Landing gear noise prediction: what is the best method ?

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ONERA

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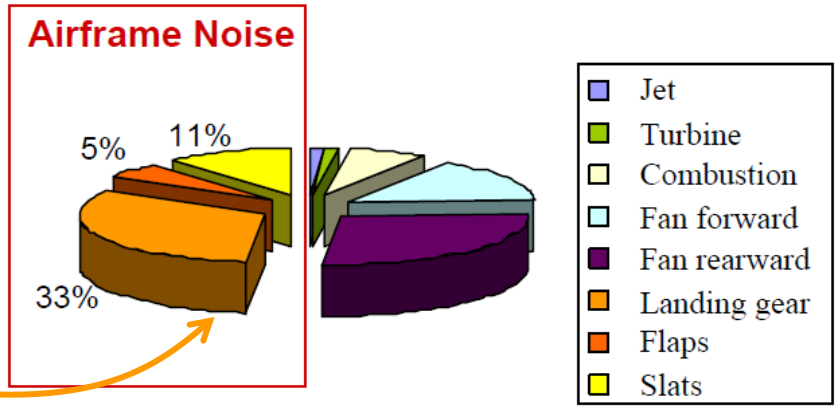
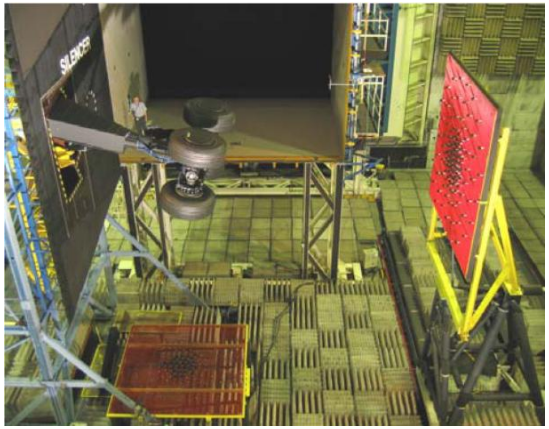
Context (1/2)

In the years 70-90 : due to continuous progress in reducing propulsion noise (fan / jet / combustion), aerodynamic noise (slat / flap / landing gear) gradually emerge from aircraft overall noise at approach/landing

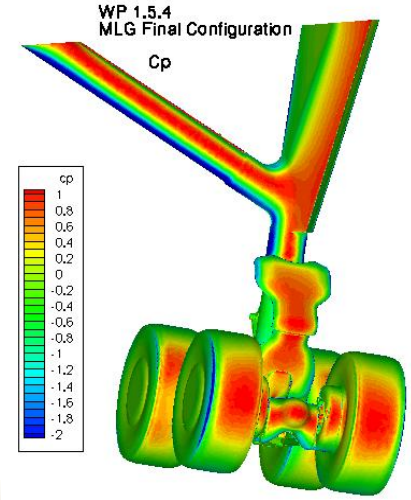




1990-2000 : acceleration of experimental/numerical studies, and strong expression of need for accurate numerical prediction tools

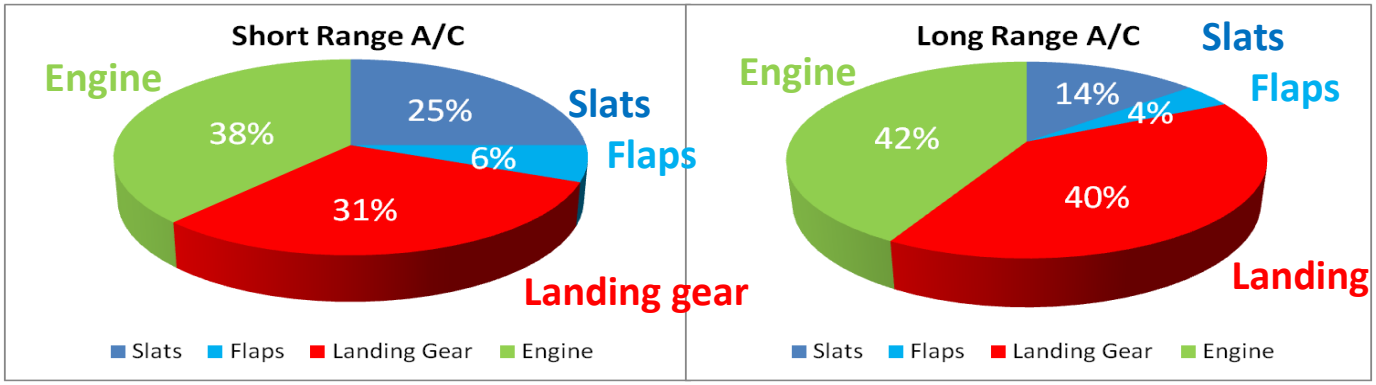
Silence® project (EU-2001-2005)

- DNW test
- DLR's computation with TAU



Context (2/2)

2005 : Airbus A380 first flight : landing gear noise dominates at approach/landing



LG noise is **50 %** of airframe noise in short range aircraft but **70 %** in long range aircraft

A320: 2 x 2 = 4 wheels

MTOW = 78 tons

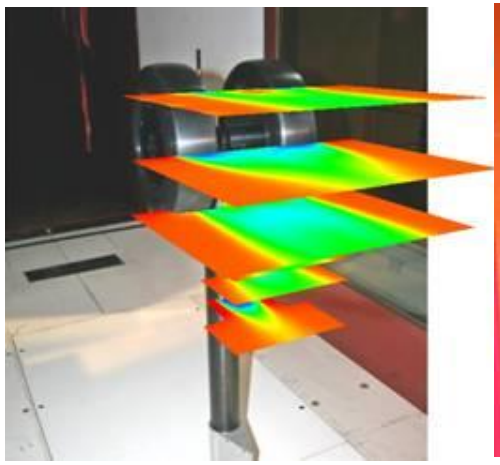
A380: (2 x 4) + (2 x 6) = 20 wheels

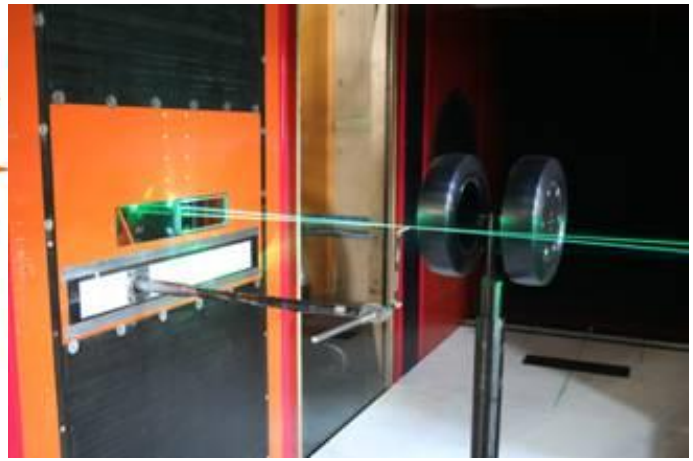
MTOW = 500 tons

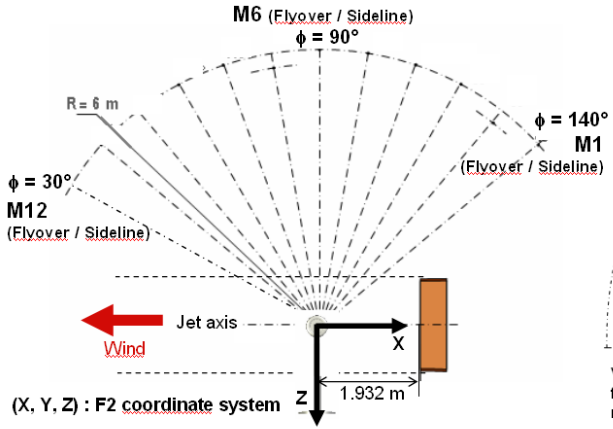
→ 2005-2015: large effort put on improving the numerical methods for LG noise prediction

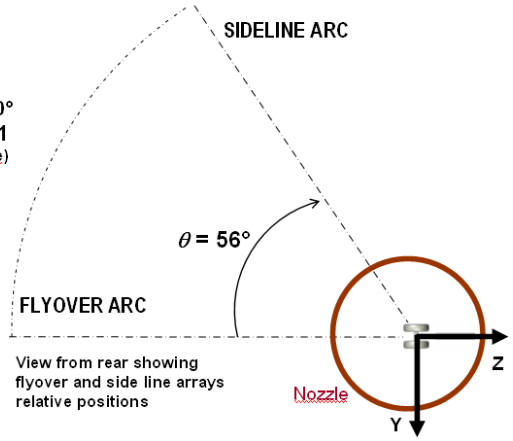
LAGOON : LAnding Gear nOise database and CAA validatiON

- Project launched by Airbus in 2006 (with Onera, DLR and Southampton University)
- Main objective : to build an aerodynamic/acoustic experimental database on a two-wheel simplified landing gear for the validation of up-to-date numerical methods for flow and noise prediction



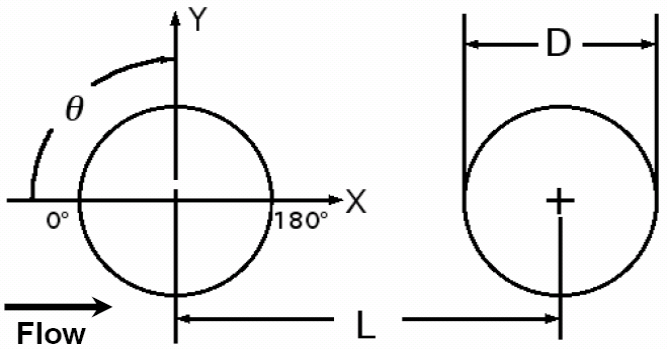






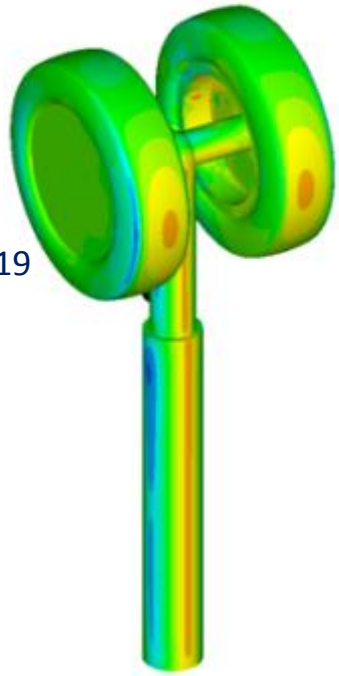
BANC : Benchmark for Airframe Noise Computations

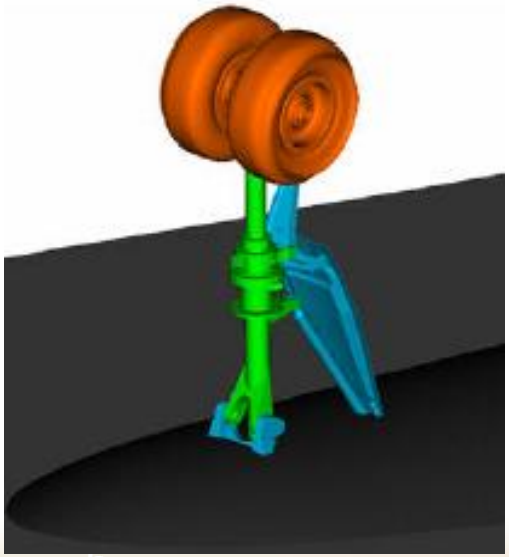
- 2009 : NASA initiative. Objective : to provided documented test-cases to the community, and organize the comparisons of numerical simulations and experimental data
- 8 proposed test-cases, 4 of them in the « Landing Gear » category:



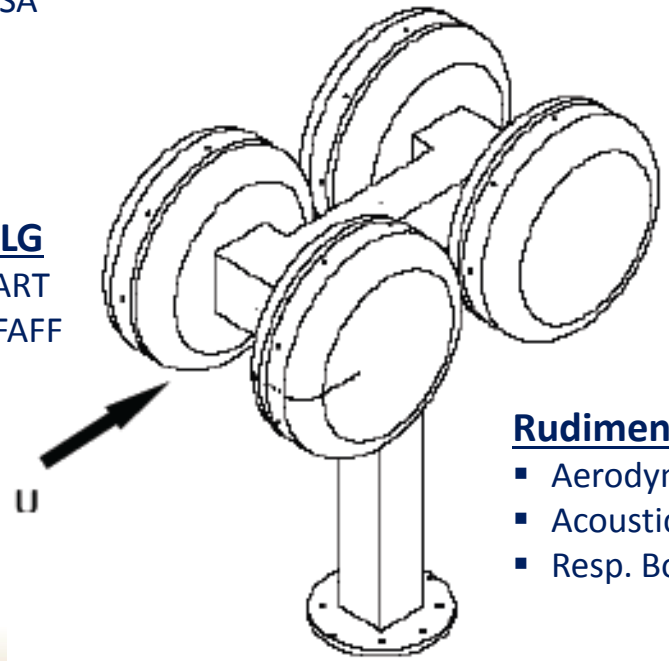
In-line tandem cylinder
- Aerodyn. tests: BART
- Acoustic tests : QFF
- Resp. NASA

LAGOON
- Aerodyn. tests. : F2
- Acoustic tests : Cepra19
- Resp. Onera/Airbus





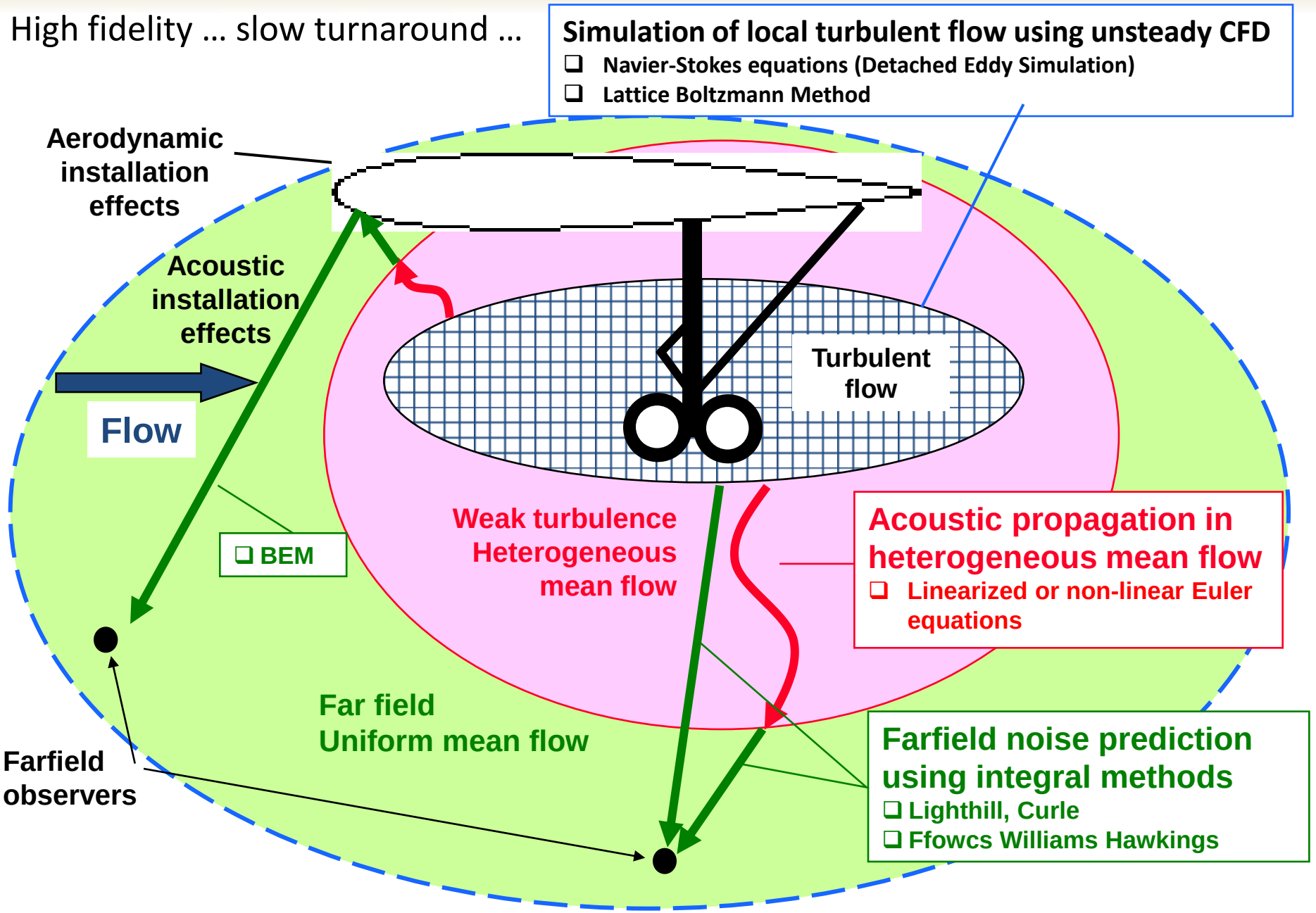
Gulfstream Nose LG
- Aerodyn. tests: BART
- Acoustic tests : UFAFF
- Resp. NASA



Rudimentary LG
- Aerodyn. tests: NAL (Inde)
- Acoustic tests : NAL (scale ½)
- Resp. Boeing

LG noise numerical prediction methods :

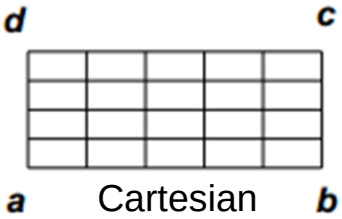
High fidelity … slow turnaround …

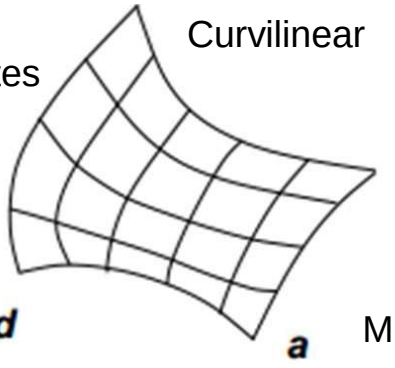


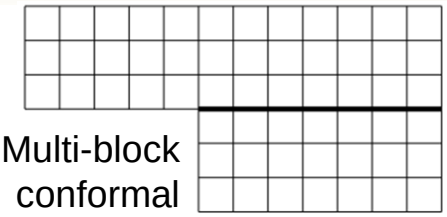
Turbulent flow simulation using unsteady CFD : building grid is critical !

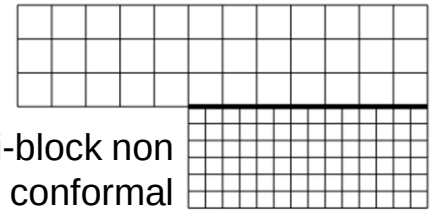
Multiblock structured grids

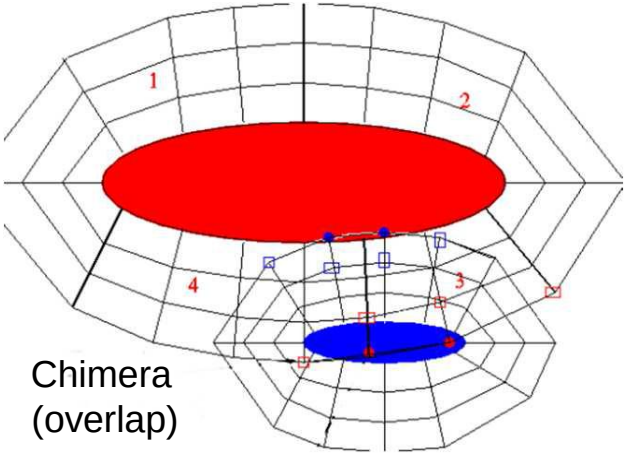
Matrix blocks : points described by coordinates and 3 indexes (in 3D)

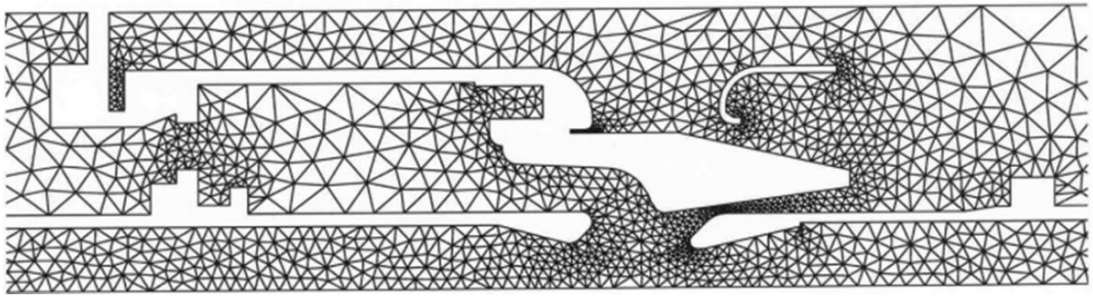










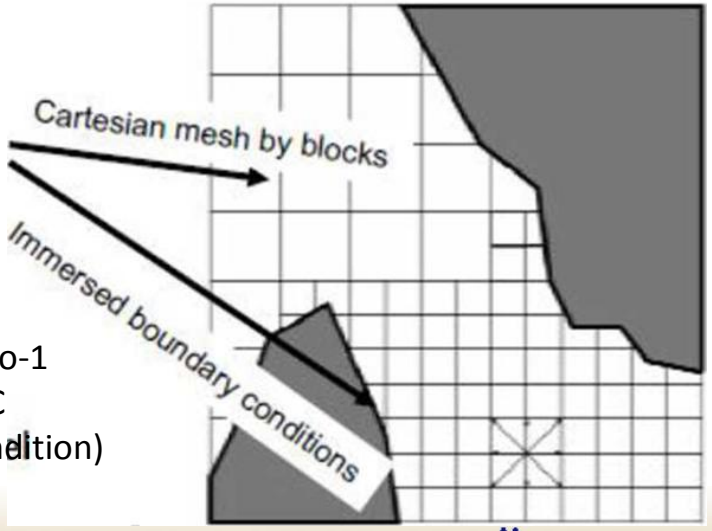


Unstructured grids

- Nodes/elements
- Elements with 4 to 8 nodes (in 3D)
- Nodes : number + 3 coordinates
- Elements : number of nodes

Octree grids

- Cartesian with cubic cells
- Connections 1-to-2 or 2-to-1
- Often associated with IBC (Immersed Boundary Condition)
- Basis of LBM



Presentation objective and outline

Objective : to show/compare several selected numerical computations achieved by Onera and other partners in the BANC framework on the LAGOON configuration (but also others …) based on different CFD methods and grids

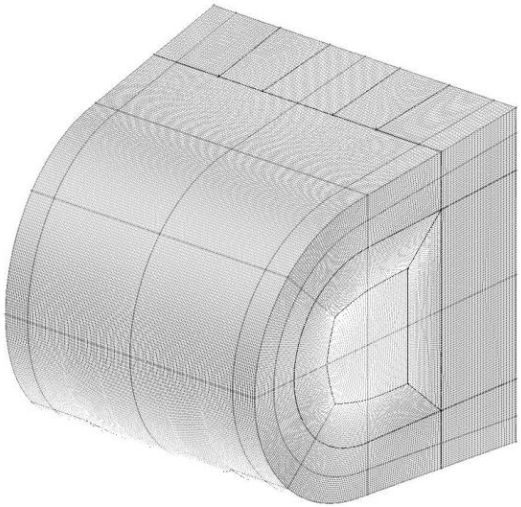
Outline

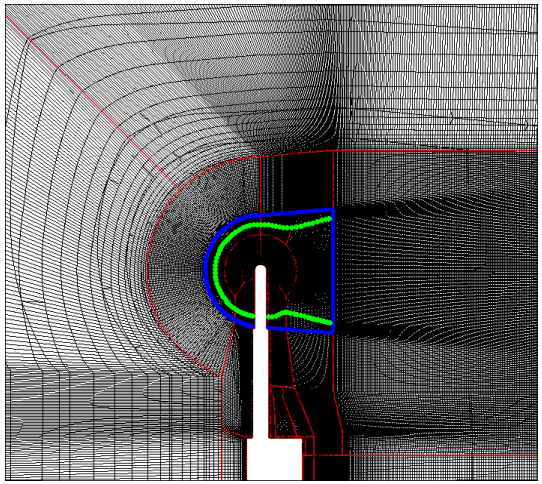
- Multiblock structured grid (*elsA* solver)
  - Conformal (1-to-1) block connections
  - Chimera
  - IBC-Chimera (under progress)
- Unstructured grid (*CEDRE* solver)
- Lattice Boltzmann Method
  - LaBS solver (Airbus contribution)
  - PowerFLOW solver (EXA contribution)
- Comparison of selected results from BANC-III synthesis (*)
  - Aerodynamics
  - Acoustics
- Conclusions

