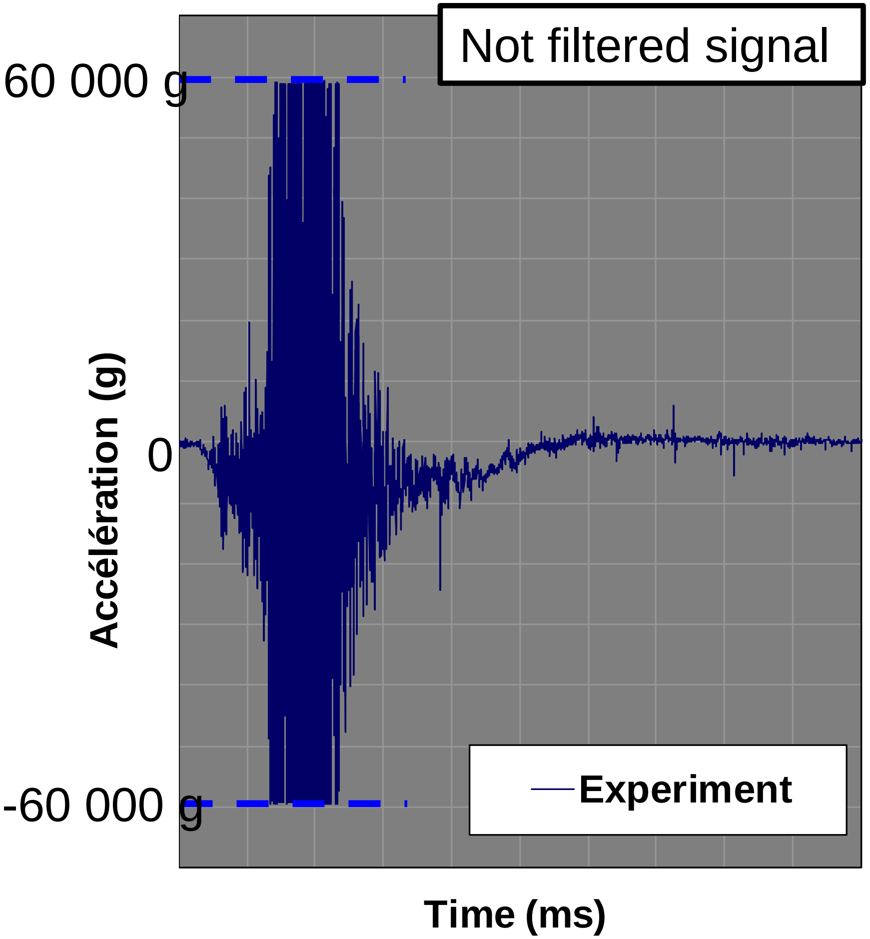


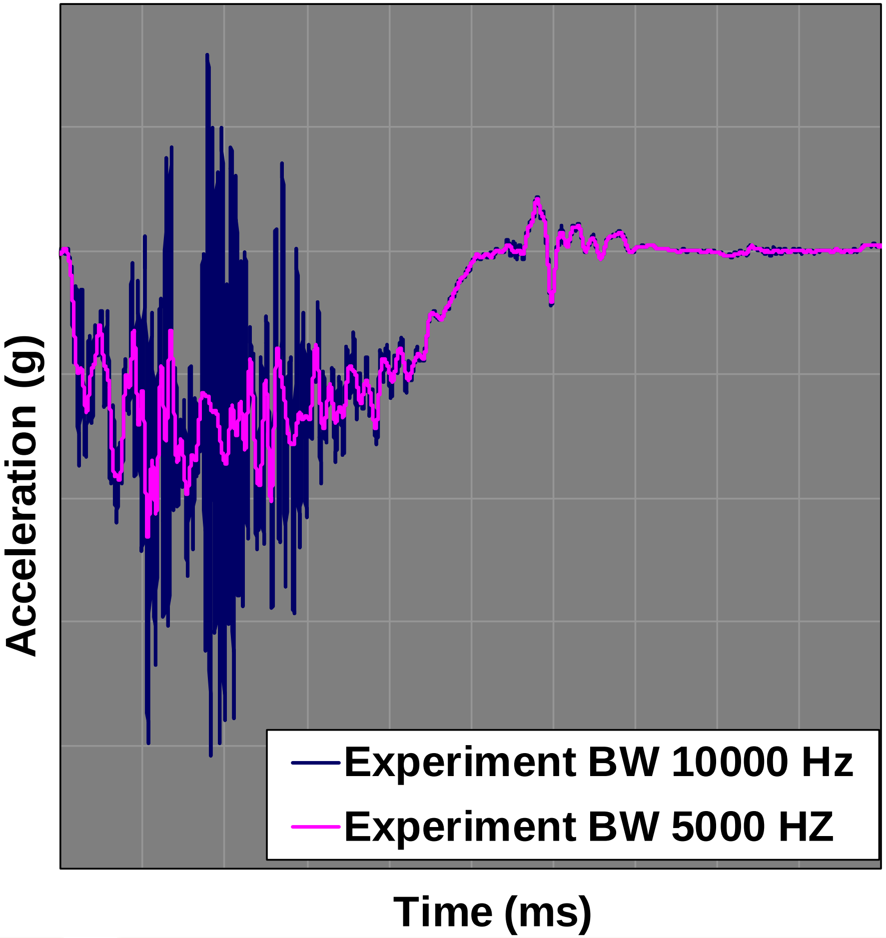
Projectile before impact



Projectile recovery after the test

EXPERIMENTAL RESULTS





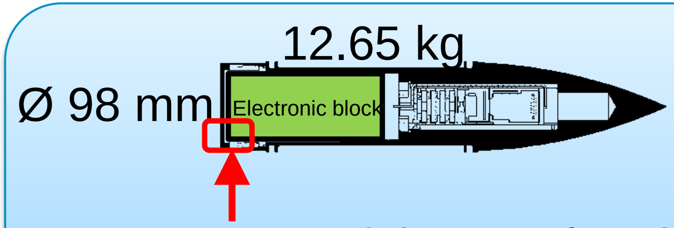
Raw signal provided by the sensor

- Longitudinal acceleration
- The signal overruns 60 000 g
- The sensor keeps its full integrity

Butterworth filter (Fc = 10 kHz and 5 kHz)

NUMERICAL SIMULATIONS

- Purpose: evaluate the sensor response at the point of interest thanks to numerical simulation



Measurement of the acceleration signal at the block mounting parts

- **Method:**

① Penetration simulation with a 3D full description of projectile => output = acceleration time history values at the location of the deported sensor

② Convolution of the calculated value (cf. slide ‘sensor modelling / signal convolution’)

