A decade of jet noise simulation at Onera: a review

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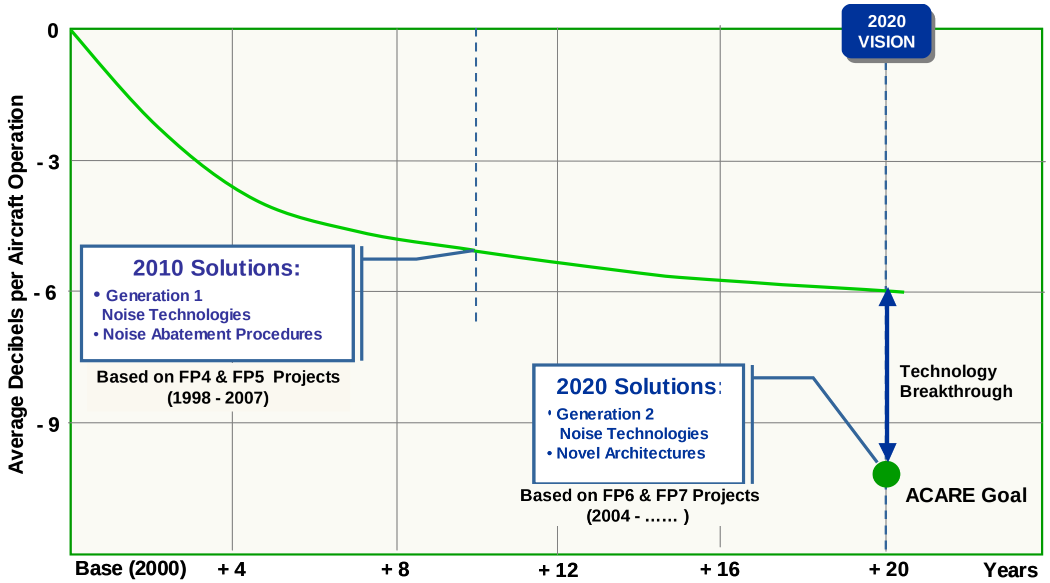
Outline

- Context and objectives
- Methodology
- Simulations and assessments
  - Single stream nozzle
  - Double stream nozzle
  - From structured to unstructured flow solver
  - Installation effects
  - Noise reduction devices
- Analysis tools
- Conclusions

Context and objectives

Context

- Aircraft noise reduction
- ACARE objectives
- Development of new noise reduction concept

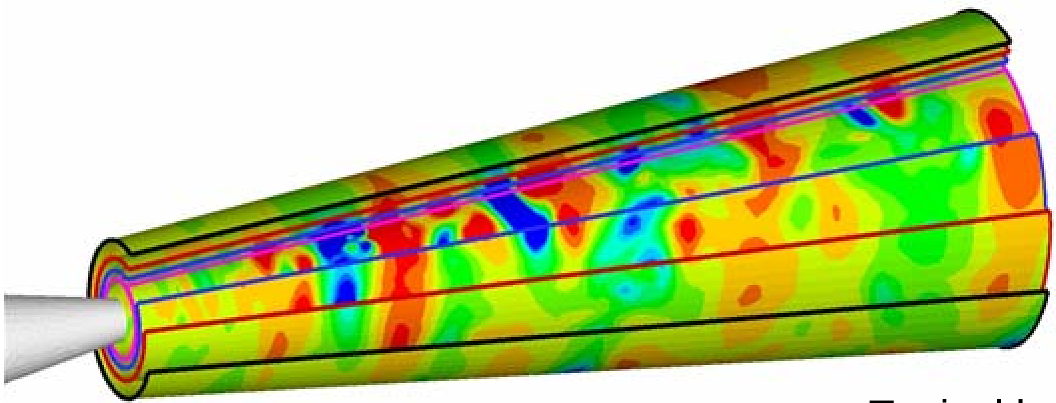


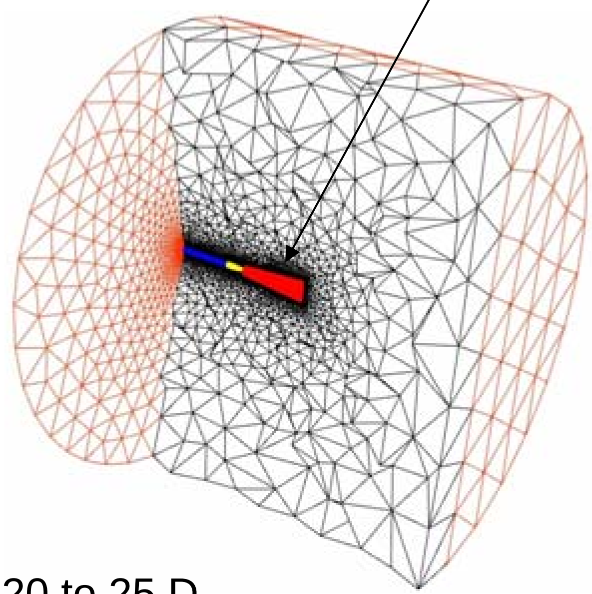
Objectives

- Estimate far field radiated noise by jets representative of industrial configuration
  - Acoustics consideration during design process
  - Assessment of the potential of noise reduction devices
- Understand the noise production mechanisms

Methodology
Principle

- Hybrid approach :
  - unsteady flow simulations to compute the noise sources in the jet
  - Integral formulation for far field noise radiation





Typical length: 20 to 25 D

- Choice of the integration surface, compromise between:
  - To be sure to enclose all volume sources
  - To keep low aerodynamics computational costs
  - To limit numerical dissipation