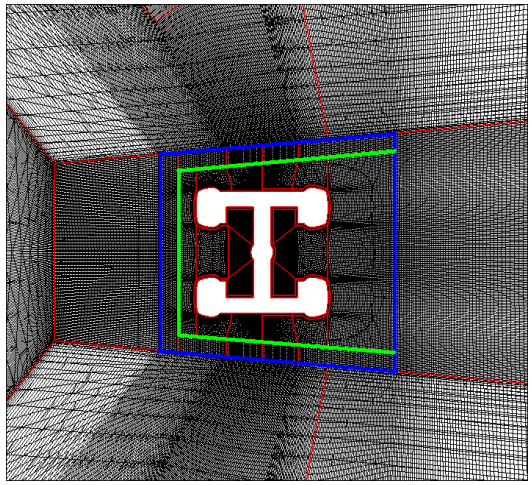
(*) AIAA-2015-2846

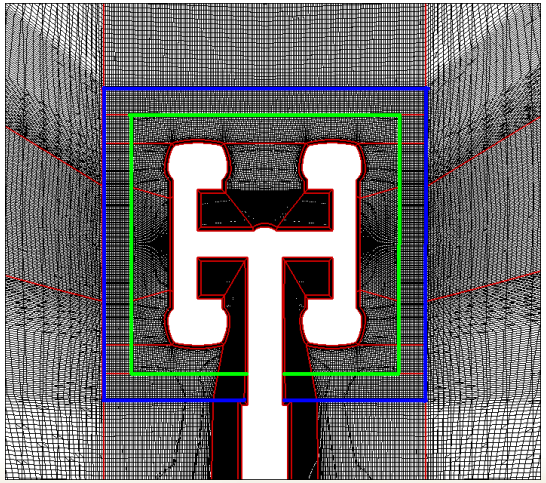
Multiblock structured grid (elsA solver) : conformal connections

- 34 10^6 mesh points - 111 conformal (1-to-1) structured blocks
- Blocks built against 2 continuous closed surfaces around the wheels for FW-H integration
- Constraints on maximum cell size inside these surface for acoustic requirements



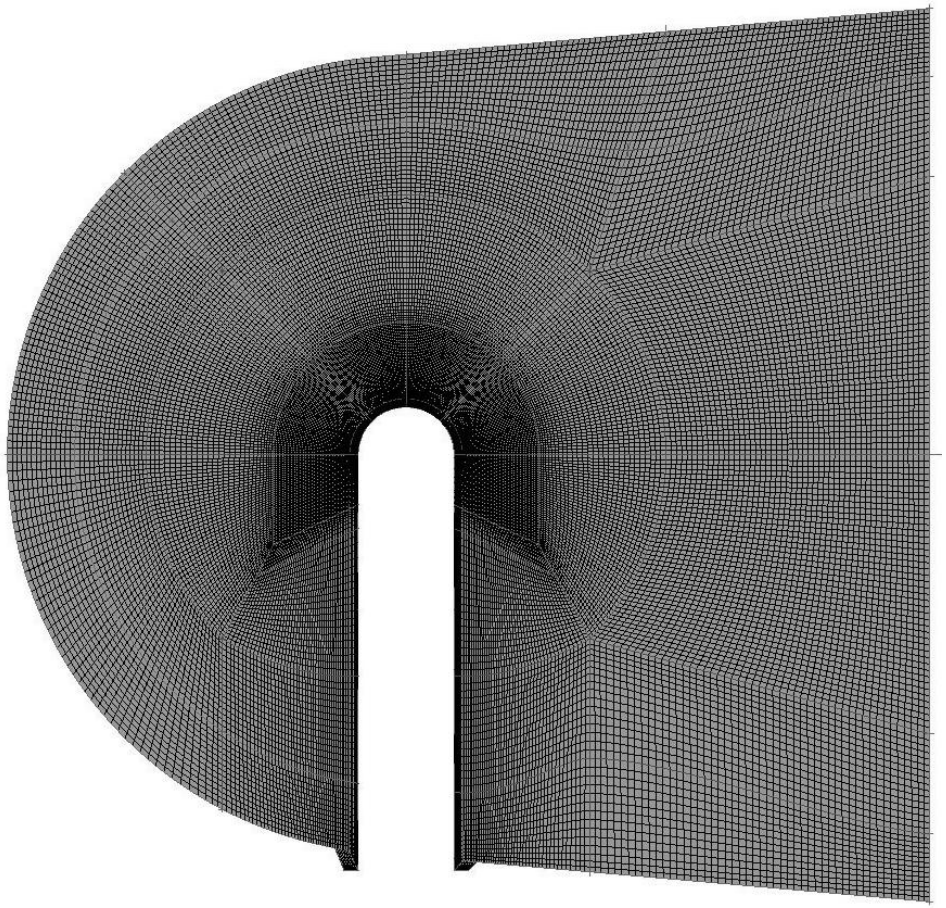






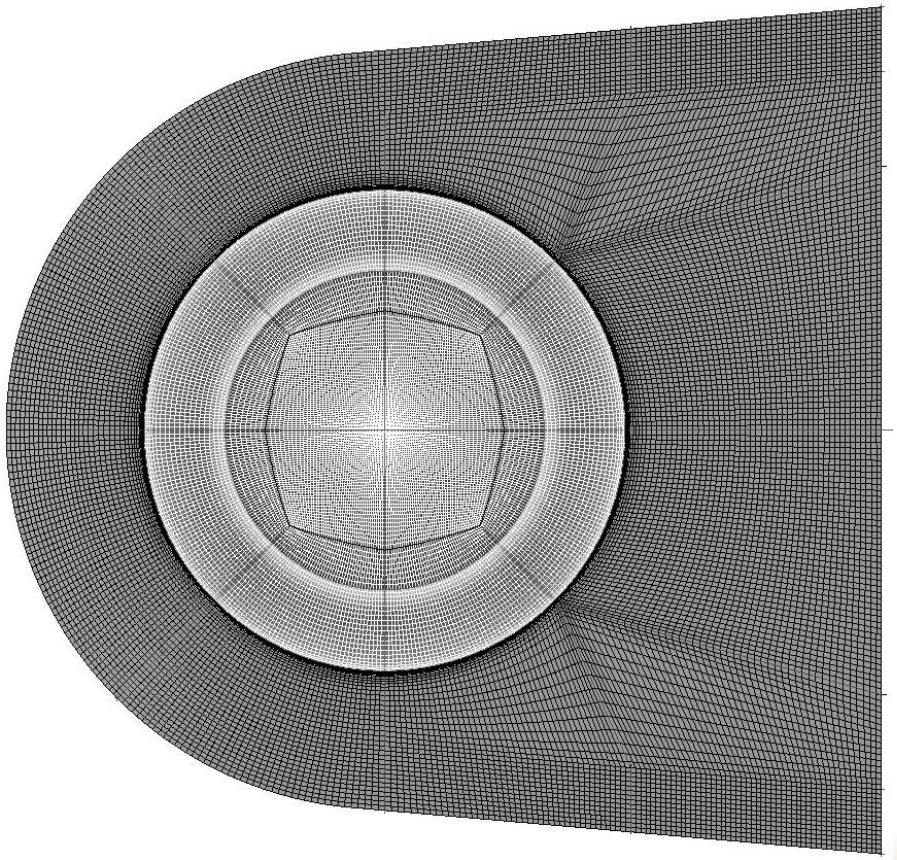
Multiblock structured grid (elsA solver) : conformal connections

Grid details in vertical plane / flow direction

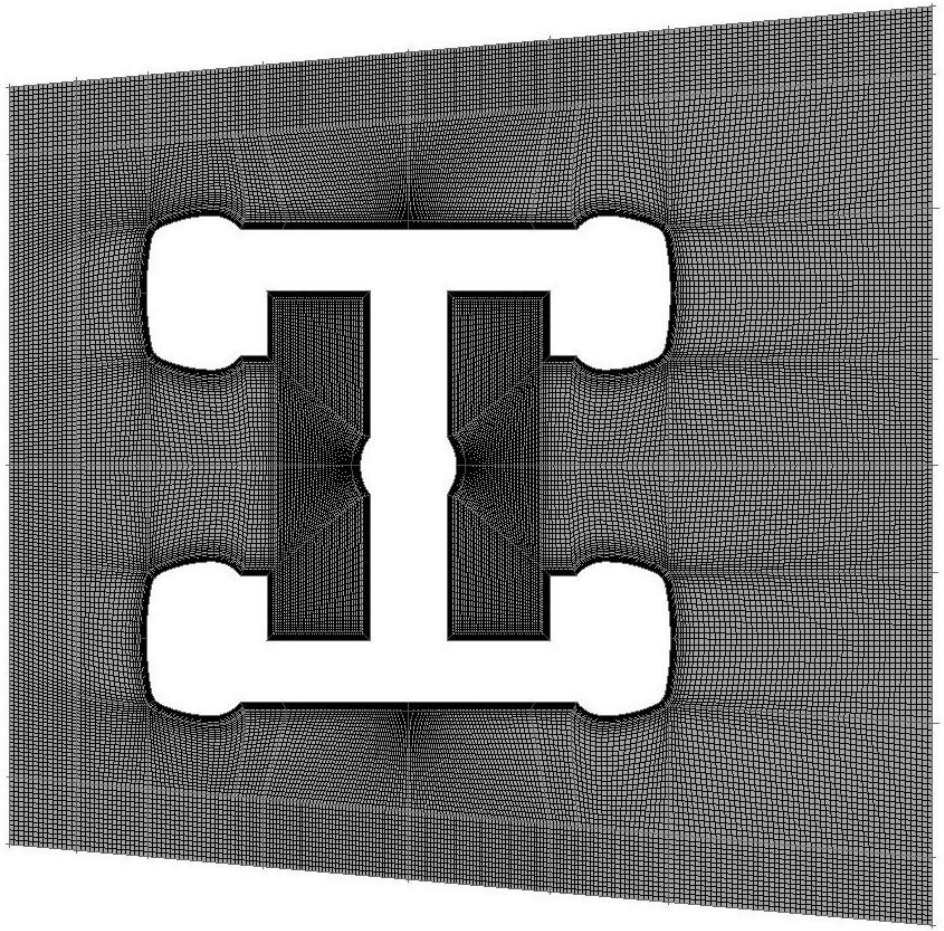


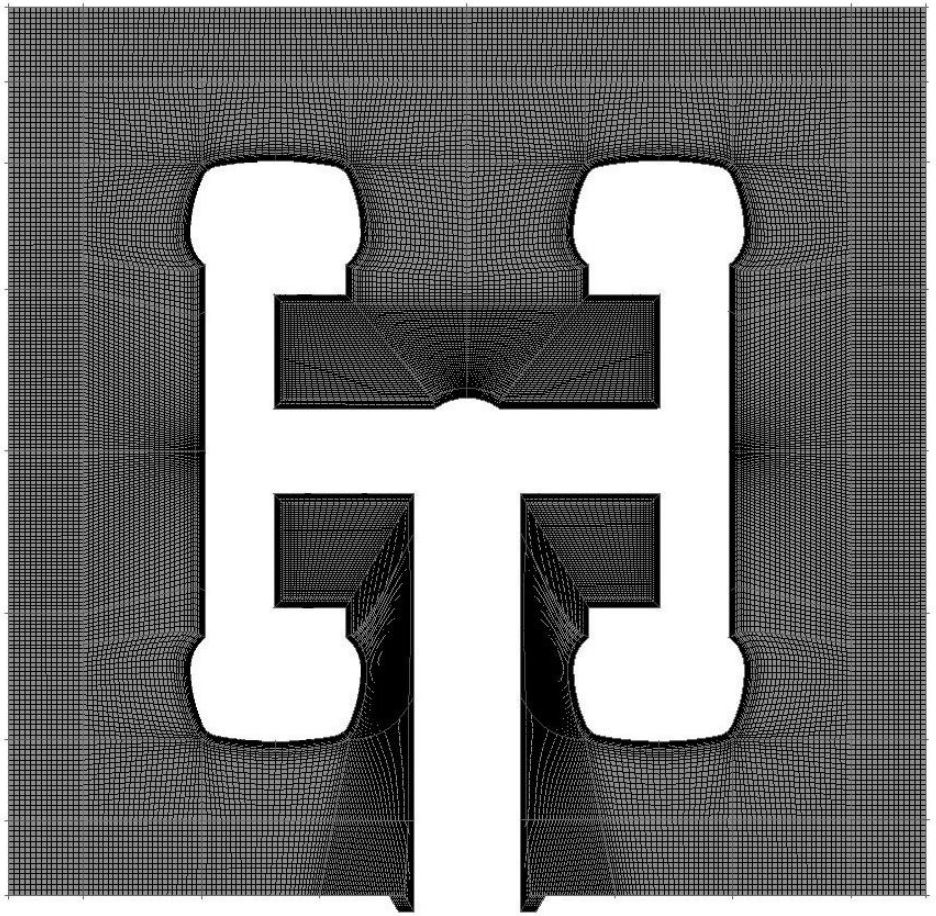
Median plane

Wheel external plane



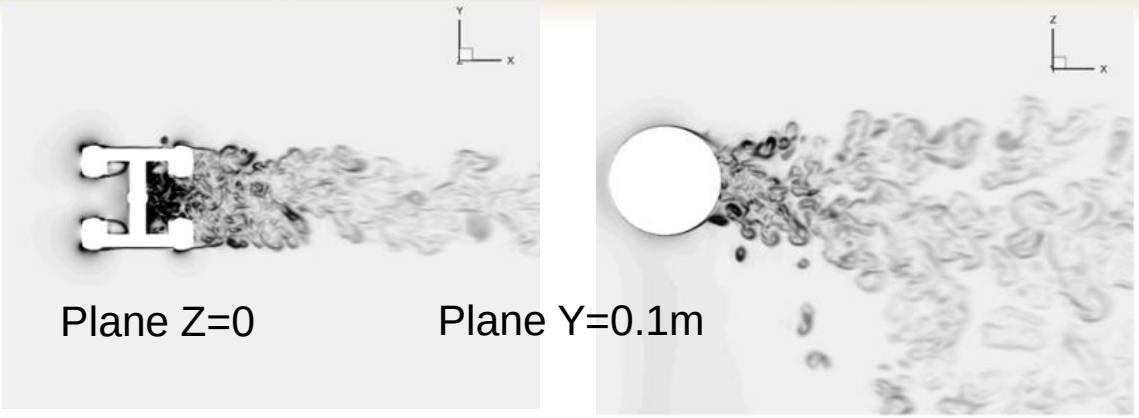
Multiblock structured grid (elsA solver) : conformal connections

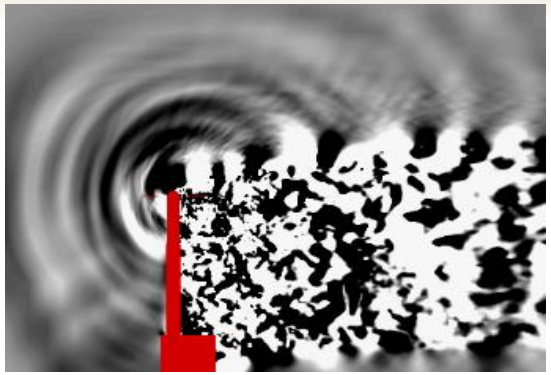




…. Grid development with ICEM-CFD : 3 months !

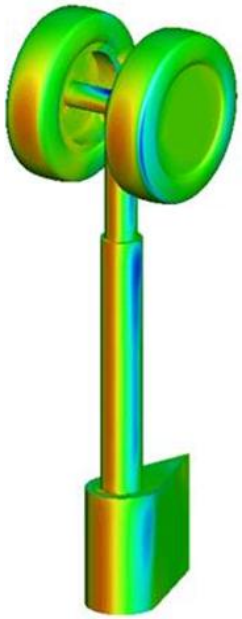
ZDES (*elsA* solver)and acoustic prediction in farfield (FW-H – *KIM* solver)



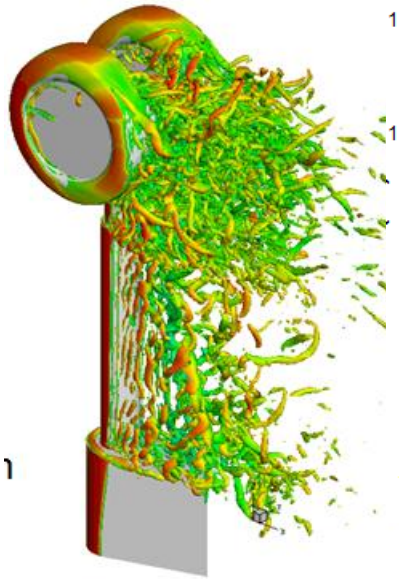


Pressure fluctuations

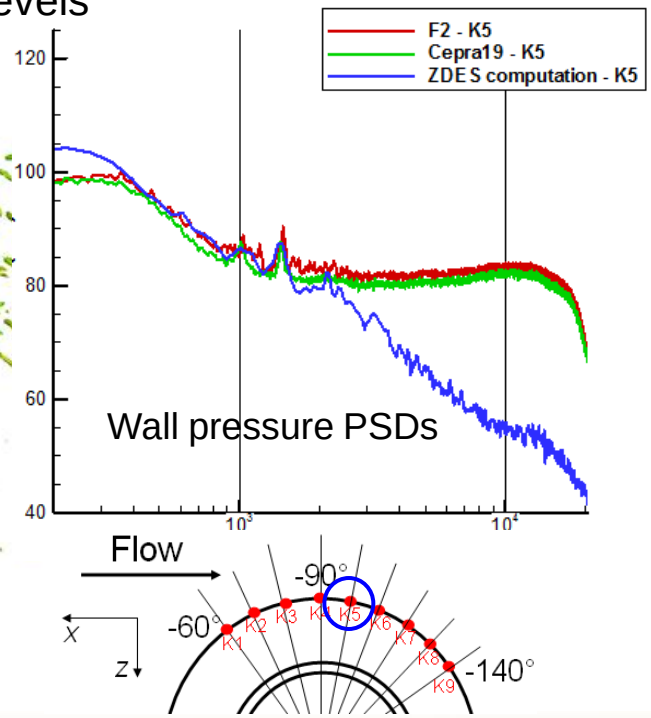
Grad(ρ) levels

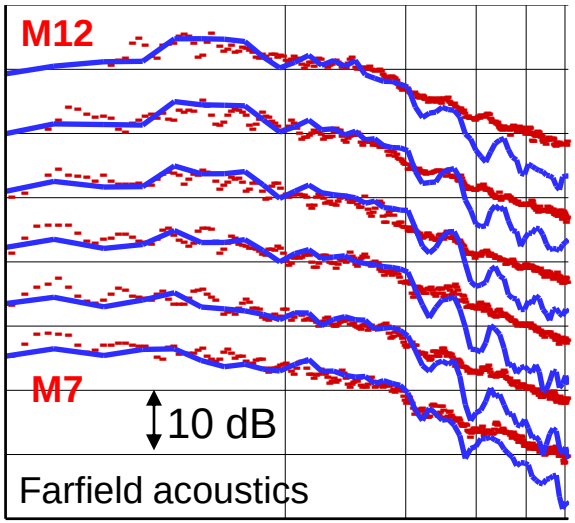


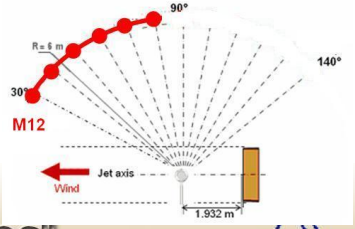
Cp distribution



One iso-contour of the Q-criterion

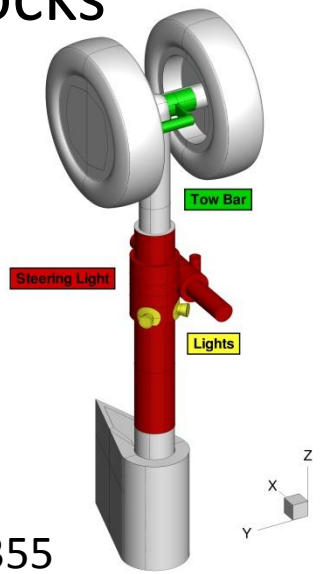




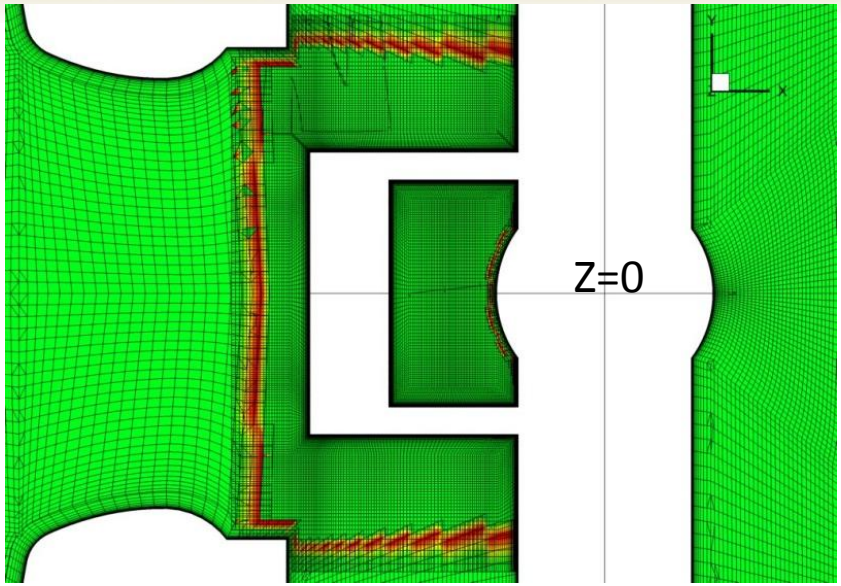


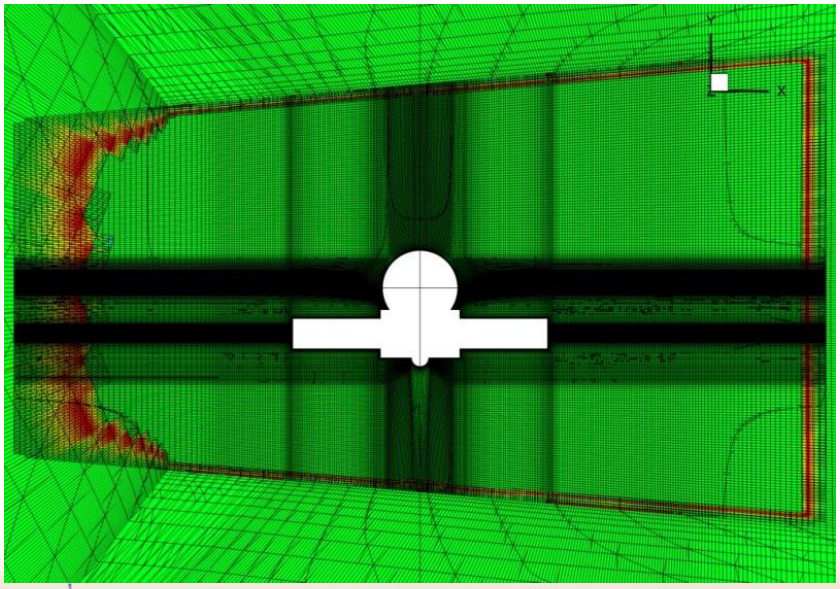
Multiblock structured grid (elsA solver) : additional Chimera blocks

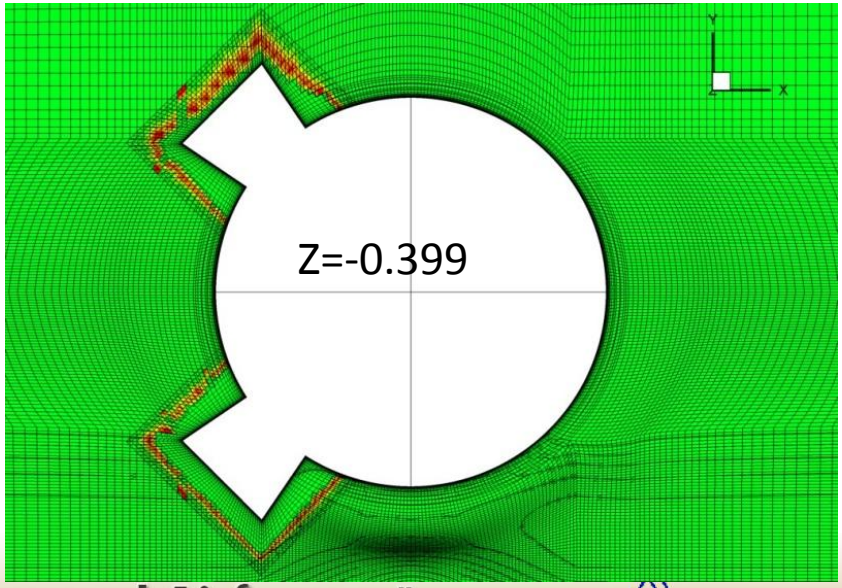
- LAGOON configuration #2
- Structured grid
- 67 million mesh points
- Use of Chimera grids
- 4 sets of grids :
  - the baseline
  - around the tow bar
  - around the steering light
  - around the lights