③ Comparison with recorded signal of the deported sensor

① **Physical value**

$$\left(\boldsymbol{m.s^{-2}}\right)$$

$$\vec{\boldsymbol{\gamma}}(\boldsymbol{t})$$

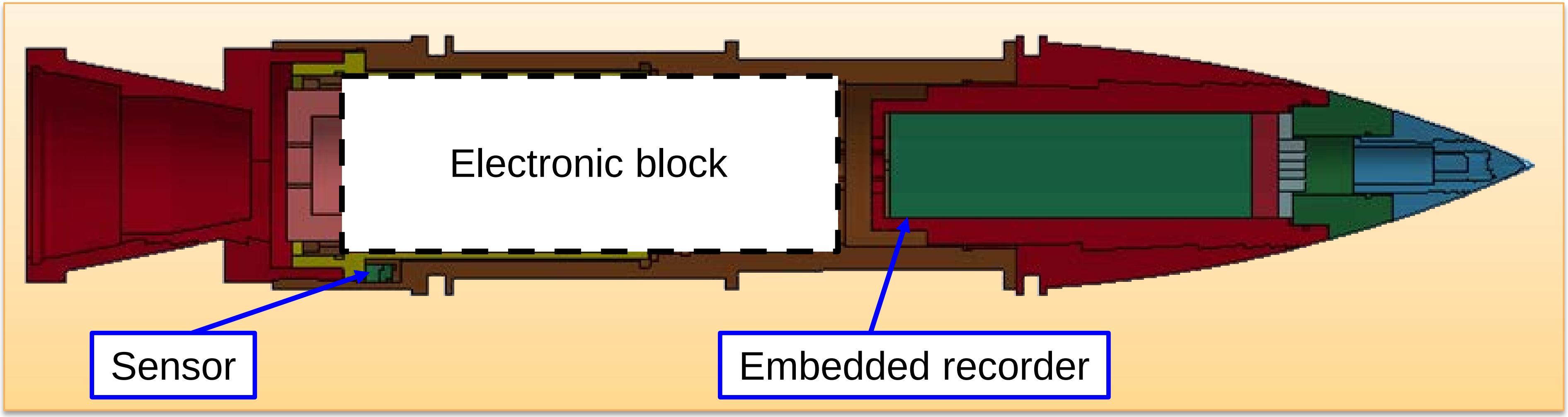
② **Sensor response**

$$(\boldsymbol{m.s^{-2}} \rightarrow \boldsymbol{pC\ or\ mV})$$

$$\boldsymbol{S_{sensor}(t) = G(f) \otimes \gamma(t)}$$

③ **Comparison between** sensor response ‘from simulation’ / sensor response from the experiment

