

# La simulation numérique en aéroacoustique aéronautique : quelle place pour la LBM ?

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Groupe de travail « Schémas de Boltzmann sur réseau »  
Institut Henri Poincaré - 06.05.2015



retour sur innovation

# Plan

- **Domaine d'activité, besoins en simulation numérique**
  - L'Onera et l'aéroacoustique en aéronautique
  - Bruit aérodynamique et effets d'installation
- **Simulation numérique aéroacoustique : les outils classiques**
  - Méthodes hybrides CFD/CAA
  - Les codes aérodynamiques et acoustiques à l'Onera
  - La LBM : l'Onera dans LaBS
- **Exemple : bruit de train d'atterrissage**
  - Géométries disponibles pour la validation
  - Cas du train d'atterrissage simplifié LAGOON
    - Simulations numériques basées sur elsA et CEDRE
    - Simulations numériques basées sur PowerFLOW et LaBS
- **Bilan**

# Onera : centre français de recherche aéronautique et spatiale

Force d'innovation, d'expertise et de prospective  
pour l'industrie, l'État et l'Europe

Un portefeuille  
d'activités équilibré

- 1/3 civil
- 1/3 défense
- 1/3 dual

- Épic créé en 1946
- Tutelle du ministère de la Défense
- 2 101 personnes
- 220 doctorants et post-doctorants
- 210 M€ de budget
- 38 M€ d'investissements
- 62 % d'activité contractuelle
- 1<sup>er</sup> parc de souffleries en Europe
- Un institut labellisé Carnot

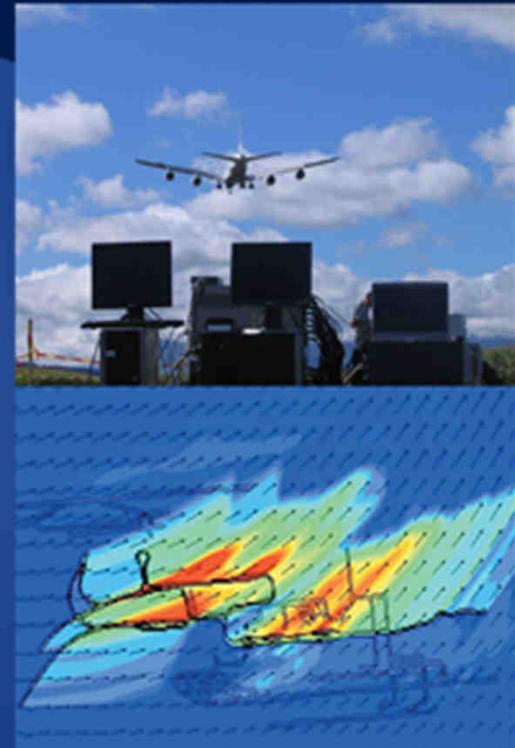
# Retour sur innovation : avance technologique et succès industriels

- Toute la gamme Airbus (A380, A350, A320 Neo) et Falcon (7X)
- Moteurs (Safran)
- Hélicoptères (Airbus Helicopters)
- Ariane 5 → 6
- Missions spatiales

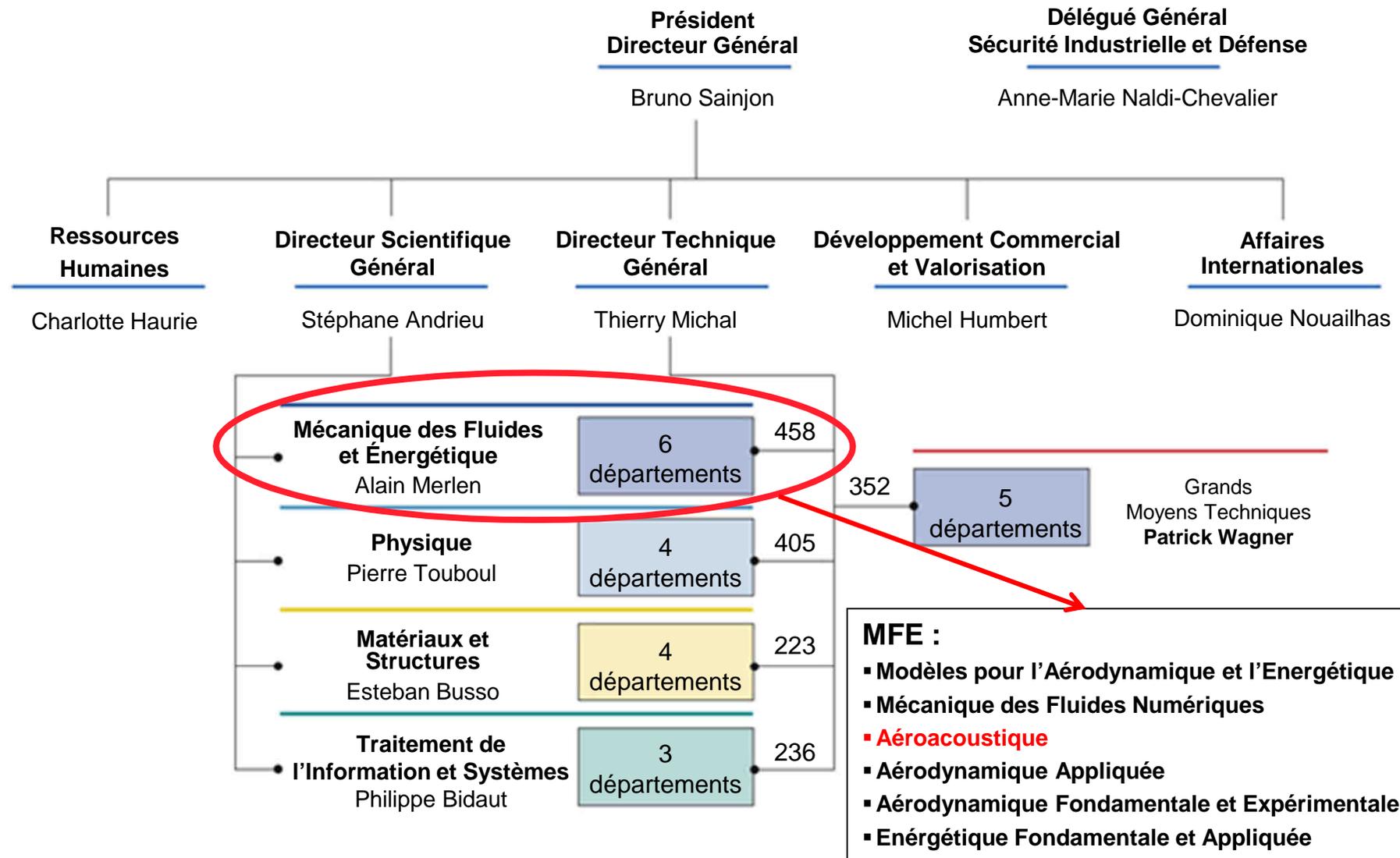
# Retour sur innovation : progrès des connaissances et enjeux sociétaux

## Les enjeux de l'environnement

- Réduction du bruit
- Réduction des émissions polluantes
- Carburants alternatifs



# Organisation



# Département Aéroacoustique (DAAC)

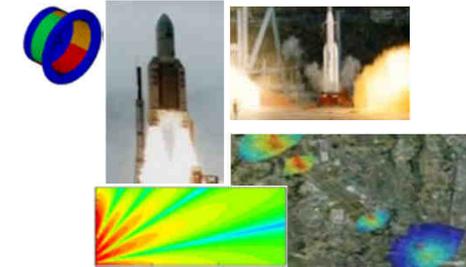
Coordination numérique : Eric Manoha  
Coordination essais : Renaud Davy  
IROQUA: Laurent Leylekian  
Xnoise : Denis Gély  
Qualité : Hélène Gounet

## Département AEROACOUSTIQUE

Denis Gély

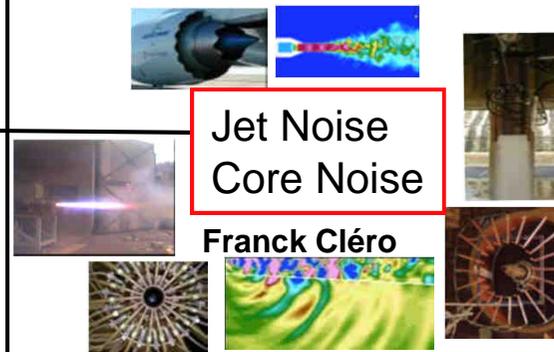
### Environment, Impact & Propagation

Patrice Malbéqui



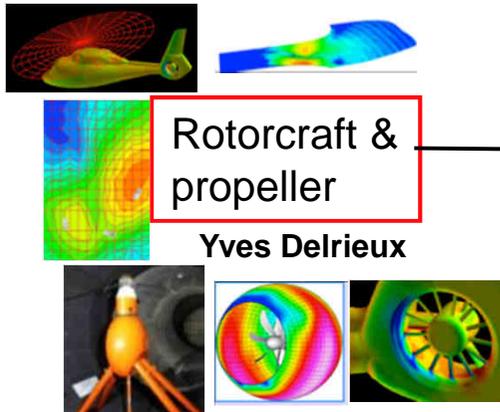
### Jet Noise Core Noise

Franck Cléro



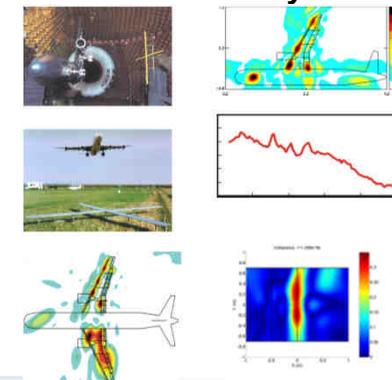
### Rotorcraft & propeller

Yves Delrieux



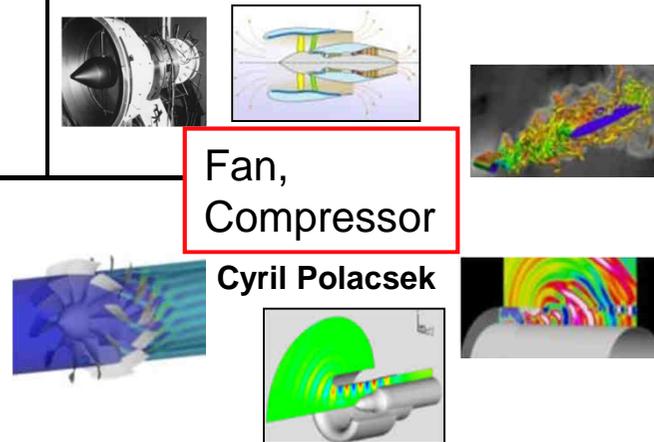
### Sources Identification

Vincent Fleury



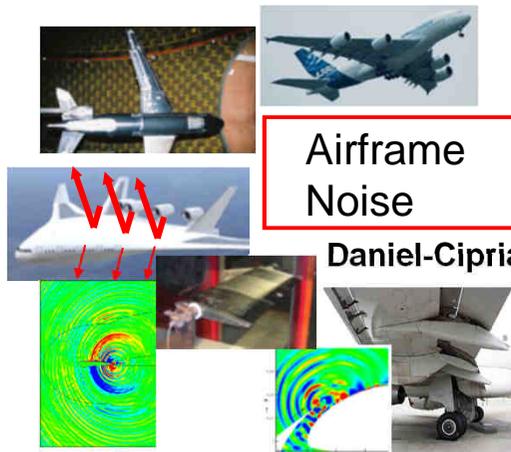
### Fan, Compressor

Cyril Polacsek



### Airframe Noise

Daniel-Ciprian Mincu

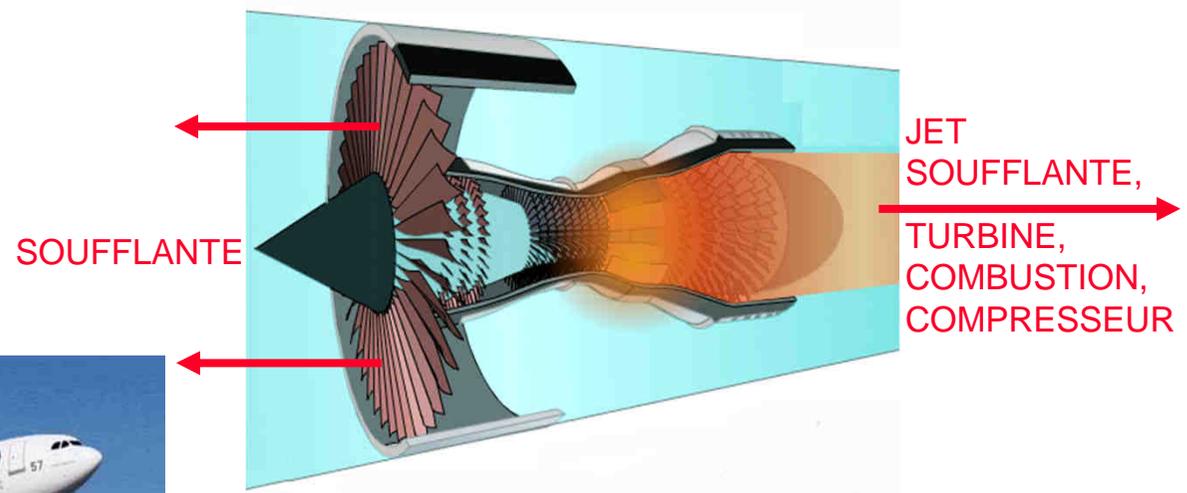


# Sources de bruit d'un avion civil

Bruit externe = **Bruit de propulsion** + **Bruit aérodynamique** + Effets d'installation

## Bruit de propulsion

Turbofan  
Double flux  
Haut taux de dilution



## Bruit aérodynamique

Système hypersustentateurs :

