Numerical Simulation of Acoustic Effects of Engine Installation for New Concepts of Aircrafts

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ONERA

CEAS – X^2 NOISE Workshop

"Aeroacoustics of New Aircraft & Engine Configurations"

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Context

* *Future aircraft projects*
* *Engine noise shielding by airframe*
* *Numerical simulation*

Tools for numerical simulation of acoustic shielding effects

Noise source modeling

- Engine noise sources (fan, jet) are very complex
- Interesting results can be obtained by using simplified source : distribution of monopoles

Noise prediction

Acoustic propagation simulation

May include effects of :

- Scattering on complex solid bodies
- Refraction through non-uniform mean flows

In-house solvers developed at *ONERA*

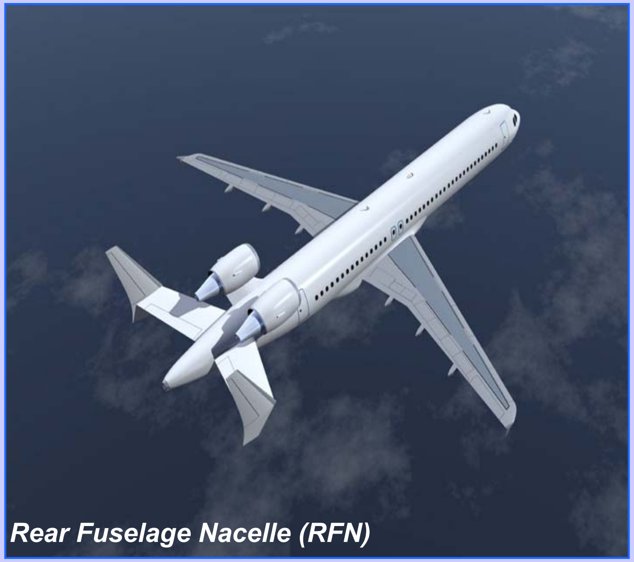
	BEMUSE	***sAbrinA***
Solved equation(s)	**Helmholtz**	**Euler (in pertubation form)**
Numerical method	**Boundary Element Method** **Variational formulation**	**Finite difference, high order spatial schemes and filter**
Grid	**Body surface** **Unstructured**	**Fluid** **Structured**
Scattering effect on rigid bodies	**Yes**	**Yes**
Refraction effects through non uniform flow	**No flow** **(uniform flow under progress)**	**Yes**

In-house solvers developed at *ONERA*

Part I : BEMUSE code

BEMUSE solver : *Context of design*


Over Wing Nacelle (OWN)


Rear Fuselage Nacelle (RFN)

European Projet *ROSAS* (*Research On Silent Aircraft conceptS*)

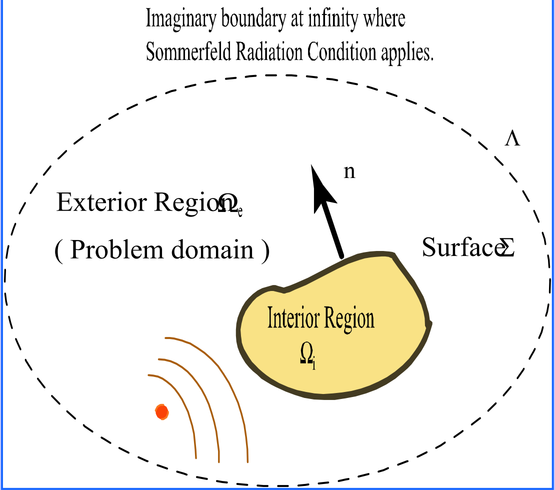
ONERA's objectives in task 3.3.3 (« Numerical work »):

** Fuselage, wing and empennage shielding effects assessment*
** Acoustic scattering from distribution of point sources*
** Geometry : ROSAS aircraft, scale 1:1 Model with up to 100,000 Degrees Of Freedom (DOF)*
** Frequency : up to fan blade passing frequency (BPF)*
** Running on parallel PC Cluster (powerful / cheap)*

Code design :

** Parallel BEM (Boundary Element Method) code*
** Built from existing BEM modules (electromagnetism)*
** Computer : ONERA's PC Cluster : 32 biprocessor PCs*

Boundary Element Method



Helmholtz equation $\Delta p(x) + k^2\ p(x) = 0 \quad \left(k = \frac{\omega}{c}\right)$

Rigid boundary condition on Σ : $\frac{\partial p}{\partial n} = 0, \ x \in \Sigma$

Sommerfeld radiation condition on Λ

Integral solution using a free-space Green function

$$\int_\Sigma \left[p(y) \frac{\partial G(x,y)}{\partial n} - \frac{\partial p}{\partial n}(y) G(x,y) \right] dy = \begin{cases} p(x) & x \in \Omega_e \\ \frac{1}{2} p(x) & x \in \Sigma \\ 0 & x \in \Omega_i \end{cases}$$

$$G(x,y) = \frac{e^{-ik\|x-y\|}}{4\pi\|x-y\|}$$

Discretization using a shape function [N] to interpolate p and its derivative on n DOF on Σ

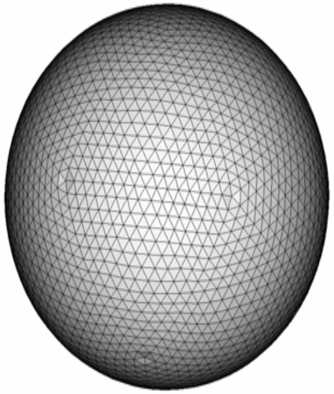
$$\frac{1}{2} p(x) = \sum_{i=1}^{n} \int_\Sigma \frac{\partial G(x,y)}{\partial n} [N] dy \{p(x_i)\} - \sum_{i=1}^{n} \int_\Sigma G(x,y) [N] dy \left\{ \frac{\partial p}{\partial n}(x_i) \right\}$$

Set of n linear equations : $[H]\{p\} = -[G]\left\{\frac{\partial p}{\partial n}\right\}$

