Pyroshock Simulation for qualification of space electronic equipments

CH. DE FRUYTIER

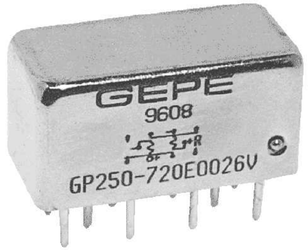
O. VERLINDEN

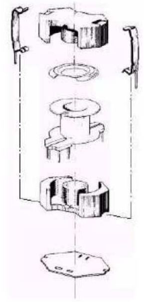
D. WATTIAUX

Contents

Sensitive components of electronic units

- Structural parts are not sensitive





- Sensitive components

* Relays
- Chatter, transfer
- Permanent damage

* Magnetic components: brittle failure, cracks

* Crystals, brittle epoxies, glass diodes, wires, leads
- Brittle failures, cracks
- Bond fracture
- Broken wires

Pyroshock testing methods

- **Full scale testing using actual flight hardware**

  - **Drop tables**

    * Velocity step instead of acceleration step (bad at low frequency)

    * One axis/one direction: six shocks instead of one

  - **Electrodynamic shaker**

    * input to the test item is spatially overcorrelated, as opposed to the real uncorrelated shock excitation caused by pyro separations

    * 200 - 300 g max in time domain; one order of magnitude too low

  - **Mechanically excited ringing structures**

  - **Pyrotechnically excited ringing structures**

    * Plate testing using explosives is the best method of simulating pyro shock events where fullscale flight hardware are not available or too costly.

ETCA pyroshock test facilities

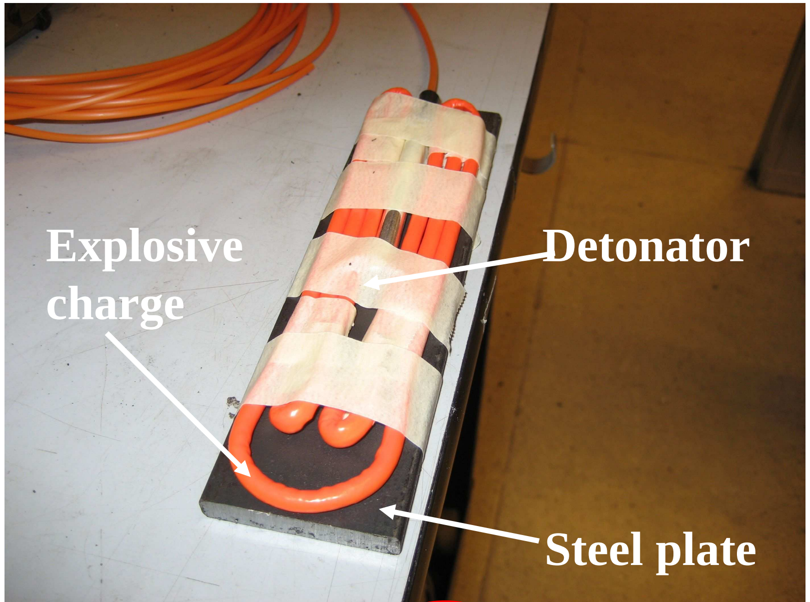
- **Mechanical structure:**
  - Double plate (aluminium, steel)
  - Simple plate (aluminium, steel)
  - Simple plate + square (aluminium, steel)
  - More complex set-up…

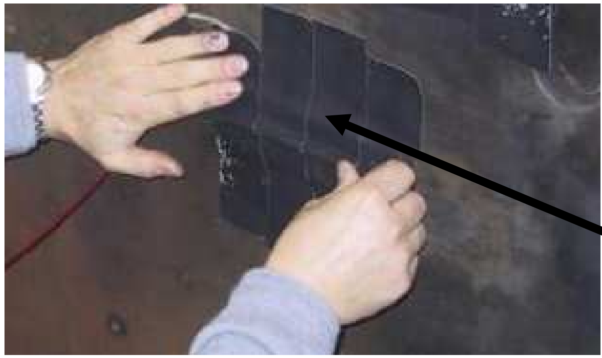
- **Excitation devices:**
  - Explosive (nominal)
  - Dropping hammer
  - Pneumatical jack

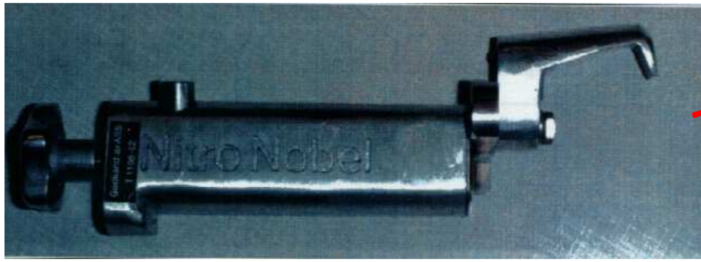
- **Measurements:**
  - Acceleration
  - Quick Calculation of the SRS's

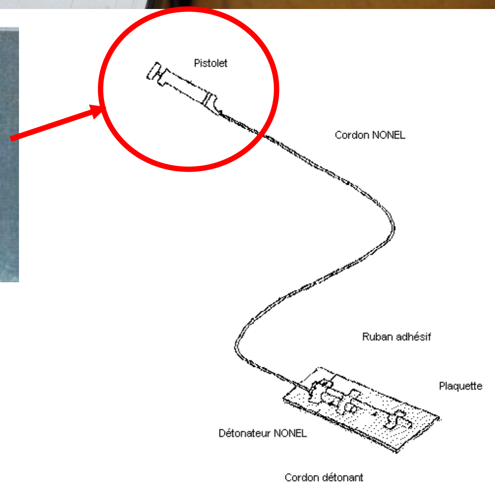
Excitation – Explosive charge

- ❑ **Using of Non-electric detonator**
- ❑ **Detonator and explosive charge are fixed on a steel plate**
- ❑ **A gun causes the explosion of the detonator and so, of the explosive charge**







