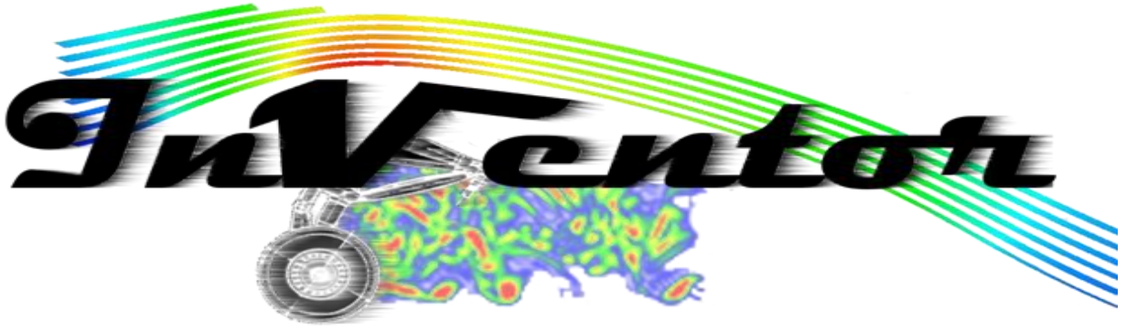


Flow permeable materials for landing gear noise reduction

Francesco Avallone
Delft University of Technology

Contributors to the presentation:
Daniele Ragni, Alexandros Koutsoukos, Marc Terracol, Miro Gondrum, Matthias Meinke, Shuai Li, Lars Davidson, Shia-Hui Peng

The INVENTOR project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 860538



INnoVative DEsign of INstalled Airframe ComponenTs For Aircraft NOise Reduction

AIRBUS SAFRAN LANDING SYSTEMS DASSAULT AVIATION University of Southampton RWTH AACHEN UNIVERSITY Trinity College Dublin Coláiste na Tríonóide, Baile Átha Cliath The University of Dublin

University of BRISTOL CHALMERS nlr TU Delft Delft University of Technology ONERA THE FRENCH AEROSPACE LAB

DLR von KARMAN INSTITUTE FOR FLUID DYNAMICS CERFACS ERDYN Anticipate Act Assess upstream CFD

Key Objectives

- Aeroacoustic investigation of quasi-**realistic landing gears** and **high-lift devices**.
- Benchmark **low-noise solutions** aiming at preserving the component performance.

Content

- The experimental setup and results
- Numerical simulation approaches and results
  - TUD
  - ONERA
  - RWTH
  - UTC
- Conclusions

Experimental setup and results

Simplified LAGOON wind tunnel model

A simplified LAGOON model has been developed with:

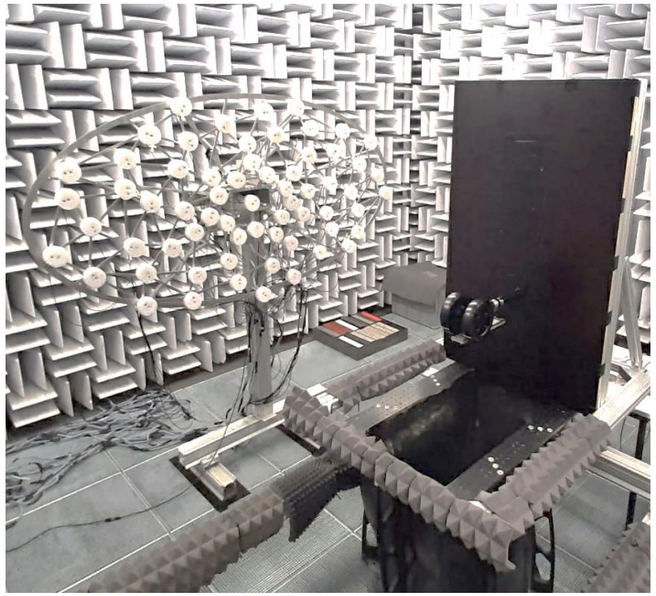
- **Wheels**
- **Torque-link**
- **Brakes**
- **Porous fairings**

Experimental study

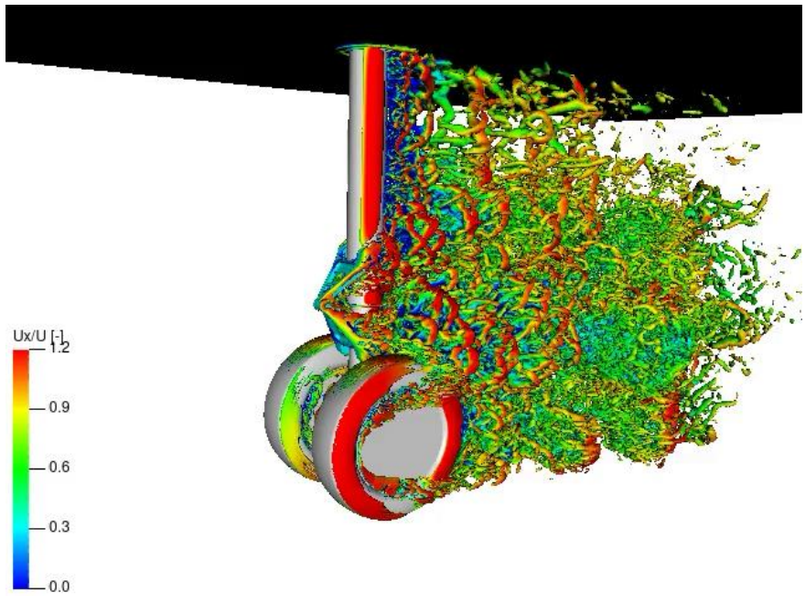
- ❑ Assessing the effects of each of the components
- ❑ Benchmarking of low-noise porous fairings

Numerical investigation

- ❑ Study the details of the noise generation mechanisms and aerodynamic interaction
- ❑ Comparison of fully-resolved geometries or equivalent fluid-models



TUD A-tunnel test

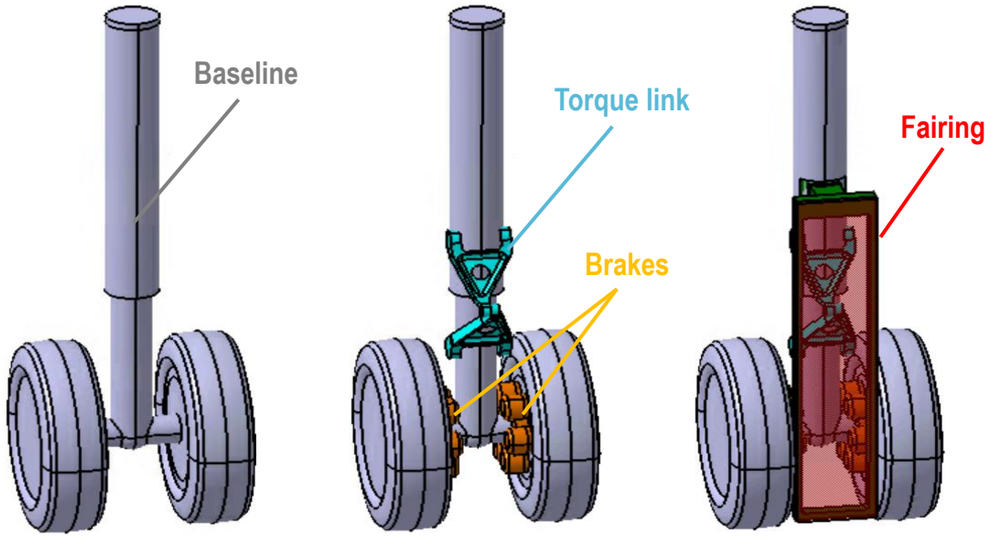


TUD LBM simulation

Simplified LAGOON wind tunnel model

Model specifications

Baseline model (BL):
original LAGOON landing gear (LG)
Components: **brakes (BK)** and **torque link (TL)**
Fairings: fully covering LG axle, brakes and torque link

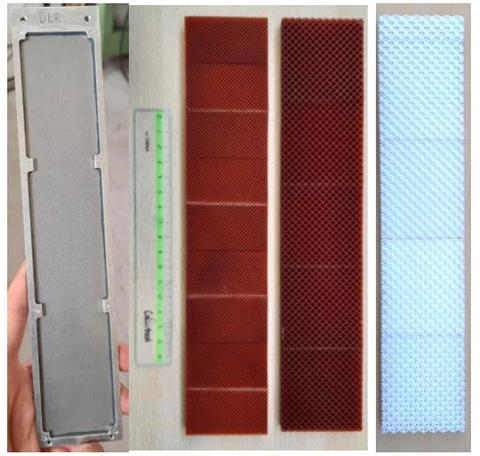


LAGOON LG configurations

Tested fairings

A total of **18 samples** were tested:

- 12 x DAV: metallic wool, straight/helical/oriented perforations
- 3 x TUD: diamond-lattice
- 2 x ONERA/DLR: wire mesh
- Fully solid



Porous Materials samples

Experimental setup

Noise Source Localization & Quantification

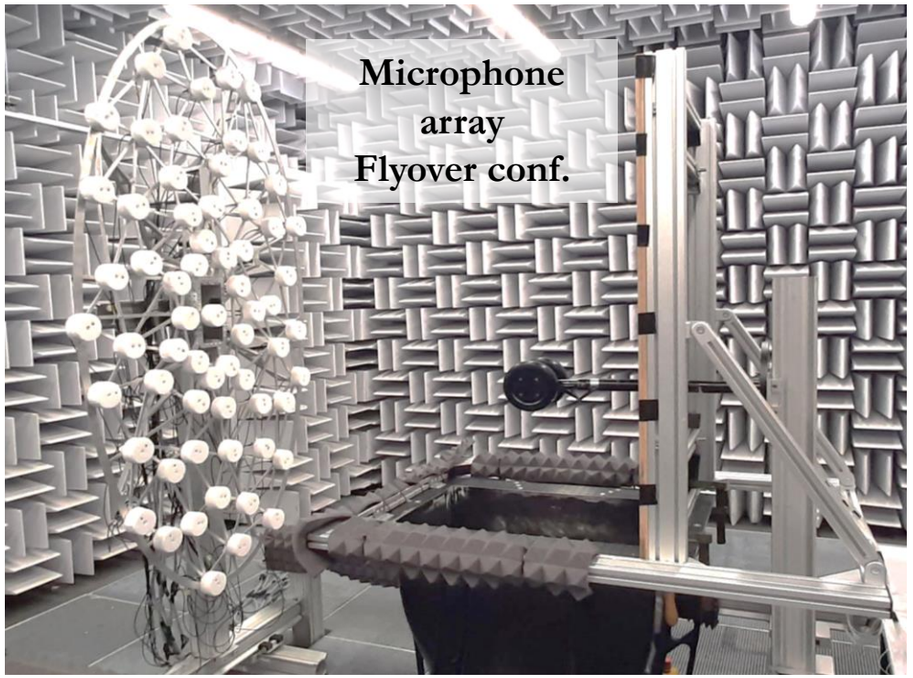
- Free-stream Velocity: 15, 25, 35 m/s
- 10 cm wheels in 40x70 cm^2
- Sampling rate: f_s = 51.2 kHz
- Acquisition time: T = 20 s
- Distance LG axle-microphone array:

