Large Eddy Simulation of the tonal noise generated by a gate valve in nuclear power plants

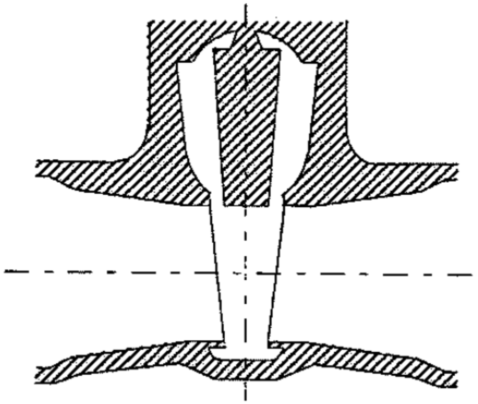
R. Lacombe, P. Lafon, F. Daude, F. Crouzet, J. Berland (EDF R&D, LaMSID)
C. Bailly (LMFA)
W.D. Henshaw (LLNL)

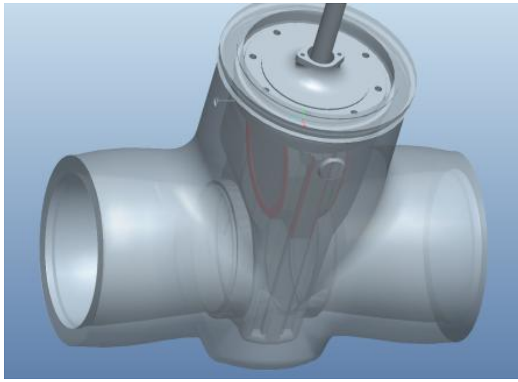
11th Symposium on Overset Composite Grids and Solution Technology
Dayton, OHIO USA

Introduction

Industrial Background

- Motivations : tonal noise generated by gate valves in steam channel of power plants

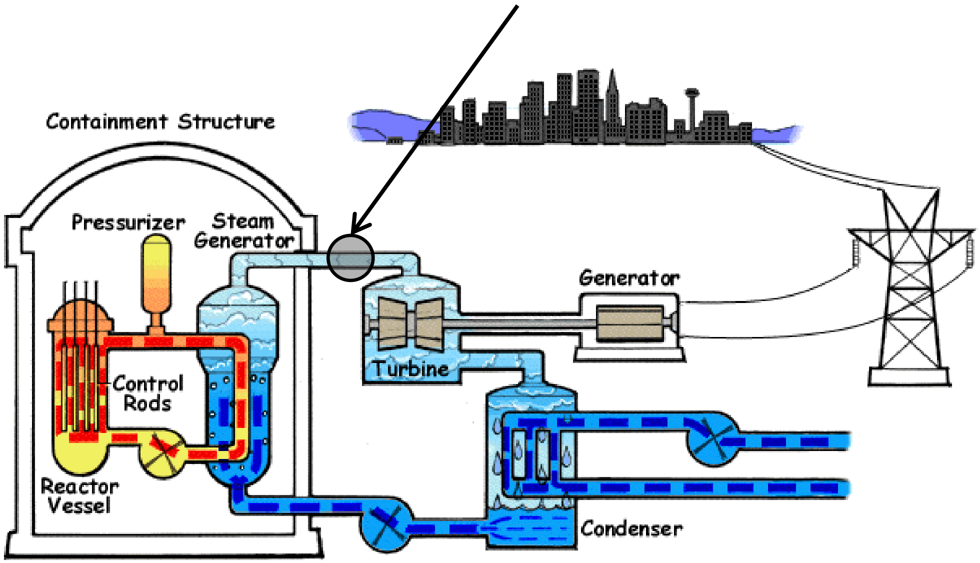




- Non-linear aeroacoustic interactions in confined flows
- High noise and vibration levels

- Needs of tools to understand and predict this phenomenon
  - Non-linear interaction
  - Complex geometry

Steam Isolation Valve



http://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html

Scheme of a PWR

Introduction

Physics of the aeroacoustic interaction (example of a side branch)

