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IMPROVING ACOUSTIC STEALTH

Analysis of the vibro-acoustic behavior of a submarine hull on a wide frequency range using experimental and numerical approaches

Valentin Meyer[1], Laurent Maxit[2]

[1] Naval Group Research, Ollioules, France
[2] Laboratoire Vibrations Acoustique, INSA Lyon, France

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POWER AT SEA

CONTEXT

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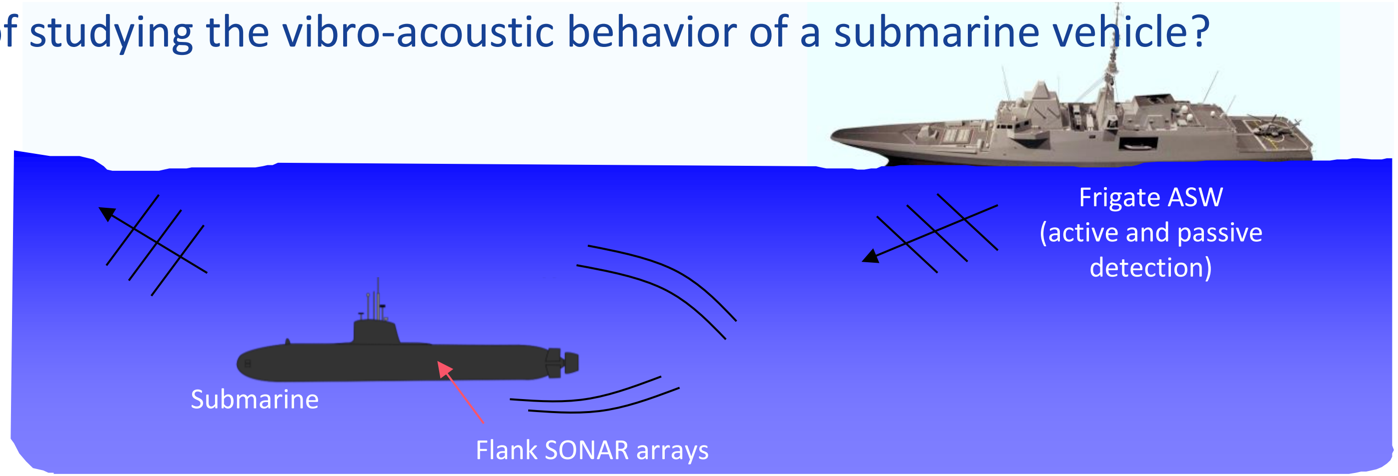
Interest of studying the vibro-acoustic behavior of a submarine vehicle?



Hull acoustic performances	Operational capability
Far-field radiated noise	Acoustic stealth
Reflection/scattering	Target strength
Self radiated noise	Sonar performances

