WAVE APPROACH FOR NONLINEAR SIMULATIONS OF PYROTECHNIC SHOCKS INCLUDING MEDIUM FREQUENCIES

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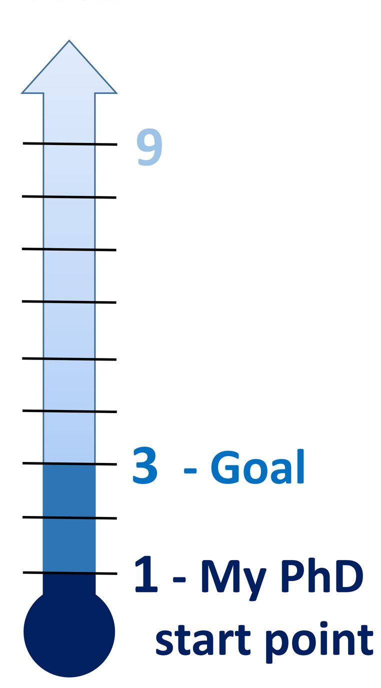
Funding **: ArianeGroup, DGA**

Context

ArianeGroup is increasingly interested in vibration simulation. Simulating the pyrotechnic shocks in SYLDA structure could size the detachment technology. Covering both the large and the medium frequencies is a real challenge that defeated classical numerical softwares, such as explicit finite elements methods. An alternative is proposed by the Variational Theory of Complex Rays (VTCR) [1].

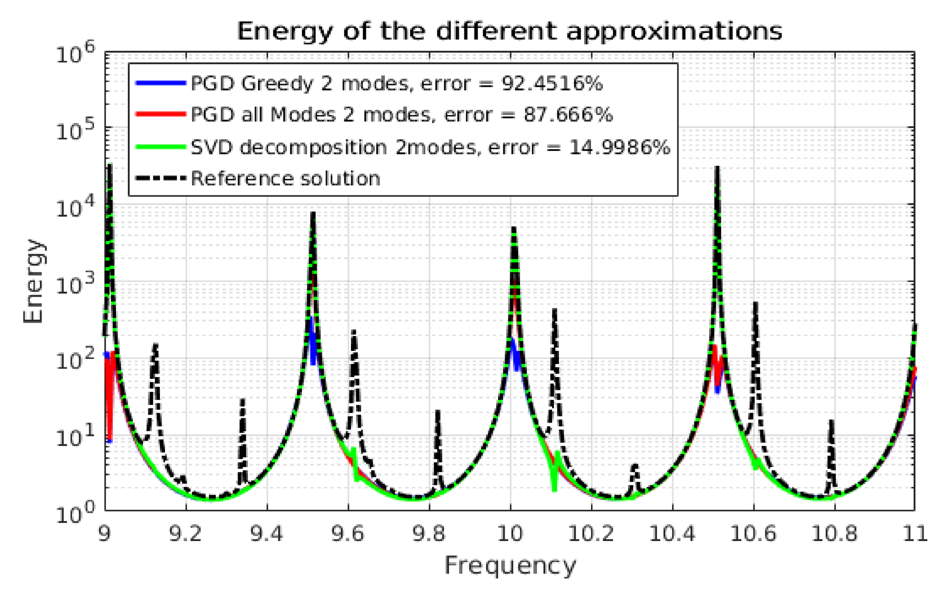
The VTCR is a frequential method that uses waves as shape functions. Currently, it solves linear problems. The goal is to extend it to nonlinear problems, as present in pyrotechnic shocks. Nonlinearities are computationally expensive due to frequency-time inversions. The first key point is to reduce it by proposing a large frequency band resolution.



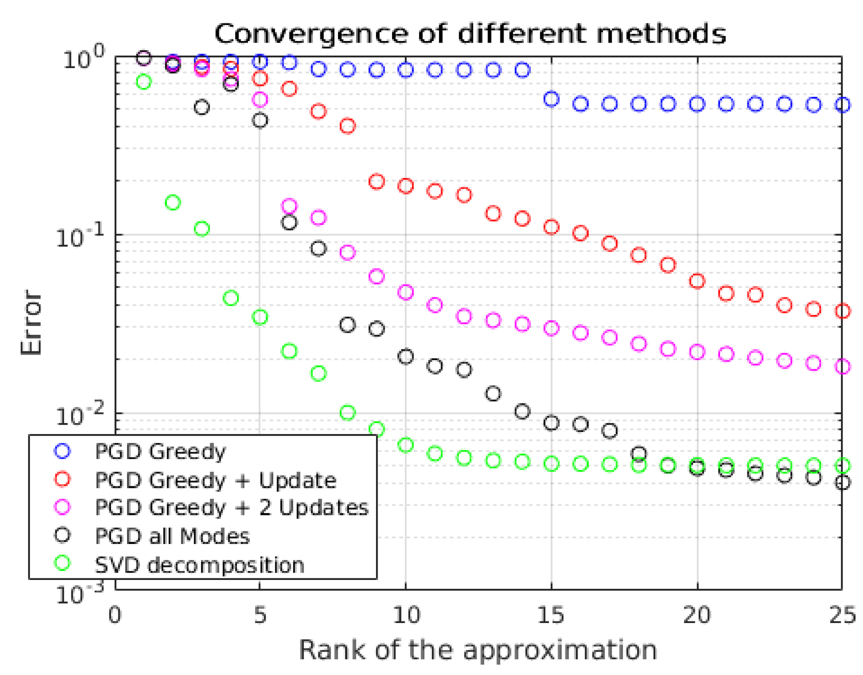
First step to nonlinear problems : large band resolution