Methodology
Implementation

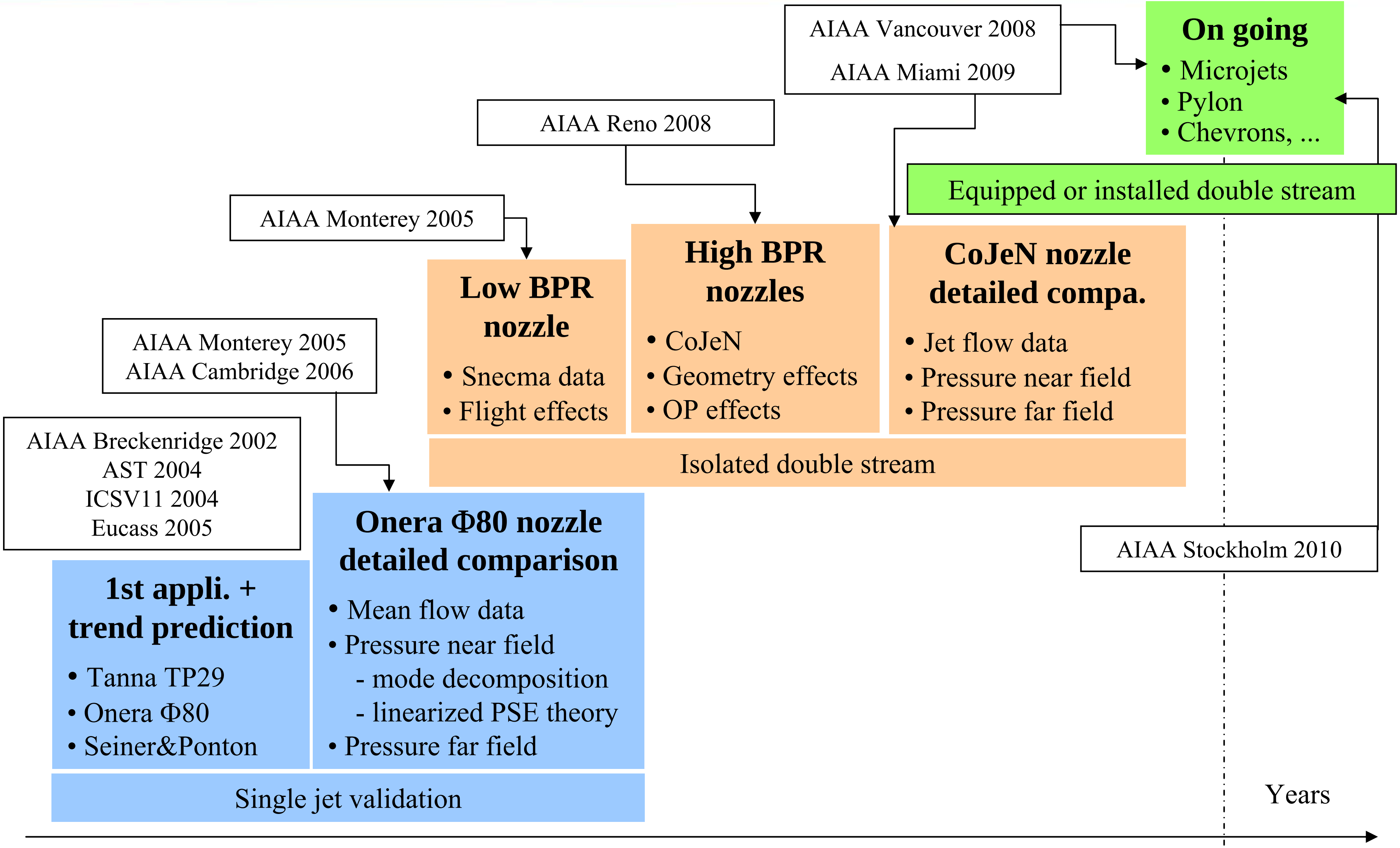
Flow computations

- LES simulations with MILES approach
  - Numerical dissipation instead of turbulent viscosity
  - Hypothesis that small scales structures do not influence the radiated noise
- Boundary layers in the nozzle not resolved
- When the jet is in established state
  - Acoustic storage for a minimum time of 100D/Uj on the integration surfaces

Far field acoustic propagation

- Code KIM developed in Onera
- Ffowcs-Williams & Hawkings : better results especially for hot jets
- Kirchhoff

Simulations and assessments

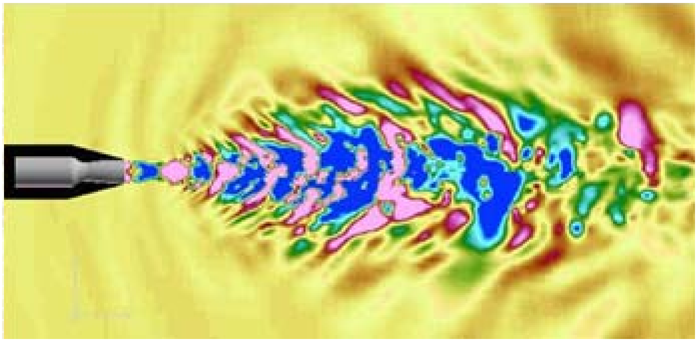


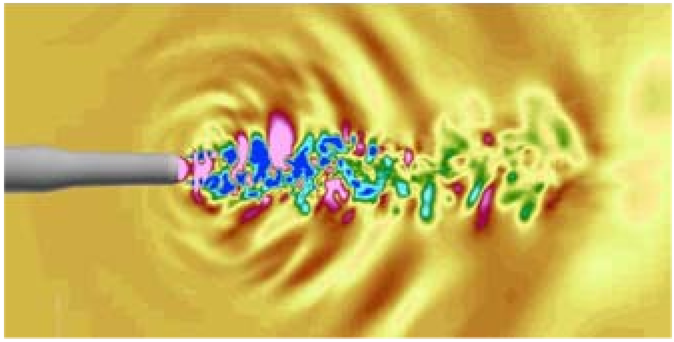
Single stream nozzles
First simulations

- In-house code MSD: massive parallel, structured and multi block flow solver
- Activities on three different jets: about 2 000 000 cells per configuration

	D (mm)	U_j (m.s^{-1})	T_i (K)	$M_j = U_j/c_j$	$M_e = U_j/c_a$
Seiner & Ponton	91.44	1120	1370	2.00	3.30
Onera Φ80	80.00	410	900	0.70	1.20
Tanna Φ2”	50.80	325	400	0.87	0.96

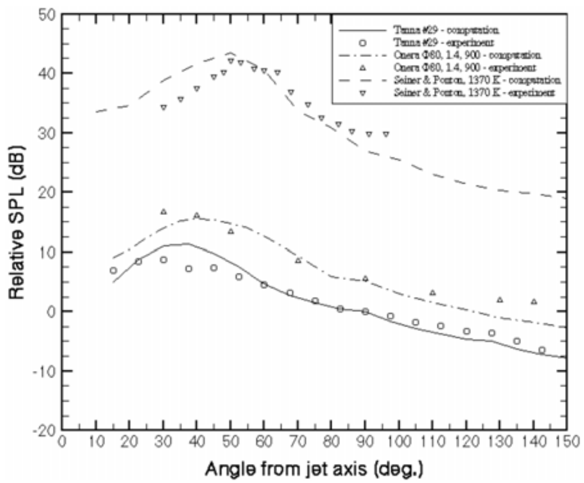
- Different scales
- Different velocities: subsonic and supersonic
- Different temperatures