- Becs de bord d'attaque
- Volets de bord de fuite

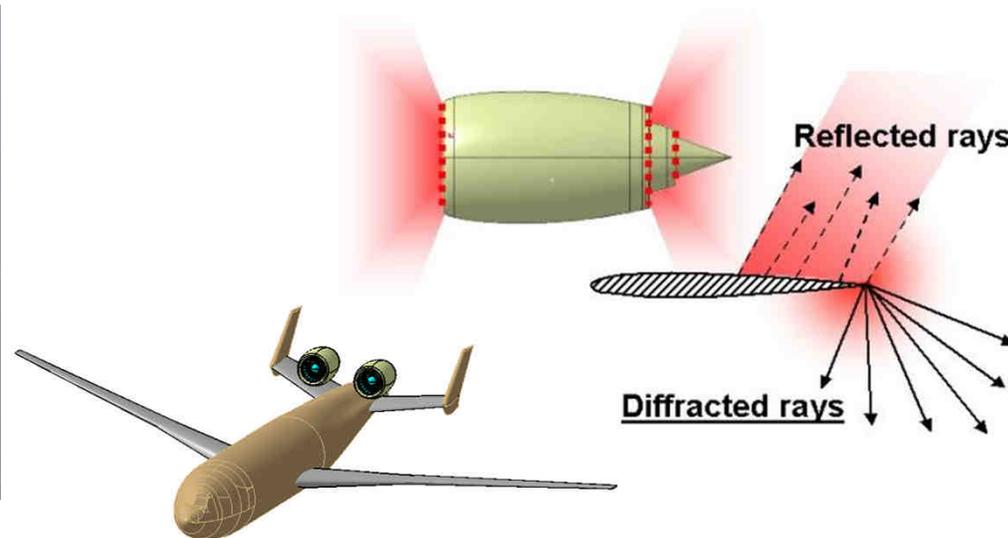
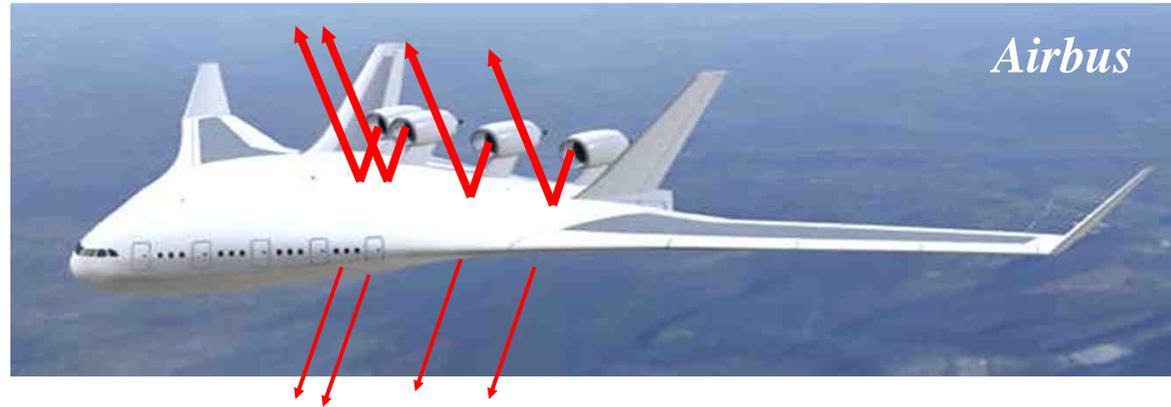
Trains d'atterrissage

Fentes, Cavités, etc

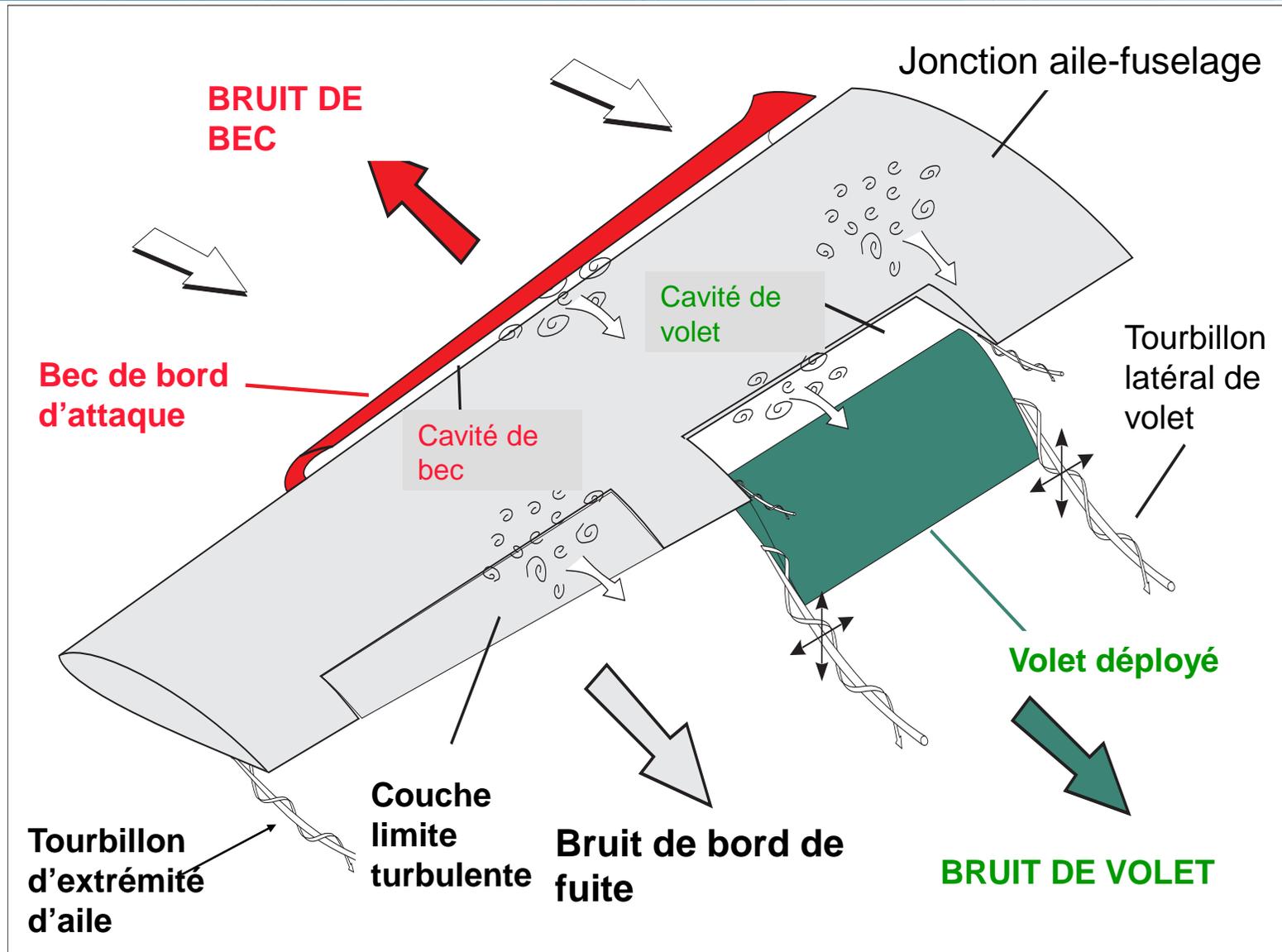


# Effets d'installation

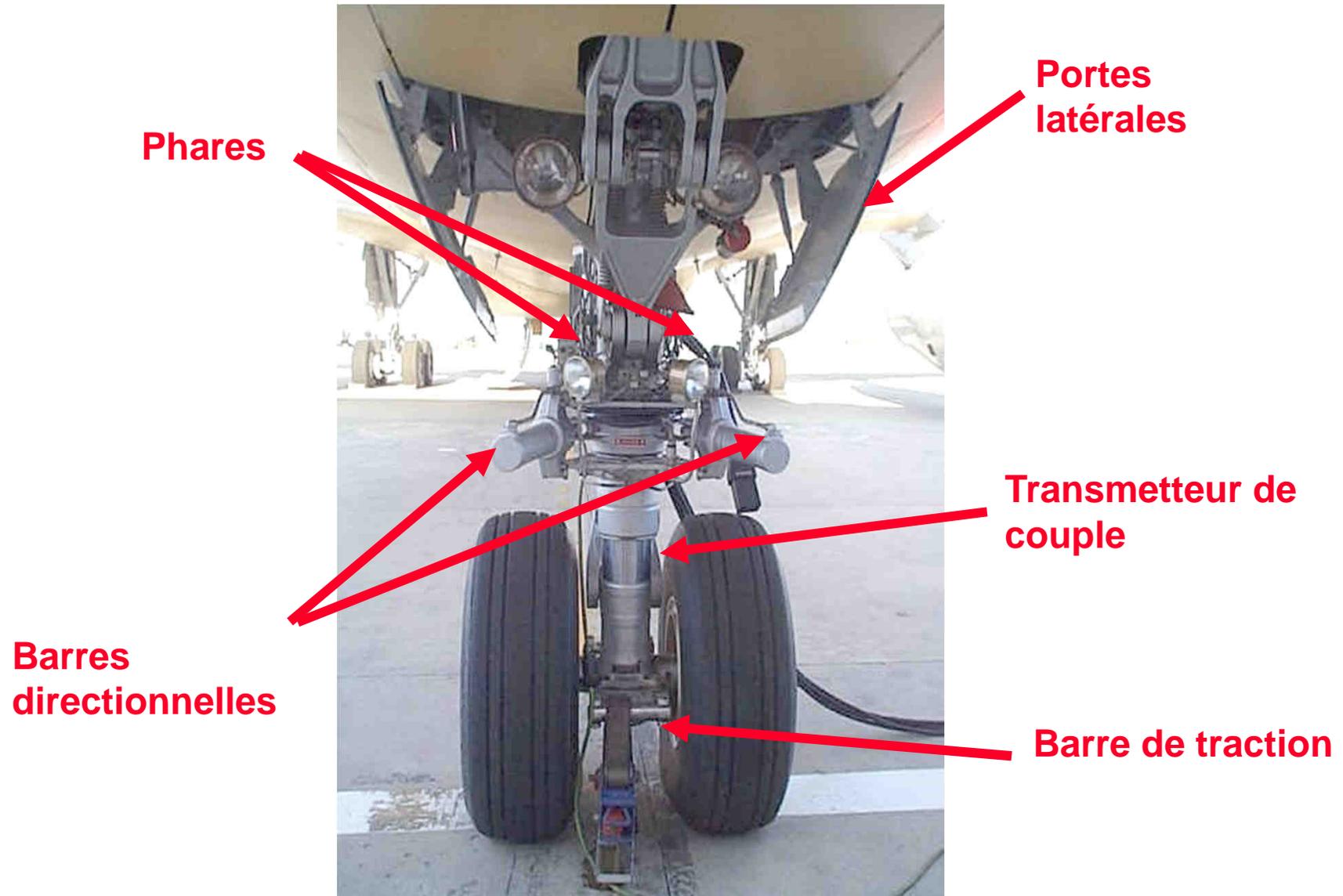
Masquage du bruit de propulsion par la structure



# Sources de bruit aérodynamique sur une aile hypersustentée



# Sources de bruit aérodynamique sur un train d'atterrissage



## **Les méthodes de simulation numérique**

- **Aérodynamique**
- **Acoustique**

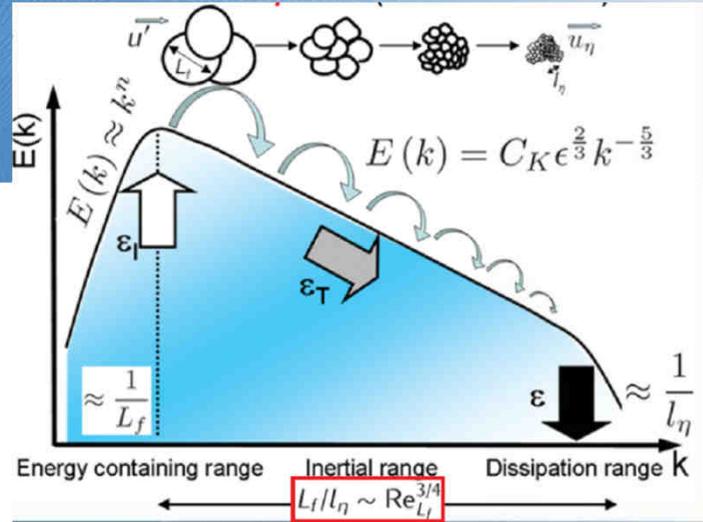
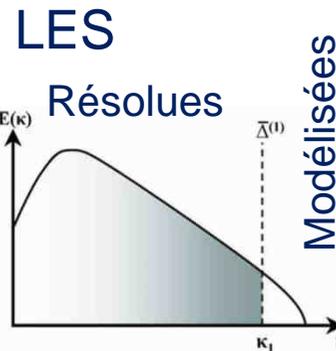
# Principales méthodes CFD

Discrétisation  
des équations  
de Navier-  
Stokes

$$U = U_0 + U_t$$

$U_0 =$  champ moyen constant  
 $U_t =$  fluctuation turbulente

RANS (stationnaire)  
URANS = RANS +  $\partial/\partial t$   
Structures résolues : aucune  
Structures modélisées : toutes



Spectre de turbulence Sagaut, Deck, Terracol, 2006

DNS  
Résolues : toutes (dans les  
limites du maillage ...)  
Modélisées : aucune

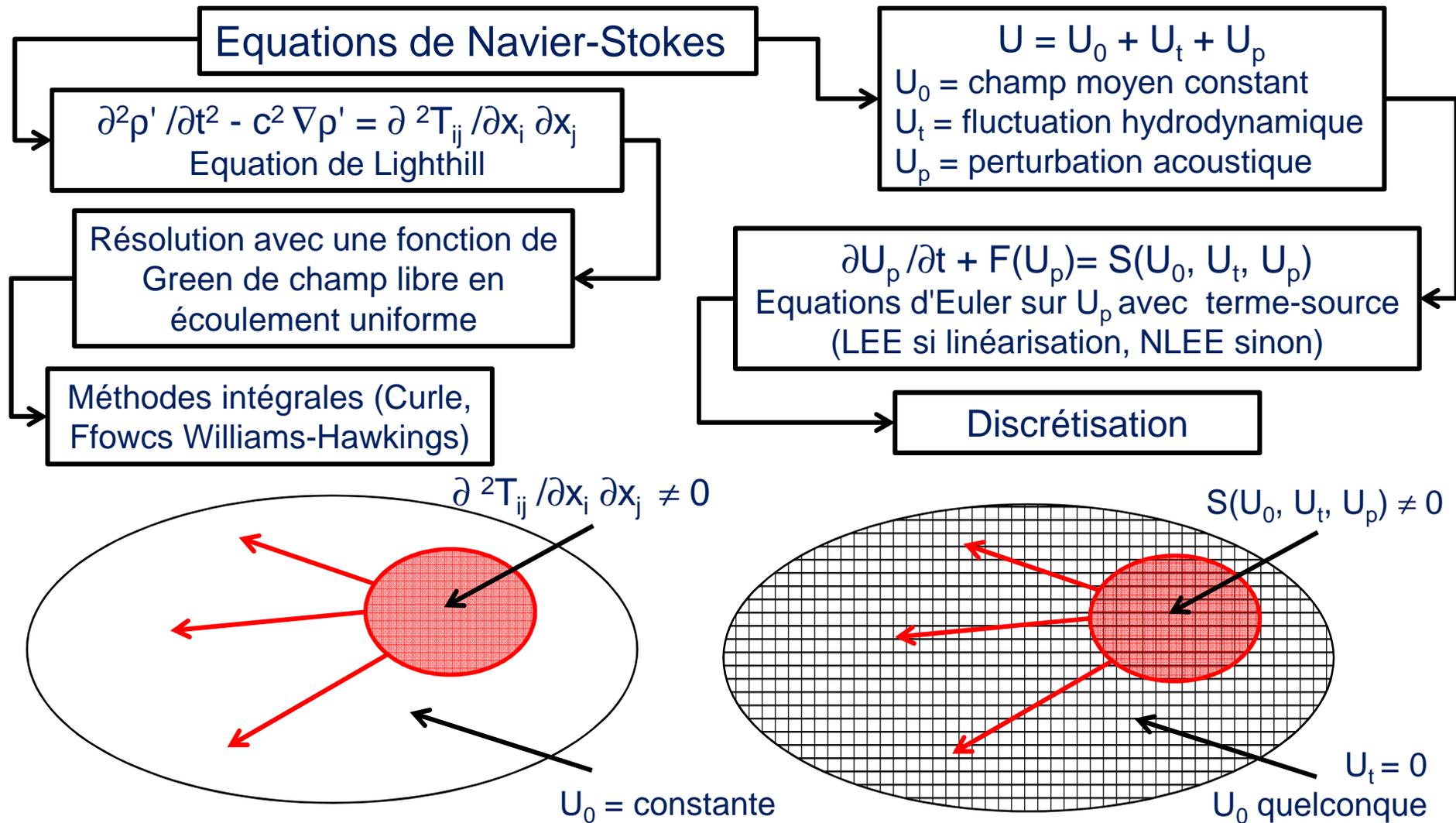
DES = hybride RANS/LES

- Couches limites attachées : URANS
- Régions décollées : LES
- Zonal DES (ZDES) : localisation automatique de la transition URANS/LES
- Delayed DES (DDES) : idem avec "protection" de certaines régions pariétale