[H] and [G] are n x n symmetric plain matrices

BEM computations

1) *BEMUSE code on PC (1 node)*
2) *SYSNOISE code on UNIX workstation*



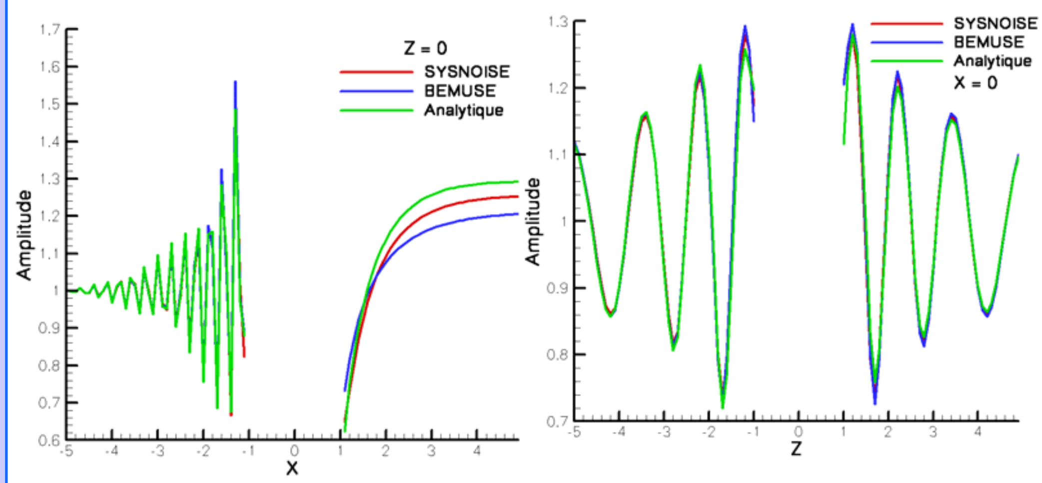
Unstructured grid :
2562 DOF

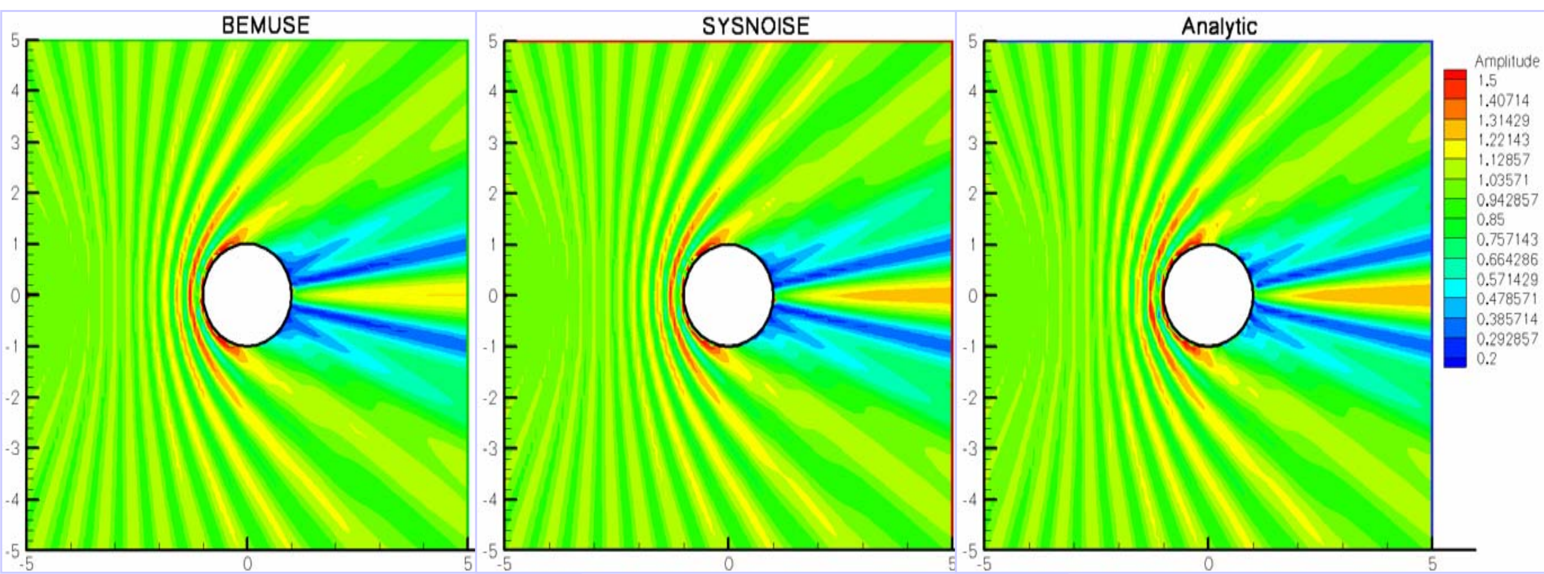
Analytical solution

$$(r,\theta,\varphi)=\sum_{l=0}^{+\infty}\sum_{m=-l}^{+l}v_l^m\,\frac{h_l^{(1)}(kr)}{k\,\frac{\partial}{\partial r}h_l^{(1)}(k)}\,Y_l^m(\theta,\varphi)$$

BEMUSE validation

Acoustic scattering on a rigid sphere : r = 1
Incident spherical wave : frequency = 600 Hz
Normalized frequency kr = 11





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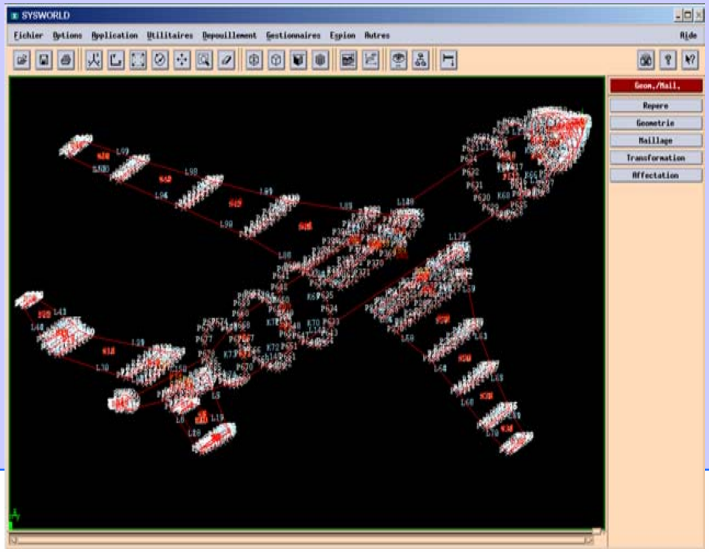
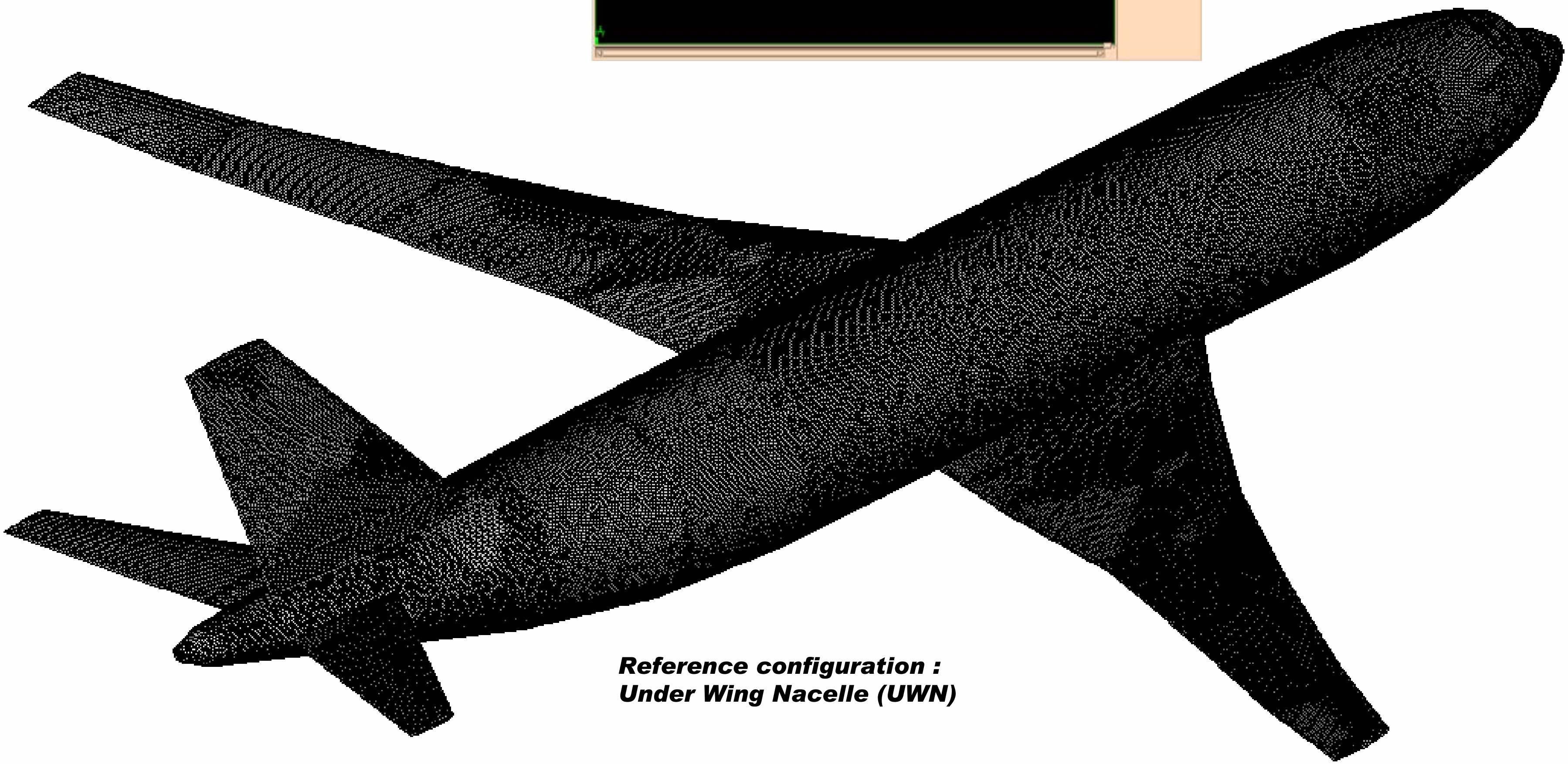
Grid construction

- ROSAS aircraft UWN, OWN, RFN
- Up to 110,000 DOF
- Simplified but realistic shape
  - Analytical sections
  - Direct junction wing/fuselage

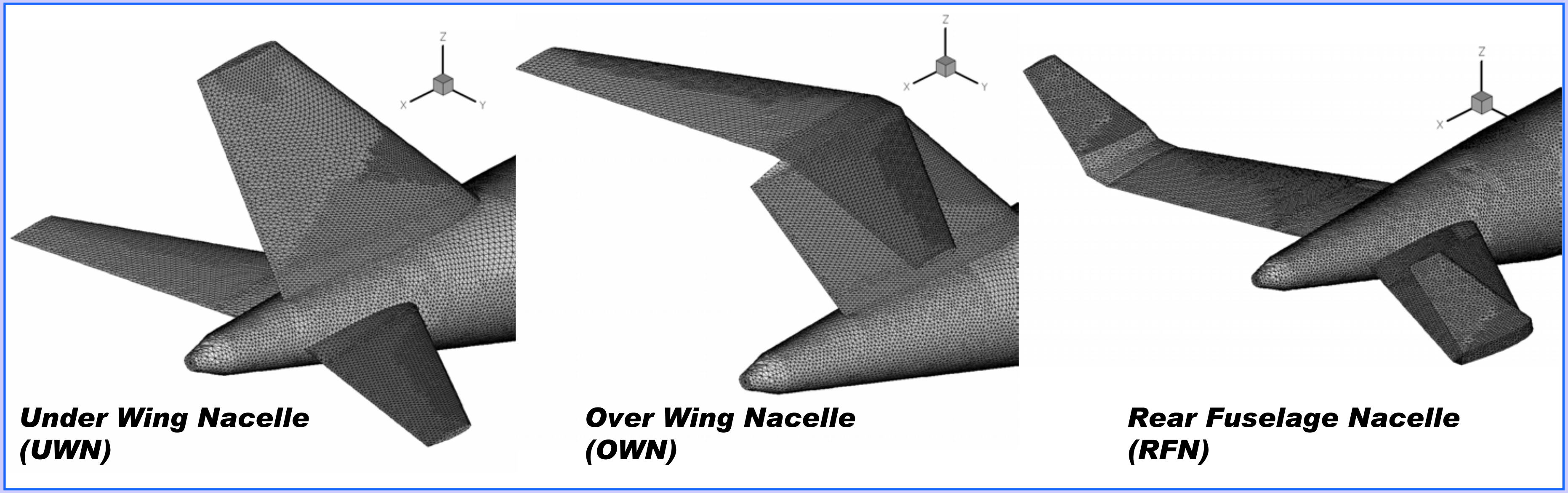


SYSTUS software



Reference configuration :
Under Wing Nacelle (UWN)