  Flyover: 1.05 m

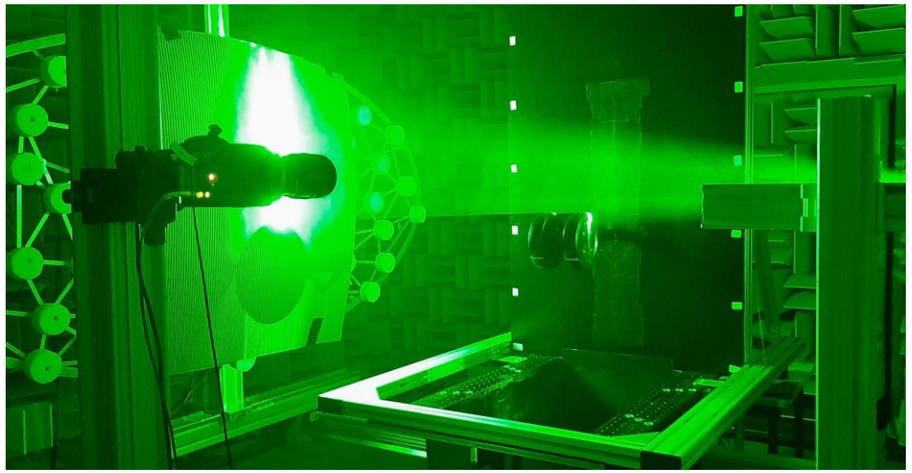
  Sideline: 1.36 m

Planar PIV (2D2C)+ Stereo PIV (2D3C)

- Free-stream Velocity: **35 m/s**
- 2 x LaVision Imager sCMOS, Quantel EverGreen Laser (200mJ/p)
- 1000 vector fields per test
- About 1mm spatial resolution
- FOV: 180 x 240 mm^2

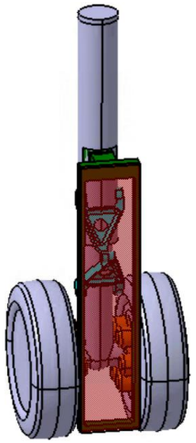


A-tunnel acoustic measurements

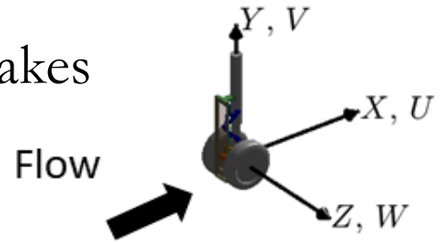


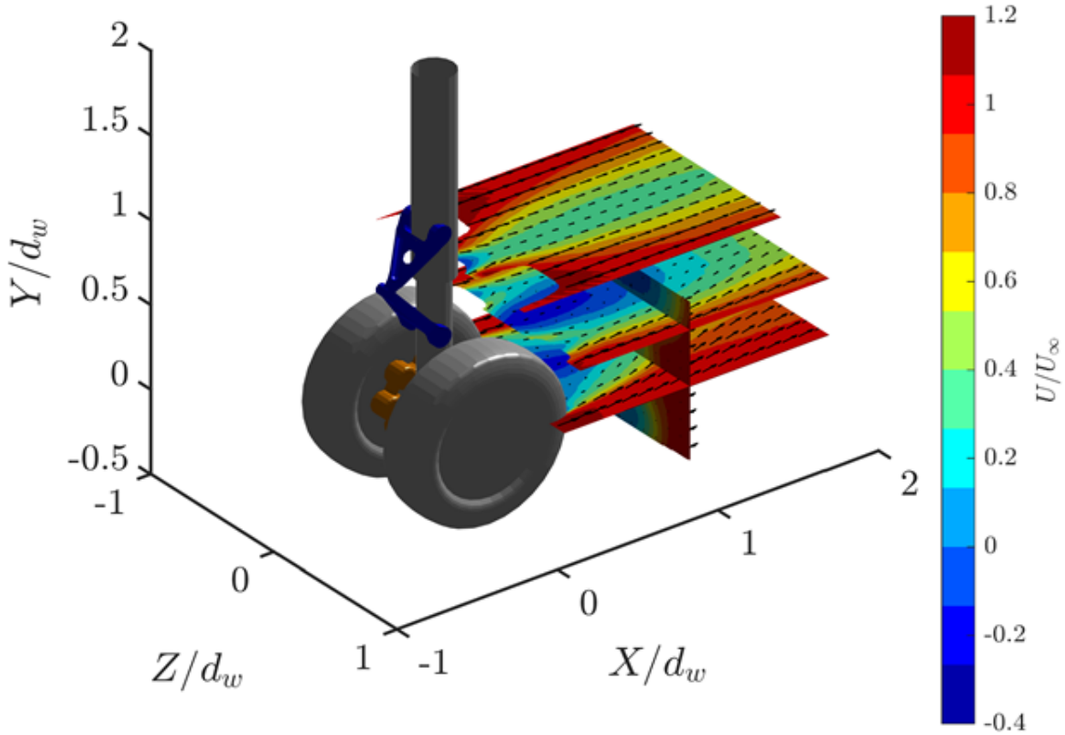
A-tunnel PIV measurements

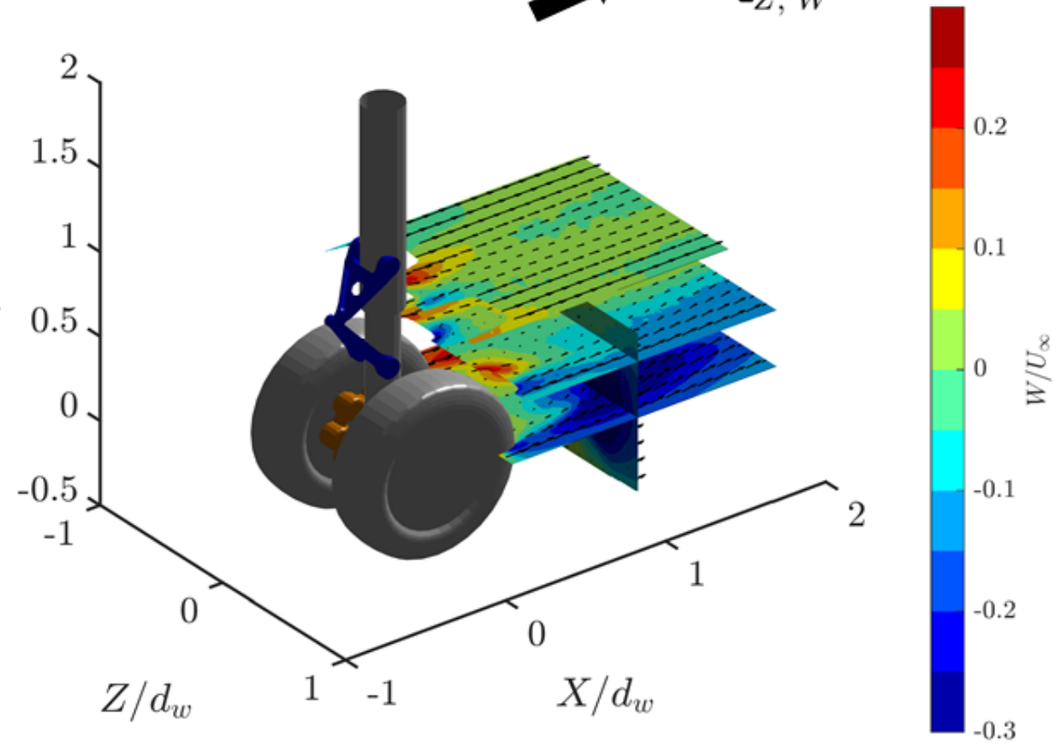
Experimental results – flow field



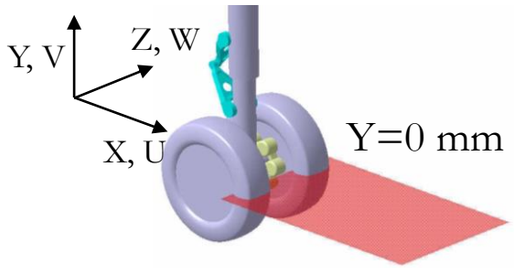
- Instantaneous vortical shedding visible from wheels, brakes and torque link
- Mean wake show acceleration around the wheels and low-speed wakes