GOALS

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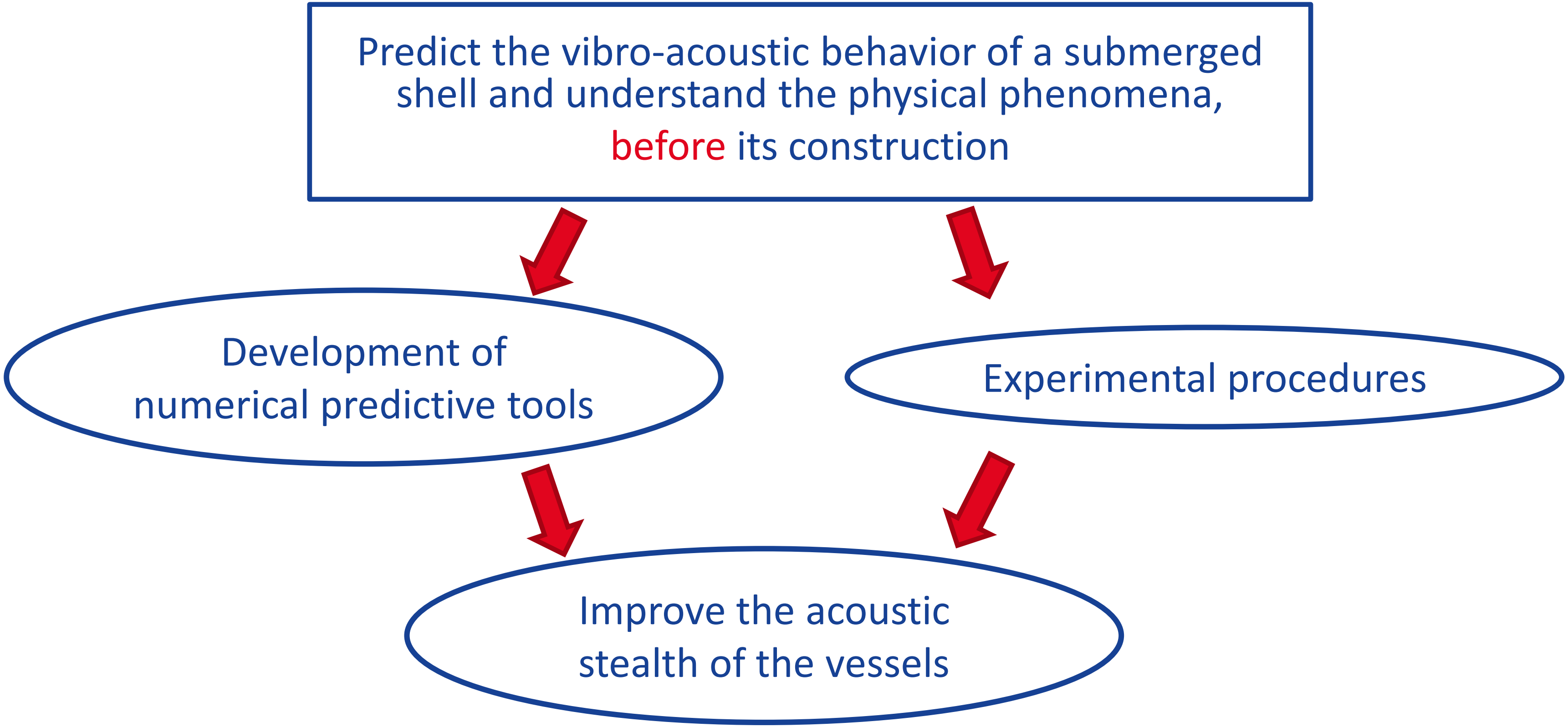

CURRENT CHALLENGES IN NUMERICAL MODELING

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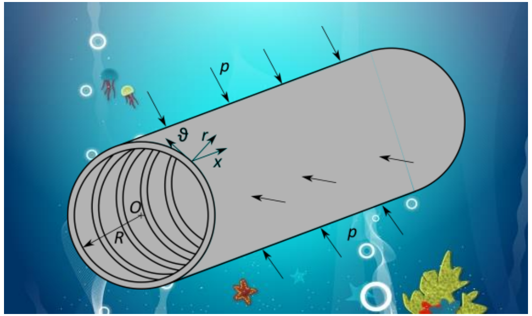
- SONAR is able to detect a noise source from a few Hz to dozens of kHz
  - ➢ Techniques to predict the vibro-acoustic response for a wide frequency range
  - ➢ Simplified model of a cylindrical shell submerged in an infinite fluid medium



Low frequency range: FEM/BEM

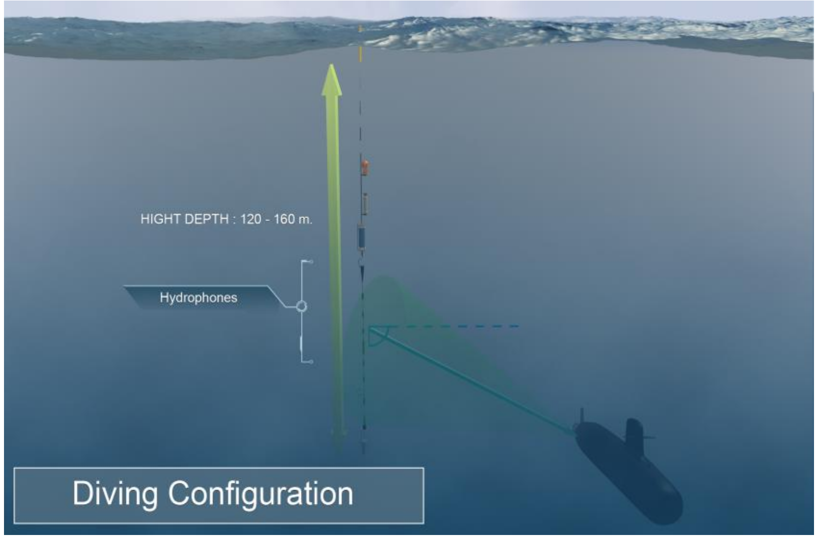
- Structural complexity
- Calculation cost depends on mesh size

High frequency range: SEA

- Energy balance between subsystems
- Strong assumptions
- Only global results

How to model on a wide frequency range?