LBM (Lattice Boltzmann Method)

- Equation de Boltzmann d'une fonction de distribution de vitesse (comportement mésoscopique d'un gaz) + collisions
- Faibles Mach seulement
- Facilité de mise en données : maillages octree, frontières immergées

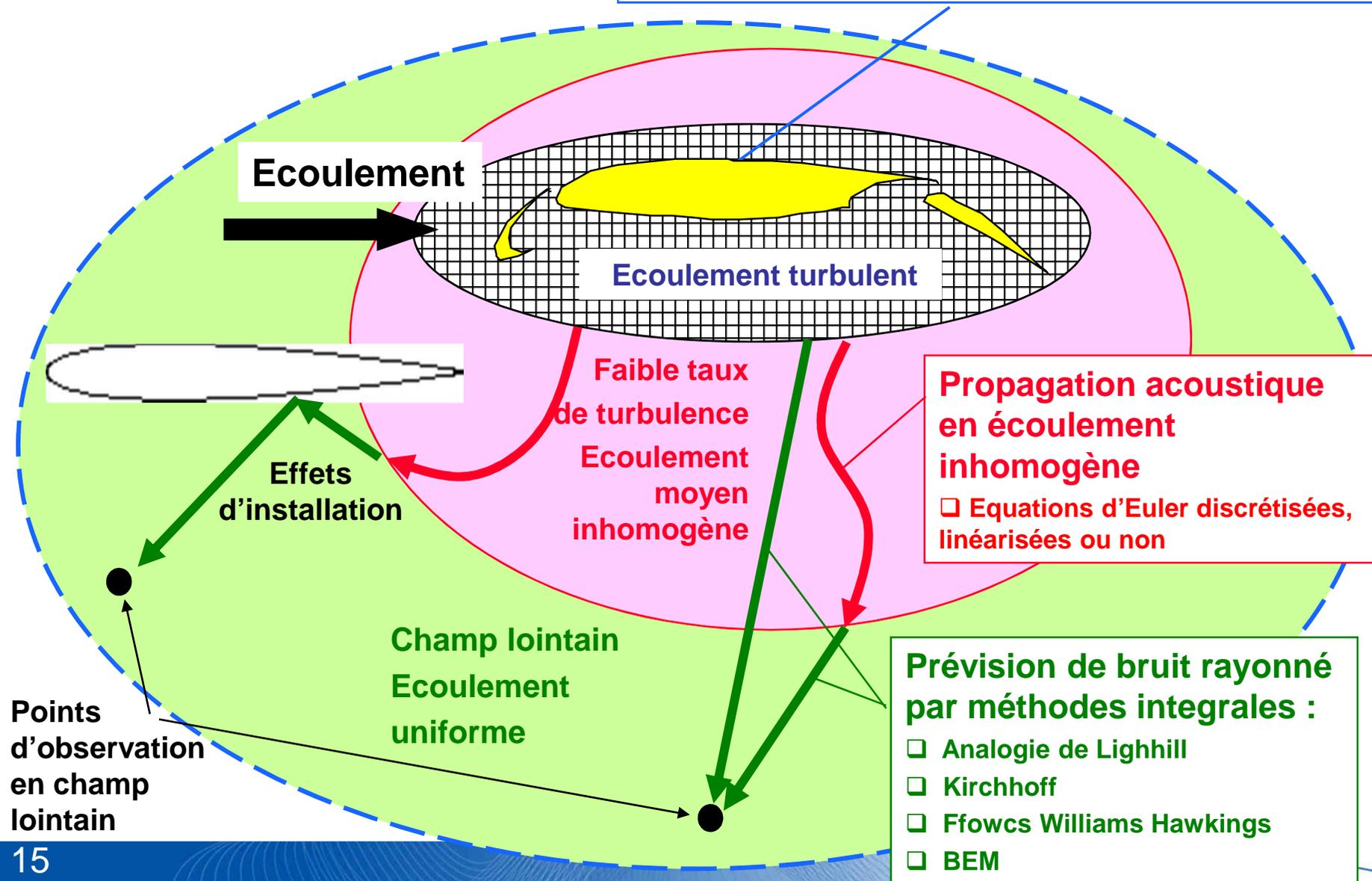
# Principales méthodes en aéroacoustique numérique



# Méthodes hybrides : CFD + acoustique

## Simulation écoulement turbulent local :

- RANS + instabilités, RANS + modèle stochastique
- URANS, LES, NLDE, DNS
- Lattice Boltzmann Method



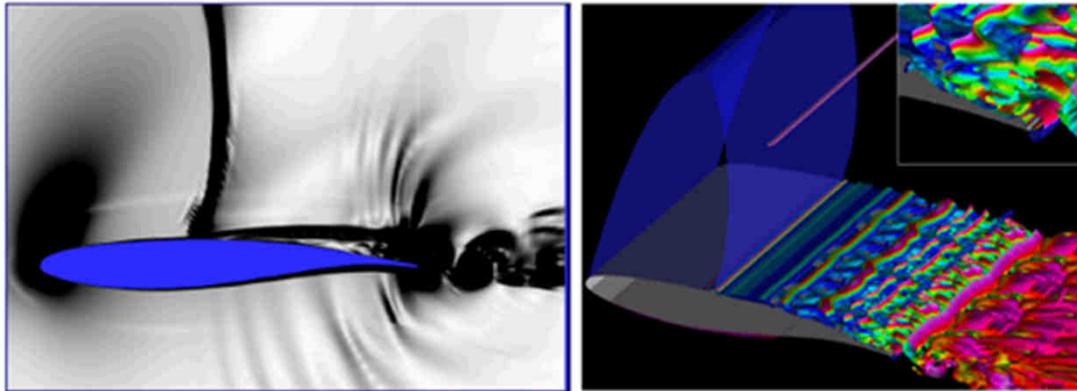
## **Les codes Onera**

- **Aérodynamique**
- **Acoustique**
- **... LBM**

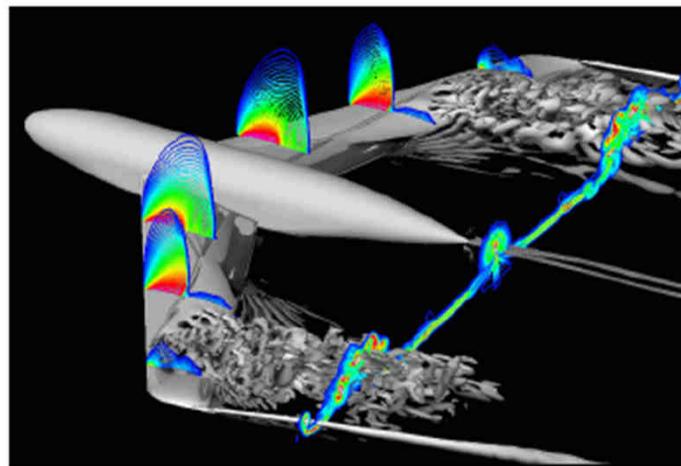
# Unsteady CFD based on LES (DES) *e/sA* solver

Block-structured, finite volume

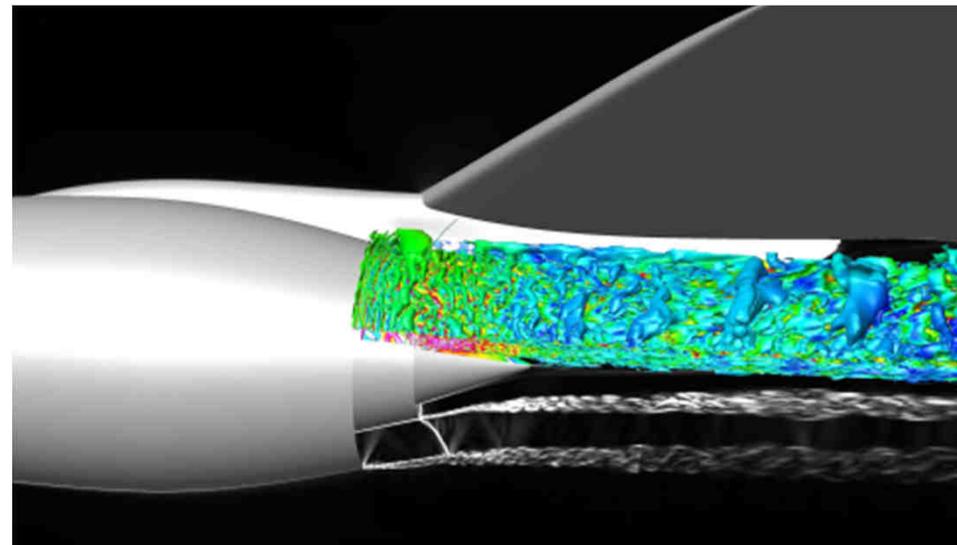
DES : Attached boundary layers solved by RANS, large structures solved by LES



Coaxial jet



Buffeting



Aeroacoustic applications : airfoil, high-lift wing, jet, landing gear

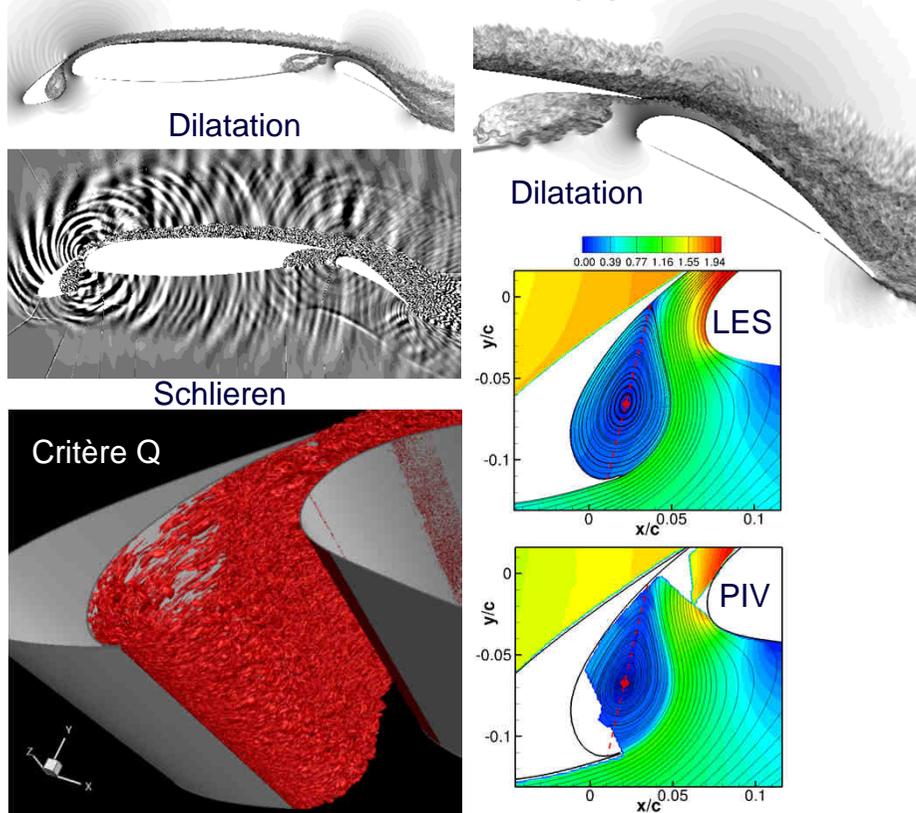
# Unsteady CFD and CAA

## *FUNK* research solver

Navier-Stokes / Euler, Block-structured grids, finite volume and high order finite difference  
 Full or perturbed variables (NLDE / CAA)  
 Adapted to industrial cases and developement of new functionalities

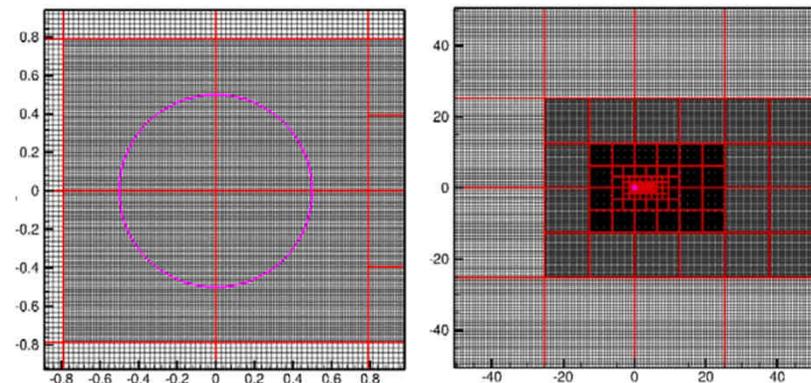
### LES high-lift wing (LEISA2)

Computer JADE (CINES) -  $N_{xyz} \sim 2.6$  billion points  
 4096 coeurs / 10688 domaines -  $T_{CPU} \sim 6\,200\,000$  h

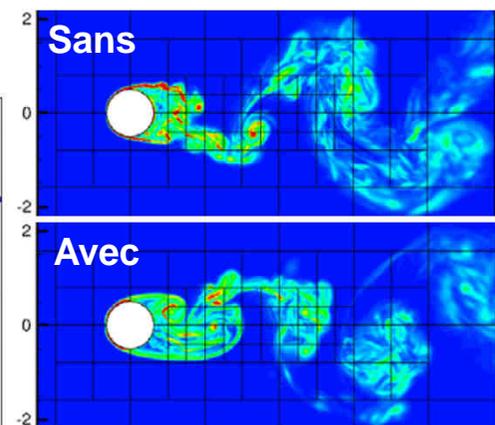
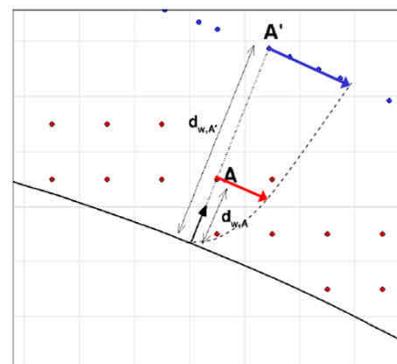


### Development of IBC techniques

Pre-process with *Cassiopee* toolbox



Lois de parois  
 laminaires/turbulentes



Loi Poiseuille

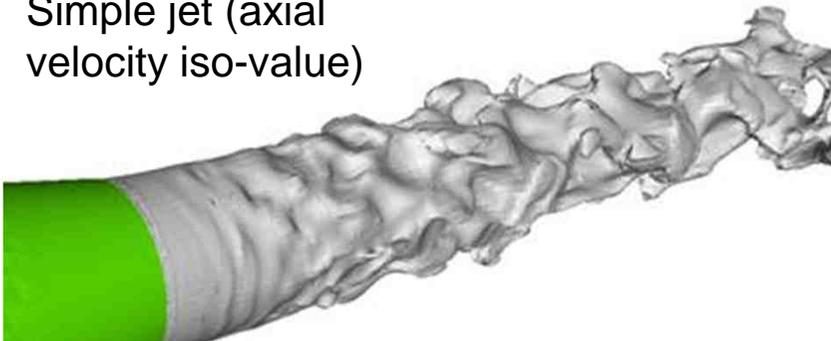
# Unsteady CFD based on LES/DES CEDRE solver