NUMERICAL MODEL DESCRIPTION



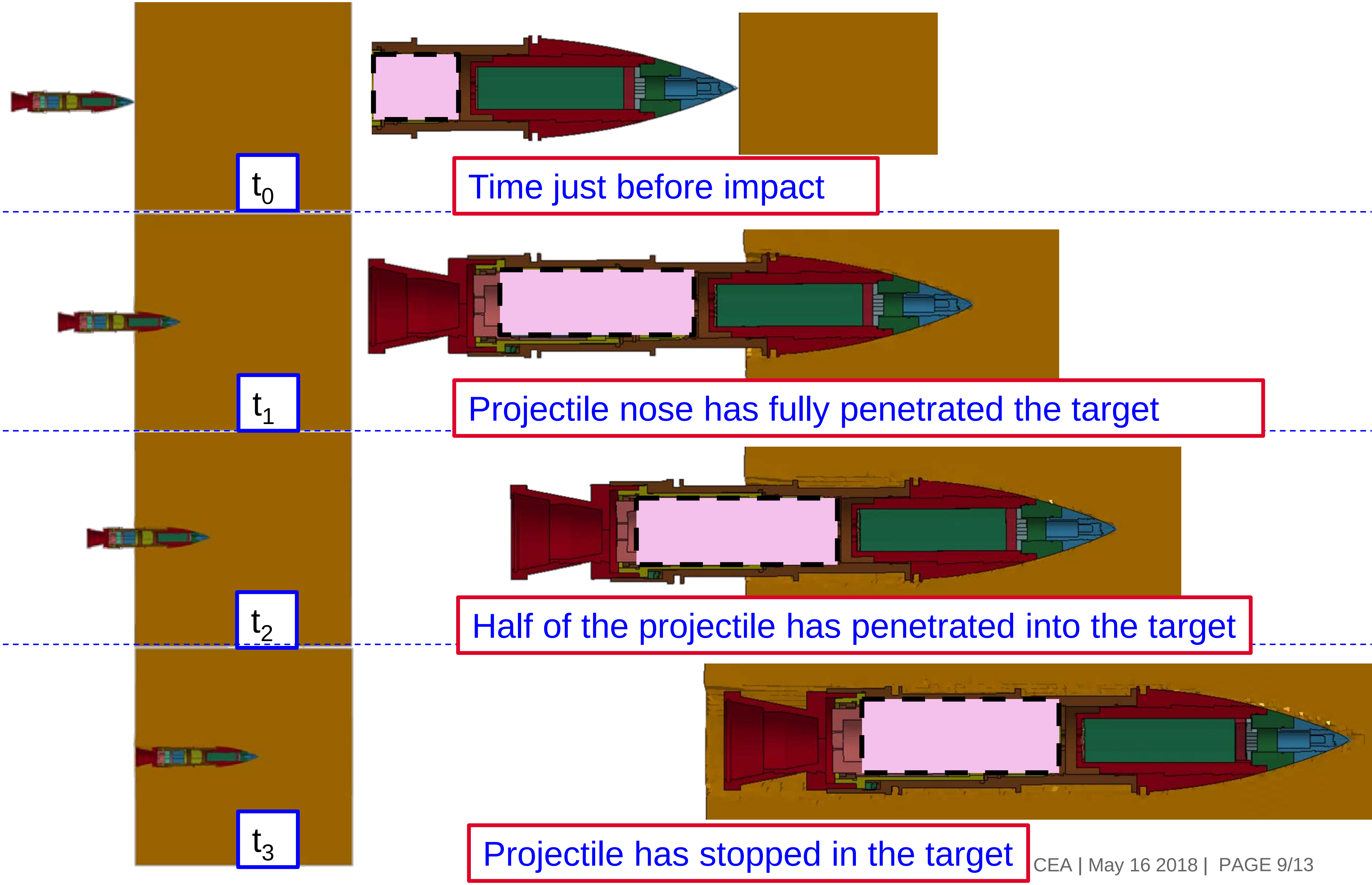
Finite element model

- Total mass: 12.6 kg
- 325 000 brick elements
- Target: 3.3 M brick elements

Simplified assumptions

- No preload, only tied interfaces between components: sensor is tied to the steel confinement
- Finite elements erosion is enabled to allow the projectile to progress through the target
- Target : Elastic and plastic behavior in Ls-Dyna combined with MAT_ADD_EROSION
- No gravitational loads are applied

NUMERICAL SIMULATIONS: RESULTS



Time just before impact

Projectile nose has fully penetrated the target

Half of the projectile has penetrated into the target

Projectile has stopped in the target

NUMERICAL SIMULATIONS: RESULTS

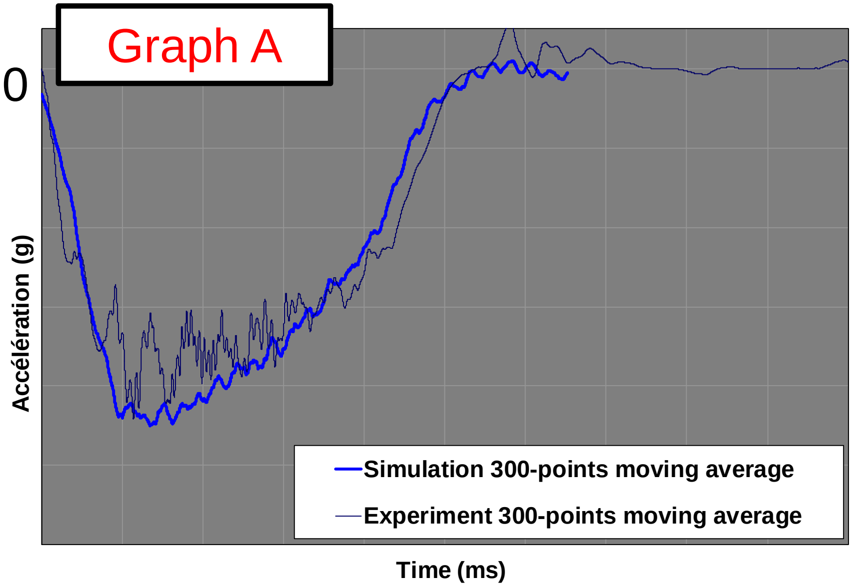
- Graph A: acceleration vs time signals comparison experiment / simulation at low frequencies range (curves are smoothed with a 300-pt moving average ≈ low pass filter)