CHALLENGES IN MEASUREMENTS



Sketch of the MARS500© hydrophone array

Experiments at sea are:

- costly and time-consuming
- not ideal to understand the physical phenomena
- only when the submarine is built

How can the vibro-acoustics of a stiffened shell be measured?

Contents

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1. The CTF method

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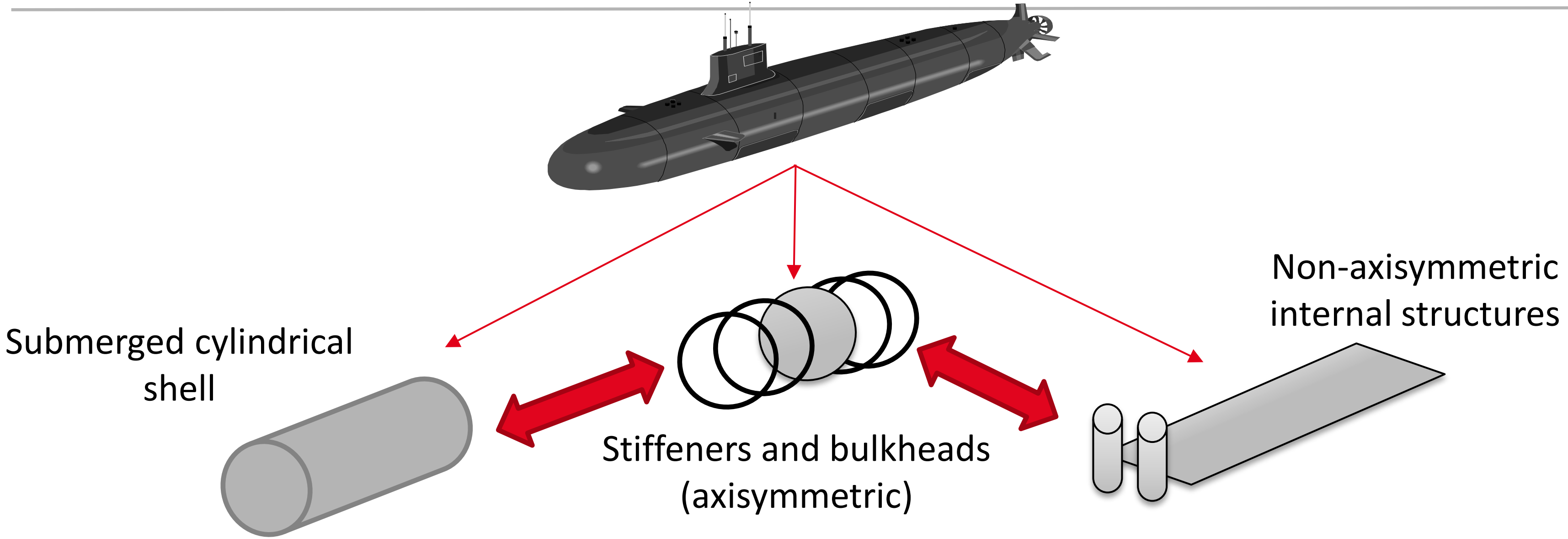
A SUB-STRUCTURING APPROACH:



*L. Maxit, J.-M. Ginoux, Prediction of the vibro-acoustic behavior of a submerged shell non periodically stiffened by internal frames, JASA 128(1):137-151, 2010.

**V. Meyer, L. Maxit, J.-L. Guyader, T. Leissing, Prediction of the vibroacoustic behavior of a submerged shell with non-axisymmetric internal substructures by a condensed transfer function method, JSV, 360:260-276, 2016.