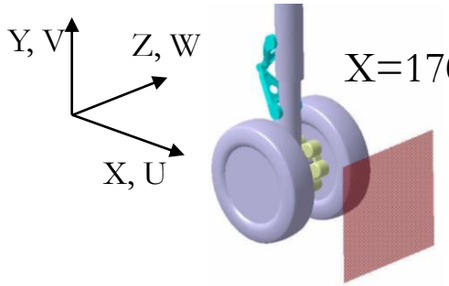






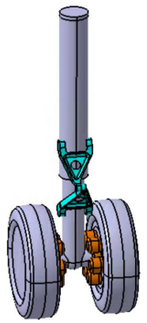
Experimental results – comparisons

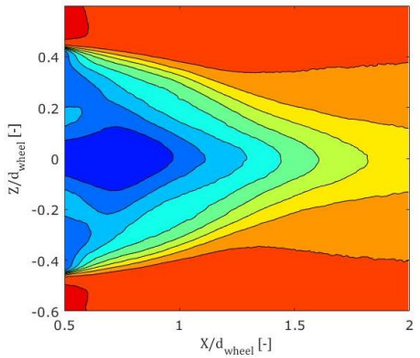


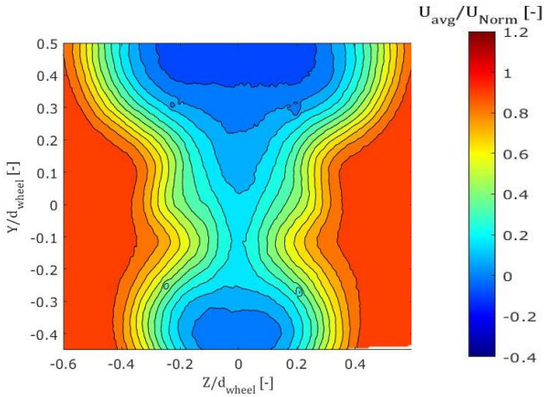


The fairing enhances the **wake deficit**

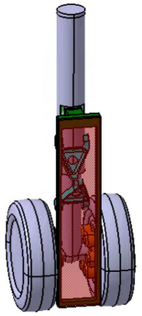
Baseline

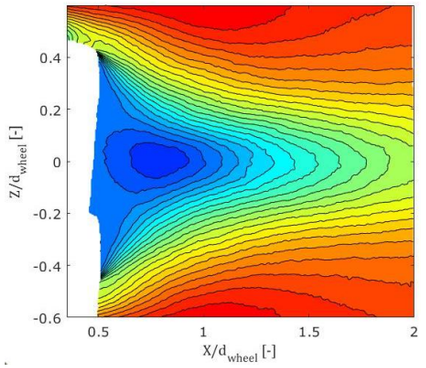


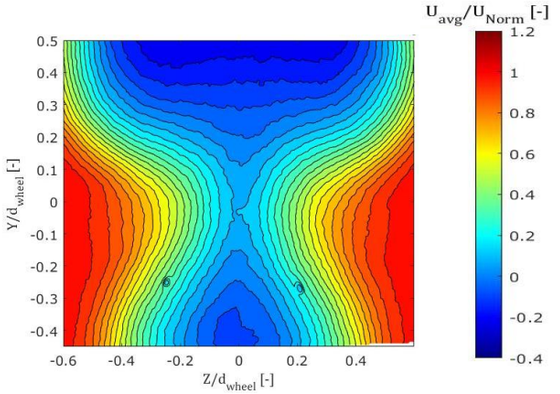




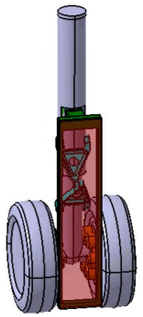
Solid Fairing

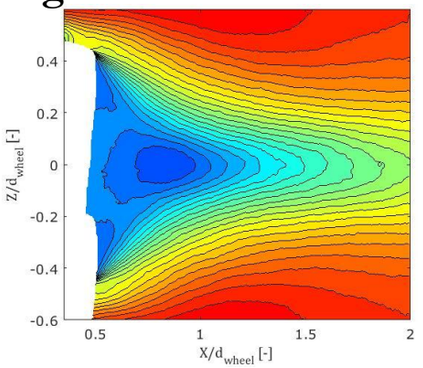


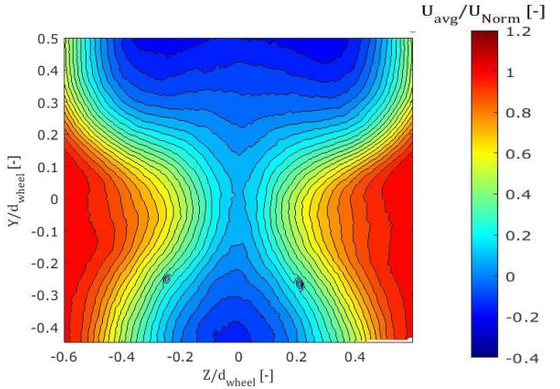


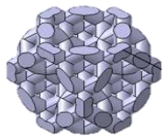


Diamond Fairing





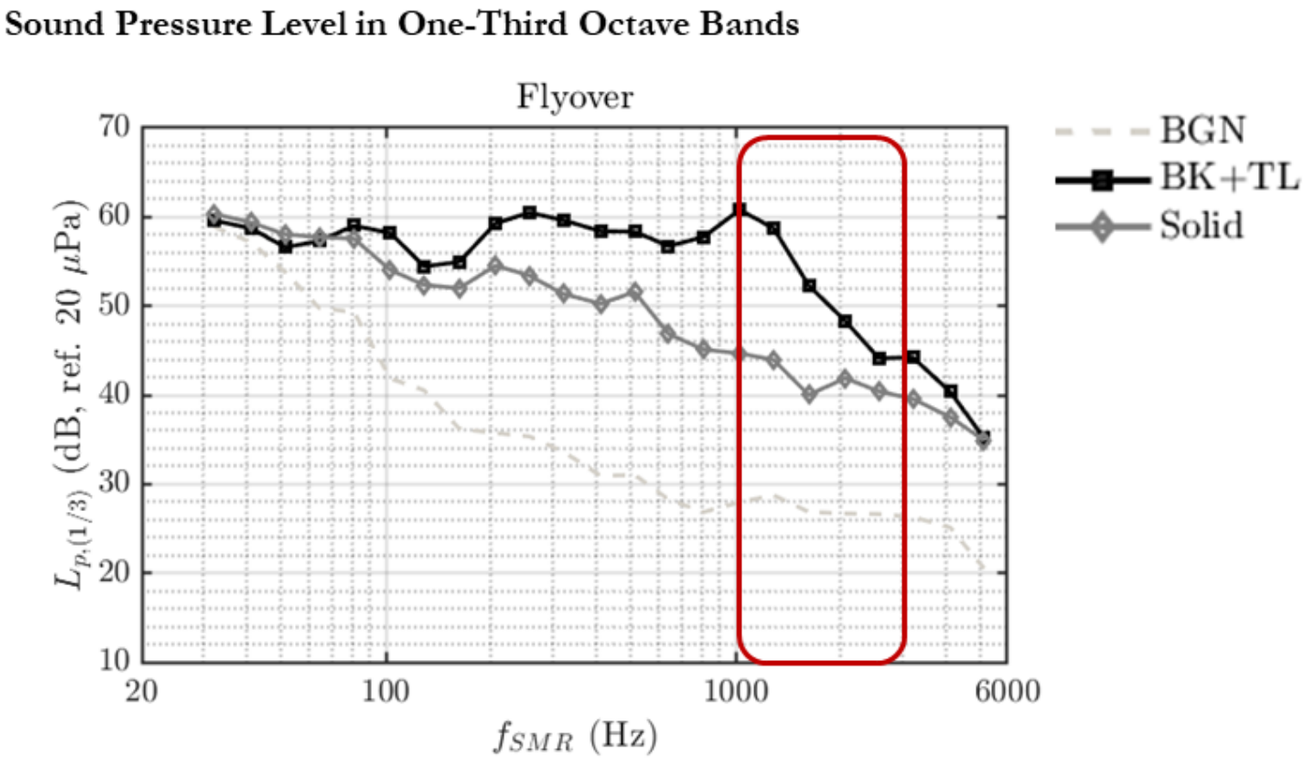




Cell size 2.5 mm

Experimental results – far-field noise

The solid fairing reduces the noise, by inhibiting the shedding of the different components

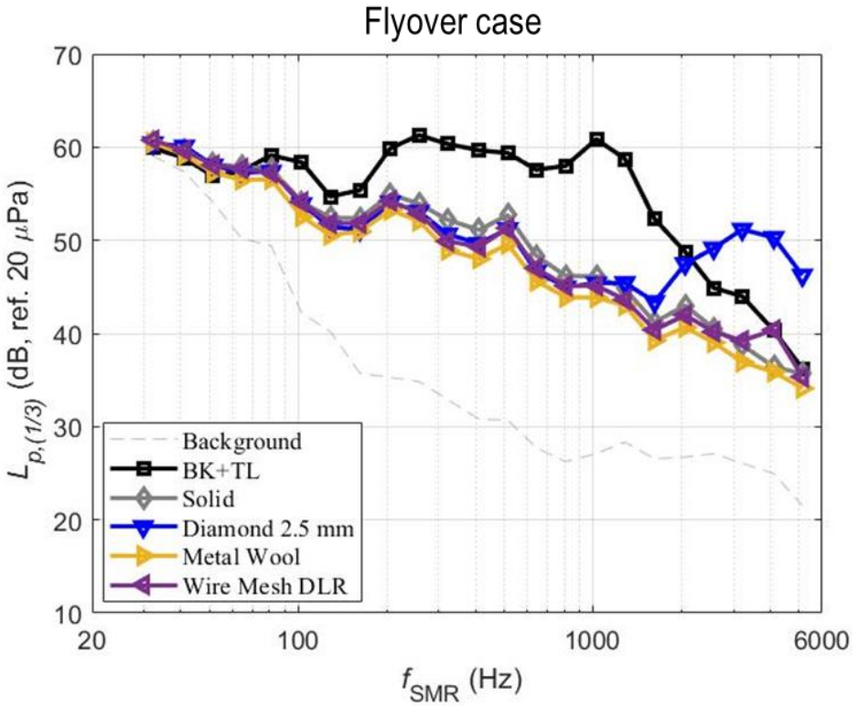


Frequency range scaled to Short Medium Range Aircraft level following ($U = 72$ m/s; $d_w = 1.2$ m)

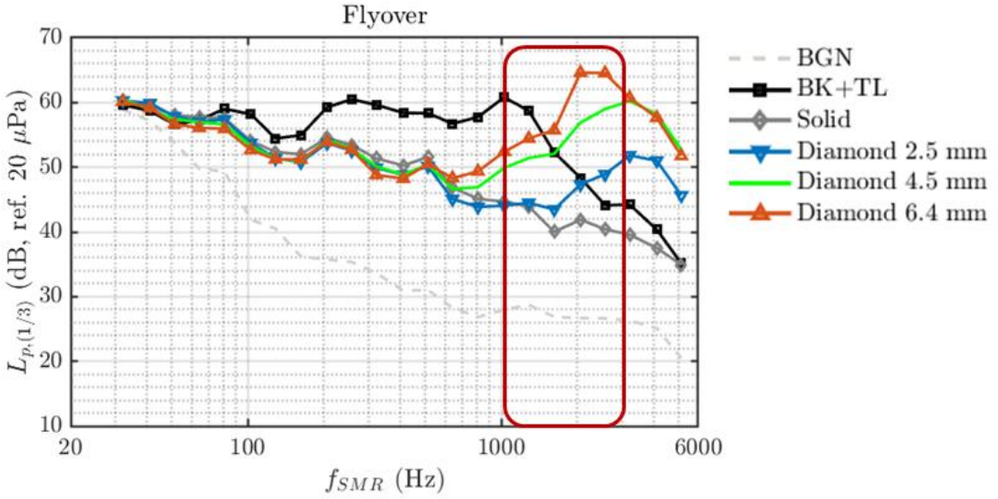
Experimental results – far-field noise

Top Aeroacoustic performers :

- ❑ Wire mesh (DLR WM) fairing
- ❑ Metal wool fairing
- ❑ Diamond-lattice fairing (2.5mm)







Frequency range scaled to Short Medium Range Aircraft level following (U = 72 m/s; d_w = 1.2 m)

Numerical approaches and results

Numerical setup

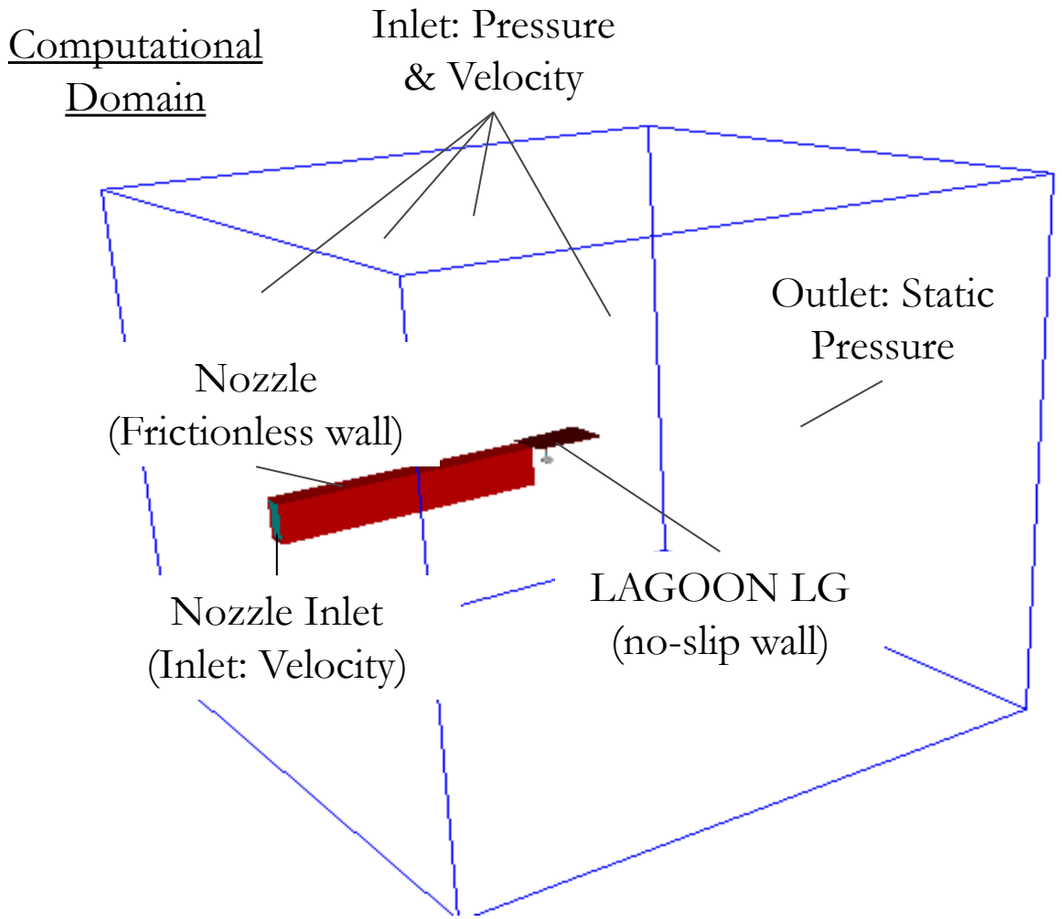


Solver: LBM-VLES 3DS PowerFLOW

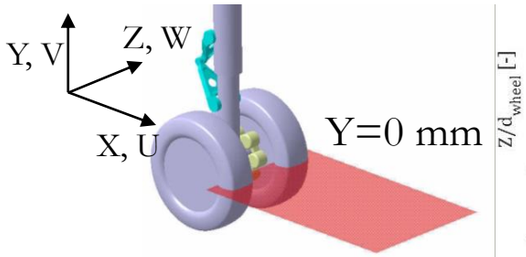
Domain Dimensions

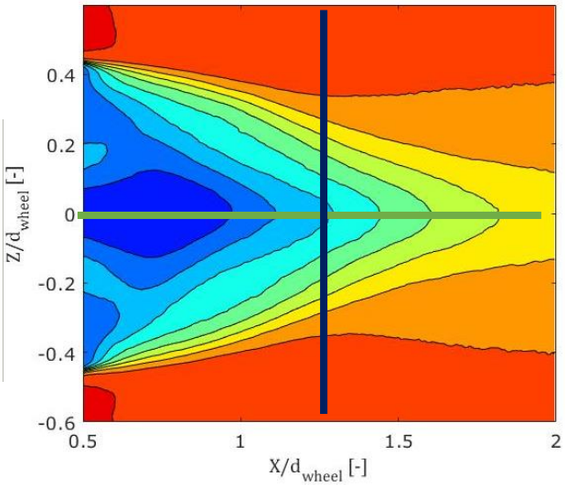
- Nozzle Length: 4.5 m
- Computational Domain: 70×70×70 [m × m × m]