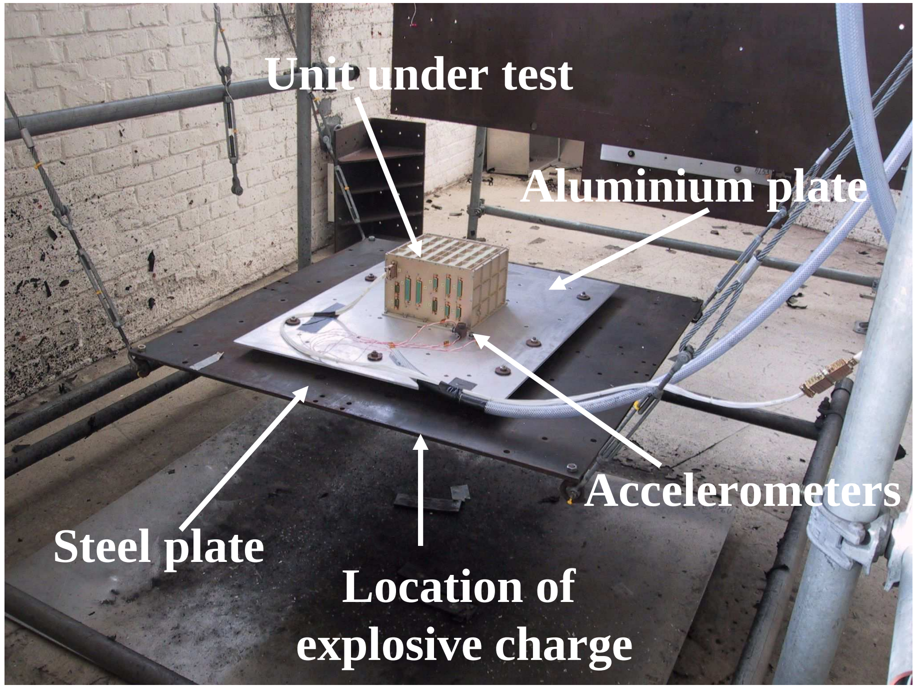


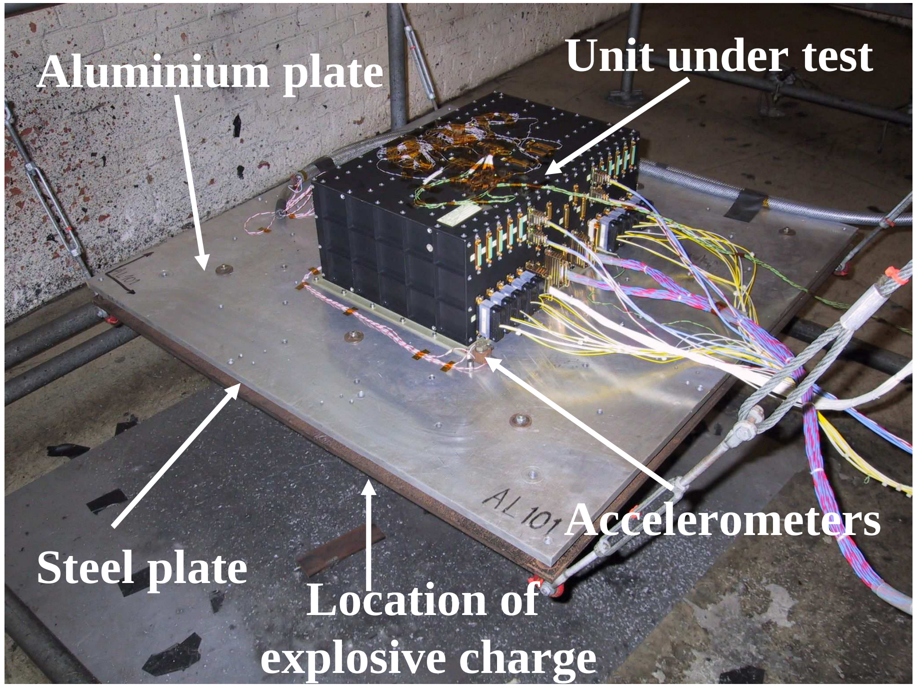
Charge fixed with tape to the set-up

ETCA pyroshock test facilities

Some standard configurations…

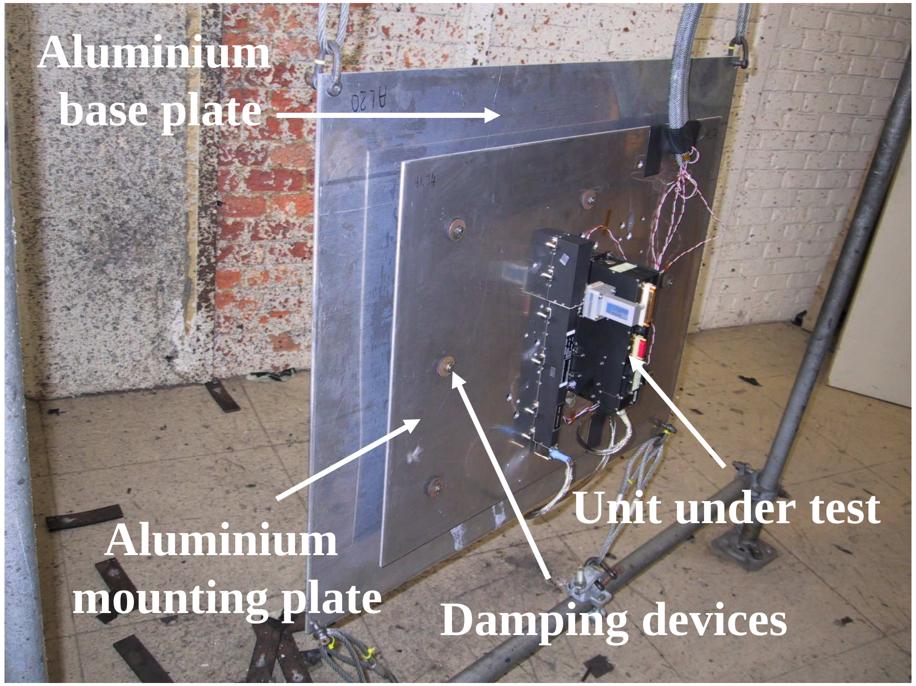
- ❑ **Double plate set-up**

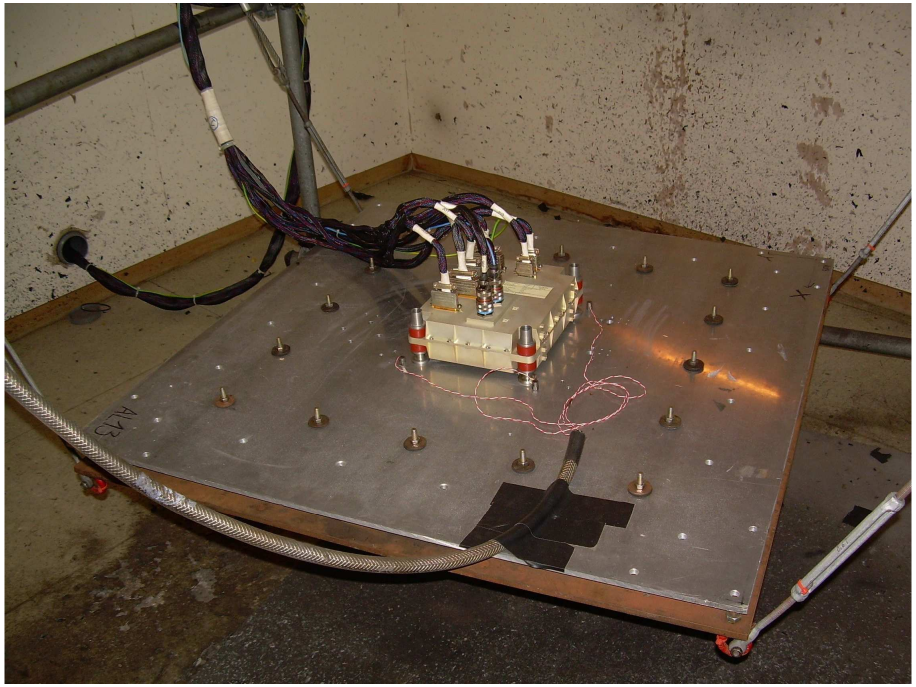




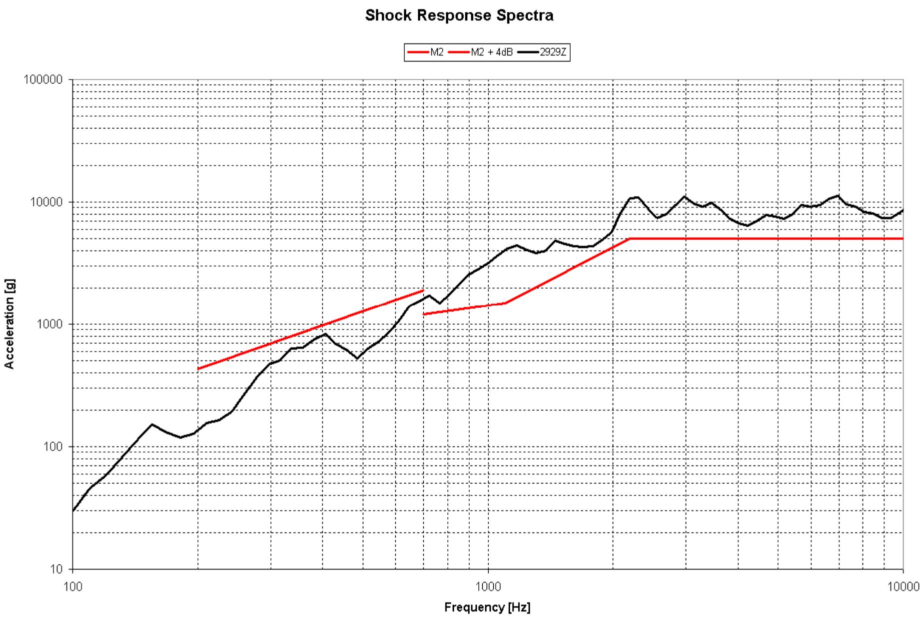
Some standard configurations…

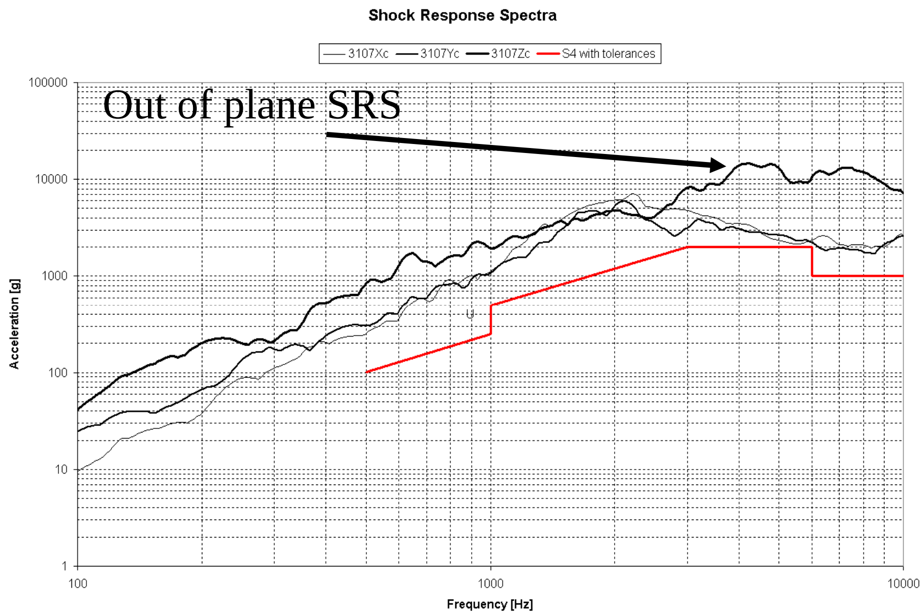
- Double plate set-up





Some results of double plate set-up…

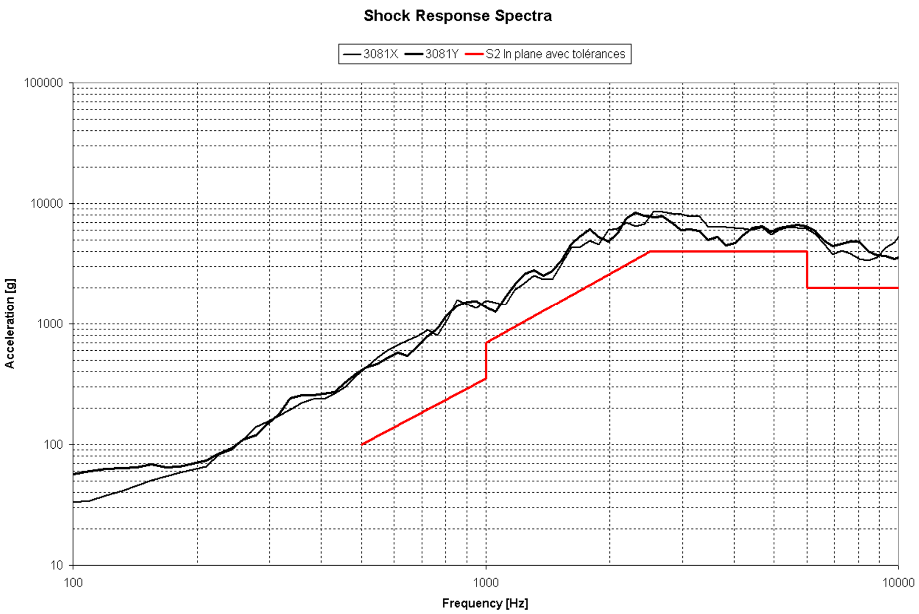


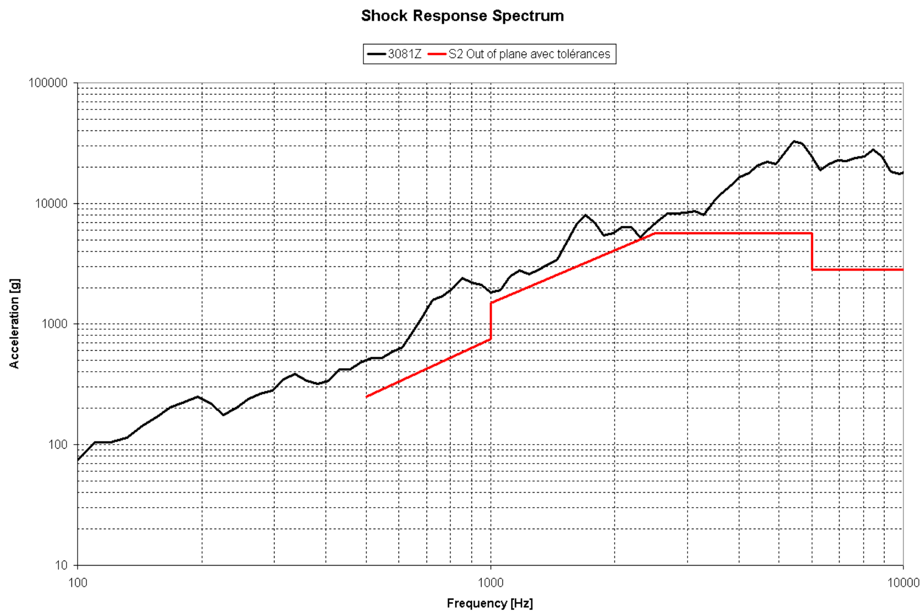


Specification M2 - Ariane 5
Out of plane axis only

Specification S4
3 axes simultaneously

Some results of double plate set-up…





S2 In plane **S2 Out of plane**

❑ Main parameters to tune on double plate set-up:

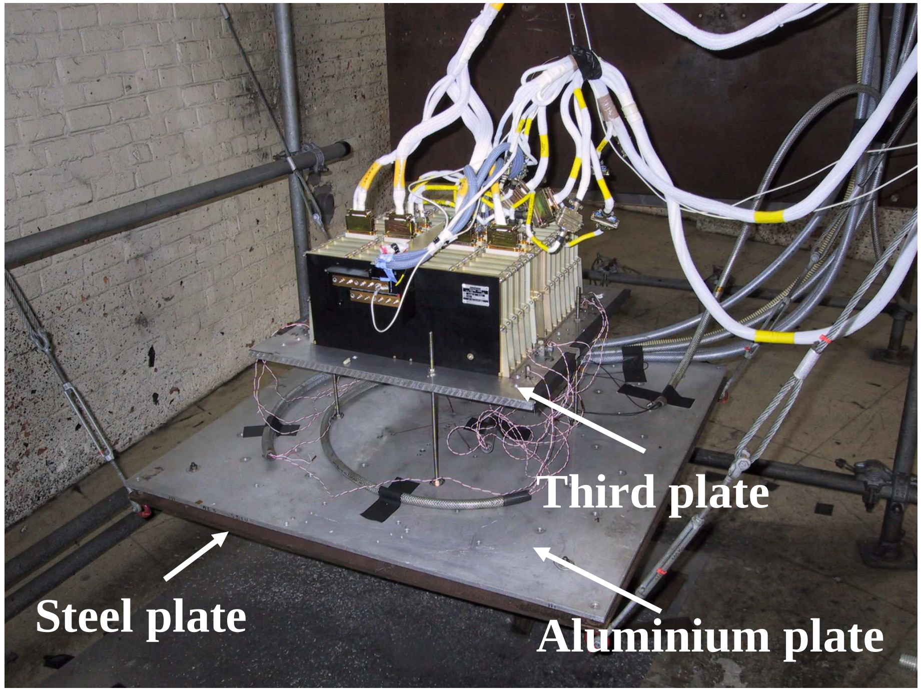
- ❑ Quantity of explosive charge
- ❑ Material of base plate and mounting plate
- ❑ Dimensions of mounting plate
- ❑ Number of damping devices between the plate
- ❑ Location of damping devices
- ❑ Location of explosive charge
- ❑ …

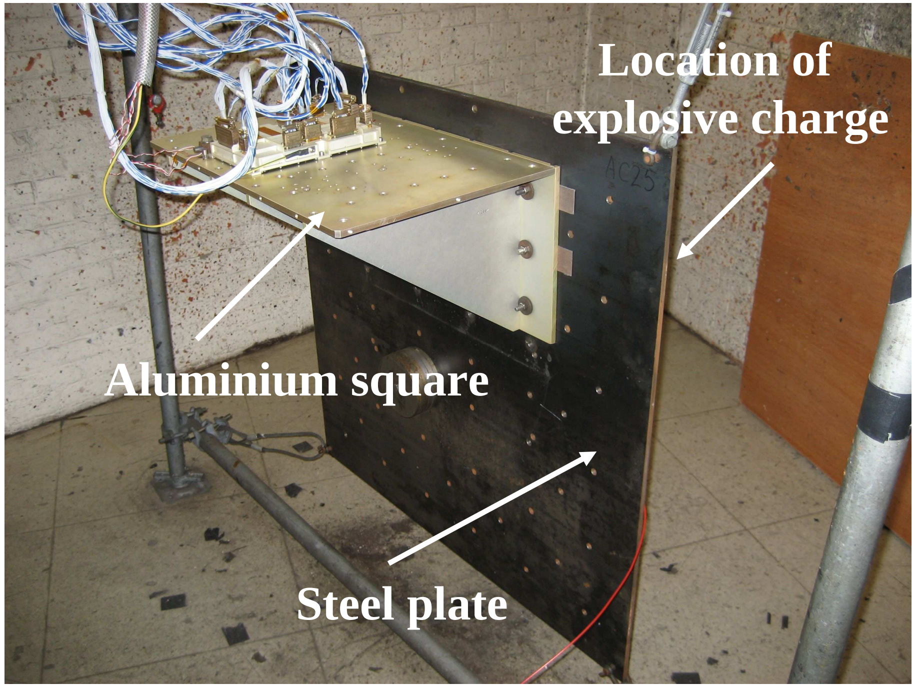
❑ Drawback of double plate set-up:

- ❑ Out of plane axis is over-tested

ETCA pyroshock test facilities

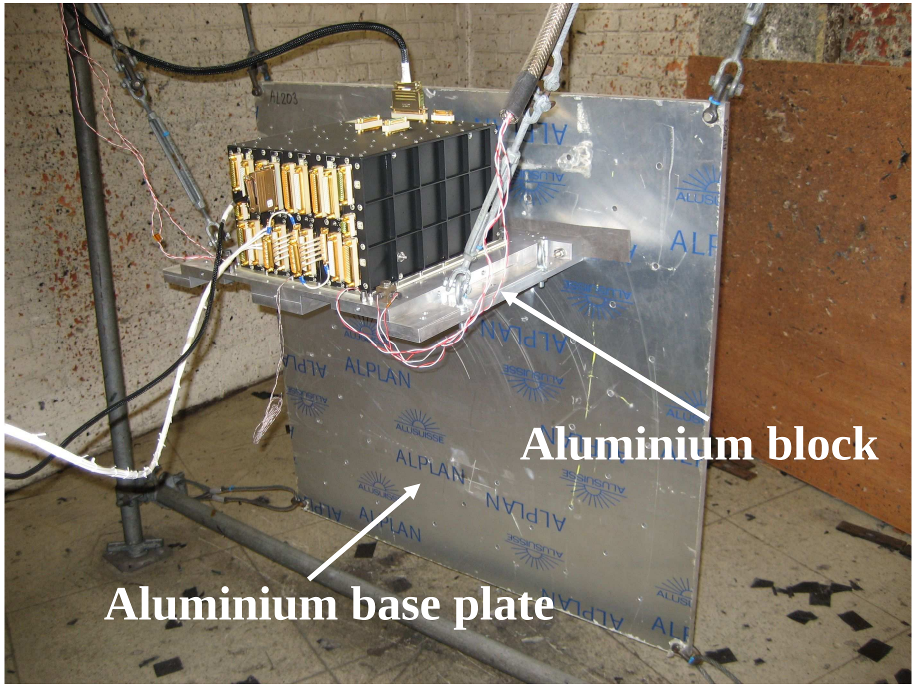
Some specific configurations…

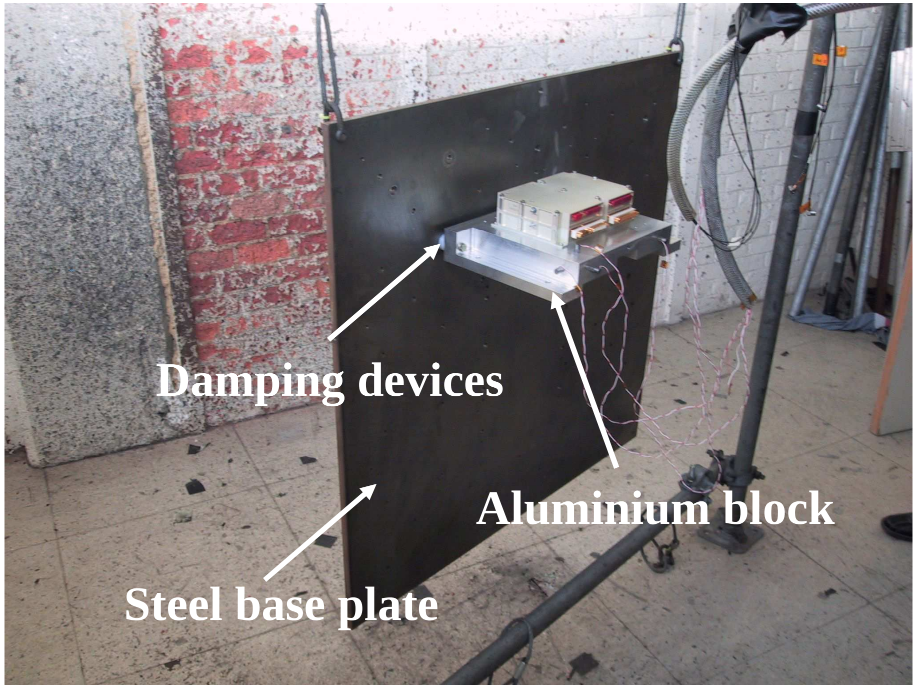




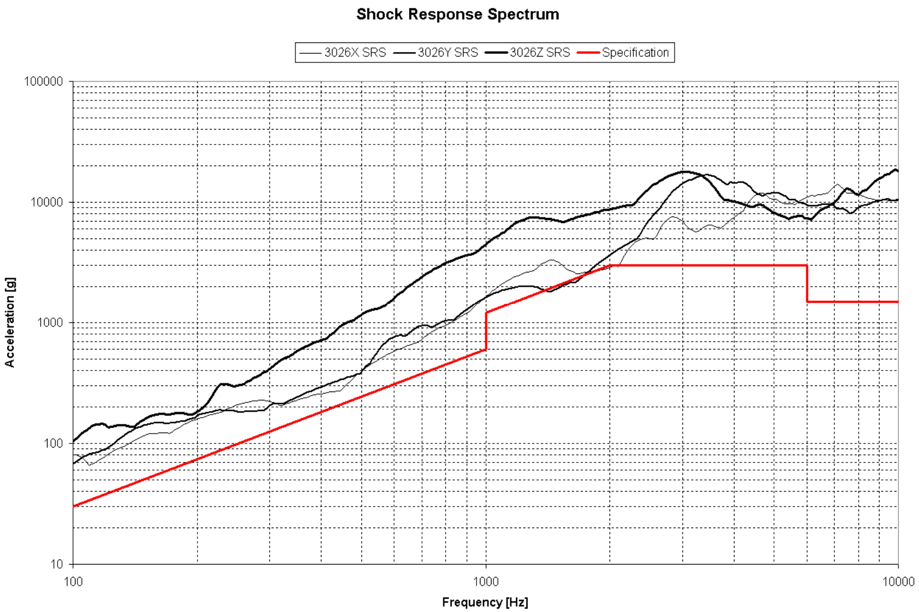
ETCA pyroshock test facilities

Some specific configurations…

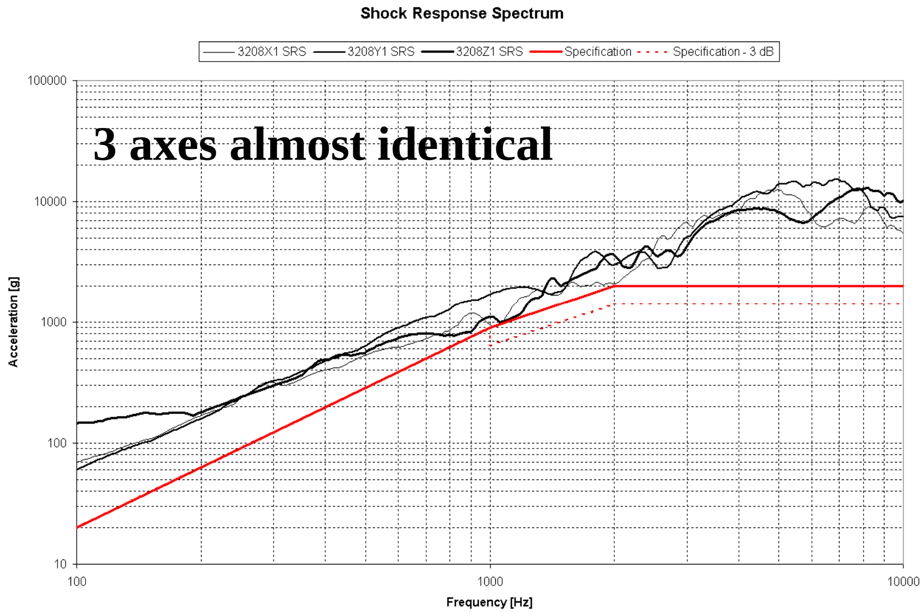




Some results of specific configurations…

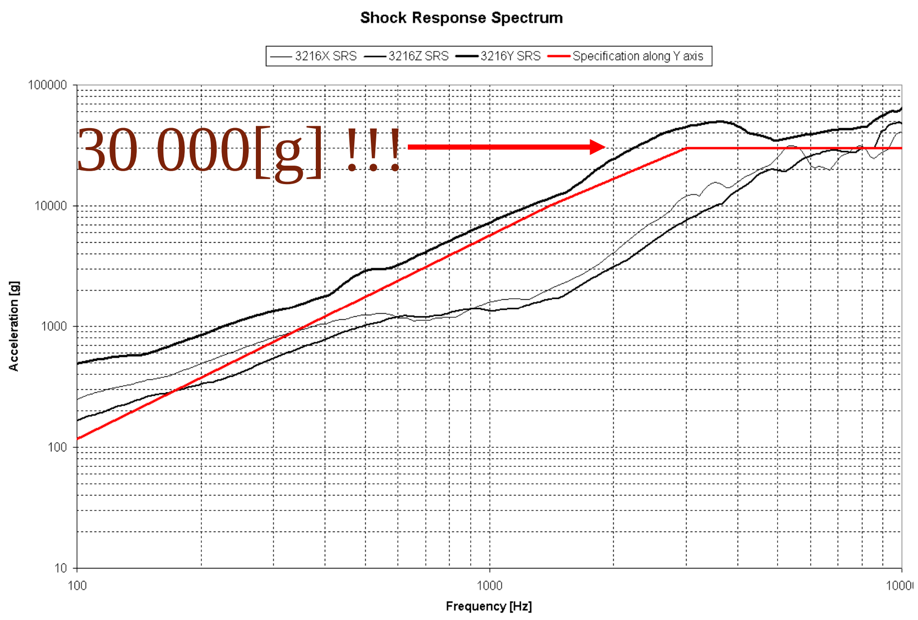


With Aluminium square

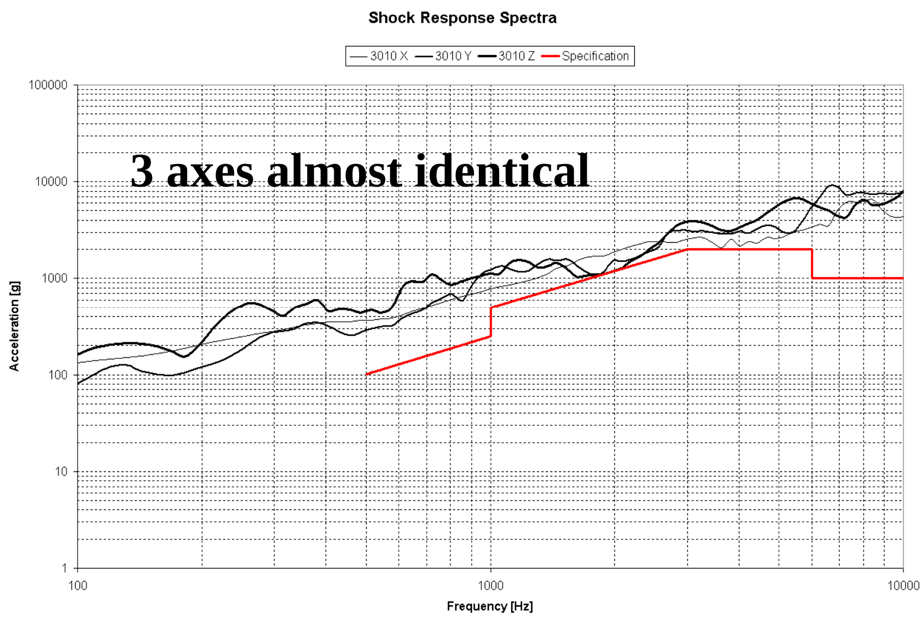


With Aluminium block

Some results of specific configurations…

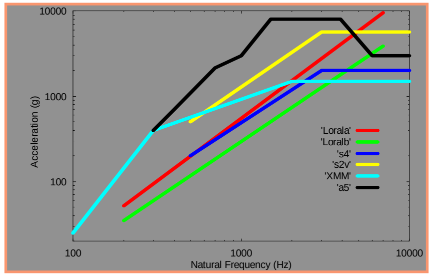


One high level axis set-up



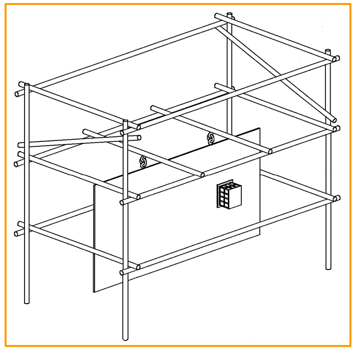
With Aluminium square

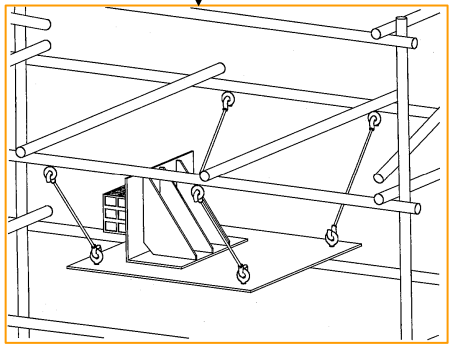
Specified level and unit (through mass and dimension mainly)

