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Towards the direct computation of the aerodynamic sound generated by a gate valve in nuclear power plants

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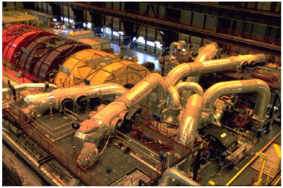
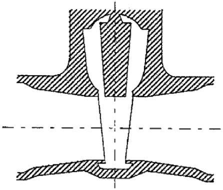
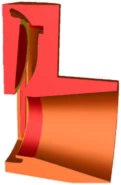
Industrial problem

Noise generated in flows by valves in pipe systems of power plants







- Non-linear aeroacoustic interactions in confined flows
- Undesirable high pressure acoustic levels, noxious excitation of structural vibrations ...
- Need of unsteady data for:
  - prediction of noise sources,
  - propagation of the noise generated,
  - understanding of physical phenomena.

Direct computation of aerodynamic noise (DNC)

- Computation of the aerodynamic and the acoustic fields in the same simulation (via DNS or LES),
- Need to accurately resolve high-wavenumber fluctuations,
- Use of low-dissipative and low-dispersive schemes (FD, ...).

⇒ Development of *Code_Safari* (Emmert PhD 2007, Daude *et al.* AIAA Paper 2008):

- Compressible turbulent flows,
- Coupling between flow and acoustics,
- Application to configurations with industrial relevance.

3-D compressible unsteady Navier-Stokes equations written in curvilinear coordinates:

$$\partial_t \left(\frac{1}{J} \mathbf{U} \right) + \partial_\xi \left(\mathbf{F}_\xi - \mathbf{F}_\xi^\nu \right) + \partial_\eta \left(\mathbf{F}_\eta - \mathbf{F}_\eta^\nu \right) + \partial_\zeta \left(\mathbf{F}_\zeta - \mathbf{F}_\zeta^\nu \right) = \mathbf{0}$$

- Conservative variables $\mathbf{U} = (\rho, \rho\mathbf{u}, \rho e)^T$,
- J transformation Jacobian $(x, y, z) \rightarrow (\xi, \eta, \zeta)$,
- Perfect gas, Newtonian fluid, Fourier law, Sutherland's law.

Geometrical conservation relations:

$$\partial_\xi \left(\nabla \xi \right) + \partial_\eta \left(\nabla \eta \right) + \partial_\zeta \left(\nabla \zeta \right) = \mathbf{0}$$

- Conservative form for spatial metrics (Thomas & Lombard AIAA J. 1979)

Numerical discretization

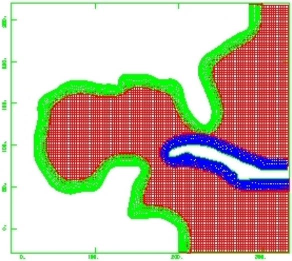
- Spatial discretization: optimized centered finite difference schemes (Bogey & Bailly JCP 2004)
- Time integration: explicit Runge-Kutta schemes
- Selective filtering: optimized centered low-pass filters (Bogey & Bailly JCP 2004)
- LES strategy: approach based on relaxation filtering (Bogey & Bailly JFM 2009)

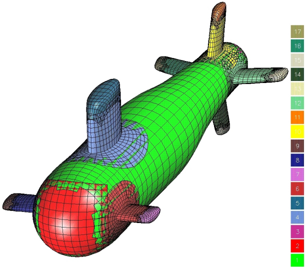
Present numerical method:

- Spectral-like accuracy,
- Limited to Cartesian meshes
  $\Rightarrow$ Difficulty to tackle complex geometries.

Multi-domain approach

- Use of overset-grid techniques with high-order interpolation procedure (Delfs AIAA Paper 2001),
- Use of the free library *Overture* developed at Lawrence Livermore Laboratory (Henshaw 1998),

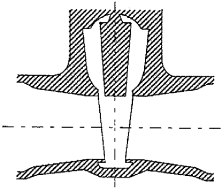


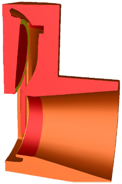


- Communication performed via high-order Lagrangian polynomials (Scott & Sherer JCP 2005, Desquesnes *et al.* JCP 2006):

1. Motivations
   - Background
   - Context
2. Modeling and computational aspects
   - Governing equations
   - Numerical algorithm
3. Application to the gate valve problem
   - Simplified valve geometry
   - Computational representation
   - Toward the real geometry ...
4. Conclusions and future work
   - Conclusions
   - Future work

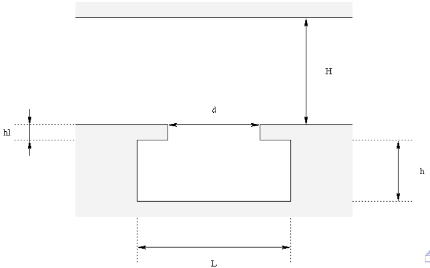
- Real-life geometry (too complex details to model)



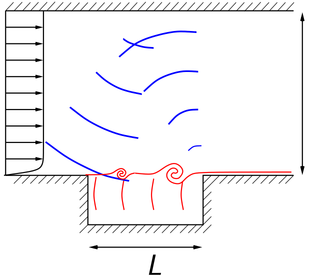


Ability of *Code_Safari* to reproduce fluid/acoustic couplings ?