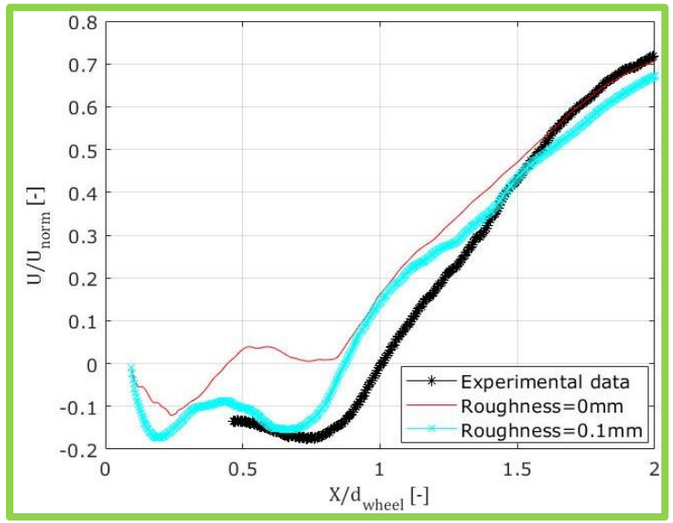
p_∞ [Pa]	100700
ϱ_∞ [kg/m^3]	1.21
U_∞ [m/s]	34.7
Turbulence length [m]	0.0001
M_∞	0.1019
ReD (10^5)	3.56
Roughness [mm]	0.1