Unstructured grids

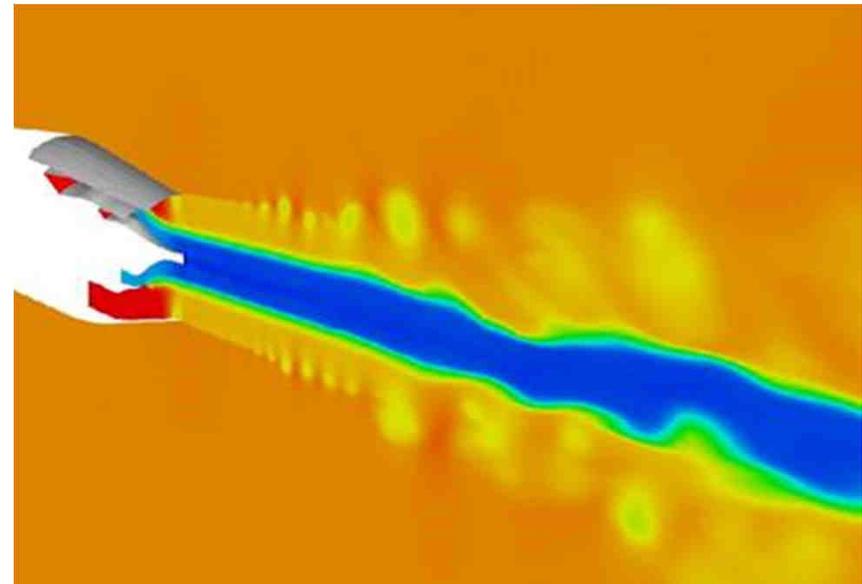
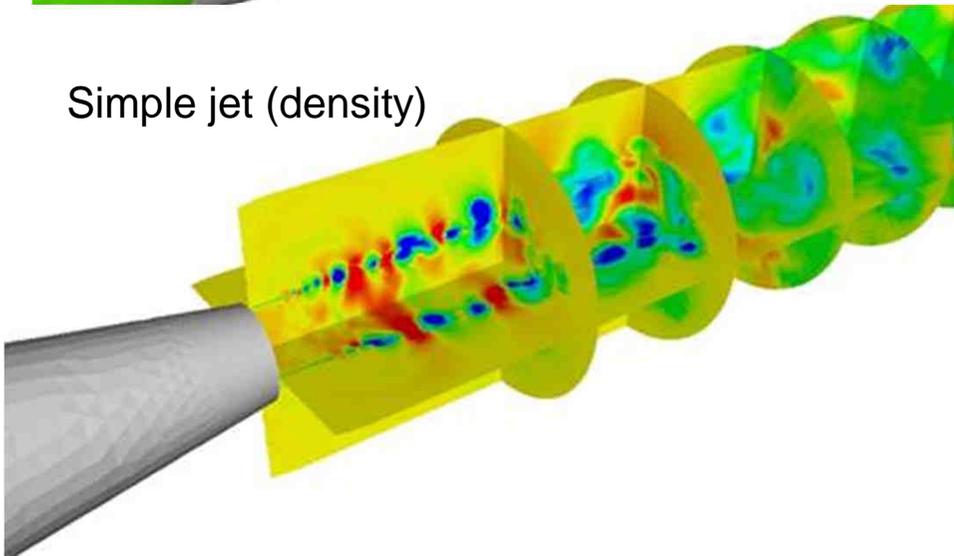
Unsteady CFD : Monotonic Integrated Large Eddy Simulation

Aeroacoustic applications : jet, landing gear

Simple jet (axial  
velocity iso-value)



Simple jet (density)

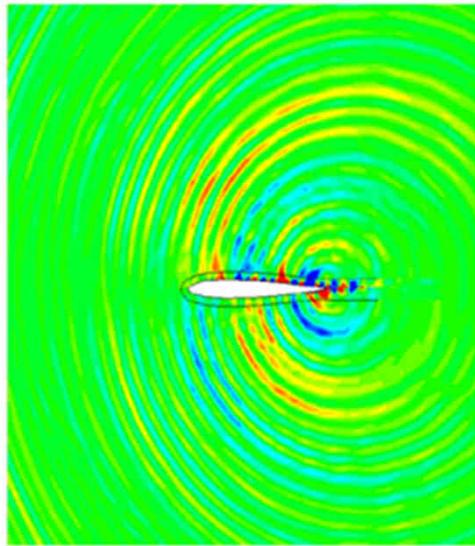


Coaxial jet (density)

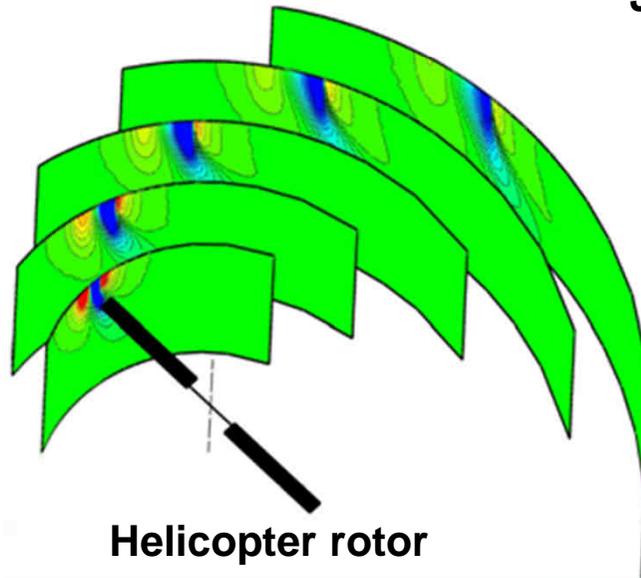
# Integral methods : Ffowcs Williams – Hawkings, Kirchhoff

## Solvers : KIM, MIA

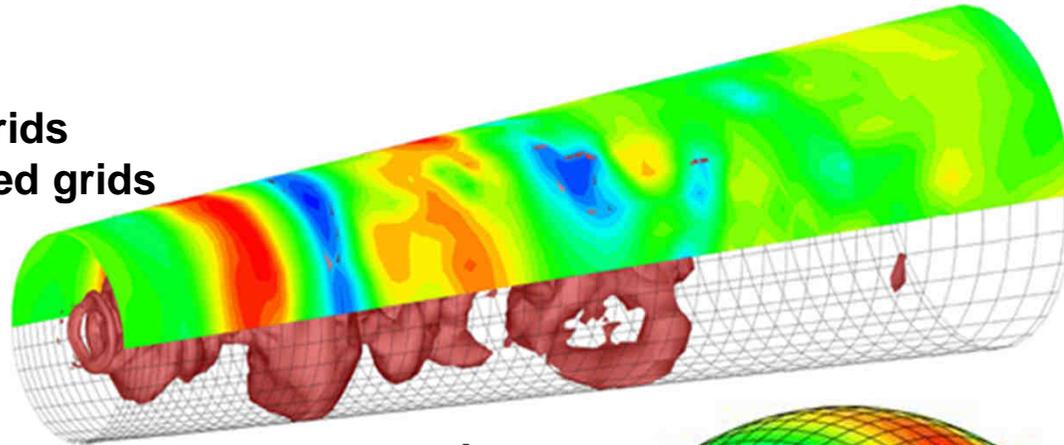
- Multi-purpose integral formulations for acoustic radiation
- Several available formulations (FW-H, Kirchhoff)
- Tonal and large band noise
- Time/frequency domains
- Moving, porous, supersonic grids
- Hybrid structured / unstructured grids
- Parallelised



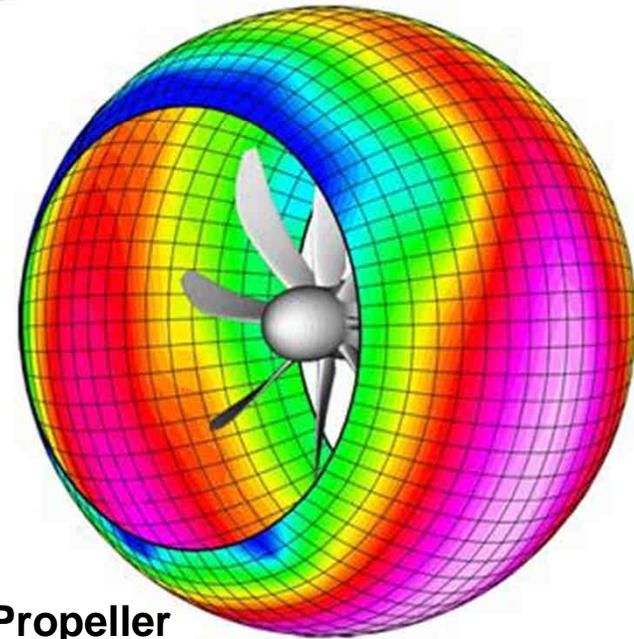
Airfoil



Helicopter rotor



Jet

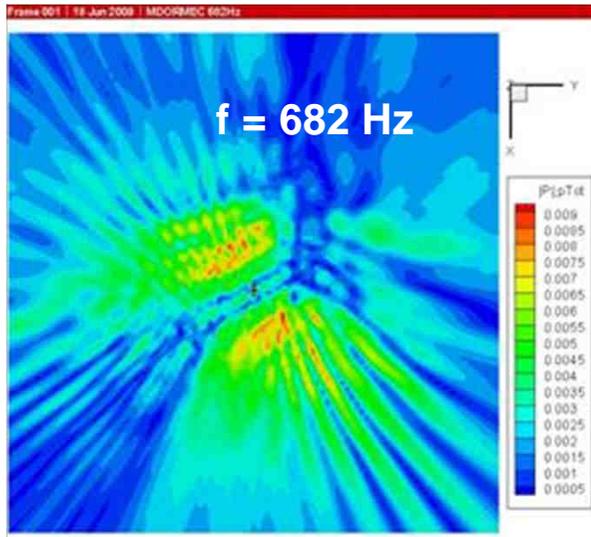
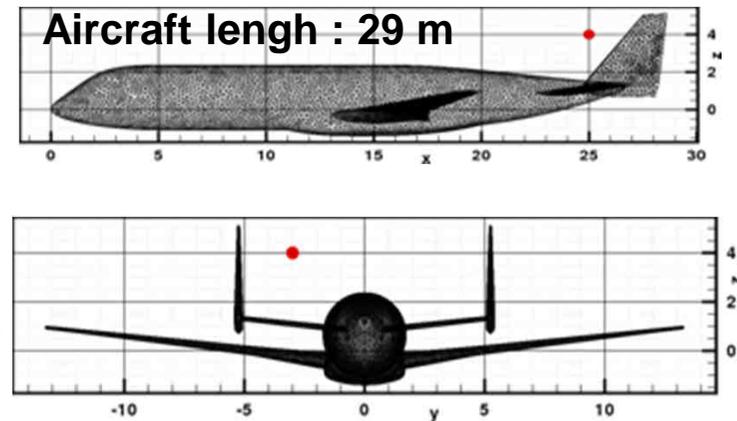
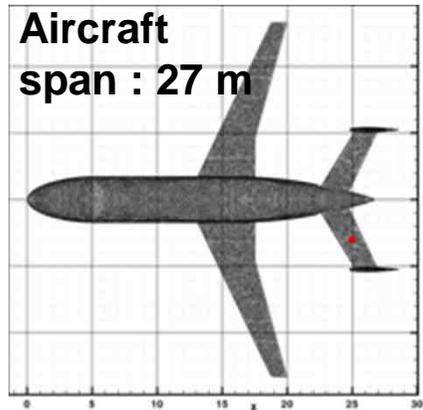


Propeller

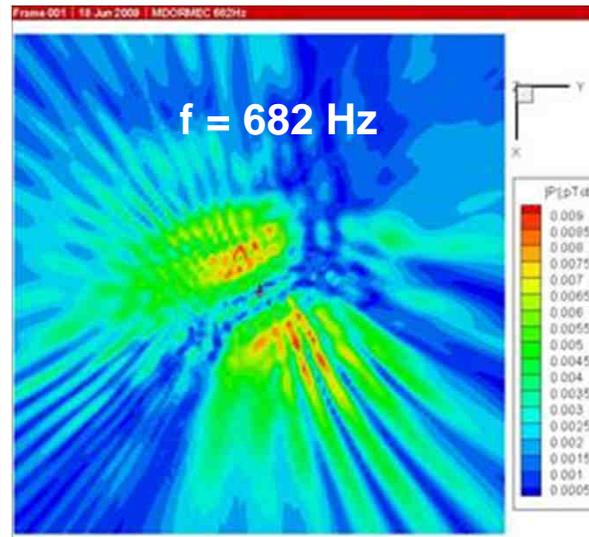
# Boundary Element Method Solver : Bemuse

- Boundary Element Method
- Solution of Helmholtz equation with condition limits on surfaces
- Acceleration method A.C.A. (Adaptive Crossing Approximation)
- Parallelisation under progress

## Benchmark ONERA/DLR 's BEM solvers



BEMUSE



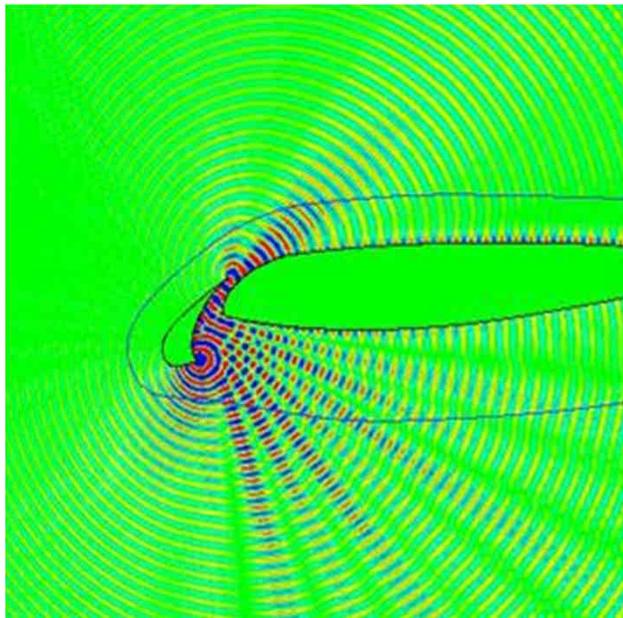
DLR's BEM code

→ Other exemple of recent computation : A320 aircraft :

- $f = 1000 \text{ Hz}$
- Mesh : 630 000 cells
- RAM size : 54 Go
- CPU : 84 hours (single processor)

