ONERA

THE FRENCH AEROSPACE LAB

retour sur innovation

LAGOON: An Experimental Database for the Validation of Landing Gear Noise Prediction Methods

Eric Manoha, Jean Bulté (ONERA)
Vlad Ciobaca (DLR)
Bastien Caruelle (Airbus-France)

13th CEAS-ASC Workshop & 4th Scientific Workshop of X3-Noise
Resolving Uncertainties in Airframe Noise Testing and CAA Code Validation
1-2 October 2009, Bucharest

ONERA
THE FRENCH AEROSPACE LAB

DLR

AIRBUS

retour sur innovation

Outline

- Context
- LAGOON : objectives and overview
- The LAGOON model
- Experimental set-ups and programmes
  - F2
  - CEPRA19
- Mean flow identification F2/CEPRA19 (3D RANS CFD by DLR)
- Steady/unsteady aerodynamic measurements
  - Overview of F2 measurements
  - Limited comparison F2/CEPRA19 (on-board sensors, 5-hole probe)
- Acoustic measurements
  - « Signal-to-noise ratio » in CEPRA19 – F2
  - Early use of microphone antenna in both facilities
- Conclusions

Context

- Numerical simulation of airframe noise → landing gear
- Existing tools available to airframer : analytical or semi-empirical prediction methods, working at global aircraft level, but calibrated over existing aircraft, and consequently restricted to conventional configurations
- Emergent hybrid CFD/CAA methods based on :
  - Unsteady CFD (LES, DES) using structured/unstructured grids
  - Numerical acoustics (integral methods, CAA)

  should efficiently complement existing tools to
  - Improve understanding of noise generation and radiation mechanisms
  - Predict noise from all contributing components (absolute value of radiated acoustic energy)
  - → Contribute to design low noise components
- But : only partially validated, mostly by comparison with available analytical solutions (propagation) or (incomplete) experimental data
- Strong need for reliable high quality experimental database for validation

Objectives of the LAGOON project

Airbus answers to this need by funding the LAGOON project
LAnding Gear nOise database and CAA validatiON

Objectives/approach

- Design / manufacture a dedicated two-wheel landing gear model
  - Simple generic shape (adapted to large range of modelling techniques)
  - Modular structure (for further increasing complexity using add-on parts)
- Achieve a two-step experimental program :
  - Unsteady / steady aerodynamic measurements in ONERA's ***F2*** closed section, aerodynamic windtunnel for CFD validation (noise source generation)
  - Aeroacoustic measurements in ONERA's ***CEPRA19*** anechoic, silent, open-jet windtunnel for CAA validation (noise propagation in non-uniform flow)
  - Checking that flows in both WTs are rather identifical (steady CFD computations by DLR, on-board static pressure taps)
- Perform computations with available CFD/CAA, then compare and assess the results with experimental data

Overview of the LAGOON project

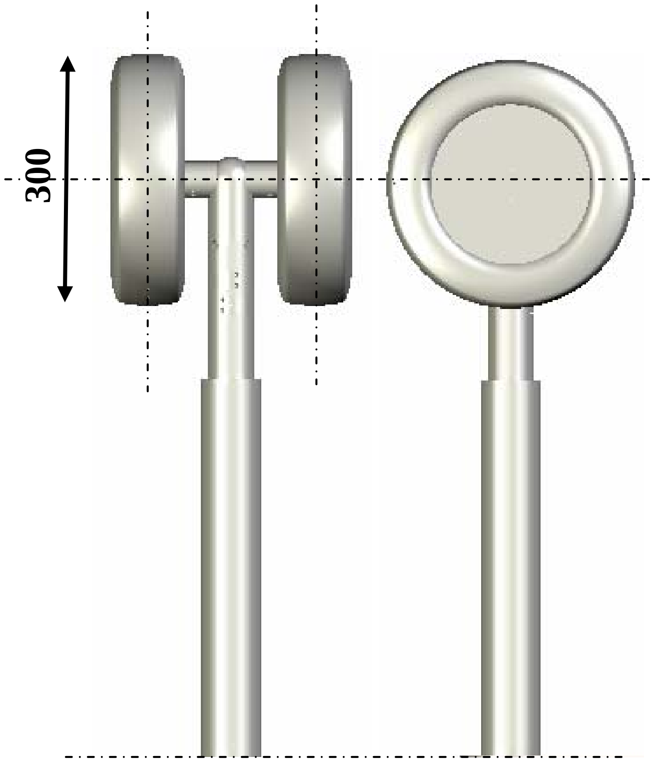
- Partnership
  - Airbus-France (Project Funding and Manager – B. Caruelle)
  - ONERA (experimental program, CFD/CAA activities)
  - DLR (CFD in support of experimental program, CFD/CAA activities)
  - Southampton University (CFD/CAA activities)
  - Airbus-UK (technical advisor)

- Planning and main milestones (2006-2010)
  - Model design and manufacture (2006)
  - CFD in support of experimental program (2006-2007)
  - Aerodynamic tests (june 2007) → AIAA-2008-2816
  - Aeroacoustic tests (april 2009) → AIAA-2009-3293
  - CFD/CAA activities (2008-2010)

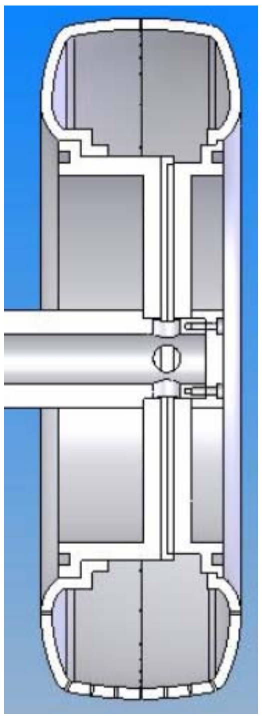
The LAGOON model

- General shape
- Onboard instrumentation

LAGOON simplified nose landing gear model



CAD views

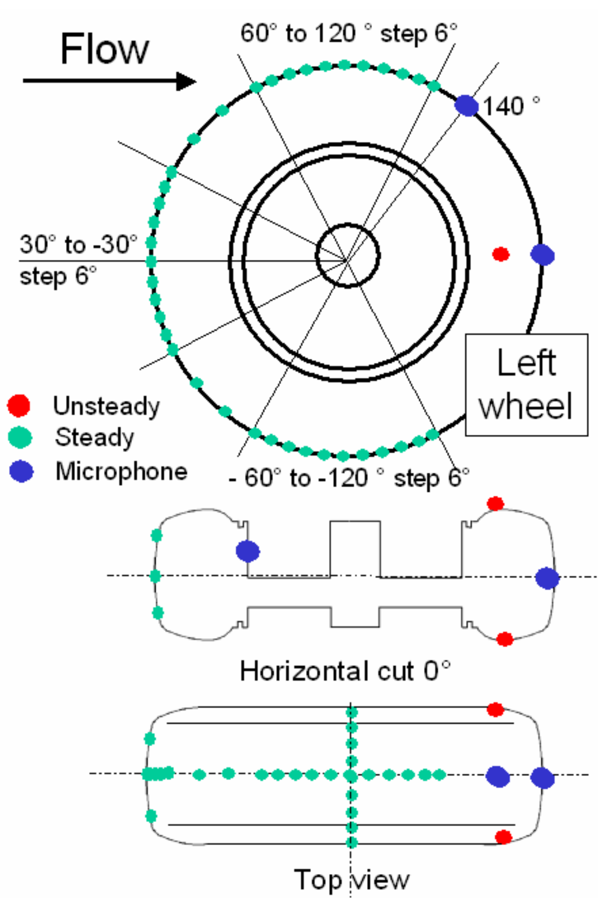


Wheel section

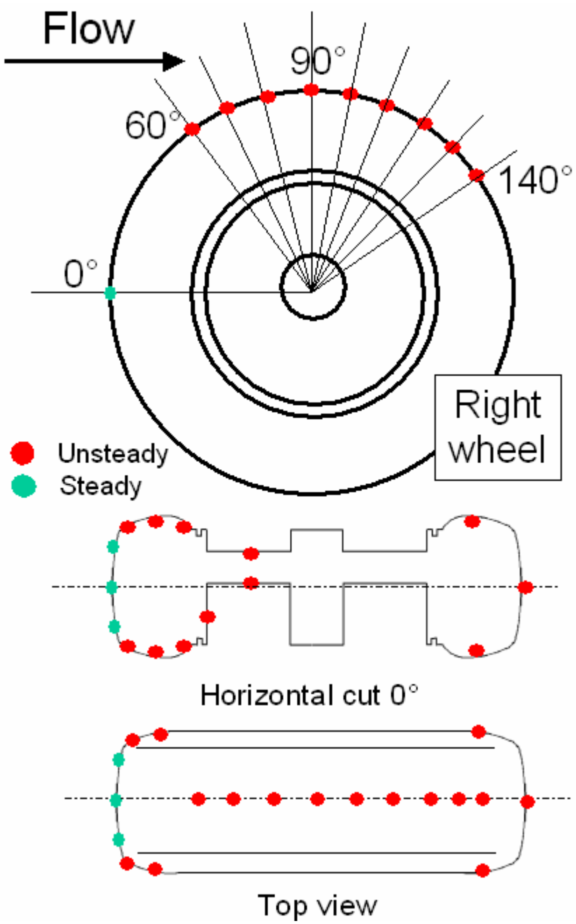
Wheel diameter : 300 mm
Scale : 40 % of Airbus A320 NLG
Blockage coefficient < 6 % in F2
Yaw angle range : ± 15°

Onboard instrumentation

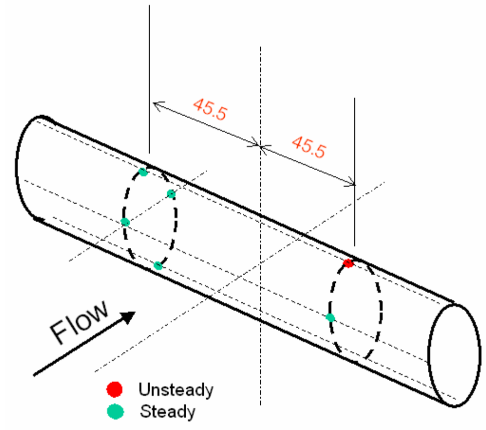
- 64 static pressure taps
- 27 Kulite unsteady pressure transducers
- 2 microphones (¼'')



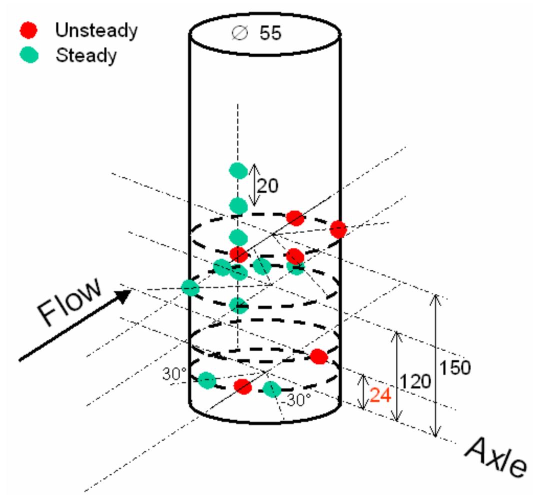
Left wheel



Right wheel



Axle



Main leg

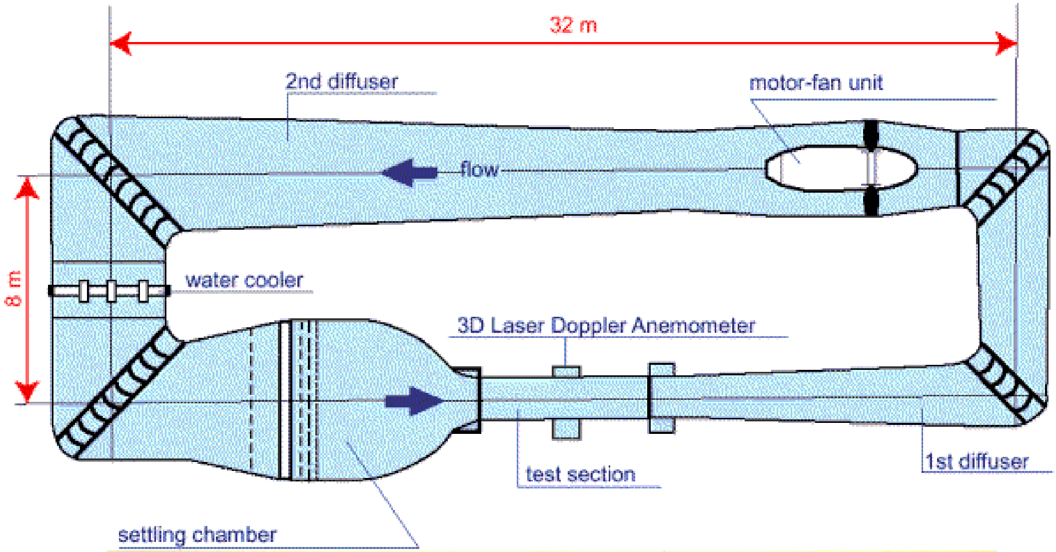
DLR AIRBUS ONERA THE FRENCH AEROSPACE LAB

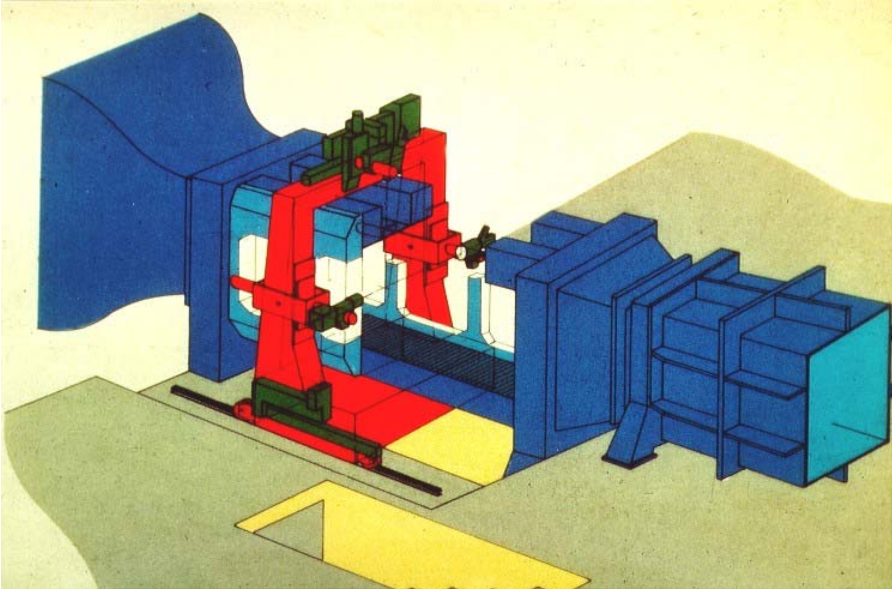
Experimental set-ups and programmes

- *F2* closed section aerodynamic WT
- *CEPRA19* open-jet aeroacoustic WT

F2 aerodynamic windtunnel

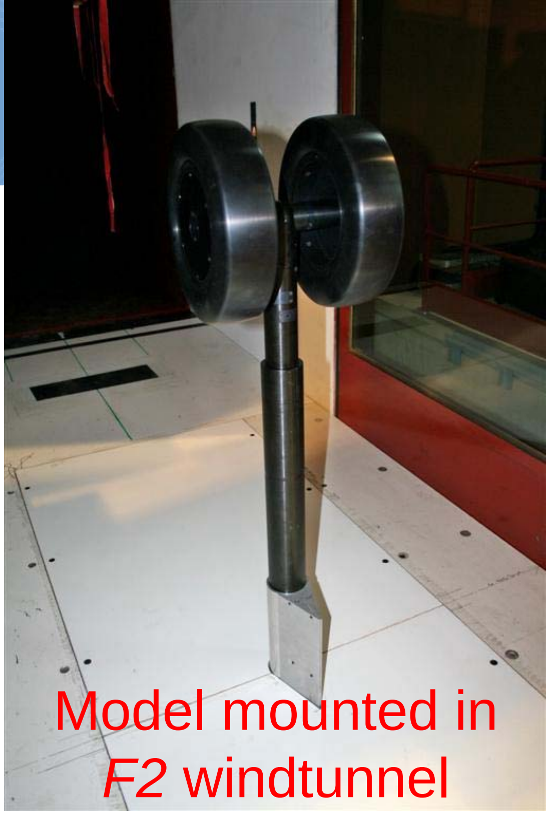
- **Research facility** - large size models
- Test section dimensions : **Length = 5 m, Width = 1.4, Height = 1.8 m**
- 12 bladed fan (680 kW)
- Velocity from 0 to **100 m/s**
- Total temperature control by a water cooler (± 1°C)
- **Low level of turbulence** in the test section (less than 0,05 %)
- **Built-in optical device support system**
  - LDV : 3 velocity components
  - Mobile frame : whole test section accessible in a volume of X = 0.5 m, Y = 0.6 m, Z = 1 m
  - Seeding of the flow by incense smoke
  - Special treatments for unsteady measurements
- **Wall support for probes** (DS4) with four degrees of freedom





LAGOON experimental program in F2

- Preliminary tests
  - Boundary layer transition artificial tripping
  - Vibration tests
- Flow conditions
  - Mach numbers 0.10, 0.13, 0.15, 0.18, 0.20, 0.23, 0.25, 0.28
  - Yaw angles -12.5° to +12.5° every 2.5°
- Mean flow survey (Yaw 0° & 5° only)
  - Static pressure taps
  - 2D PIV
  - 2D and 3D LDV
  - 5-hole probe (for comparison with CEPRA19)

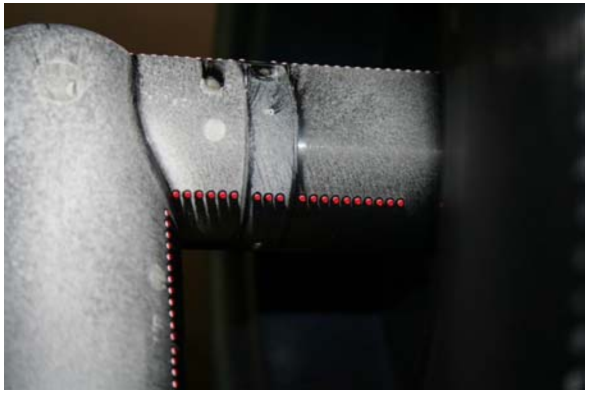


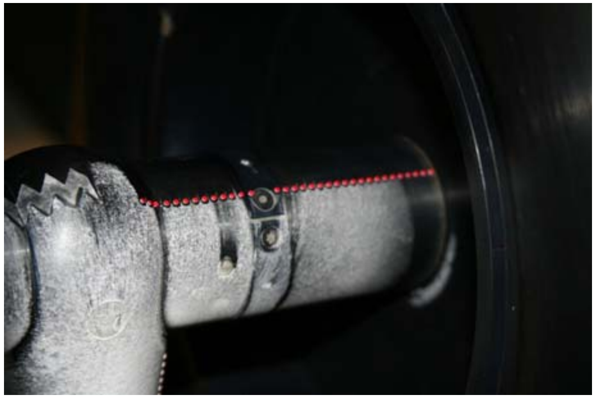
- Unsteady flow survey
  - Unsteady wall pressure transducers
  - 2D and 3D LDV
  - Cross Hot Wire probe (XHW) combined with unsteady 2D LDV (2-point measurement)
- Acoustic measurements using a wall-mounted acoustic antenna