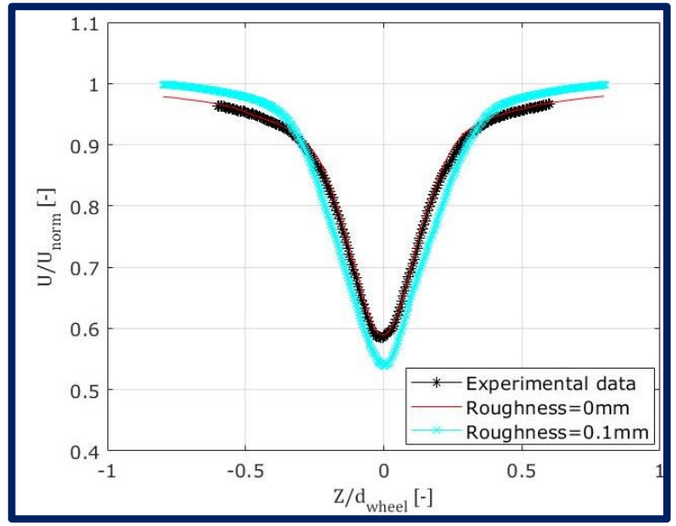


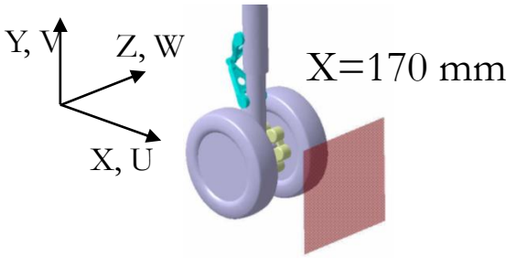
Time-averaged flow field

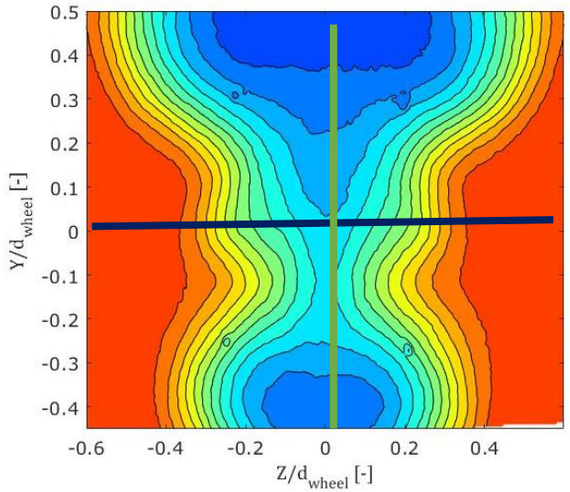


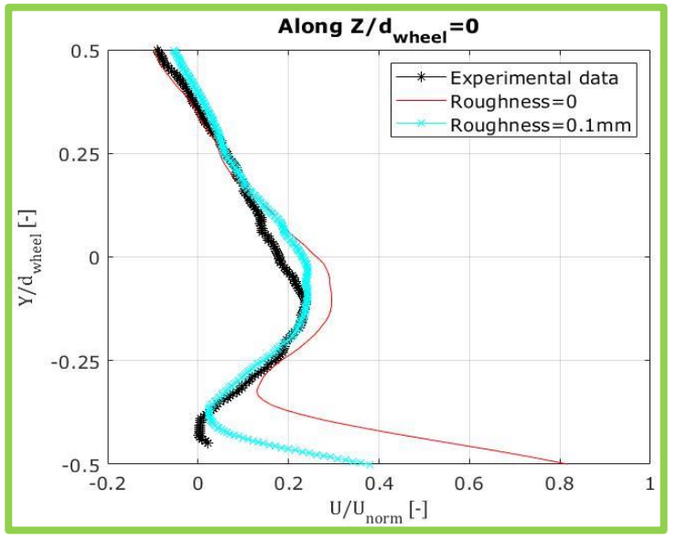


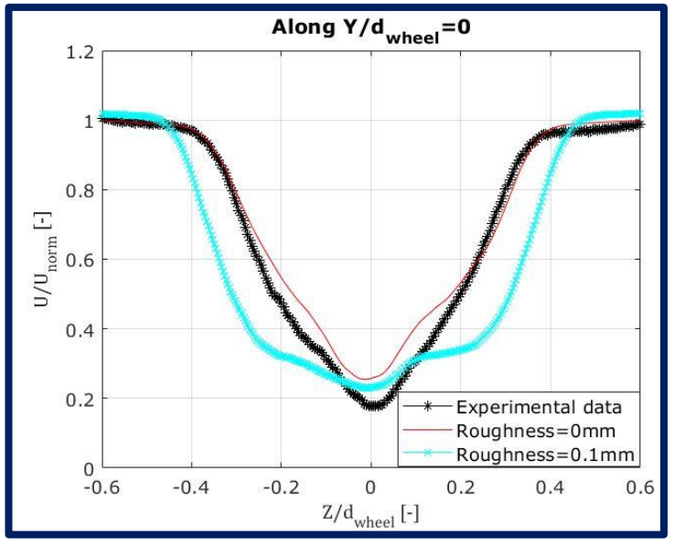






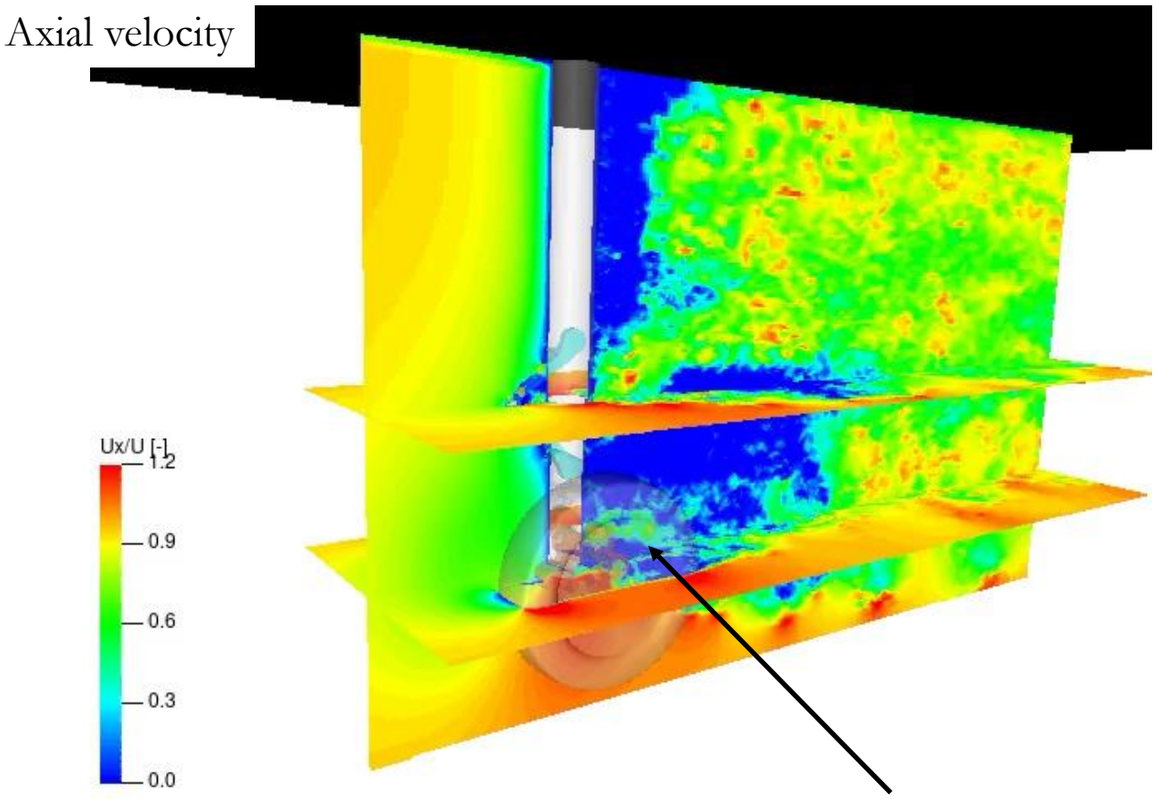






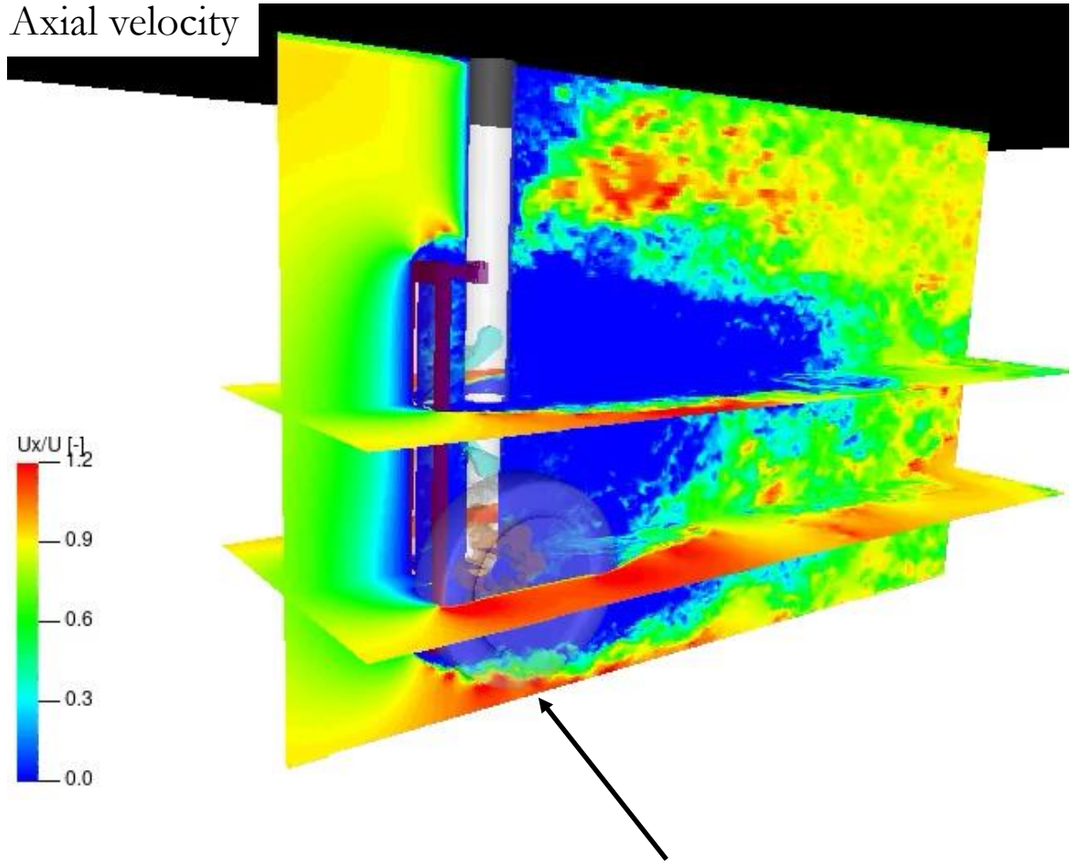
Instantaneous flow field w/o fairing

Baseline



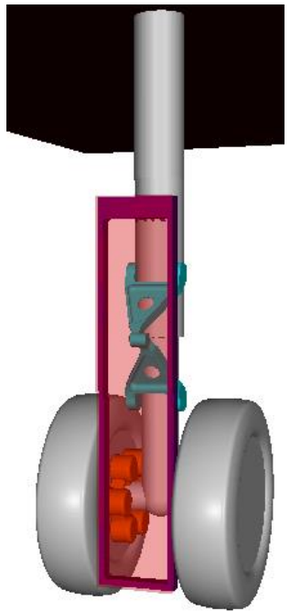
Flow mixing downstream the torque link and brakes and at the wheels and at the axle.

Solid fairing



Shear layers detachment due to the solid fairing.

Equivalent fluid model characterization



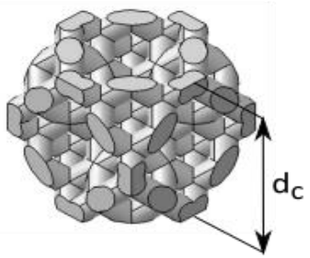
Volume of the fairing to be modelled in PowerFLOW as an acoustic porous medium (APM):

Porosity $\varphi = 0.614$

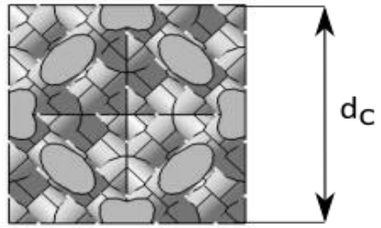
d_c (mm)	Por. (%)	d_{strut} (mm)	d_{pore} (mm)	R_v (1/s)	R_i (1/m)
2.5	61.7	0.412	0.472	4,431	15,320

Viscous resistivity

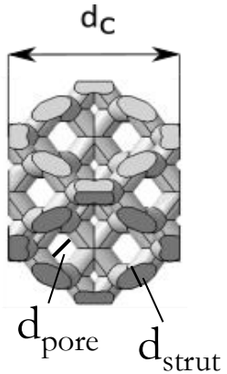
Inertial resistivity



iso



front/side/top

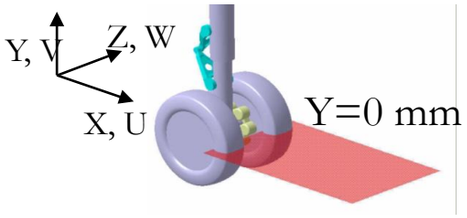


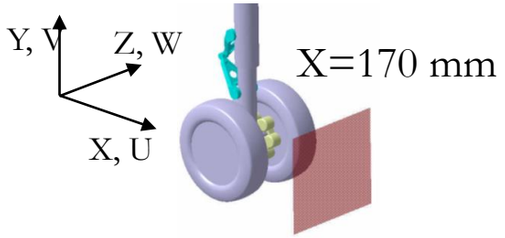
45 deg.

Diamond unit cell definition

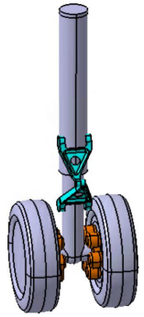
- No surface roughness
- Uniform+homogeneous fluid region