Grid details of the empennage region



Early computations

* Mid-size grids : 30,000 DOF, UWN, OWN, RFN
* Low frequency : 150 Hz

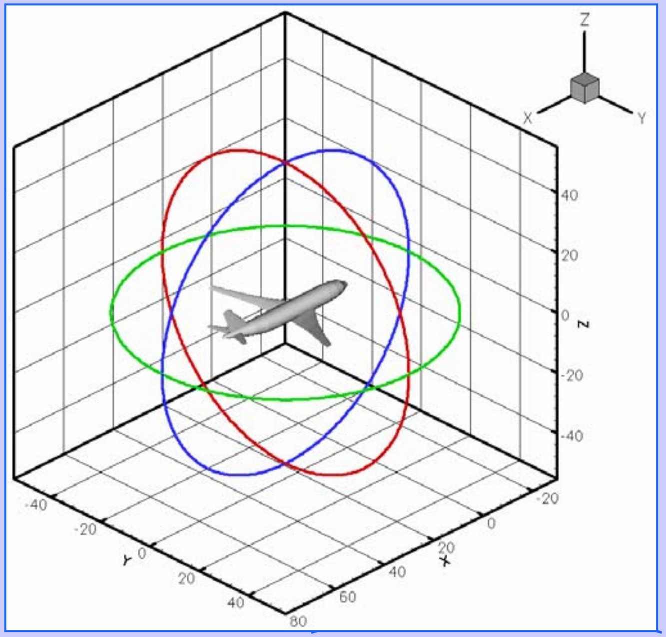
Results

Pressure distribution at aircraft surface

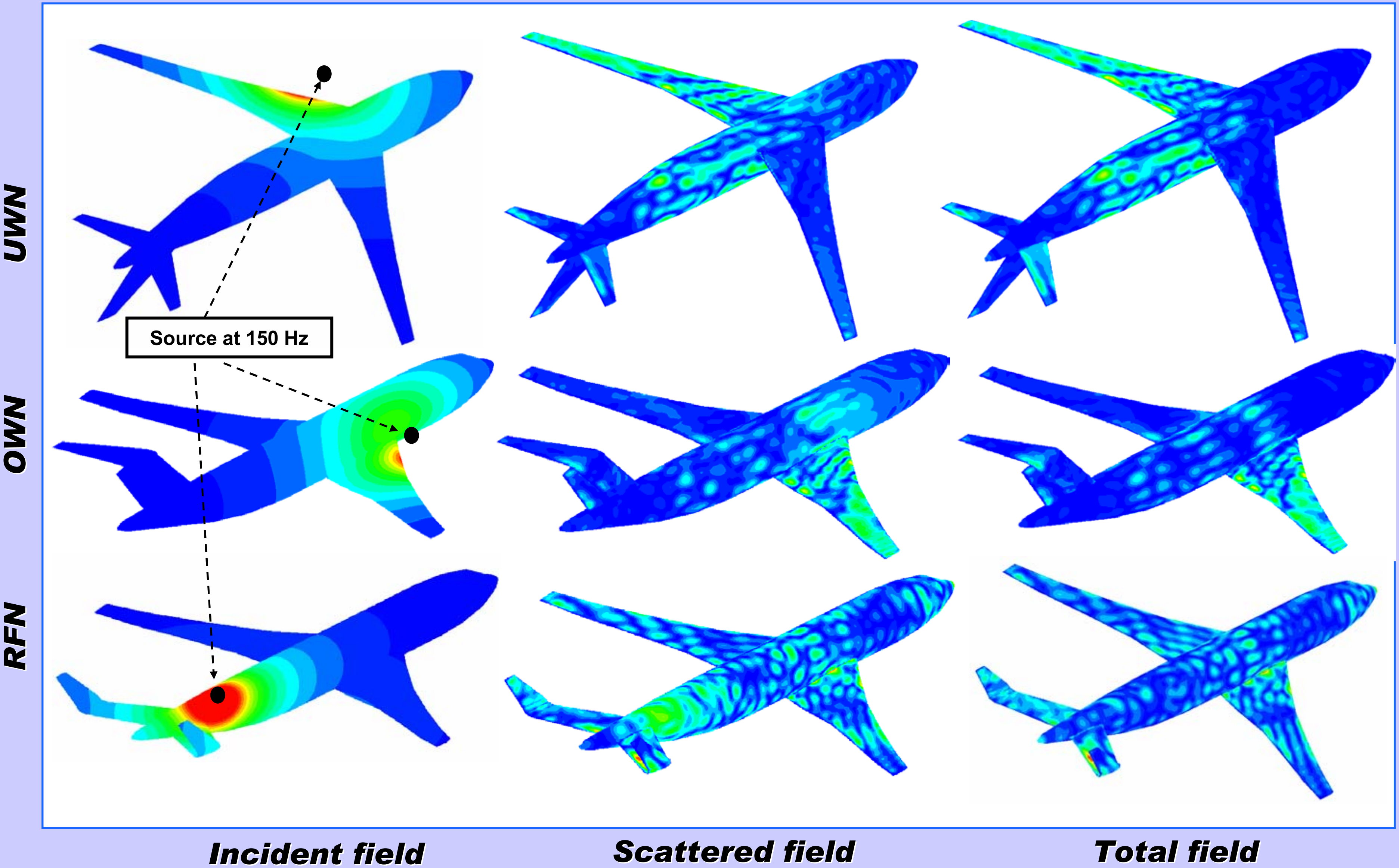
- **Incident, scattered, total fields**

Directivity diagrams

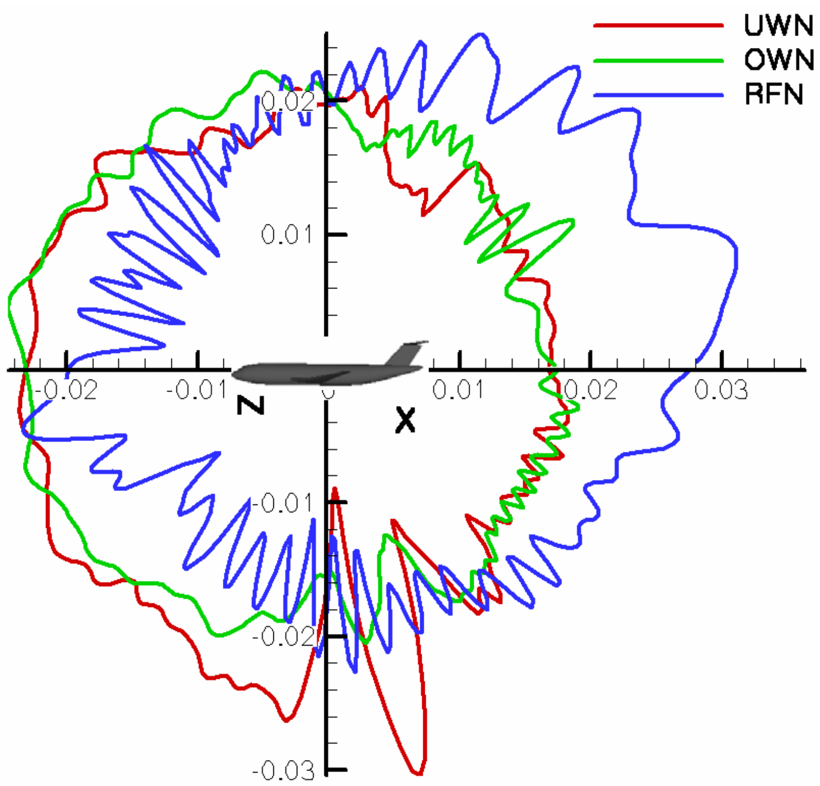
- **Circles in XY, XZ and YZ planes**
- **Centered at fuselage center X = 25 m**
- **Mid-field : R = 50 m (one fuselage length)**