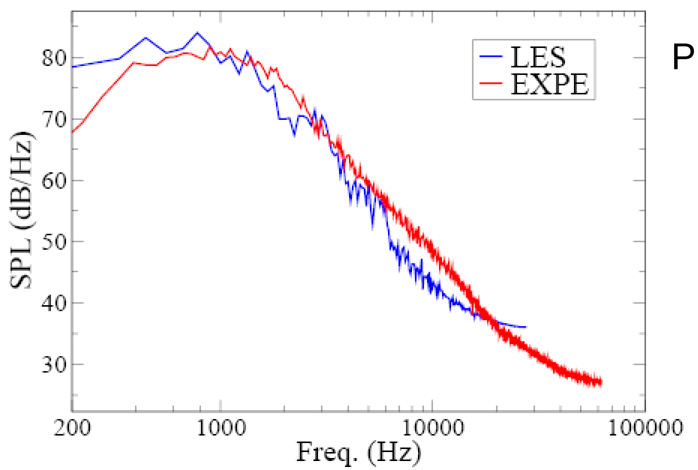

Seiner & Ponton


Phi 80 (Onera)

Single stream nozzles
Results

- Similar results on the three jets
- Too short potential core length
  - Due to overestimation of turbulent kinetic energy
    - Lack of resolution in the boundary layer
  - Consequence: overestimation of Sound Pressure Levels
- After rescaling by a constant value: good relative agreement

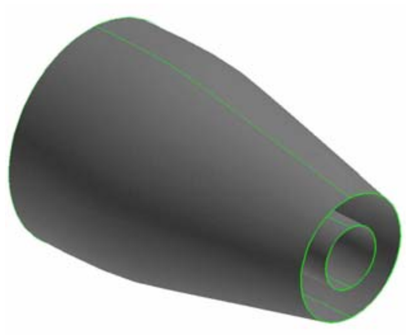


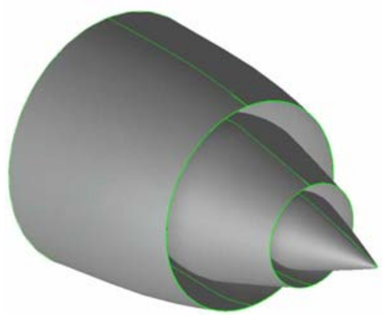


Next step: Isolated double stream nozzle

Isolated double stream nozzles
Case of CoJeN European Project

- High By-Pass Ratio double stream nozzle from CoJeN European Project
- 2 nozzles : Coplanar (CO) and short cowl (SC)





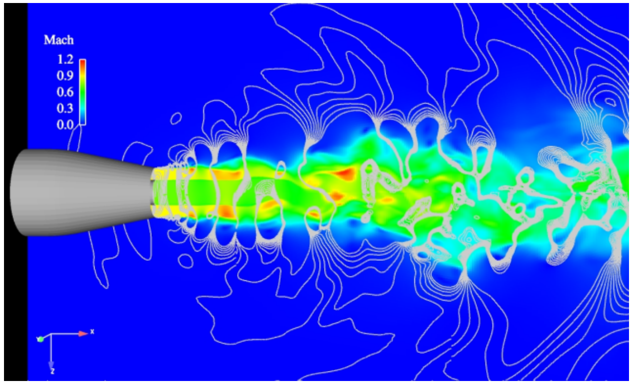
- About 4 500 000 cells on both grids
- Generating conditions

	Point 2	Point 3
Primary flow	Tt = 850 K, M = 0.69	Tt = 880 K, M = 0.81
Secondary flow	Tt = 335 K, M = 0.84	Tt = 335 K, M = 0.84

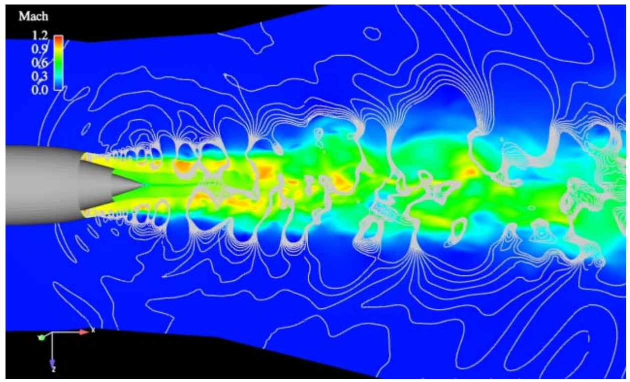
- Large database of measurements available for comparisons

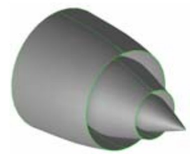
Isolated double stream nozzle
Aeroacoustics results

Mach number and pressure isocontours



coplanar geometry





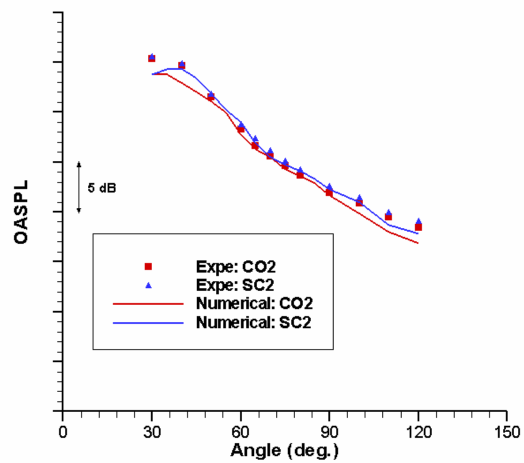
short cowl geometry

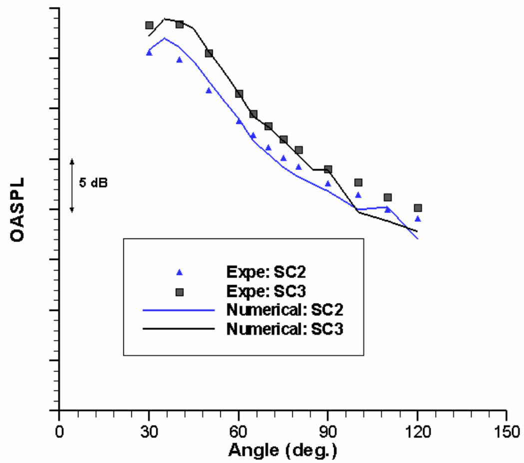
Noise levels overestimated by 6 dB

After rescaling by constant value …

Satisfactory noise prediction

Effect of geometry and operating conditions well reproduced numerically





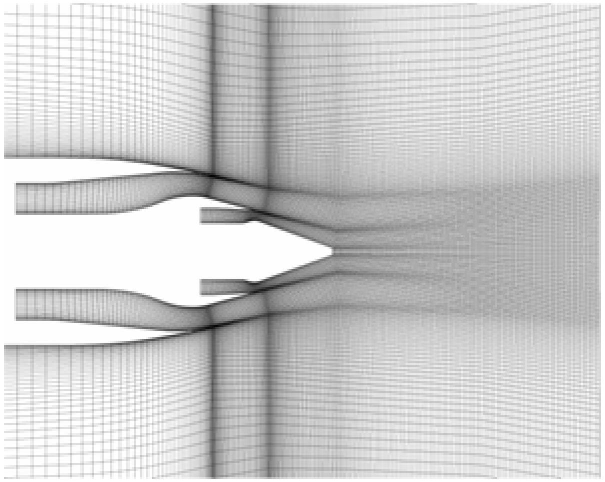
Decision to use non-structured solver for future applications