Interaction between

Flow instability

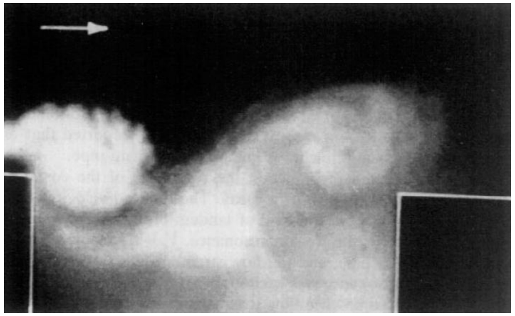
Unsteady vorticity field

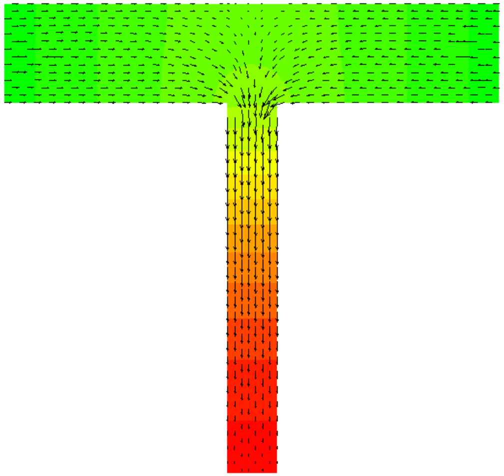
Rossiter's mode (number of vortices in the cavity length)

Acoustic resonance

Acoustic particle velocity field

Acoustic mode





Two physics with different characteristic length scales

Lock-in phenomena: coupling between Rossiter's and duct modes

Introduction

Numerical approach

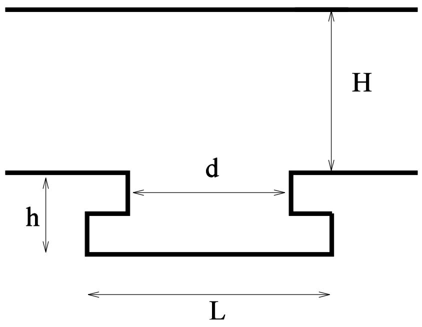
- The simulation needs to:
  - Compute the aerodynamic and acoustic fields in the same simulation
  - Accurately resolve high wavenumber fluctuations
  - Use low-dissipative and low-dispersive schemes
  - Deal with complex geometry

- Development of *Code_Safari*
  - Compressible turbulent flow
  - Coupling between flow and acoustic
  - Application to configurations with industrial revelance

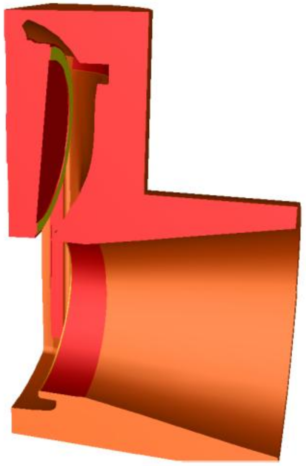
Introduction

Step of the study

- First study on a simplified 2D geometry to show the ability of *Code_Safari* to capture the nonlinear aeroacoustic interaction



- Numerical simulation on the real geometry
  - Complex 3D geometry



Outlines

Modeling and computational aspects

Numerical approach

Use of Overset grids

Simplified two-dimensionnal geometry

Simplified 2D geometry and flow conditions

Computational domain

Results

Real geometry

Meshing from a CAD

Computational domain and flow conditions

Results

Conclusions & Perspectives

Outlines

Modeling and computational aspects

Numerical approach

Use of Overset grids

Simplified two-dimensionnal geometry

Simplified 2D geometry and flow conditions

Computational domain

Results

Real geometry

Meshing from a CAD

Computational domain and flow conditions

Results

Conclusions & Perspectives

Modeling and computational aspects

Numerical approach

- Simulation performed with *Code_Safari* (Emmert PhD 2007, Daude *et al.* AIAA Paper 2008)*.*
  - 3D compressible unsteady Navier-Stokes equations written in curvilinear coordinates
  - Spatial discretization: optimized high order centered finite difference schemes (Bogey & Bailly JCP 2004)
  - Time integration: explicit Runge-Kutta schemes
  - Selective filtering: optimized centered low-pass filters (Bogey & Bailly JCP 2004)
  - LES strategy: approach based on relaxation filtering (Bogey & Bailly JFM 2009)