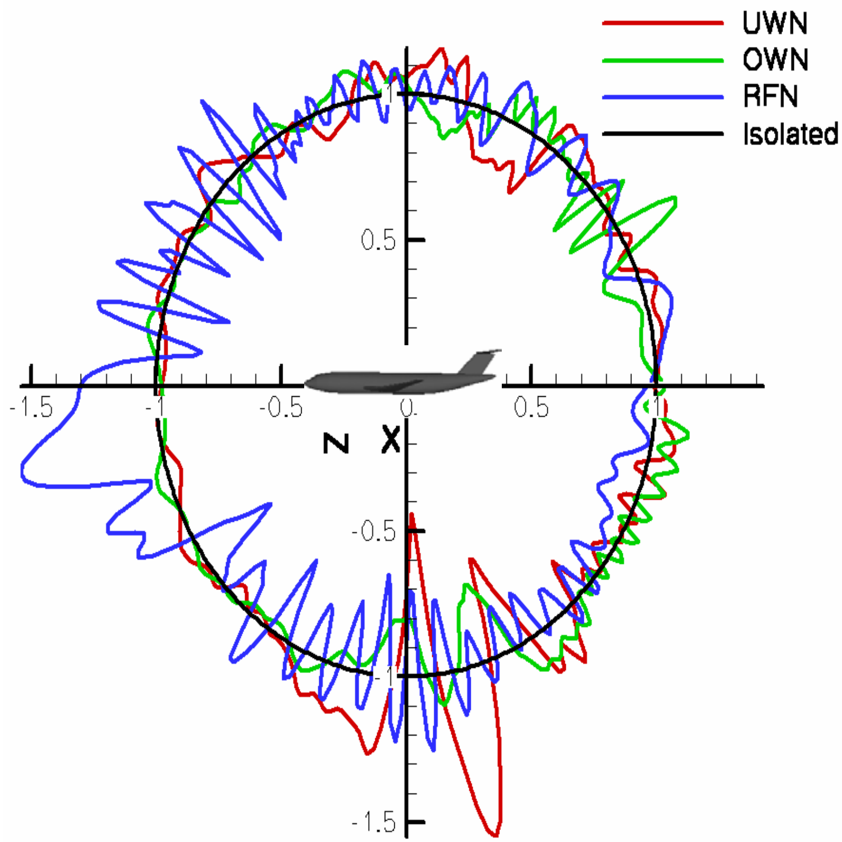
Results: Pressure distribution at aircraft surface



Results : *Directivity diagrams in the ZX plane (r = one fuselage length)*



Not corrected from the distance source-observer



Corrected from the distance source-observer

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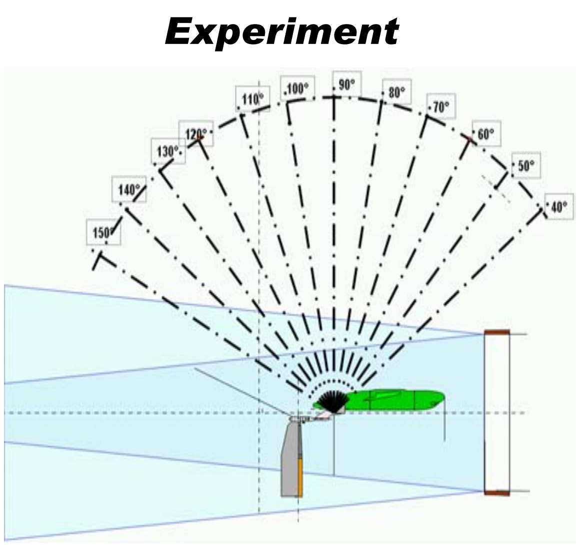
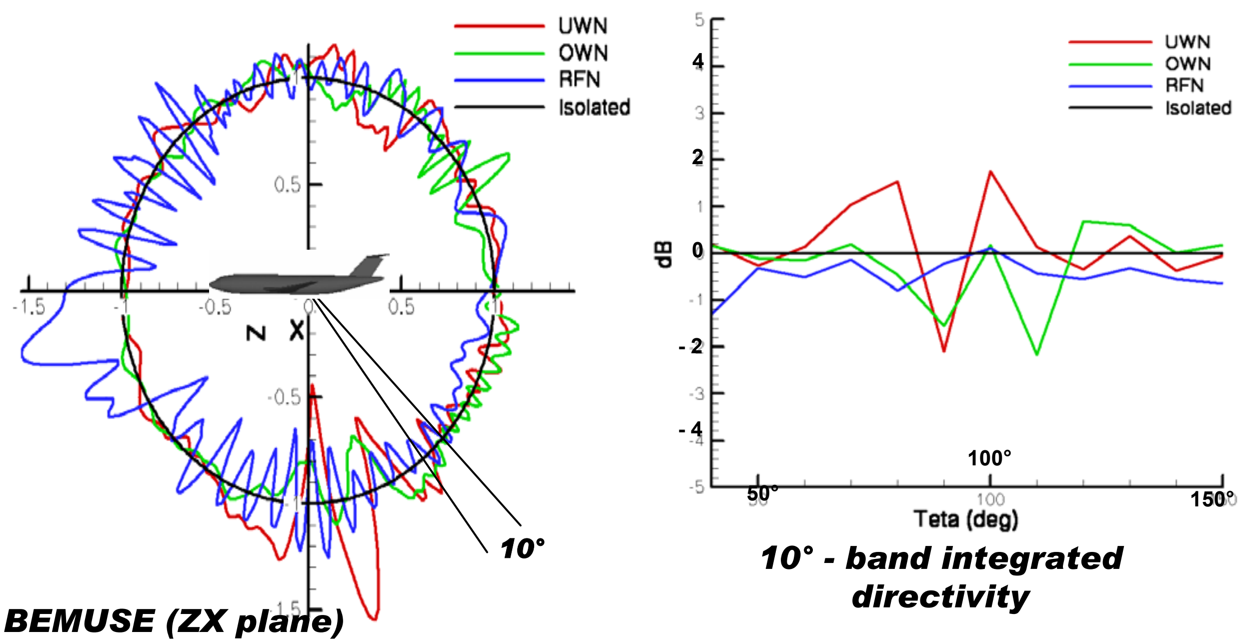
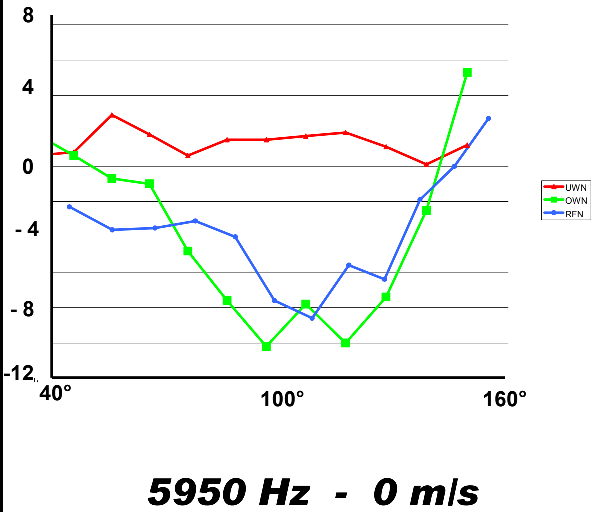
Results : Tentative of comparison with CEPRA 19 experiments (ROSAS campaign)

	BEM computation	Experiment
Aircraft	ROSAS Aircraft	Airbus aircraft
Scale	1:1	1:11 (1:16 w.r.t. ROSAS A/C)
Source	Monopole (at the engine inlet)	TPS (certainly not spherical)
Frequency	150 Hz (→ 2.4 kHz at 1:16)	6 kHz
Observer	R = 50 m (one fuselage length)	R = 6 m (two fuselage lengths)







Application of BEMUSE to installation effects studies : Next steps

- **Computations on larger grids (110,000 DOF) and at higher frequencies (under progress)**

- **Grids : - half - grids (aircraft symmetry), under progress**
  - more realistic grids (from aircraft CAD files)

- **Improve the fan source model, derive a jet noise source model**

- **Implement and test a convected wave equation (propagation in uniform flow)**

- **Go to higher frequencies : Develop Fast Multipole Method (FMM) (under progress)**

In-house solvers developed at *ONERA*

Part II : sAbrinA code

sAbrinA

(*Solver for Aeroacoustics BRoadband INteractions from Aerodynamics*): a 3D multi purposes CFD / CAA code

FLU3M
Industrial CFD software , structured, finite volume, multidomain

E3P
Acoustic propagation via Euler perturbation equations, finite difference high order schemes, monodomain

PEGASE
Unsteady CFD :
LES/DNS
NLDE

sAbrinA

Solver for Aeroacoustics of BRoadband INteractions from Aerodynamics

- Navier-Stokes or non linear Euler equations, in their conservative form
- Complete or Splitted (mean flow / perturbations) variables
- (Explicit, centered) 2nd order Finite Volumes or 6th order Finite Differences space schemes
- (Explicit) 3rd order or (Implicit) 2nd order time marching scheme
- (Explicit) 10th order filter schemes
- Curvilinear, multi-domains meshes
- Specific (rigid wall, symmetry, periodicity, exit) boundary conditions

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CAA tasks : formulation

Conservative Euler equations $\partial_t \mathbf{u} + \nabla \cdot \mathbf{F}(\mathbf{u}) = \mathbf{S}$

Assuming perfect gas state law and neglecting remote massic forces :

$$\mathbf{u} = \begin{Bmatrix} \rho \\ \rho \mathbf{v} \\ \rho \dfrac{\mathbf{v}^2}{2} + \dfrac{1}{\gamma - 1} p \end{Bmatrix} \quad \mathbf{F}(\mathbf{u}) = \begin{bmatrix} \rho \, {}^t\mathbf{v} \\ \rho \mathbf{v} \otimes \mathbf{v} + p\mathbf{I} \\ \left(\dfrac{\rho \mathbf{v}^2}{2} + \dfrac{\gamma}{(\gamma - 1)} p \right) \left({}^t\mathbf{v} \right) \end{bmatrix}$$