Z=-0.355

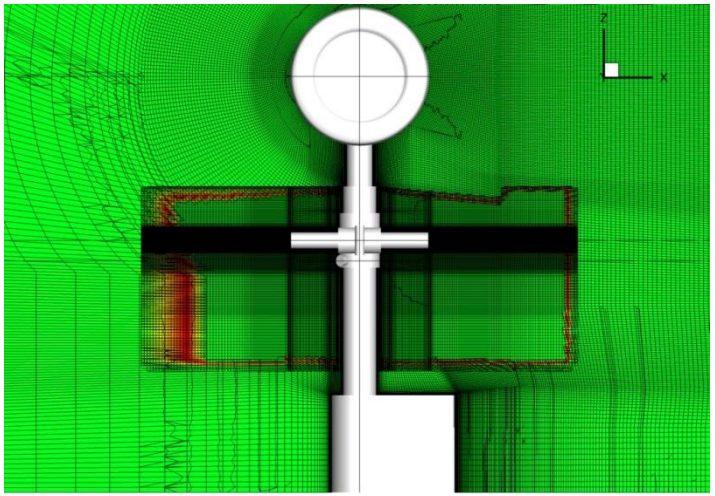




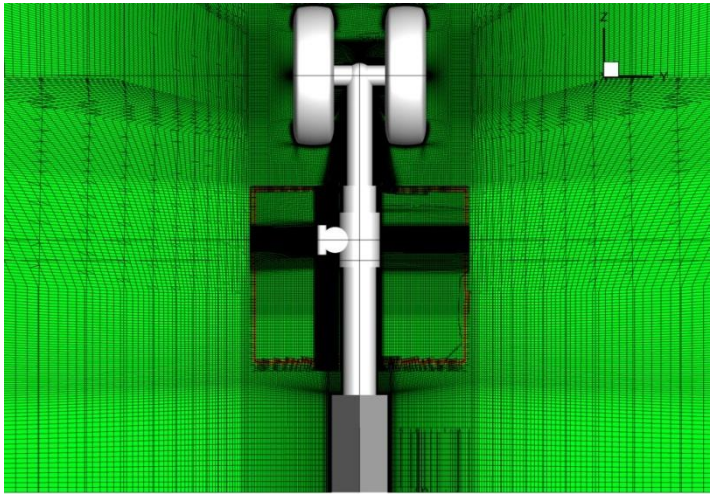


Multiblock structured grid (elsA solver) : additional Chimera blocks

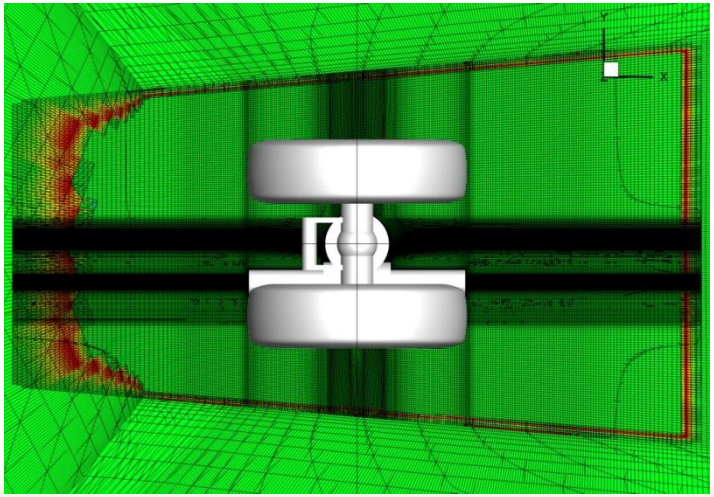
Y = 0



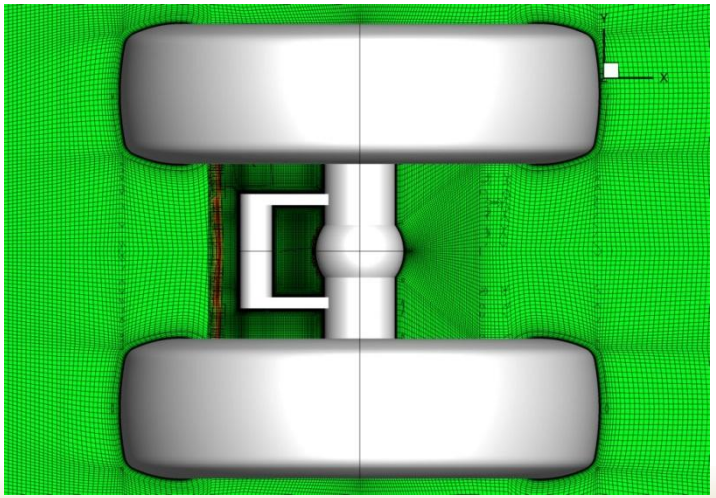
X = 0



Z = -0.355

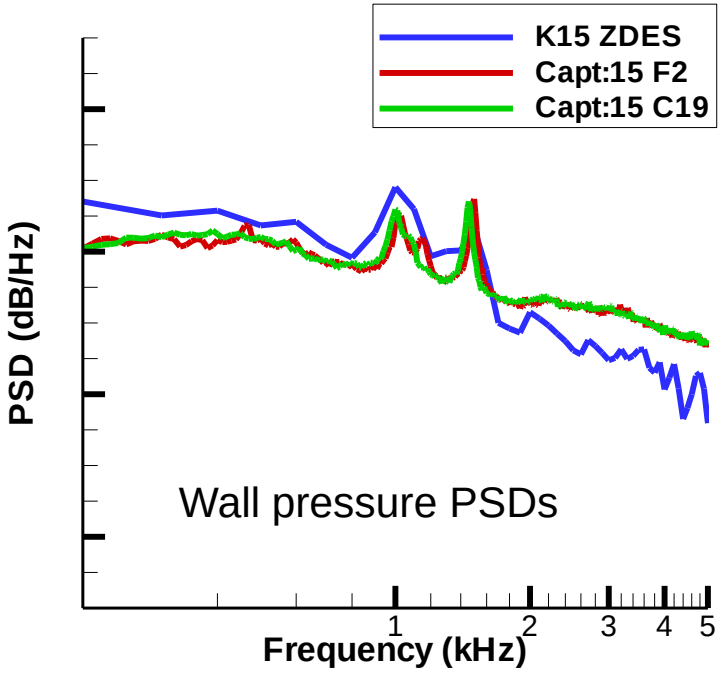


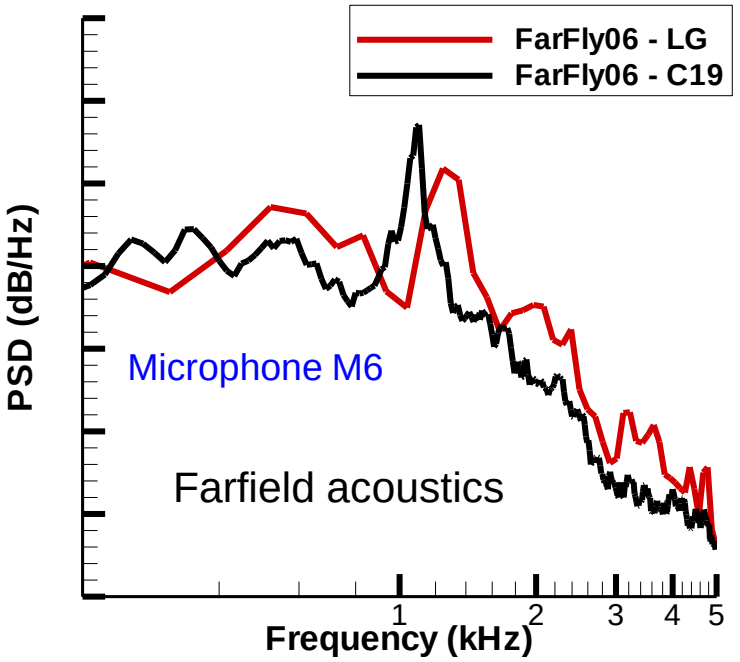
Z = 0

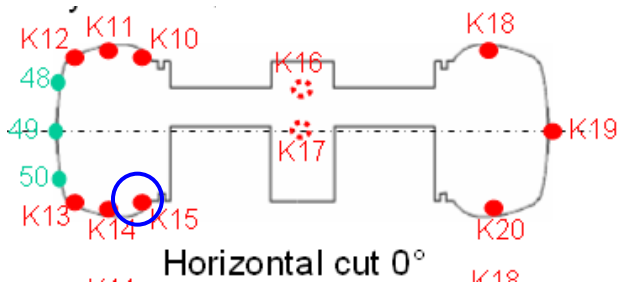


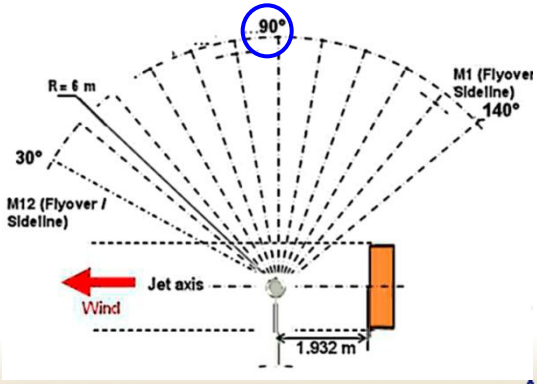
ZDES (*elsA* solver) results

Acoustic prediction in farfield (FW-H – *KIM* solver – solid surface)

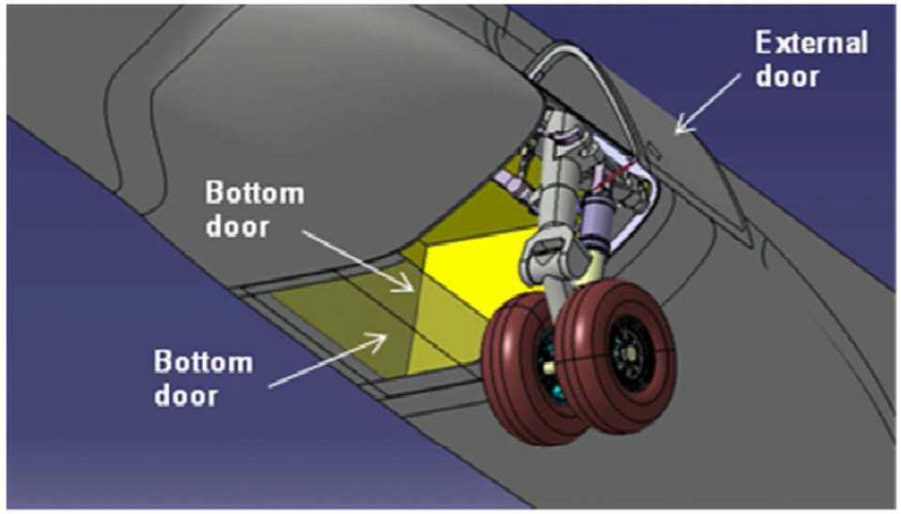








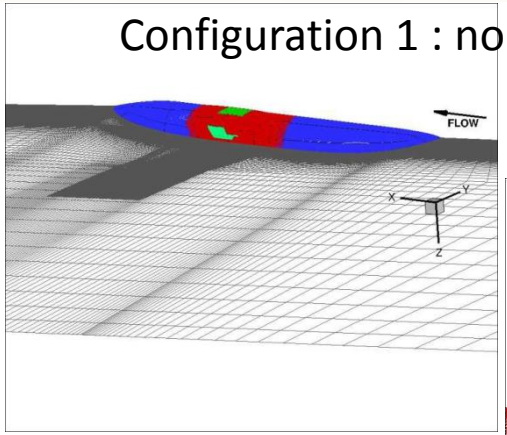
Further application of elsA/Chimera in Clean Sky GRA

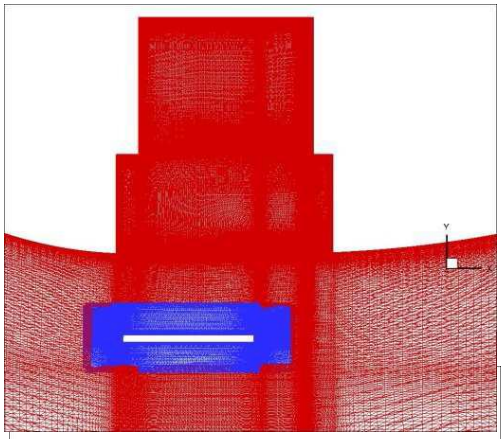


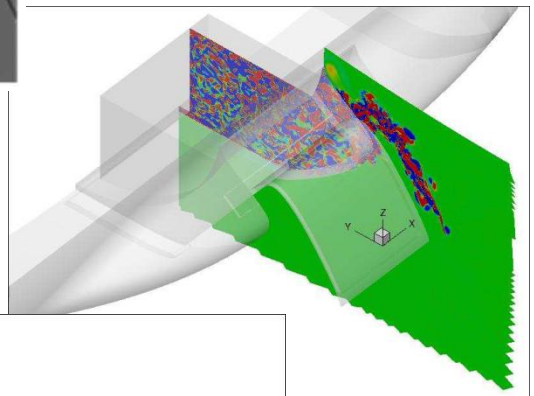
Configuration 1 : no LG, doors open

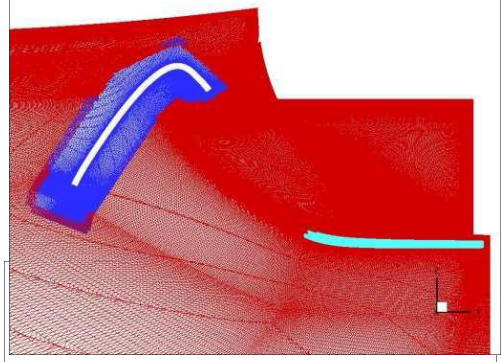
73 M points

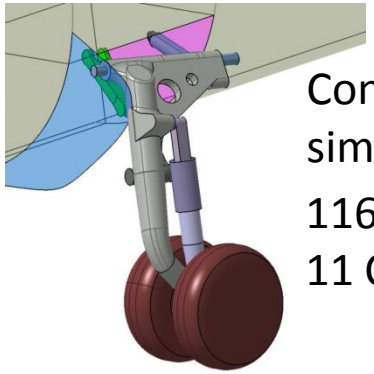
7 Chimera blocks









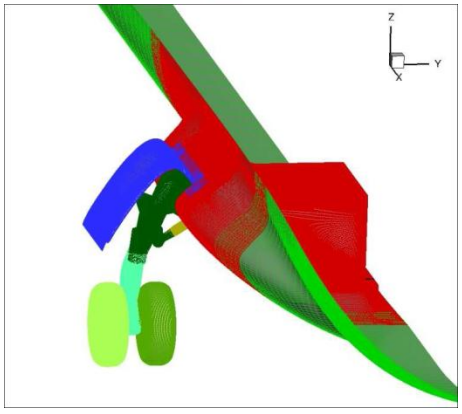


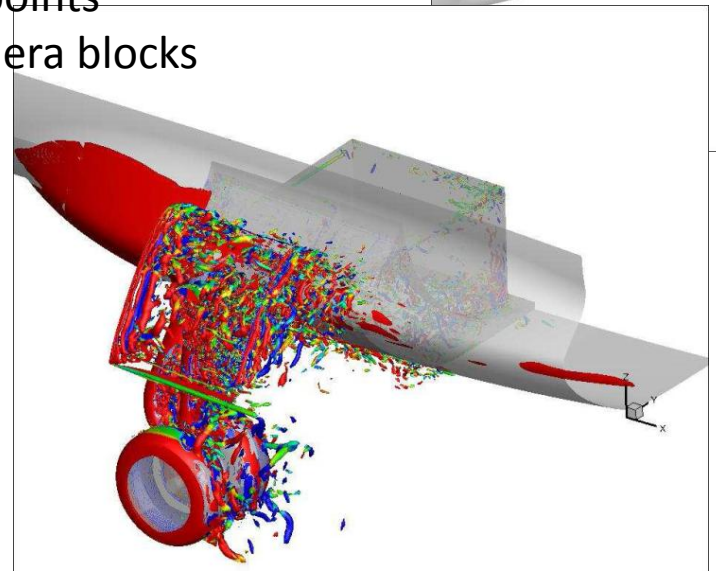
Configuration 2 :

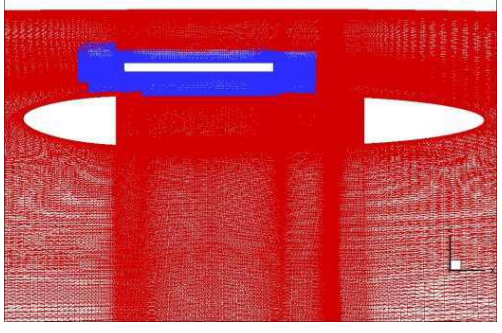
simplified LG, doors open

116 M points

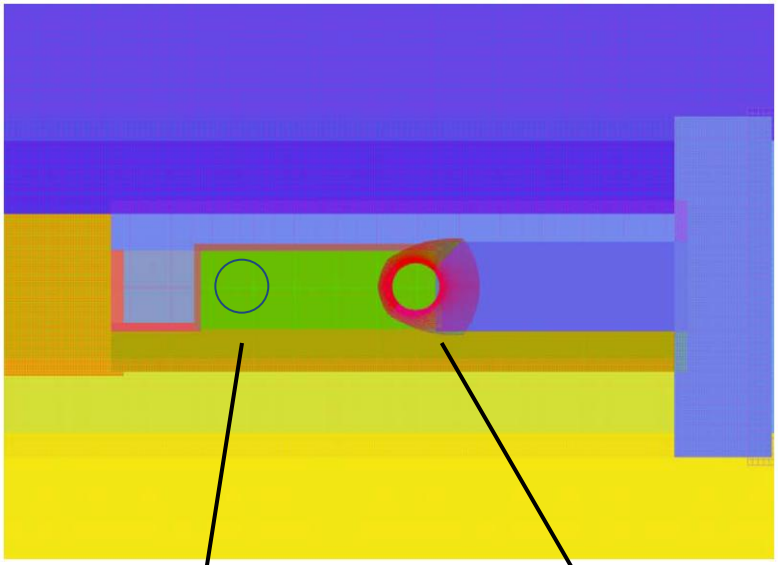
11 Chimera blocks

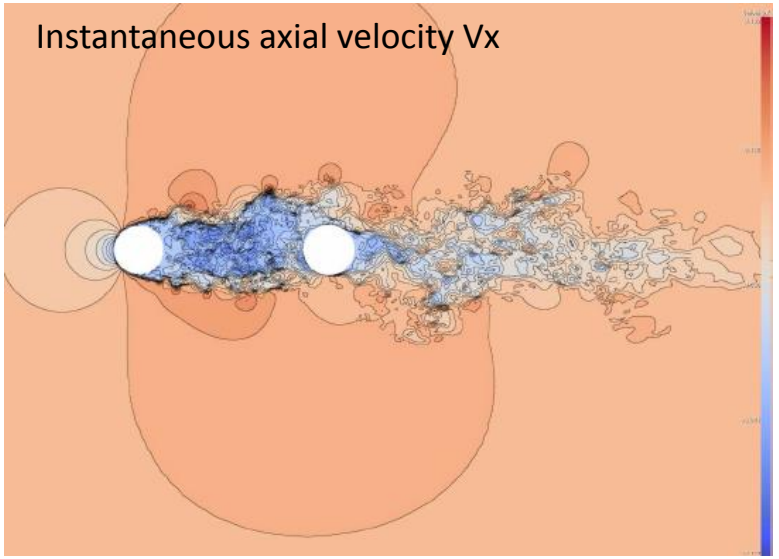


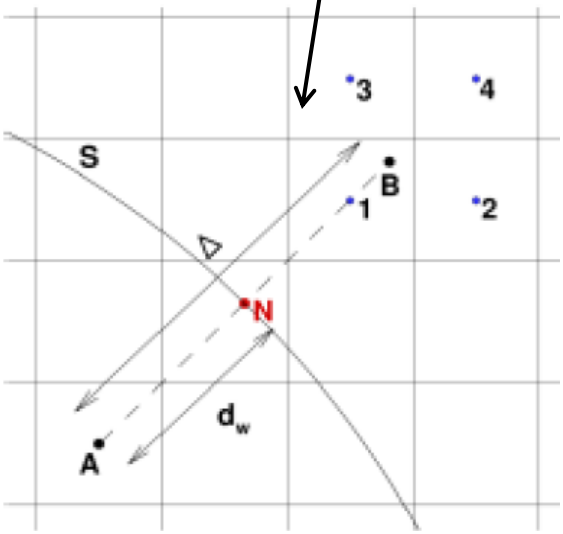




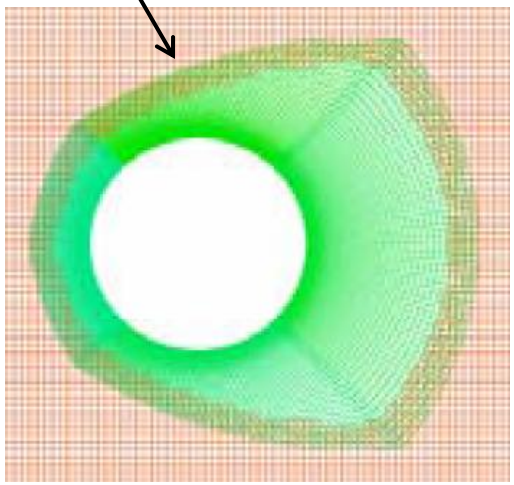
Development of Chimera/IBC (Immersed Boundary Condition)







Ghost cells IBC



Body-fitted Chimera block

Octree grid generation :

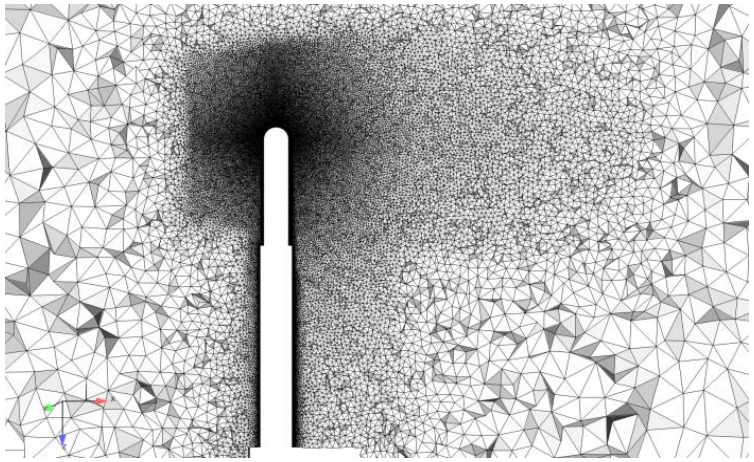
- Overlapped Cartesian blocks
- Grid refinement in the wake
- About 15 M cells
- Upstream cylinder : IBC
- Downstream cylinder : « body-fitted » Chimera

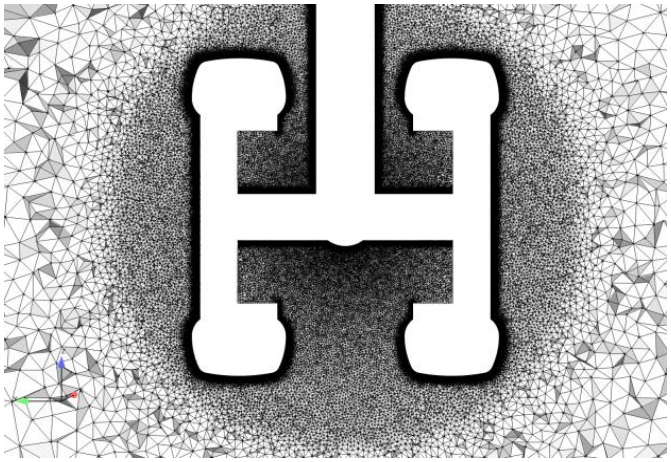
Two interpolation methods :