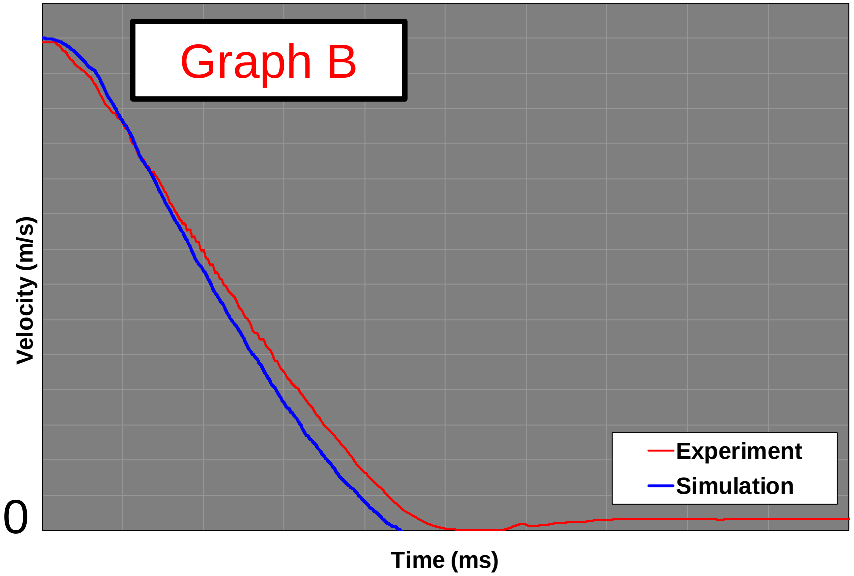
- Good agreement between simulation and experimental acceleration signals
  - Peak acceleration is the same, duration of penetration in the target is the same

- Good agreement between simulation and experimental velocity time histories (Graph B)

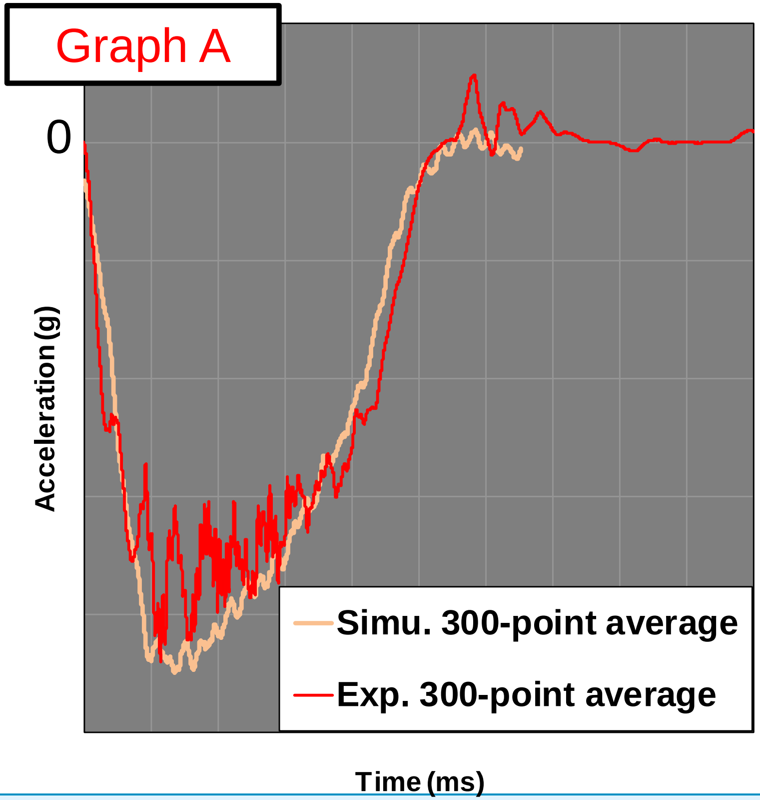
►Simulation results match experimental data