$\mathbf{S}$ = external sources

Mean flow / perturbation splitting : $\mathbf{u} = \mathbf{u_p} + \mathbf{u_0}$

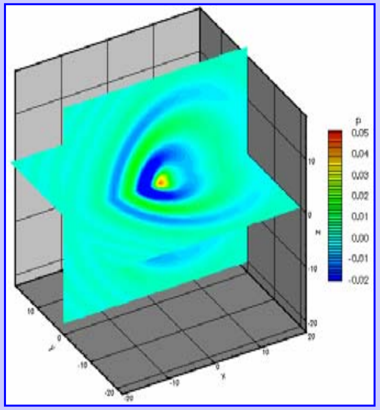
$\mathbf{u_0}$ → Mean flow

$\mathbf{u_p}$ → Perturbation

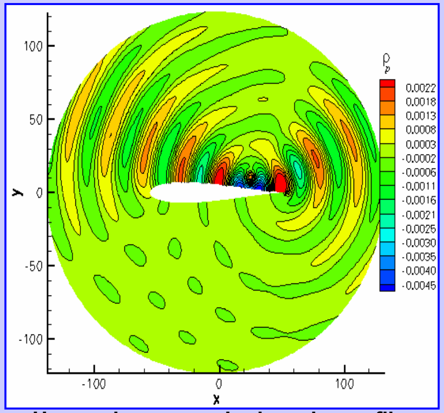
Full (<u>non-linearized</u>) conservative Euler equations in perturbation formulation :

$$\partial_t \mathbf{u_p} + \nabla \cdot \left[\mathbf{F}(\mathbf{u_p} + \mathbf{u_0}) - \mathbf{F}(\mathbf{u_0}) \right] = \mathbf{S}$$

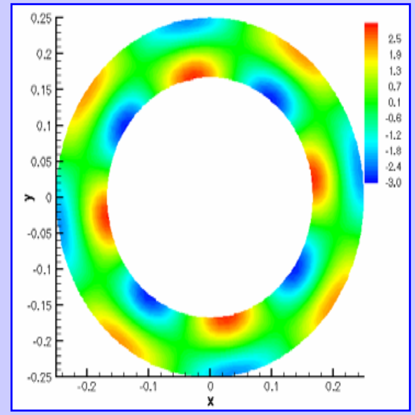
Validation of *sAbrinA* on CAA complex test cases



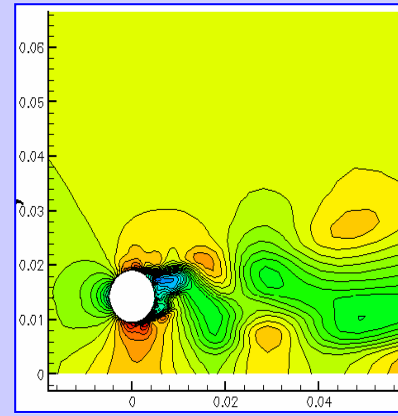
Harmonic source & uniform flow



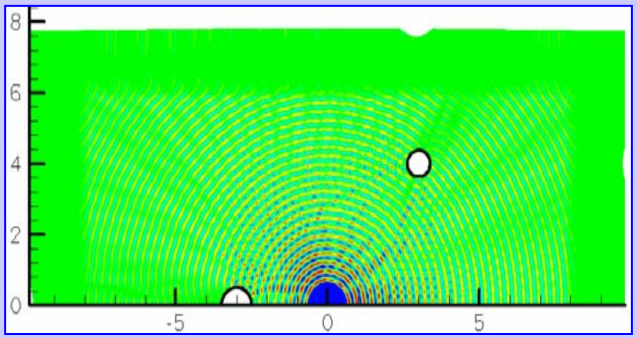
Harmonic source, Joukowsky profile



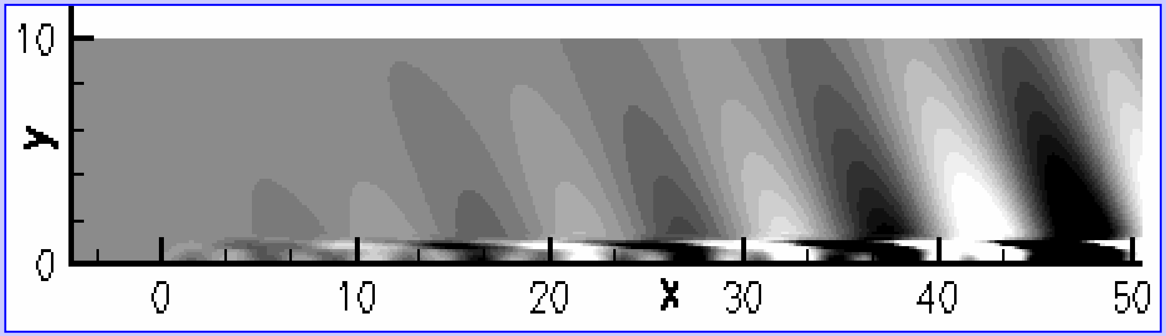
Ducted mode & uniform flow



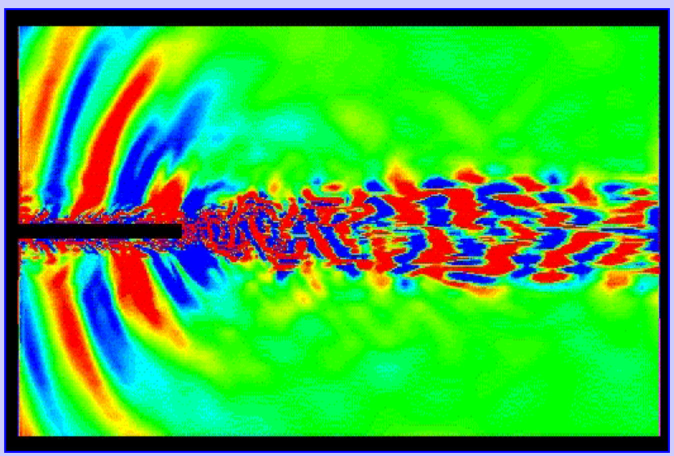
Aeolian tone noise



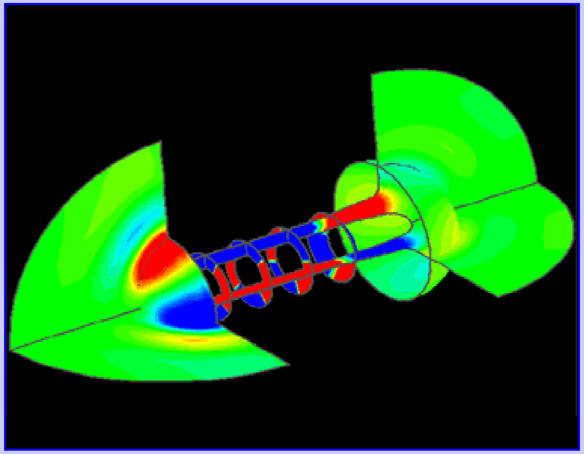
Harmonic source & multiple obstacles



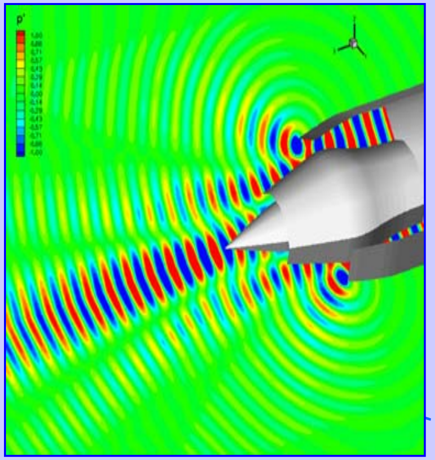
Harmonic source & supersonic shear layer