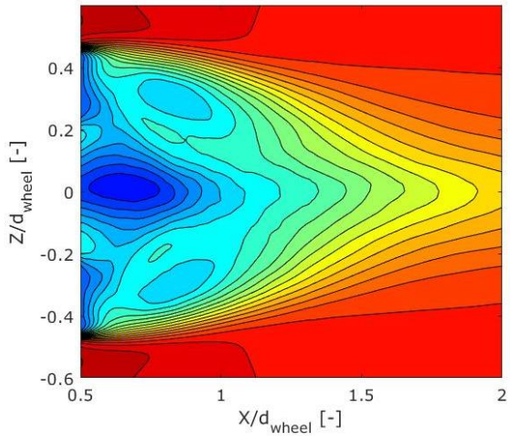
Time-averaged flow field w/o fairing

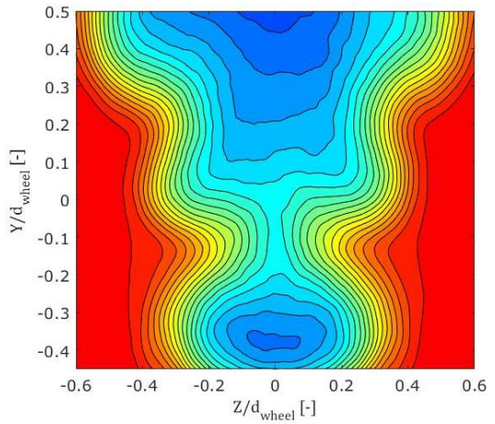


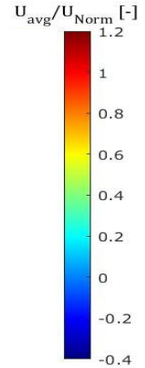


Baseline

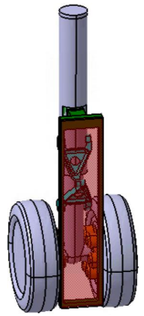


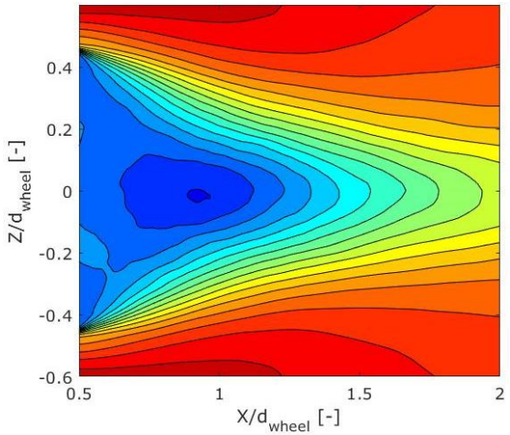


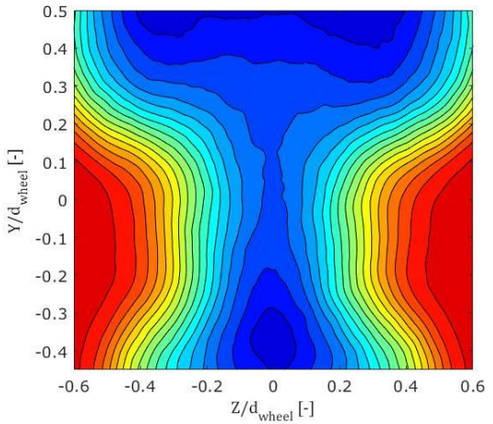


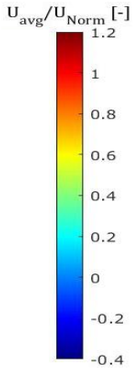


Diamond fairing-FEM





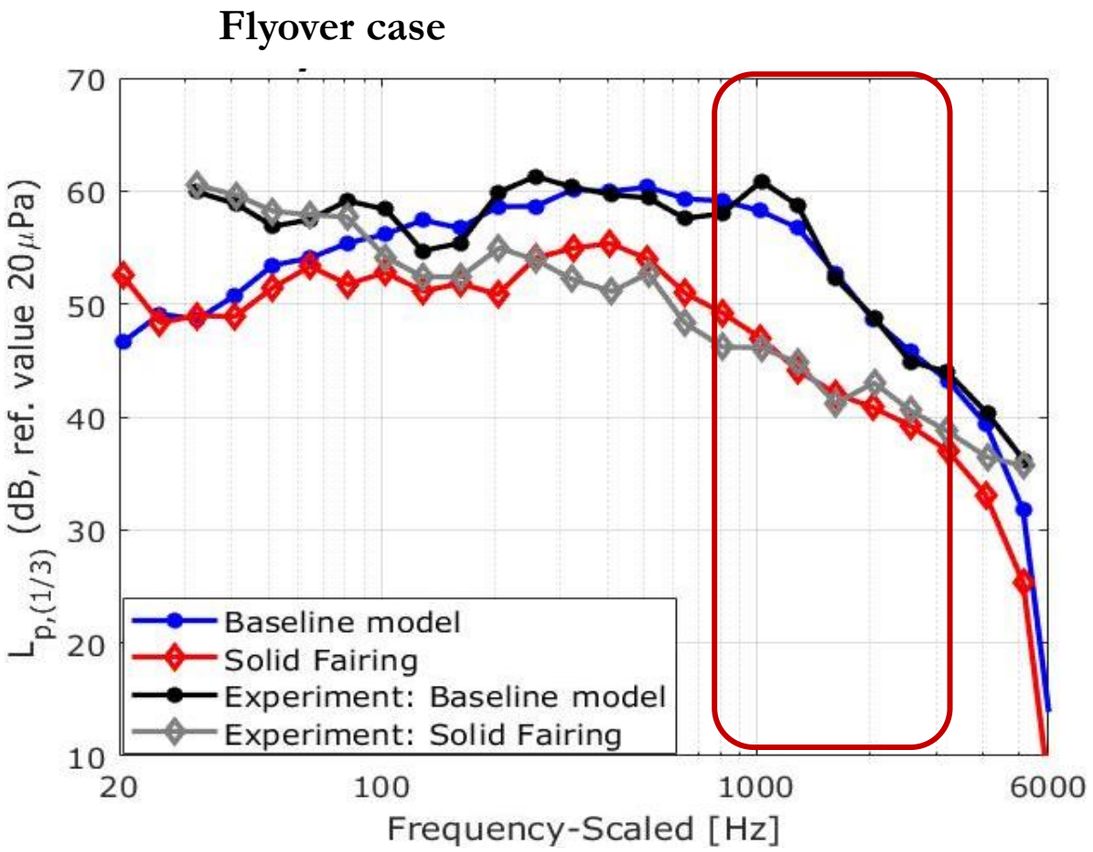


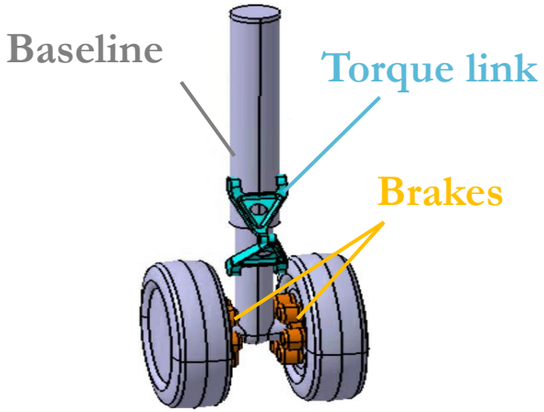


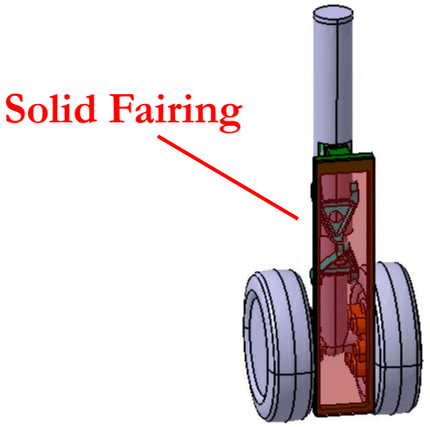
Similar velocity contours with the experiments.

Different low-velocity area behind the wheels attributed to the different flow mixing in the vicinity of brakes and torque link, resulting in larger recirculation (more negative velocity values).

Far-field noise

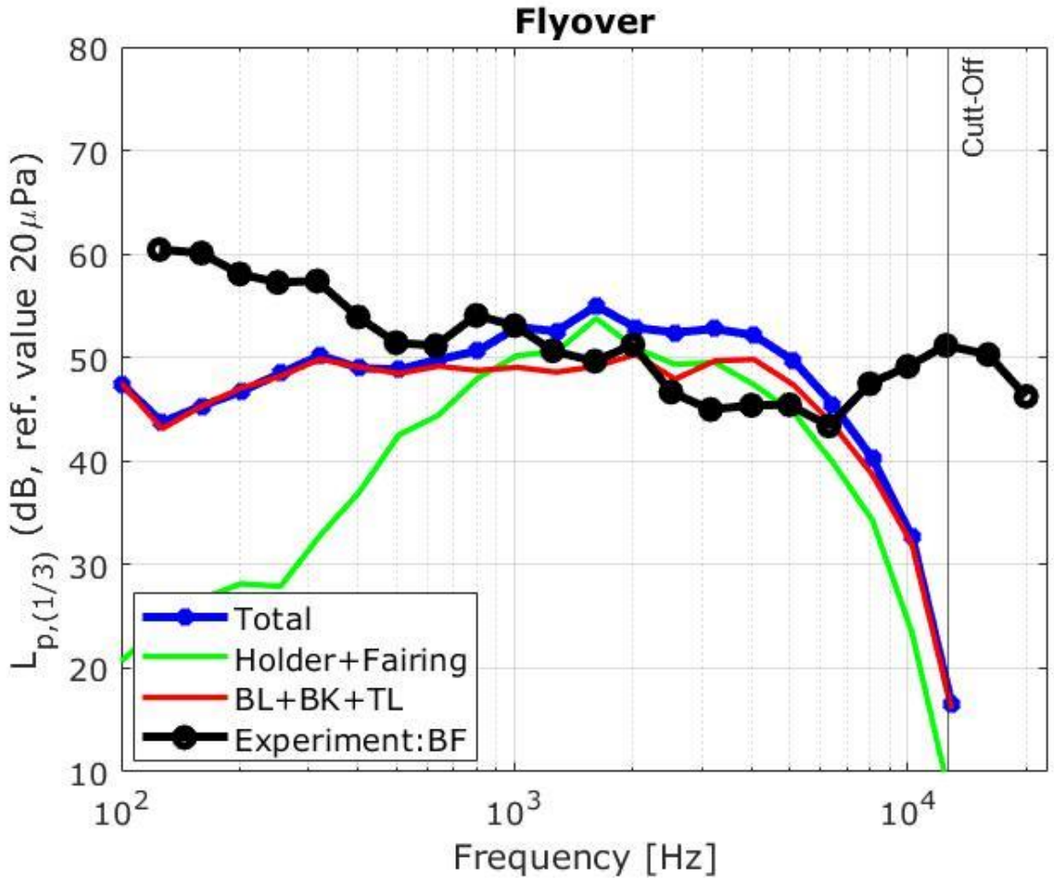


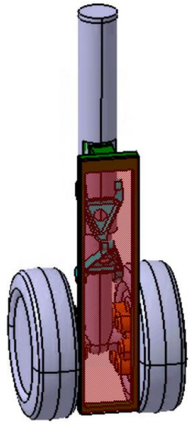




- Good agreement between solid surface formulation and experiments, 12dB noise reduction in solid-fairing model.
- Baseline model: Axle+Wheels+Brakes are the dominant noise source. Brakes and Torque links contribute to noise enhancement in high frequencies.
- Solid-fairing: Holder+Solid fairing equal contribution as Baseline model (axle+wheels).

Far-field noise with porous fairing





Diamond Cell Fairing

Major difference of the two spectrum is noticed in the high frequency regime where the experimental increase is not observed in the numerical case.

The Equivalent model is not able to properly compute the high-frequency behaviour of the actual diamond fairing.

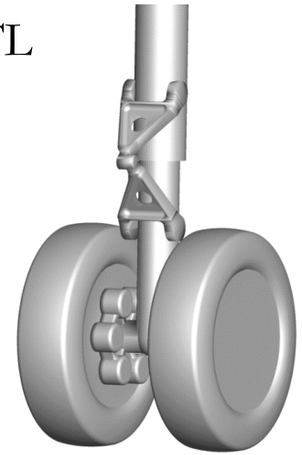
Is this increase related to the wake flow between the pores?

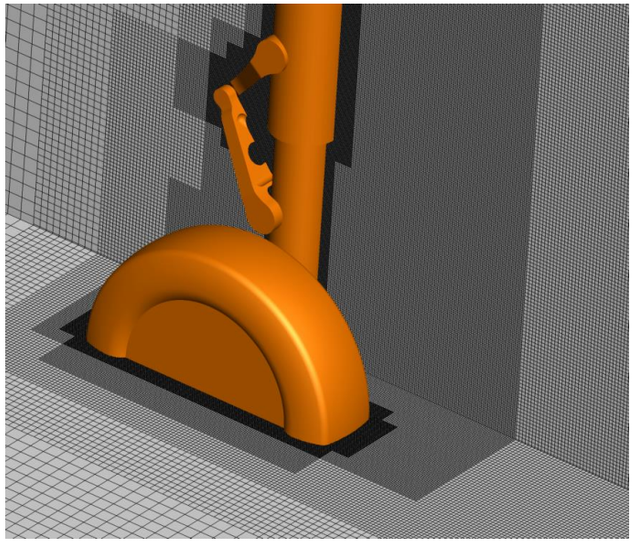
ONERA's simulation strategy

Numerical method

- In-house ONERA's FUNk Finite-Volume solver
- ZDES 2020 approach (*Deck & Renard. Towards an enhanced protection of attached boundary layers in hybrid RANS/LES methods. JCP, 2020)*
- IBC on Octree Cartesian grids
- Adapted SA wall law (+Laminar wall law where necessary)

LG+BK+TL





Flow-through fairings modeling

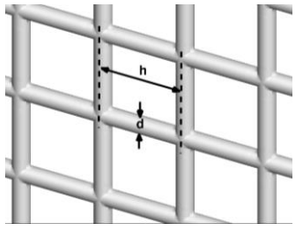
Reconstruction of flow variables at the wire mesh surface, as an additional Immersed Boundary

1 - Pressure drop across the wire mesh $K \simeq \left(0.5 + 26 Re_d^{-1}\right) \dfrac{1-\beta^2}{\beta^2}$

2 - Velocity components: normal flow rate conservation + flow deflection

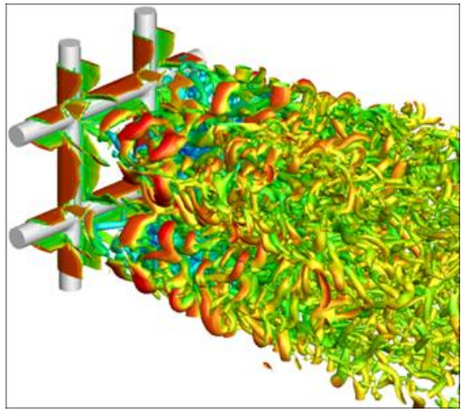
$$\Delta_v = \frac{u_{t,down}}{u_{t,up}} \simeq \left[\left(\frac{K}{4}\right)^2 + 1\right]^{\frac{1}{2}} - \frac{K}{4}$$

3 – Turbulent viscosity: mixing length model $\mu_t = \rho\, C_t \cdot d \cdot |u_w|$