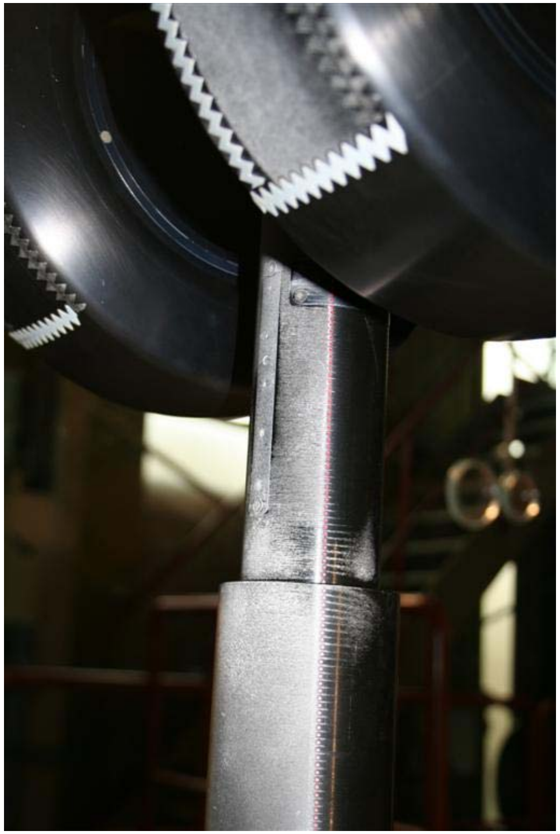
PIV-LDV only at M = 0.18 and 0.23
Yaw = 0° and 5°

Boundary layers transition artificial tripping
Visualizations using acenaphten in F2

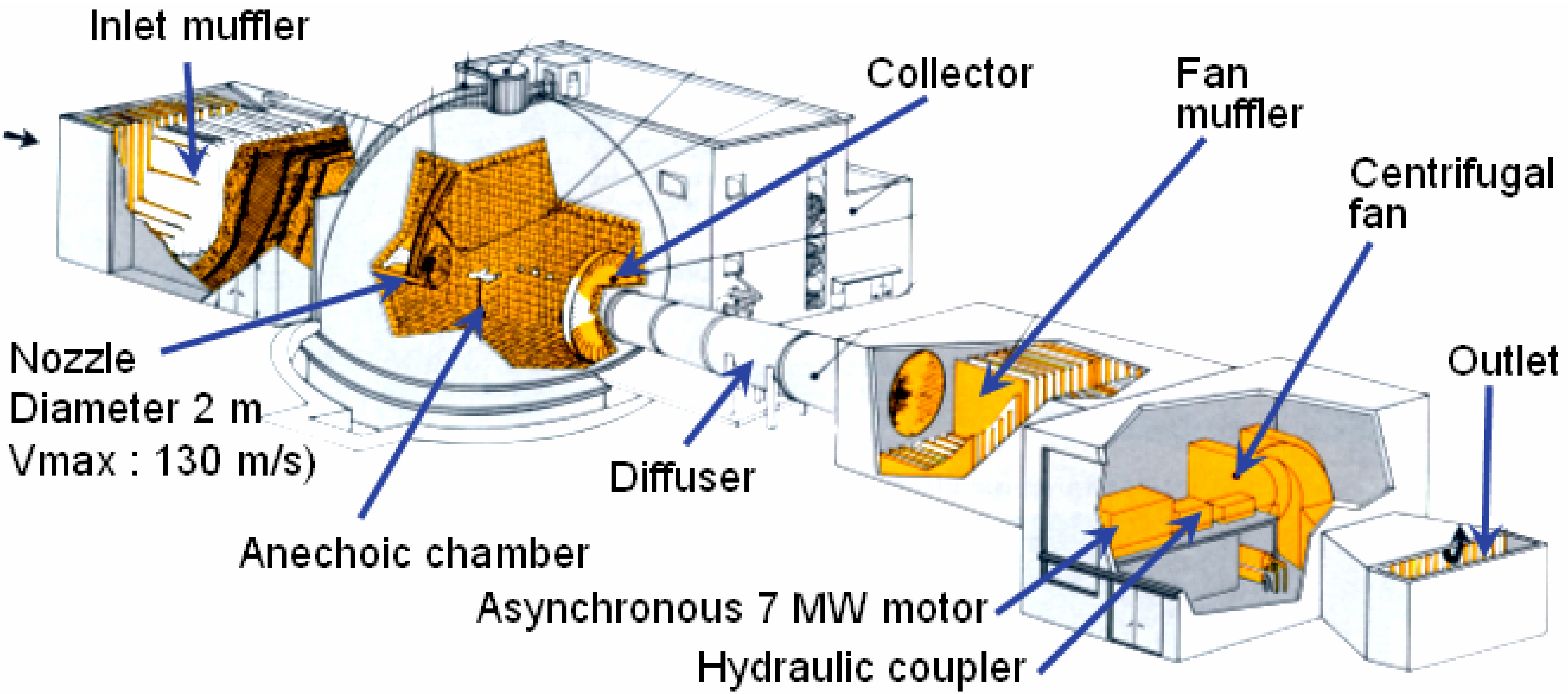
- Motivation : CFD validation requires to know the exact position of transition
  → tripping device required on wheels, axle, main leg
- 4 successive acenaphen visualizations to adjust position and nature of device
- Combination of « Zig-Zag » (on wheels) and « CAD-CUT » (on cylinders) device



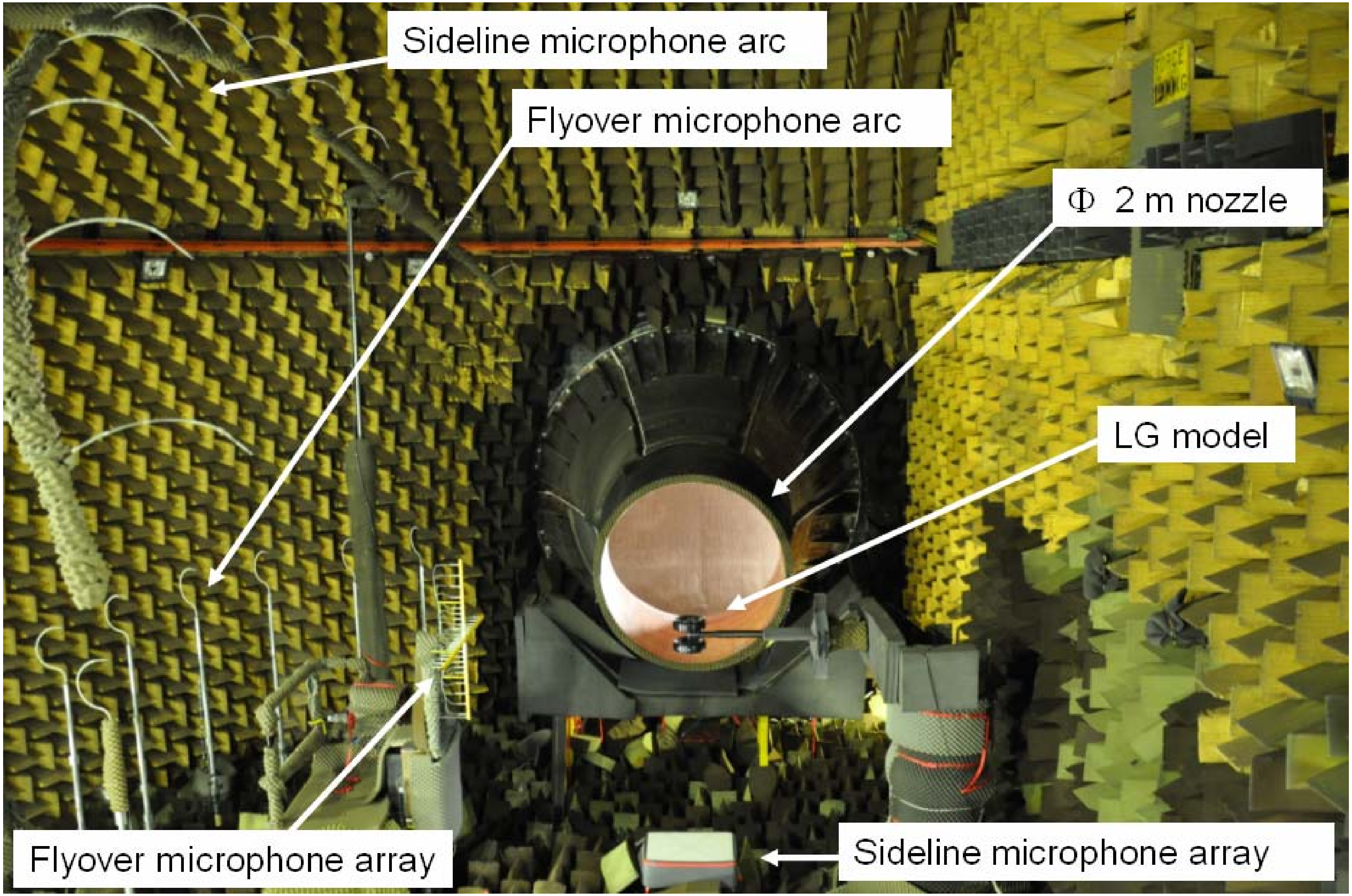




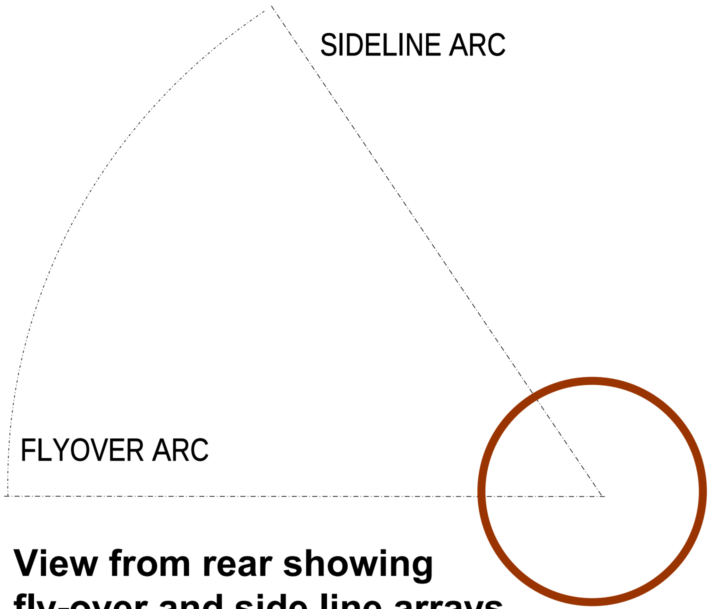
CEPRA 19 aeroacoustic windtunnel



LAGOON set-up in CEPRA 19



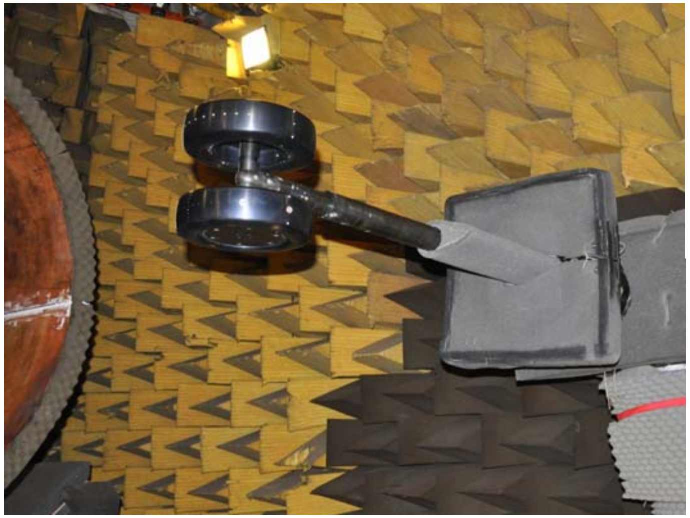
LAGOON set-up in CEPRA 19
Acoustic instrumentation : total 156 channels



View from rear showing fly-over and side line arrays relative positions

Two (flyover/sideline) arcs of 12 farfield microphones at distance 6 m

Flyover 41-microphone antenna



LAGOON model

Sideline 58-microphone antenna

Distance 2 m

LAGOON CEPRA19 experimental program : tested configurations

- Model geometries
  - **Full model**
  - Main leg only
  - Empty WT (background noise)

- Yaw angles
  - **+5°, 0°,** -5°

- Wind velocities
  - Mach numbers 0.10, 0.13, 0.15, **0.18**, 0.20, **0.23**, 0.25, 0.28

Note : **bold values** : flow conditions

1) for detailed aerodynamic measurements in F2
2) to be computed with unsteady / CAA in the project

Flow identification F2 / CEPRA19

- **RANS CFD including installation effects**

Flow identification (CEPRA19 / F2) using CFD
Objective, numerical approach, grids, computations

Objective

To compute the F2/CEPRA19 mean flows including all aerodynamic installation effect

CFD approach

- **Code : TAU (DLR)**
- **Numerical method : RANS**
- **Model turbulence : two-equation Menter SST k-ω**
- **Grid : unstructured**

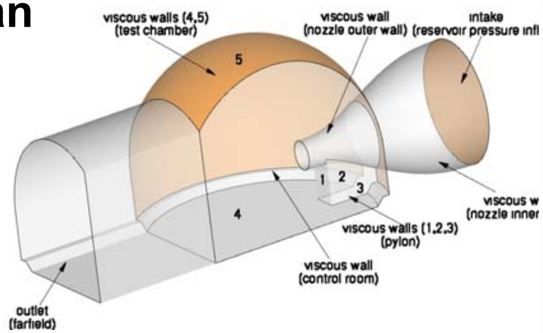
Grids size

- **Landing gear : 4.5 Mpoints**
- **F2 (closed) WT : 4 Mpoints**
- **CEPRA19 (open) WT : 8 Mpoints**

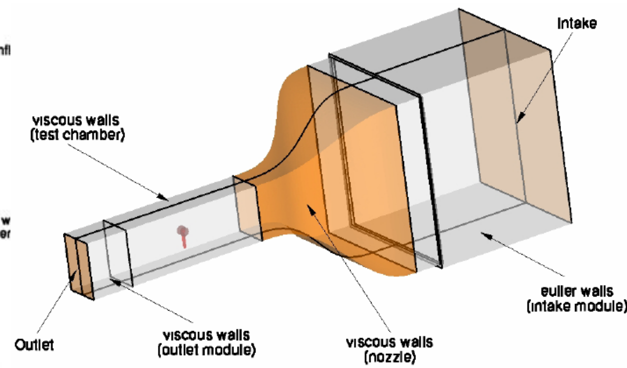
Computations

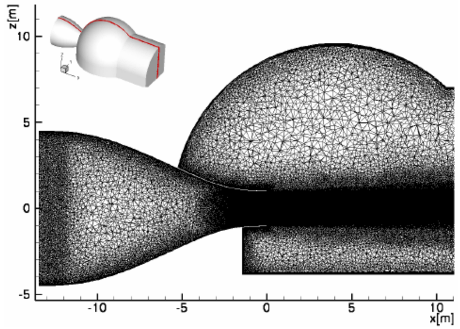
- **Mach number : 0.25**
- **Reynolds number : 1.75M (based on wheel dimeter)**
- **Free field / F2 / CEPRA19**

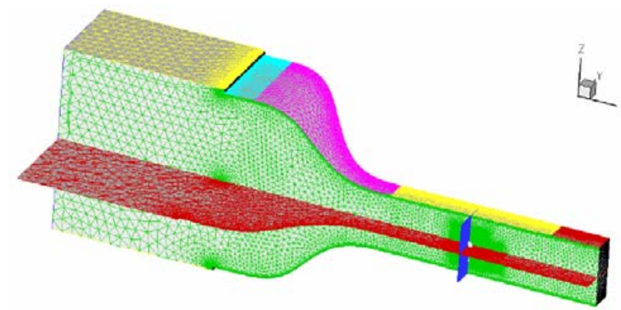
CEPRA19

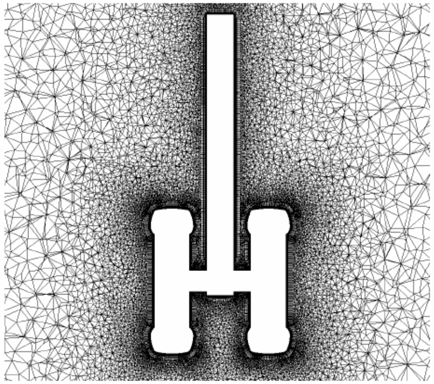


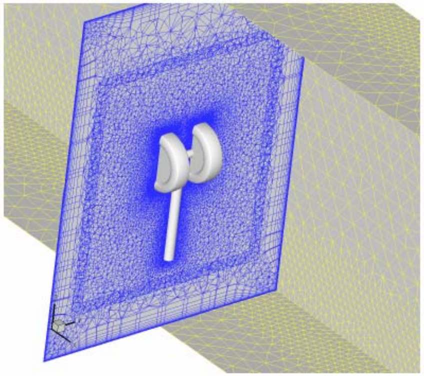
F2



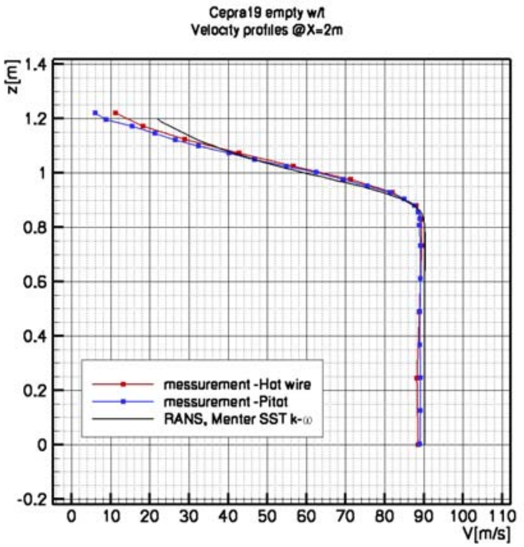




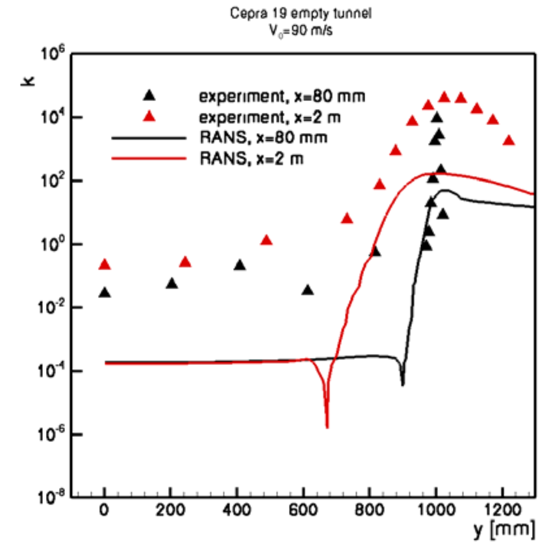




CEPRA19 empty section
- Open jet flow
- Profiles for V = 90 m/s
- 2 m downstream the nozzle