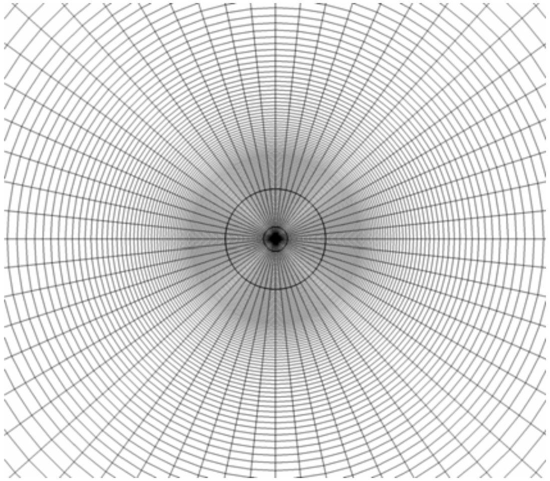
From structured to non-structured flow solver

- Comparison of the two flow solvers developed by ONERA
  - MSD structured
  - CEDRE non-structured

- Geometry
  - Double stream nozzle: Silence(R)/VITAL BPR 9 nozzle
  - High power testing point

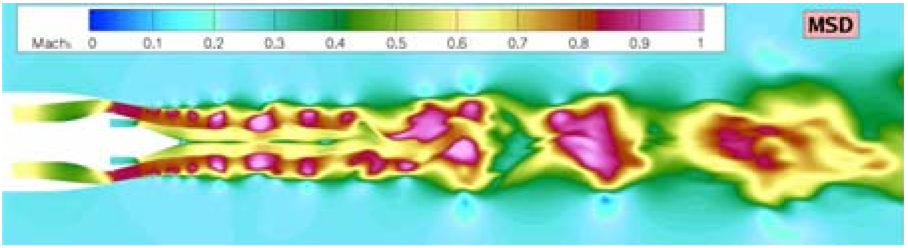
- Structured mesh
  - 4,250,000 cells
  - 61 azimuthal planes

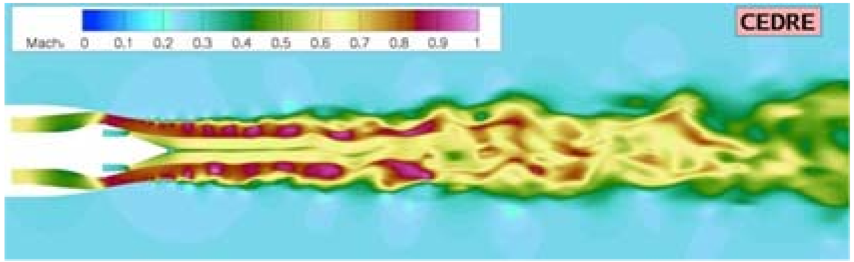




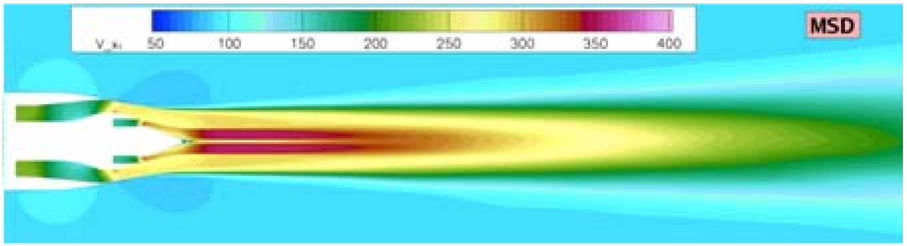
From structured to non-structured flow solver
Instantaneous and mean flow velocity results

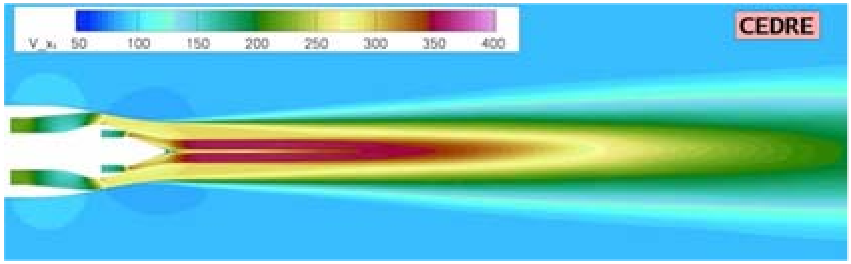
Structured solver (MSD) | Non-structured solver (CEDRE)





Instantaneous Mach number



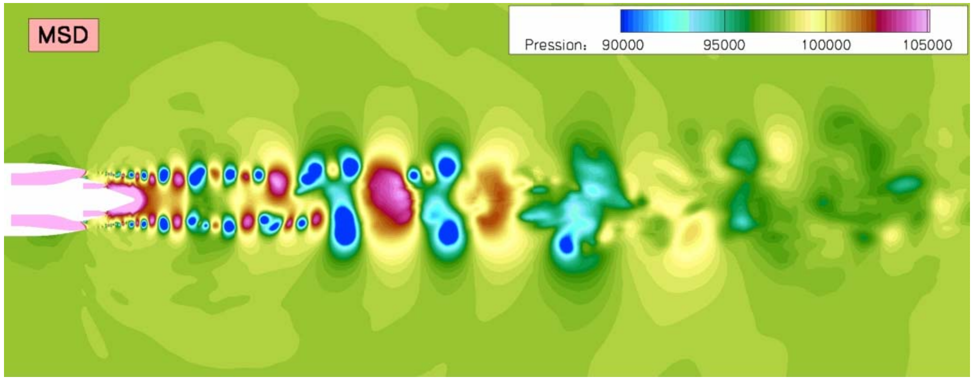


Mean axial velocity

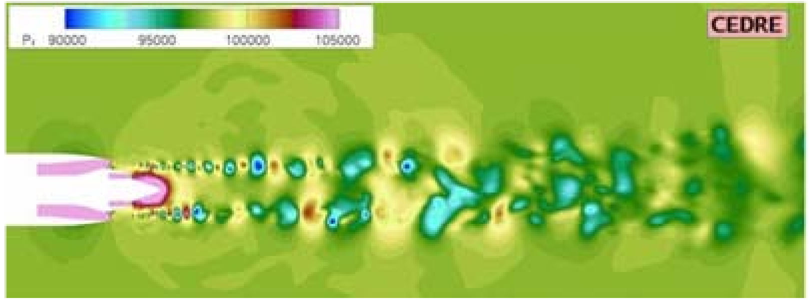
- MSD results slightly more turbulent
- Good qualitative agreement between the solvers