- Simple 2-D geometry: **ducted cavity model**



Simplified valve geometry



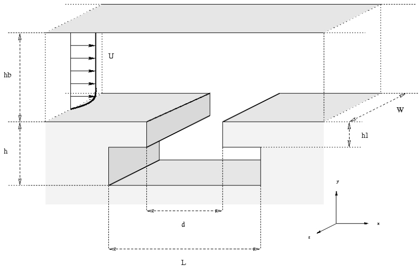
Two physics (two characteristic length scales):

Rossiter's mode	Tranverse duct mode
$\mathrm{St}_R = \dfrac{n_R - \alpha}{M_0 + 1/\kappa}$	$\mathrm{St}_d = \dfrac{n_d L}{2 H M_0}$

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

$$\boxed{\mathrm{St}_R \approx \mathrm{St}_d}$$

Case configuration retained for studies

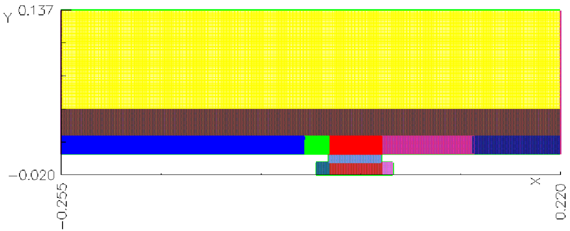


- Partially covered,
- $h = 0.02$ m,
- $W = 0.2\ h$
- $M_0 = 0.18$,
- $Re_H = 5.6 \times 10^5$,
- Exp. obv. at $M_0 = 0.18$: 2RM couples with 1DM

- Upstream boundary layer:
  - Mean flow profile:

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

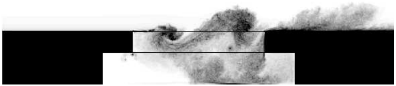
Computational representation



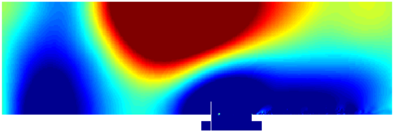
- 11 composite grids,
- 38×10^6 points,
- Computed by $N_{\text{procs}} = 206$ processors,
- $\Delta y^+ = 11$ of inflow profile,
- No turbulent fluctuations added,
- Periodic boundary conditions in spanwise direction,
- Slip conditions on the upper duct wall.

Numerical results

Two physics: turbulence in the cavity & acoustic waves in the duct



Spanwise average vorticity modulus

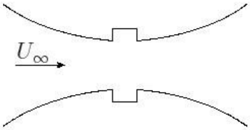


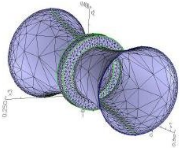
Pressure fluctuations

2nd Rossiter mode and 1st Duct mode dominant

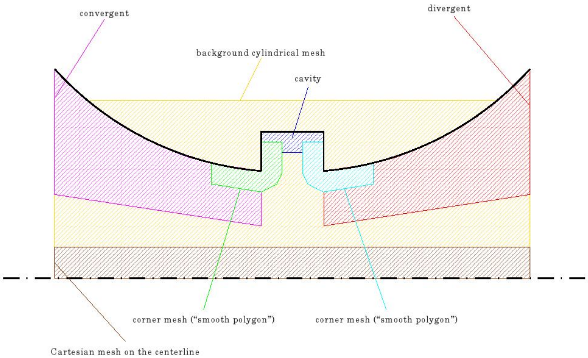
- Lock-in phenomena well retrieved,
- overset-grid approach: to adapt the cell size to the dynamics investigated.

Introduction of an intermediate geometry:

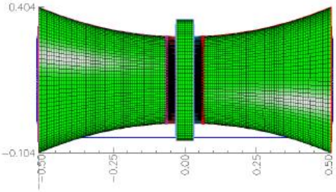


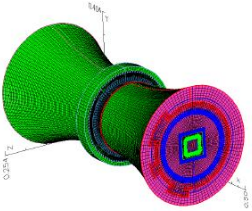


Mesh strategy:

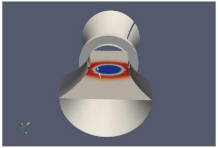


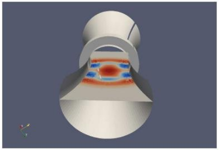
Computational domain:

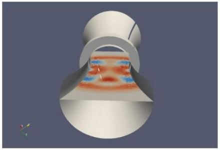




Preliminary results: acoustic pressure pulse





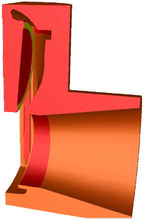


- overset-grid approach: to realize grids around realistic geometries

- High-order finite difference schemes on overset grids suitable for compressible LES on CAA applications:
  - Large-Eddy Simulation of (simple) confined cavity flow,
  - Prediction of flow/acoustics coupling.
- Overset-grid strategy suitable:
  - to preserve the high-accuracy of FD schemes on non-trivial bodies,
  - to adapt the cell size to the dynamics investigated,
  - to realize grids around realistic geometries.

Future work

- To perform the LES of the flow in the intermediate geometry,



- To deal with the real-life geometry:
  - CAO details "suitable" for CFD computations (general problem for industrial components)
  - Computational domain (based on the strategy used for the intermediate geometry),
  - Very small geometrical details $\Rightarrow$ Very fine cells near the walls $\Rightarrow$ Improvement of the time integration (DTS)

Thank you

for your

attention!!