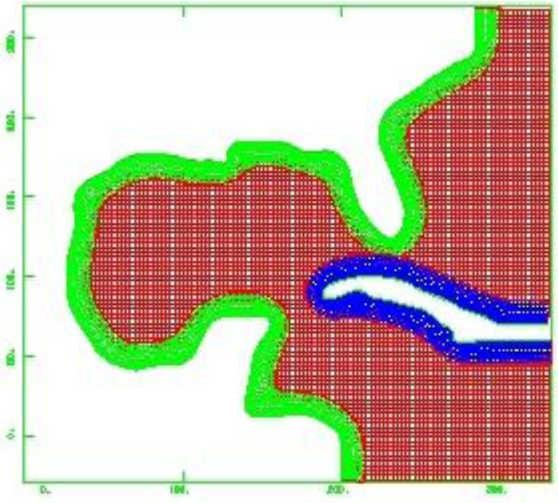
- Limited to cartesian meshes
  - Overset-grid techniques to extend to complex geometry

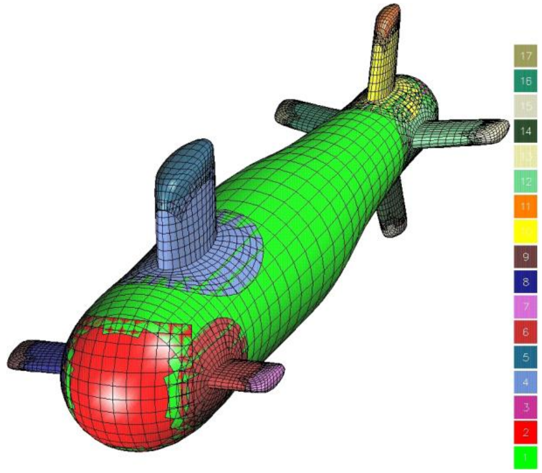
Modeling and computational aspects

Use of overset grids

- Use of overset-grid techniques with high order interpolation procedure (Delfs AIAA Paper 2001)

- Use of the free library *Overture* developed at Lawrence Livermore National Laboratory (Henshaw 1998)





- Communications performed via high-order Lagrangian polynomials (Scott & Sherer JCP 2005, Desquesnes *et al.* JCP 2006)

Outlines

Modeling and computational aspects

Numerical approach

Use of Overset grids

Simplified two-dimensionnal geometry

Simplified 2D geometry and flow conditions

Computational domain

Results

Real geometry

Meshing from a CAD

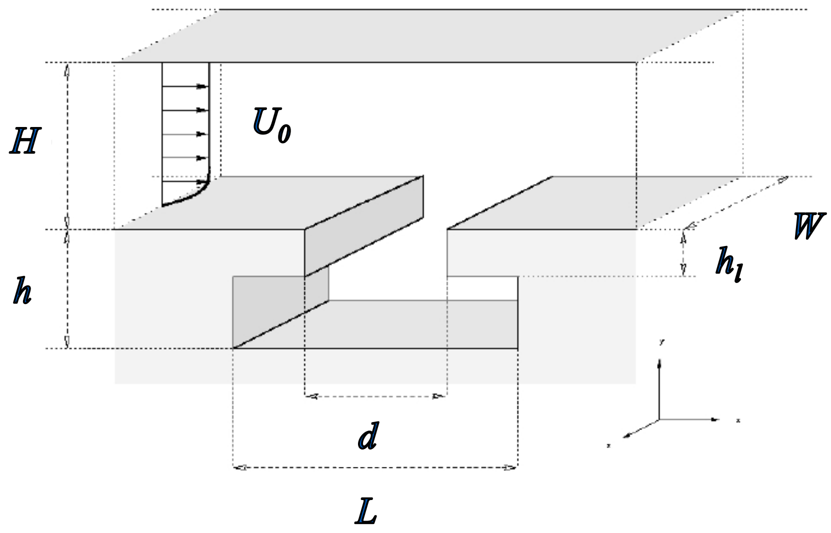
Computational domain and flow conditions