PRINCIPLE OF THE CONDENSED TRANSFER FUNCTION METHOD

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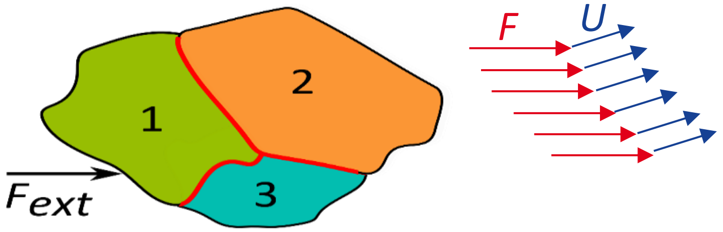
- Extension of the admittance method for line coupled systems:



$$Mechanical\ admittance\ Y = \frac{displacement\ U}{force\ F}$$

Solving the coupling forces between the subsystems:

$$[F_c] = \left([Y_{ij}^1] + [Y_{ij}^2] + [Y_{ij}^3]\right)^{-1}[\tilde{U}]$$

- Requires only characteristics from the uncoupled subsystems
- The admittances can be calculated by any method

THE CTF METHOD APPLIED TO STIFFENED SUBMERGER CYLINDRICAL SHELLS

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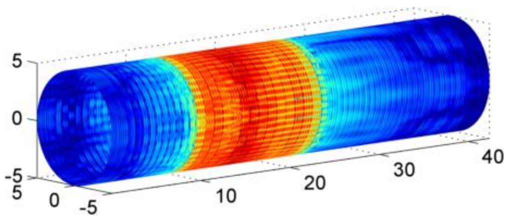
Calculation of the admittances for each subsystem :

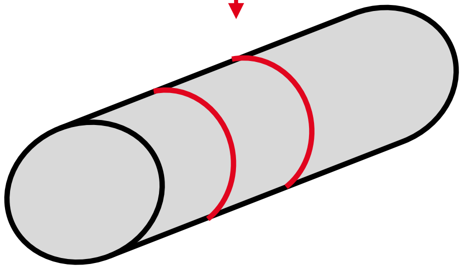
Fluid-loaded cylindrical shell
Analytical solution

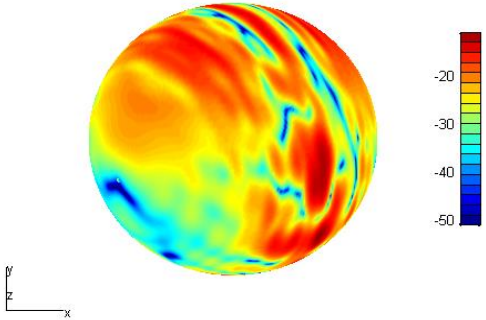
Stiffeners and bulkheads
Finite Elements Method

CTF Method



Radial displacements





Far-field radiated pressure

THE CTF METHOD AS AN INDUSTRIAL TOOL

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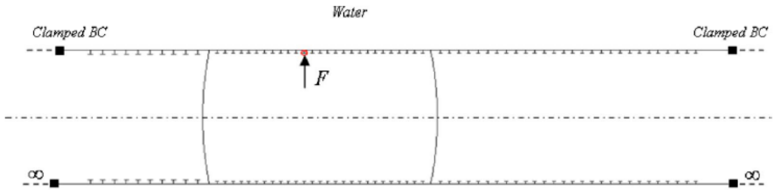
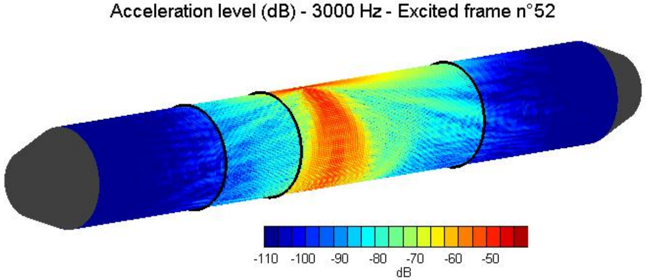
ORCAA: tool developed at Naval Group for vibro-acoustics predictions





Advantages of the hybrid method:

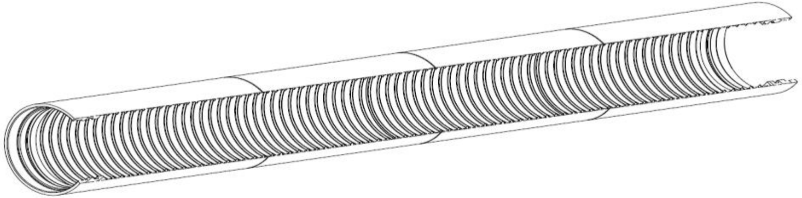
- Low computation costs compared to FEM/BEM
- Possibility to couple subsystems described by different approaches
- No theoretical frequency limit for the CTF method
- High versatility compared to analytical methods: different stiffeners spacing, various internal structures