# Computational AeroAcoustics Solver : sAbrinA-V0

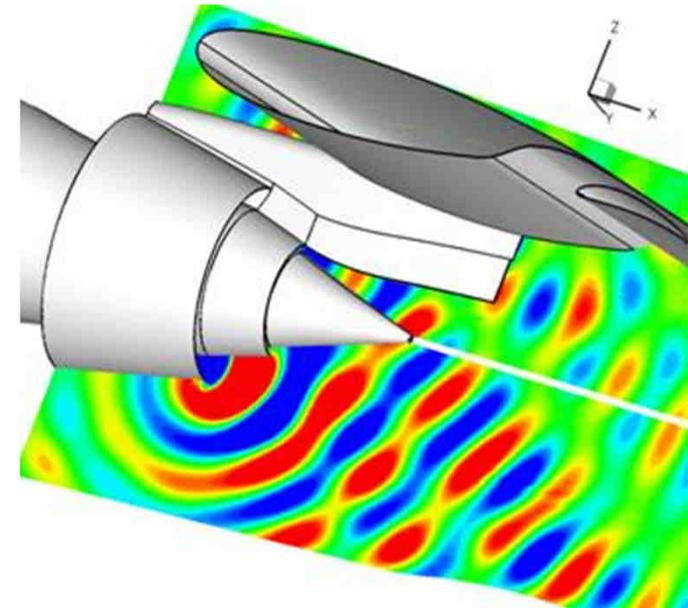
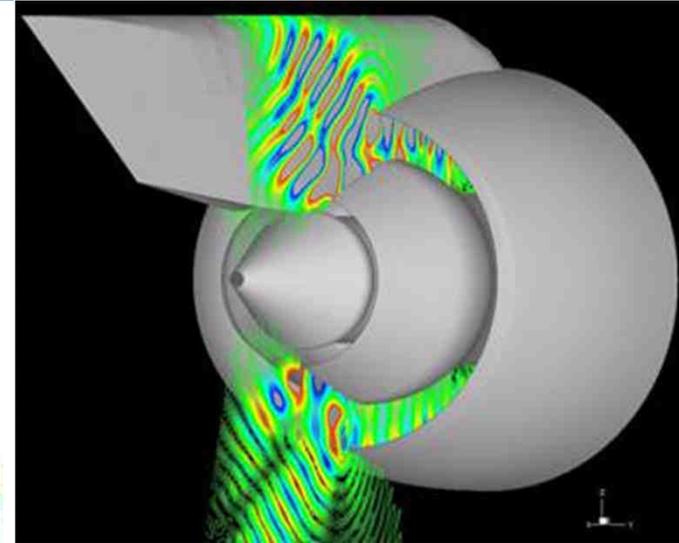
- Non-linear Euler equations in perturbation
- Finite-Difference high-order schemes
- Block-structured grids
- Acoustic scattering on surfaces (hard walls / liners)
- Acoustic propagation in inhomogeneous flows



Airframe noise



Aft fan noise  
(isolated or installed)

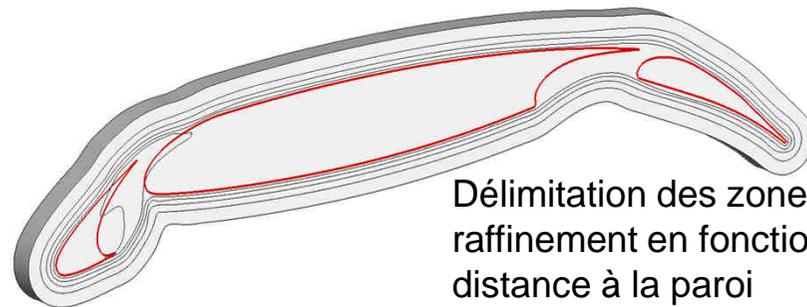
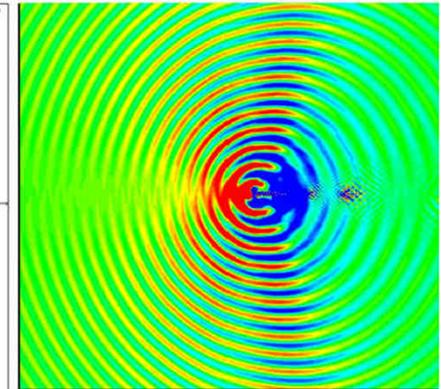
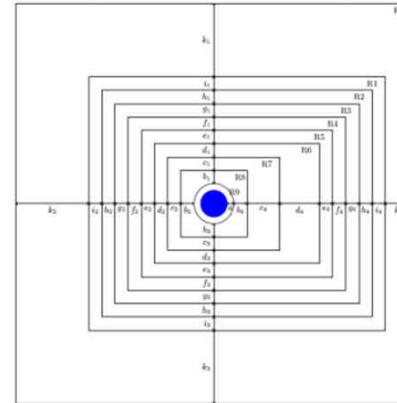
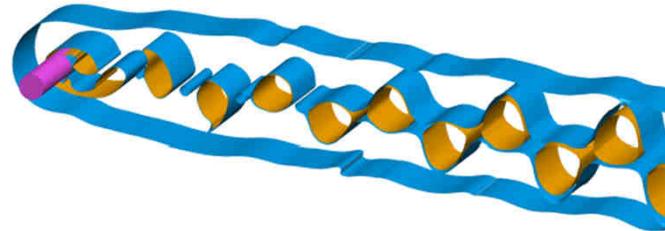


# LaBS (Lattice Boltzmann Solver) : l'Onera dans le projet



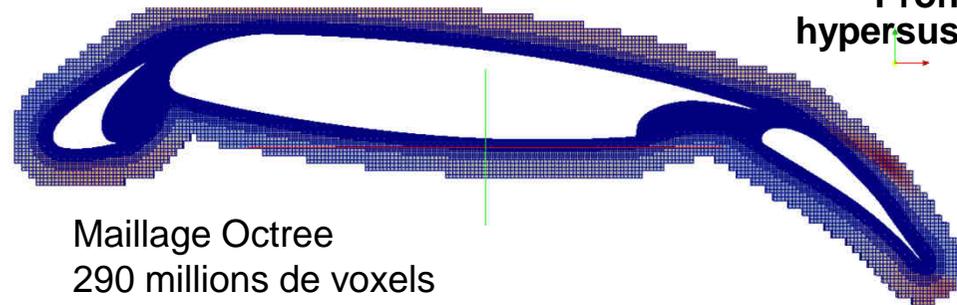
- **LaBS** : évaluation du code sur des cas-tests acoustiques : cavité, cylindre, profil hypersustenté
- **CLIMB** : Poursuite de l'évaluation du code sur des cas-tests "aéroacoustiques (profil hypersustenté, atterrisseur) et aérodynamiques basse vitesse
- Développements dans le code : conditions de raccords 2:1 pour l'acoustique, couplage aéro-thermique, portage sur GPU

Cylindre bas Reynolds

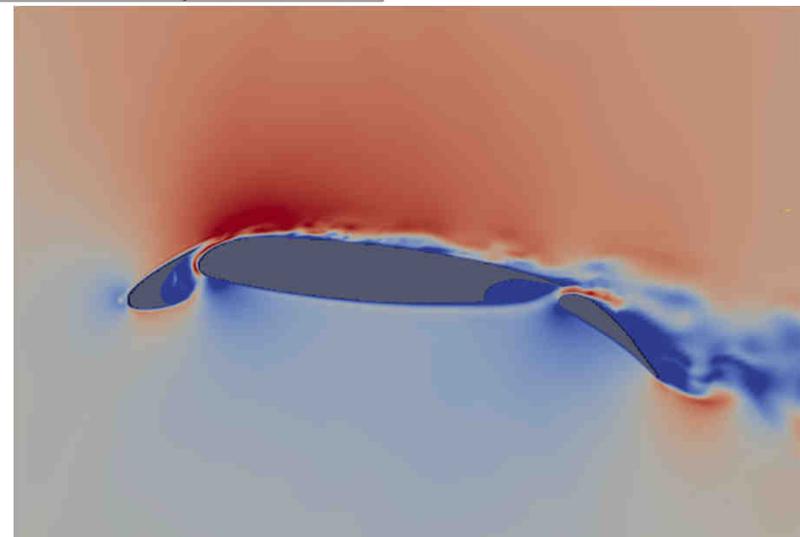


Délimitation des zones de raffinement en fonction de la distance à la paroi

Profil hypersustenté



Maillage Octree  
290 millions de voxels

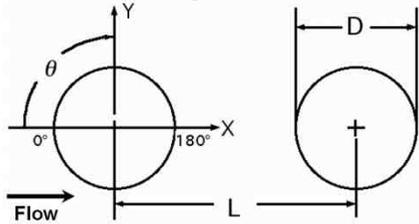


## **Simulation du bruit de train d'atterrissage**

- **Géométries disponibles pour la validation**
- **Calculs sur la géométrie LAGOON avec elsA, CEDRE, PowerFLOW, LaBS**

# Bruit de train d'atterrissage : géométries disponibles pour la validation

## Benchmark for Airframe Noise Computations

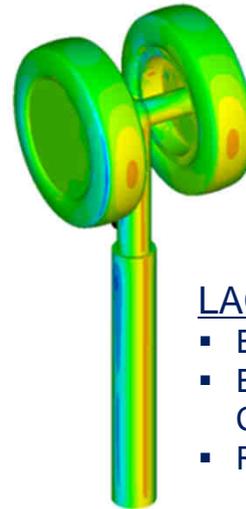
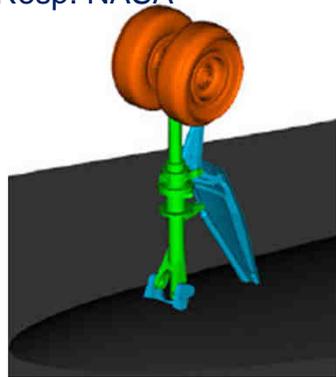


### In-line tandem cylinder

- Essais aérodyn. : BART,
- Essais acoustiques: QFF
- Resp. NASA

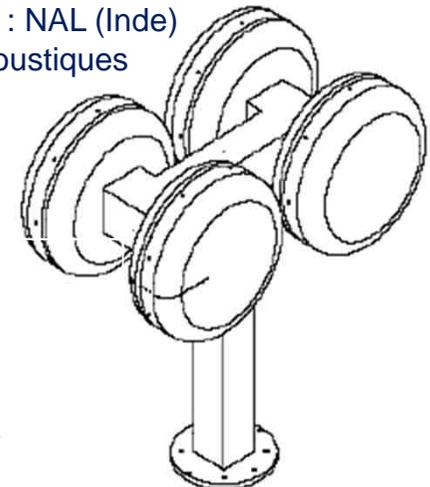
## Gulfstream Nose LG

- Essais aérodyn. : BART
- Essais acoustiques: UFAFF
- Resp. NASA



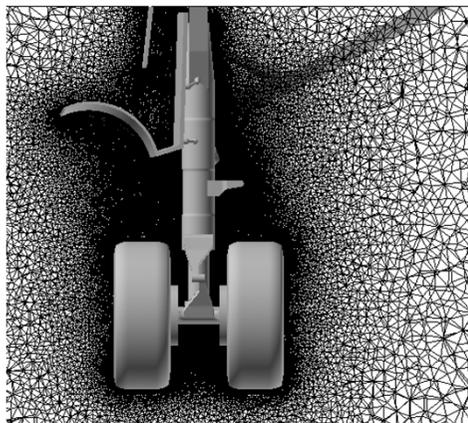
## Rudimentary LG

- Essais aérodyn. : NAL (Inde)
- Pas d'essais acoustiques
- Resp : Boeing



## LAGOON

- Essais aérodyn. : F2
- Essais acoustiques: Cebra19
- Resp. Onera / Airbus

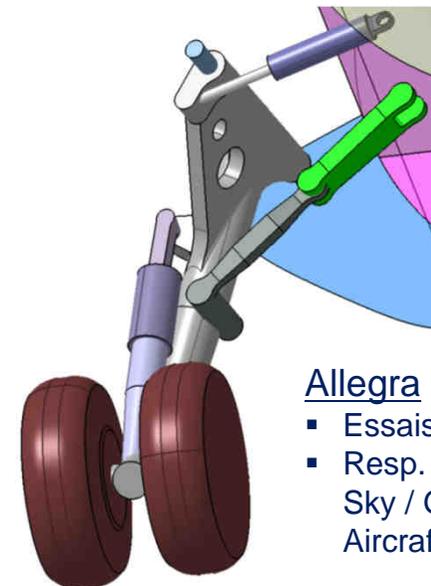


## LEG

- Essais aérodyn. : JAXA-LWT2
- Essais acoustiques: RTRI
- Resp. JAXA

## Train générique

- Essais : DNW (Openair)
- Resp. : Messier-Dowty-Bugatti

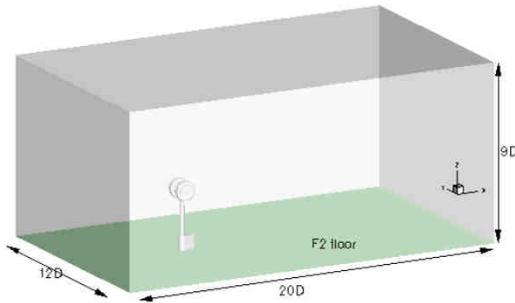


## Allegra

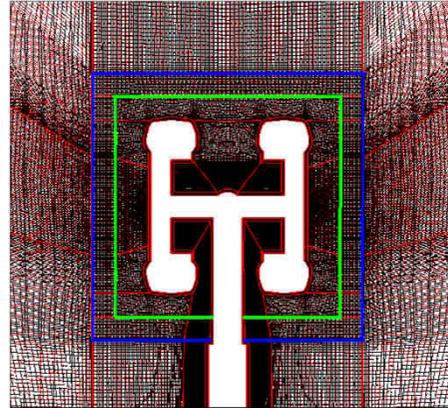
- Essais : Pininfarina
- Resp. : Alenia (Clean Sky / Green Regional Aircraft)

# LAGOON : ZDES (elsA)

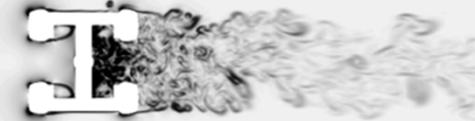
## Maillage structuré multiblocs, raccords conformes



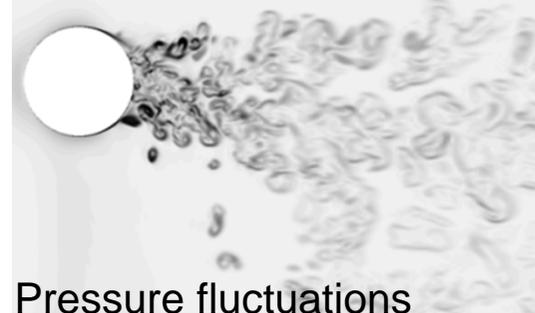
Maillage structuré multiblocs,  
raccords conformes  
33. 10<sup>6</sup> points Re = 1.55 10<sup>6</sup>



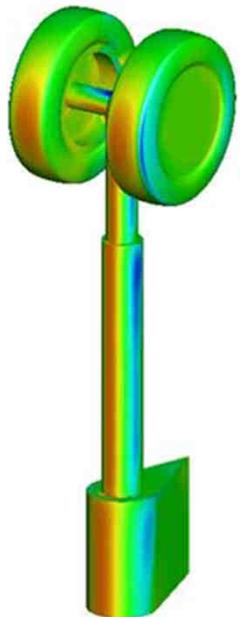
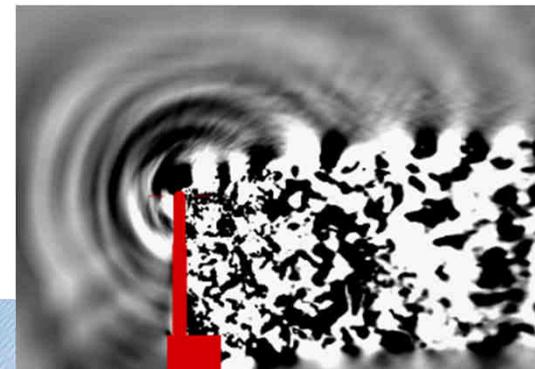
Iso-contours of  
Grad( $\rho$ ), plane Z=0