Instead of resolving the problem frequency by frequency, we are searching a low rank solution (Prepered Generalized Decomposition : PGD method)[2],[3] :

$$A_\omega \approx A_\omega^M = \sum_m^M \Lambda_m(\theta)\lambda_m(\omega)$$

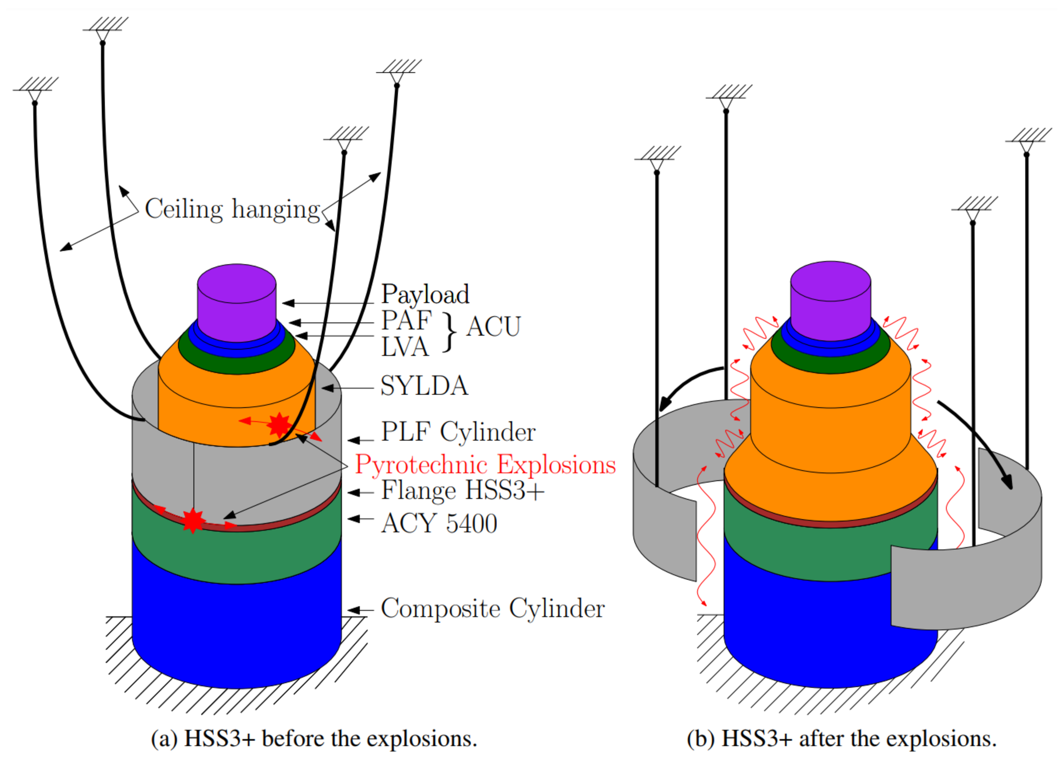


Large band approximated solutions in a square acoustic cavity with different methods (adimensional parameters)

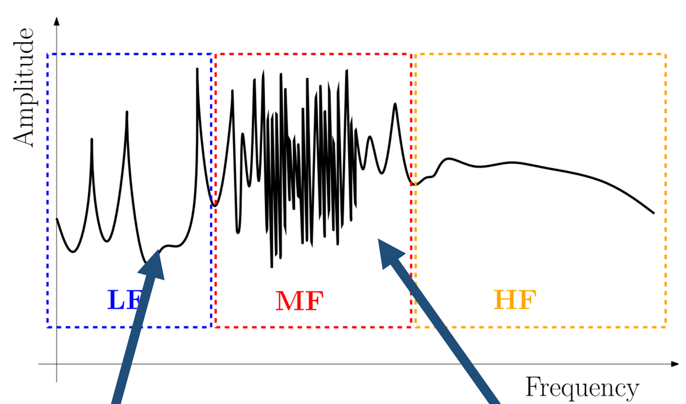


Different methods were developped for large band resolutions, some with good convergence properties