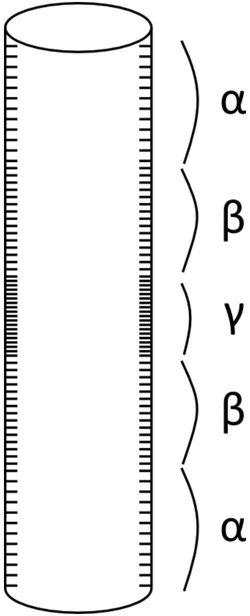
2. Experimental work

DESCRIPTION OF THE SUBSYSTEMS

Stiffened cylinder in steel

- Length: 1,5 m
- Radius: 100 mm
- Thickness: 1,5 mm
- Two end caps
- 3 different stiffeners spacing divided in 5 sections





EXPERIMENTAL SETUP

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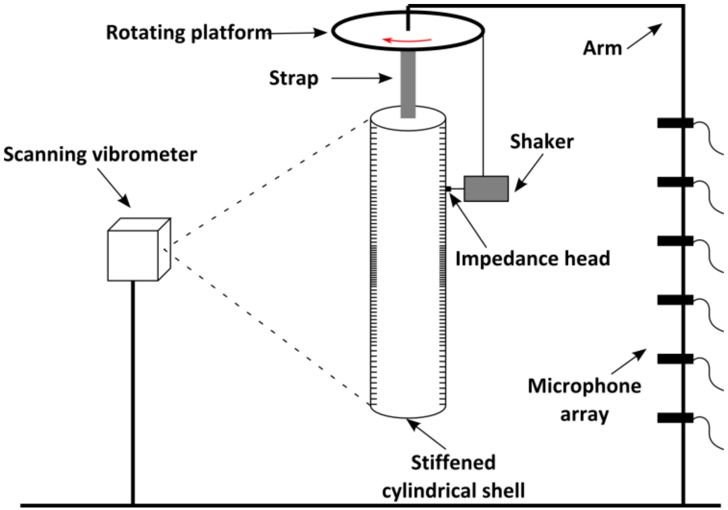
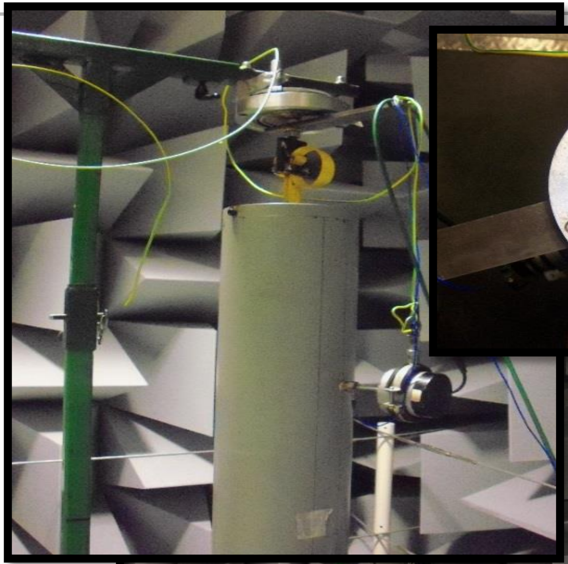
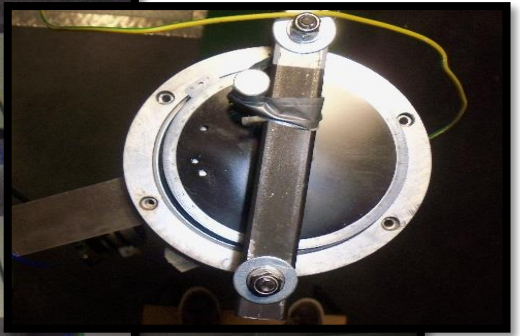
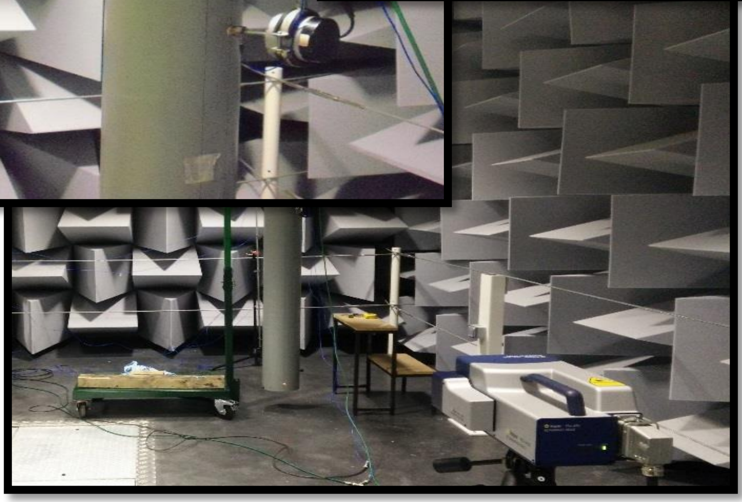
- In air
- Semi-anechoic room