Trailing edge noise

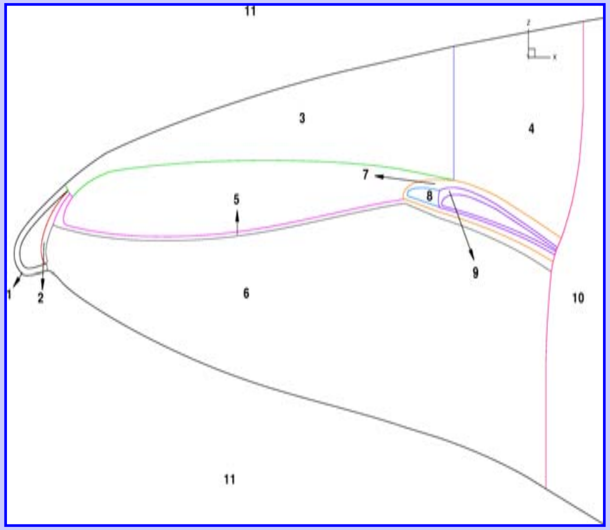


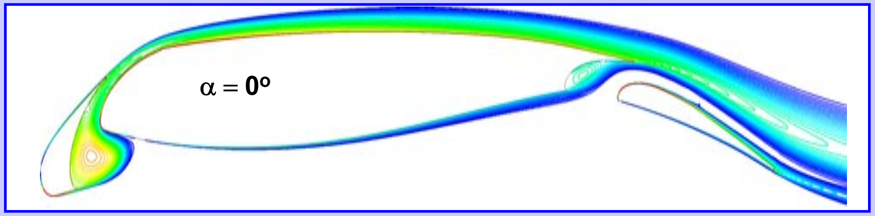
Rotor/stator interaction noise

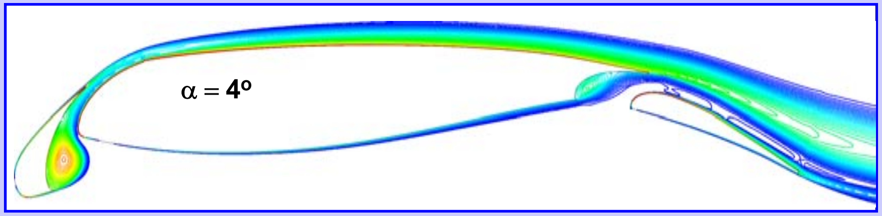


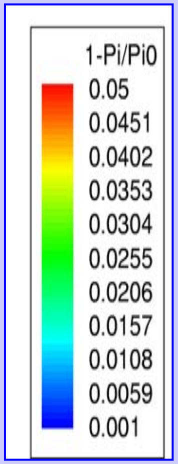
Downstream fan noise

Application :
2D acoustic scattering from a point source located in the vicinity of a high-lift wing immersed in a non-uniform flow









RANS viscous mean flow grid topology and results (0° & 4° incidence)

CAA computation strategy

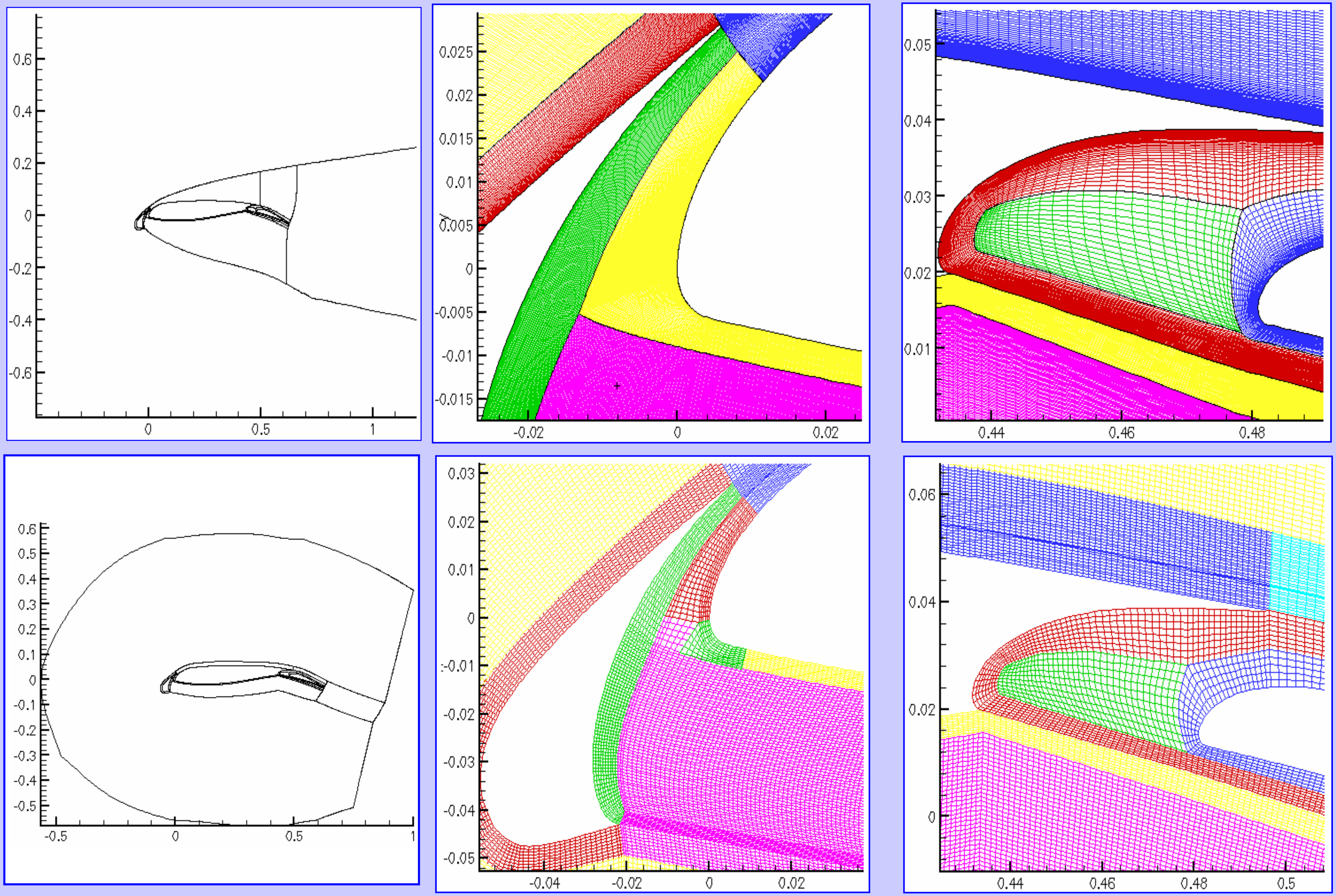
- ❑ **Build a homogeneous CAA grid**
- ❑ **Interpolate the mean flow from CFD to CAA grid**
- ❑ **Perform 2D CAA computations**
  - *** without mean flow (validation vs. BEM)**
  - *** with non-uniform mean flow**

CAA grid derivation (*R. Guénanff*)