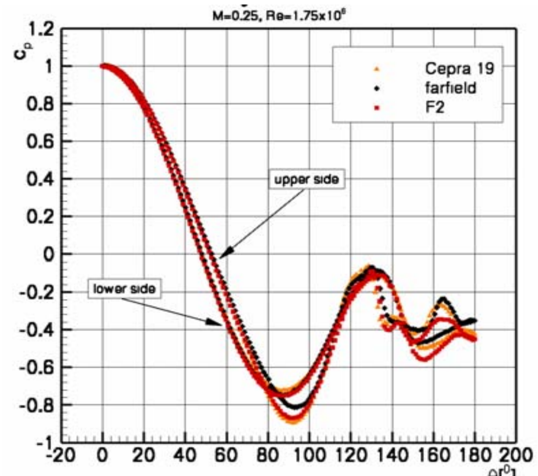


Mean velocity

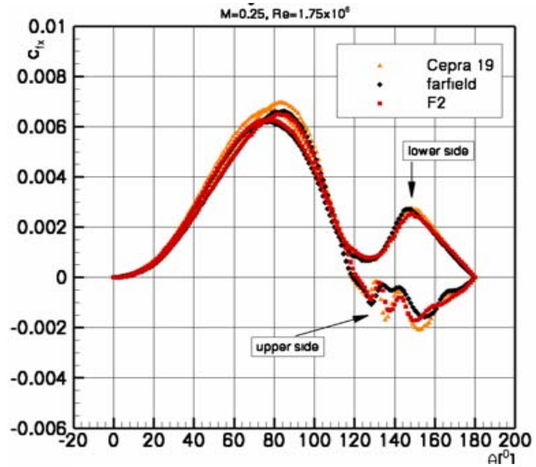


Turbulent kinetic energy *k*

CEPRA19 / F2 / Freefield
- Variation of static pressure coefficients and friction coefficients around the (mid-wheel) circumference of the left wheel (median plane)

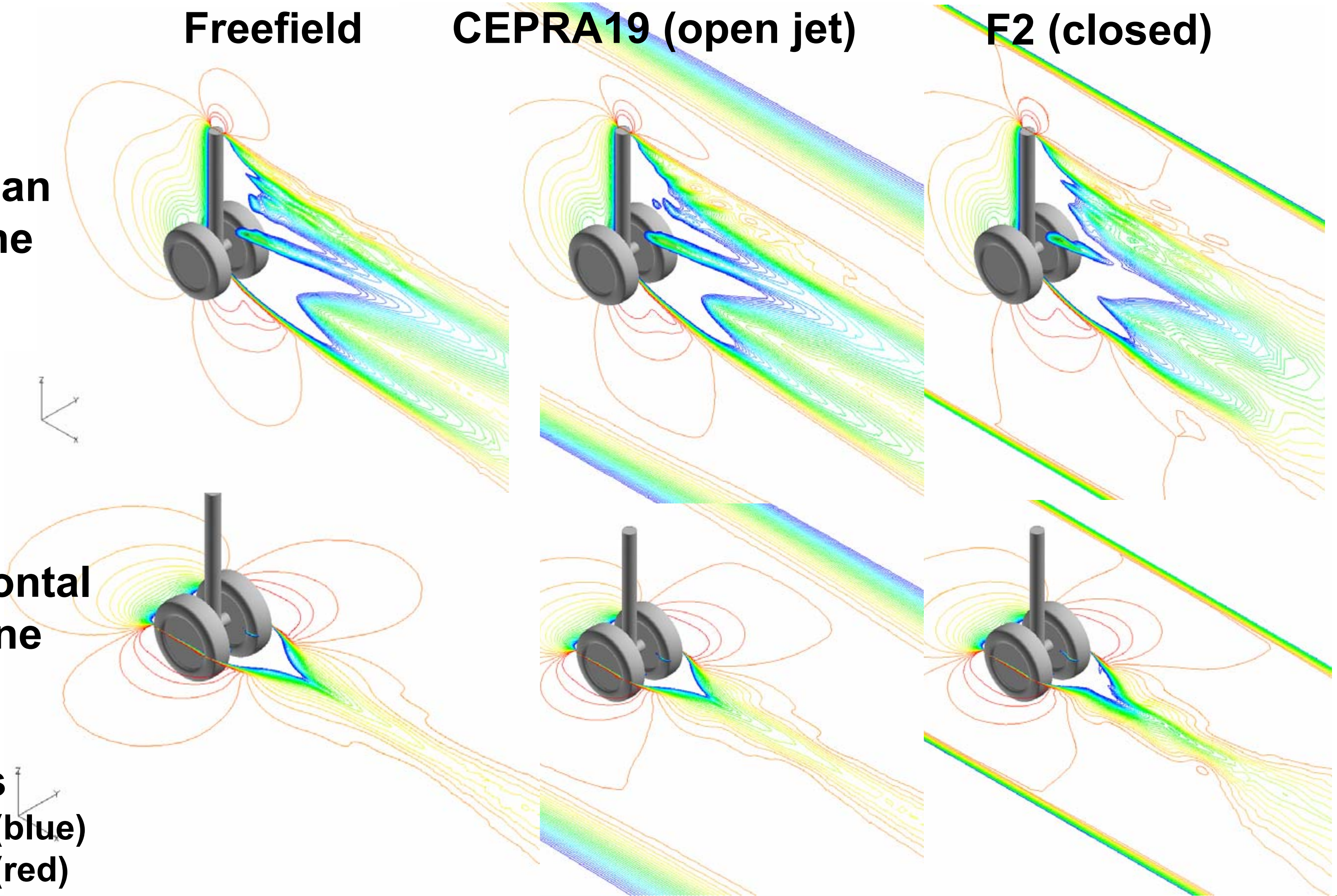


Static pressure coefficient



Friction coefficient

Flow identification (CEPRA19 / F2) using CFD
Results : mean velocity isocontours



Median plane

Horizontal plane

Levels
45 m/s (blue)
90 m/s (red)

Mean flow measurements in F2

- 2D PIV
- 2D & 3D LDV

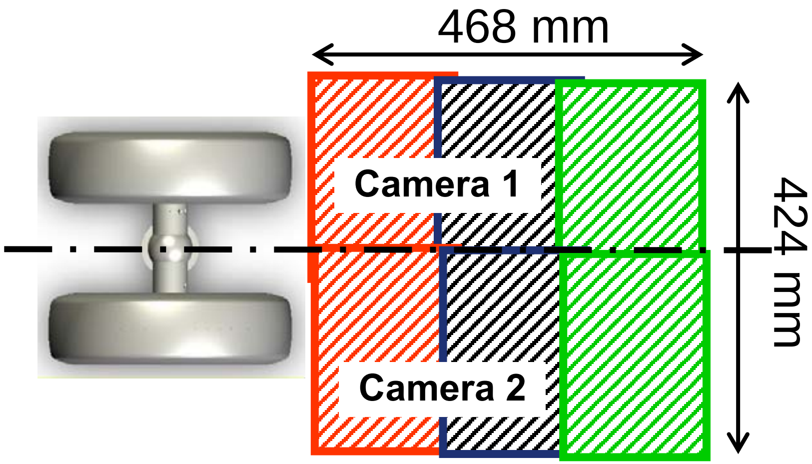
2D PIV set-up

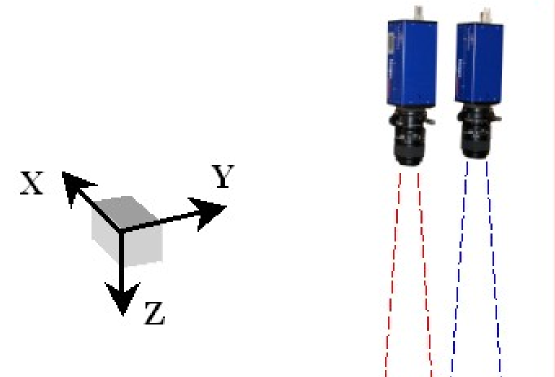
Laser

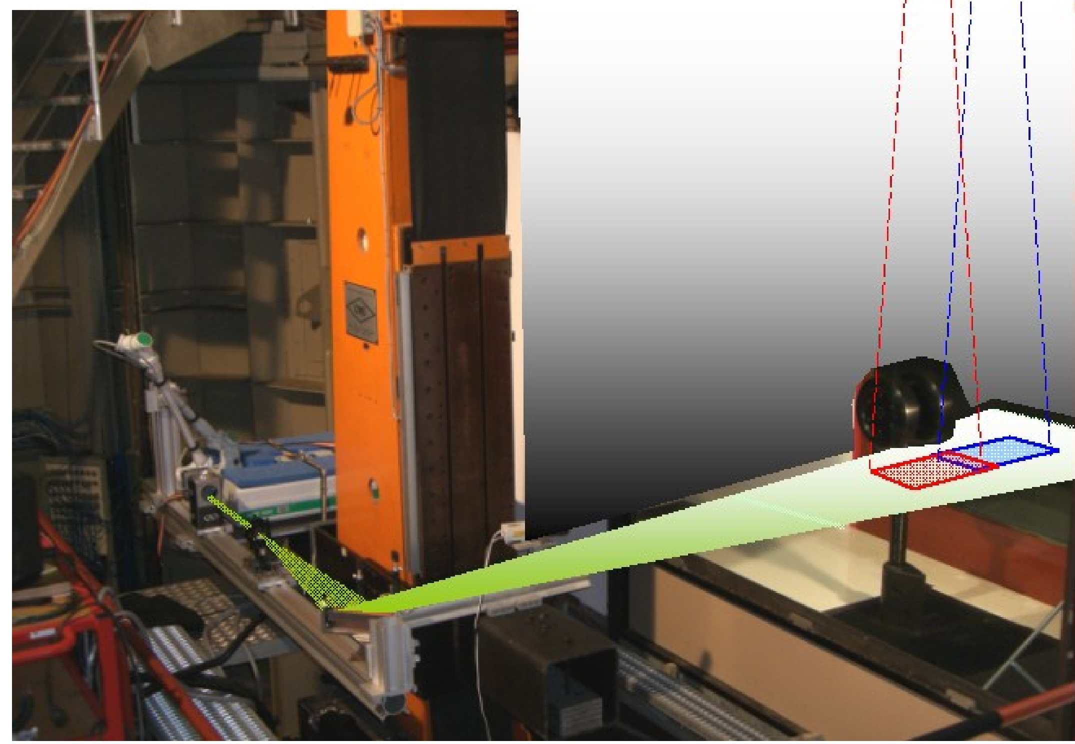
- Beam diameter 9 mm. Laser sheet thickness : 0.6 mm
- 2 cavities of 0.35 J à 532 nm (after frequency doubling)
- Energy : 11 000 J / m-2. Impulsions duration : 6 ns
- PIV image acquisition frequency : 4 Hz
- Inter-image time step : 10 µs

Cameras

- 2 cameras 12 bits, CCD 1376 x 1040 pixels
- Objective 105 mm f/8
- Distance camera - Laser sheet : 2.80 m
- Image size 222 mm x 168 mm (0.161 mm/pixel)
- Velocity maps : 86 x 65 vectors
- 1000 PIV images per velocity map