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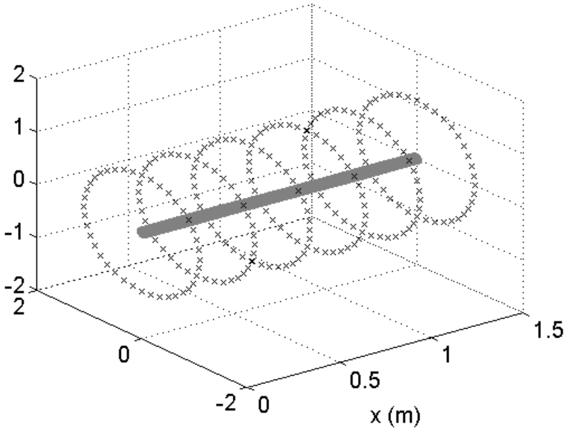
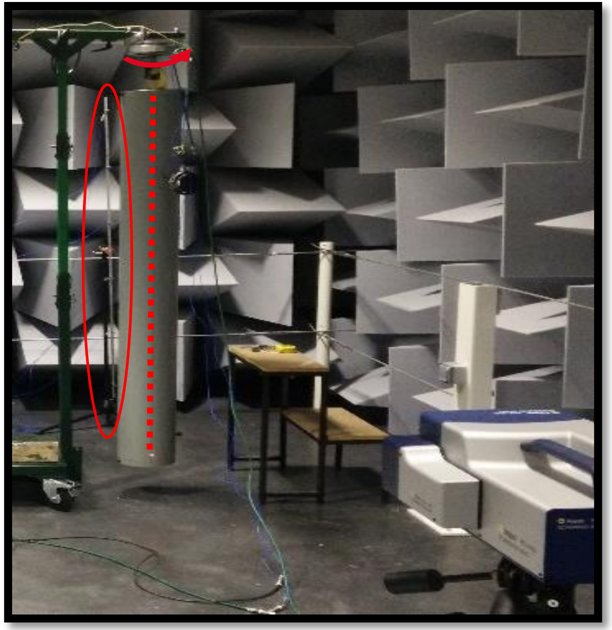
DEFINITION OF THE SCANNING GRID

- The maximum distance between two consecutive measurement to capture the physics is 15 mm
- It results in 101 points lengthwise
- Measurement every 9° on half the cylindrical shell (assumption of symmetrical system)
- Microphone array to measure the pressure around the cylindrical shell





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3. Results and discussion

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MAPS OF RADIAL VELOCITIES

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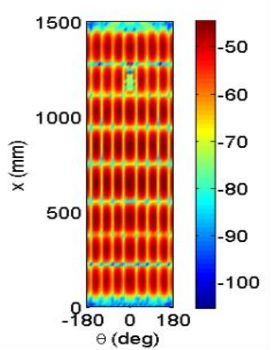
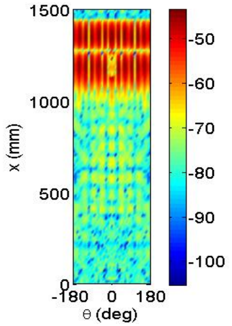
<tr><td>Experimental Work</td><td>1980 Hz