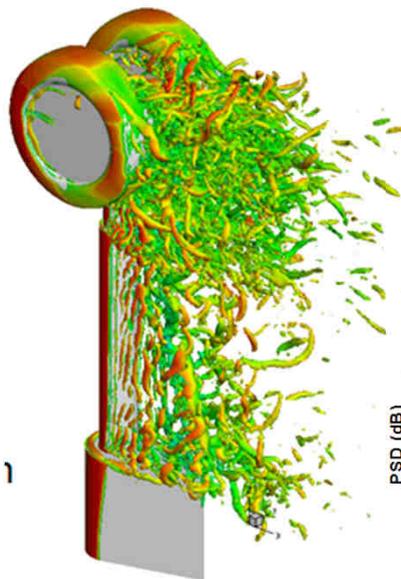
Iso-contours of Grad( $\rho$ ),  
plane Y=0.1m



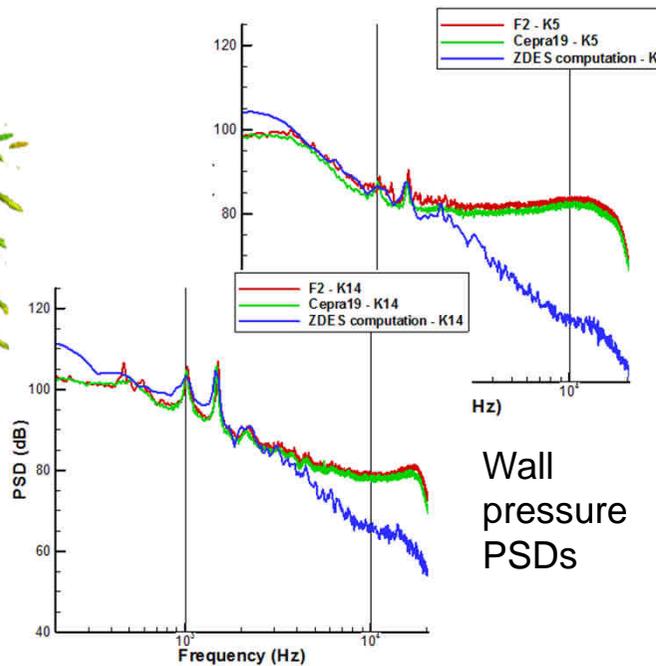
Pressure fluctuations



Cp distribution

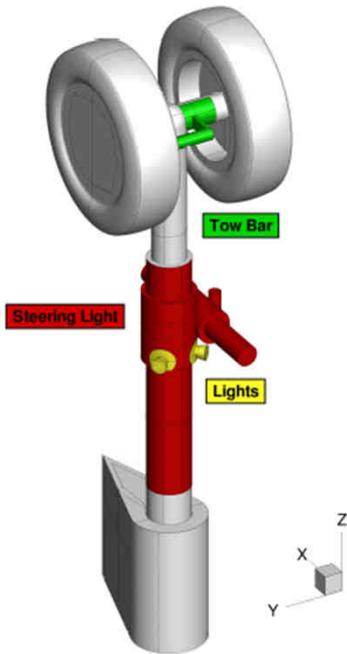
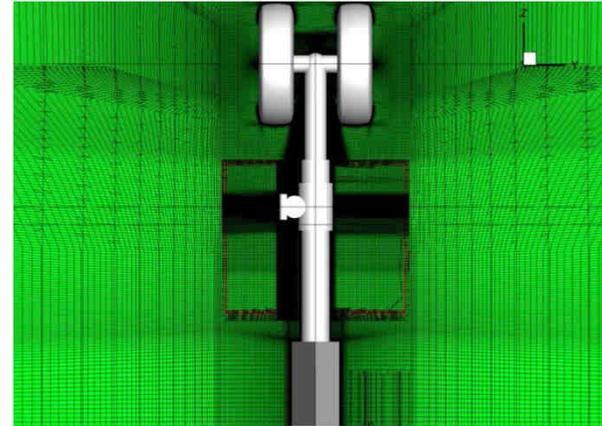
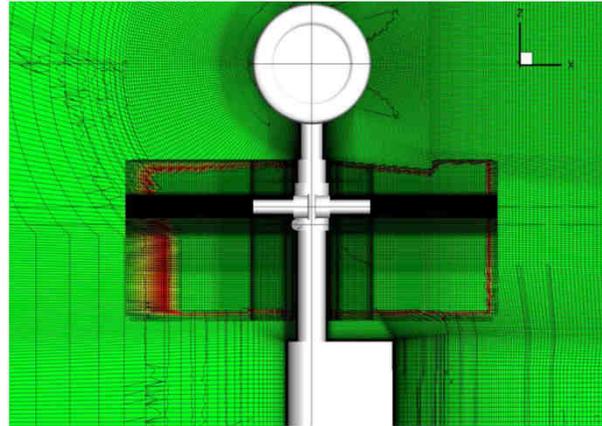
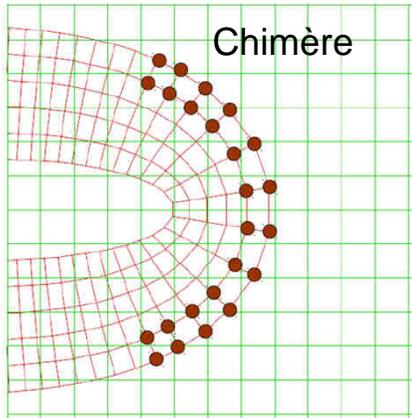


One iso-contour  
of the Q-criterion

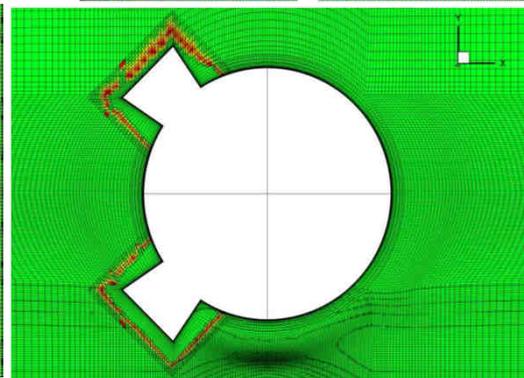
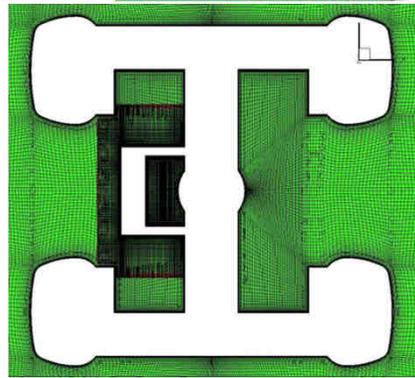


# LAGOON : ZDES (elsA)

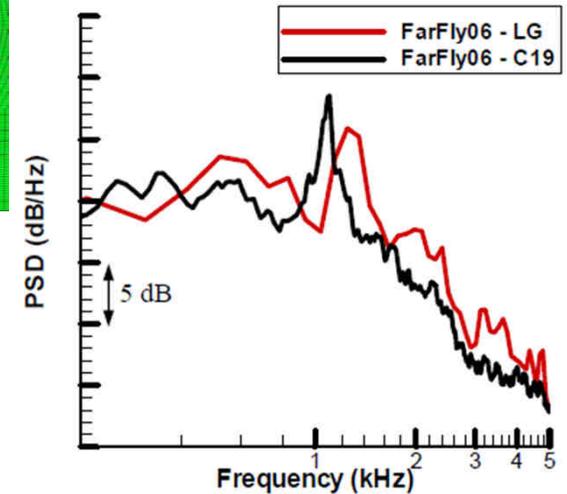
## Maillage structuré multiblocs, technique Chimère



LAGOON #2

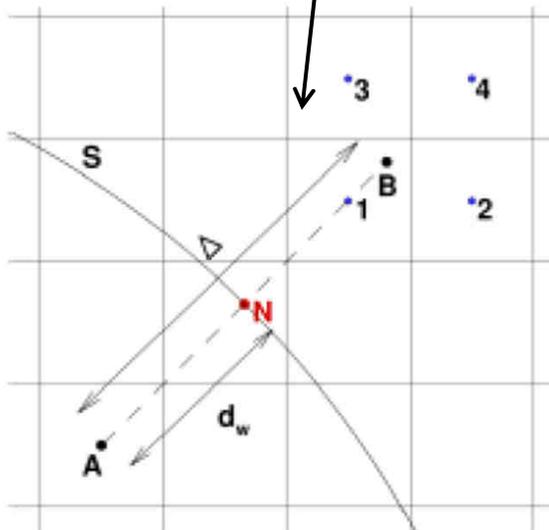
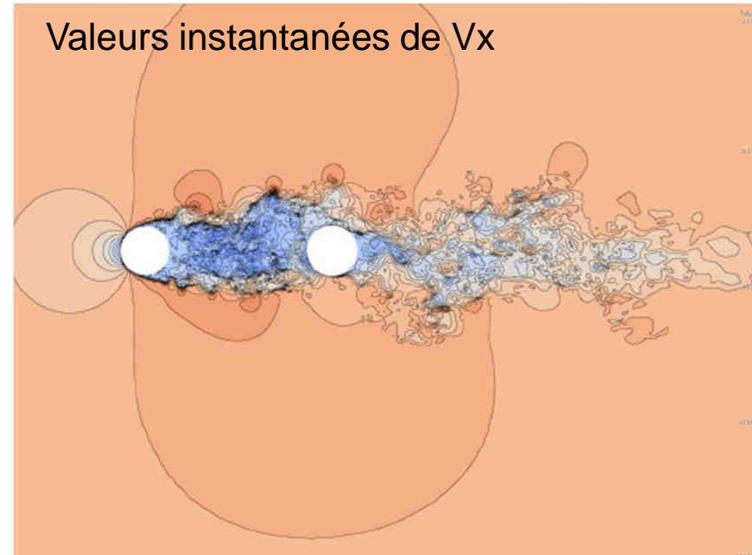
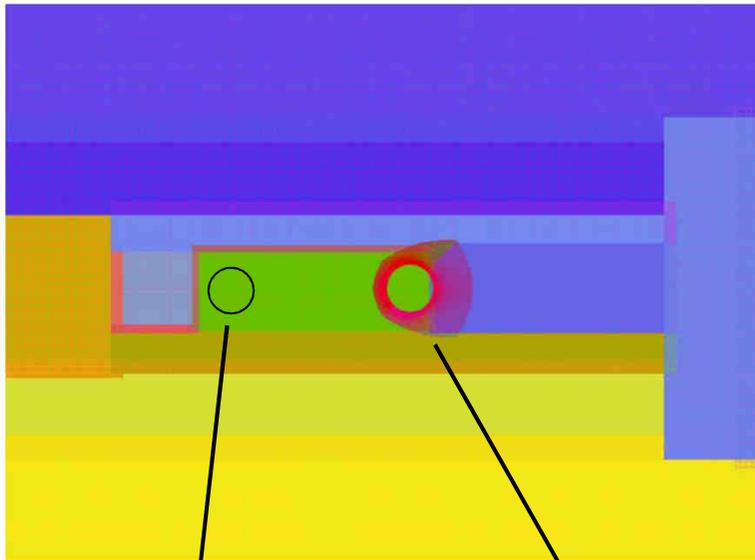


Maillage structuré multiblocs, raccords conformes  
Blocs Chimère  
62.  $10^6$  points  
Re =  $1.55 \cdot 10^6$

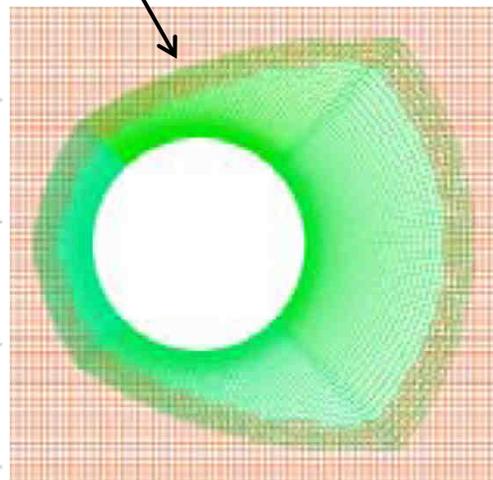


Bruit en champ lointain

# Développement Chimère / IBC (Immersed Boundary Conditions) dans *FUNK* (objectif : implémentation e/sA)



Cellules fictives IBC



Body-fitted Chimère

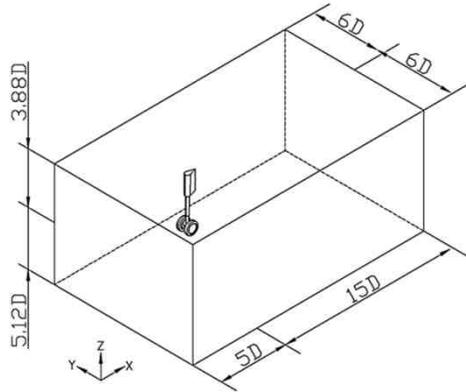
Génération du maillage octree :

- Blocs cartésiens recouvrants
- Raffinement dans le sillage
- Environ 15 M cellules
- Cylindre amont : IBC
- Cylindre aval : « body-fitted » Chimère

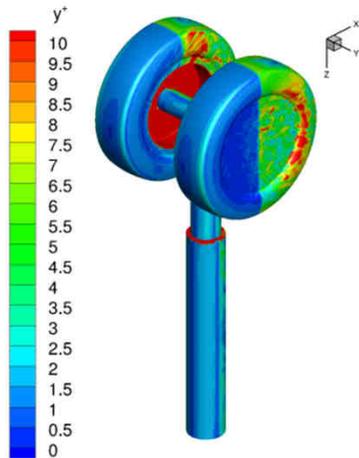
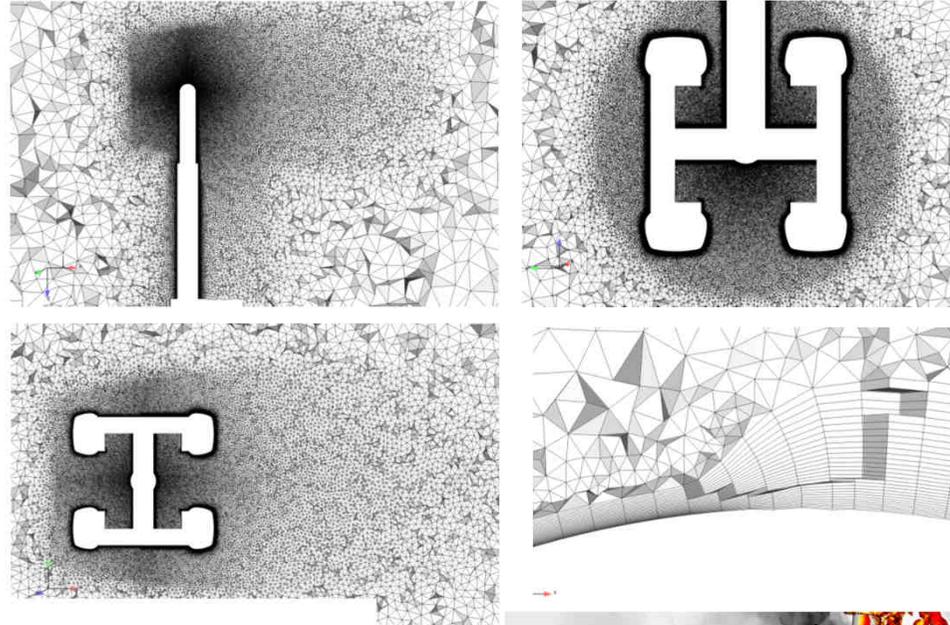
Deux types d'interpolation (Cassiopée) :