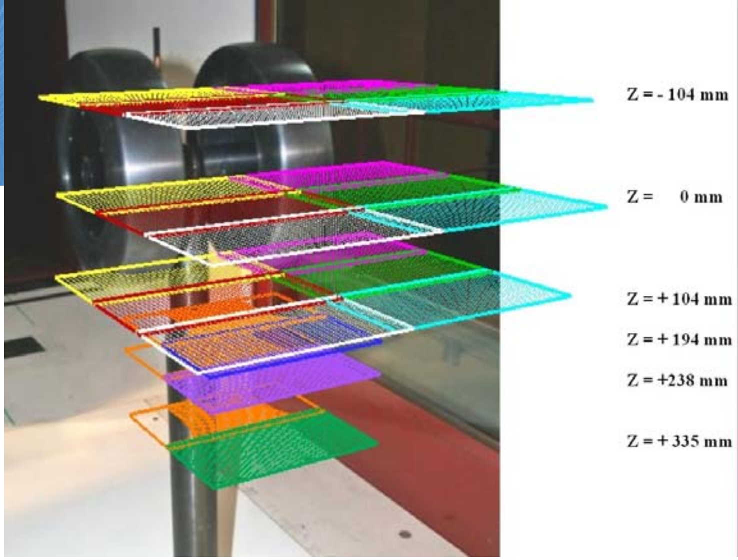




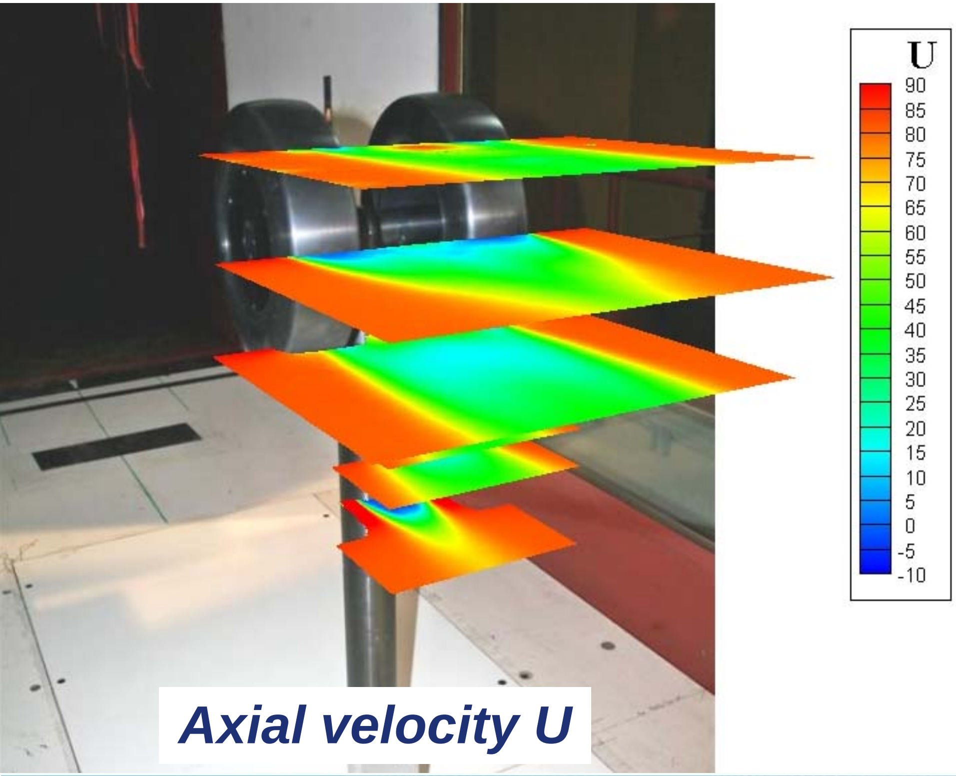


2D PIV – Mean flow results

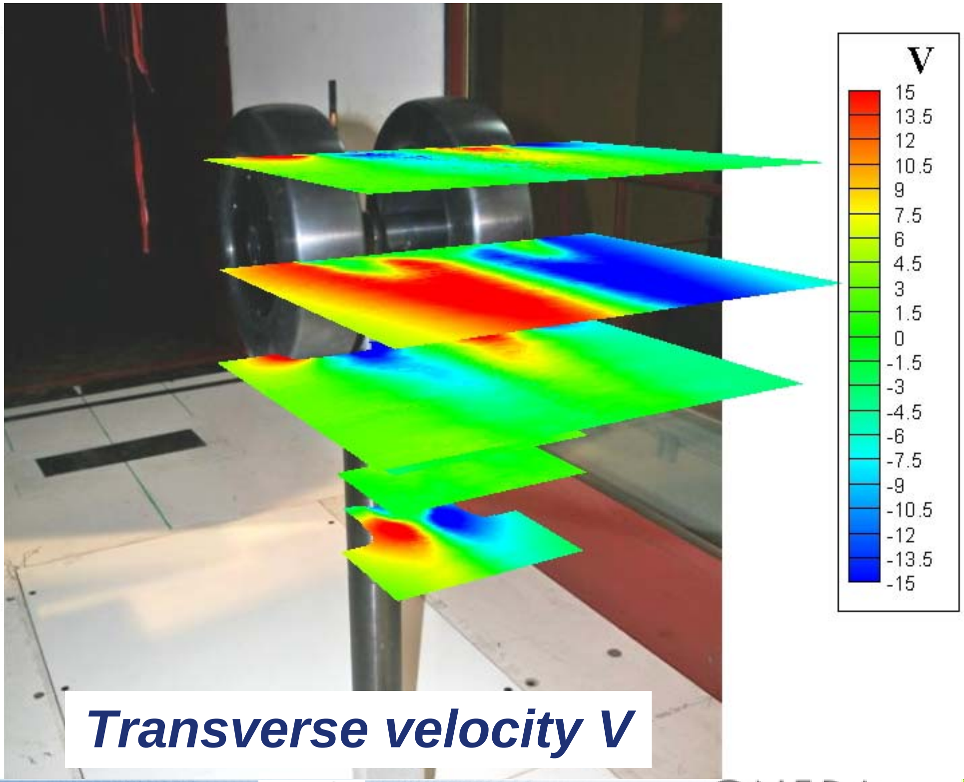
Chosen horizontal planes of interest



- Mach 0.23
- Yaw angle 0°



Axial velocity U

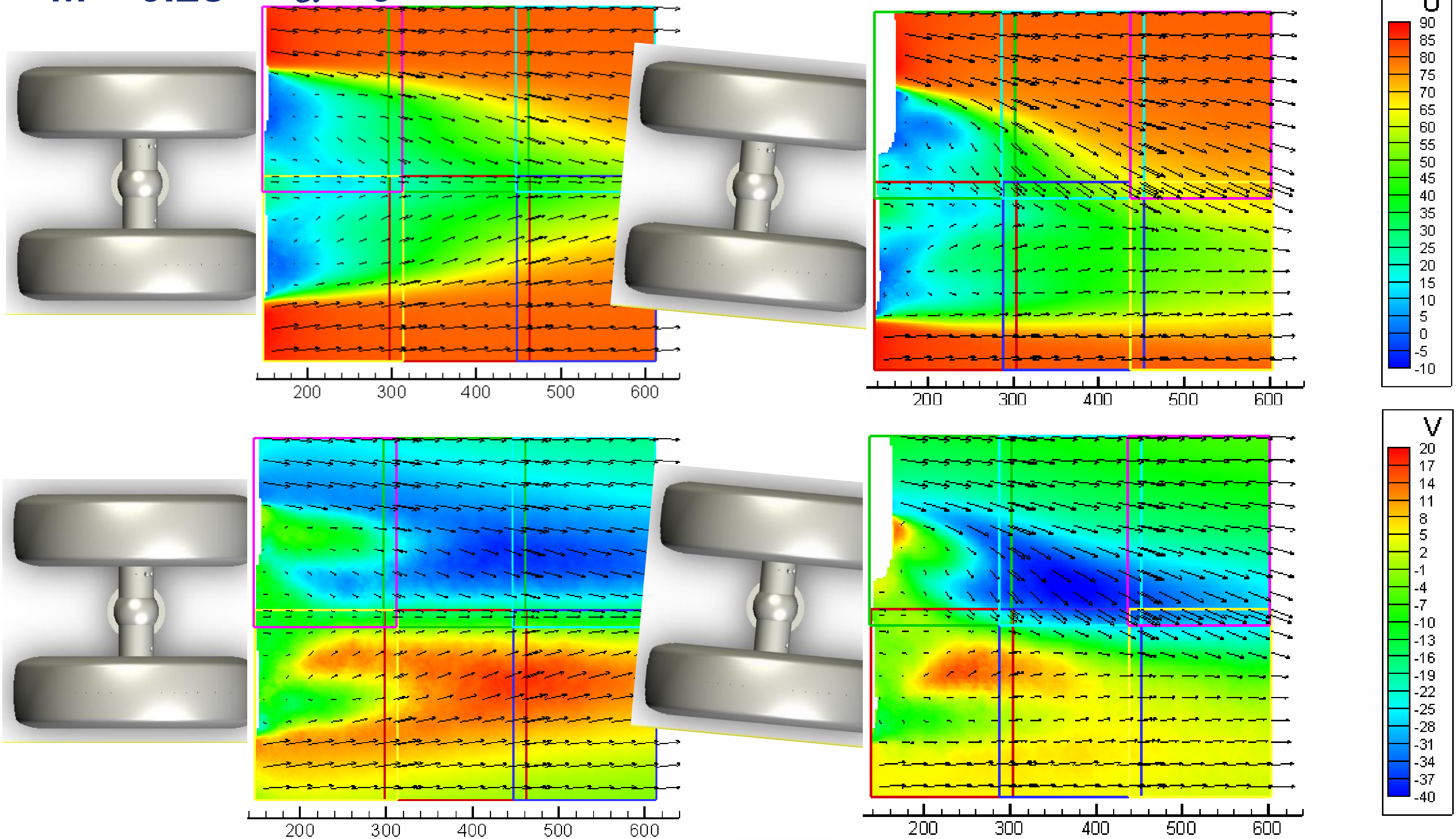


Transverse velocity V

DLR AIRBUS ONERA THE FRENCH AEROSPACE LAB

2D PIV – Mean flow results at Z = 0
Influence of yaw angle 5°

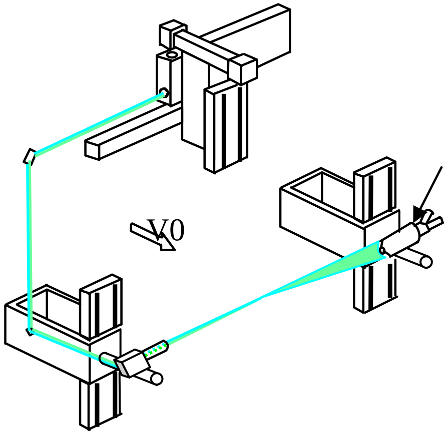
***M* = 0.23 - α = 0°** | ***M* = 0.23 - α = 5°**

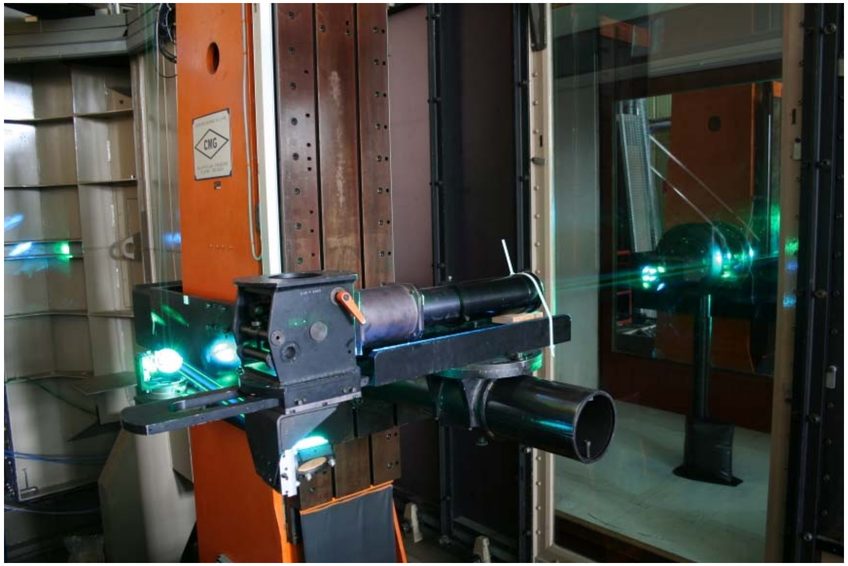


2D LDV and 3D LDV set-up

2D LDV set-up

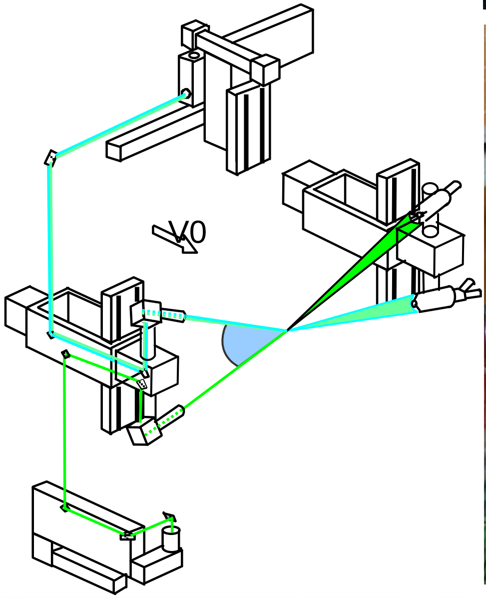
Measured velocity components : U, W

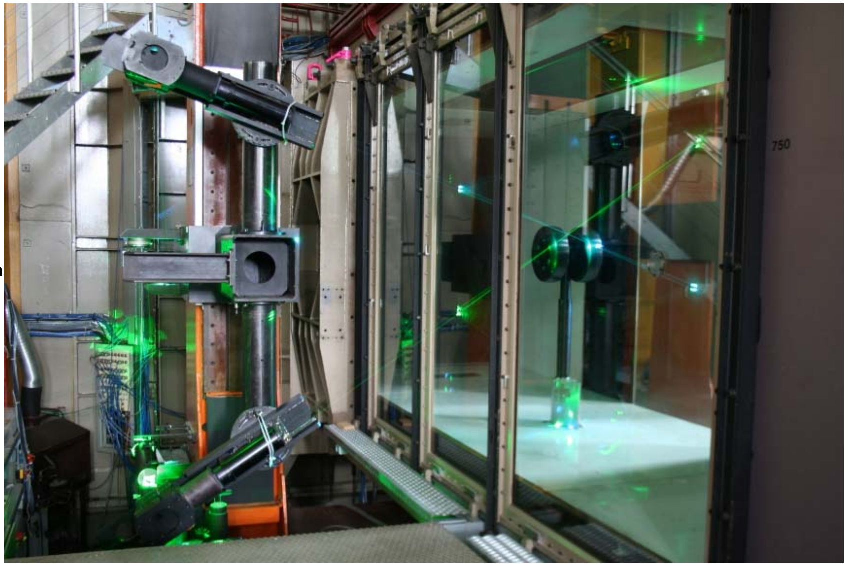




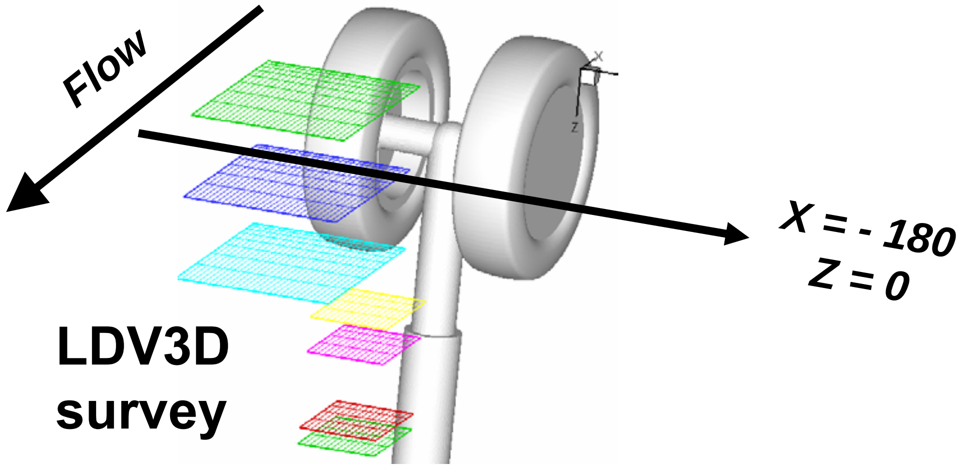
3D LDV set-up

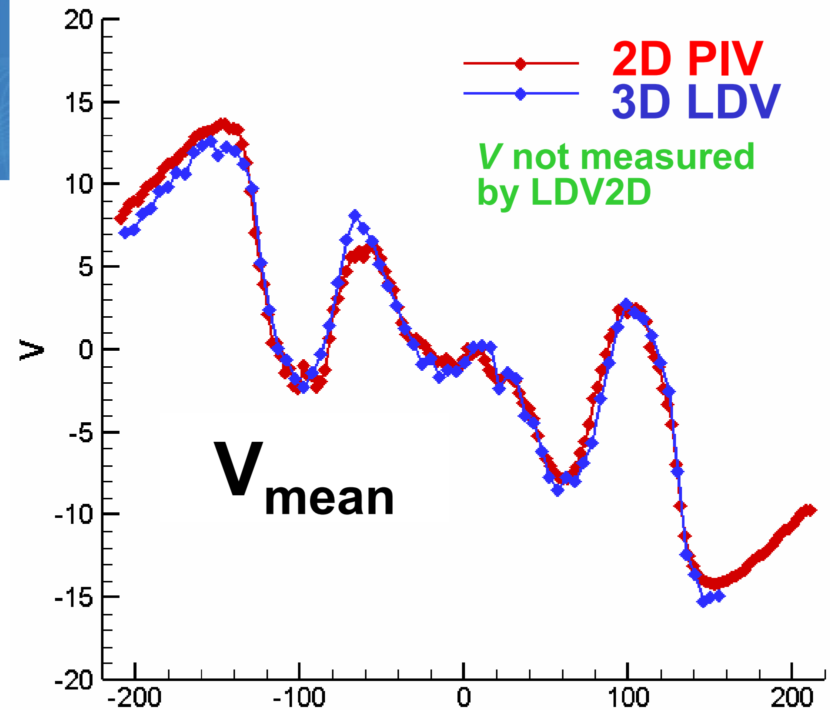
Measured velocity components : U, V, W

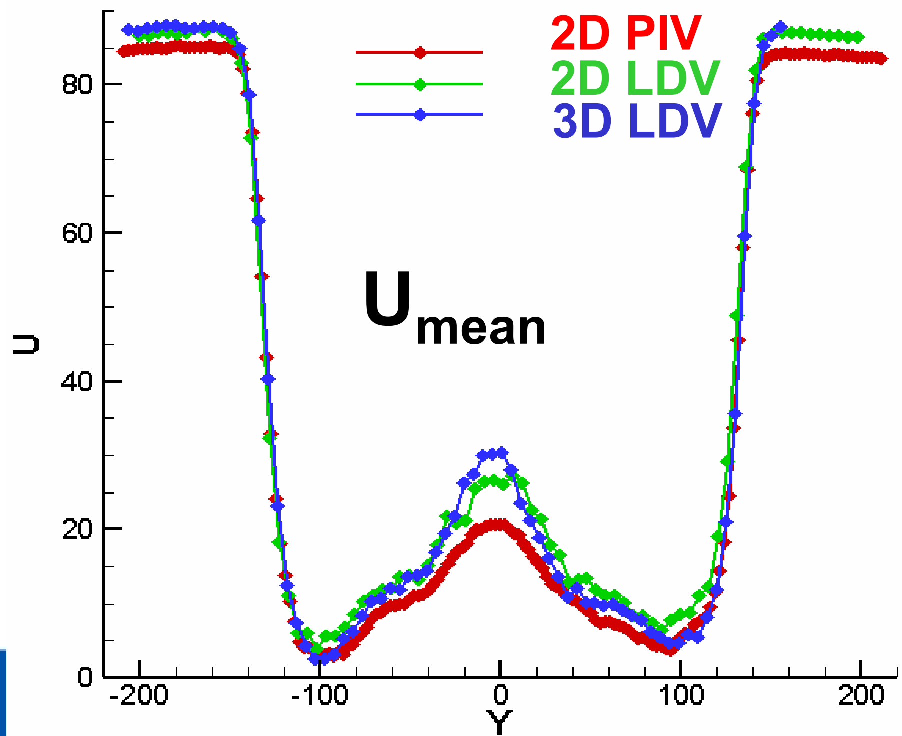


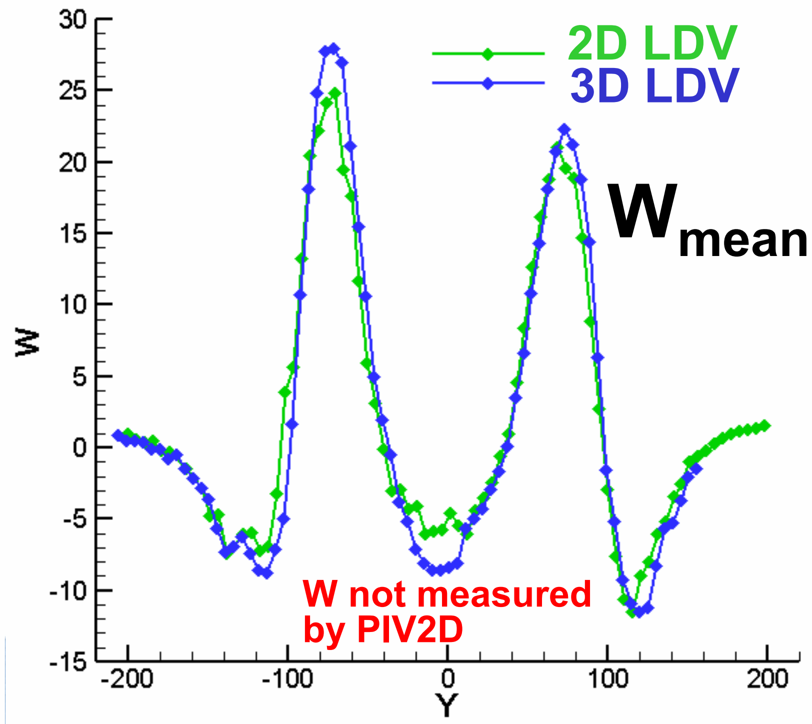


Comparison LDV (2D & 3D) vs. 2D PIV along *Y* at *X* = - 180 and *Z* = 0





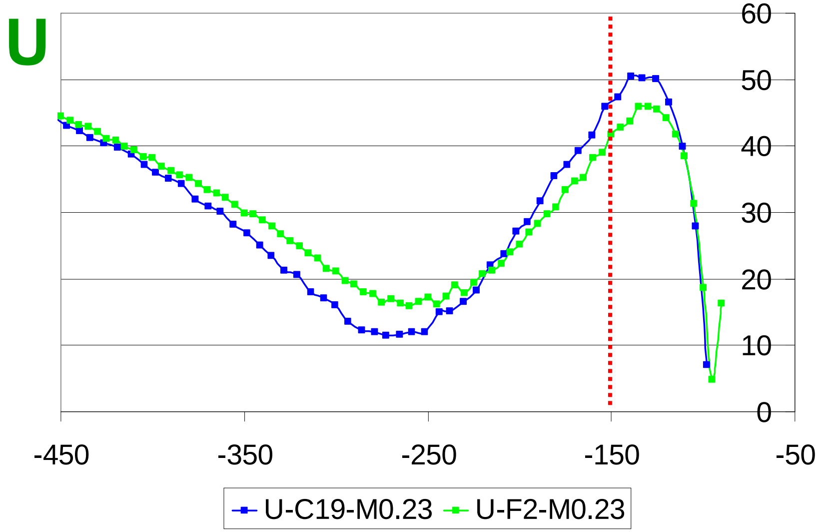


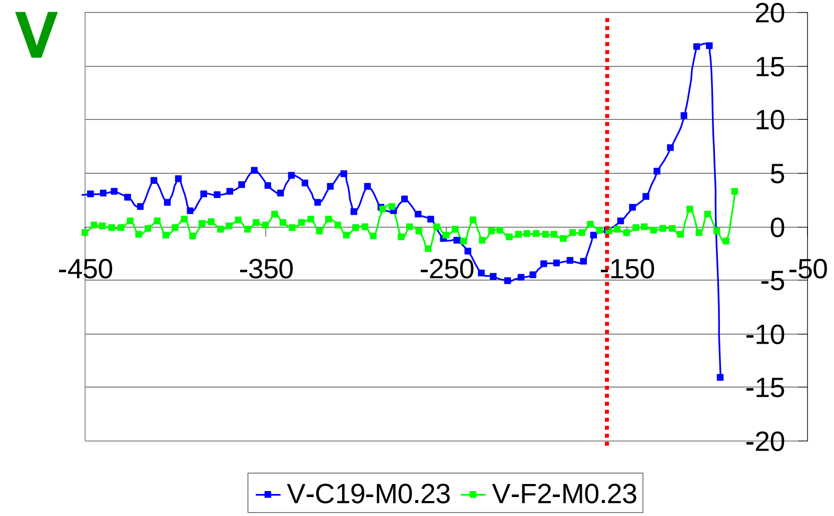


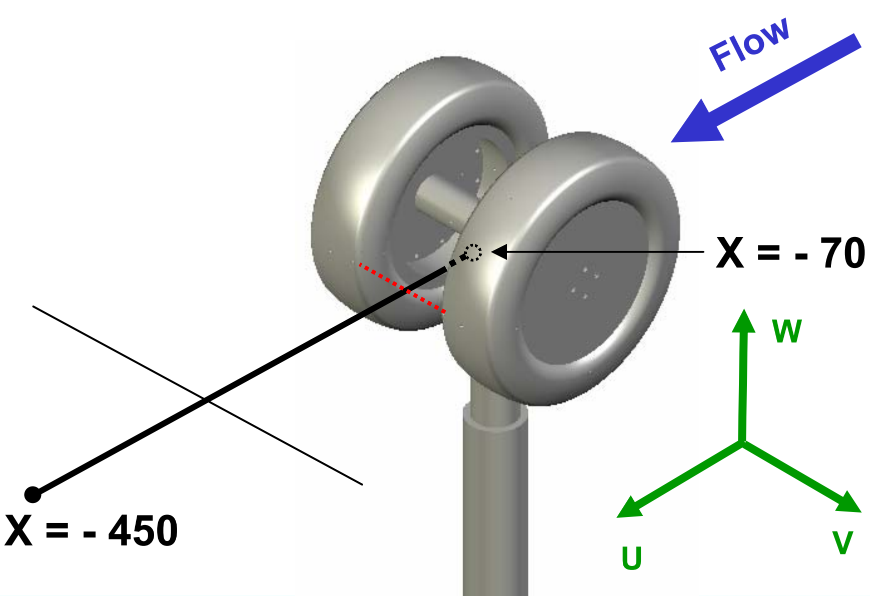
Mean flow identification F2 / CEPRA19

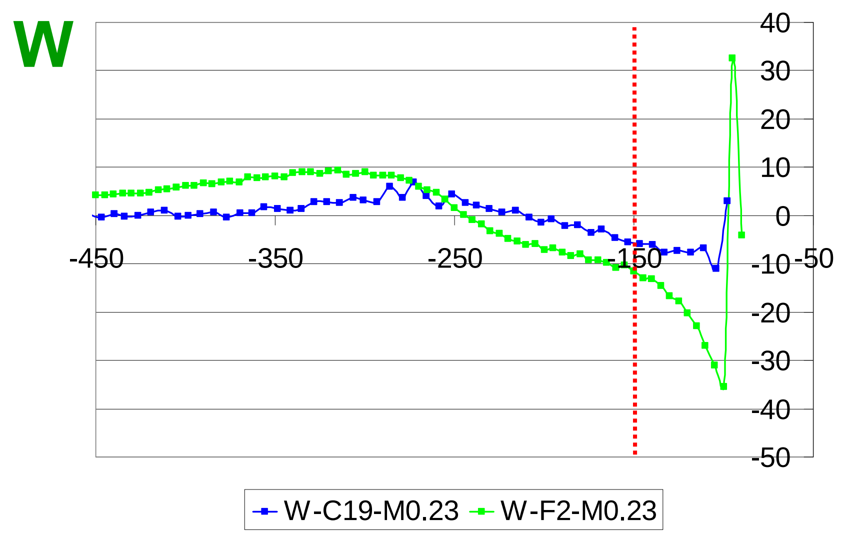
- Limited measurements in both WTs with a 5-hole probe
- Static pressure taps on wheels