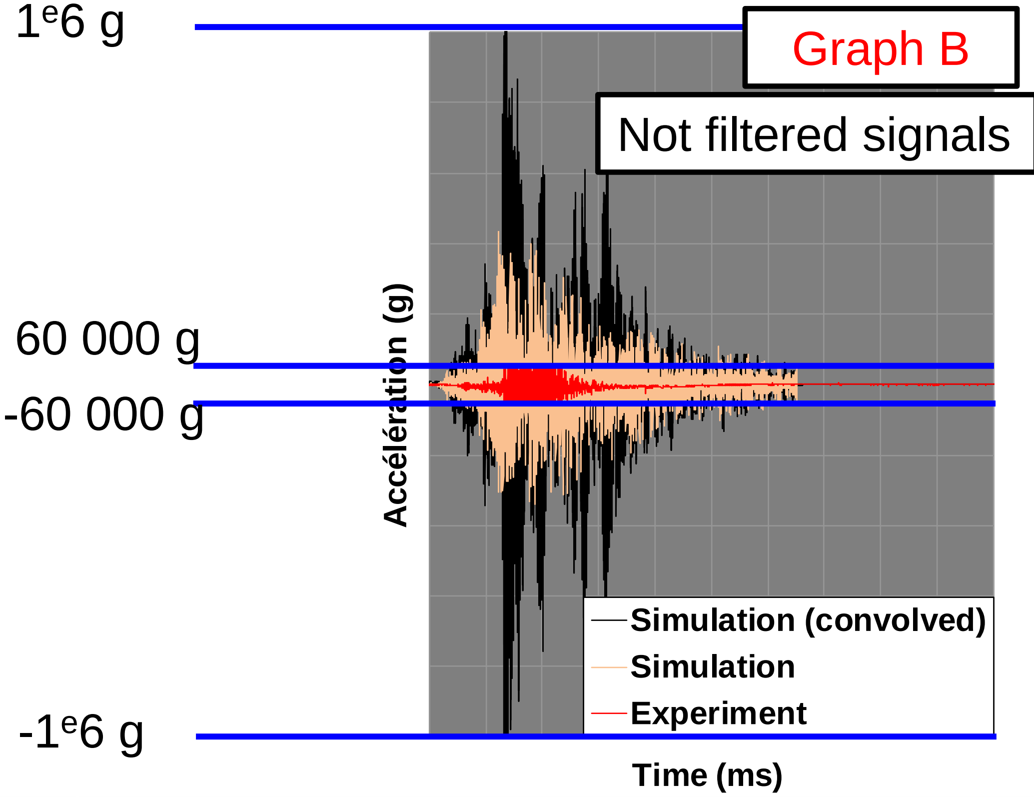
► At low frequencies range (Graph A): calculated acceleration time history matches the experimental data => same duration and amplitude of accelerations





SENSOR BEHAVIOUR APPLIED TO NUMERICAL SIGNAL





Calculated averaged signal of acceleration

- Low frequencies validated by experiment as it has previously been shown

Extended bandwidth signal

- 0 - 300 000 Hz
- The highest acceleration amplitudes are due to sensor resonant frequency

Graph B: Simulated sensor response **is significantly different** from the experiment for the high frequencies range

CONCLUSION

- The mechanical environnement can be used as input for Industry to design fuzes: it has to be characterized

- The 60 000 g sensor used in our experimental setups has several limitations:
  - acceleration range is too low
  - frequency range, where gain is constant, is lower than our requirements
  - resonant frequency can disturb measurement

- The study shows an approach that gives a more accurate fuze mechanical environment focused on high frequencies
  - Based on high performance numerical simulation (evaluation of the physical acceleration signal that is to be to measured)
  - Simulation combines ideal sensor behavior at high frequencies without mechanical stops
  - In practice, sensor bandwidth has been increased

- Observations & Future Works
  - Resonant frequency is preponderant and provides the highest, non-physical acceleration amplitude
  - Sensors need to be improved to collect more physical information:
    - Increase maximum range
    - Increase maximum bandwidth

Thank you for your attention

Questions?

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Gramat | BP 80200 46500 Gramat
T. +33 (0)5 65 10 54 32 | F. +33 (0)5 65 10 54 33
Etablissement public à caractère industriel et commercial |
RCS Paris B 775 685 019

Direction
Département
Service