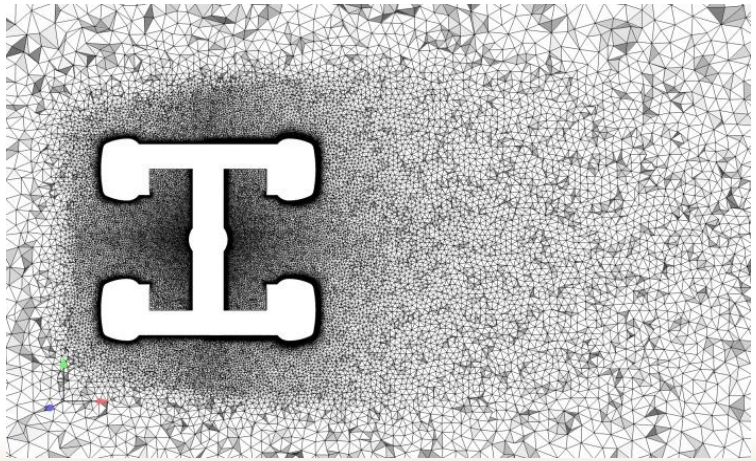
- Chimera interpolations : connection between Cartesian blocks and body-fitted blocks
- Interpolations for Immersed Boundary Condition

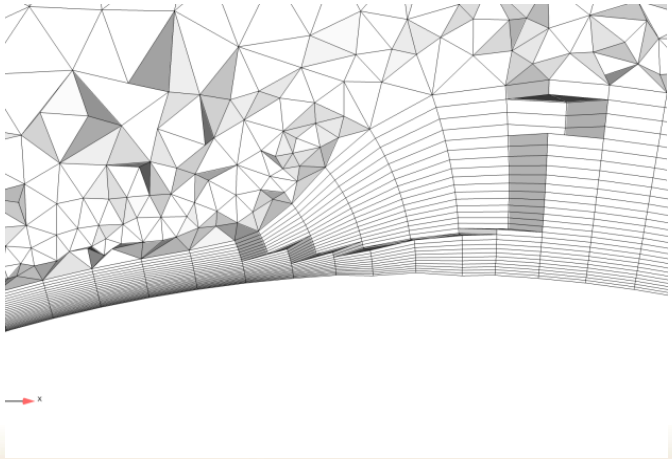
Unstructured grid (CEDRE solver) : grid topology

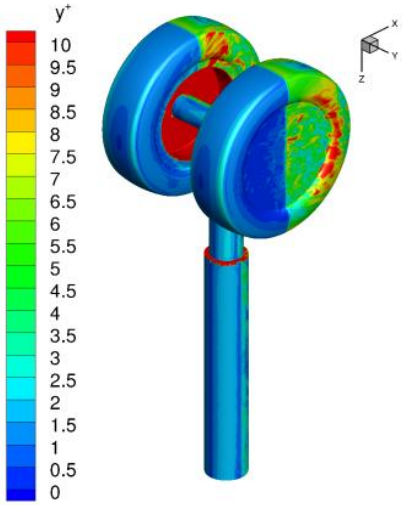
- 61 million elements hybrid mesh (20 million prisms, 41 million tetrahedras)
- First cell size 10 µm. Y+ around 1.5 - 7.5
- 25 prismatic layers with 6 % growth rate
- Grid generation with CENTAUR : about 2 weeks





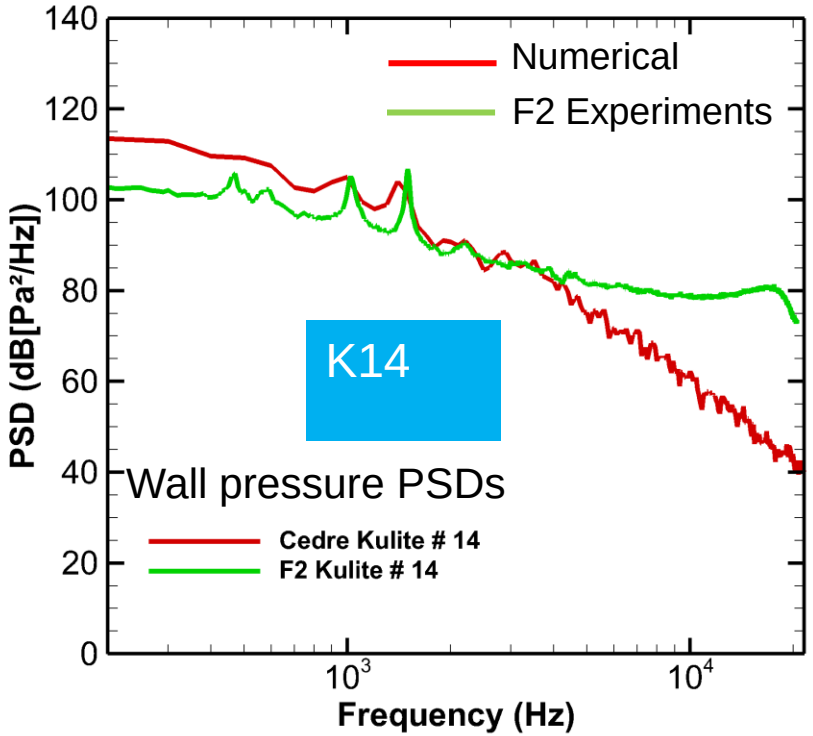


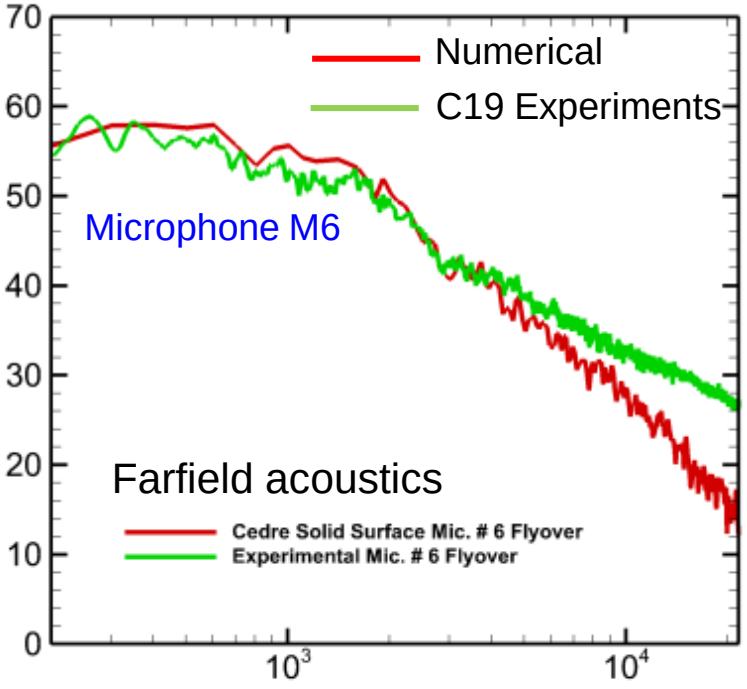


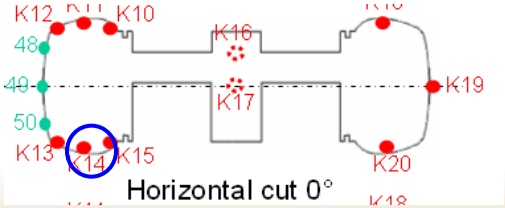


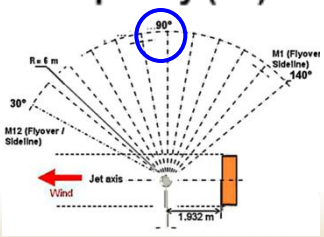
Unstructured grid (CEDRE solver) : grid topology

- Zonal Detached Eddy Simulation mode II + FW-H (KIM solver) on solid/porous surfaces
- Δt = 1µs for CFL < 1 everywhere except for some prisms at the BL
- Implicit 1st order in time 2nd order in space ROE type numerical schemes
- 102 ms of useful signal obtained.



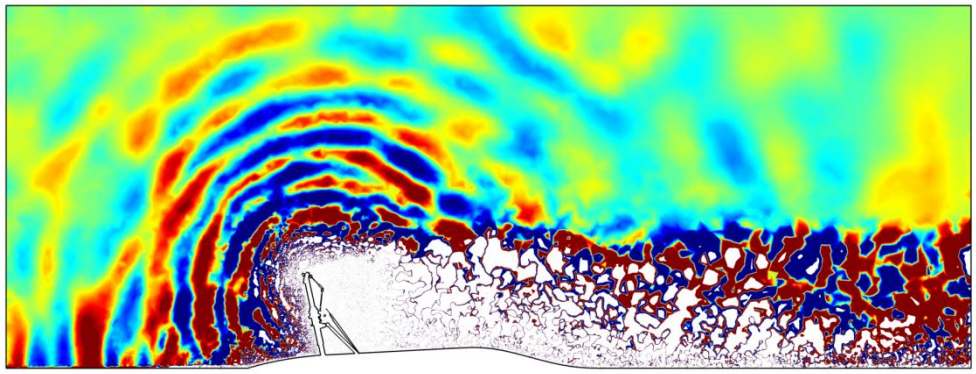


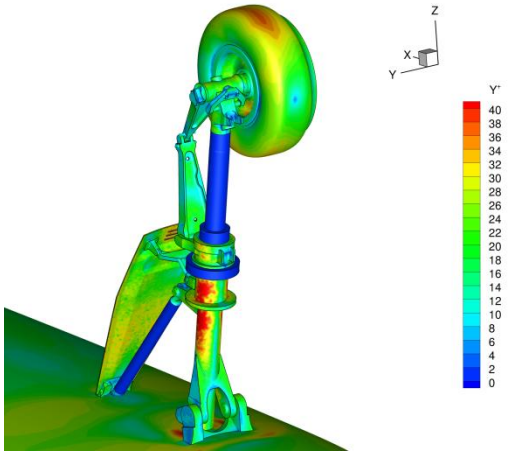


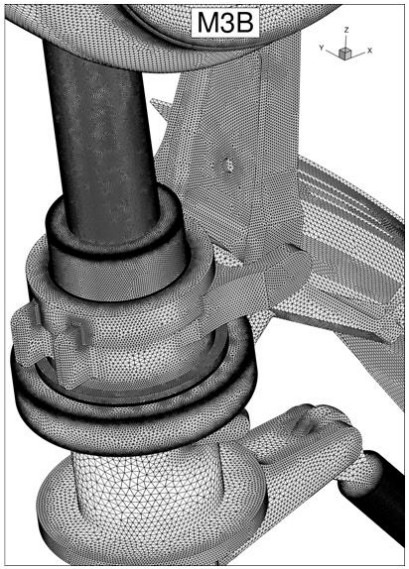


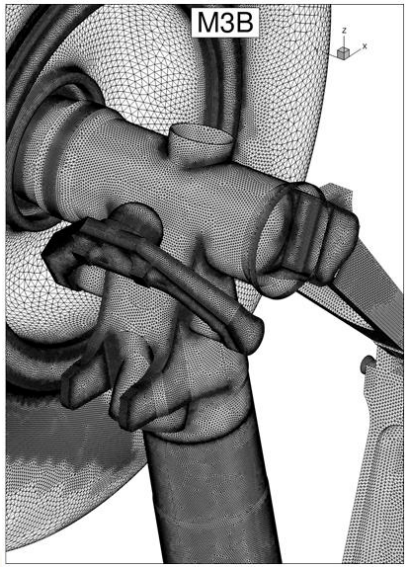
Unstructured grid (CEDRE solver) of PDCC-LG (BANC)

- 81 million elements hybrid mesh (9 million prisms, 72 million tetrahedras)
- Grid generation with CENTAUR : about 1 month
- ZDES (Mode II) + FW-H (KIM solver) on solid/porous surfaces





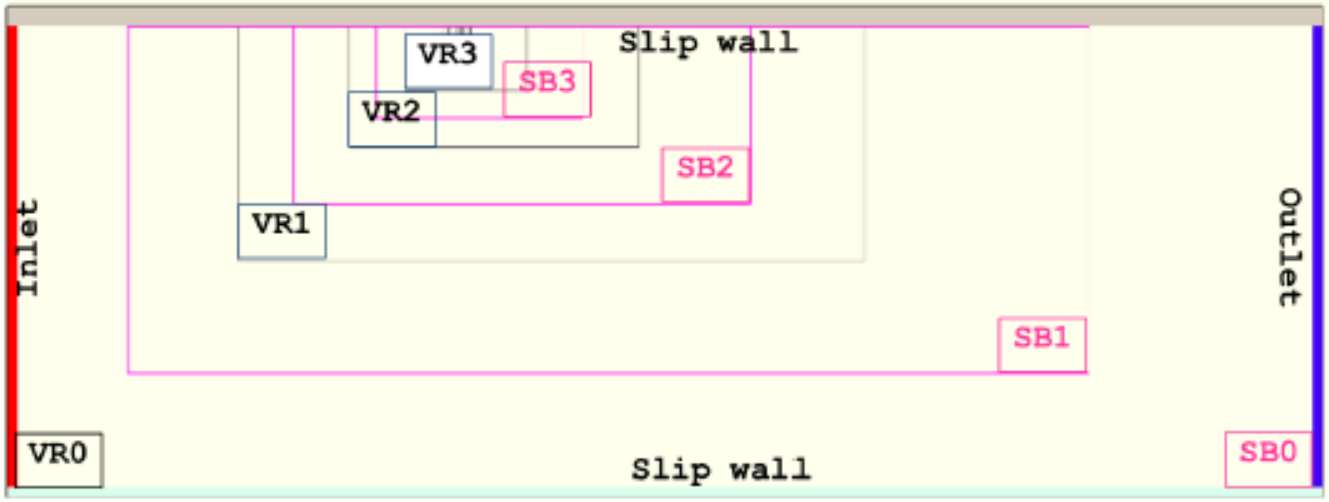


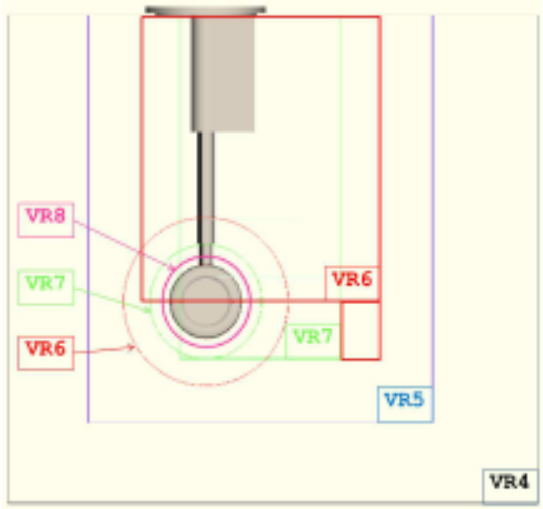


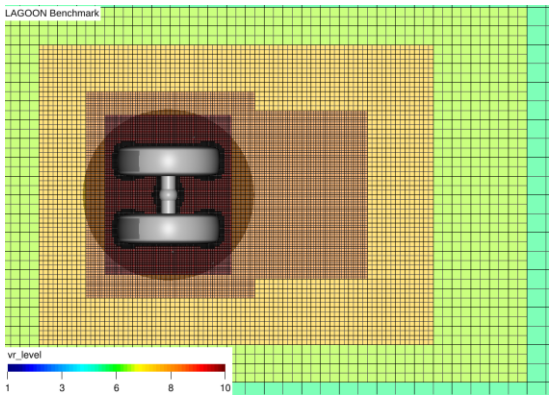
Lattice Boltzmann Method (PowerFLOW solver) : grid topology

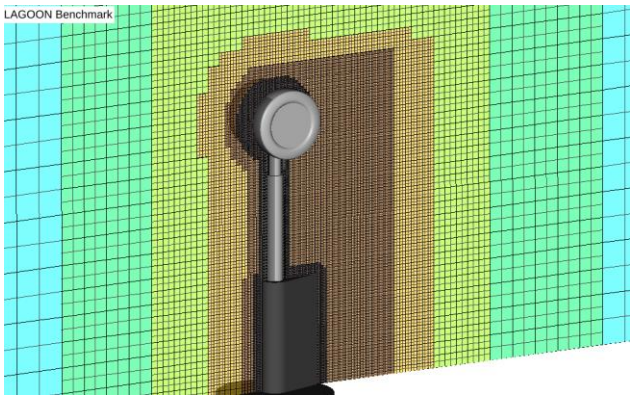
Courtesy of D. Casalino (EXA) from BANC III

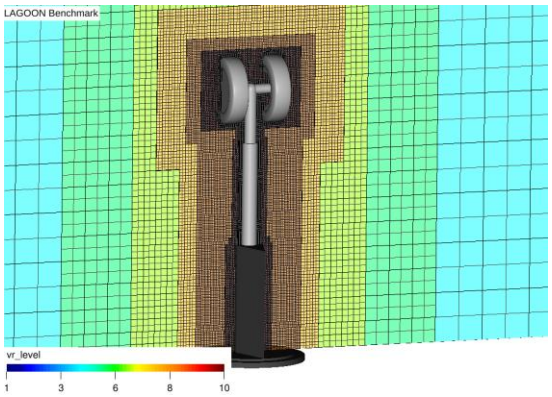
Hybrid wind tunnel configuration









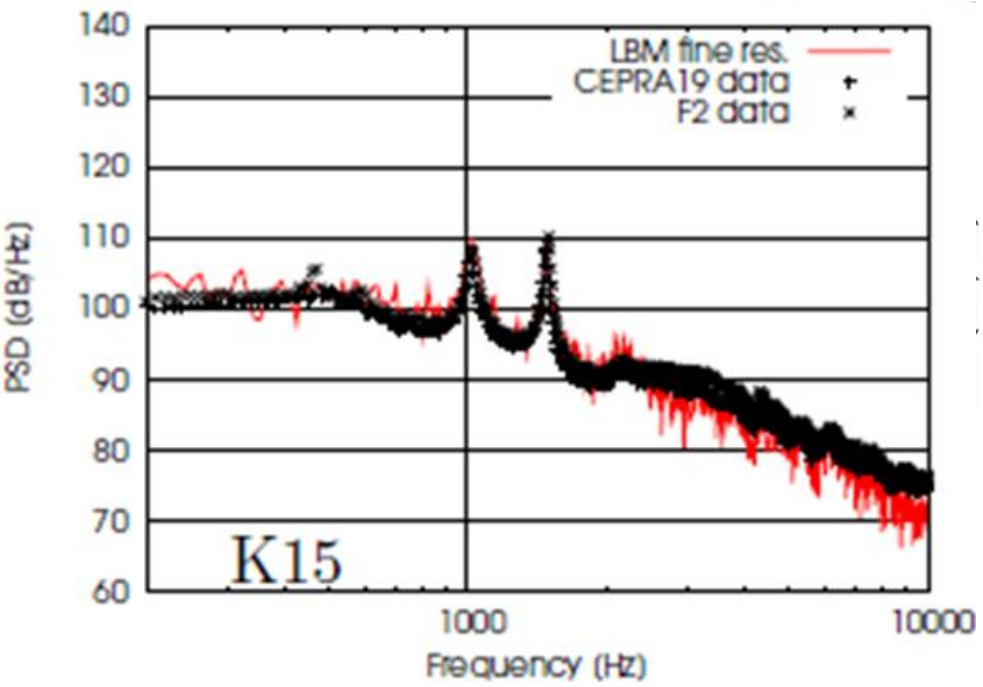


VRs (coarse resolution, every 2nd line) – Total 123 millions voxels

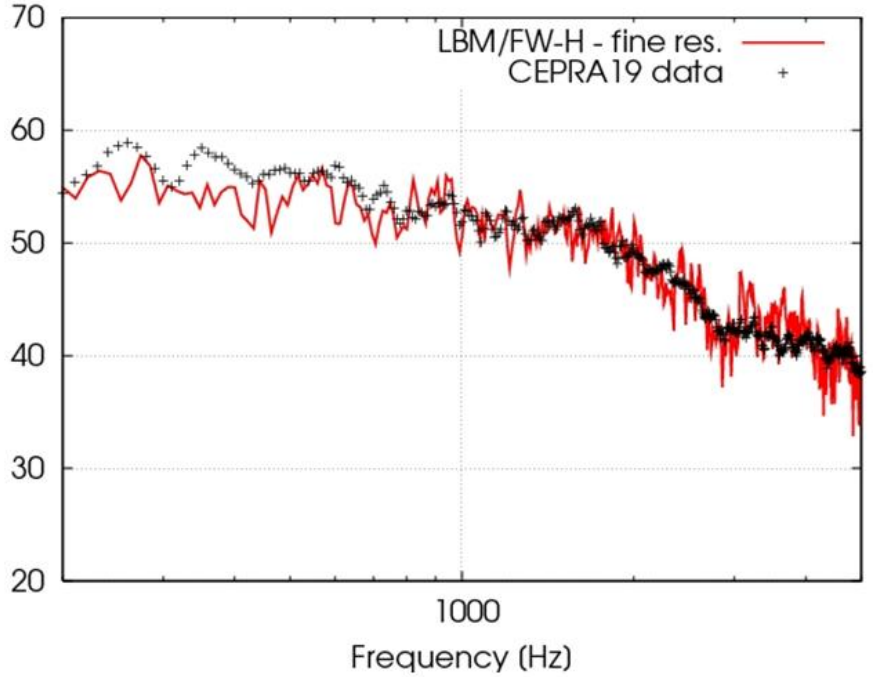
LBM (PowerFLOW solver) : nearfield/farfield results

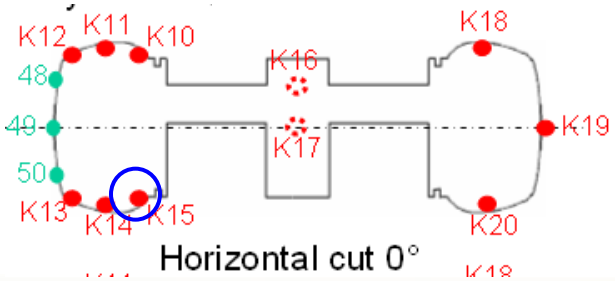
Courtesy of D. Casalino (EXA) from BANC III

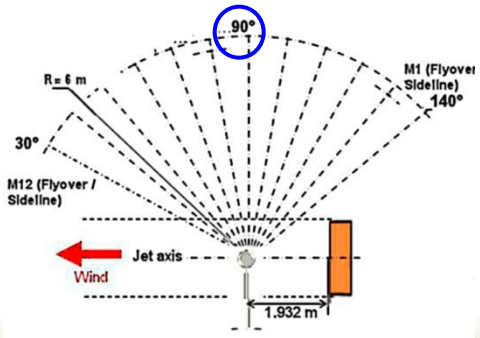
Wall pressure PSDs



Farfield acoustics



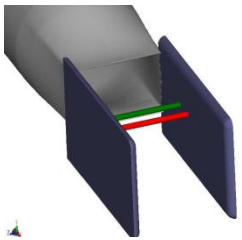


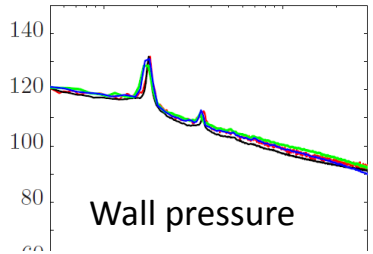


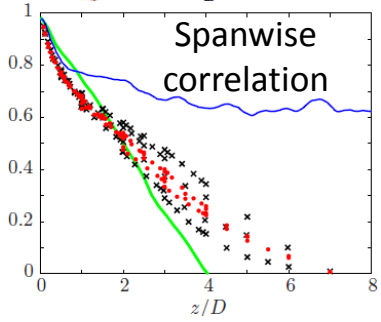
EXA activities with PowerFLOW in the BANC framework