Blocks structure ***Slat region*** ***Flap region***

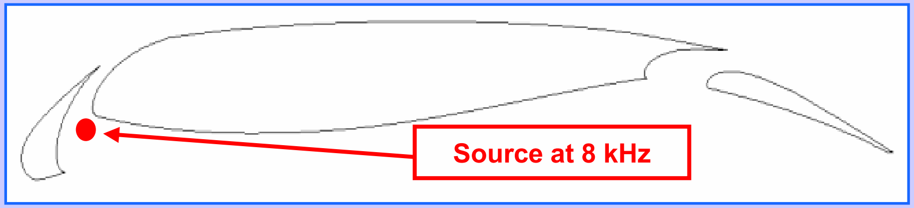
CFD grid

CAA grid

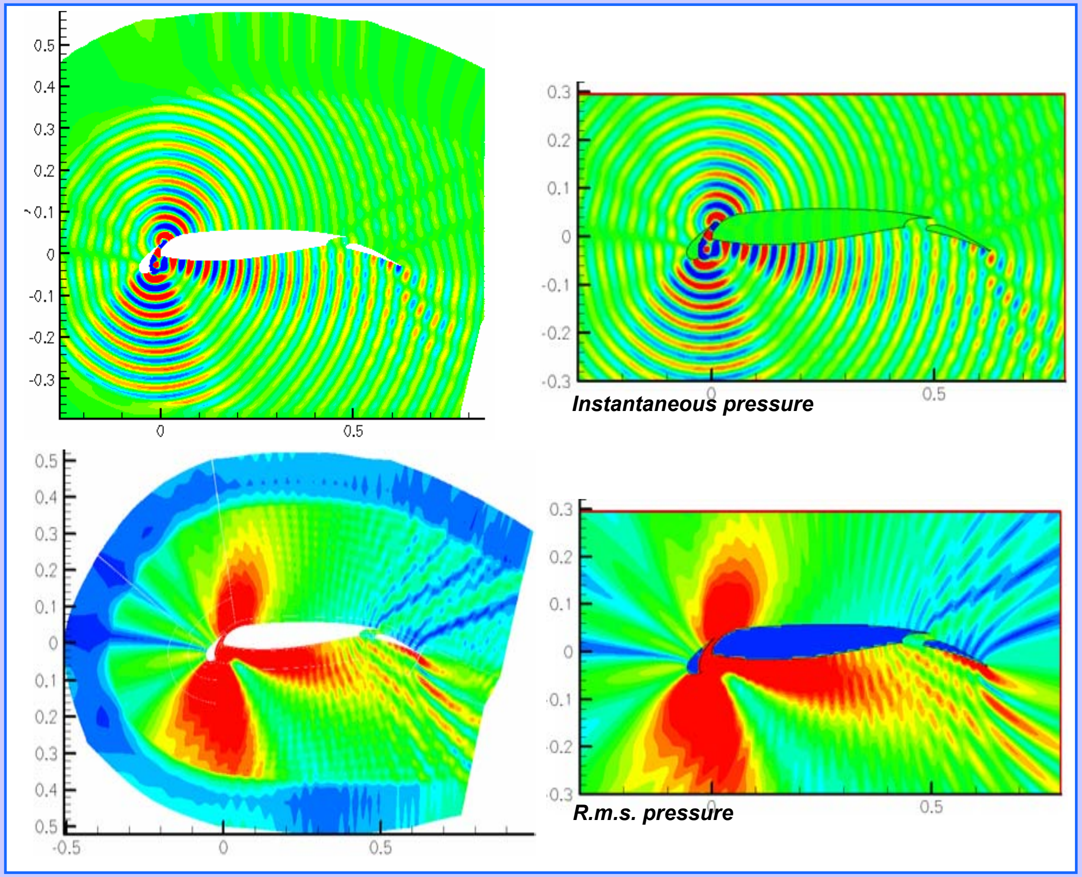


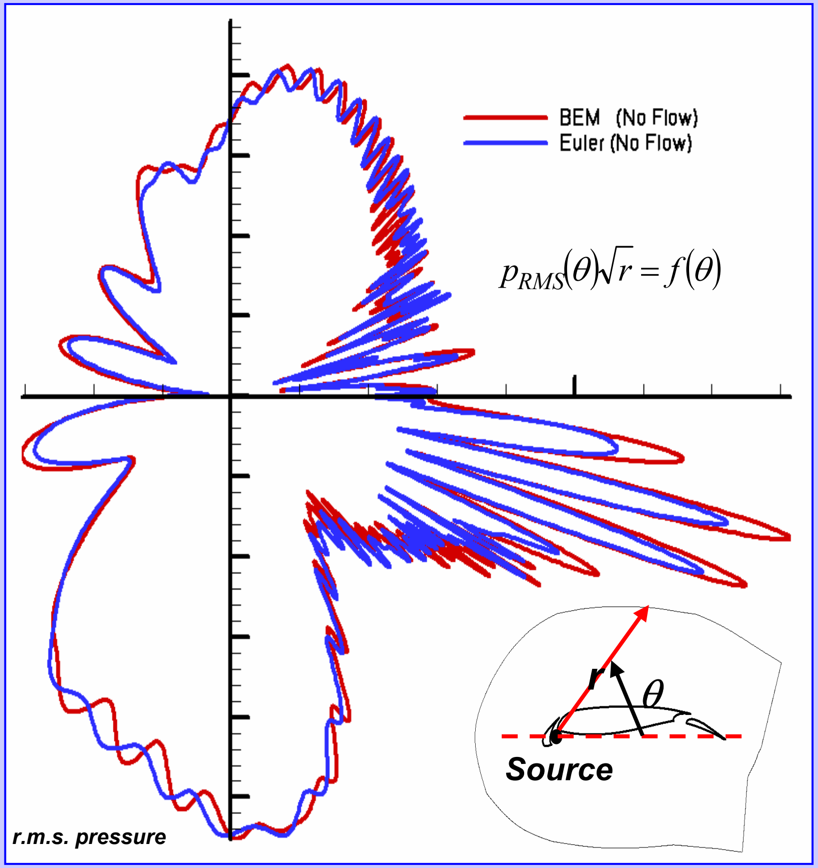
- ***Grid adapted up to 30 kHz***
- ***Mean flow interpolation from the CFD to the CAA grid : use of TECPLOT routine***

Early computations (in the context of airframe noise characterization)
Monopole located inside the slat cove
(1/2) Propagation in a quiescent medium (no flow), and validation against BEM



FD, 6th order, RK3
f = 8 kHz
Δt = 5e-7 s (= T_{source} / 250), CFL = 0.8

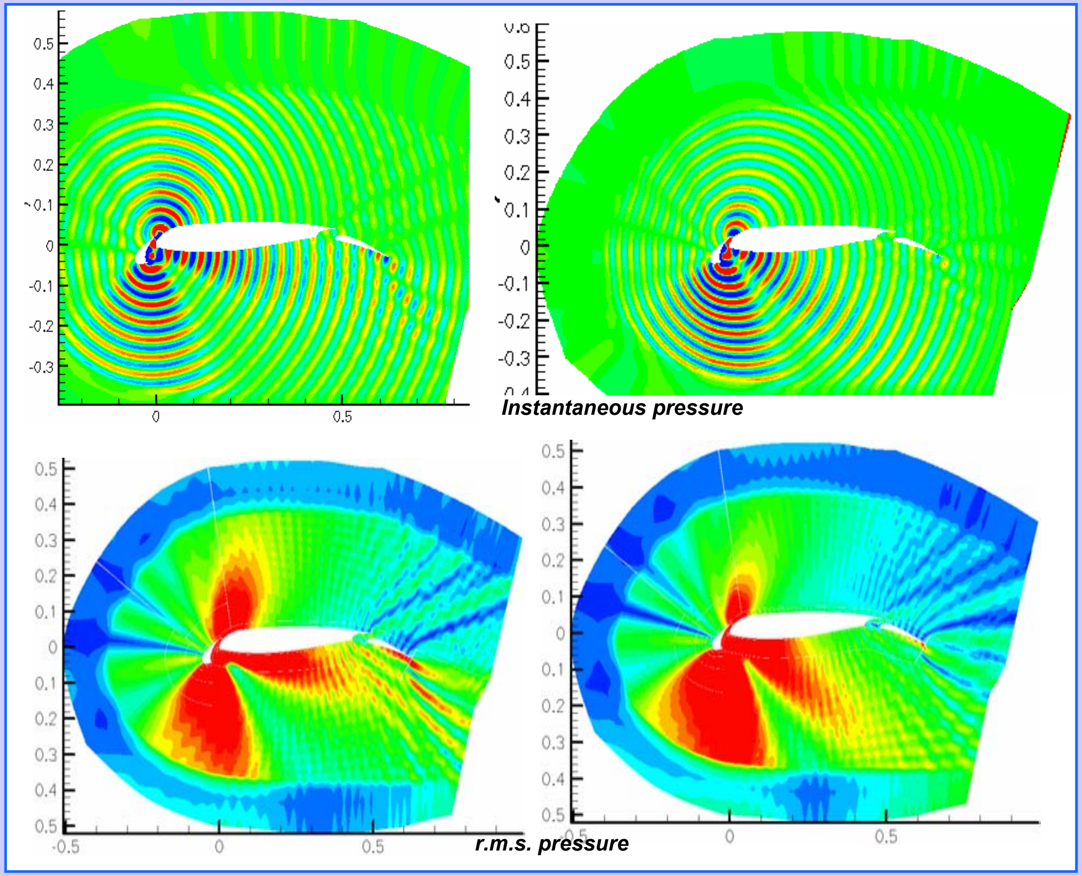


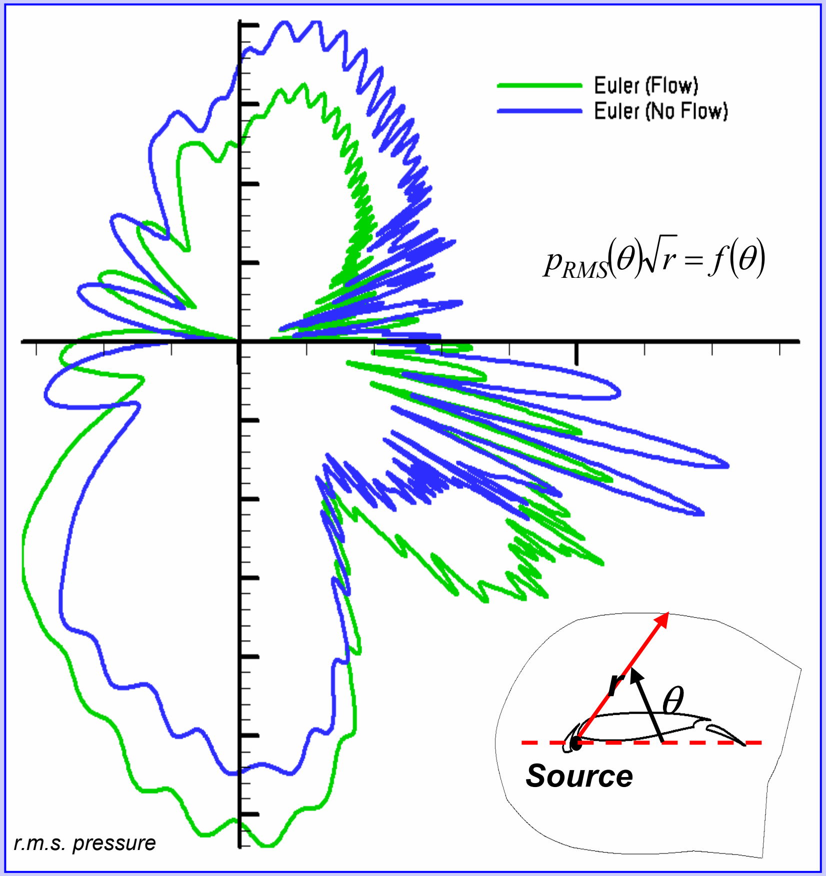


Euler (sAbrinA) ***BEM (Sysnoise)*** ***Euler (sAbrinA) vs BEM (Sysnoise)***

(R. Guénanff, E. Manoha)

Early computations (in the context of airframe noise characterization)
Monopole located inside the slat cove
(2/2) Propagation through the non-uniform (RANS) mean flow





Without mean flow *With non-uniform mean flow* *With and without non-uniform mean flow*