F2 / CEPRA 19 flow identification using 5-hole probe
Survey in X direction at M = 0.23

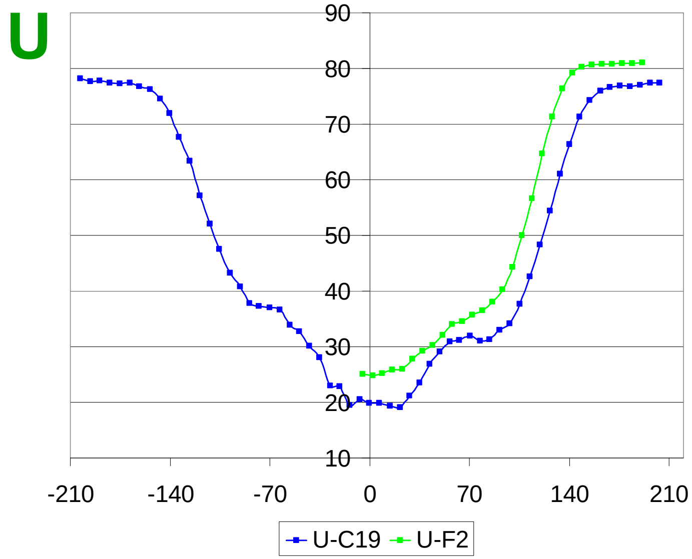


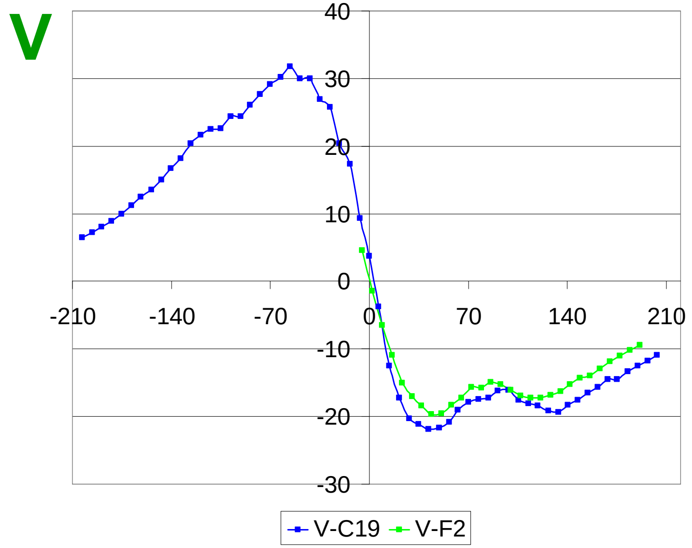


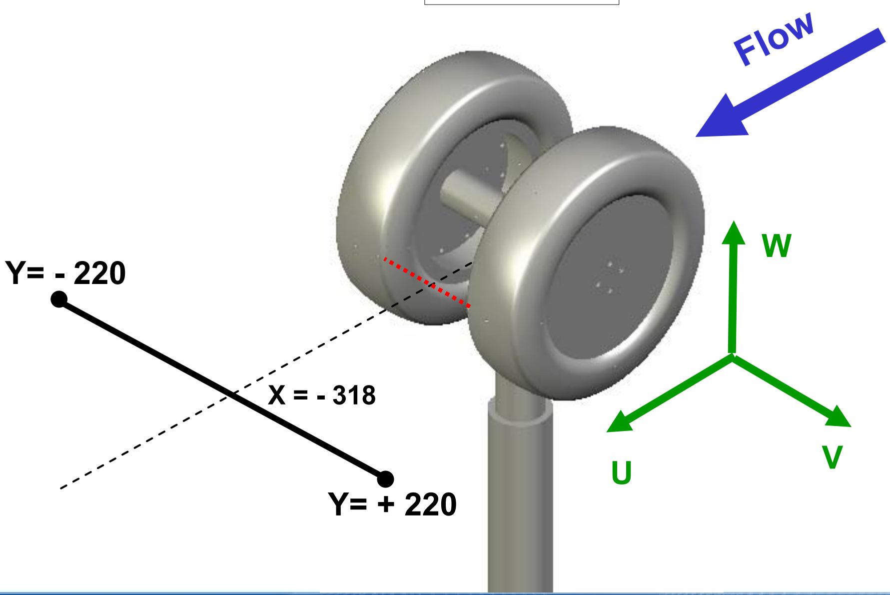


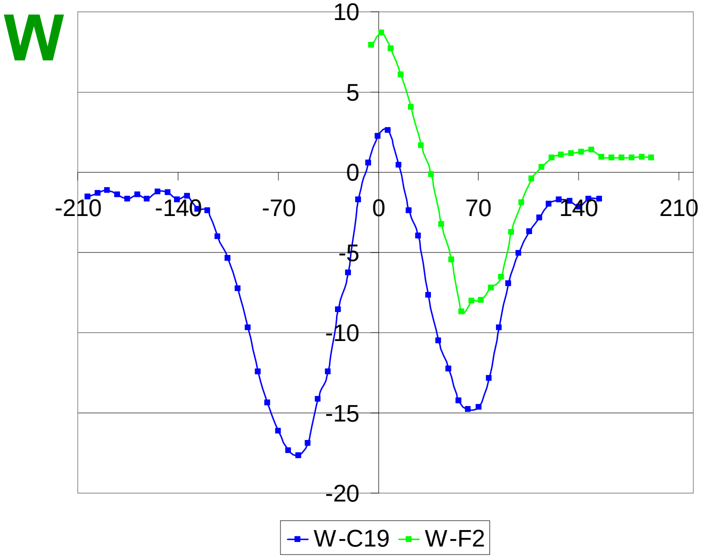


F2 / CEPRA 19 flow identification using 5-hole probe
Survey in Y direction at M = 0.23

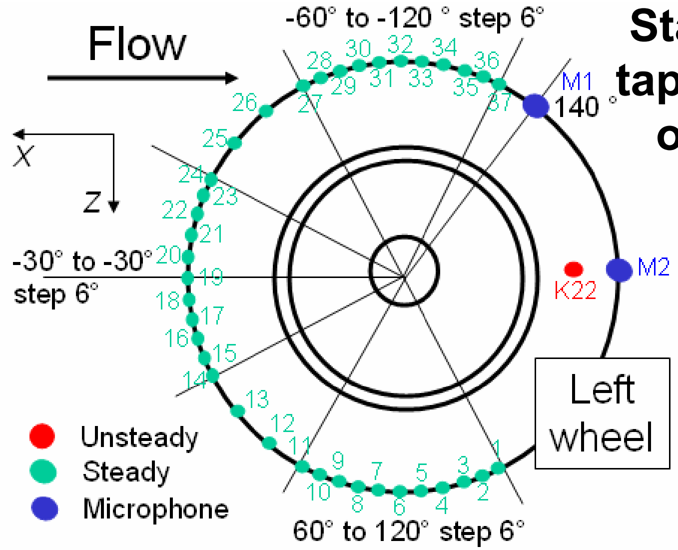




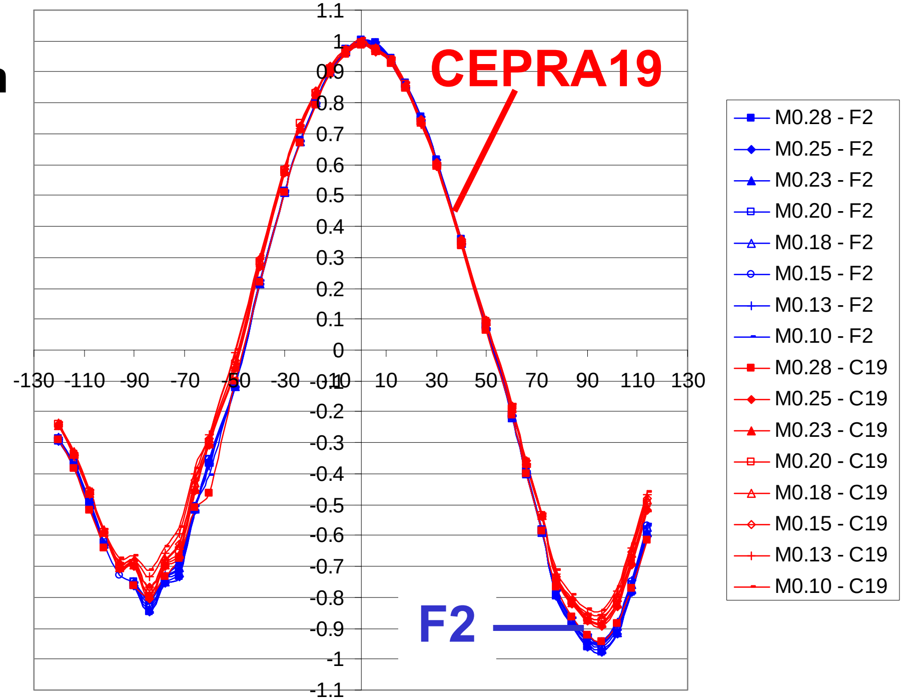




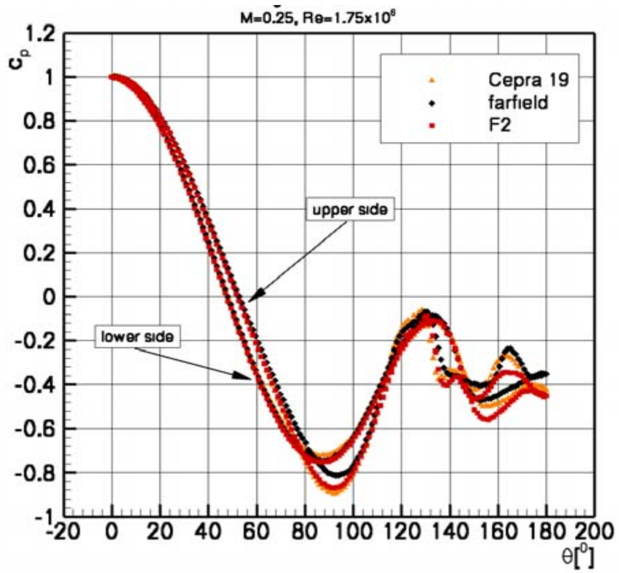
F2 / CEPRA 19 flow identification using onboard static pressure taps



Static pressure taps distribution on left wheel



<u>Measured</u> static pressure coefficients for Mach numbers 0.10 – 0.28 at F2 / CEPRA19



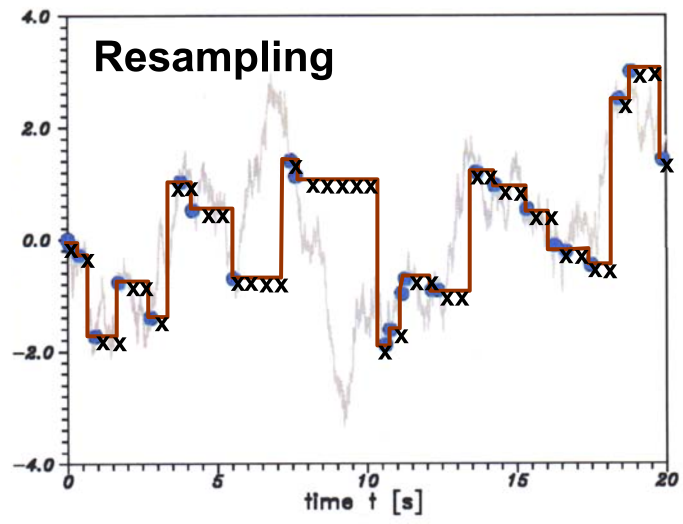
<u>Computed</u> static pressure coefficients for Mach number 0.25 : CEPRA19 / F2 / Freefield

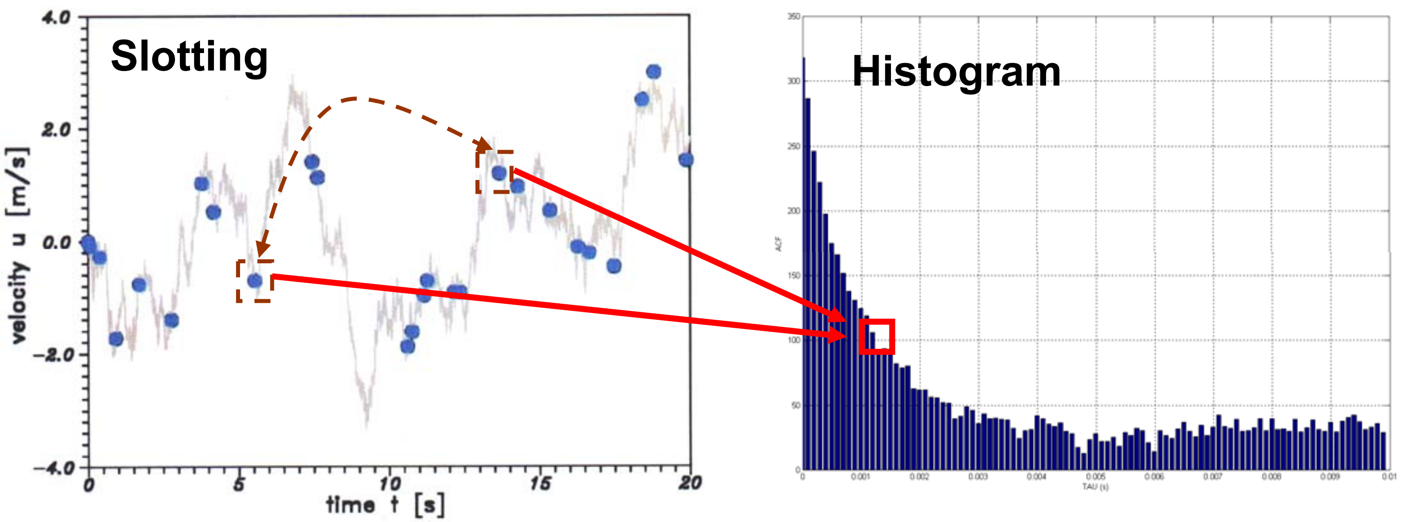
Unsteady flow measurements in *F2*

- LDV 2D & 3D
- Combined (2-point) X-hot-wire probe / LDV2D

Unsteady flow measurements using LDV

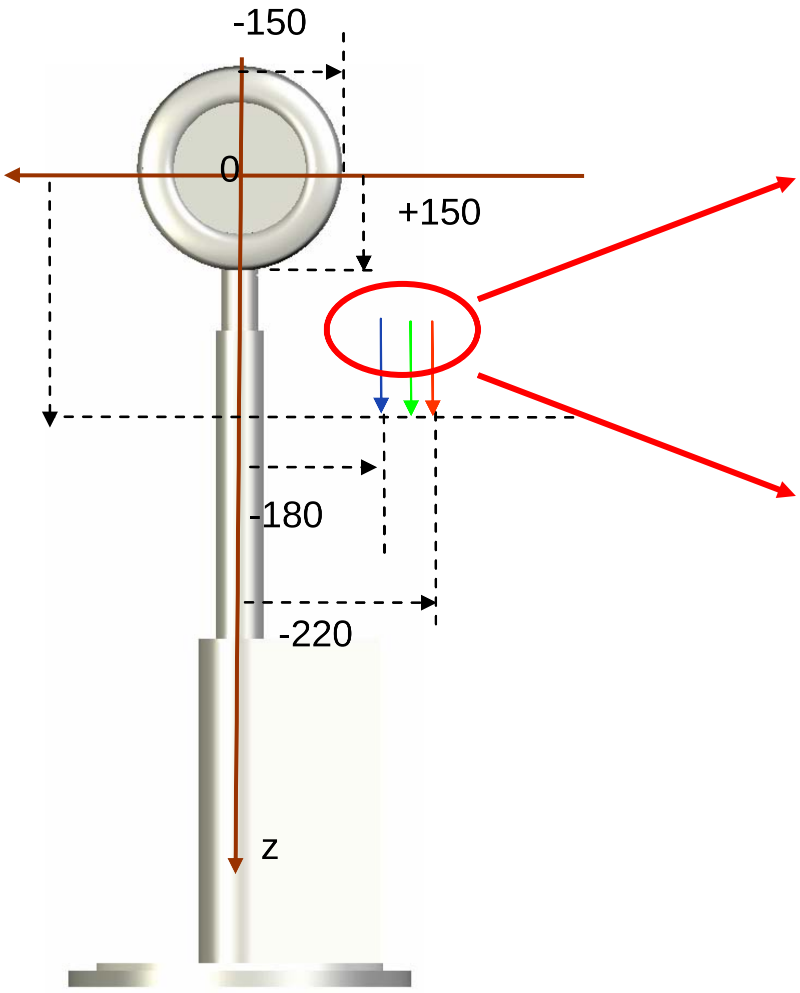
- Velocity components are not in the WT reference
- Acquisition modes
  - Coincidence mode (low data rate)
  - Random mode (higher data rate)
- LDV data sampling is random in time : classic Fourier analysis (FFT) not adapted
- Spectral analysis techniques
  - Resampling
  - Slotting (histogram)