</td><td>3580 Hz

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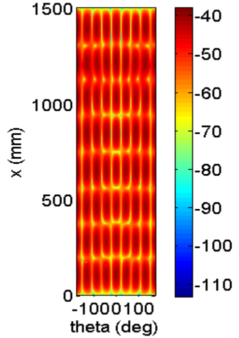
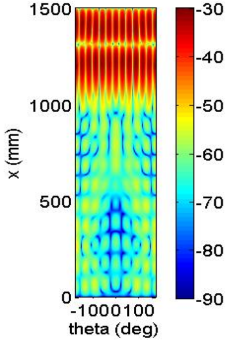
<tr><td>CTF method</td><td>
</td><td>
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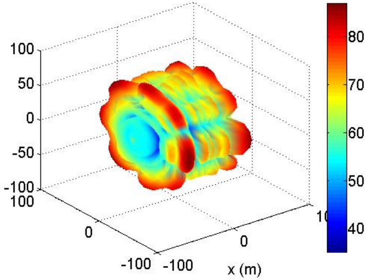
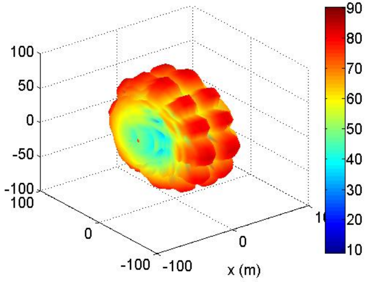
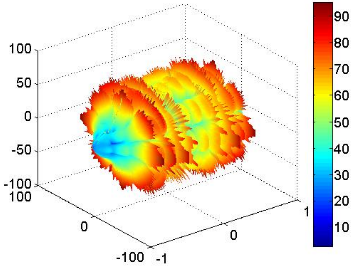
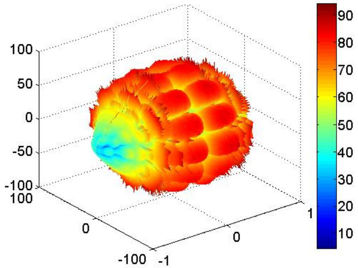
THE STATIONARY PHASE THEOREM TO CALCULATE THE RADIATED PRESSURE

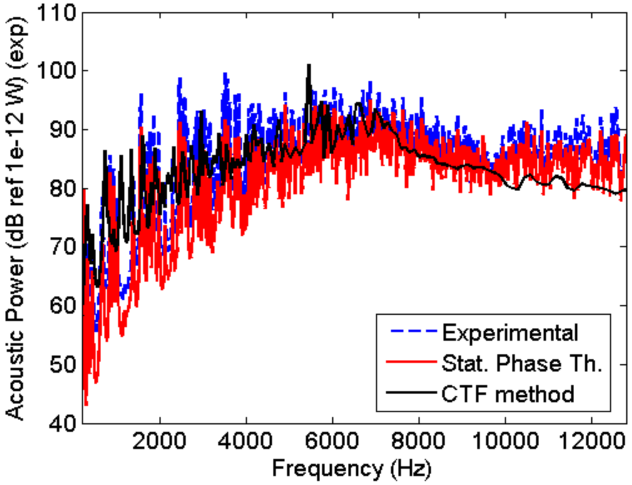
$$p(r,\xi,\theta) = \sum_{n=-\infty}^{+\infty} \frac{2j\,\rho_0\,\omega^2}{r\,k_0\,\cos\xi}\,\frac{\tilde{\tilde{W}}(-k_0\sin\xi,n)}{H_n^{(2)\prime}(R\,k_0\cos\xi)}\,e^{-jrk_0+jn(\theta+\frac{\pi}{2})}$$

	Global mode *(m,n)=(4,4)*	Local mode
Experimental Work	*1980 Hz* 	*3580 Hz* 
CTF method		

ACOUSTIC POWER RADIATED FROM THE SHELL

Power estimated by 3 means :

- full experimental: summation over the microphone array
- hybrid: experimental vibrations + stationnary phase theorem + integral over an enclosing sphere
- full numerical: CTF method + stat. phase th. + integral over an enclosing sphere



4. Summary

Summary

- A numerical method and an experimental procedure have been presented to study the response of a stiffened cylindrical shell
- The vibrations and radiated pressure of a scale model have been measured and calculated and some physical phenomena have been discussed
- Experimental validation of the numerical method

Perspectives:

- Optimization of the submarine and test new designs to improve acoustic stealth of submarines

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Thank you for your attention

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