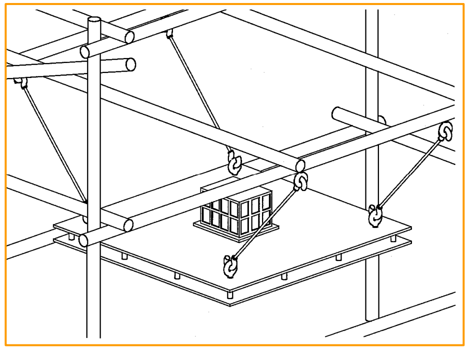


Empirical selection of test fixture and type

- **Pneumatic piston**
- **Sledge hammer**
- **Explosive**







Usual way to perform a pyroshock test campaign

- **ETCA pyroshocks data base (more than 3000 pyroshocks) is the main tool to choose a test fixture to start a calibration stage**

- **Calibration stage to reach specified levels is a very empiric process (tuning of parameters of the test facilities based mainly on ETCA know-how)**

- **To reduce time and cost of a pyroshock test campaign, interest to use models of the test facilities to know influence of set-up parameters**

- **→ Collaboration between TAS ETCA and FPMs**

Pyroshock model

Goal: develop a pyroshock model of the test facilities used by Thales Alenia Space Etca (Belgium – Charleroi) in order to predict the influence of some operating parameters on the SRS calculations

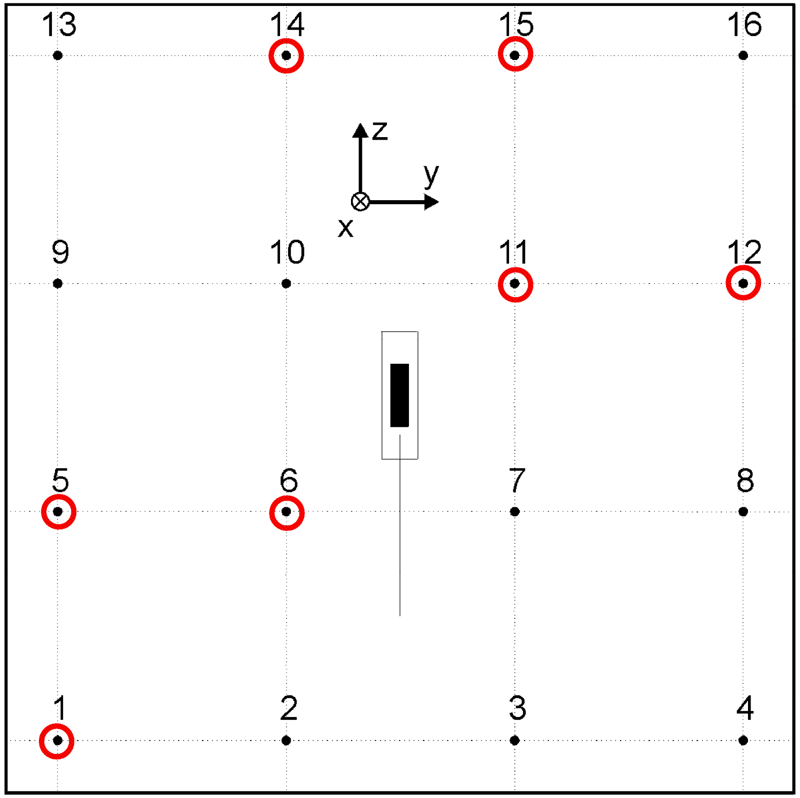
The pyroshock model requires

Dynamic model of the test facility → Finite Element Method (FEM)

Mathematical description of the excitation sources → Equivalent Mechanical Shock (EMS)

Used configuration:

square steel plate vertically suspended



Detonating cord length:

0, 4, 10, 20, 30, 50 cm

Acquisition parameters:

F_{sample} = 100 kHz

N_{sample}= 8192 pts

Low pass filter with a cutoff frequency of 10 kHz

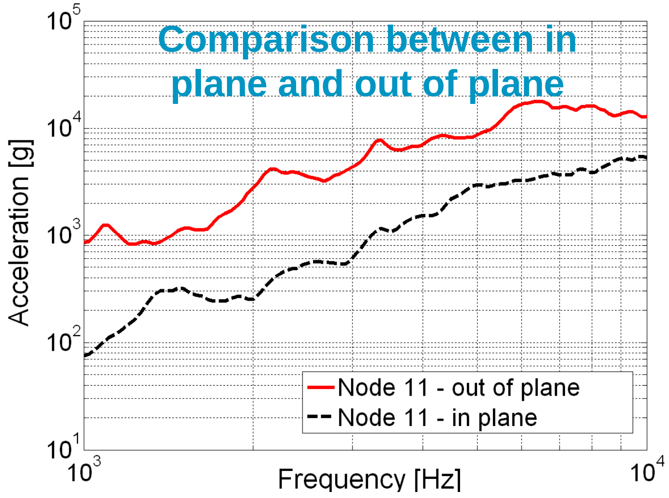
Characteristics of the plate:

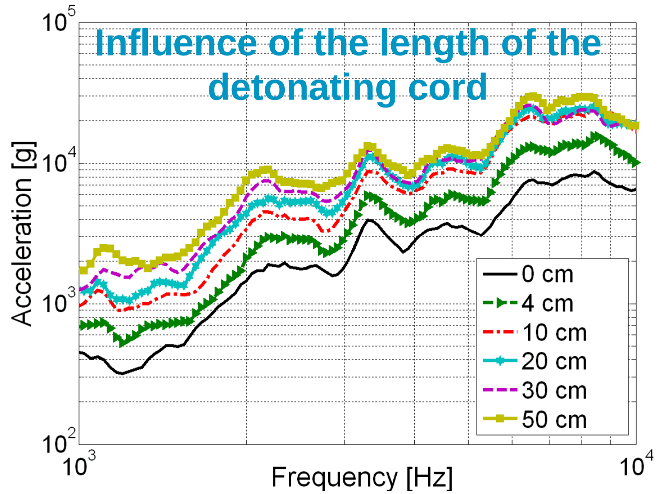
Steel material

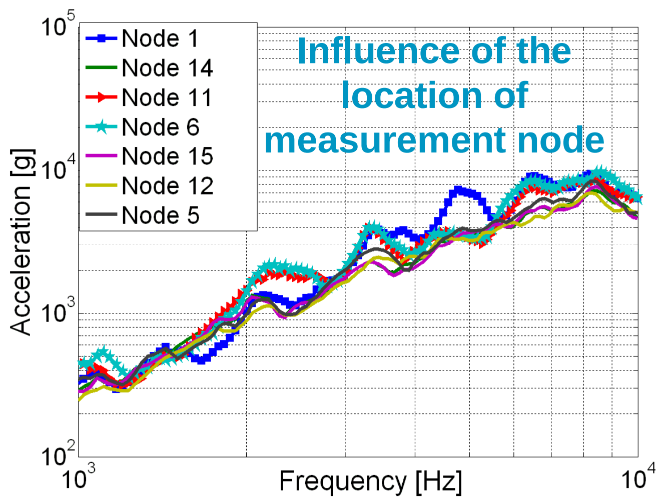
Area= 1 m²

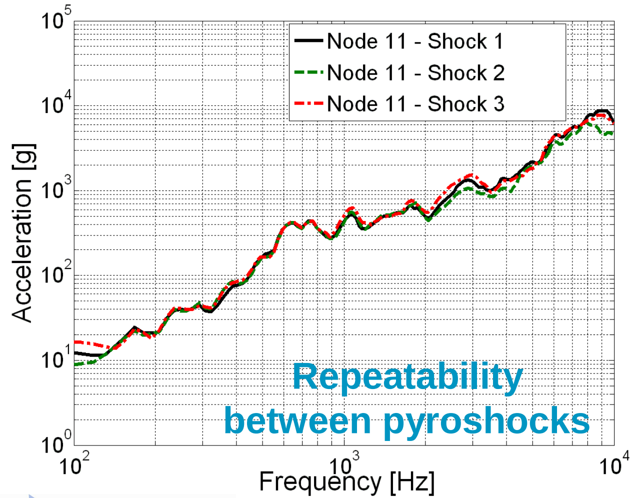
Thickness= 15 mm

Main experimental results









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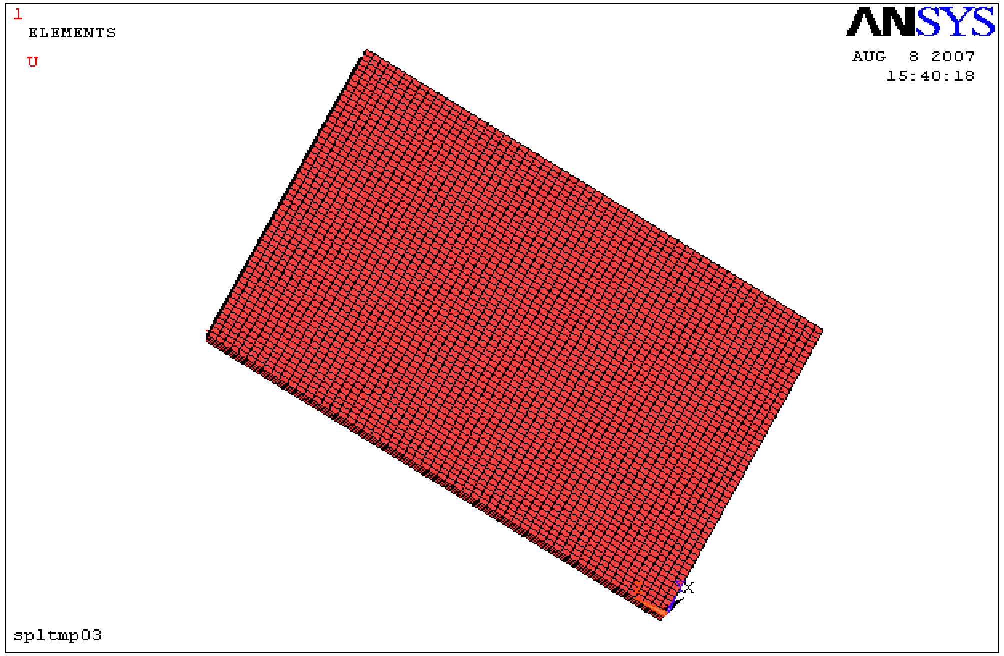
Finite Element Model of the test facility

FE model built under ANSYS 8.1 software

- Modelling of the plate with SOLID45 elements
- Six elements per bending wavelength
- Three elements along the thickness