Results

Conclusions & Perspectives

Simplified two-dimensionnal geometry

Simplified 2D geometry and flow conditions



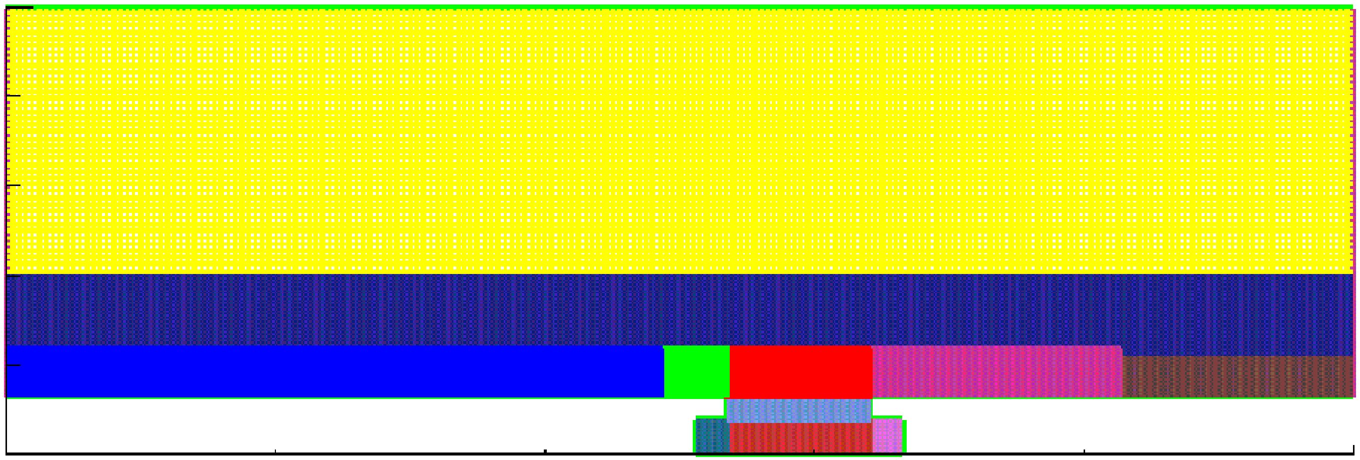
- 2D cavity in a duct, extrusion in z direction
- Dimensions
  - $H = 0.115$ m
  - $h = 0.020$ m
  - $d = 0.050$ m
  - $L = 0.061$ m
  - $h_l = 0.008$ m
- Flow conditions
  - $0.1 < M_0 < 0.25$

- Experiments have also been done on this geometry
- Flow profile upstream the cavity fits the experimental one
  - Upstream boundary layer defined by

$$\frac{u_b(y)}{U_0} = \left(\frac{y}{\delta}\right)^{1/n}$$ with $\delta = 8.8$ mm and $n = 8.5$

Simplified two-dimensionnal geometry

Computational domain



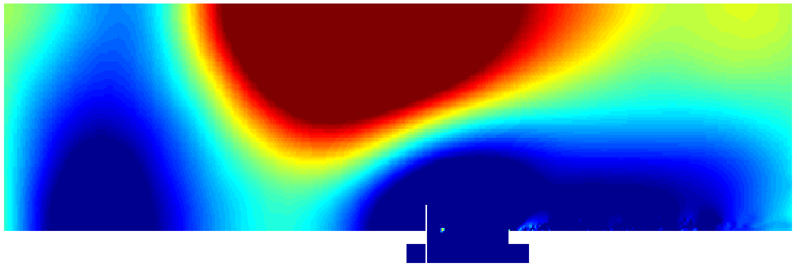
- 11 composite grids
- 38 million points
- Periodic boundary conditions in the spanwise direction
- Slip condition on the upper duct wall