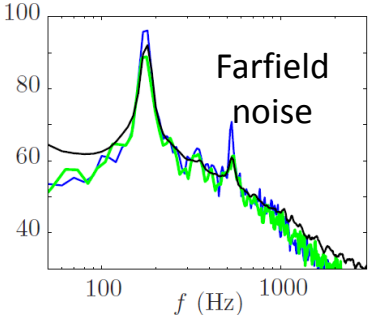
Landing Gear Category test-cases

Tandem Cylinder

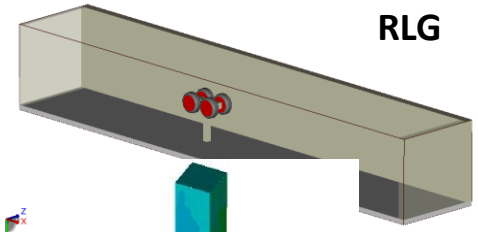


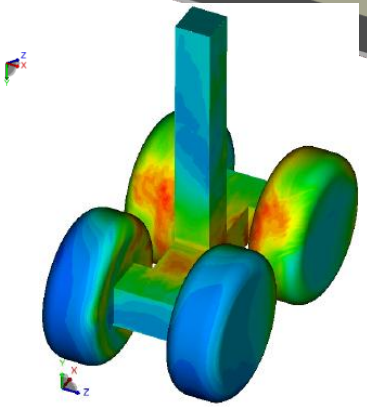


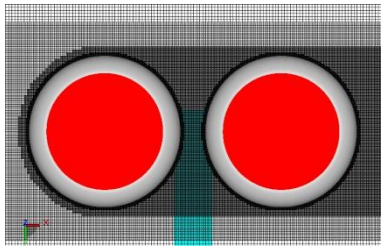


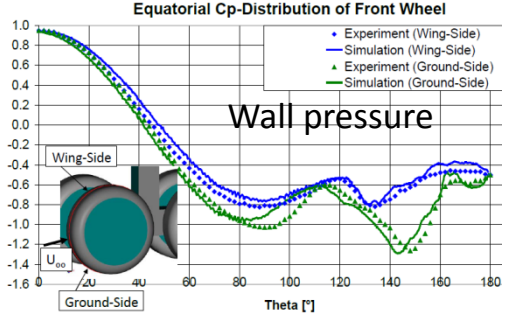


RLG

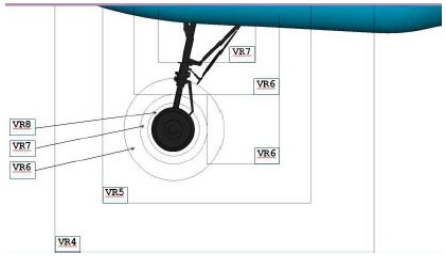


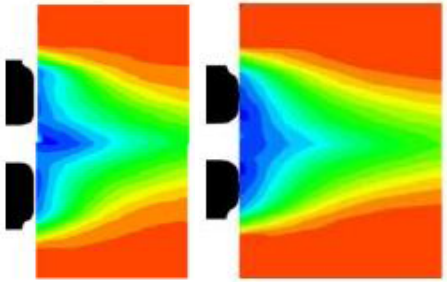


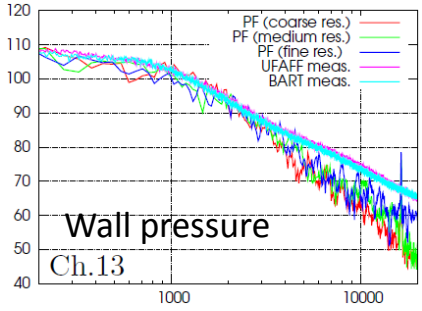


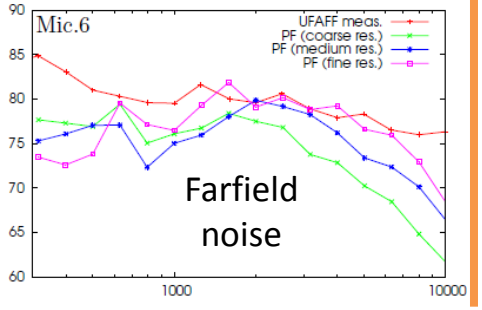


Gulfstream NLG

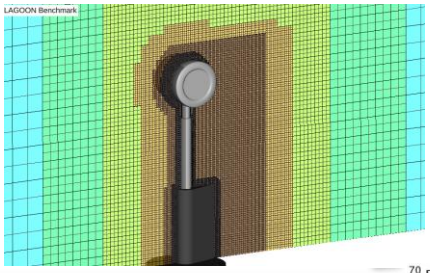


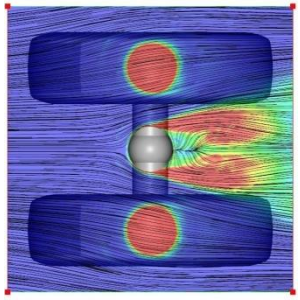


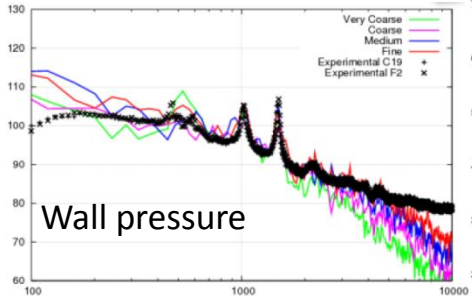


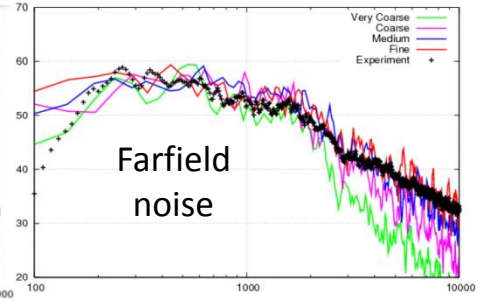


LAGOON







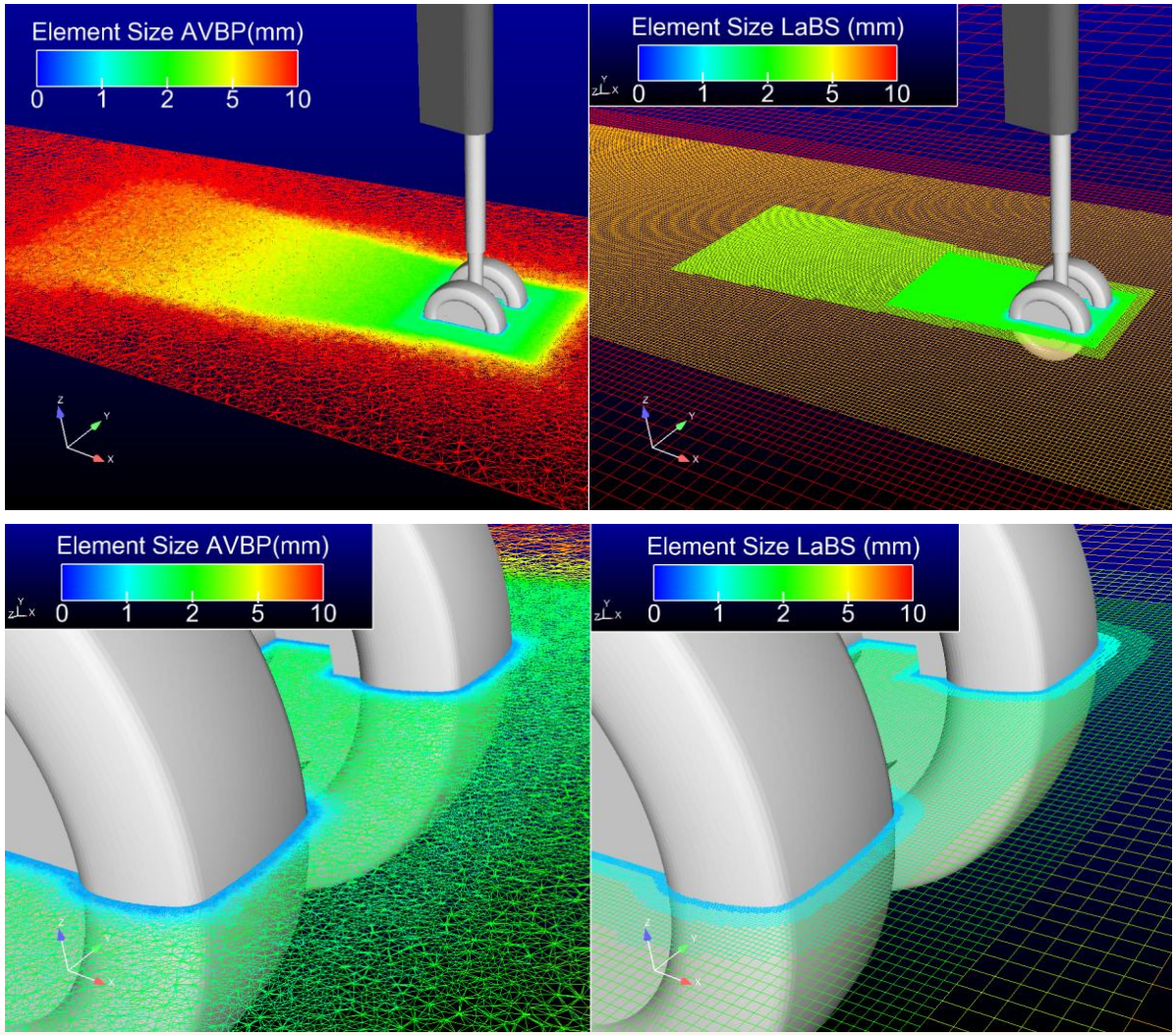


Lattice Boltzmann Method (LaBS solver) : grid topology

Courtesy of A. Sengissen (Airbus) from BANC III

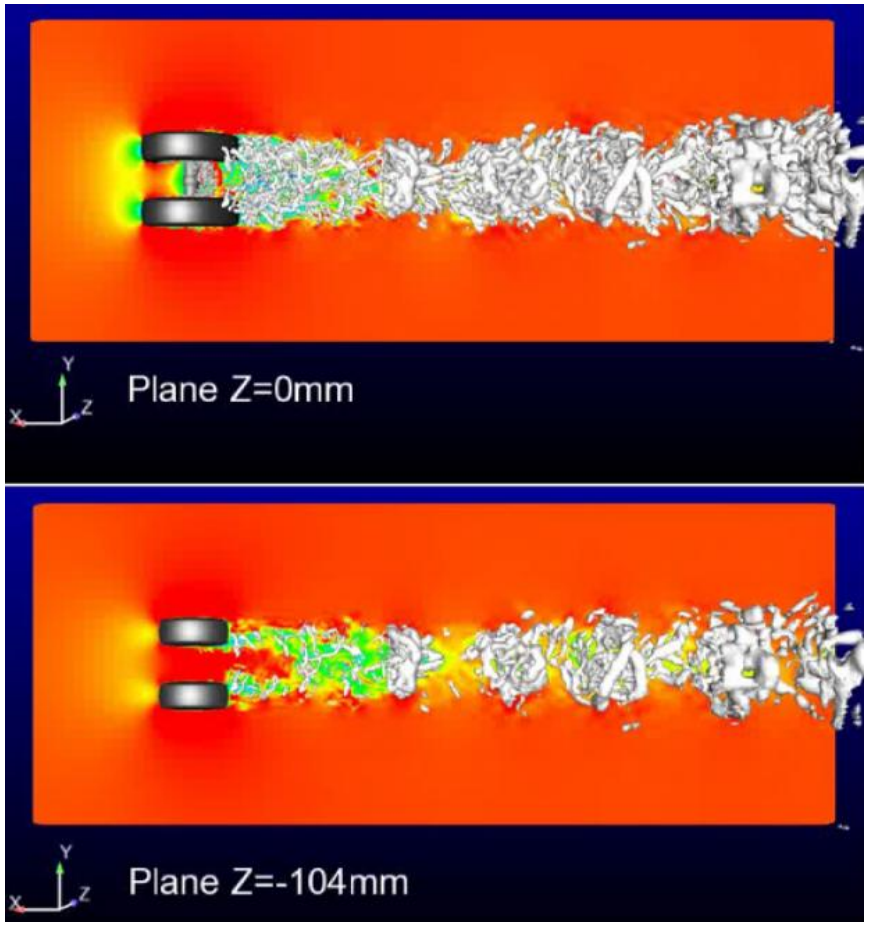
- LaBS : LBM solver developed by a french consortium led by Renault, CS, Airbus, Ecole Centrale de Lyon and Aix-Marseille university

- Airbus activity
- Objective : to match the points distribution of a wall-modelled LES (AVBP) grid
- Wake region : 2 mm to 4 mm (based on simple shapes)
- Near wall region : 0.25mm to 0.5mm, Y+ = ~60
- Coarse/ Medium / Fine grids
  Medium grid : 40 M nodes

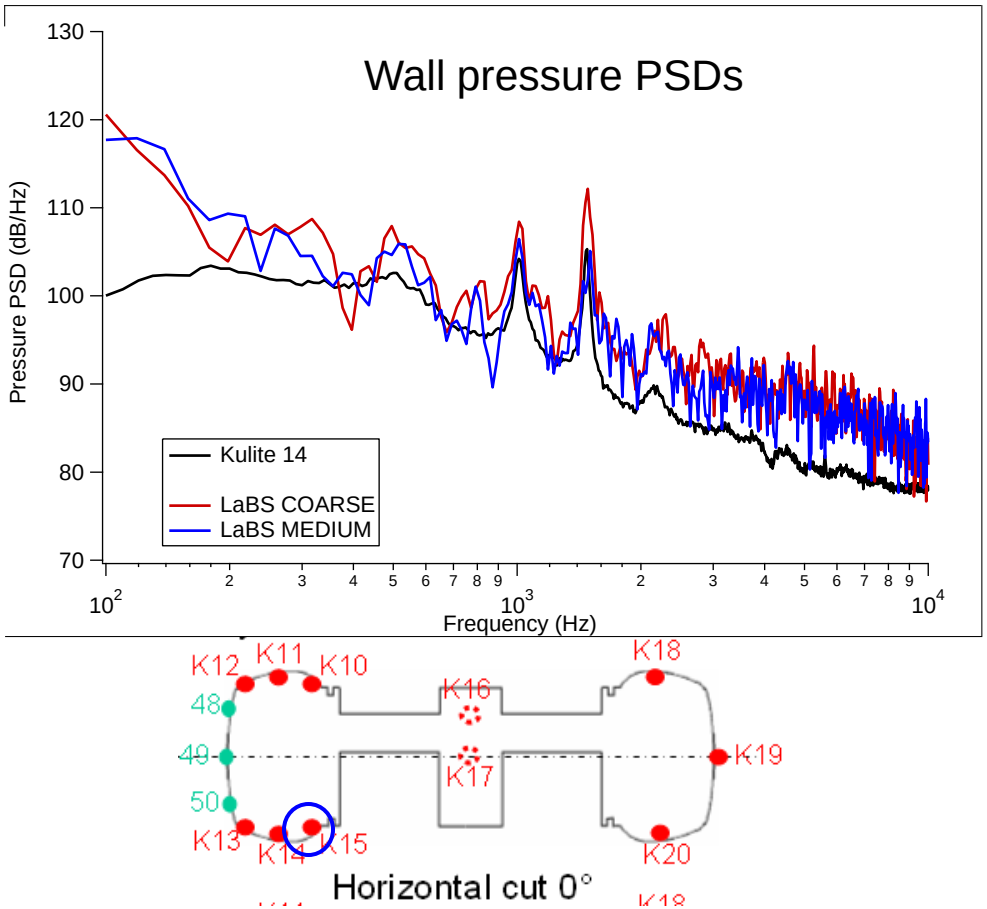


LBM (LaBS solver) : nearfield results (no acoustic results yet)

Courtesy of A. Sengissen (Airbus) from BANC III



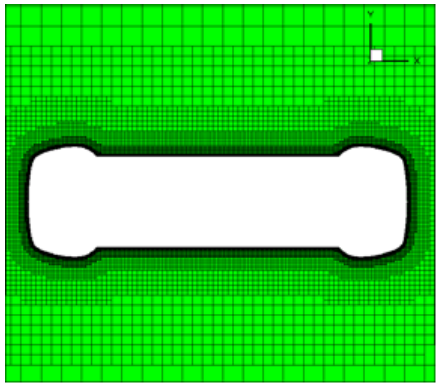
Q criterion iso -surfaces

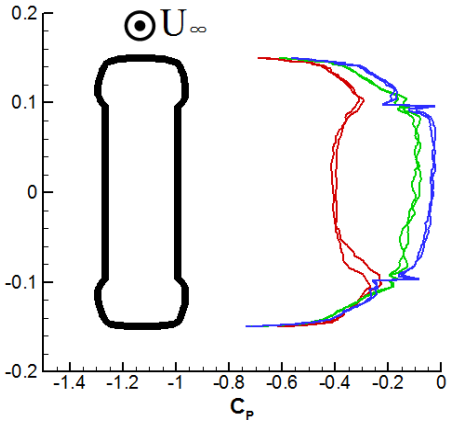


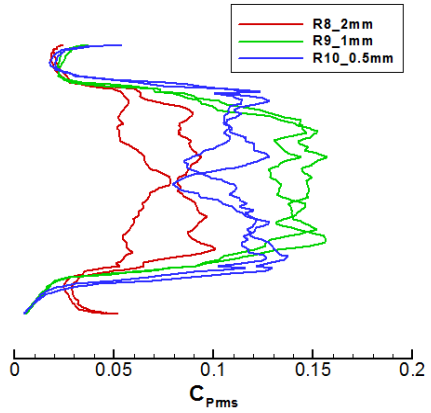
… other computations achieved on LAGOON configurations #2 and #3.

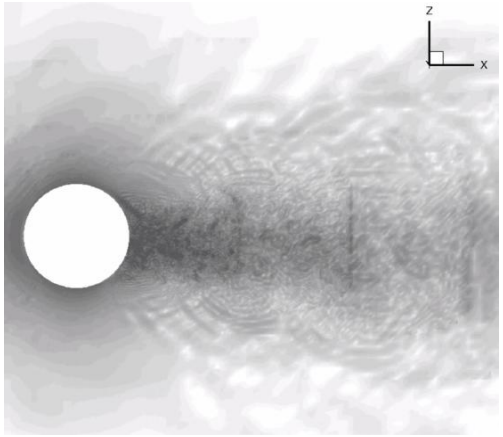
Onera activities with LaBS - Landing gear configurations