	Steel plate
E	210 GPa
ρ	7800 Kg/m^3
ν	0.3
h	0.015 m
f	10 kHz
λ	0.121 m



$$\lambda = \sqrt{\frac{2\pi}{f}} \left(\frac{D}{M_s}\right)^{1/4}$$

$$D = \frac{E\,h^3}{12\left(1-\nu^2\right)}$$

A constant damping ratio ξ has been introduced in the FE model

Model validation in the modal domain

Relative frequency difference

$$\Delta_k = \frac{\left| f_k^E - f_k^S \right|}{f_k^S}$$

Modal Assurance Criterion (MAC):

$$MAC_k = \frac{\left(\left\{ \psi_k^E \right\}^T \left\{ \psi_k^S \right\} \right)^2}{\left(\left\{ \psi_k^E \right\}^T \left\{ \psi_k^E \right\} \right) \left(\left\{ \psi_k^S \right\}^T \left\{ \psi_k^S \right\} \right)}$$

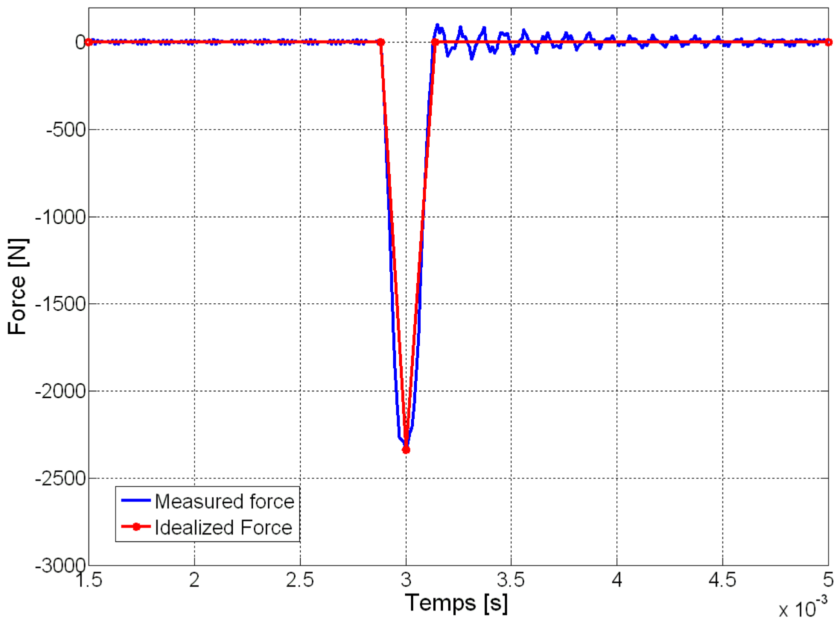
f^E (Hz)	f^S (Hz)	Δ_k (%)	MAC
47	49	3.4	0.98
92	89	3.7	0.85
124	127	2.5	0.69
231	224	2.4	0.88
282	282	0.6	0.98
457	445	2.6	0.83
488	477	2.2	0.77
493	498	1.2	0.84
564	560	0.73	0.98
622	635	2.1	0.80
738	730	1.0	0.64
790	771	2.5	0.85
796	803	0.9	0.73
897	919	2.4	0.68
898	899	0.1	0.66

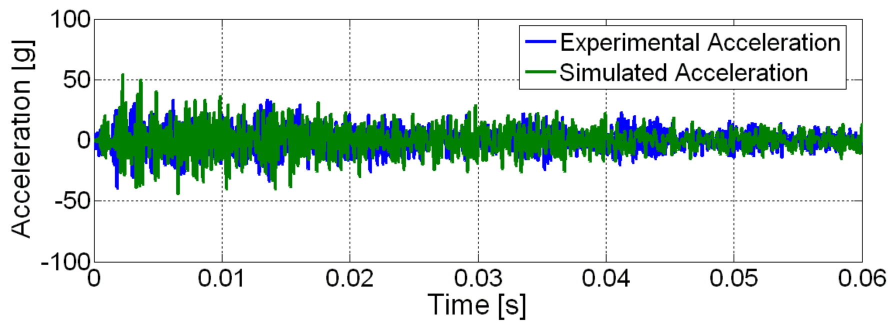
Modal identification with LSCE method (TestLab – LMS)

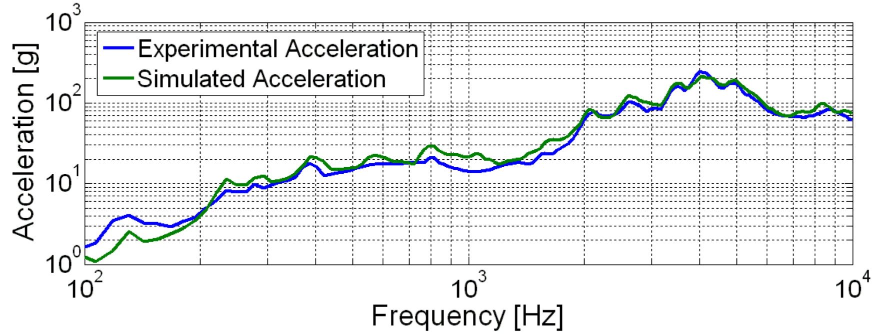
The FE model have been validated and updated until 1000 Hz
⇒ Extrapolation at higher frequencies (until 10 kHz)

Model validation in the temporal domain

Comparison between experimental and simulated accelerations





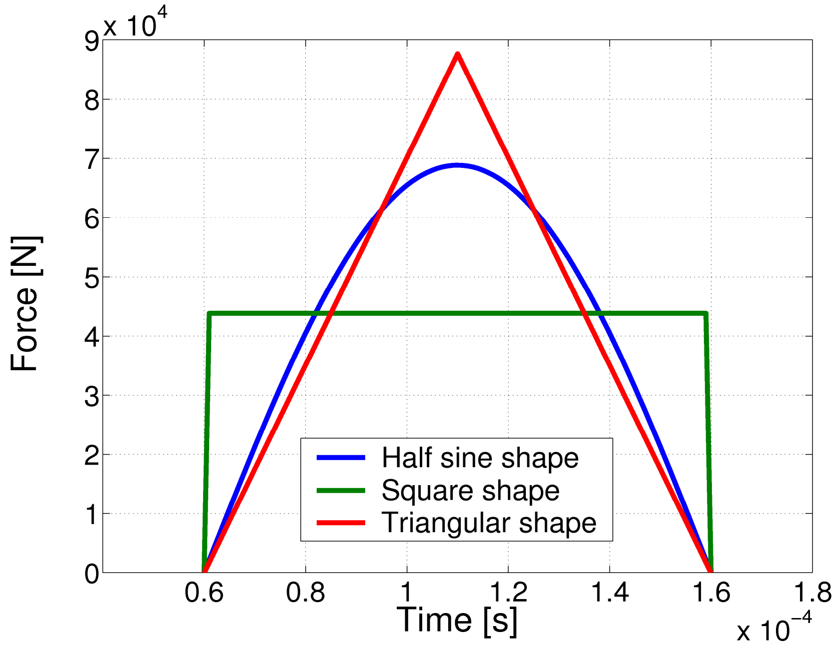


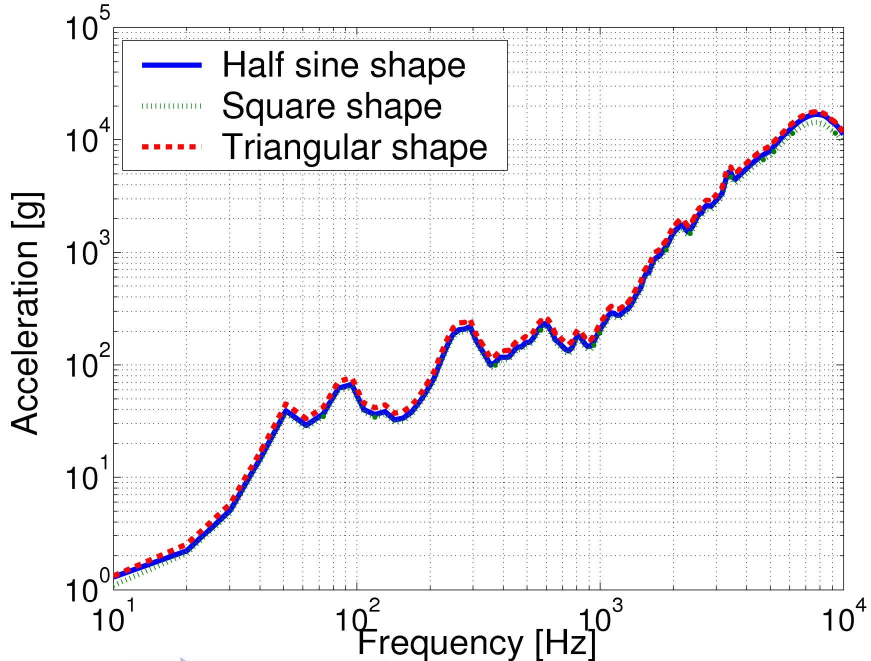
Equivalent Mechanical Shock (EMS): Definition

Definition: EMS corresponds to the mechanical force which has to be applied to the FE model to generate equivalent acceleration fields

EMS is definied by two parameters

- ❑ The intensity F_{max} of the impact
- ❑ The duration τ of the impact





Equivalent Mechanical Shock (EMS): Identification

The parameters F_{max} and τ of the EMS are deduced by an optimization process that minimize the gap between experimental and numerical results in terms of SRS :

$$\epsilon = \min_{F_{Max},\tau} \sum_{f=0\text{ Hz}}^{10\text{ kHz}} \sum_{j=1}^{N_{\text{SRS}}} \left| SRS_j^{\text{Measured}} - SRS_j^{\text{Simulated}}(F_{Max},\tau) \right|^2$$

→ Identification process costly in calculation time

In practice,

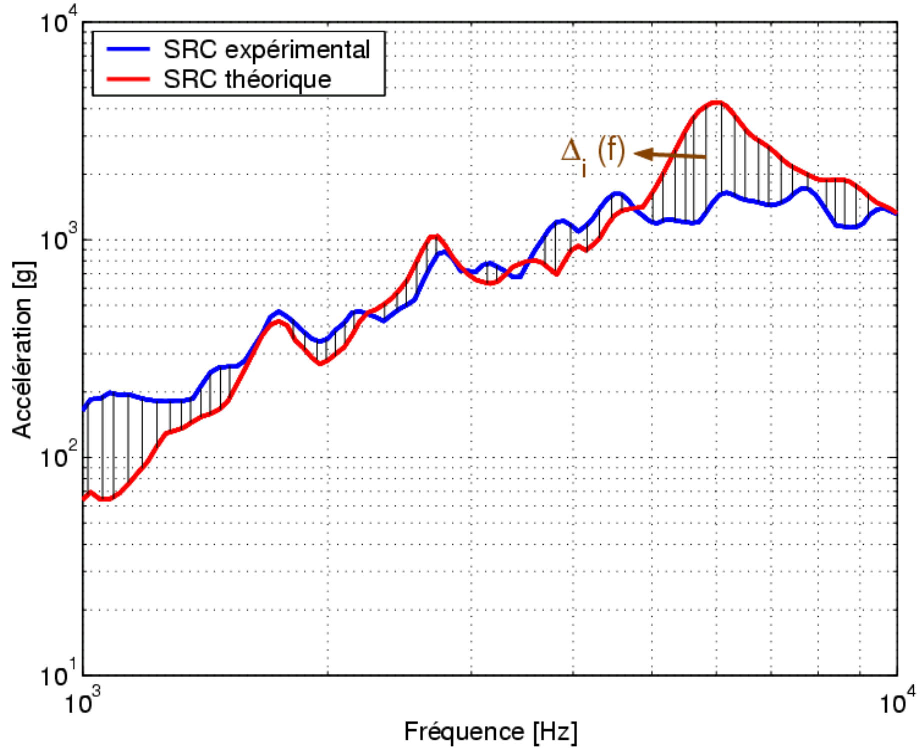
- Quantification of τ : [20:20:200] μs
- For each τ, calculation of the SRS to an unitary intensity ⇒ SRS^{ref}

$$\epsilon(\tau) = \min_{F_{Max}} \sum_{f=0\text{ Hz}}^{10\text{ kHz}} \sum_{j=1}^{N_{\text{SRS}}} \left| SRS_j^{\text{Measured}} - F_{max}\, SRS_j^{\text{ref}} \right|^2$$