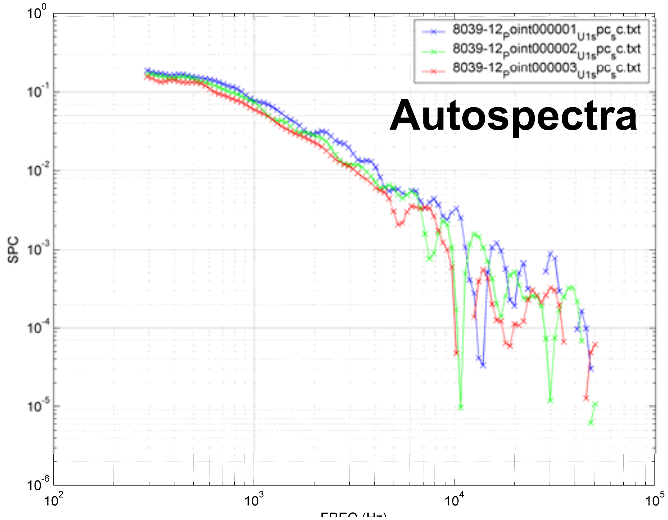


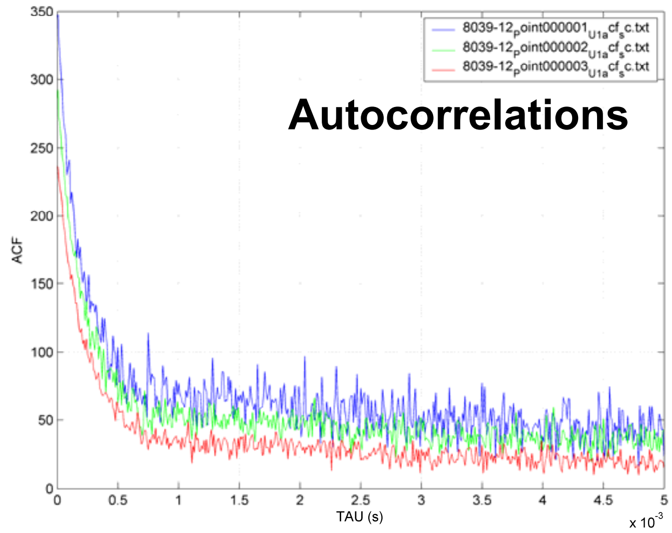


Unsteady flow measurements using LDV 2D

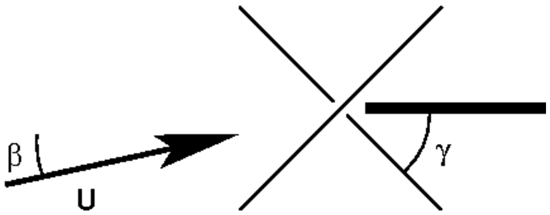
Best results obtained with random acquisition and slotting technique

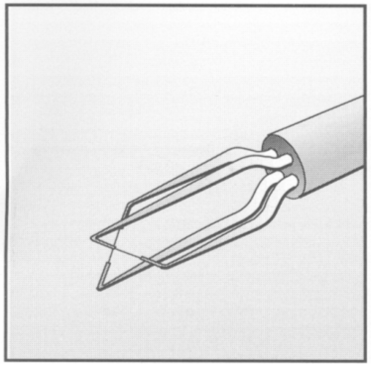




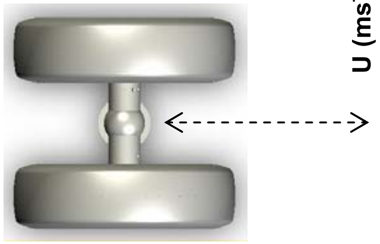


Unsteady flow measurements using cross-hotwire probe





X-wire probe



Z = 0
Y = 0

Objectives

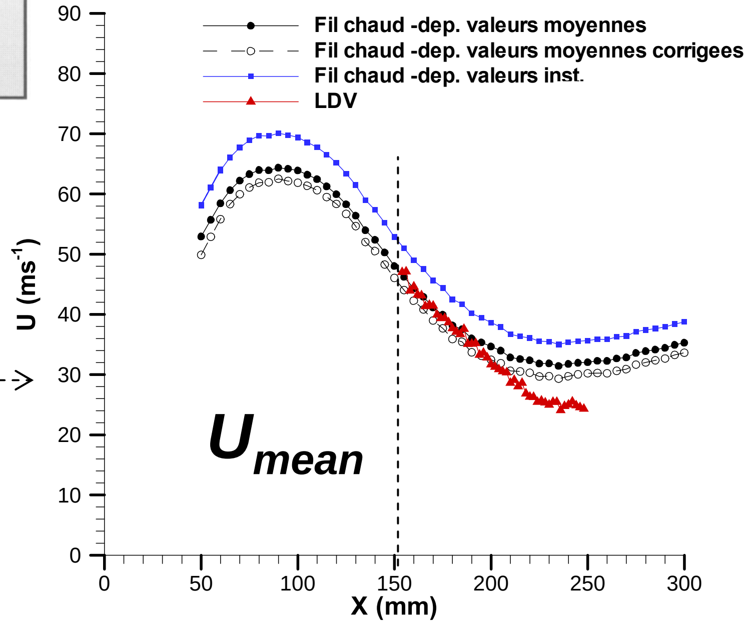
- Velocity measurements in locations with no possible access to LDV or PIV
- 2-point velocity fluctuations measurements in combination with LDV

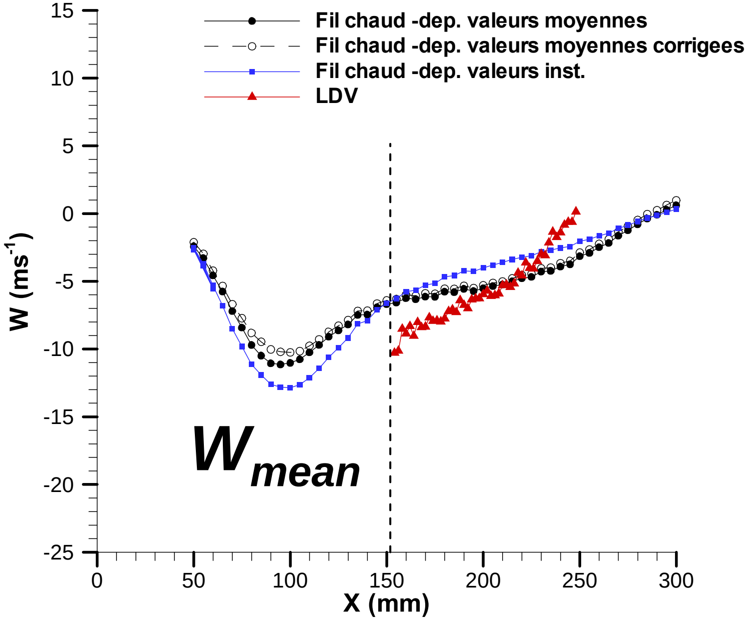
Calibration process assumes that

1) velocity component normal to wires is zero
2) velocity vector falls intside a given acceptance angular sector

→ **Conditions difficult to meet in 3D highly turbulent flows !**

Rotation 8068



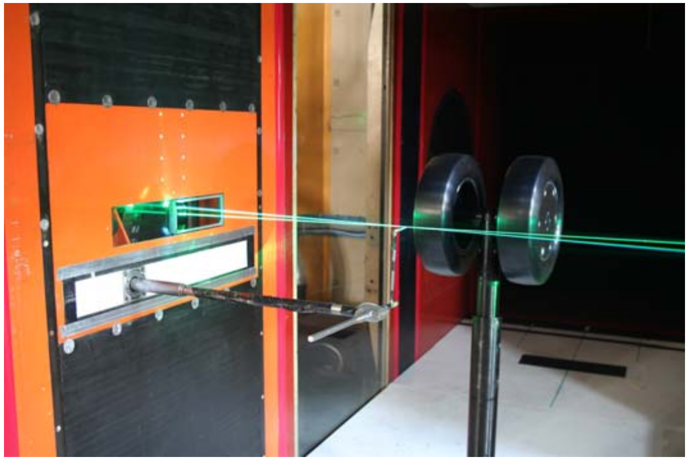


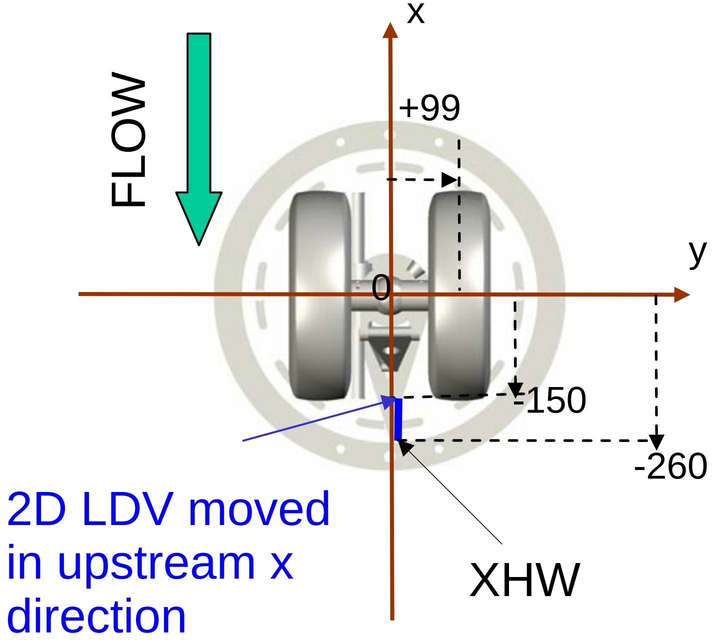
AIRBUS DLR ONERA THE FRENCH AEROSPACE LAB

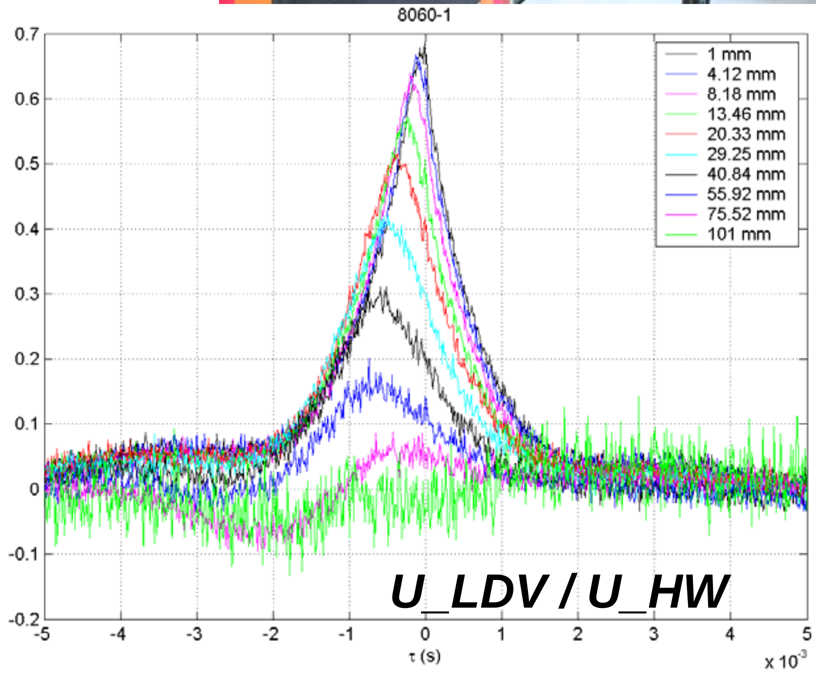
2-Point velocity correlations 2D LDV – XHW

Objectives : cross-correlations, cross-spectra and integral length scales of unsteady velocity components U, W in directions x, y, z

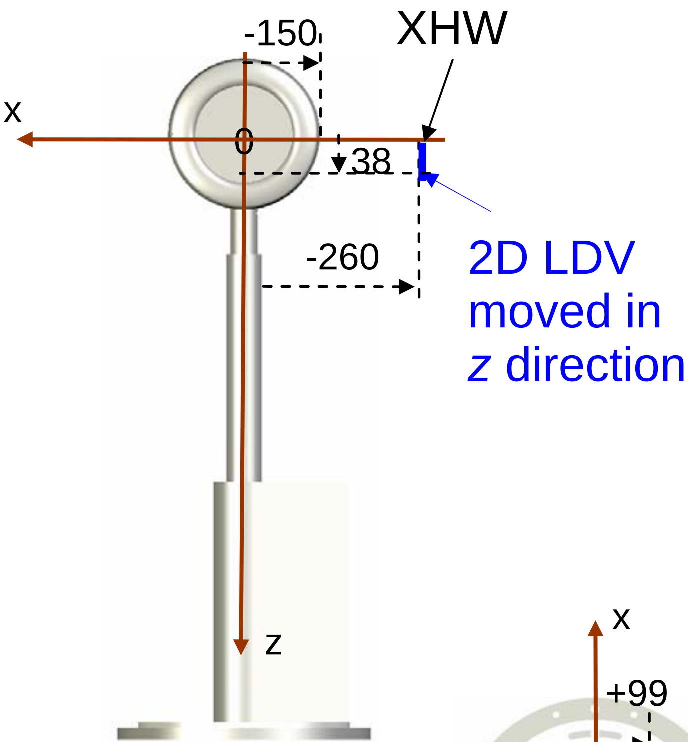
Examples of intercorrelations : XHW fixed at given position, 2D LDV moved in x, y, z directions. Slotting technique in coincidence

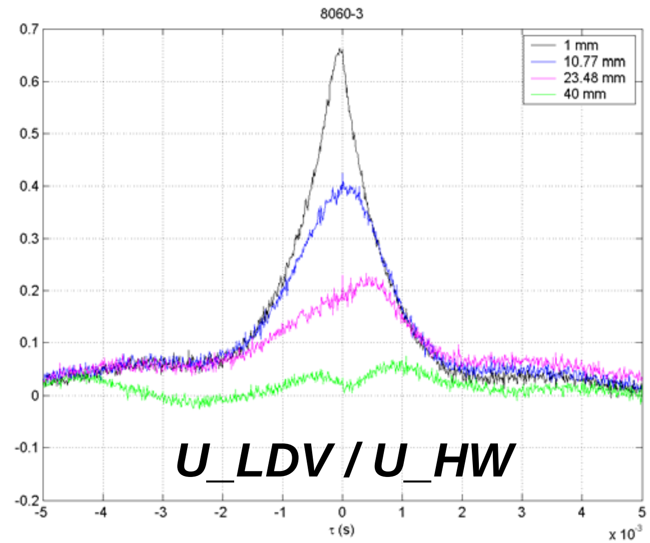


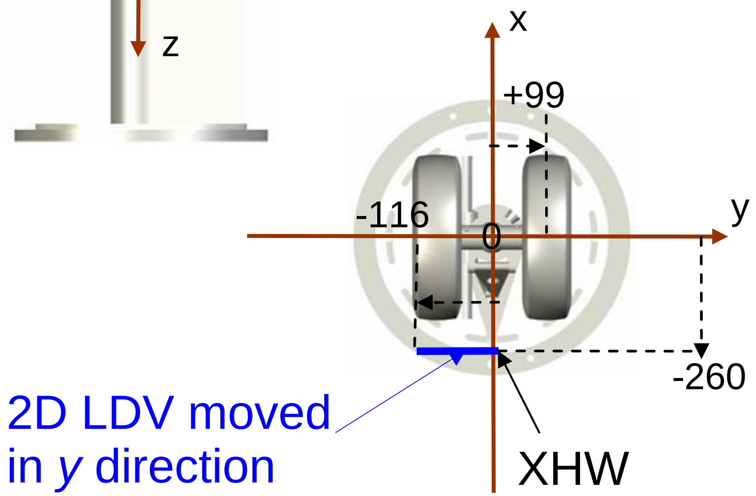


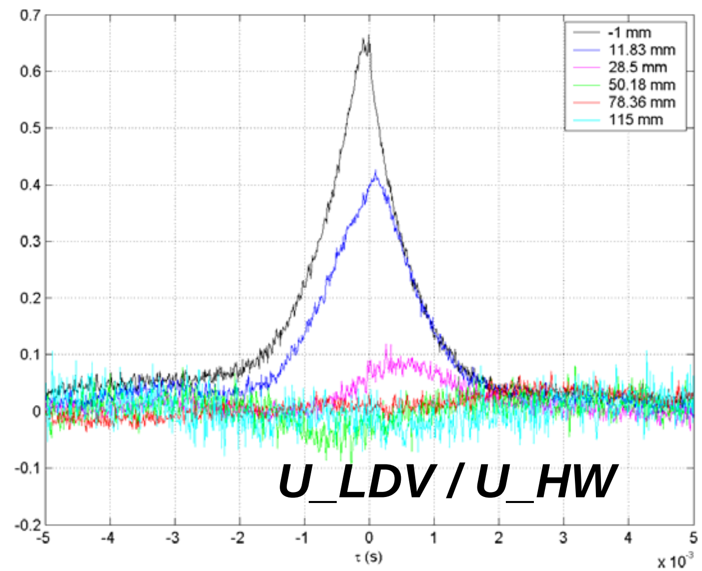


2-Point velocity correlations LDV2D – HW2D









Unsteady wall pressure measurements

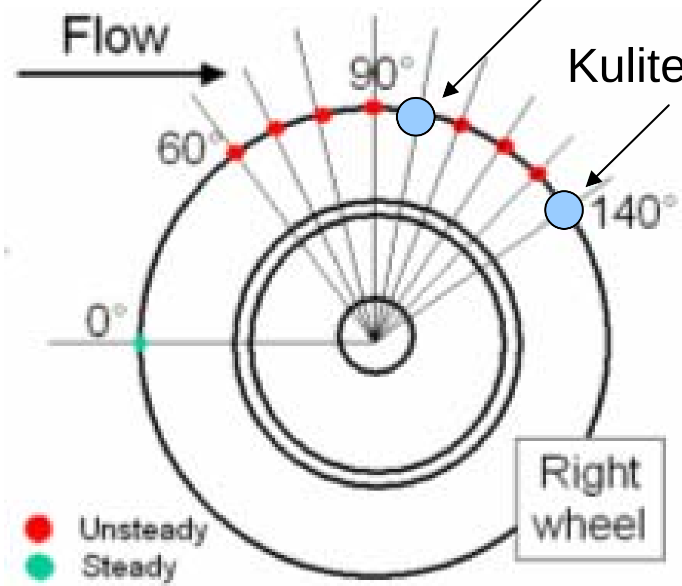
1) Some F2 results

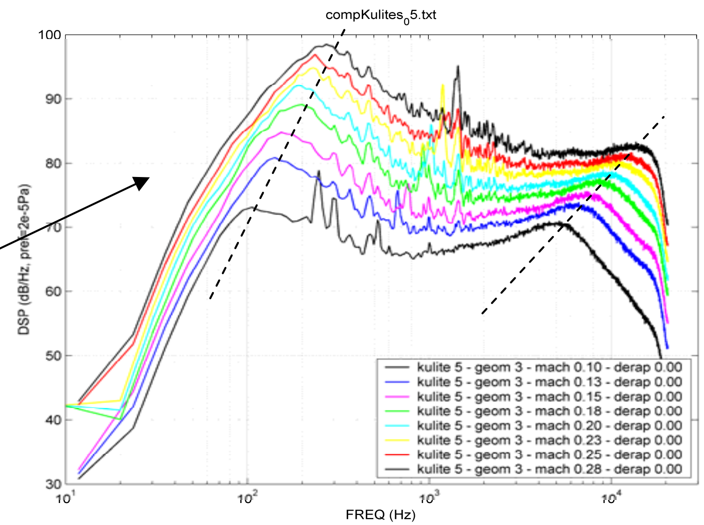
Unsteady pressure Kulite transducers Measurements in F2 (1/2) : at the wheels periphery