- Computed by 206 cores

Simplified two-dimensionnal geometry

Results

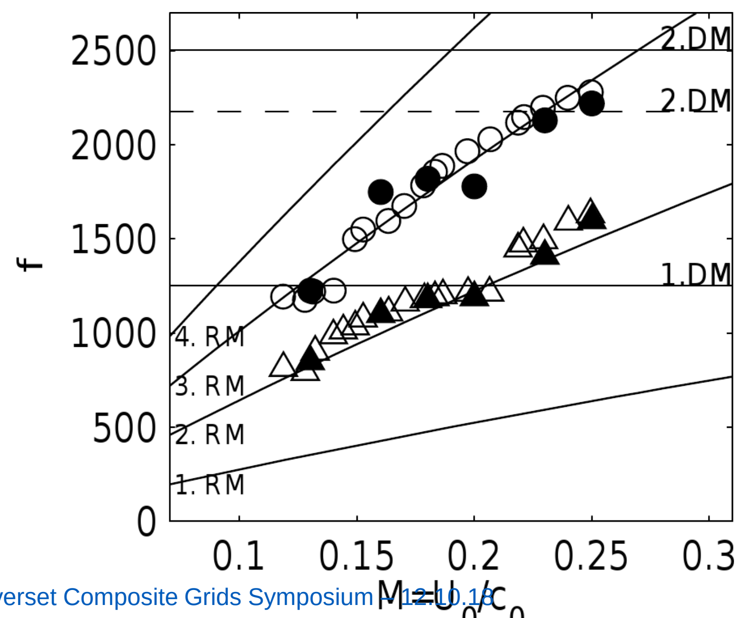
- Flow vizualisation at $M = 0.18$

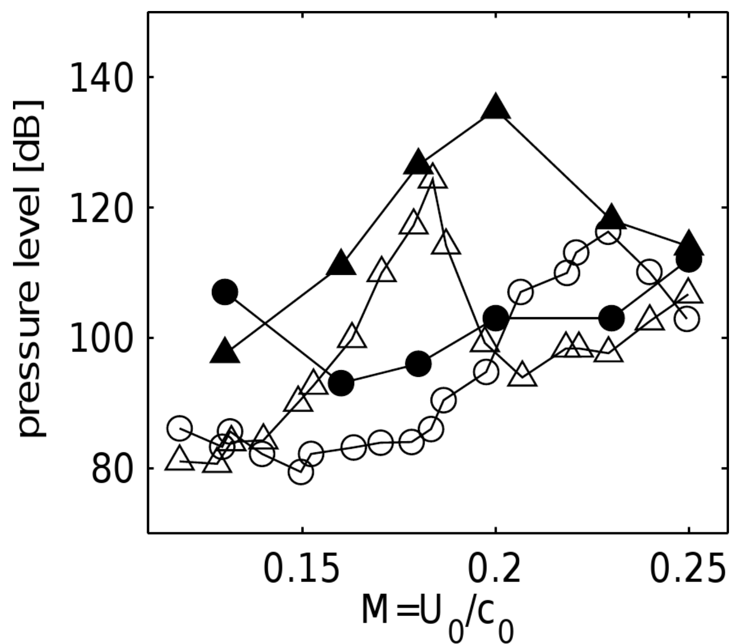


Instantaneous pressure fluctuations.
First acoustic mode duct mode

Spanwise vorticity modulus.
Second Rossiter's mode

- Comparison between numerics and experiments in term of frequency and pressure level