Statistical indicators to compare SRS

$\Delta_i(f)$: represents the difference at frequency *f* between experimental and simulated SRS in terms of frequency for node number *i*

$$\Delta_i(f) = \left| SRS_i^{simulated}(f) - SRS_i^{Measured}(f) \right|$$



$\mu(\Delta_i)$ et $\sigma(\Delta_i)$: correspond to the mean and the standard deviation of the indicator $\Delta_i(f)$ along the frequency range [1 – 10 kHz]

$$\mu(\Delta_i) = \frac{\sum_f |\Delta_i(f)|}{N}$$

$$\sigma(\Delta_i) = \sqrt{\frac{1}{N}\sum_f (\Delta_i(f) - \mu(\Delta_i))^2}$$

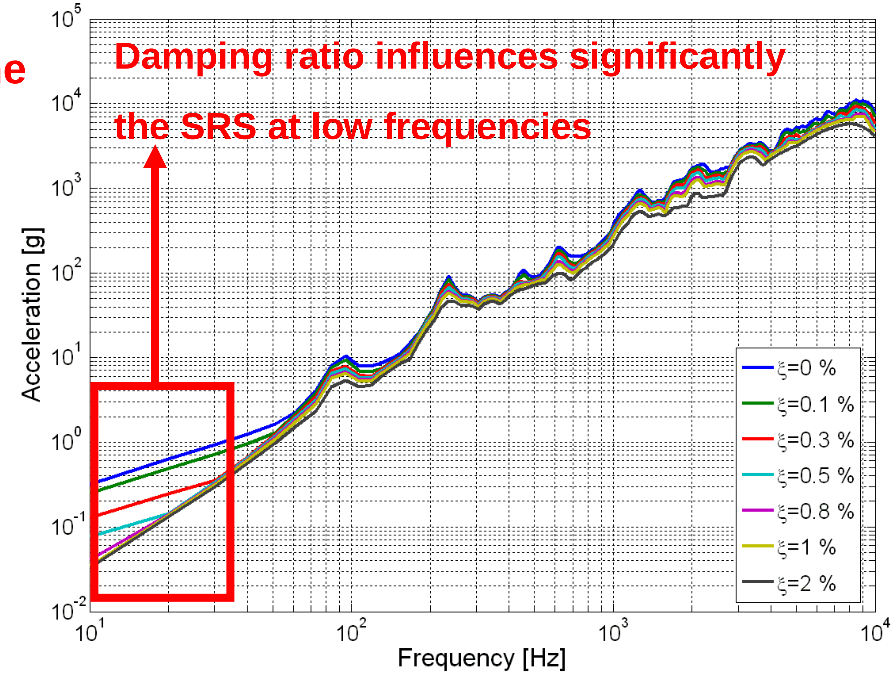
μ_G et σ_G : represent to the mean and the standard deviation respectively of the frequency difference between experimental and simulated SRS considered on the **whole set of measured nodes**.

Influence of the damping ratio ξ

EMS identified from a zero detonating cord length

ξ %	F_{max} (N)	τ (μs)	$F_{max} * \tau$ (Ns)	μ_G (dB)	σ_G (dB)
0	60612	80	4.85	0.82	0.64
0.1	83518	60	5.01	0.80	0.61
0.2	88344	60	5.3	0.84	0.61
0.3	92091	60	5.52	0.87	0.61
1	112070	60	6.72	1.07	0.98

Damping ration ξ corresponds to the mean value measured during the experimental modal analysis in the frequency range [0-1000 Hz].



Identification of the EMS

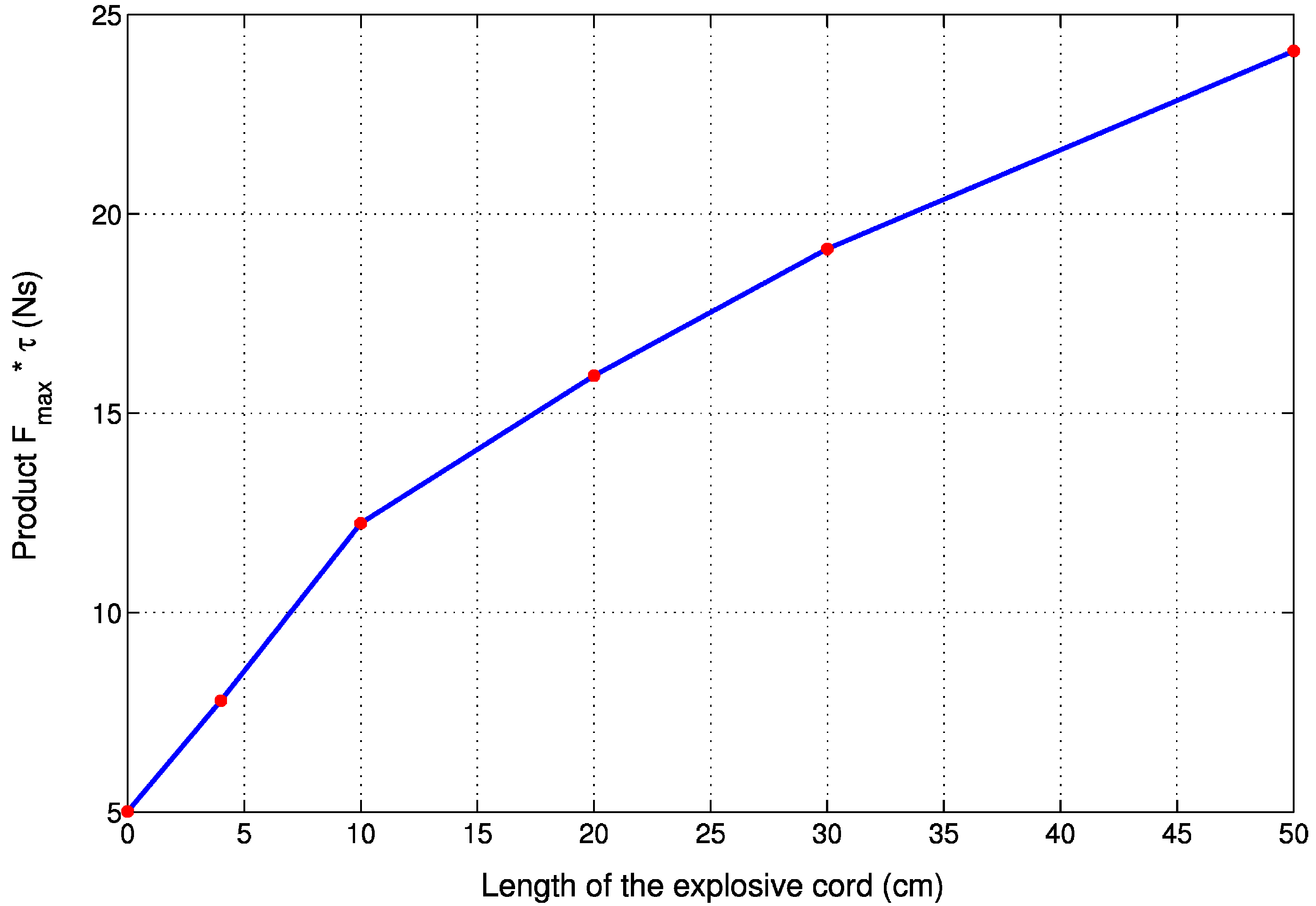
Damping ratio ξ = 0.1%

	F_{max} (N)	τ (μs)	$F_{max} * \tau$ (Ns)	μ_G (dB)	σ_G (dB)
0 cm	83518	60	5.01	0.80	0.62
4 cm	129830	60	7.79	0.76	0.57
10 cm	203980	60	12.24	0.88	0.68
20 cm	199260	80	15.94	0.84	0.67
30 cm	191210	100	19.12	1.32	1.83
50 cm	240870	100	24.09	1.27	1.16

length cord	0 cm		30 cm	
	$\mu(\Delta_i)$	$\sigma(\Delta_i)$	$\mu(\Delta_i)$	$\sigma(\Delta_i)$
node 1	1.30	0.89	3.13	4.02
node 14	0.70	0.52	0.86	0.61
node 11	0.67	0.44	0.83	0.54
node 6	0.76	0.48	1.15	0.94
node 15	0.67	0.53	0.88	0.65
node 12	0.70	0.66	0.83	0.63
node 5	0.91	0.65	1.58	0.98

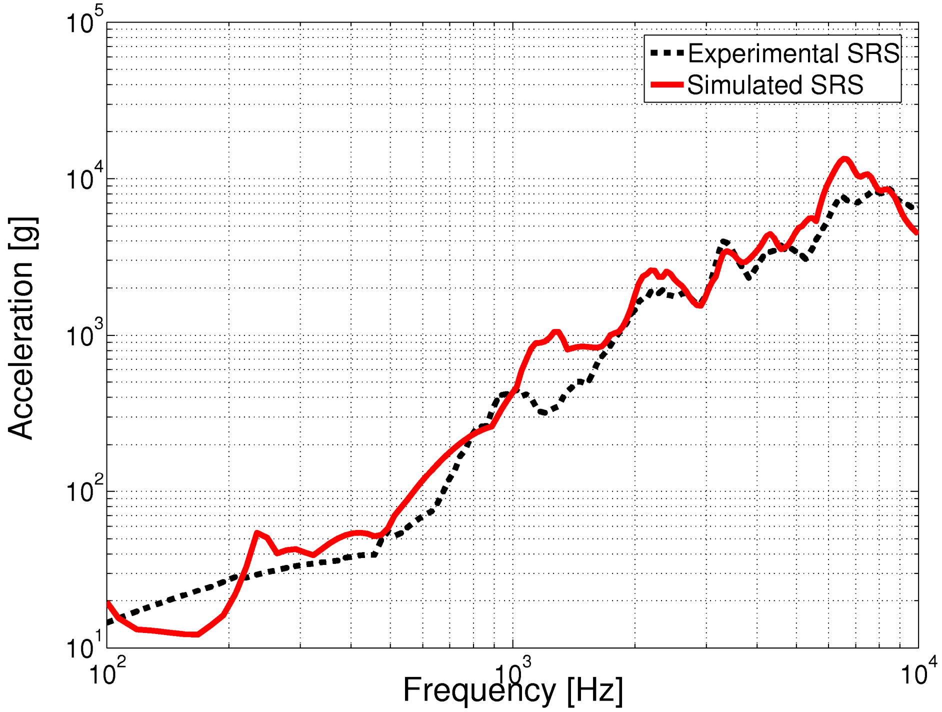
EMS reproduces in a satisfactory way, in terms of SRS, the dynamic behaviour of the plate in the orthogonal direction because the mean frequency difference is inferior than the usual tolerances (< 3 dB)