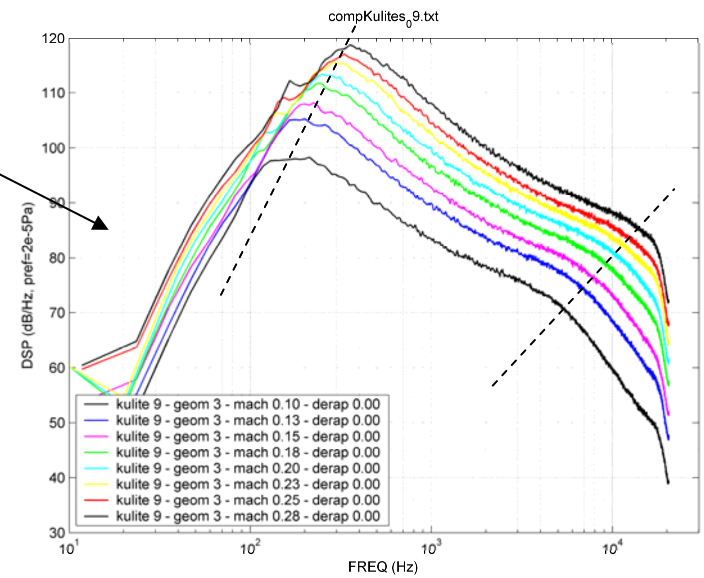
<u>Power Spectral Densities</u>
<u>at Mach numbers</u> :
0.10, 0.13, 0.15, 0.18, 0.20, 0.23, 0.25, 0.28

Kulite n° 5

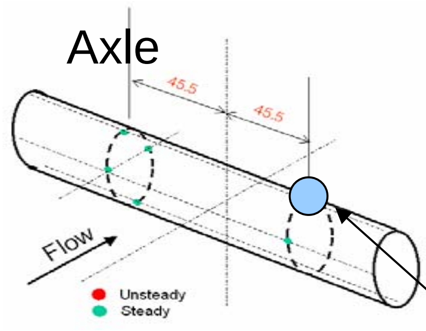
Kulite n° 9

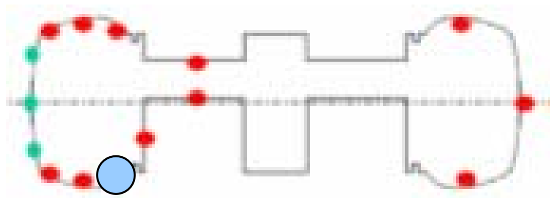






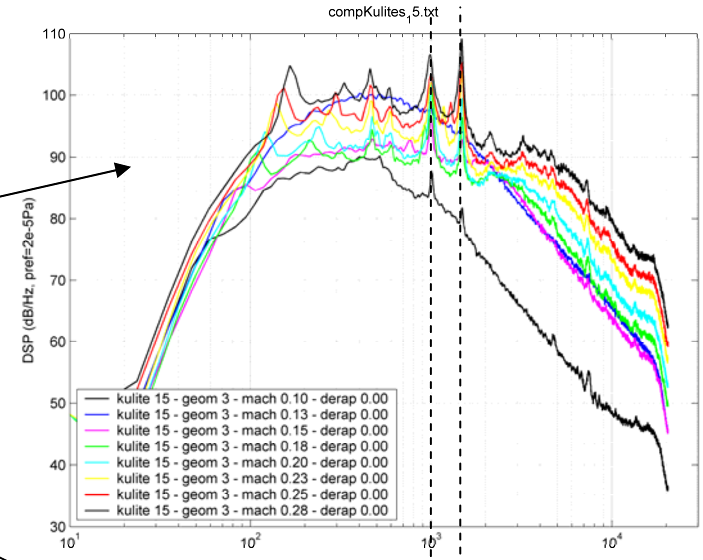
Unsteady pressure Kulite transducers Measurements in F2 (/2) : between the wheels



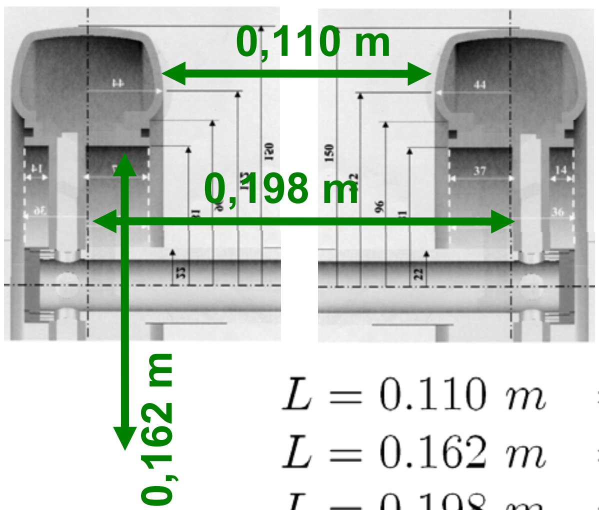


Kulite n° 15

Kulite n° 23



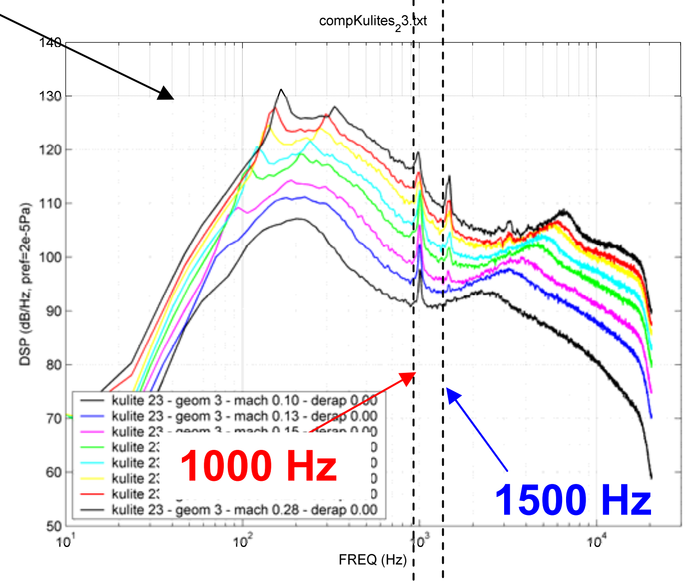
Resonant frequencies that could be linked to the dimensions of the inter-wheel "cavity" :



$$f_k = k\frac{c_0}{2L}$$

$$k = 1,\ 2, \ldots$$

$$L = 0.110\ m \implies f_1 = 1546\ Hz$$
$$L = 0.162\ m \implies f_1 = 1049\ Hz$$
$$L = 0.198\ m \implies f_1 = 859\ Hz$$



Unsteady wall pressure measurements

2) Comparison F2/CEPRA19

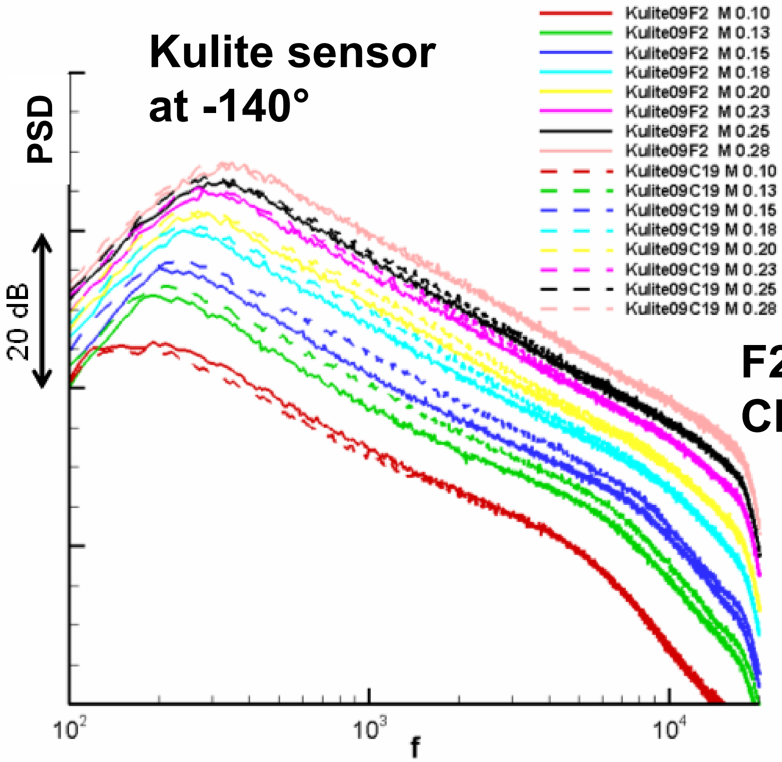
Unsteady pressure Kulite transducers
Comparison F2 / CEPRA 19 (at the wheel periphery)

Kulite sensor at -140°

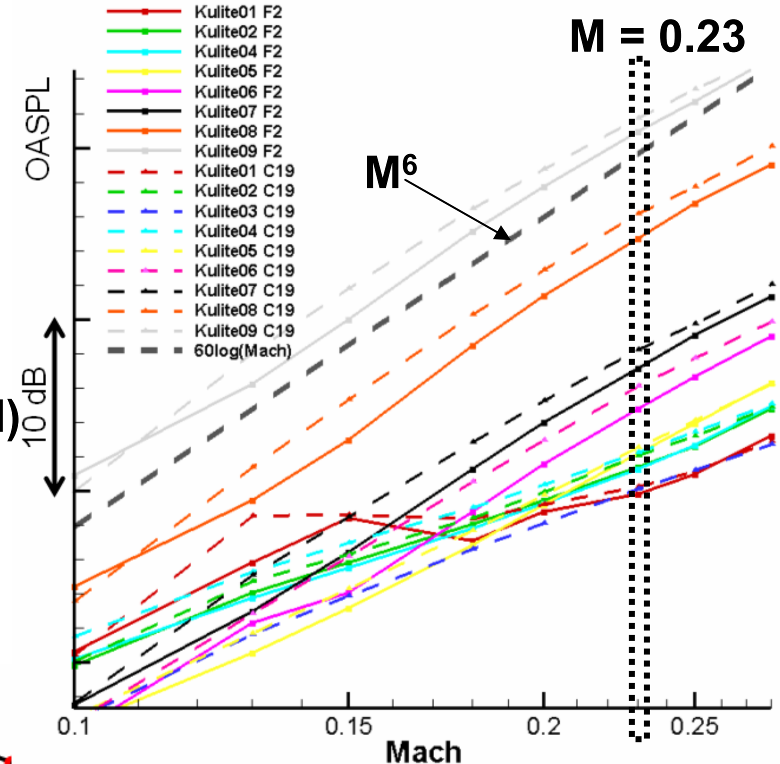
Mach numbers 0.10 – 0.28

F2 (solid)
CEPRA19 (dashed)

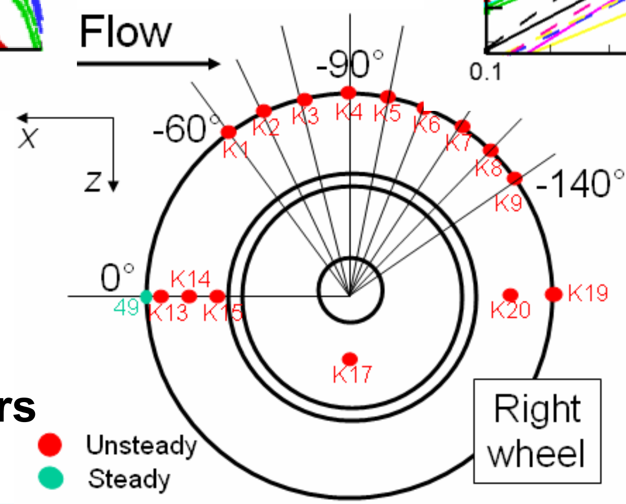
M = 0.23



Power spectral density



Overall sound pressure levels

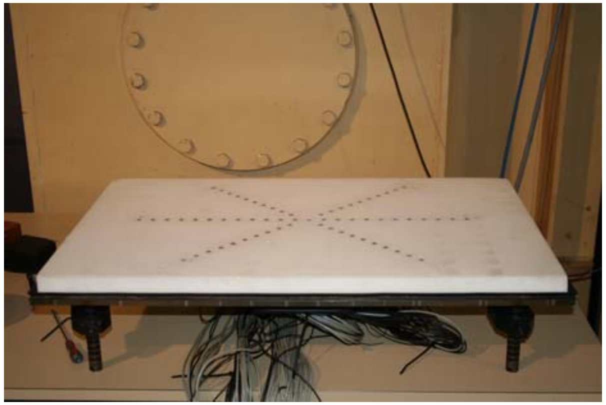


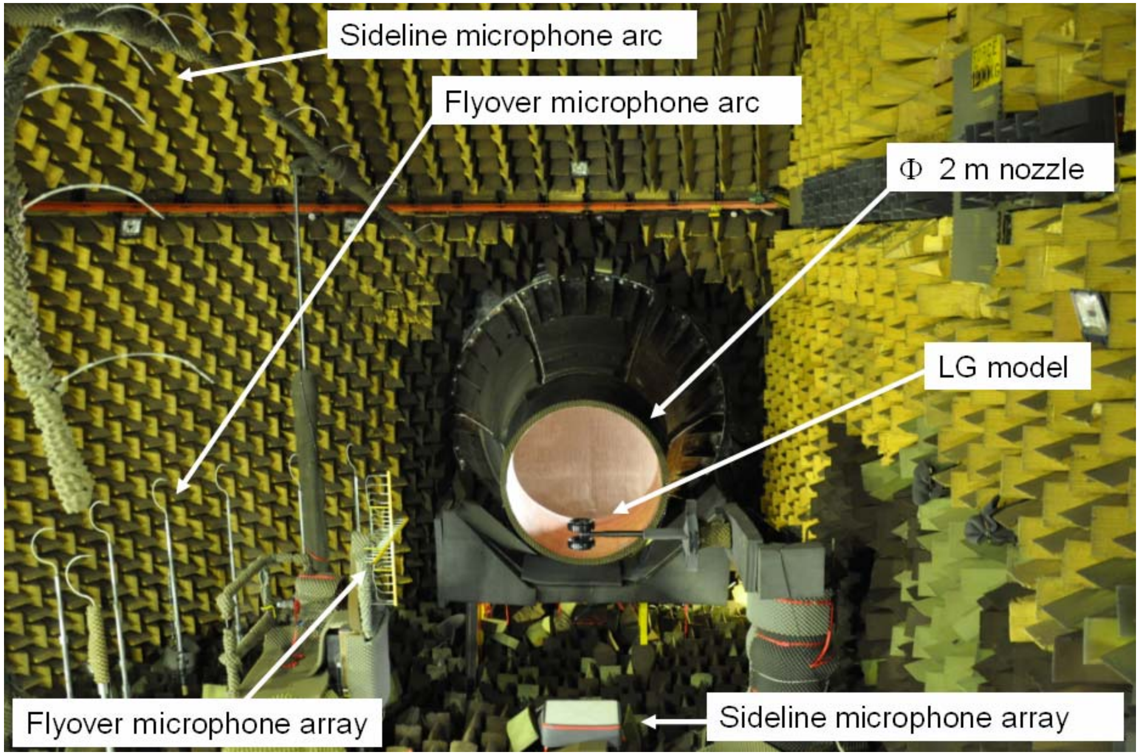
Kulite unsteady pressure sensors distribution on the right wheel

- **Acoustic measurements**
  - **Acoustic instrumentation**
  - **« Signal-to-noise » ratio in both facilities**
  - **Early use of microphone antenna in both facilities**

Acoustic instrumentation in CEPRA19 / F2

- Two arcs of 12 ¼" microphones in CEPRA19 (flyover/sideline)
- Flyover antenna with 41 ½" microphones in CEPRA19 only
- Sideline antenna with 48 ¼" microphones
  - Mounted in F2 hard-side wall in an anechoic cavity behind a Kevlar membrane
  - Also mounted in CEPRA 19





"Signal-to-noise" ratio in CEPRA19

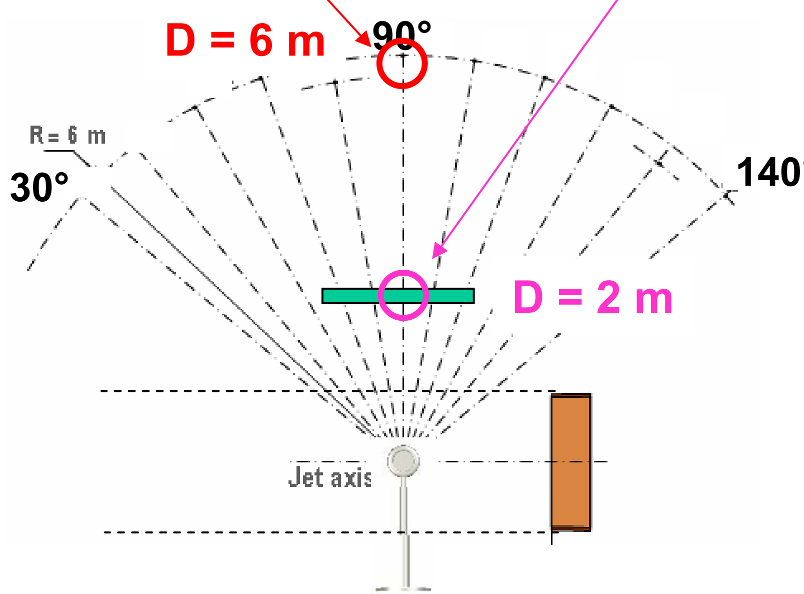
Flyover plane (1/2) : PSD at directivity angle 90° and M = 0.23