The problem : pyrotechnic shocks in SYLDA structure



It was shown that medium frequency (5 KHz) can not be neglected



Resolution strategy : FEM

Resolution strategy [4] : VTCR

The VTCR method

Intern equations

$$div(\sigma_i) = -\rho_i\omega^2 u_i \quad \sigma_i = K_i\epsilon(u_i) \quad in\ \Omega_i$$

For plates :

$$\Delta\Delta w = \frac{12(1-\nu^2)\rho\omega^2}{(1+i\eta)E}w$$

$$w_{(x)} = \int_k W_{(k)}e^{kx}$$

Low part — Fast part

$$k^4 = \frac{12(1-\nu^2)\rho\omega^2}{(1+i\eta)E}$$

Border conditions…

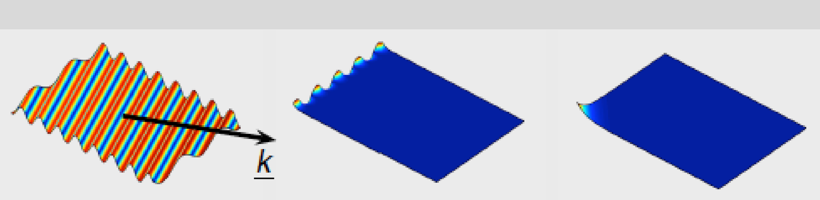
$$u_i = u_{id} \quad over\ \delta_u\Omega_i$$
$$\sigma_i n_i = F_{id} \quad over\ \delta_F\Omega_i$$

… and interface conditions

$$\sigma_1 n_1 + \sigma_2 n_2 = 0 \quad u_1 = u_2 \quad over\ \Gamma$$

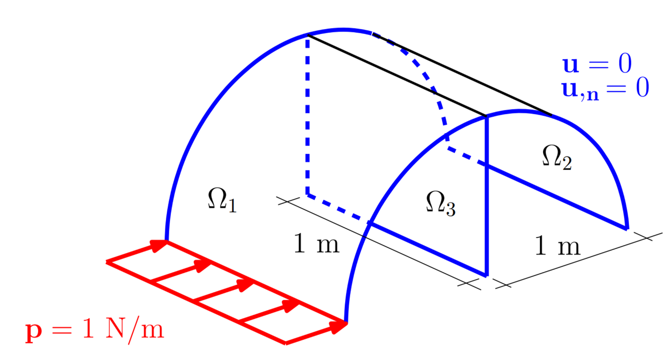
Variational formulation → **Linear system** ← **Complex ray space**

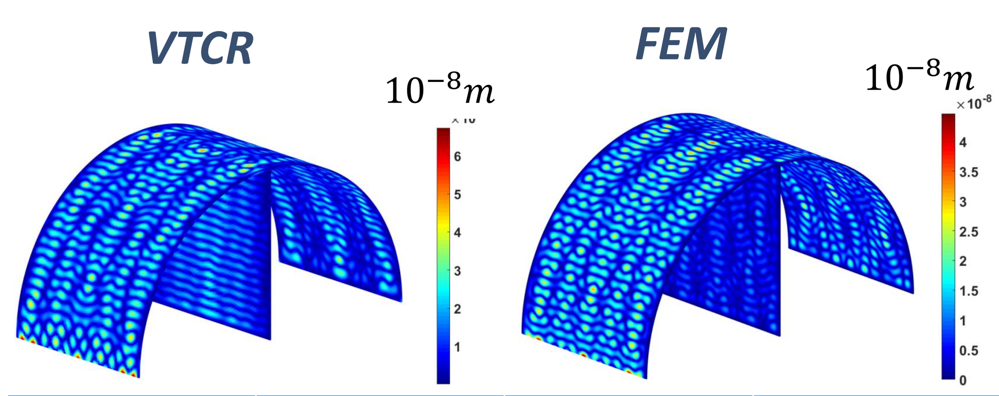
$$W_{(x)} = \int_{\varphi\in C_{int}} W_{(\varphi)}e^{k(\varphi).x}dl + \int_{\varphi\in C_{int}} W_{(\varphi)}e^{k(\varphi).x}dl + \int_{\varphi\in C_{int}} W_{(\varphi)}e^{k(\varphi).x}dl$$