Energy injected by the EMS

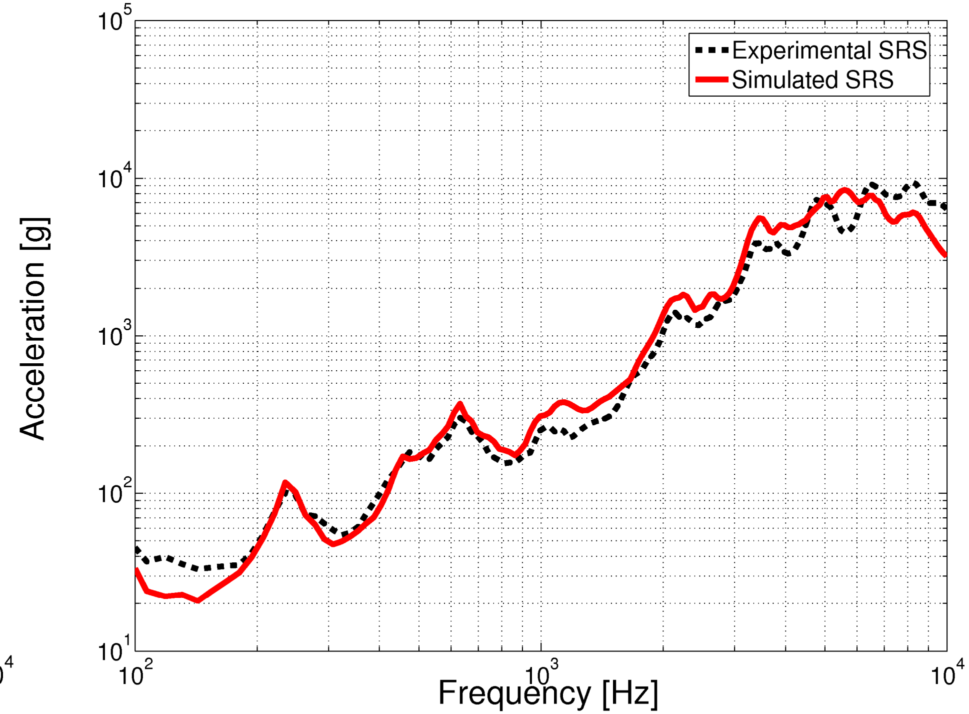


Accelerations measured in orthogonal direction of the plate

At node 1

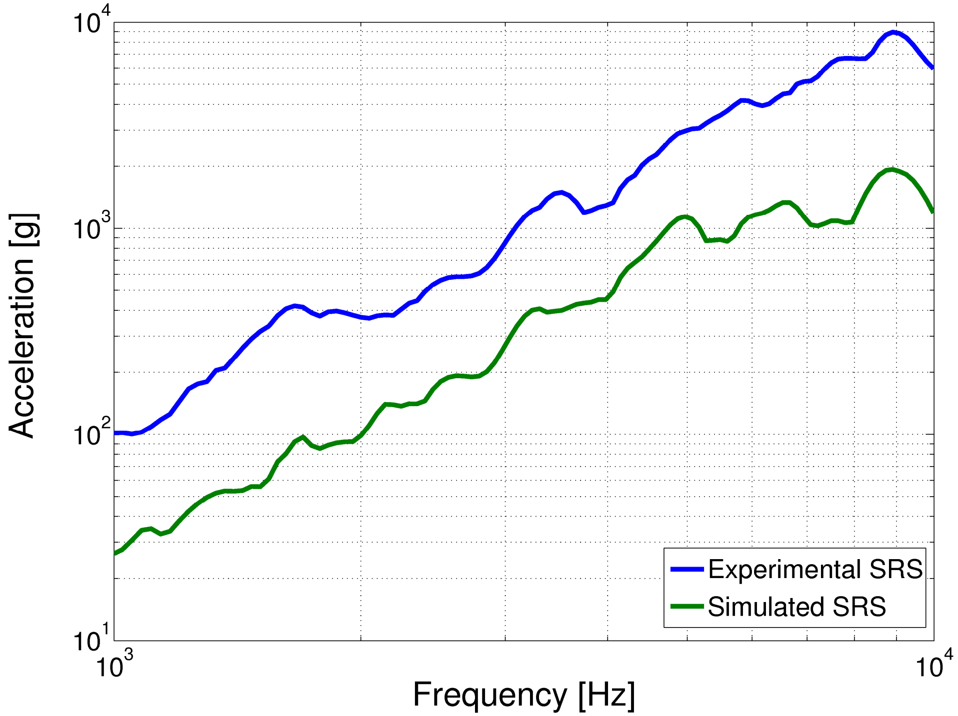


At node 6

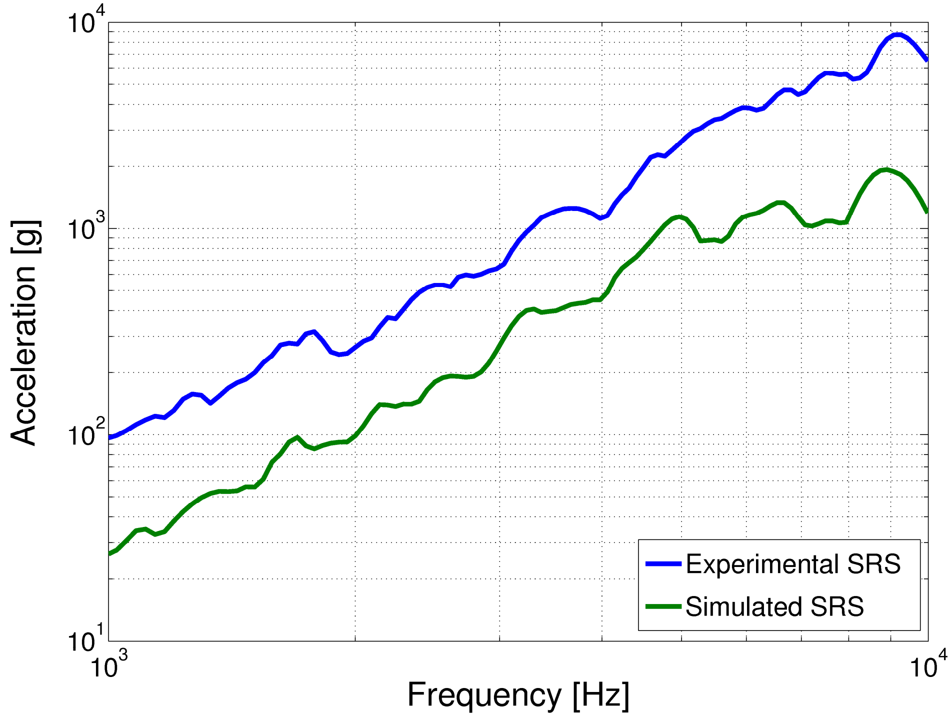


Accelerations measured in the plane of the plate

At node 6

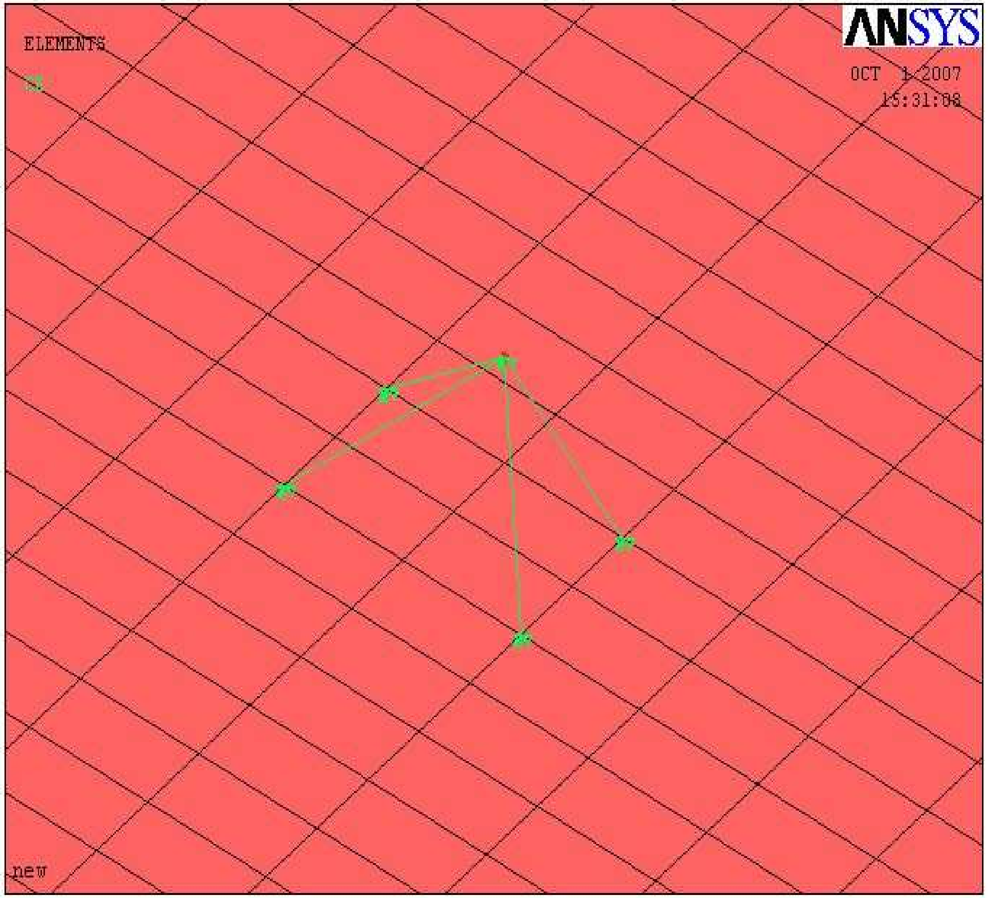


At node 11



The moment arm induced by the measure cube amplifies acceleration levels in-plane directions ⇒ introduction of the dynamic effects of the cube in the FE model

Modelling of the measure cube (1)



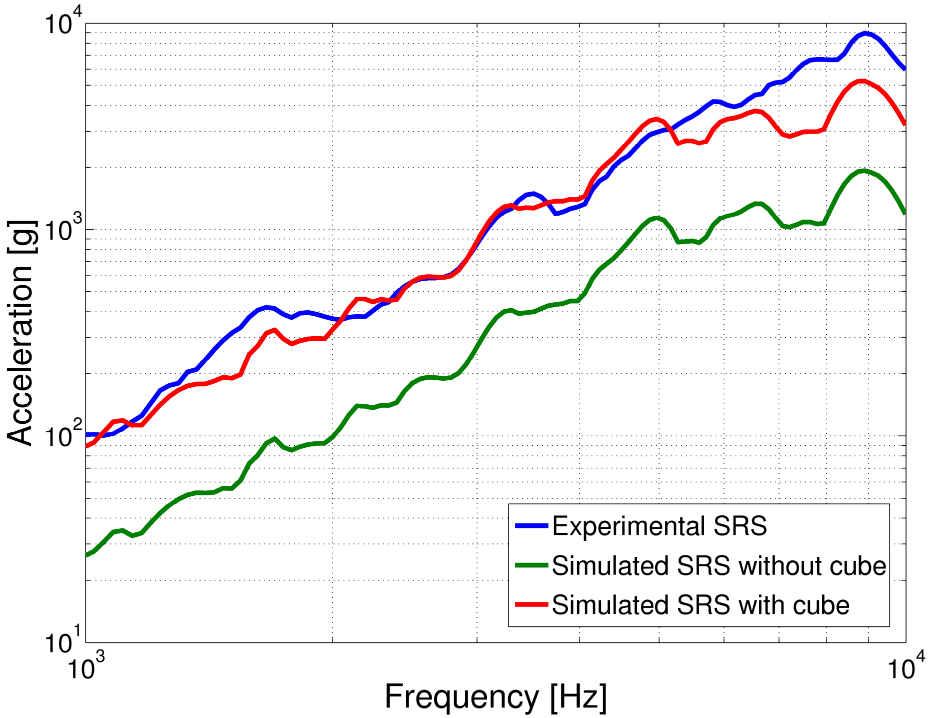
- Modelling of the moment arm with help of CERIG elements
- Cube has been represented by an undeformable pyramid having equivalent geometric dimensions (same base and same height)

Characteristics of the cube

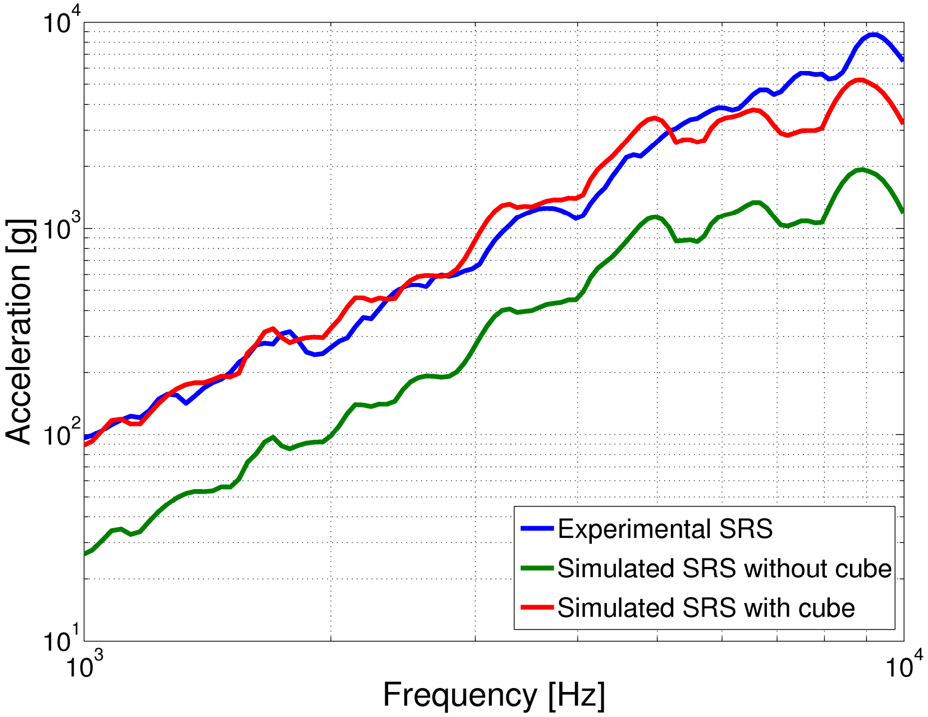
- M_{cube} = 47 g (steel)
- h_{cube} = 20 mm
- S_{cube} = 400 mm²