C_t=0.065
calibrated with DNS

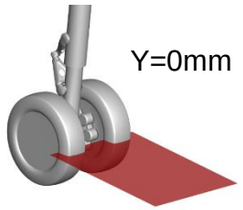
DNS



ZDES of the Baseline configuration

Δx_{min}=0.5mm
SA WL

ONERA
THE FRENCH AEROSPACE LAB



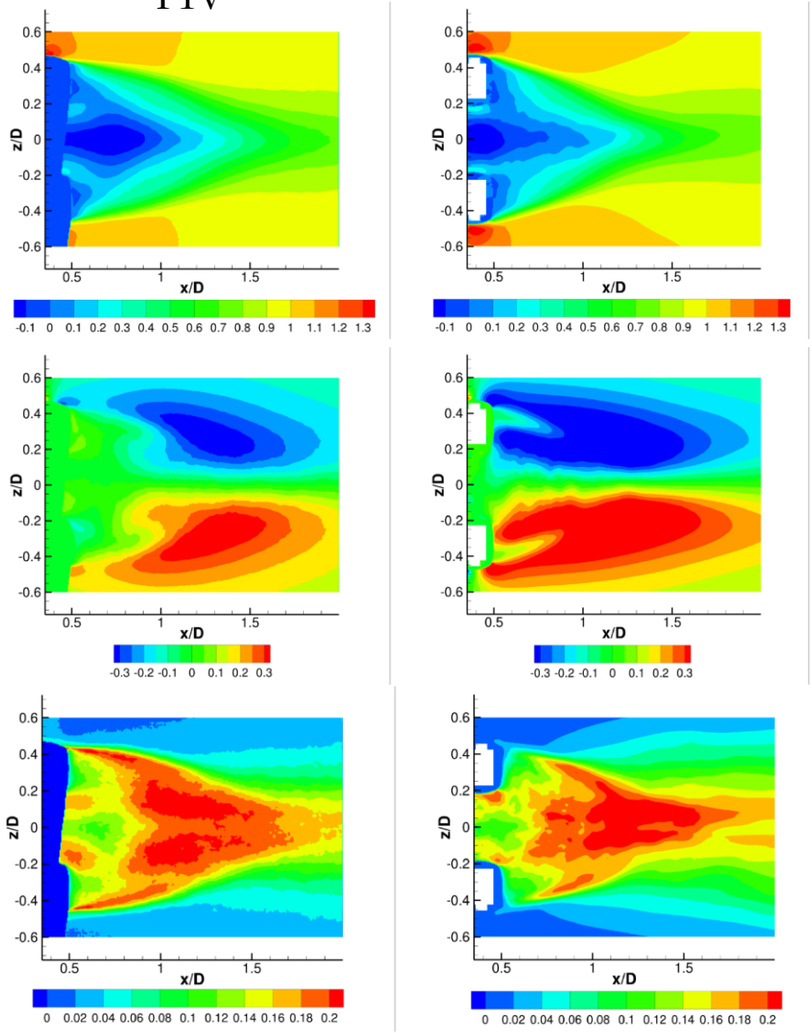
PIV

Simulation

U

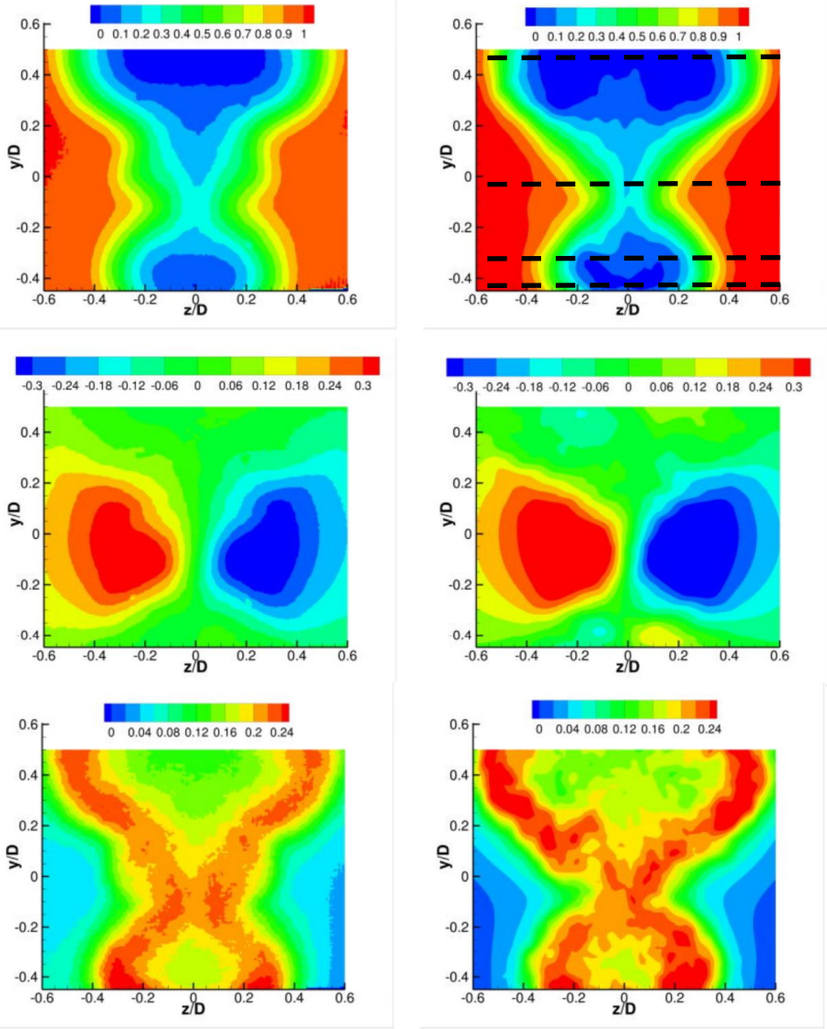
W

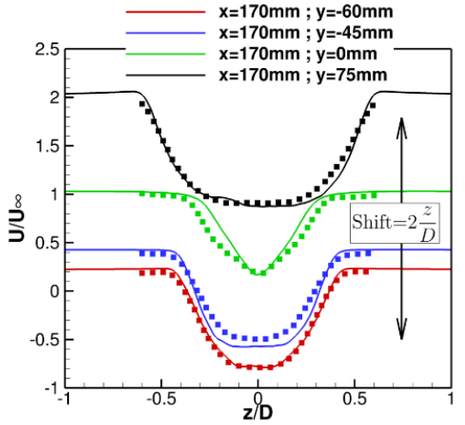
u'

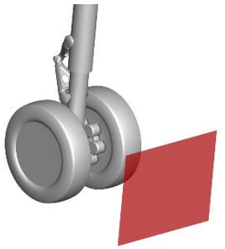


PIV

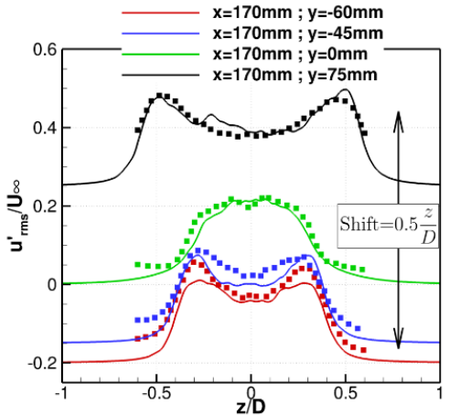
Simulation







X=170mm

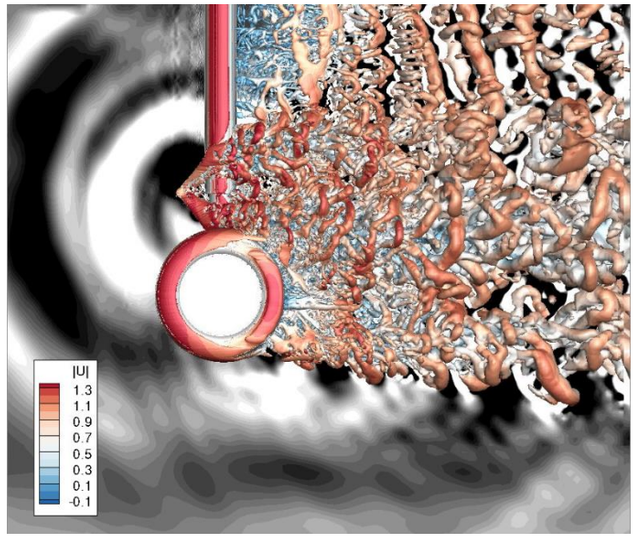


ZDES with fairings

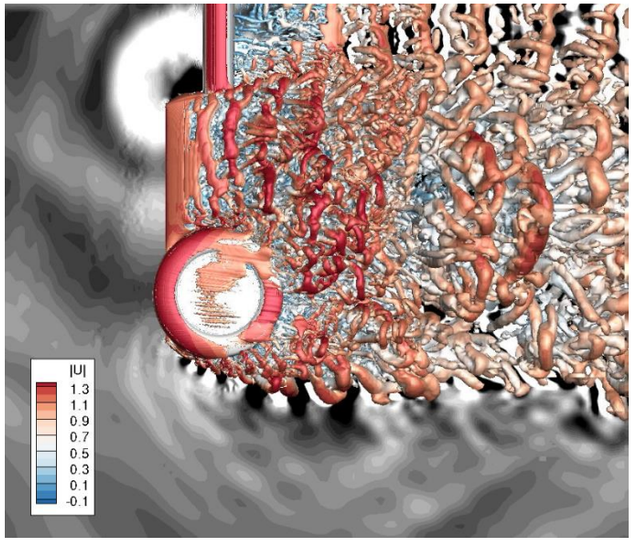
Δx_{min}=0.5mm
SA WL

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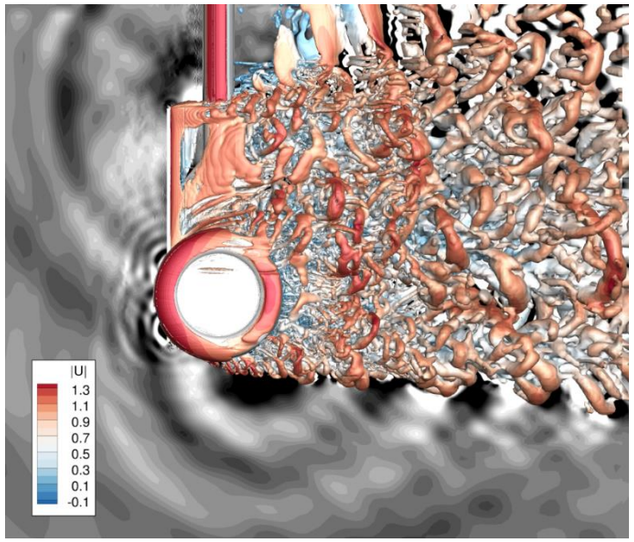
Baseline



Solid fairing

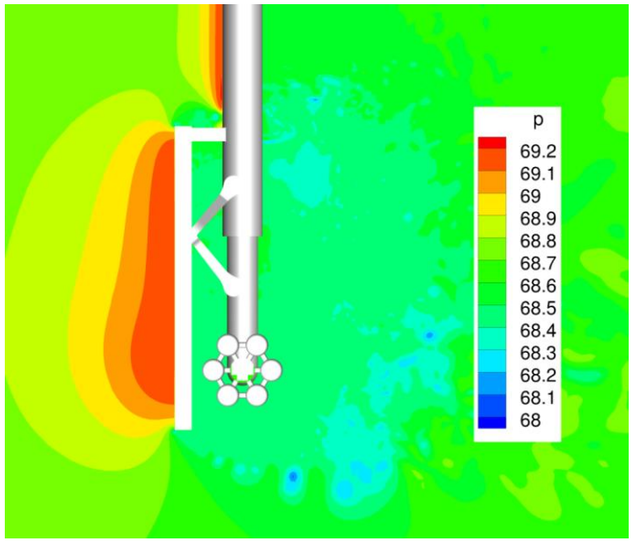


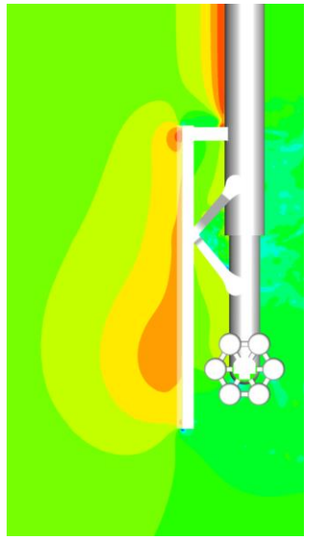
DLR wiremesh

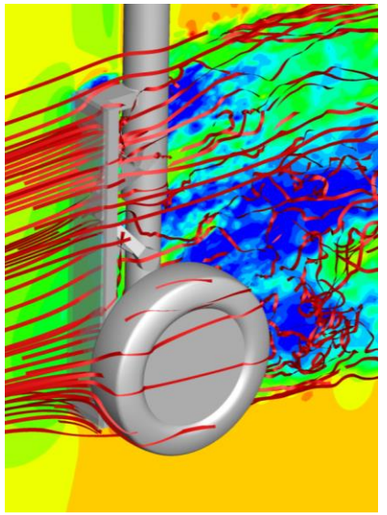


- Simulations of the controlled configuration: (Solid Fairing or Wire meshes (DLR & ONERA)

- TL noise is suppressed
- Secondary source at the support/leg junction
- Qualitative good behavior of the porous fairing: lower pressure drop vs solid fairing