Outlines

Modeling and computational aspects

Numerical approach

Use of Overset grids

Simplified two-dimensionnal geometry

Simplified 2D geometry and flow conditions

Computational domain

Results

Real geometry

Meshing from a CAD

Computational domain and flow conditions

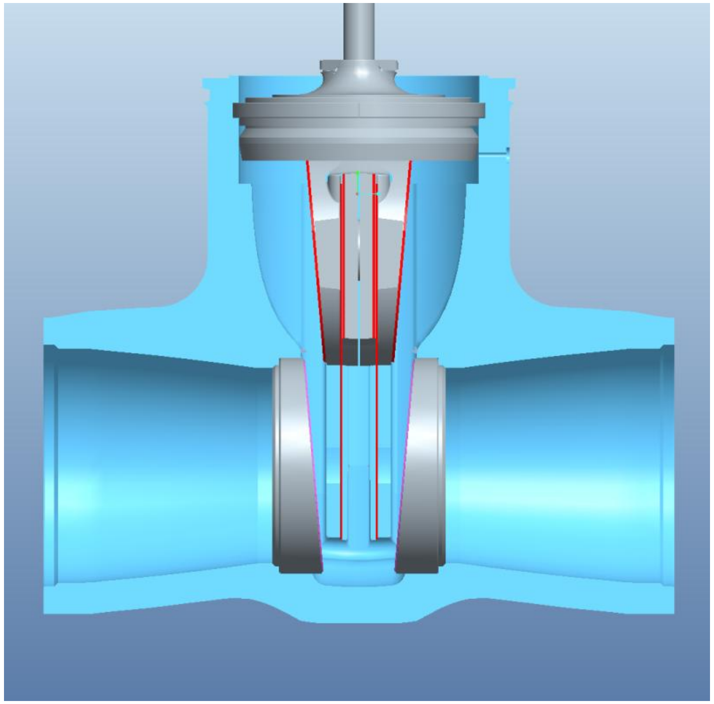
Results

Conclusions & Perspectives

Real geometry

Meshing from a CAD

- In order to take into account the complexity of the geometry, the study focuses now on the real configuration
- CAD of the valve as the starting point
  - Slight modifications, to suppress very small geometrical details (assumed to be irrevelant)
- Use *Ogen* capability to create several elementary grids
  - Triangulation of the CAD surface
  - Surface grids marching on the CAD surface
  - Extrusion of the surface grids to generate volume grids
- Create core grids
- Compute the interpolation



Real geometry

Meshing from a CAD

Real geometry

Computational domain and flow conditions

- 38 elementary grids
- 78 million points, 9 million interpolation points
- The smallest cell size at the wall, $y^+ \sim 5$