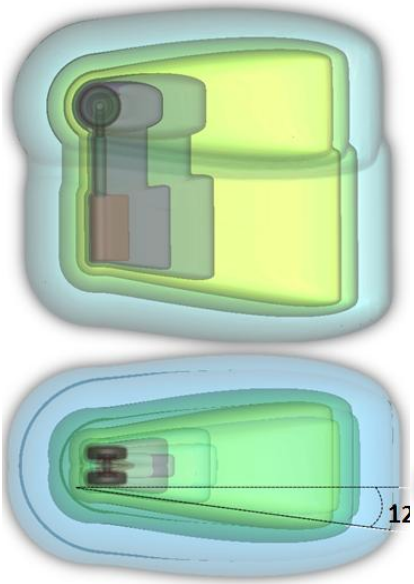
Single "LAGOON" wheel





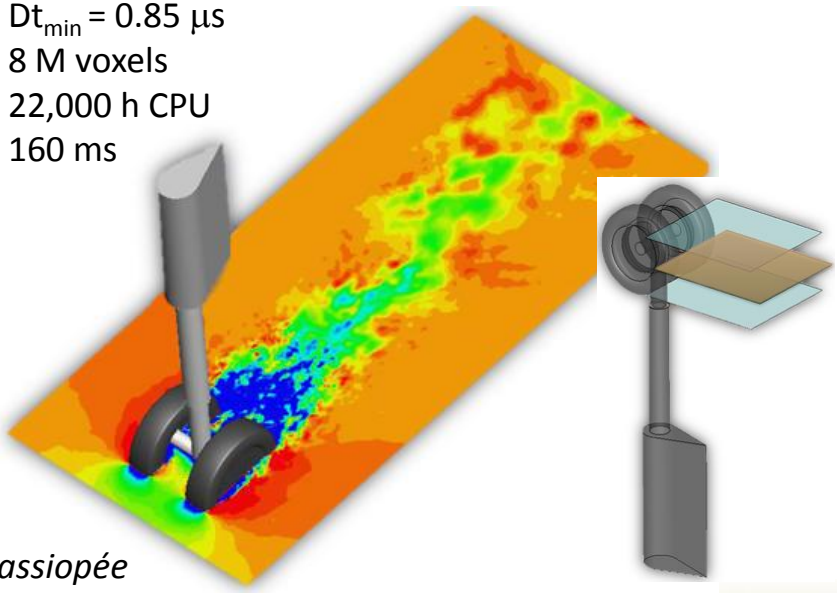


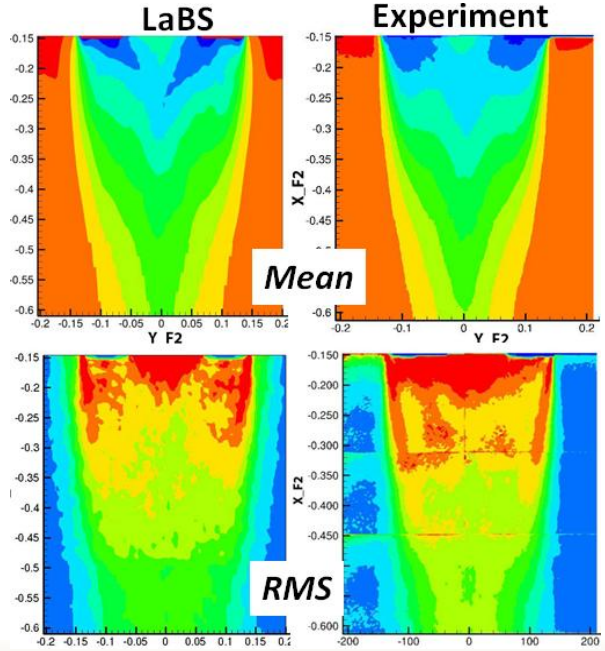




Dx_{min} = 0.5 mm
Dt_{min} = 0.85 µs
8 M voxels
22,000 h CPU
160 ms

LAGOON landing gear



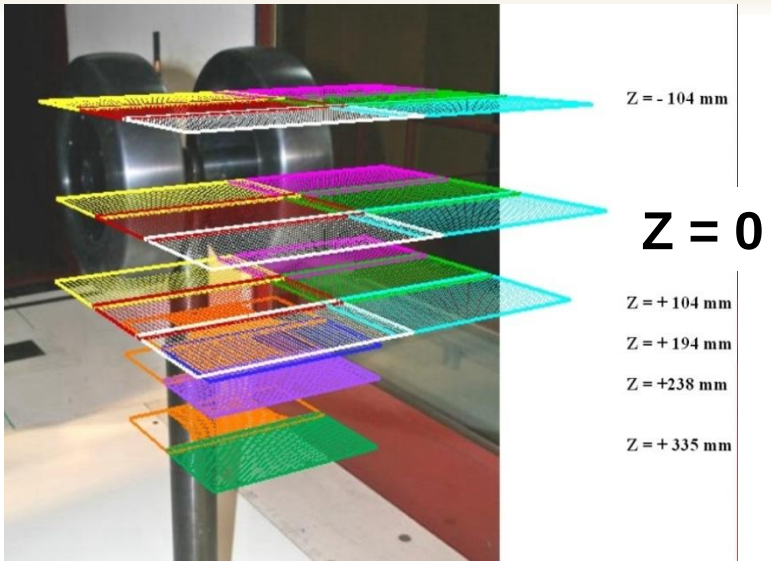


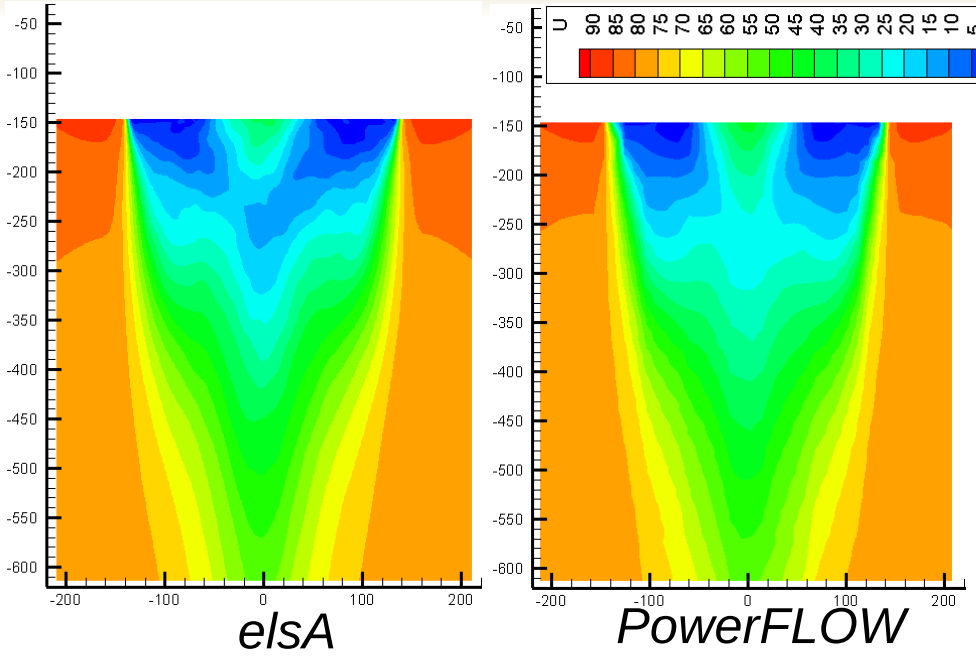
"Offsets" generation with *Cassiopée*

LAGOON case : CFD computational parameters overview

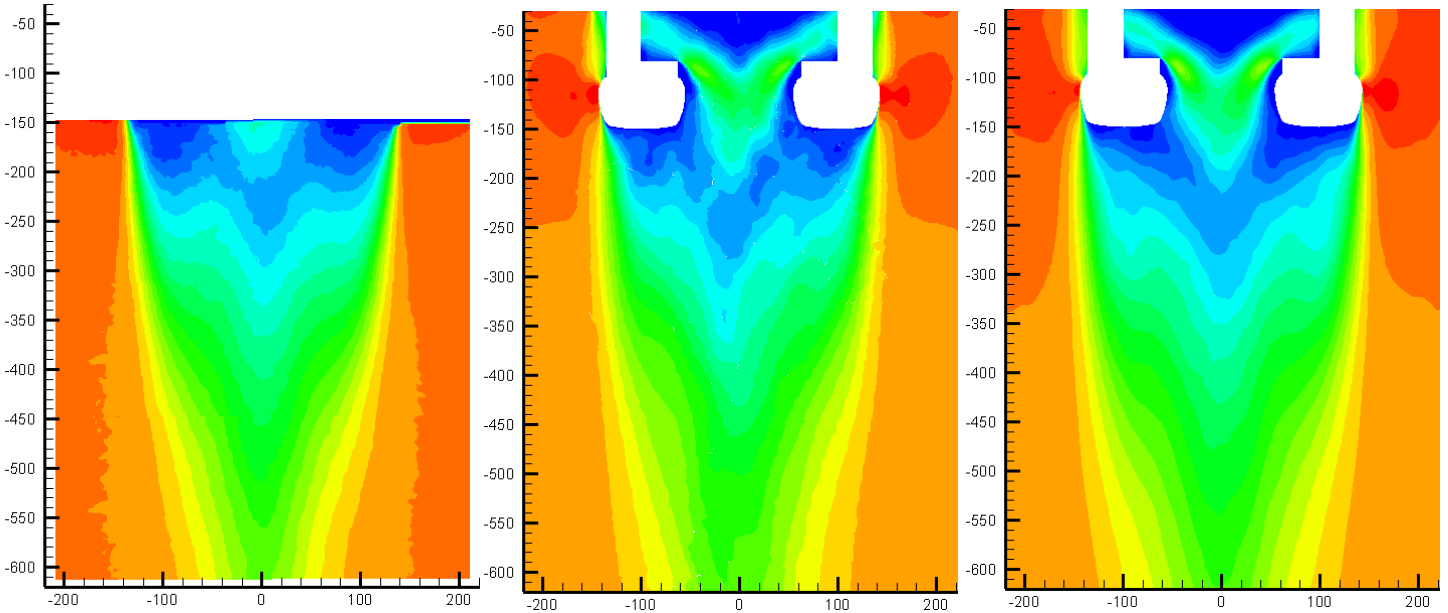
CFD solver	elsA	CEDRE	LaBS	PowerFLOW
Method	ZDES (mode I)	ZDES (mode II)	LBM	LBM-VLES
Turbulence model / subgrid scale model	SA	k-w SST	Shear Improved Smagorinsky	RNG k-e
Space/time scheme order	2/2	2/1	Not applicable	
Configuration	Freefield with floor	Freefield	Freefield with floor	Freefield
Grid	Multiblock Structured	Unstructured	Octree (10 levels 2:1)	
Number of points, nodes, elements, vertices (M=1E6)	34M points	61M elem (cell center)	40M vertices	123M elements
Minimum wall cell size (1E-6 m)	1	10	500	600
Time step (1E-6 second)	0.5	1	0.8413	0.988
Storage phase physical time (1E-3 second)	234	102	337	700
Processors number	256	480	360	272
Total clock time (hours)	1280	430	60.8	76
Total CPU time (hours)	327 680	199 900	21 880	20 780
CPU/elem/iter (1E-6 sec)	74.1	119	4.92	0.85

Velocity maps : Z = 0 - U component



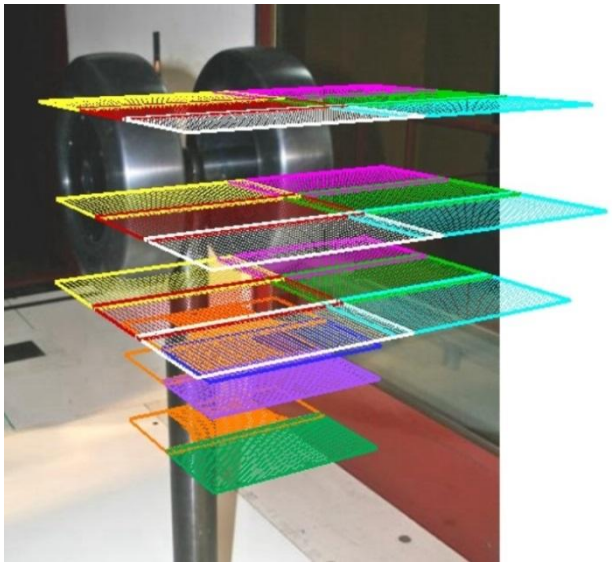


elsA PowerFLOW



Experiment - PIV CEDRE LaBS

Velocity maps : Z = 0 - V component



Z = - 104 mm

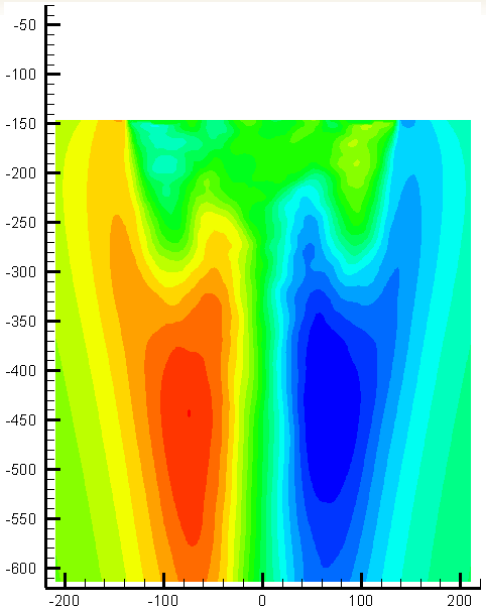
Z = 0

Z = + 104 mm

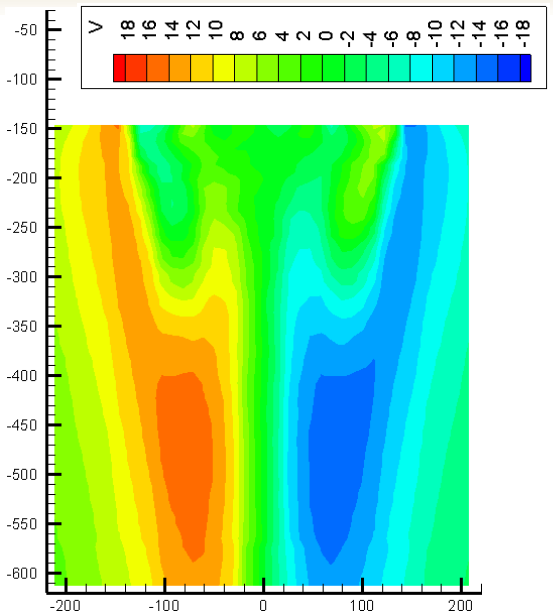
Z = + 194 mm

Z = +238 mm

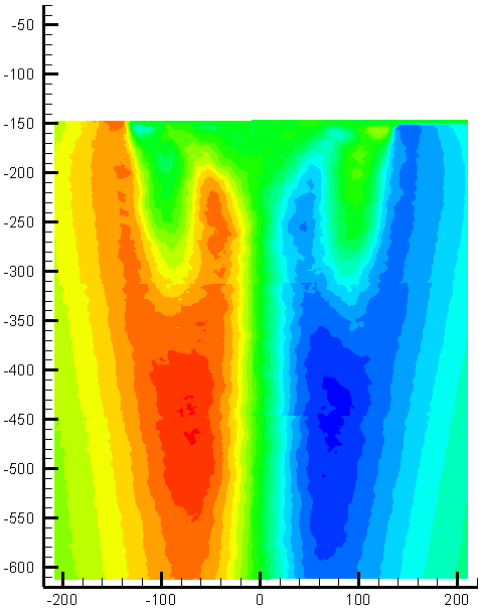
Z = + 335 mm



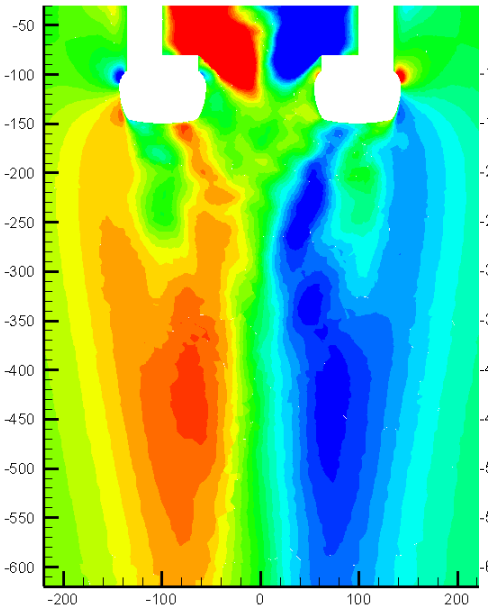
elsA



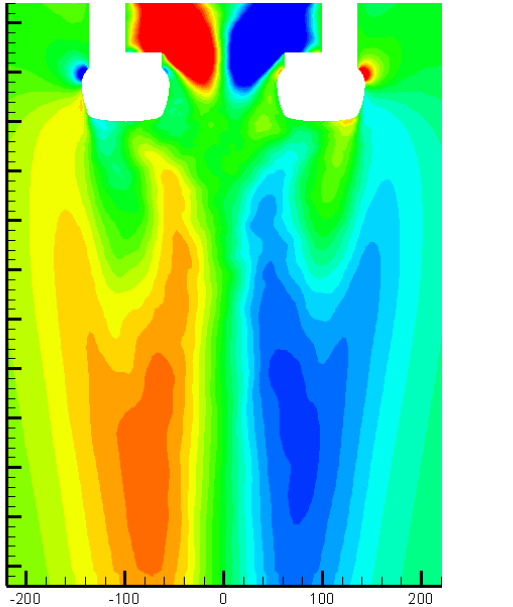
PowerFLOW



Experiment - PIV

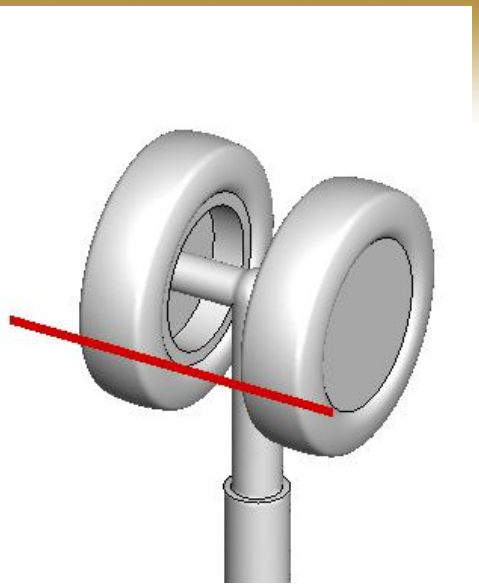


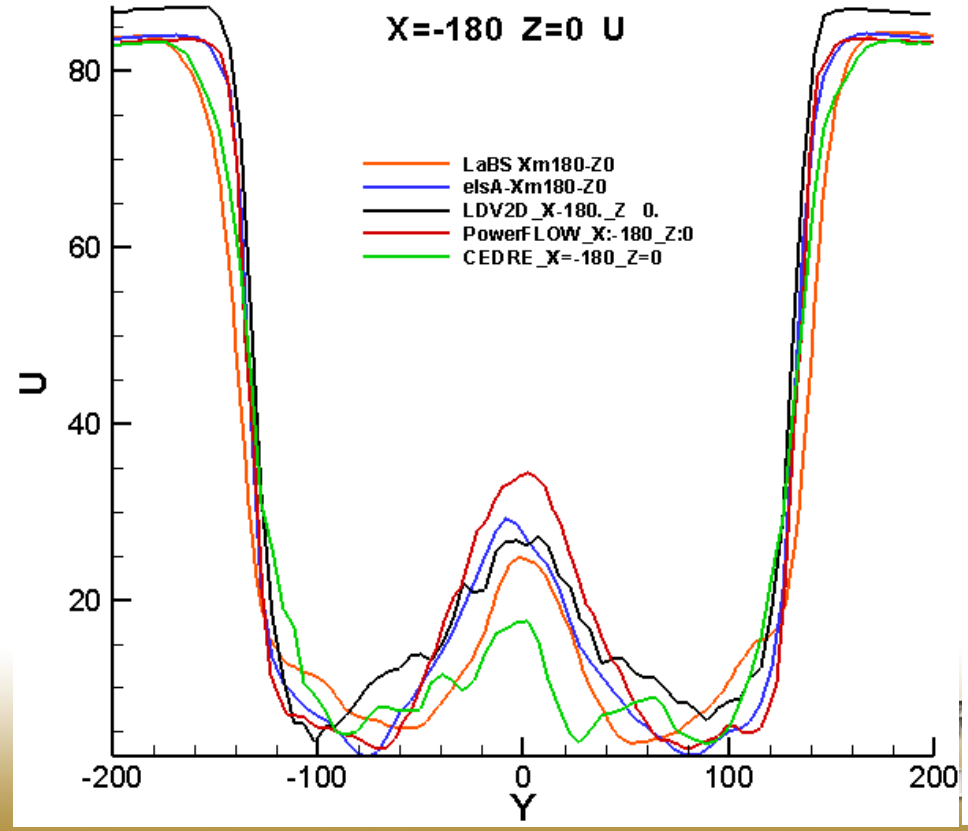
CEDRE

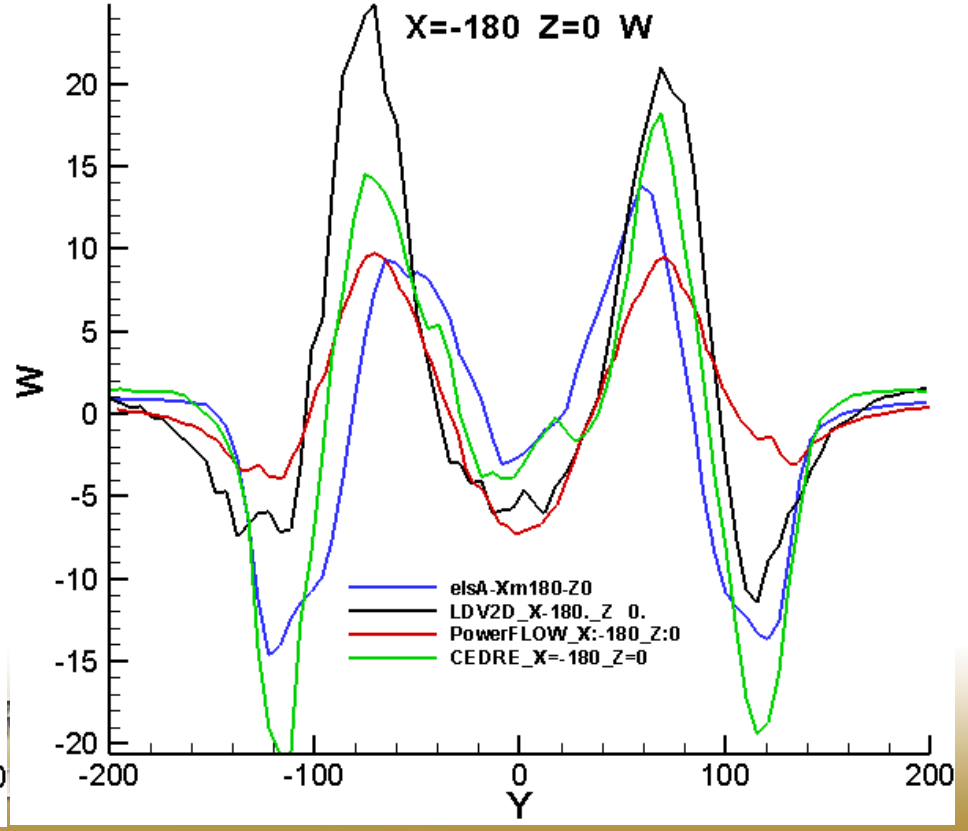


LaBS

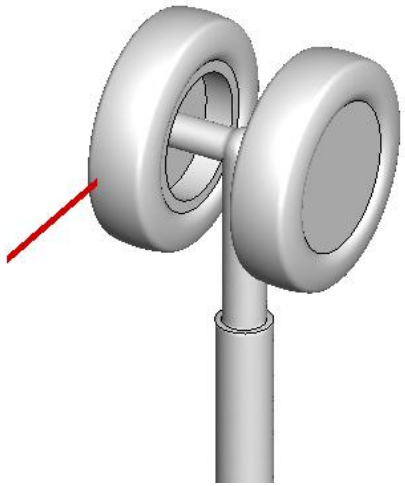
Velocity profile : Xm180_Z0
Mean U and W

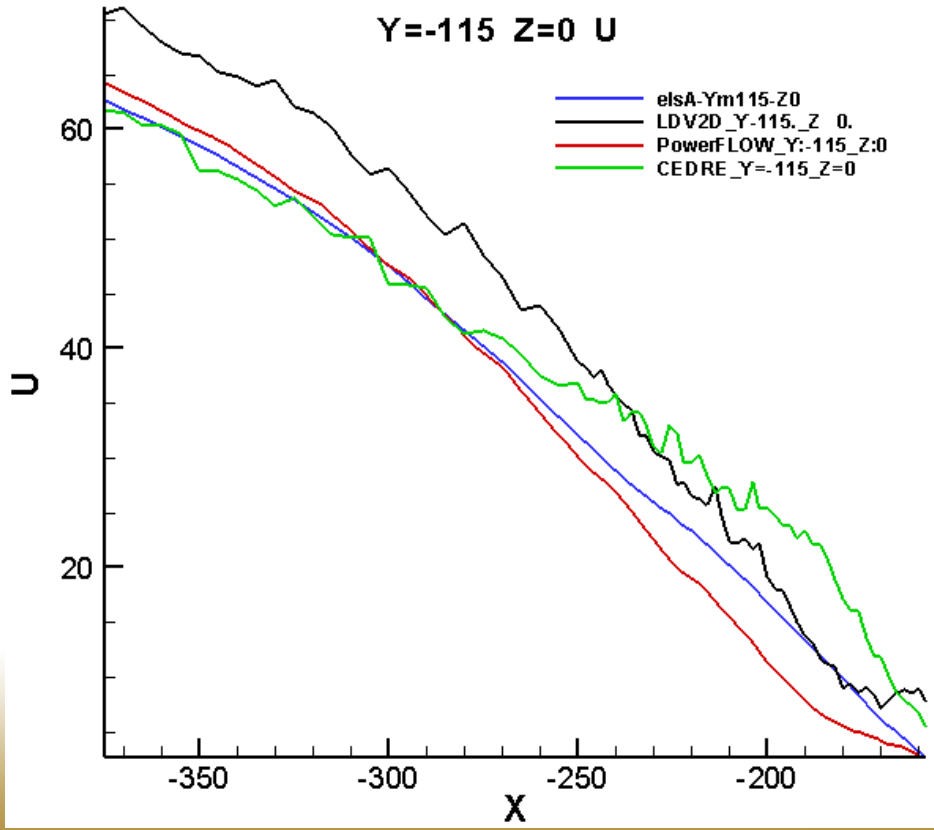


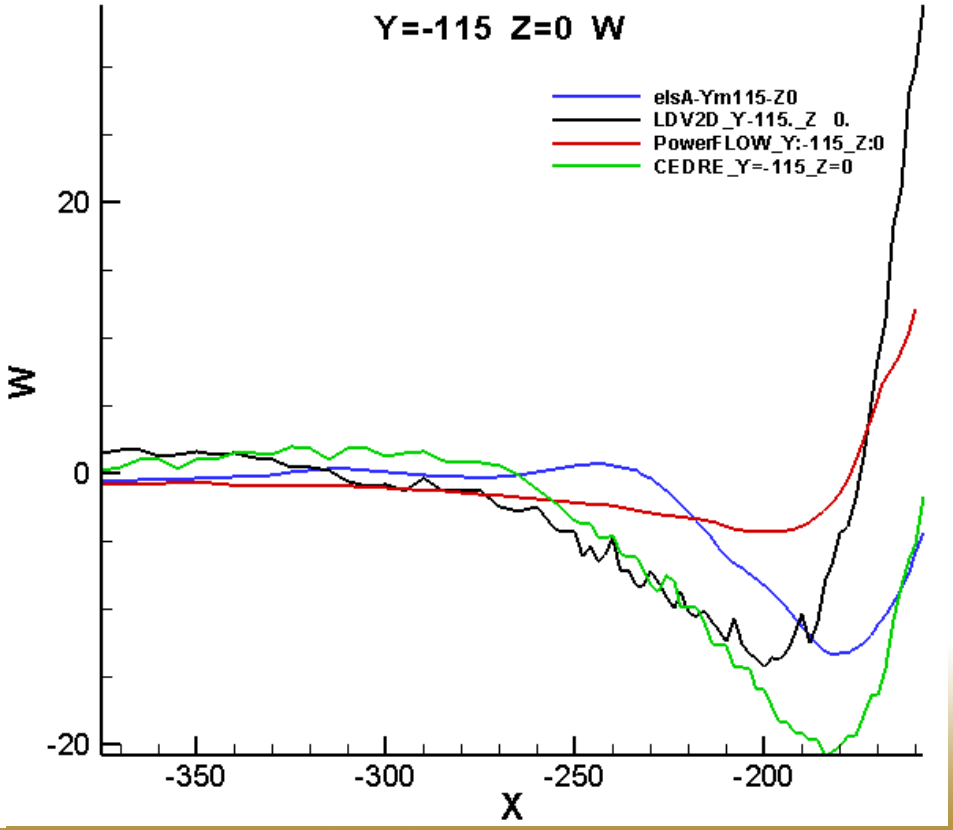




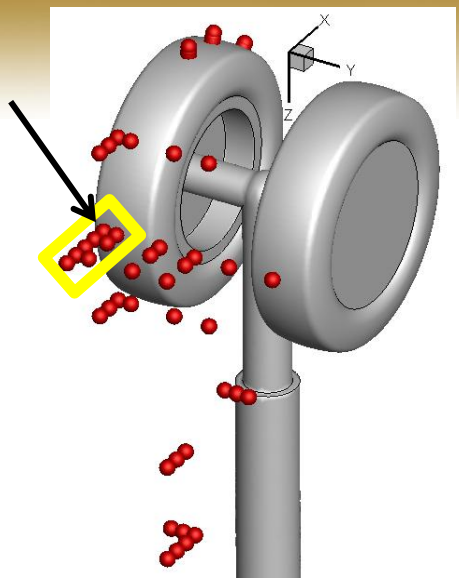
Velocity profile : Ym115_Z0
Mean U and W