From structured to non-structured flow solver
Hydrodynamic pressure comparison

Structured solver (MSD)



Non-structured solver (CEDRE)

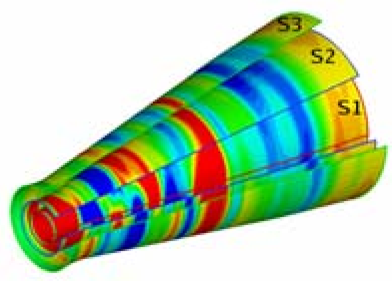


Instantaneous pressure level

- Lower pressure levels for the non-structured solver

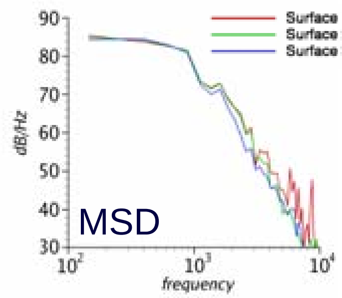
From structured to non-structured flow solver
Acoustic results comparison

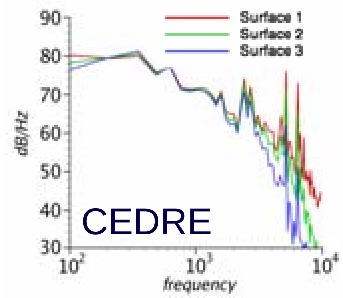
- Propagation: Ffowcs Williams and Hawkings formulation
- Stability analysis
  - Limited dissipation between the surfaces
  - CEDRE more dissipative than MSD



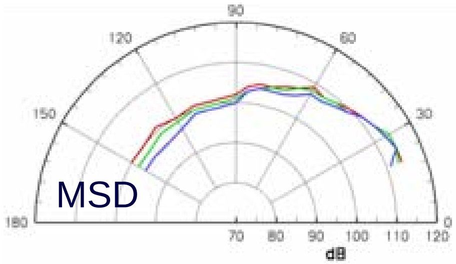
Pressure field on the storage surfaces (MSD)

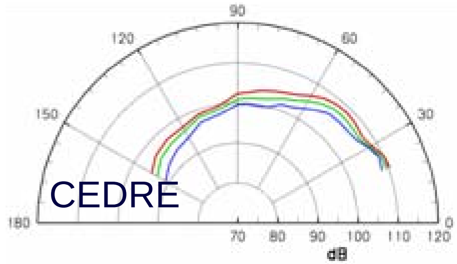
Pressure spectra at 30 degrees





Directivities





- Lower noise levels with non-structured solver

Transition from structured to non-structured flow solver opens the way to more complex geometries

Installation effects
High BPR double stream nozzle with pylon

VITAL nozzle (BPR 9)

AITEC French National Program

Unstructured flow solver CEDRE

KIM for acoustic radiation

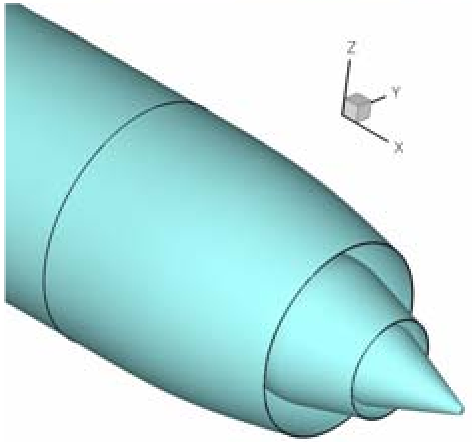
12.7 Millions cells in both cases

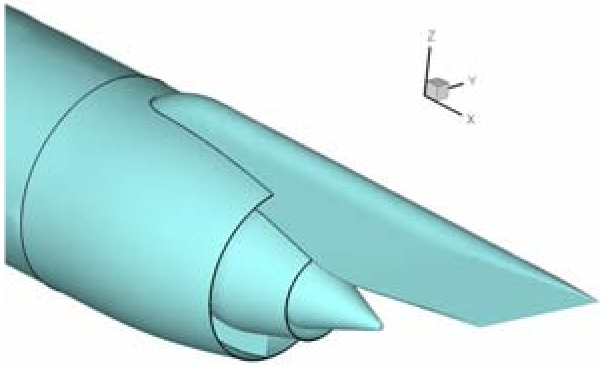
Prim: V=340m/s ; M=0.645 ; Tt=855K ; Pt=128791 Pa

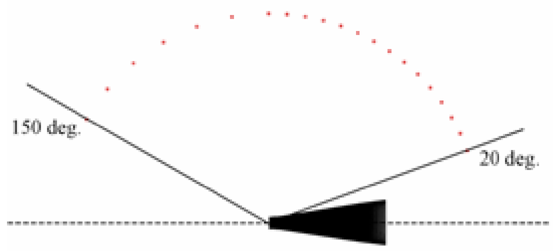
Sec: V=295m/s ; M=0.855 ; Tt=343K ; Pt=156934 Pa