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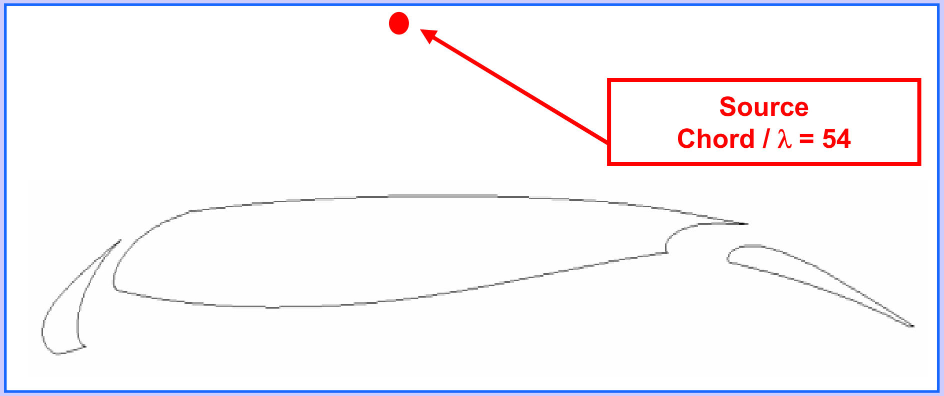
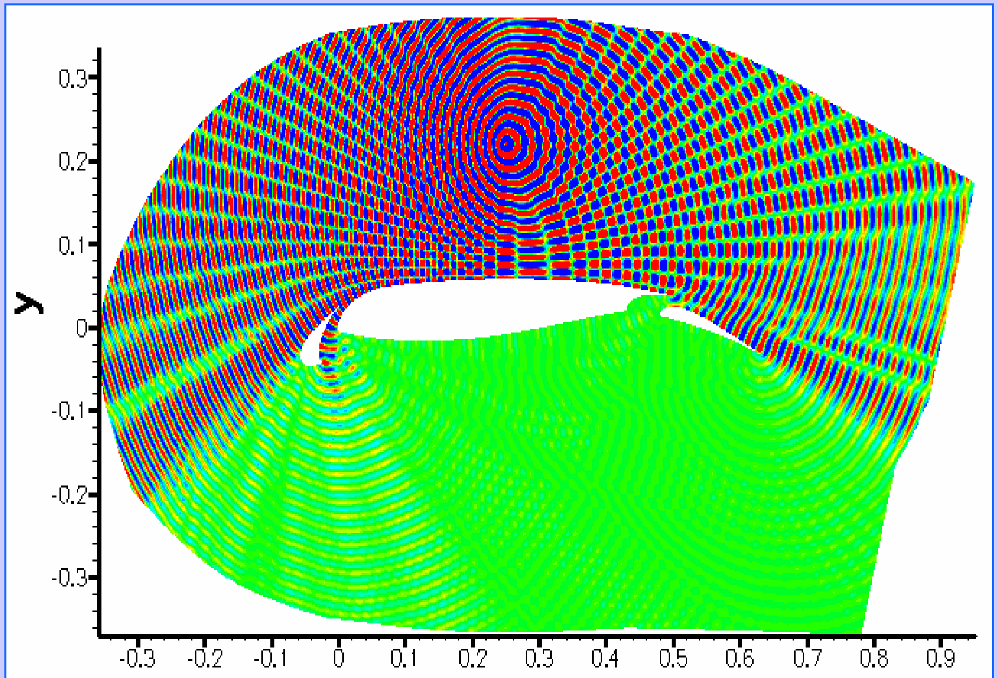
(*R. Guénanff, E. Manoha*)

Application in the context of installation effects
Monopole located above the suction side
Propagation in the non-uniform (RANS) mean flow

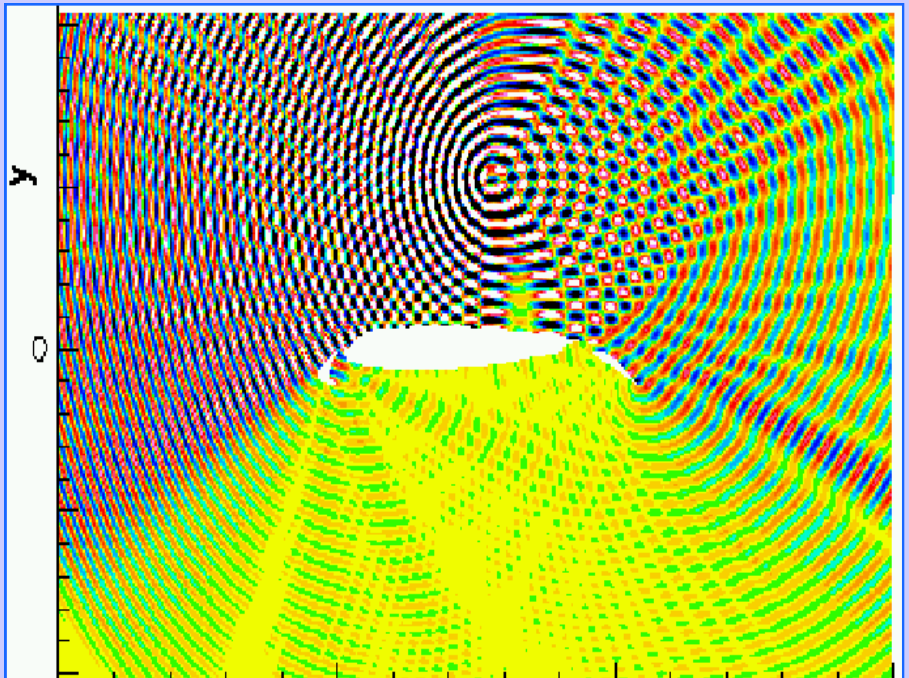


f = 21 kHz

f = 16 kHz



Instantaneous density field



Instantaneous pressure field

sAbrinA code

PIANO code (Roland EWERT, DLR)

ROSAS benchmark (TCD / DLR / IST)

(R. Guénanff)

Application of sAbrina to installation effects studies: Next steps

- Develop innovative techniques to facilitate complex meshes design (2D, 3D)
  - Non-conformal interface (R. Guénanff PhD thesis)
  - Curvilinear/Cartesian interface (G. Desquesnes PhD thesis)

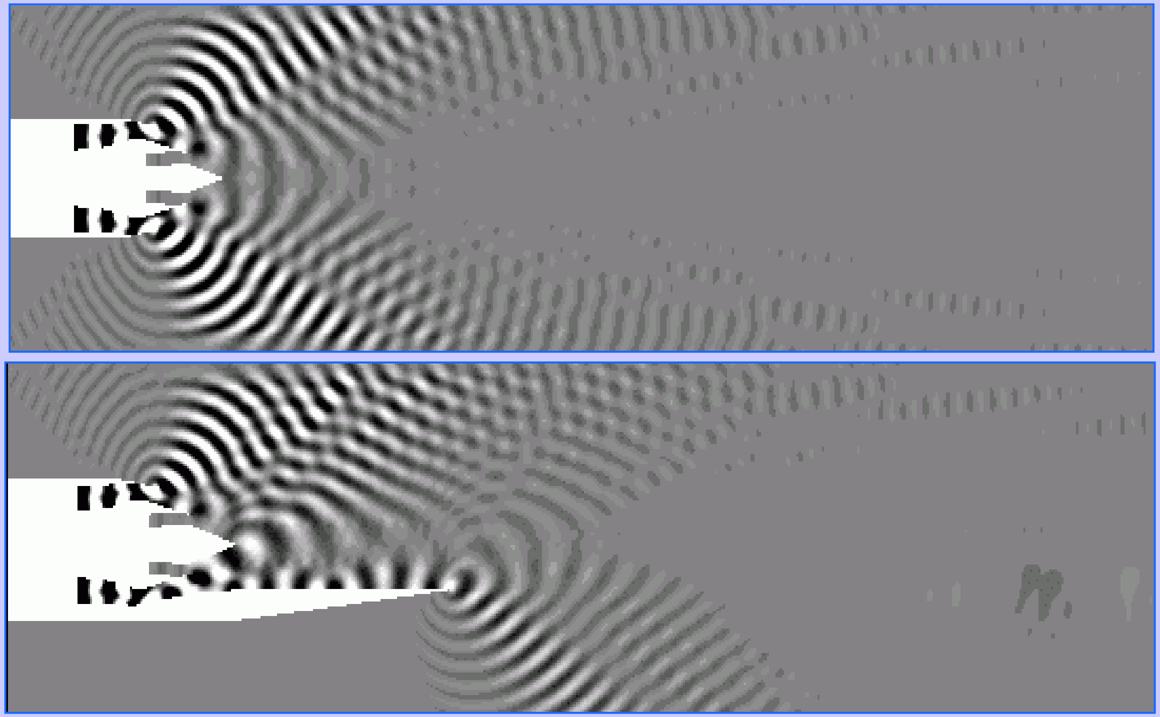
- Study installation effects on 3D realistic aircraft geometry

- Extend the *sAbrinA* capabilities to the treatment of other installation effect configurations

Other Installation effects study with *sAbrinA*

Numerical Simulation of the Downstream Fan Noise of a Coaxial Jet with a Shielding Surface

by Stéphane REDONNET, Eric MANOHA *(ONERA)*
and Owen KENNING *(QinetiQ)*



Friday 12 November, 11:25

Coming soon…

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QinetiQ