- Simulation running on cluster with 256 cores

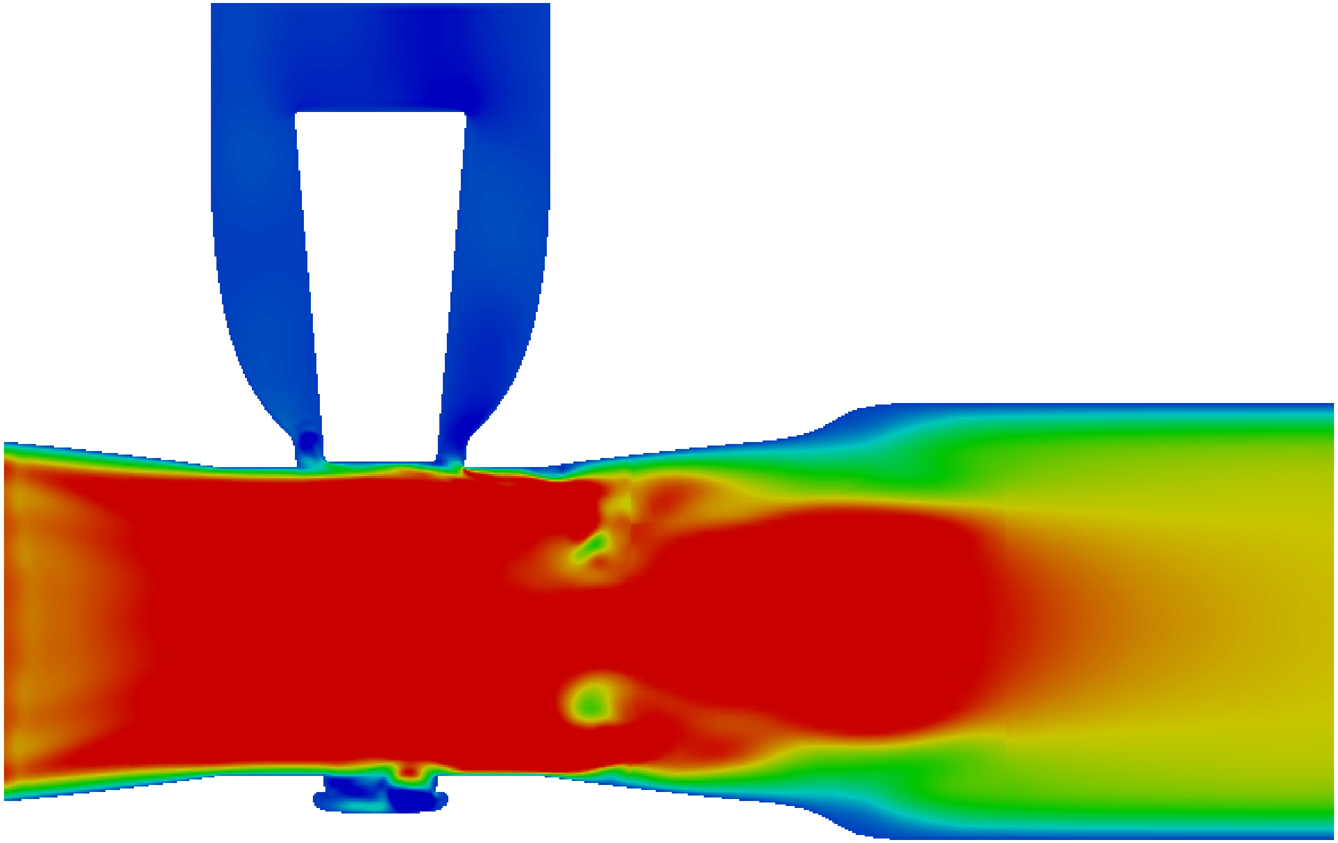
- Flow conditions
  - Mach number $M = 0.2$ upstream the cavity
  - Fully turbulent inlet flow profile
    - For lack of validation data
    - The crucial parameter is the flow profil upstream of the cavity