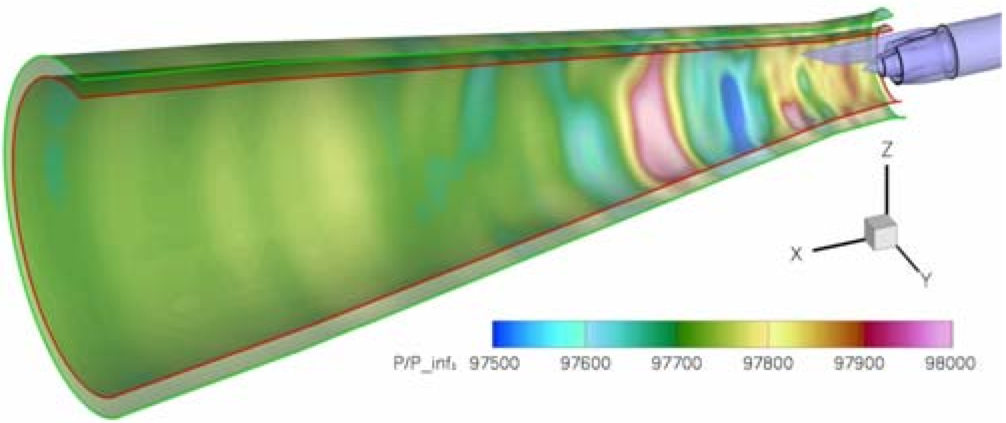
Amb: V=87.3m/s

Measurements in CEPRA19

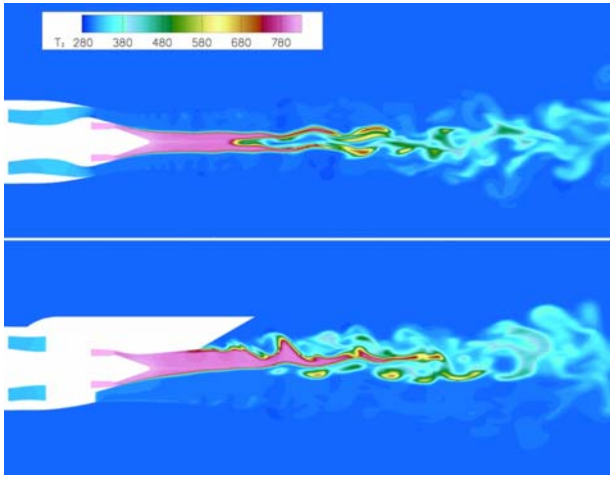




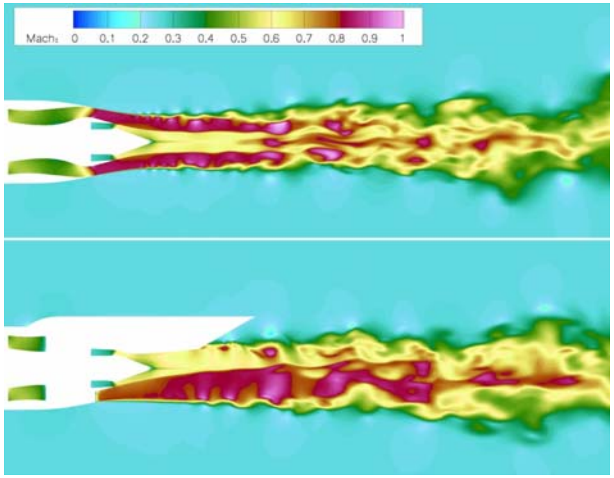




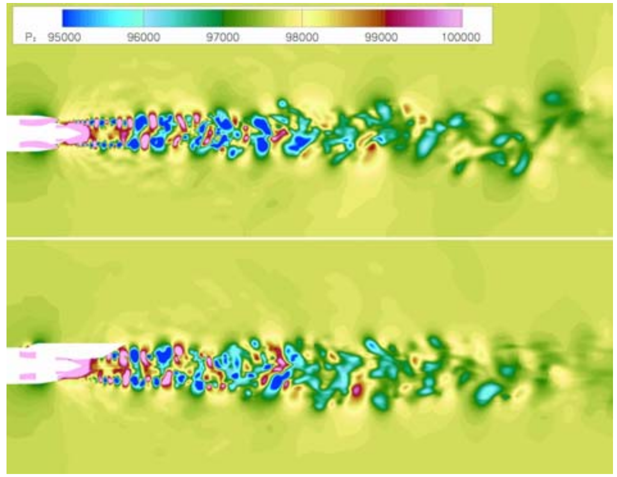
Installation effects
Aerodynamic results – Instantaneous fields