- Interpolations Chimère : raccords entre blocs cartésiens et blocs body-fitted
- Interpolations dans le fluide : valeurs aux cellules fictives au sens IBC

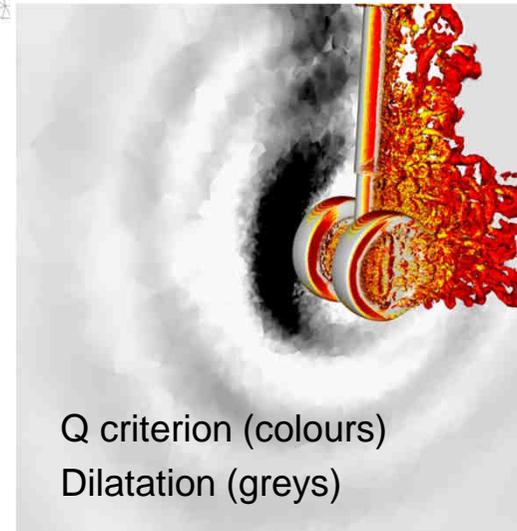
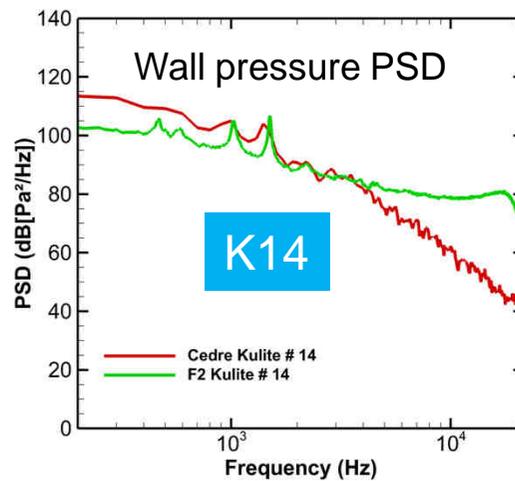
# LAGOON : ZDES mode II (CEDRE) Maillage non-structuré



Maillage non structuré hybride :  
20 M. prisms + 41 M. tetras  
First cell size  $10\mu\text{m}$ .  $Y^+$  around 1.5 - 7.5  
25 prismatic layers with 6% growth rate



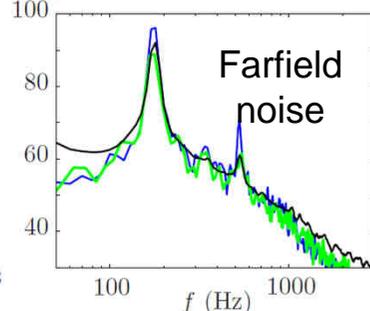
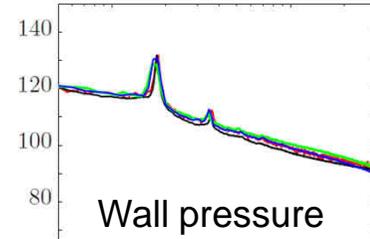
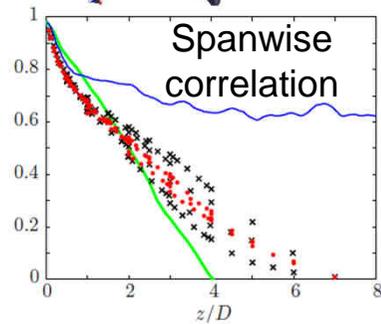
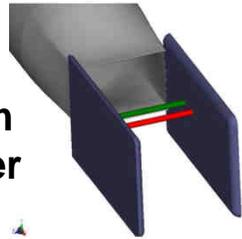
$Y^+$  distribution



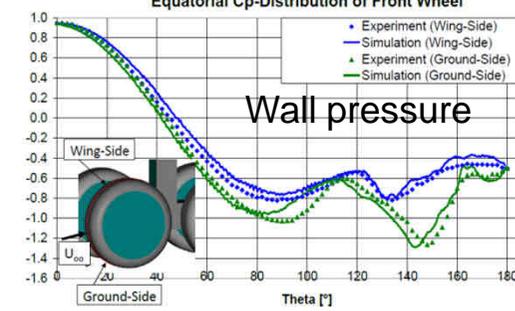
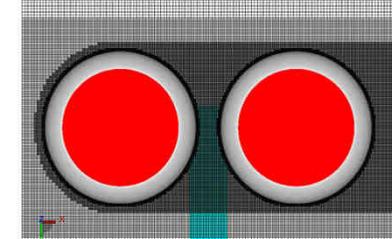
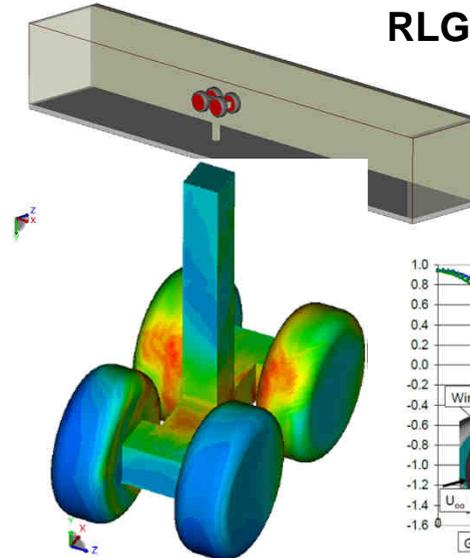
Q criterion (colours)  
Dilatation (greys)

# Cas-test BANC résolus avec PowerFLOW (EXA)

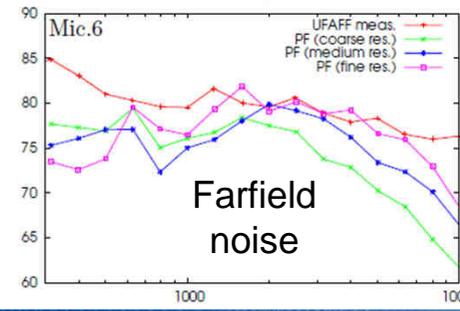
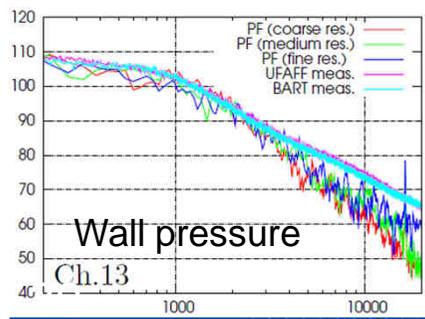
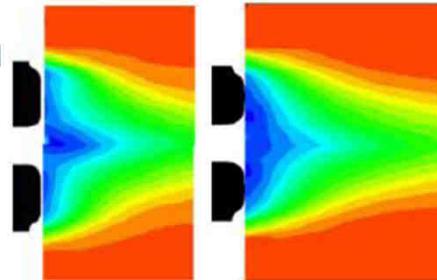
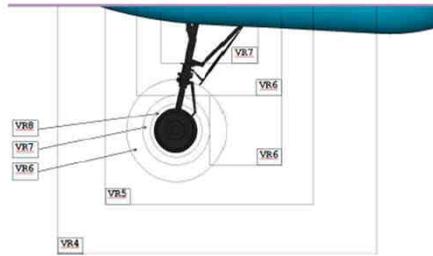
**Tandem Cylinder**



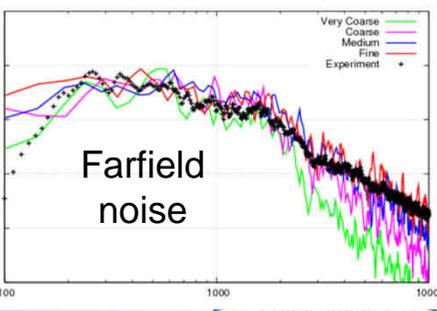
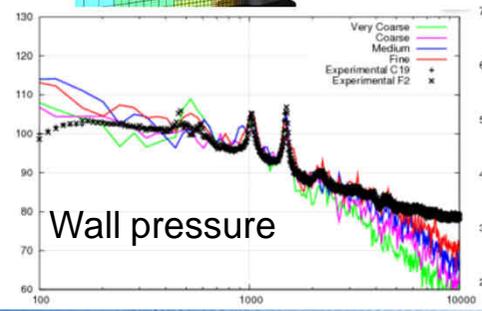
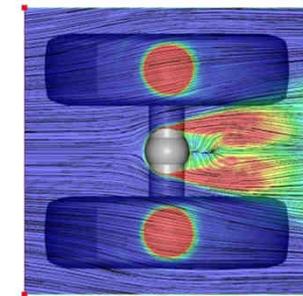
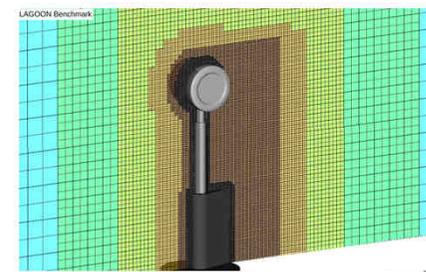
**RLG**



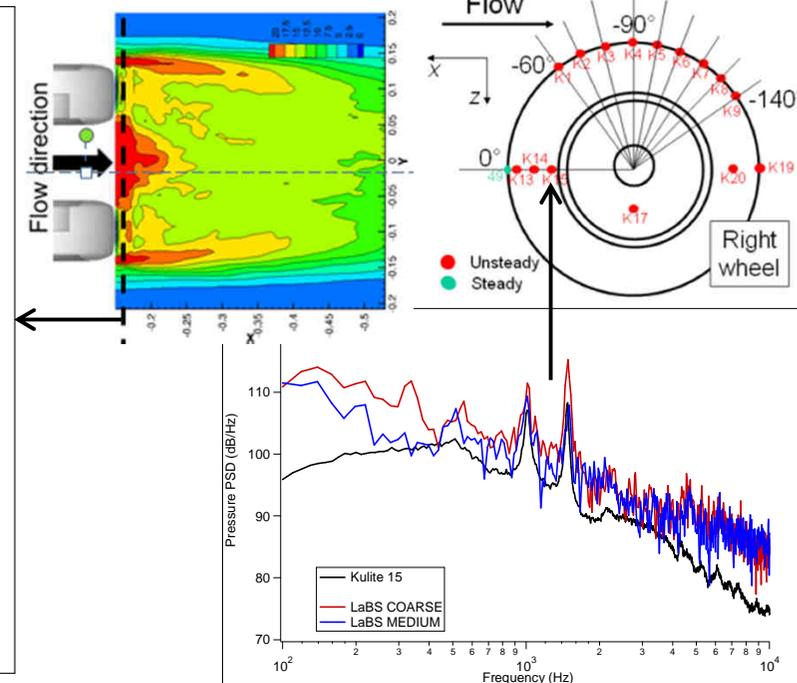
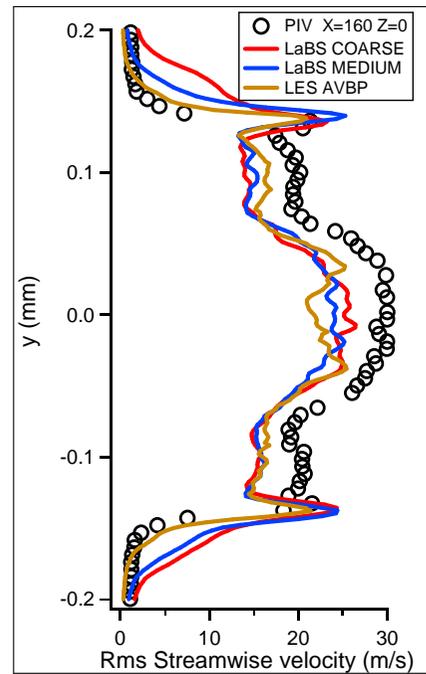
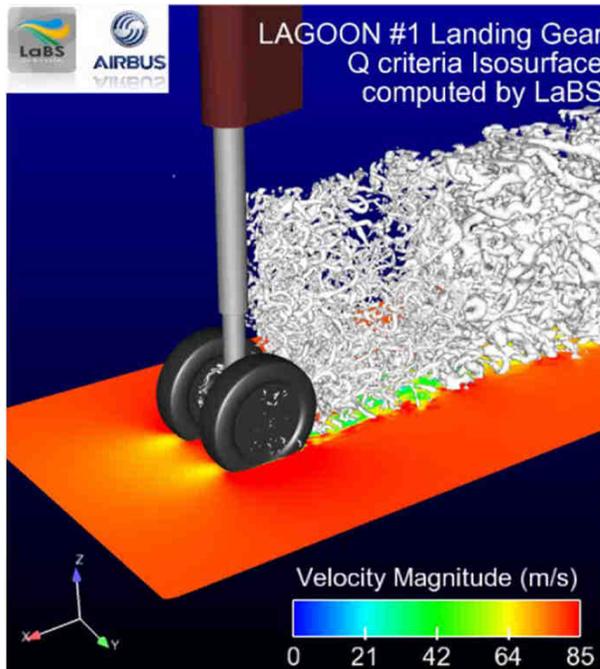
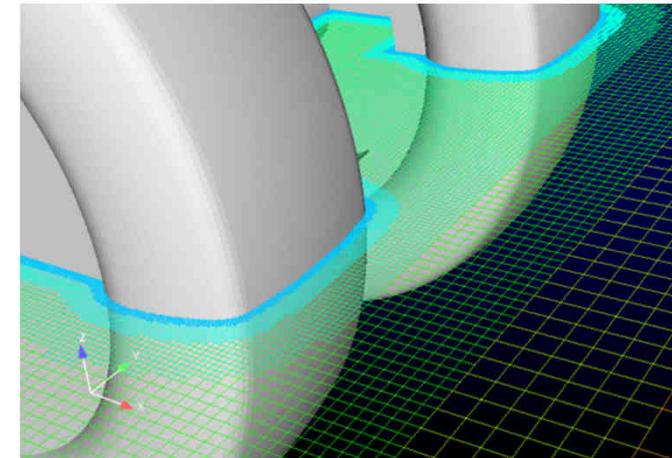
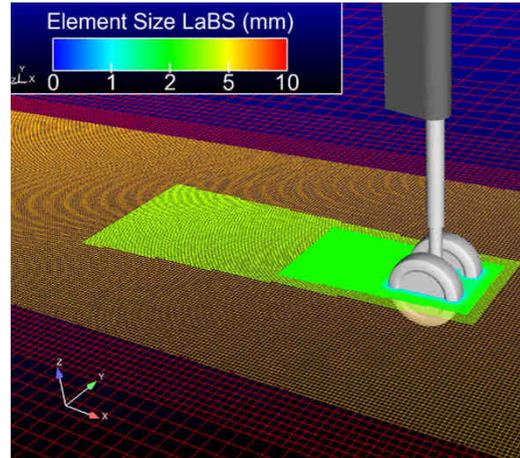
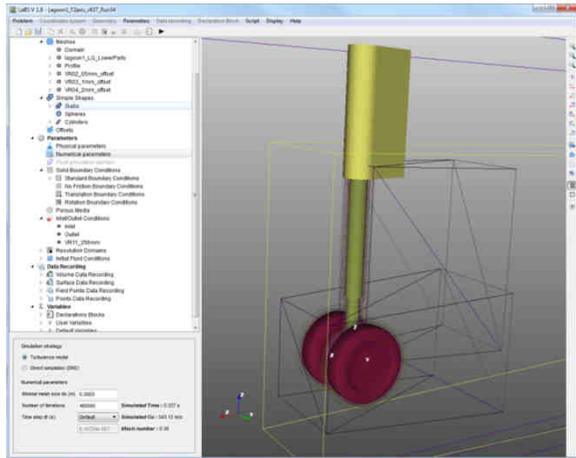
**Gulfstream NLG**