The VTCR efficiency (TAPYROSS) :

Problem solved at 1 frequency (2000Hz)





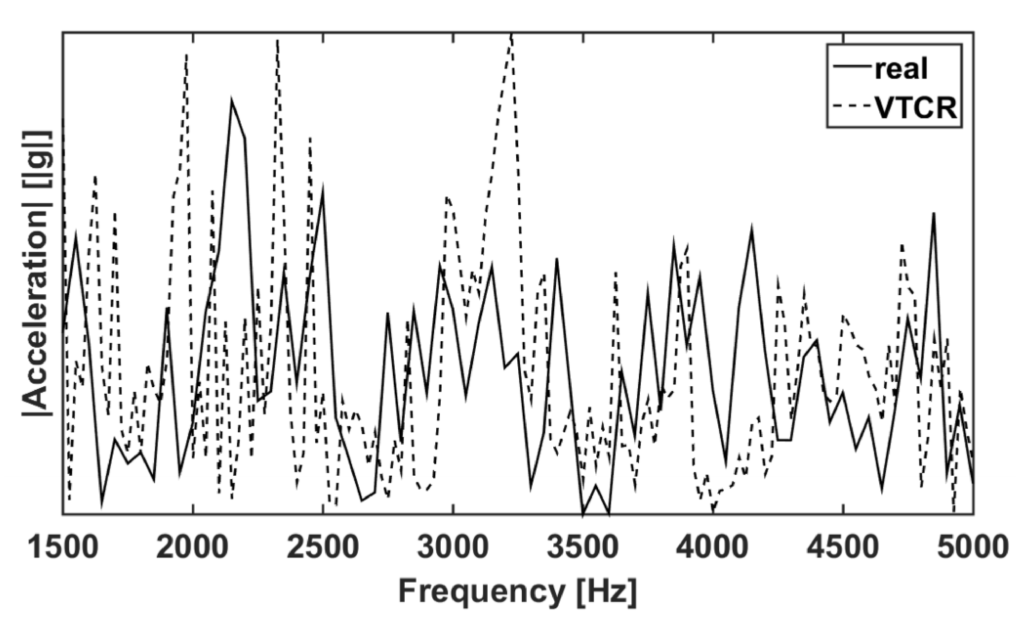
	DoFs	Time	Memory
VTCR	612	4 sec	70 Kb
FEM	3 millions	1153 sec	10 Gb

The VTCR is an adapted method for medium frequency

SYLDA simulations (TAPYROSS) :

	DoFs
In-plane propagative normal rays	$128 \times (40\ SD)$
In-plane propagative shear rays	$128 \times (40\ SD)$
Out-of-plane propagative normal rays	$256 \times (40\ SD)$
Out-of-plane evanescent rays (per boundary)	$128 \times (40\ SD)$
Out-of-plane evanescent rays (per corner)	$1 \times (40\ sd)$

Sensor near the satellite – VTCR, Out of plane response



Project milestones

Validation and extension to large band resolution in shells

TAPYROSS is a vibration software simulator using VTCR to simulate vibrations in SYLDA. We will reduce computational time by implementing the large band resolution.

Resolution of non linear problems

The objective is to extend VTCR to non linear problems as visco-plasticity and damage. We expect to develop an algorithm based on many passages between frequency and time domain, hence obtaining a large band resolution.

Conclusions

The VTCR is a strong alternative for medium frequency resolution. However, computational costs increase when the solution over a large frequency band is needed. Therefore we developed algorithms based on Propered Generalized Decompositions.

The following works will extend the large band resolution to shells. This opens the way to non linear problems.

References

[1] Variational theory of complex rays applied to shell structures: in-plane inertia, quasi-symmetric ray distribution, and orthotropic materials (2015) Alessandro Cattabiani, andrea Barbarulo, Hervé Riou, Pierre Ladevèze, Computational Mechanics DOI: 10.1007/s00466-015-1214-6

[2] A quasi-optimal coarse problem and an augmented Krylov solver for the Variational Theory of Complex Rays, L. Kovalevsky, P. Gosselet *nternational Journal for Numerical Methods in Engineering*, Wiley, 2016, 107 (11), pp.903-922

[3] Ladevèze, P., Passieux, J.-C., and Néron, D. (2010). The LATIN multiscale computational method and the Proper Generalized Decomposition. Computer Methods in Applied Mechanics and Engineering, 199:1287–1296.

[4] Chevreuil, M., Ladevèze, P., and Rouch, P. (2007). Transient analysis including the low- and the medium frequency ranges of engineering structures. Comput. Struct., 85(17-18):1431–1444.