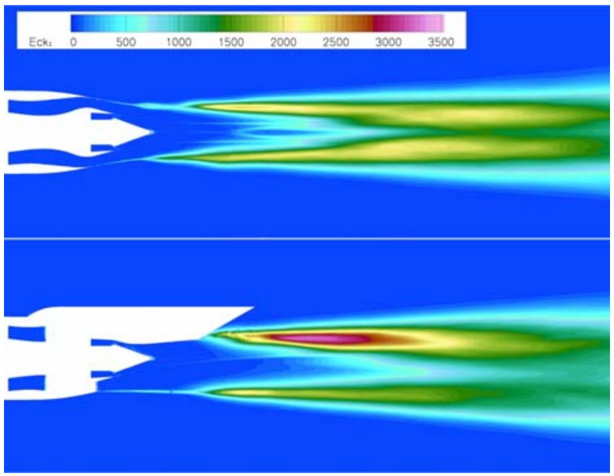
Temperature



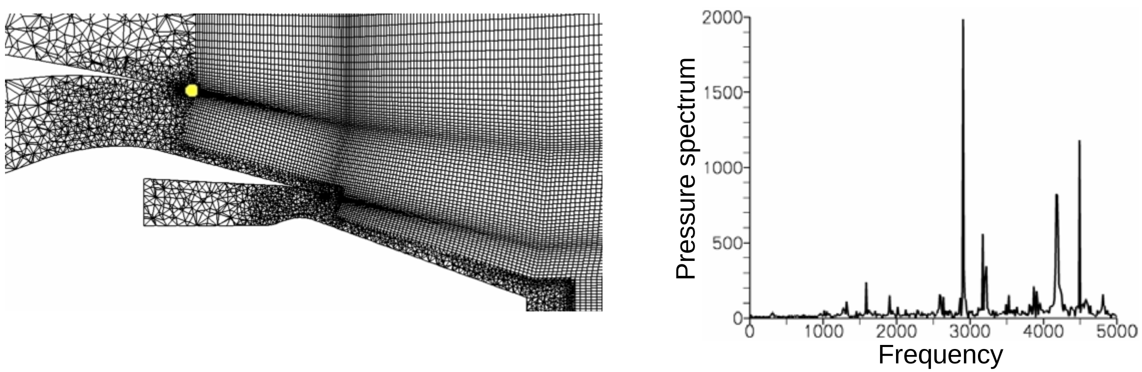
Mach number



Pressure

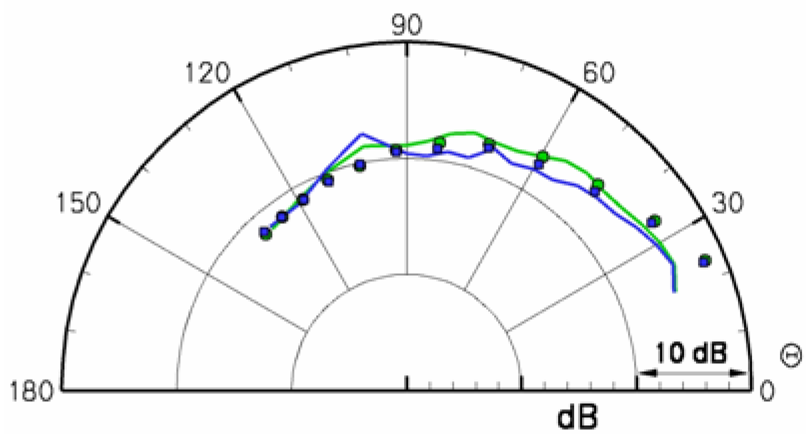


Mean turbulent kinetic energy



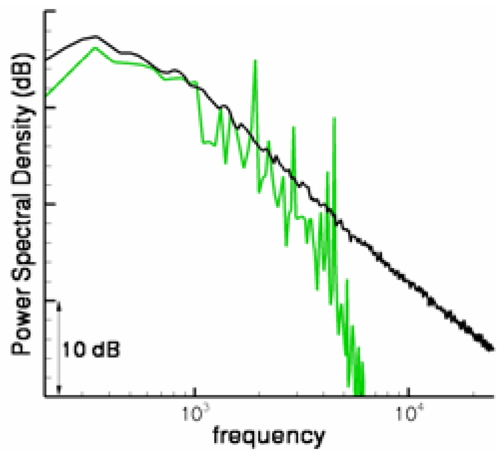
Detected vortex shedding

Installation effects
Acoustic results

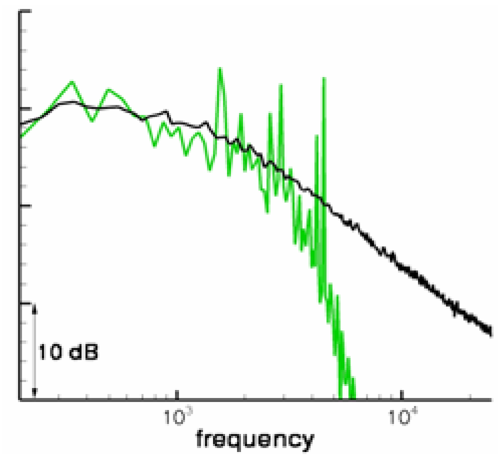


OASPL experiment (sideline: ● ; flyover: ■) and simulations (sideline: – ; flyover: –) in the bandwidth [200 Hz ; 25 kHz]. Configuration with pylon

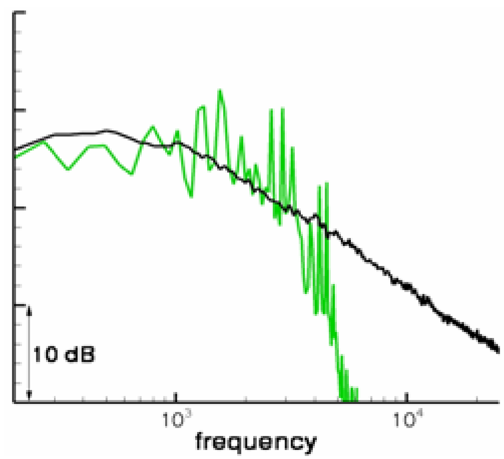
- ✓ **Good comparisons with measurements**
- ✓ **No overestimation**
- ✓ **Good reproduction of azimuthal effect in the presence of pylon**
- ✗ **Tonal noise on numerical simulations**



35 degree



60 degree

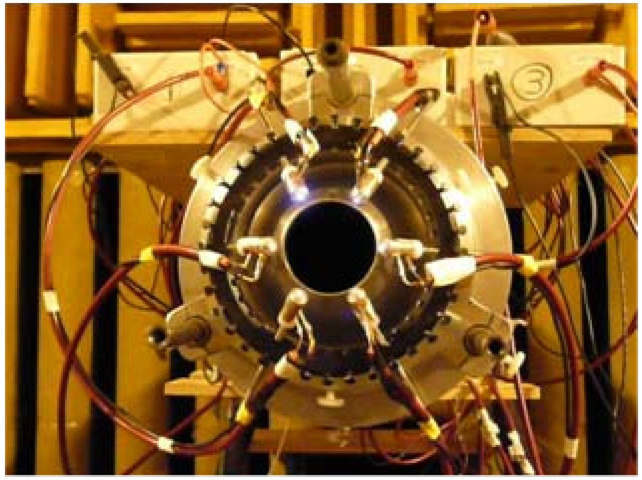


90 degree

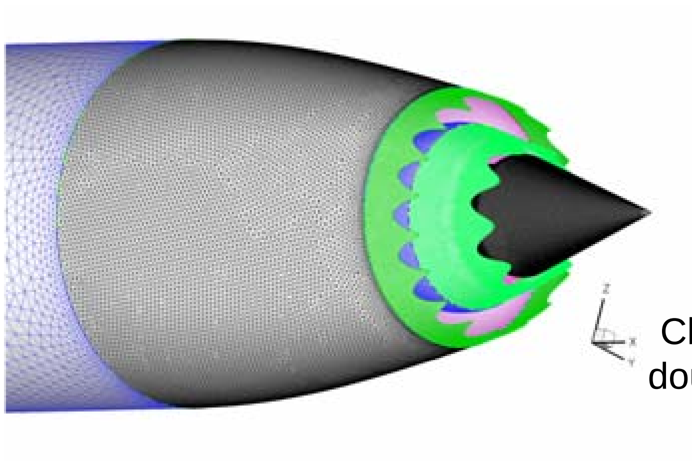
Jet noise reduction devices

Continuous micro-jets (Martel test facilities, PPrime Institute)

French National Program OSCAR



Pulsed micro-jets (ECL test facilities)
Onera's plasma actuators

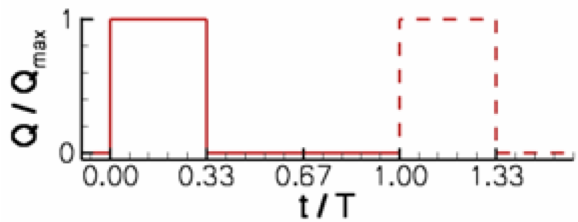


Chevrons on double stream nozzle

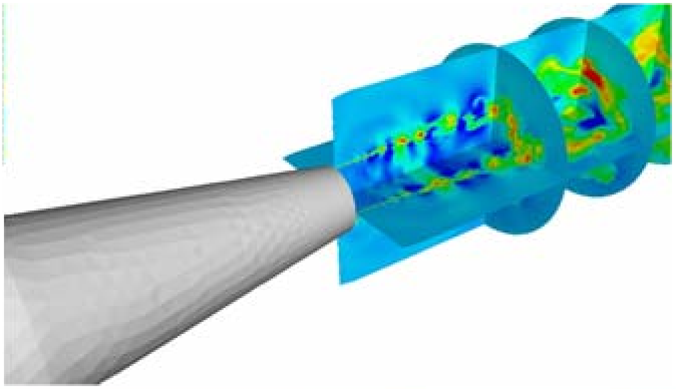
Plasma Synthetic Jet (developed at Onera and improved in OPENAIR)