Accelerations measured in the plane of the plate

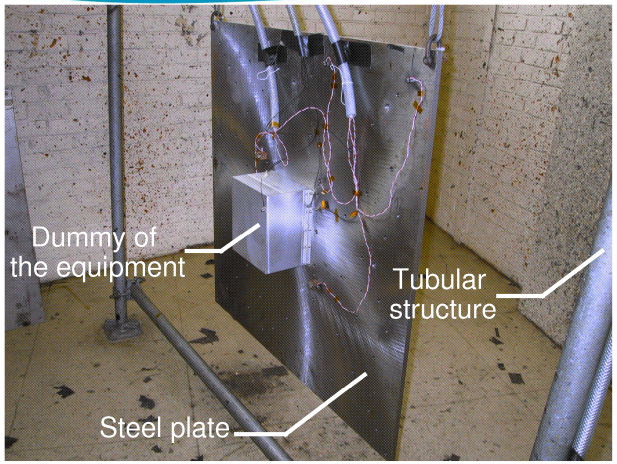
At node 6

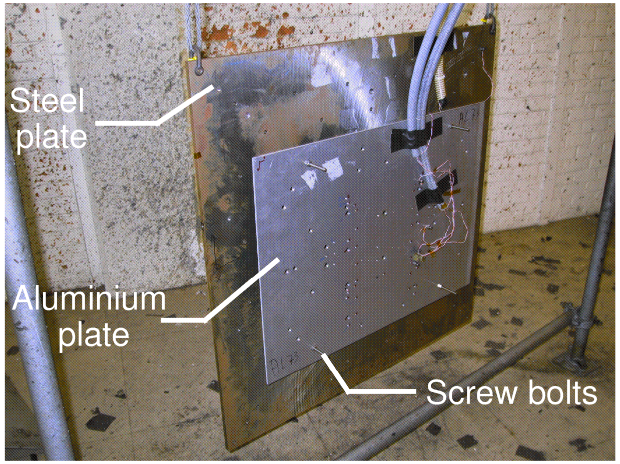


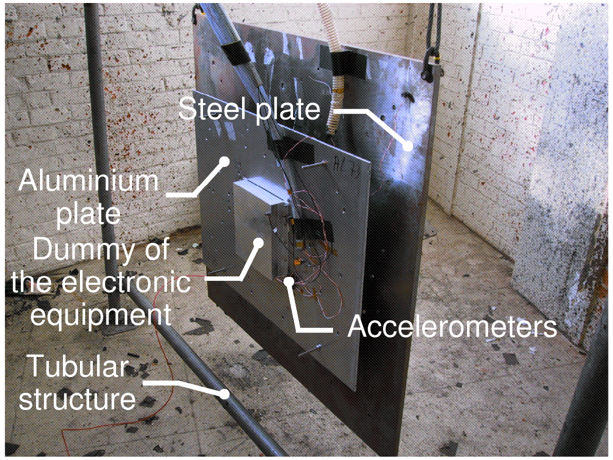
At node 11



Application to other configurations







Configuration 1 | Configuration 2 | Configuration 3

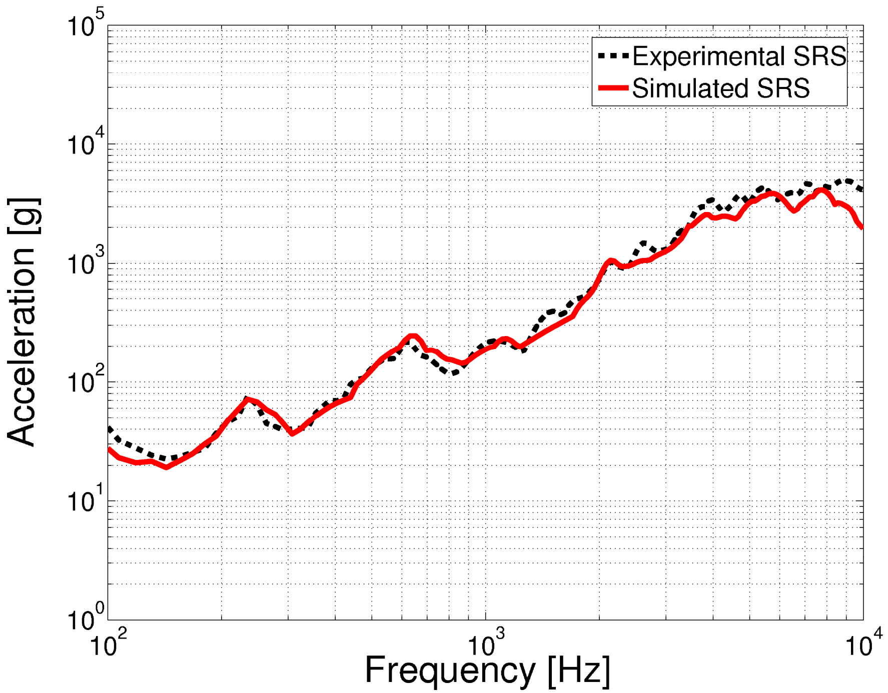
	F_{max} (N)	τ (μs)	$F_{max} * \tau$ (Ns)	μ_G (dB)	σ_G (dB)
Configuration 1	58580	80	4.69	2.43	1.53
Configuration 2	89092	60	5.34	3.36	2.35
Configuration 3	65500	80	5.24	3.35	2.88

Close to 5 Ns

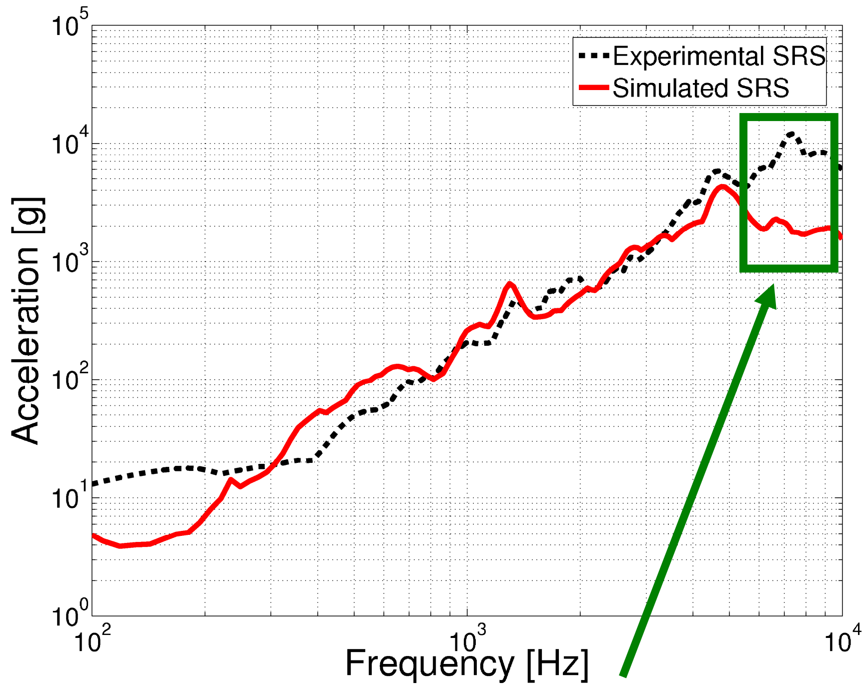
When we apply to these 3 configurations the EMS identified on the reference test facility, we obtain similar results.

Comparison between experimental and simulated SRS

Configuration 2
Steel plate

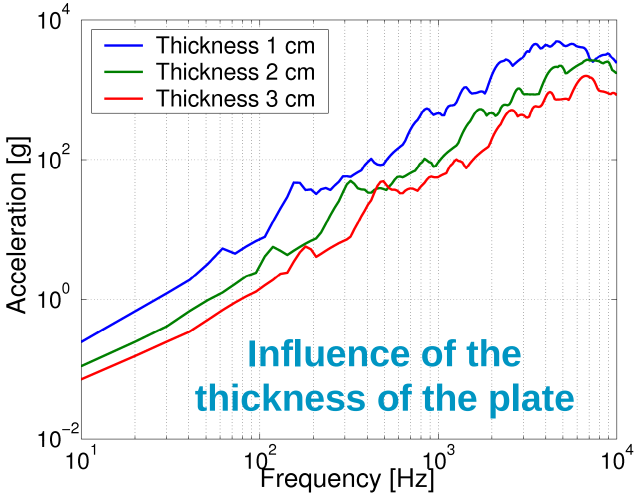


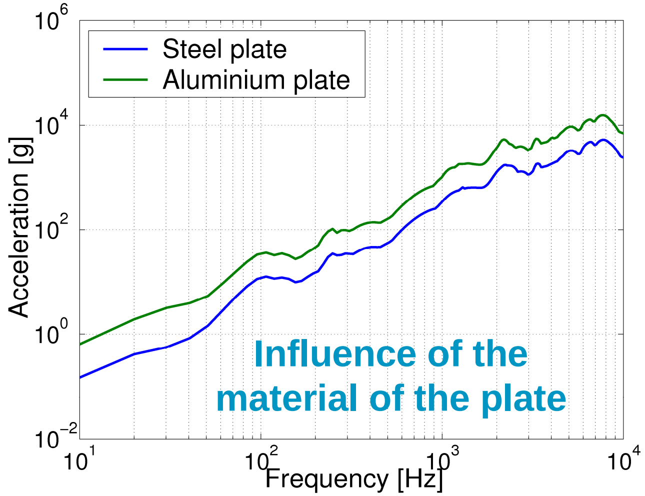
Configuration 2
Aluminium plate

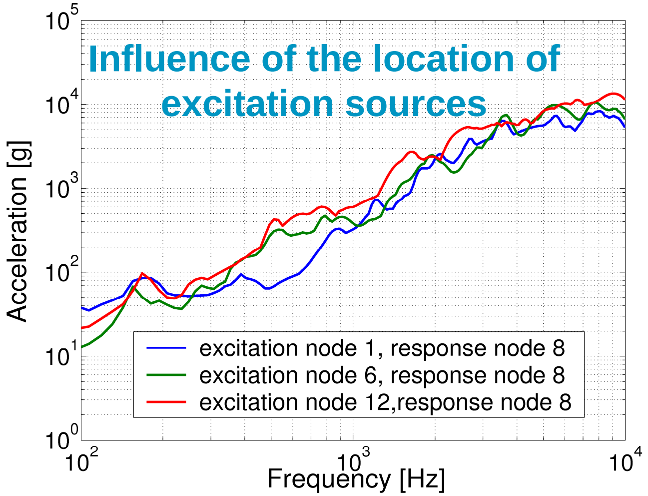


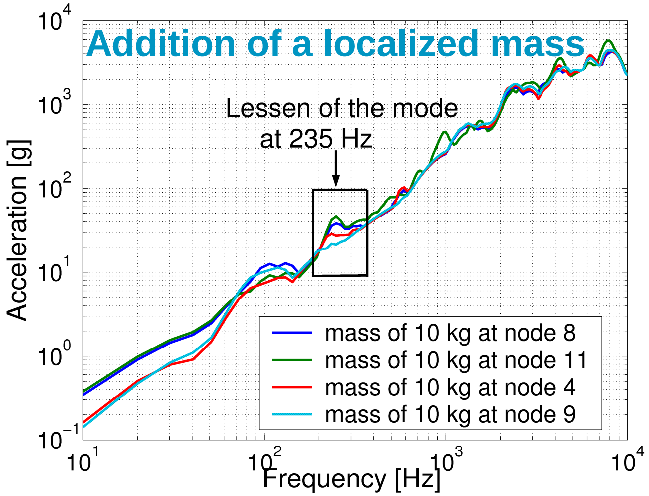
Difficulties to reproduce the SRS at high frequencies=> Modelling of the screw bolts with element beam isn't appropriated ?

Parametric analysis









- ❑ **Ability of Thales Alenia Space ETCA pyroshock test facilities to cover a large range of SRS**

- ❑ **Equivalent mechanical shock + FEM of the test facilities = new way to reduce time spent during calibration stage**

- ❑ **Parametric analysis can be performed to know the influence of main parameters of the test set-up**

- ❑ **Development of new mechanical tools to reach high level specifications in, at least, two axes simultaneously, with reduced overtesting**

CONTACTS

Ch. De Fruytier
Thales Alenia Space ETCA
Industrial Department / Mechanical conception
101 rue Chapelle Beaussart, 6032 Mont-Sur-Marchienne, Belgium
✉: christophe.defruytier@thalesaleniaspace.com

D. Wattiaux, O. Verlinden
Faculté Polytechnique de Mons
Department of Theoretical Mechanics, Dynamics and Vibrations
31 Boulevard Dolez, 7000 MONS, Belgium
✉: david.wattiaux@fpms.ac.be; olivier.verlinden@fpms.ac.be