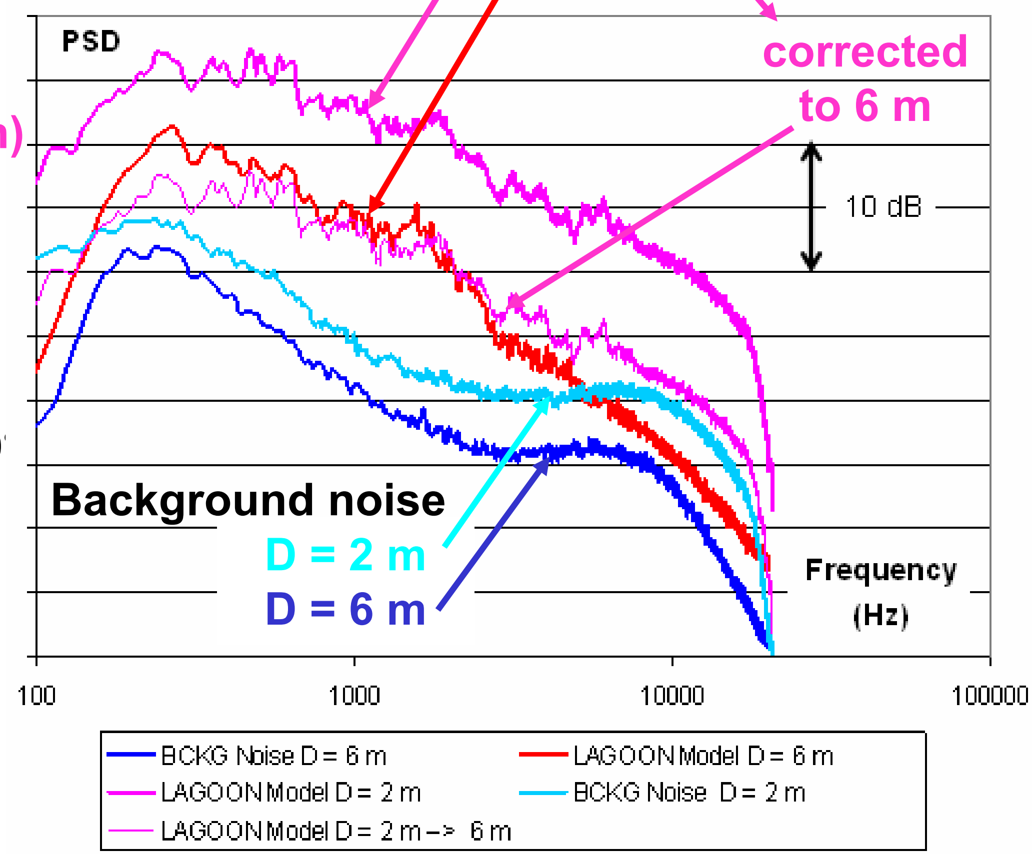
Power Spectral Density at M = 0.23

- LAGOON model
- No model (background noise)

Microphone (1/4 inch) of flyover arc

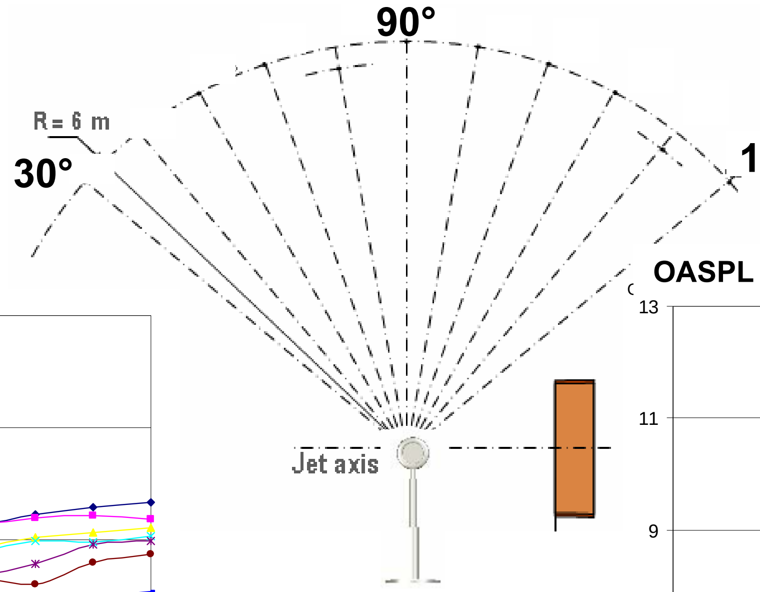
Microphone (1/2 inch) of flyover antenna



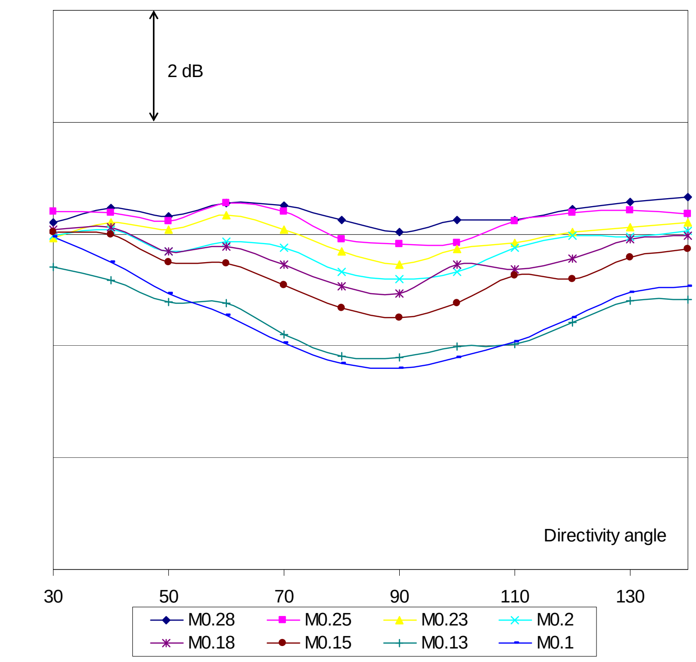


DLR AIRBUS ONERA THE FRENCH AEROSPACE LAB

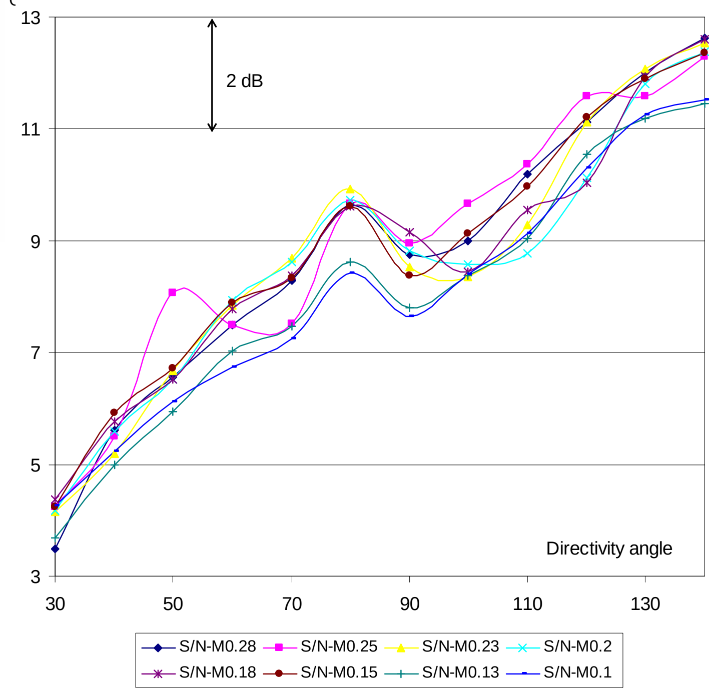
"Signal-to-noise" ratio in CEPRA19
Flyover plane (1/2) : OASPL directivities



Mach number 0.10, 0.13, 0.15, 0.18, 0.20, 0.23, 0.25, 0.28



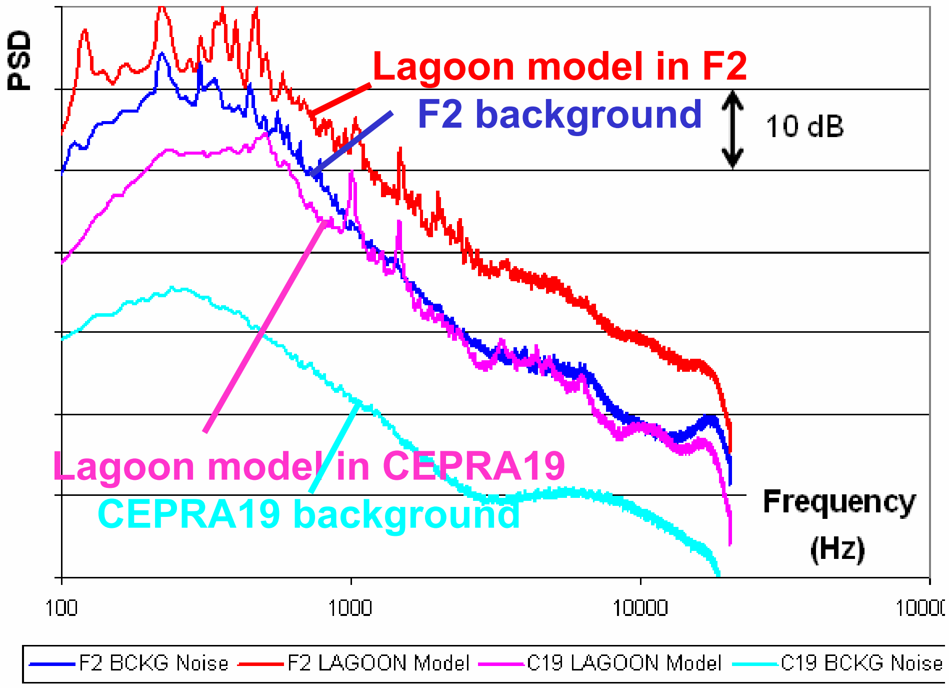
LAGOON model aerodynamic noise OASPL normalized by M^6

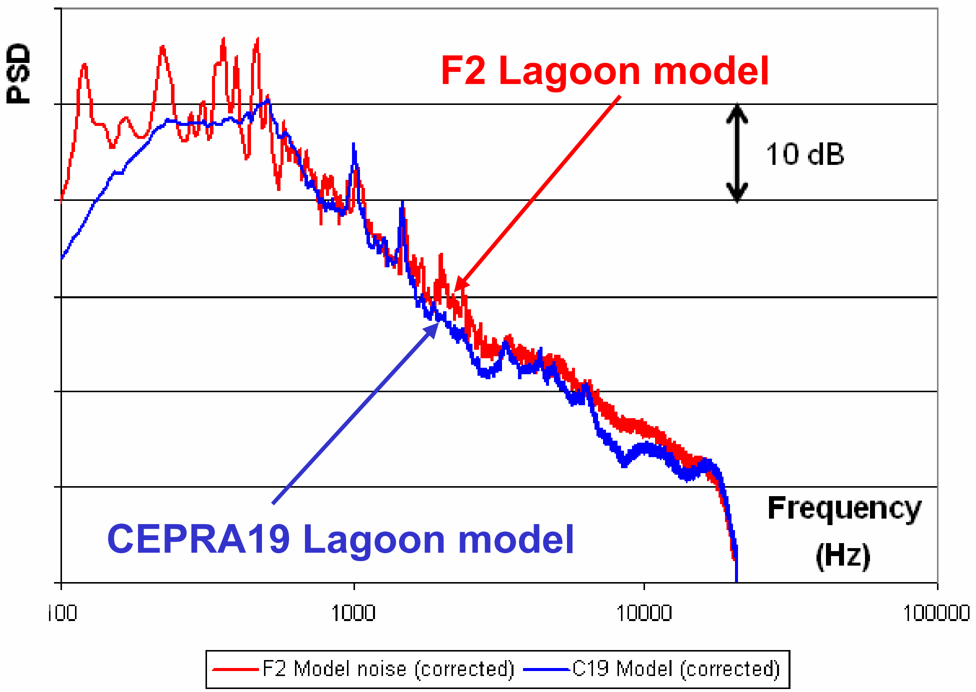


LAGOON model aerodynamic noise OASPL normalized by background noise

Comparison of “signal-to-noise” ratio in both facilities

Central microphone of sideline antenna





Signal-to-noise ratio (no corrections) :

CEPRA19 : 15 to 20 dB

F2 : 5 to 10 dB

PSD of LAGOON model aerodynamic noise corrected from :

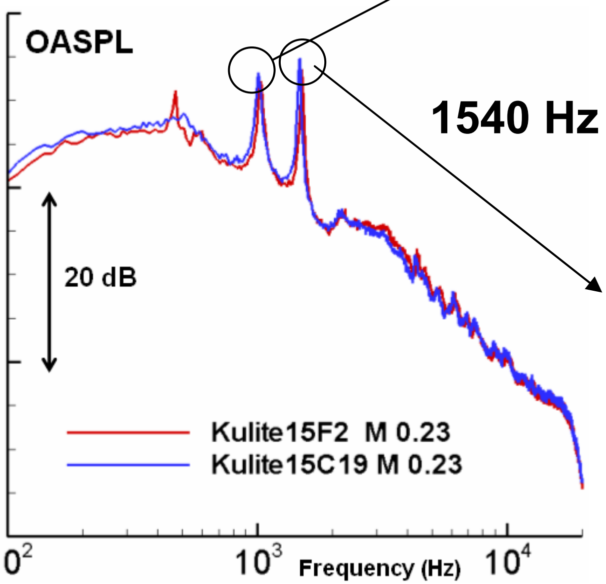
- **Model / microphone distance**
- **Background noise**

Noise maps using sideline acoustic antenna in F2 / CEPRA19
Classical beamforming maps

Noise peaks, independent of velocity, detected by Kulite sensors in the inner wheel cavity

1030 Hz

1540 Hz

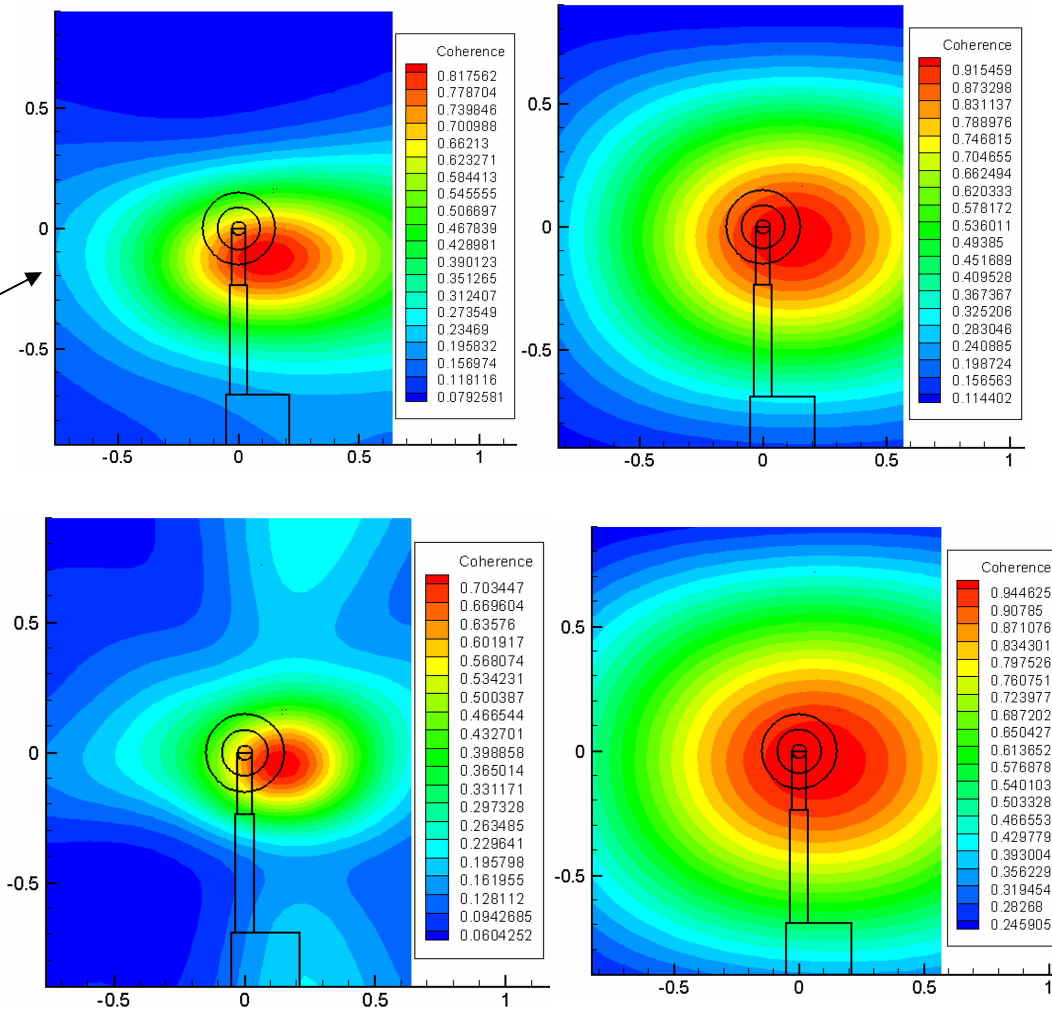


F2

CEPRA19

1030 Hz

1540 Hz



CEPRA19 vs. F2 : ⇒ **lower spatial resolution (larger distance from the model)**
⇒ **higher level of cohererence (lower background noise)**

DLR AIRBUS ONERA THE FRENCH AEROSPACE LAB

Conclusions

- LAGOON : a unique experimental effort combining
  - LG with simplified shape (applicable to large range of modelling methods)
  - Several aerodynamic device (large measurement area / cross checking)
  - Large amount of aerodynamic / acoustic data (formatting under progress)
- Aerodynamics : main trends of LG steady/unsteady flow
  - Strong three-dimensionality and turbulence levels → consequences on all measurements device
  - Reasonable identification of mean flows in both facilities → slight differences, but considered to have little effects on acoustics
  - Will give more insights in physics of LG aerodynamic noise generation
- Acoustics
  - Evaluation of signal-to-noise ratio in both facilities
  - Absolute acoustic levels considered as reliable in CEPRA19
- Perspectives : LAGOON will provide an extensive aeroacoustic database for the validation of various unsteady CFD and CAA activities,
  - to the LAGOON partners (DLR, SoU, ONERA, Airbus)
  - to others via contribution to benchmark activities …

Proposal of contribution to the on-going Benchmark on Airframe Noise Prediction organized by NASA

- Airbus recently decided to make the LAGOON database available to the aeroacoustics community, including :
  - Model shape (CAD)
  - Measurements results (steady/unsteady aerodynamics, acoustics → exact nature of data to be defined with Airbus and workshop organizers)

- On behalf of Airbus, ONERA will take over the contacts with the organizers and any interested contributor

- Unformal agreement by organizers (M. Khorrami, M. Choudhari, D. Lockard)
  - Brings balance between two other (already proposed) LG test cases : (realistic Gulfstream LG and simplified Boeing 4-wheel LG)

- Possible agenda
  - Somewhat late for immediate proposal with a view to presentation of results in May 2010 (16th AIAA Aeroacoustics in Stockholm)
  - More likely : present and propose the test-case in May 2010 to allow contributors to show results in 2011 (17th AIAA Aeroacoustics ?)