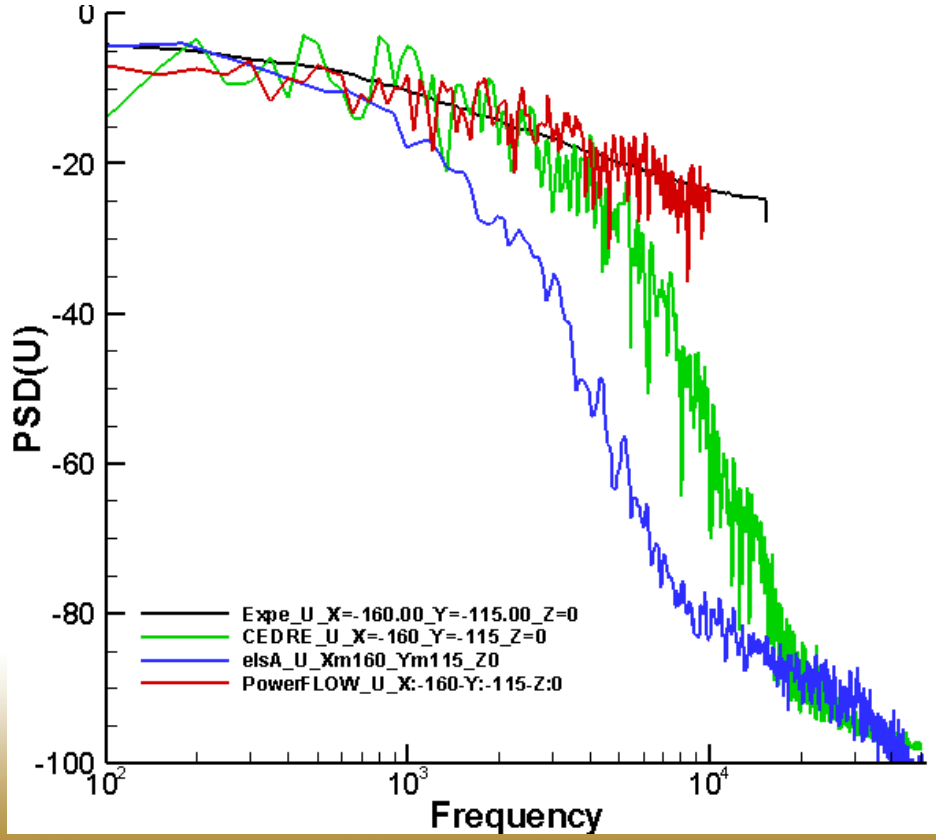


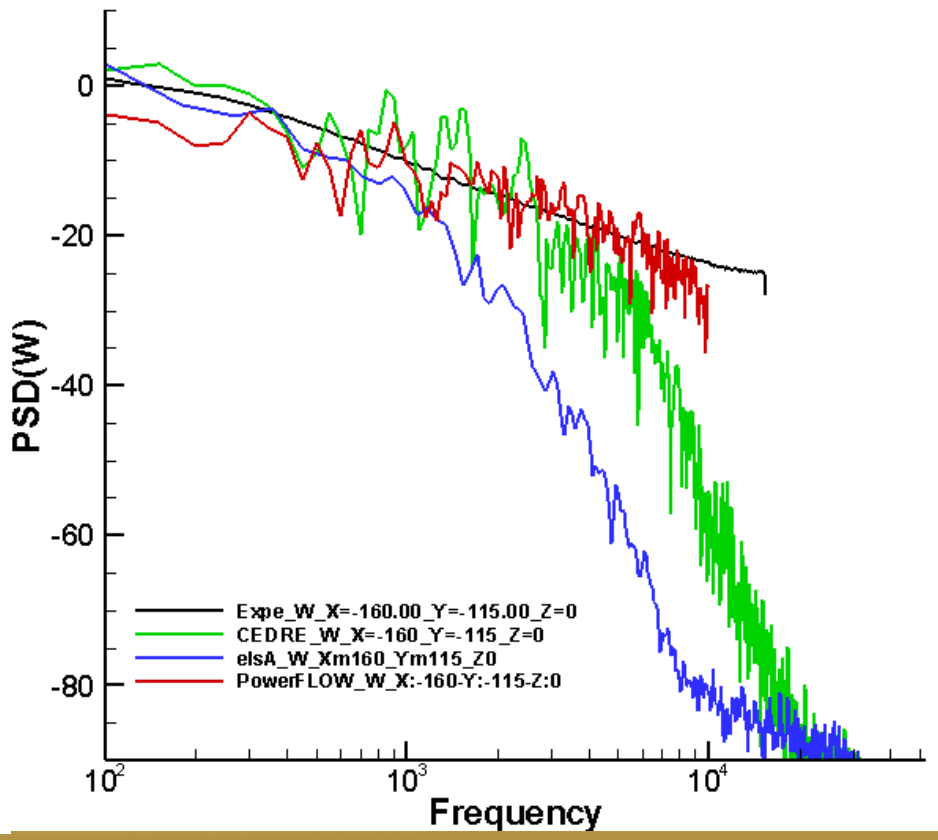




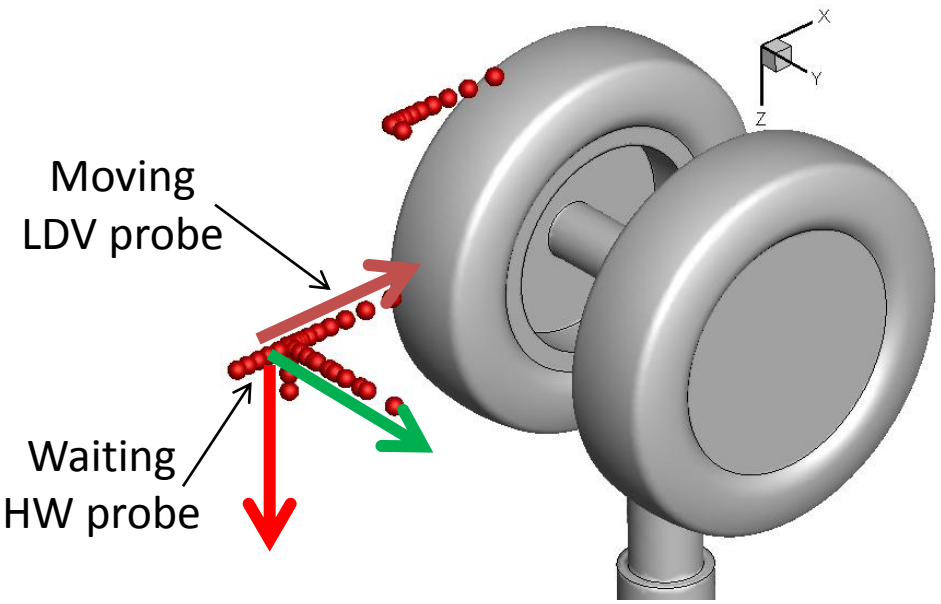
Velocity spectra : Xm160_Ym115_Z0
PSD(U) and PSD(W)

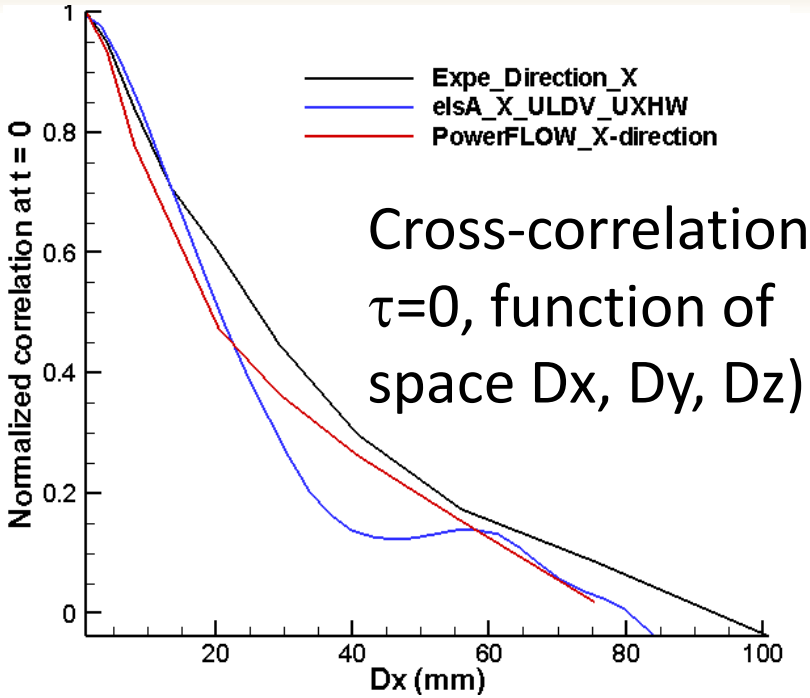






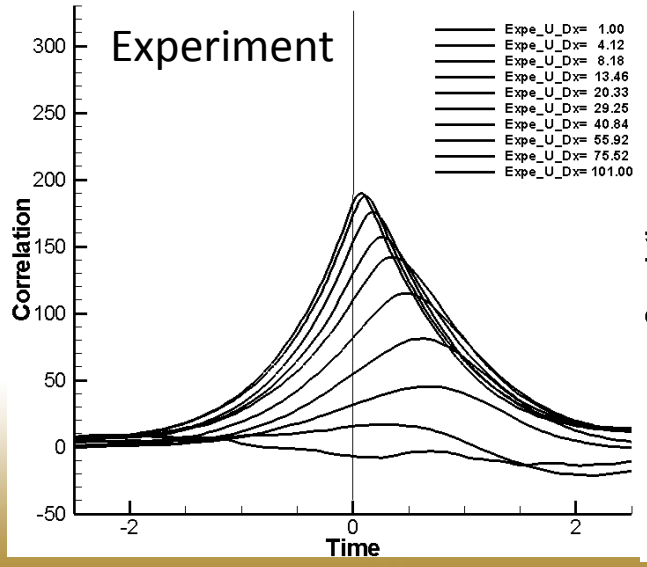
2-point (LDV2D-XHW) velocity measurements

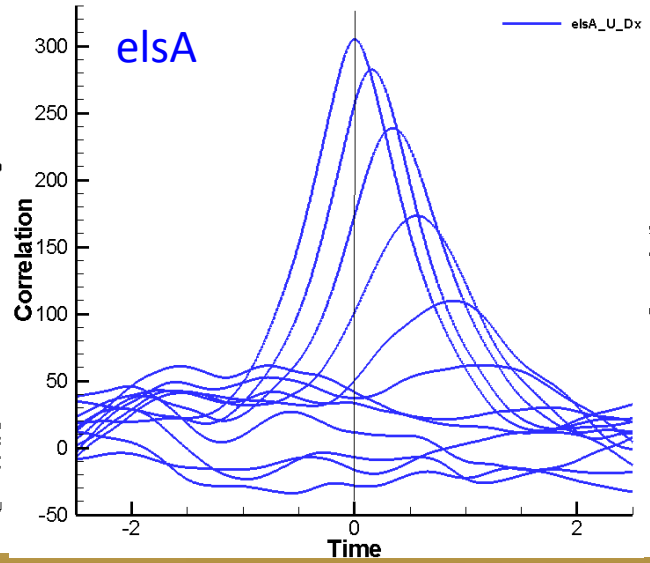


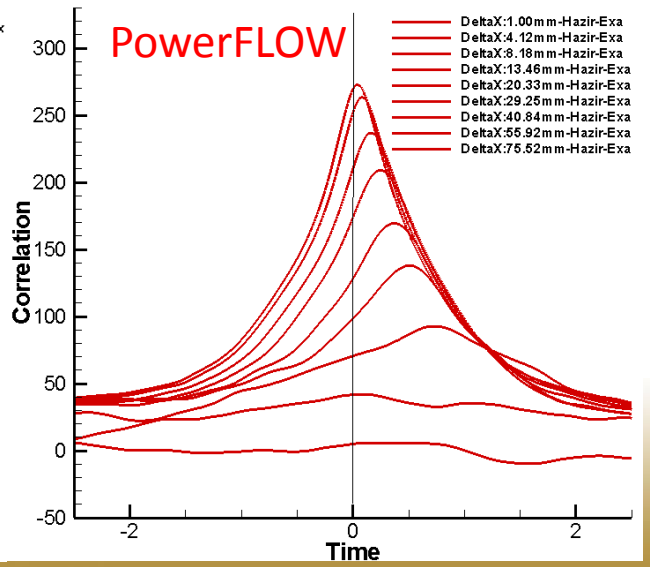


Cross-correlation at τ=0, function of space Dx, Dy, Dz)

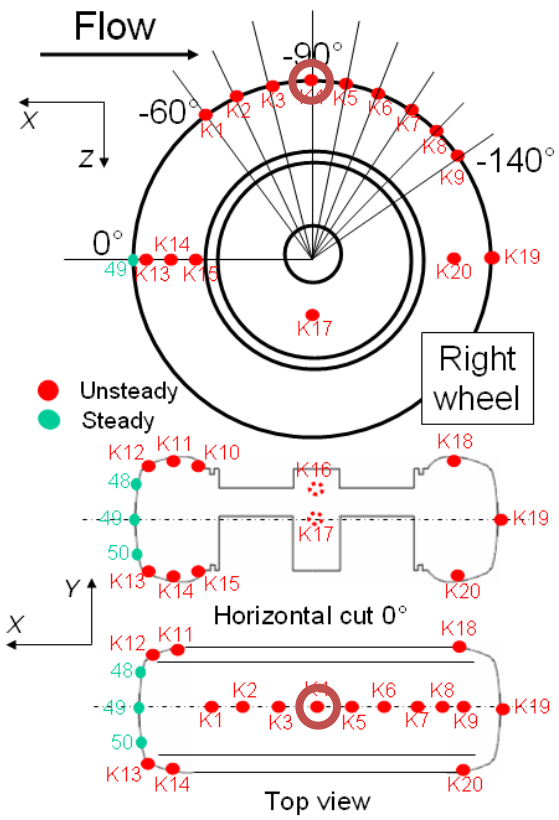
Time correlations for increasing space Dx

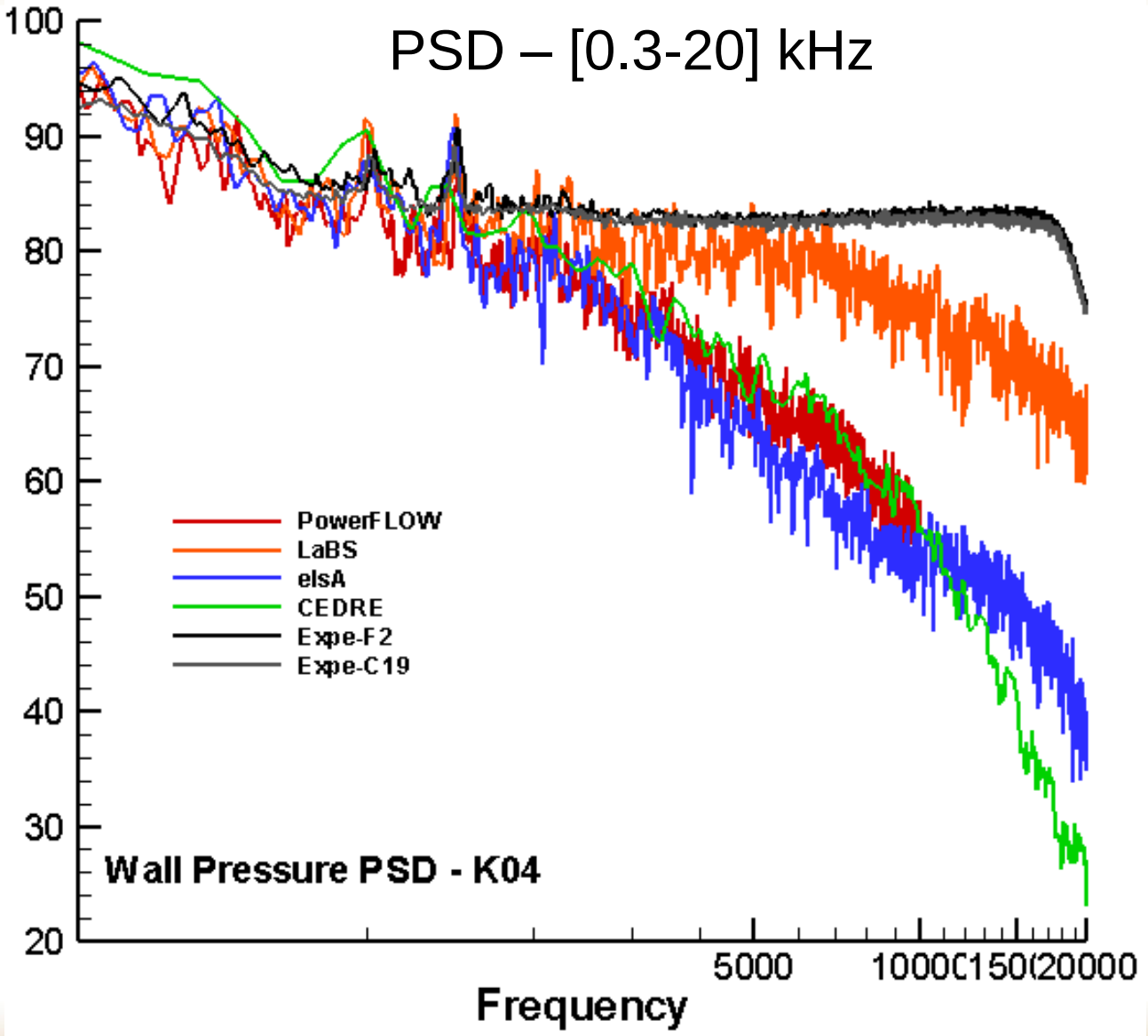




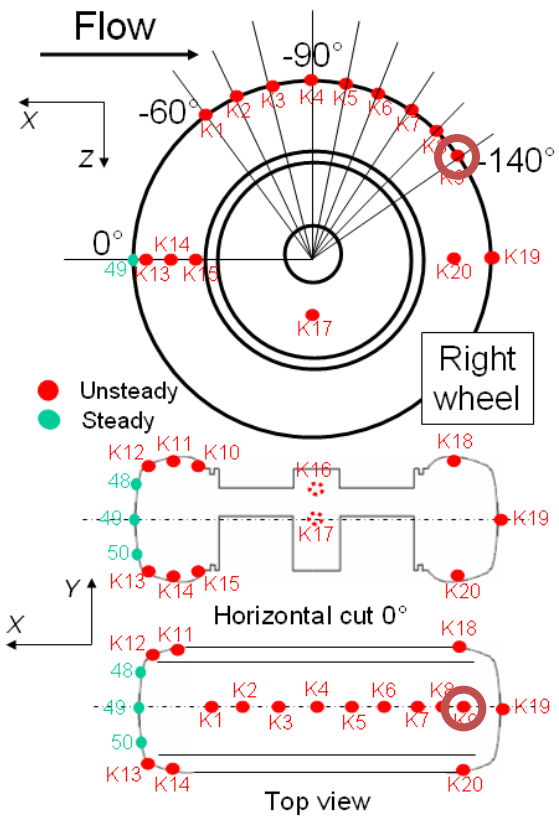


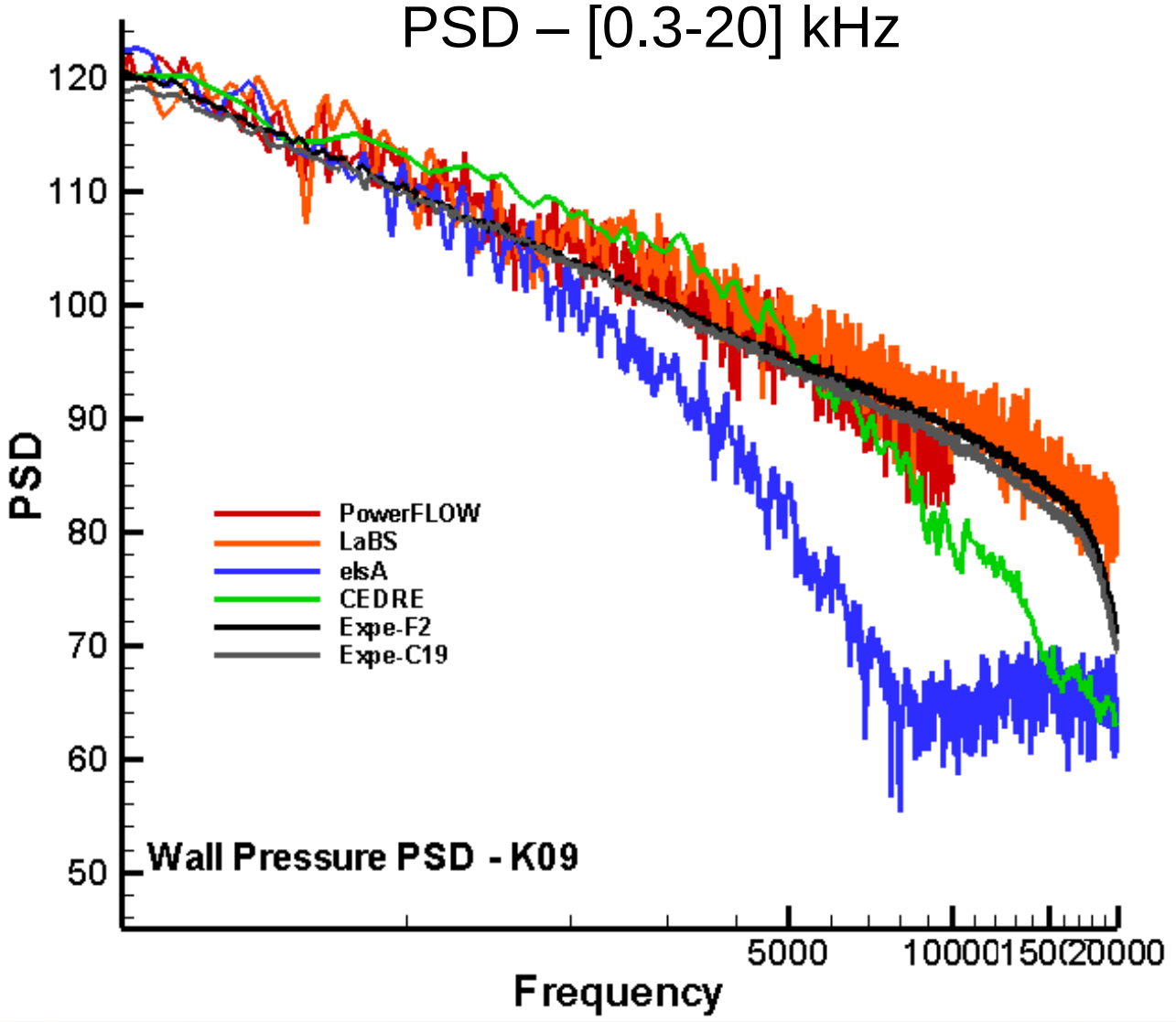
Wall pressure fluctuations PSD
Kulite #4