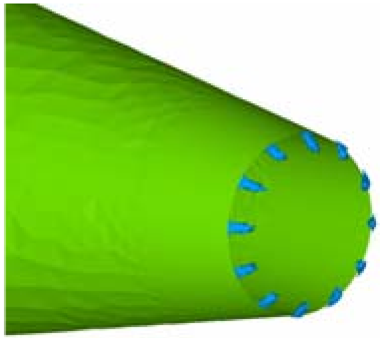
Jet noise reduction devices
Micro-jets simulations

- JEAN nozzle: single stream, D=50 mm
- 12 micro-jets, angle of injection 45°, T=288K, V=300m/s
- About 5 millions cells
- Simulations performed
  - in continuous mode
  - in pulsed mode with 2 excitation frequencies
    - St = 1.5
    - St = 0.5



- Maximum mass flow rate during 1/3 of the period



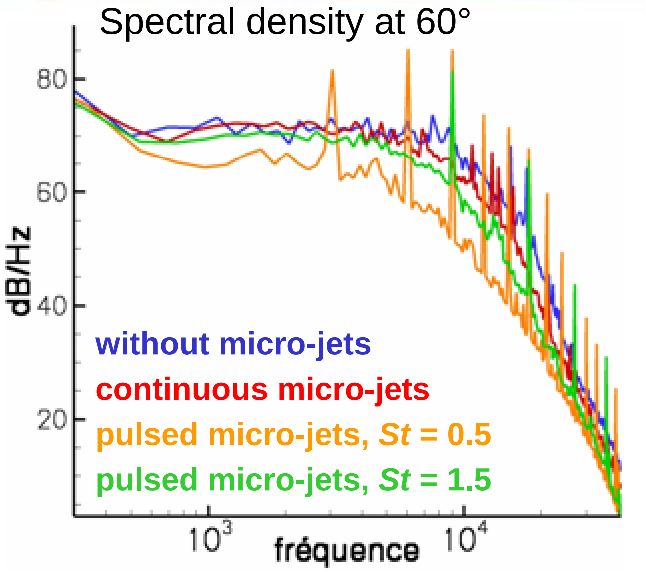


Continuous micro-jets action

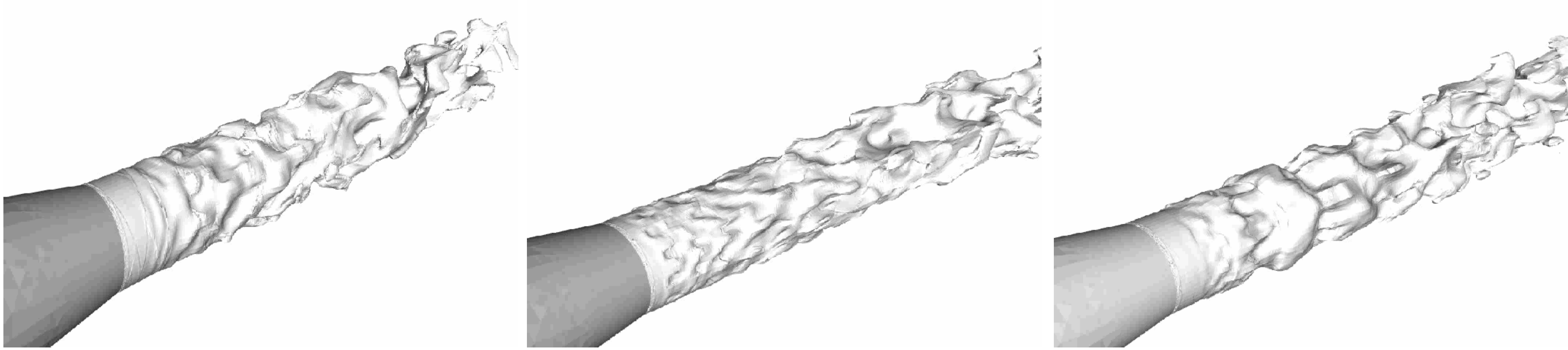
- Increase of potential core length
- Back to axisymmetry after 2-3 D

Pulsed micro-jets action

- Necessity to understand coupling mechanisms



without micro-jets | Pulsed micro-jets, *St* = 1.5 | Pulsed micro-jets, *St* = 0.5



Instantaneous axial velocity isosurface, U_x = 200 m/s

Simulations supported by analysis tools

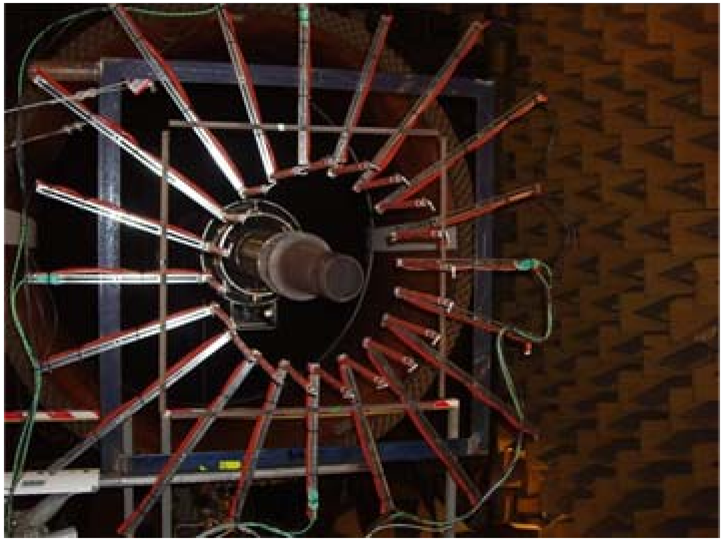
Numerical analysis

- Azimuthal decomposition technique
- Linear stability analysis
  - Classical linear stability
  - Parabolized stability equation
- Correlations
- Noise sources terms investigation
  - Noise generation mechanisms
  - Effects of noise reduction devices on the acoustic sources

Experimental analysis

- Near and far field acoustic measurements
- Aerodynamic measurements

CEPRA19 facility



Azimuthal near field acoustic antenna

Conclusions

- Hybrid methodology based on unsteady flow simulations with acoustic integral formulations for the far field radiation

- Validations through several years
  - Good simulations for relative effects
  - Absolute prediction to be improved

- More complex geometry thanks to increasing computation capacities
  - From 2 to about 30 Millions cells in recent applications

- Complement of experiments to understand noise production mechanisms

Thank you for your attention !