EDF

Real geometry

Results

- Simulation with a Mach number $M = 0.2$ upstream of the cavity



Instantaneous longitudinal velocity on a streamwise section

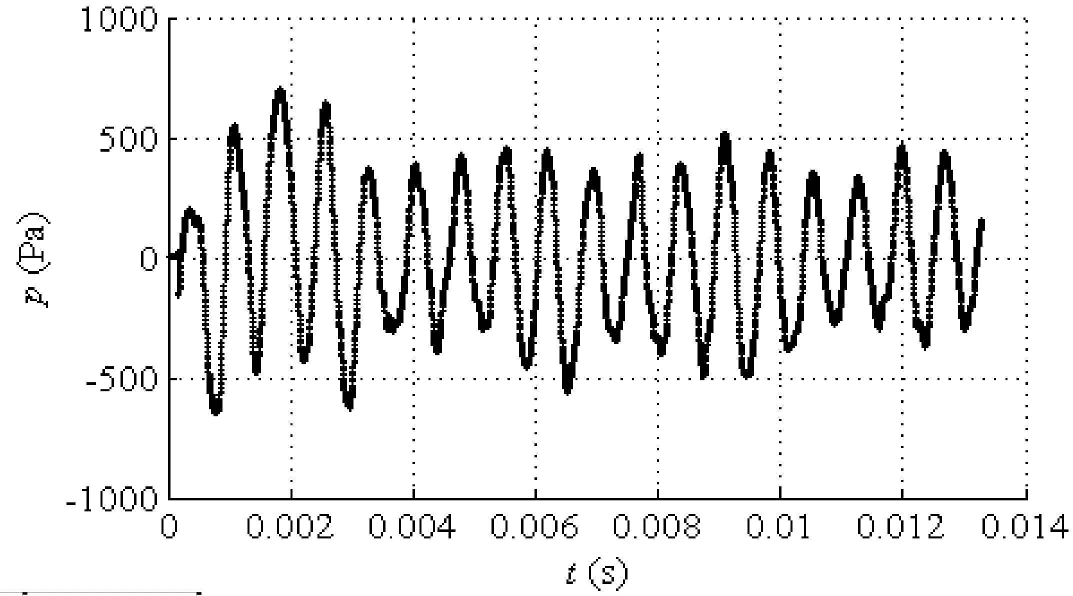
Real geometry

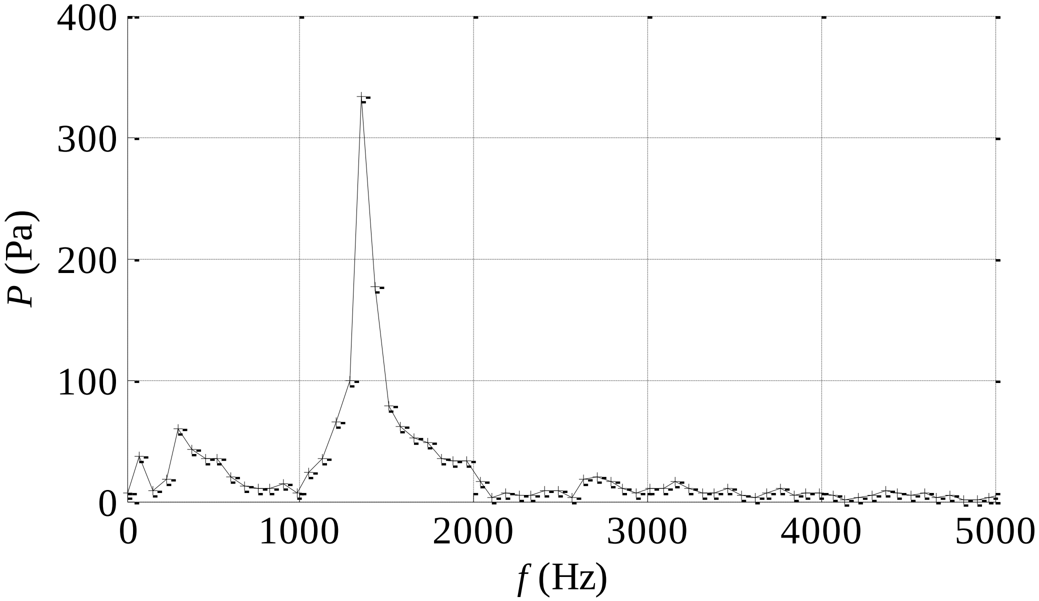
Results

Signal of a pressure probe in the bottom cavity

Right: time signal

Bottom: spectrum





A strong tonal noise is captured in a frequency range coherent with the one observed on the 2D configuration

Outlines

Modeling and computational aspects

Numerical approach

Use of Overset grids

Simplified two-dimensionnal geometry

Simplified 2D geometry and flow conditions

Computational domain

Results

Real geometry

Meshing from a CAD

Computational domain and flow conditions

Results

Conclusions & Perspectives

Conclusions & Perspectives

- 2D simulations show the ability of LES with Overset-grid strategy to capture the nonlinear aeroacoustic interaction responsible of tonal noise

- In order to take into account the real geometry, 3D simulations have been started
  - *Ogen* gives an operationnal grid for LES
  - Tonal noise well captured with the first simulation

- Experiments are coming
  - Input data for the simulation: flow profile upstream of the cavity
  - Comparison with numerics in term of frequency and pressure level