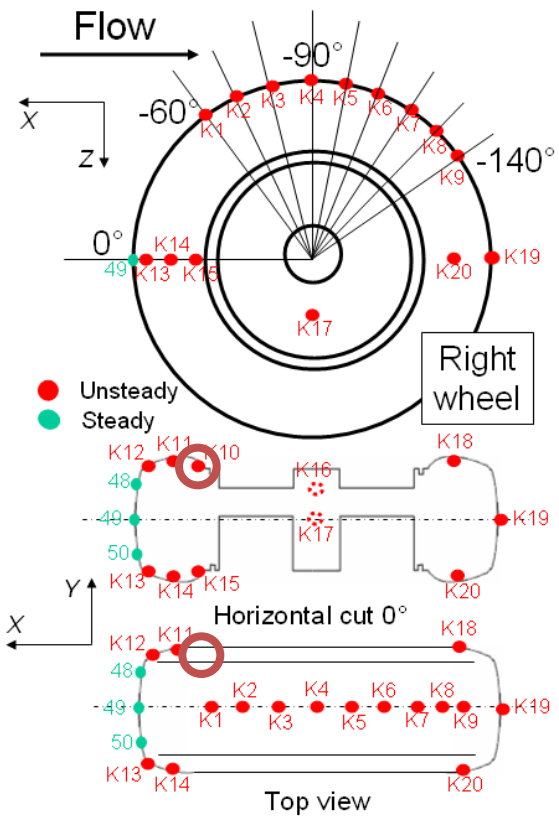


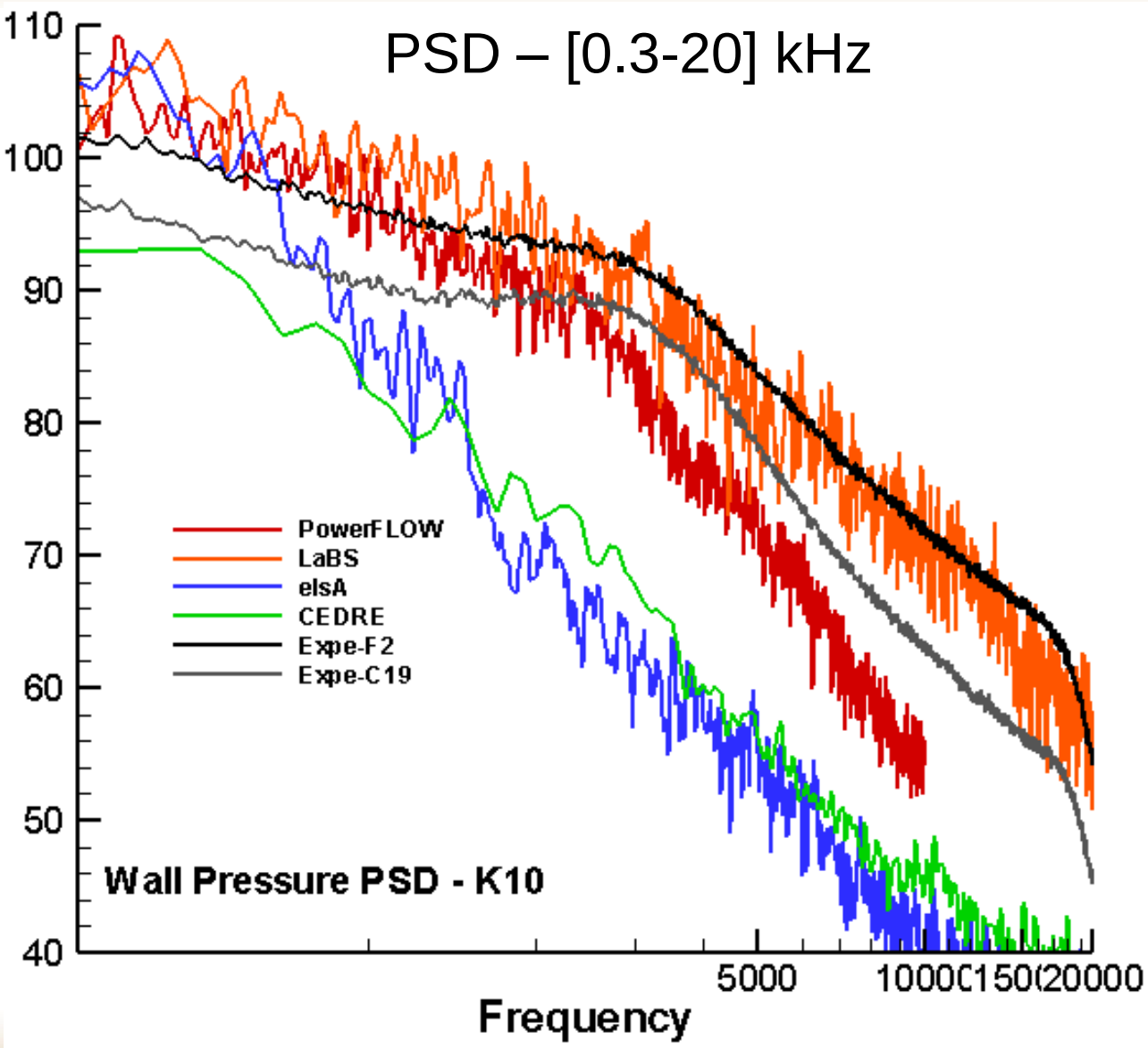
Wall pressure fluctuations
Kulite #9



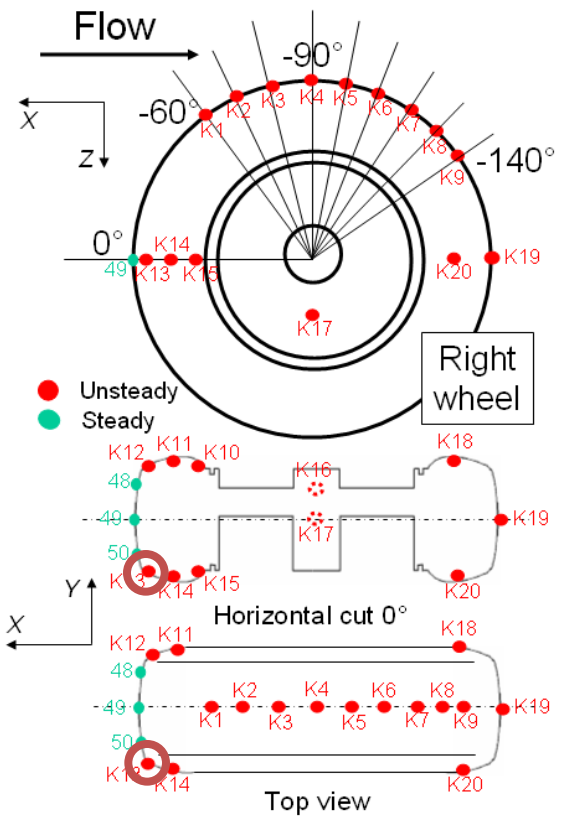


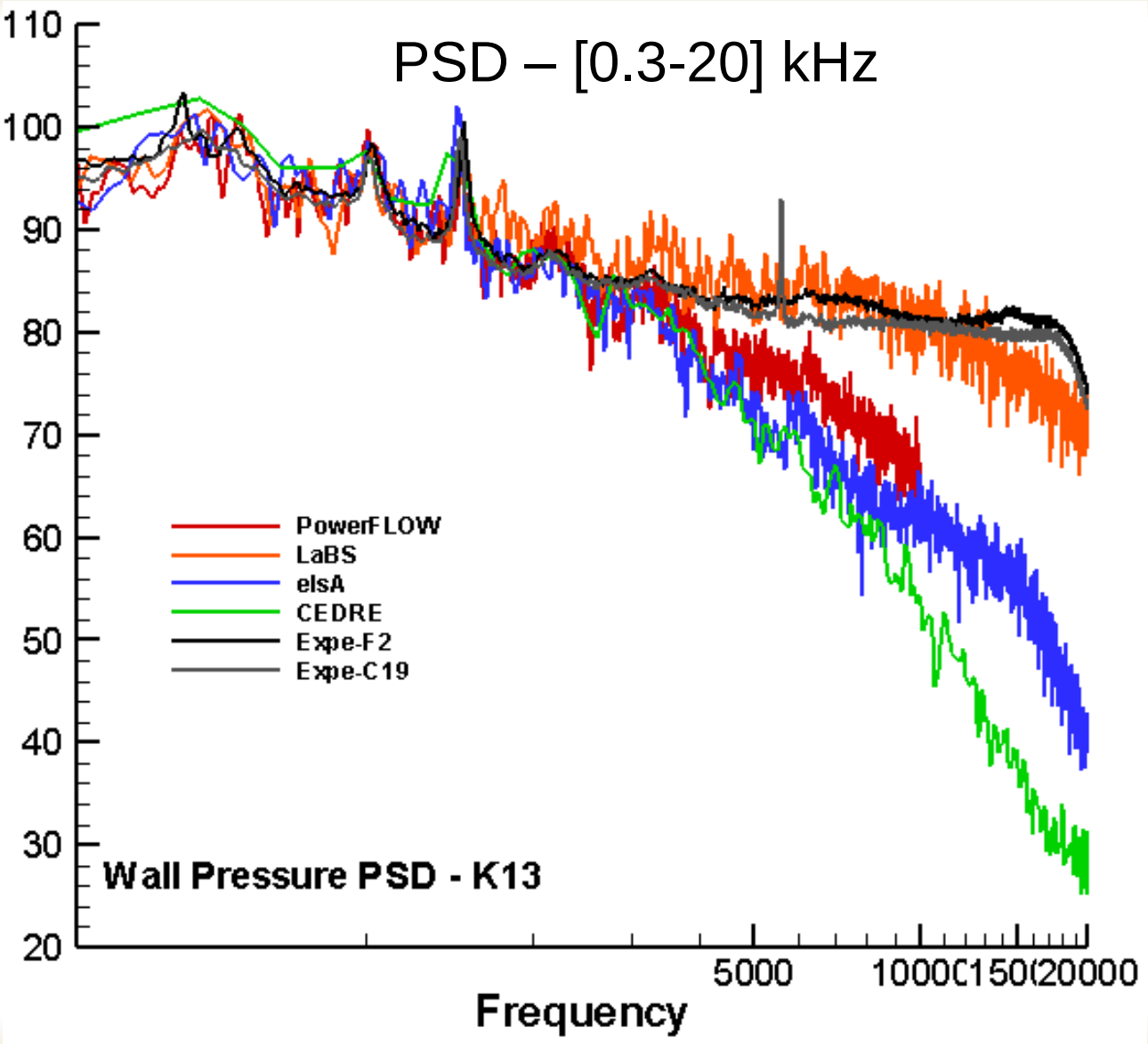
Wall pressure fluctuations
Kulite #10





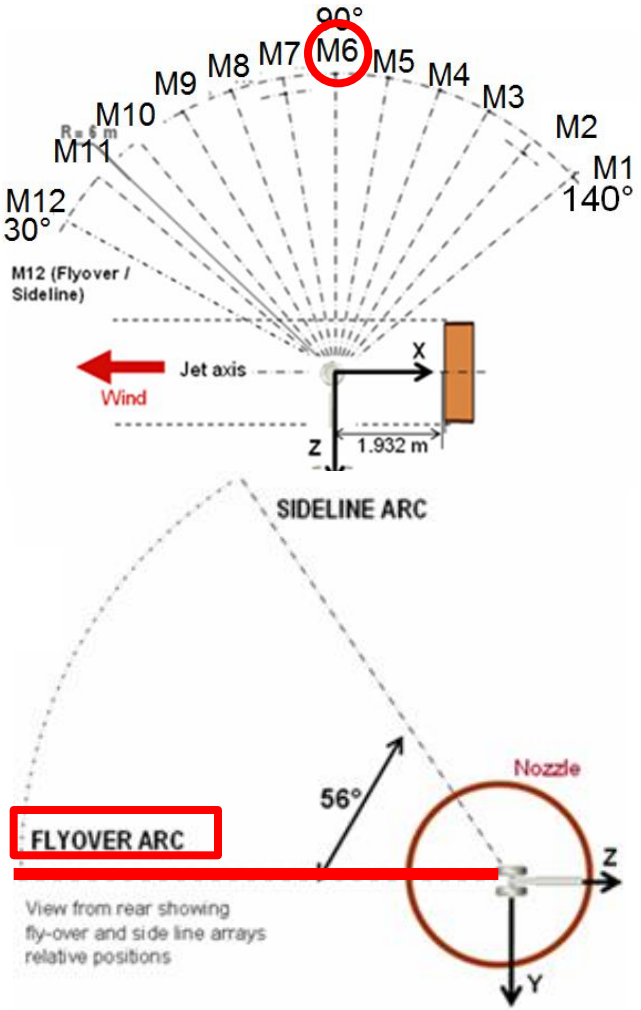
Wall pressure fluctuations
Kulite #13

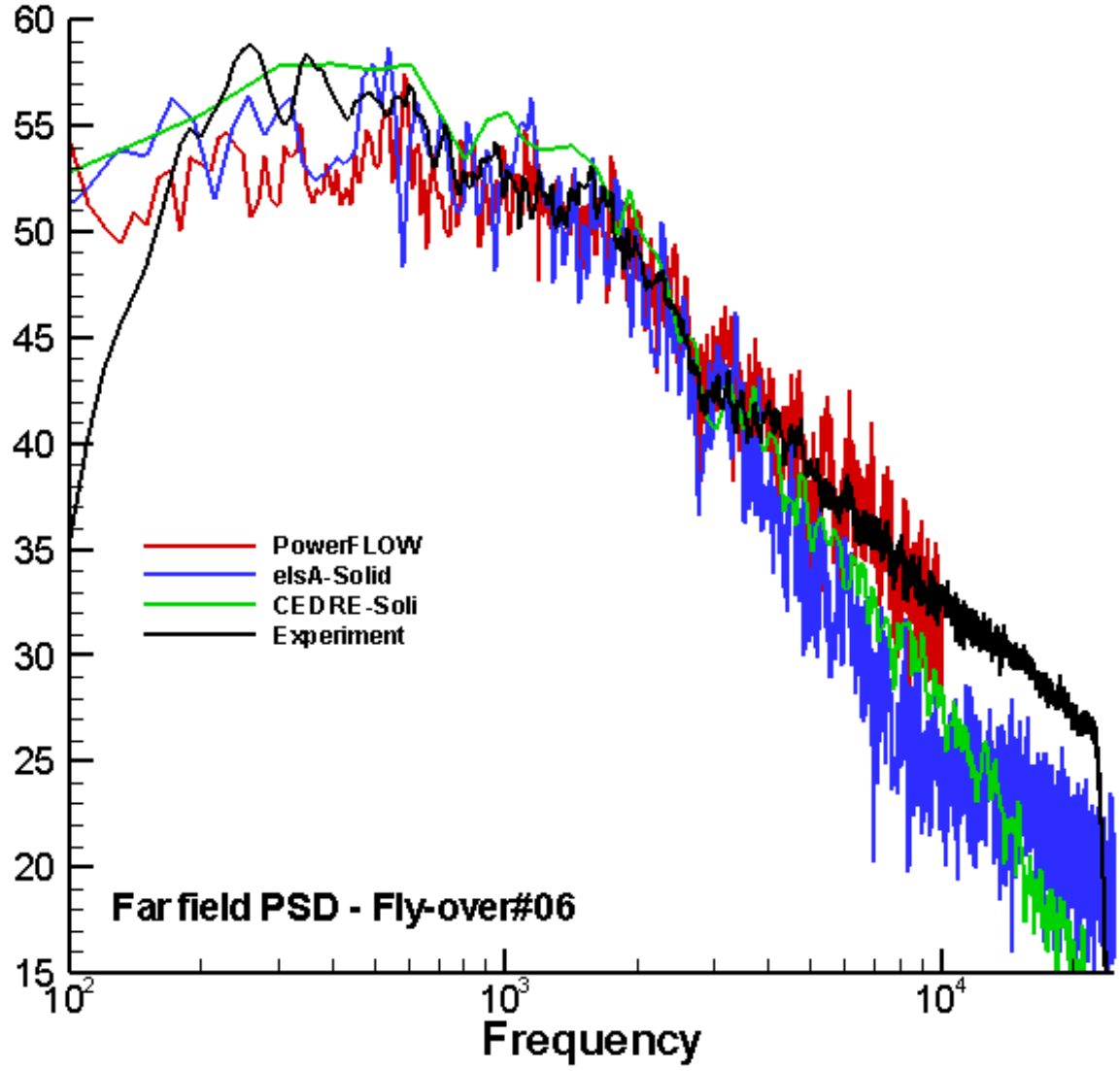




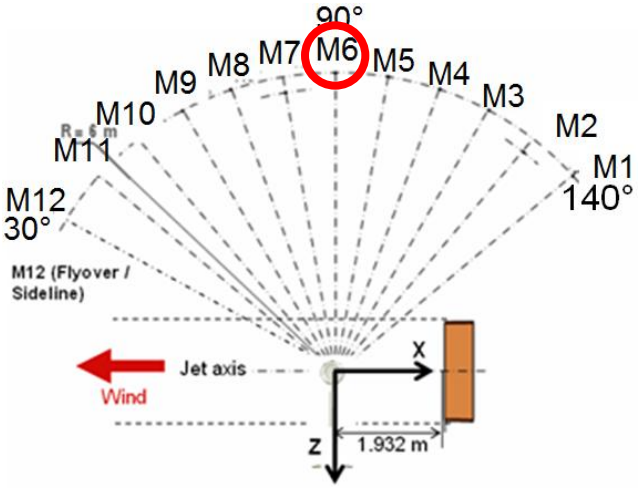
Farfield acoustics

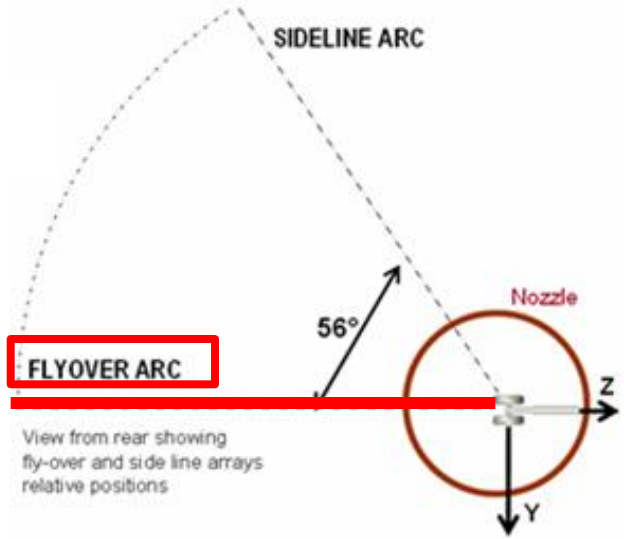
Farfield noise PSD - Flyover Microphone #6 (90°)

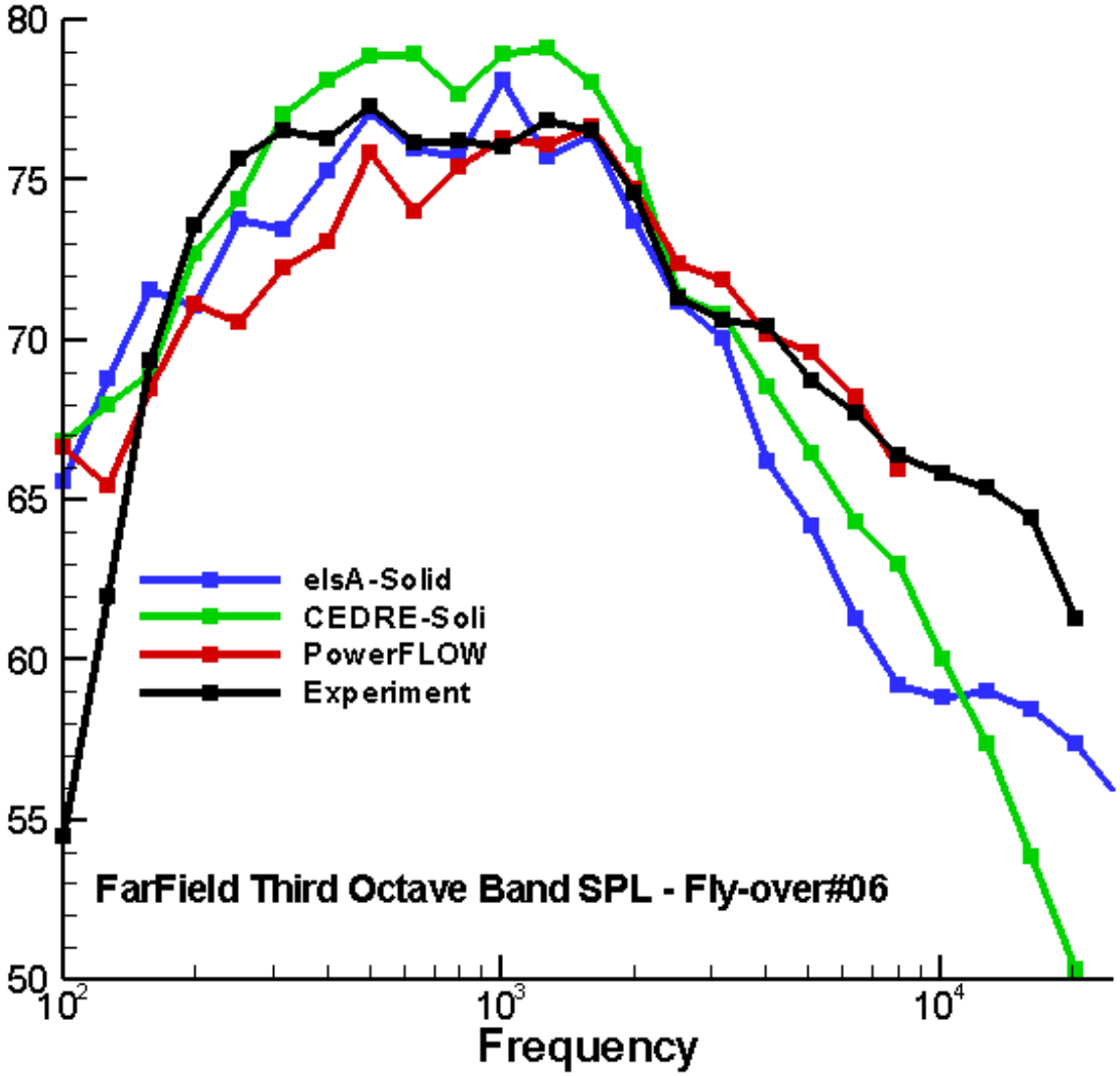




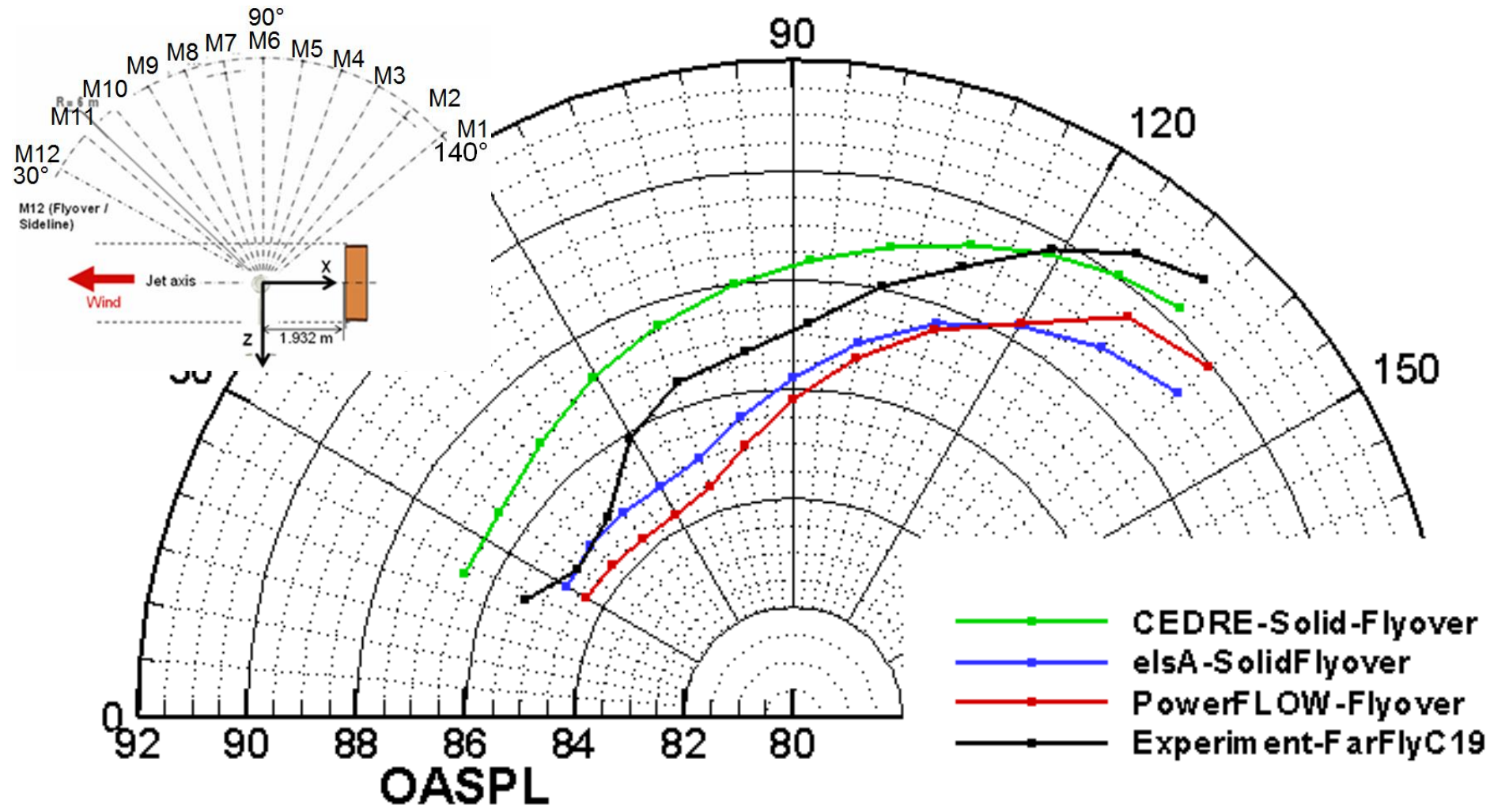
Farfield noise Third Octave Band SPL
Flyover Microphone #6 (90°)







OASPL (200 Hz – 10 kHz) directivity noise PSD
Flyover



Conclusion : what is the best method ?

- General fair agreement between predictions and experiments
  - … except in « sensitive » areas (large separations, intermittent events, …)
  - Sometimes significant dispersion of results …
  - Could be sufficient for acoustic prediction (all acoustic predictions are within 3-4 dB in the frequency domain of interest)… but CFD solvers should be in much better agreement !
- So, is there a best method ? A few hints :
  - Navier-Stokes solvers
    - Multiblock structured solvers: grid generation requires very long work and faces strong topology limitations, Chimera (overlap) techniques are an alternative, but also with inherent limitations
    - Unstructured solvers : good efficiency, but more work is required to validate precision
    - IBC could be the best alternative for NS solvers (structured/unstructured)
  - LBM solvers
    - Provide (i) the longest useful physical time with (ii) the shortest pre-process time and (iii) the shortest computational time, with (iv) globally good quality results
      → presently the best candidates for this particular aeroacoustic problem !

Call for participation to BANC-IV

- Participants to BANC-III synthesis
  - Onera (elsA)
  - NASA (CFL3D)
  - Southampton University (SotonCAA)
  - Onera (CEDRE)
  - Cerfacs (AVBP)
  - EXA (PowerFLOW)
  - Airbus (LaBS)
- We need more !
- Next session
  - BANC-IV, June 2-3 2016
  - Just after the AIAA-CEAS Aeroacoustics Conference in Lyon (France)
  - Database description and problem Statement available at: **https://info.aiaa.org/tac/ASG/FDTC/DG/BECAN_files_/BANCII.htm**