**LAGOON**



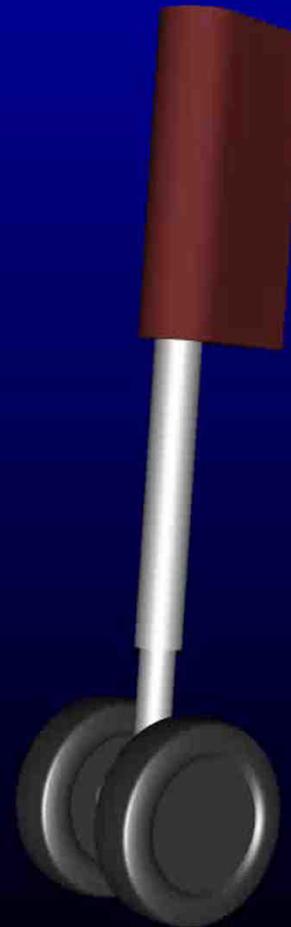
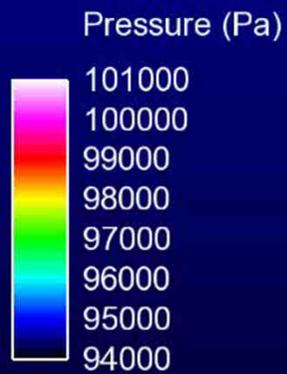
# LAGOON : LBM (LaBS) Calcul Airbus-France



# LAGOON : LBM (LaBS) Calcul Airbus-France



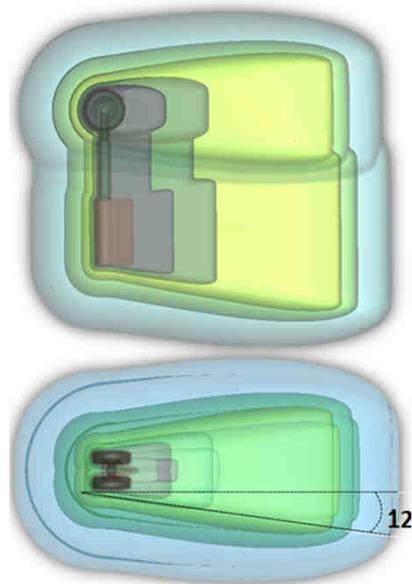
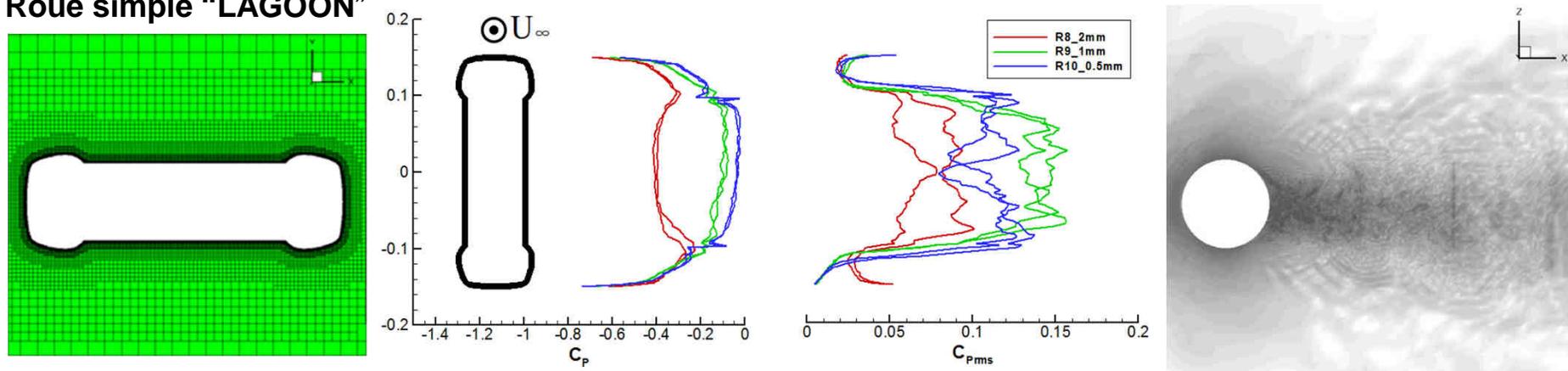
LAGOON #1 Landing Gear  
Wall pressure fluctuations  
computed by LaBS



# Travaux Onera avec LaBS (Version 1193 – Juillet 2014)

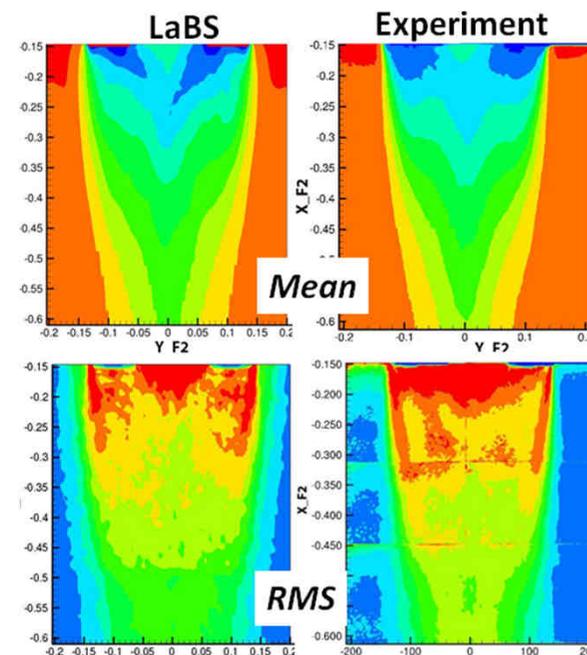
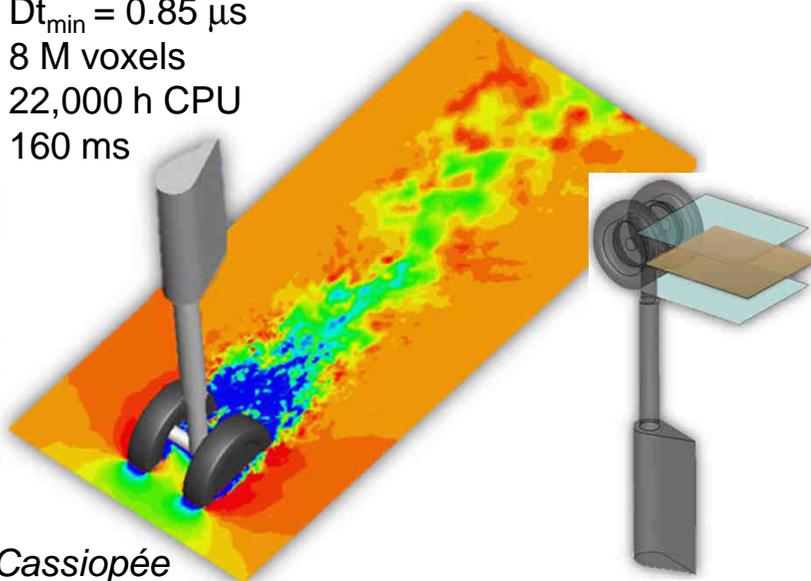
## Landing gear configurations

### Roue simple "LAGOON"



$Dx_{min} = 0.5 \text{ mm}$   
 $Dt_{min} = 0.85 \mu\text{s}$   
 8 M voxels  
 22,000 h CPU  
 160 ms

### Train LAGOON

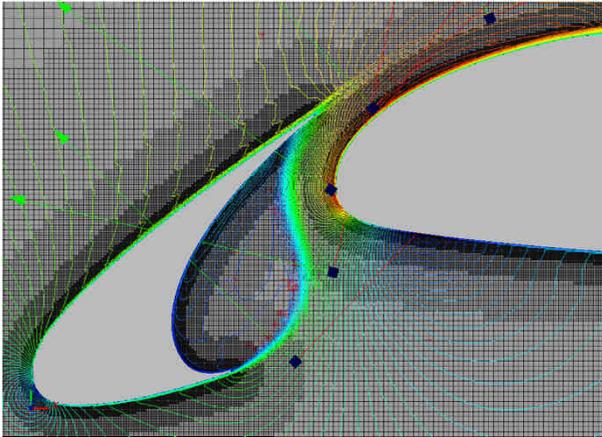


Génération "offsets" par Cassiopée

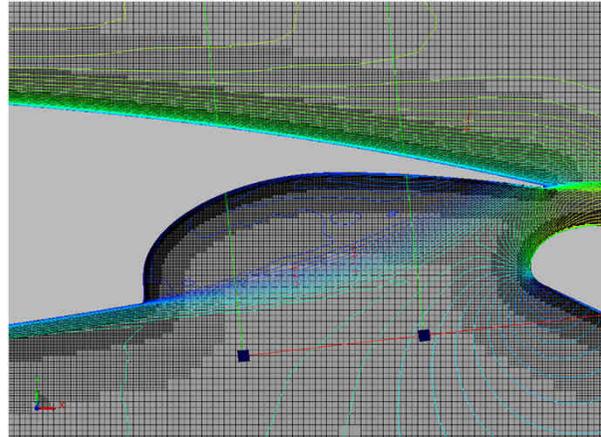
# Travaux Onera avec LaBS (Version 1373)

## High-lift wing (LEISA2)

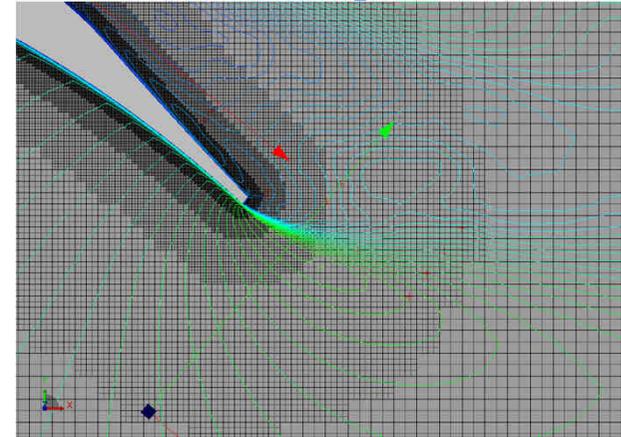
Slat



Main

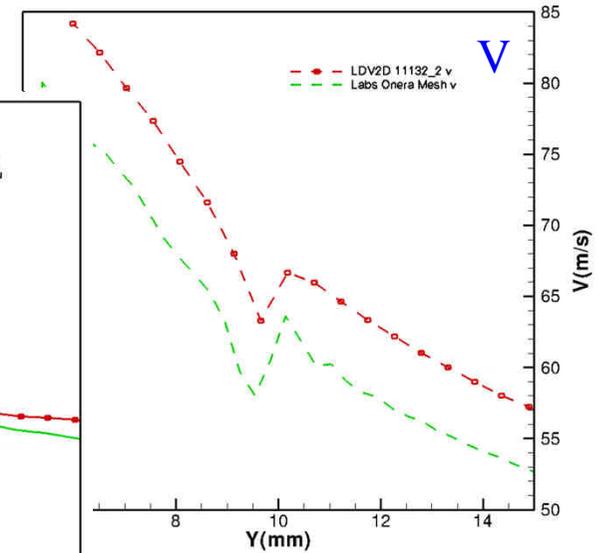
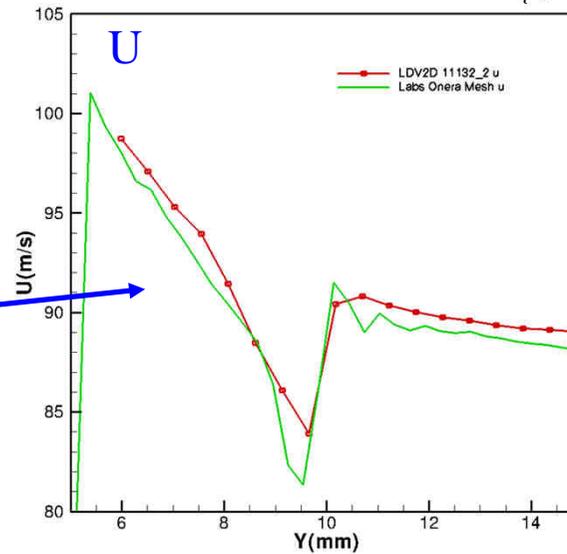
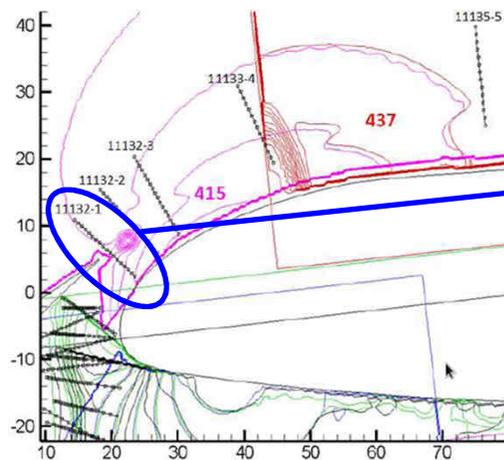


Flap



Zones VR et isovalues de la vitesse

Chord = 300 mm  
 Span = 24 mm  
 FEV : 130 M  
 $Dx_{min} = 0.05$  mm  
 $y^+ = 10$   
 $Dt_{min} = 0.08$   $\mu$ s  
 h CPU : 400k  
 480 procs



Pas encore d'acoustique ...  
 Nouveau calcul en cours

# Bilan LBM (LaBS) pour l'aéroacoustique

- **Poins positifs**

- Efficacité/simplicité de la mise en donnée de problèmes complexes (IHM, Cassiopée)
- En l'état, applicable à de nombreux problèmes de bruit aérodynamique
- Potentiel de performance CPU (et GPU ...)
- Perspectives Onera hors aéroacoustique : aérodynamique, aérothermique, plasmas, dispersion pollution, optique

- **Améliorations nécessaires à court/moyen terme**

- Difficultés de calculs avec reprises (checkpoints) → très gros fichiers
- Problèmes de déséquilibre de charge entre processeurs
- Extraction de données en champ proche pour le calcul du bruit en champ lointain (FW-H)
- Performance CPU encore en deça de PowerFLOW

- **A plus long terme**

- Gestion des interfaces de résolution pour l'acoustique (activités ECL/Onera/Airbus)
- Nouvelles fonctionnalités nécessaires pour étendre le champ d'application de l'aéroacoustique (→ jet, voilures tournantes) : Mach élevés, maillages en rotation / translation, formulation en perturbation
- Possibilité de « seeding » (calcul à partir d'un champ et d'une mise en donnée existants)