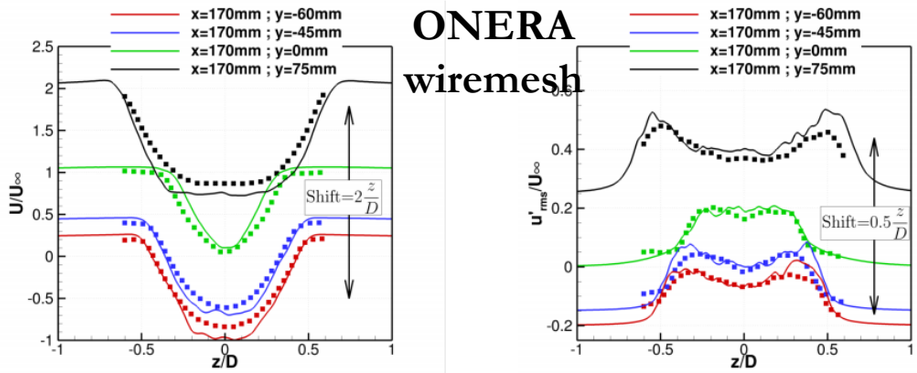




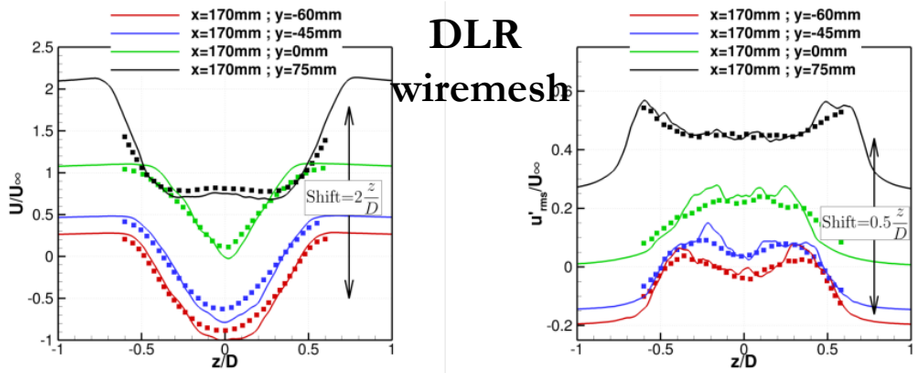


ZDES with fairings

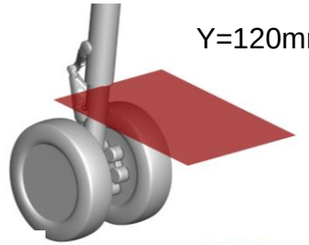
- Quantitative assessment w.r.t PIV measurements is very satisfyning
- DLR wiremesh's behavior is very close to the solid fairing's one (strong velocity decrease downstream of the fairing/torque link)



ONERA wiremesh



DLR wiremesh

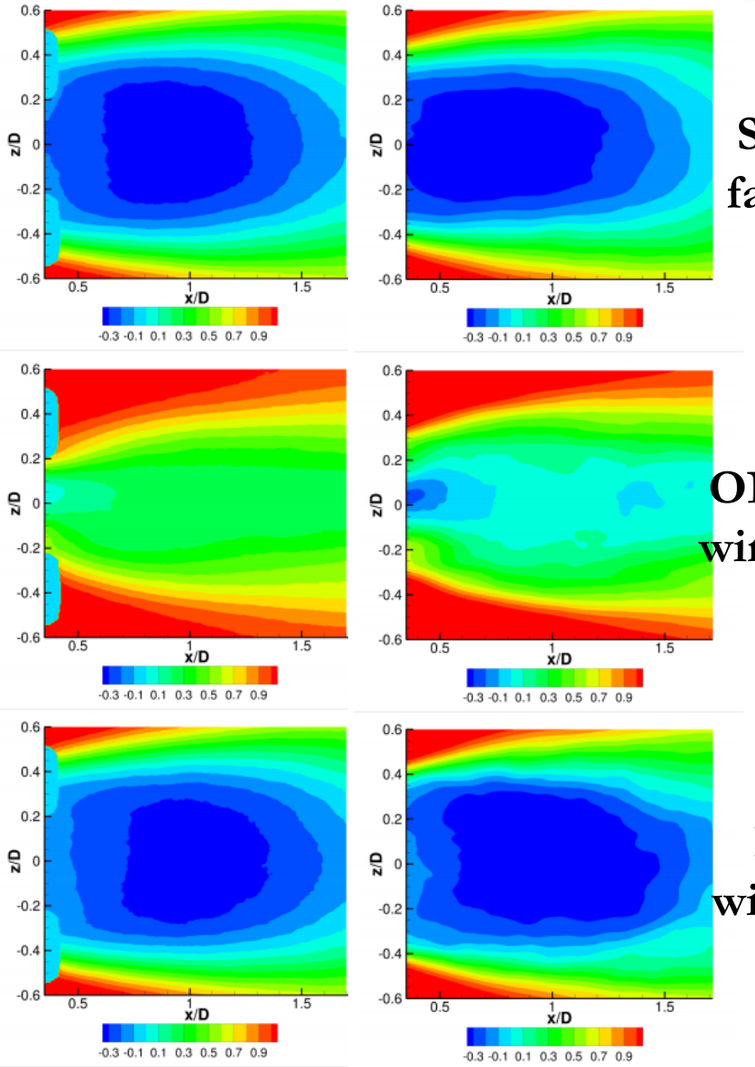


PIV | Simulation | PIV | Simulation

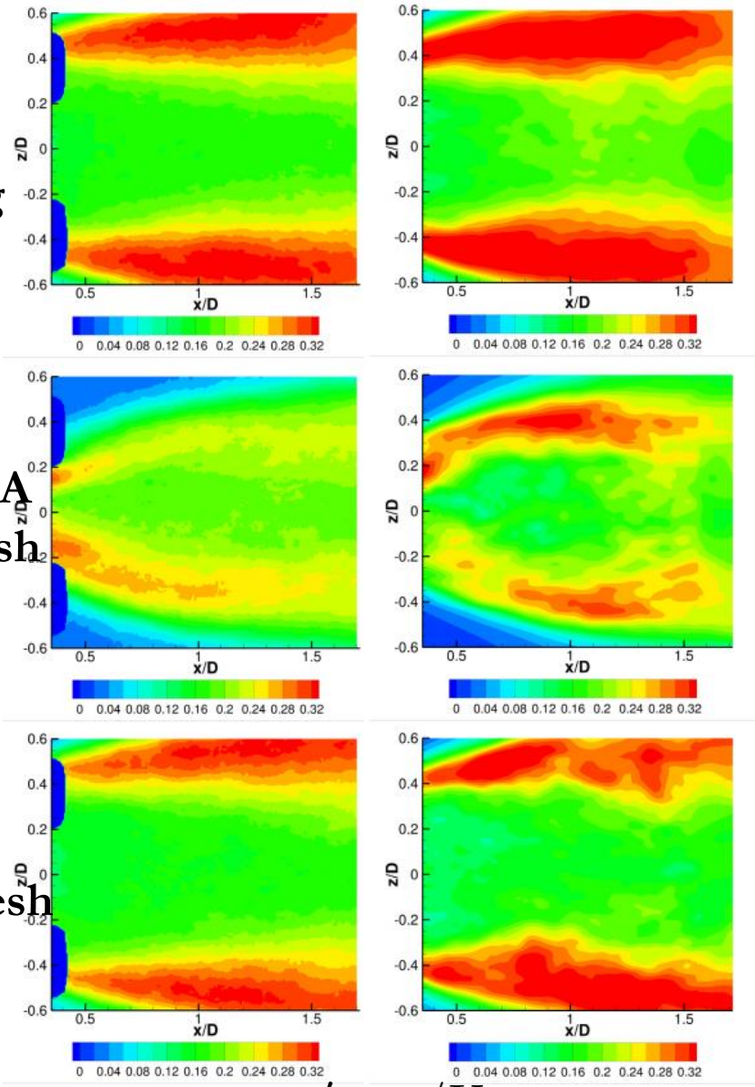
Solid fairing

ONERA wiremesh

DLR wiremesh



U/U_∞



u'_{RMS}/U_∞

Numerical method and setup

CFD: Lattice Boltzmann method

- Collison step based on countable cumulants
- Sponge region on coarsest grid refinement level

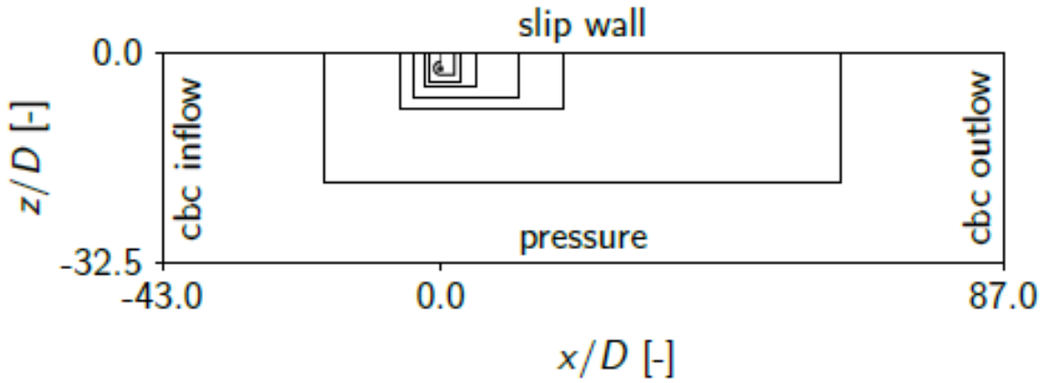
Grid resolution study

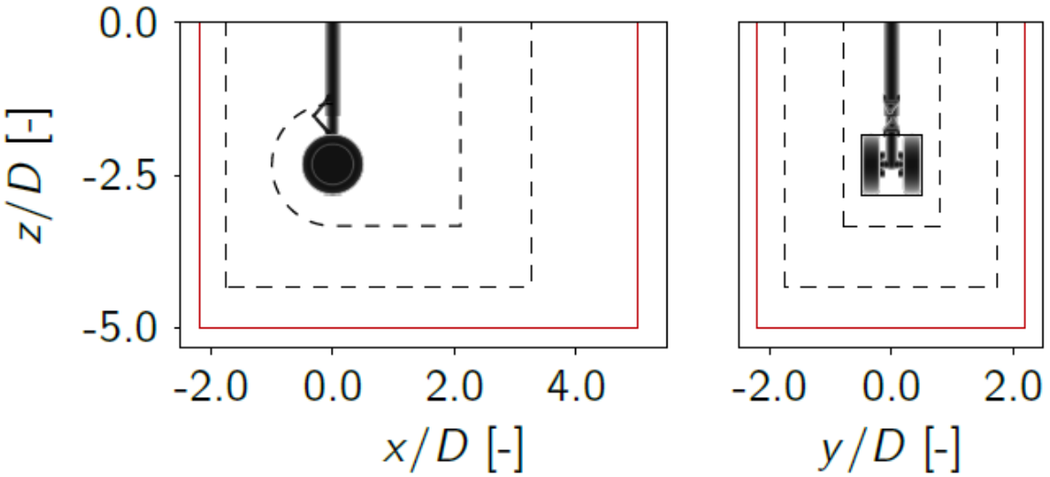
Grid	noCells/D	dt [s]	noCells
coarse	252	1e-06	150 million
medium	504	5e-07	200 million
fine	1008	2.5e-07	705 million

CAA: Ffowcs Williams and Hawkings method

- Solved in frequency domain

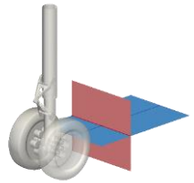
Δx_{fwh}	noElem.	noDataPoints	Storage
0.02 D	738,400	1.8e10	345.6 GB







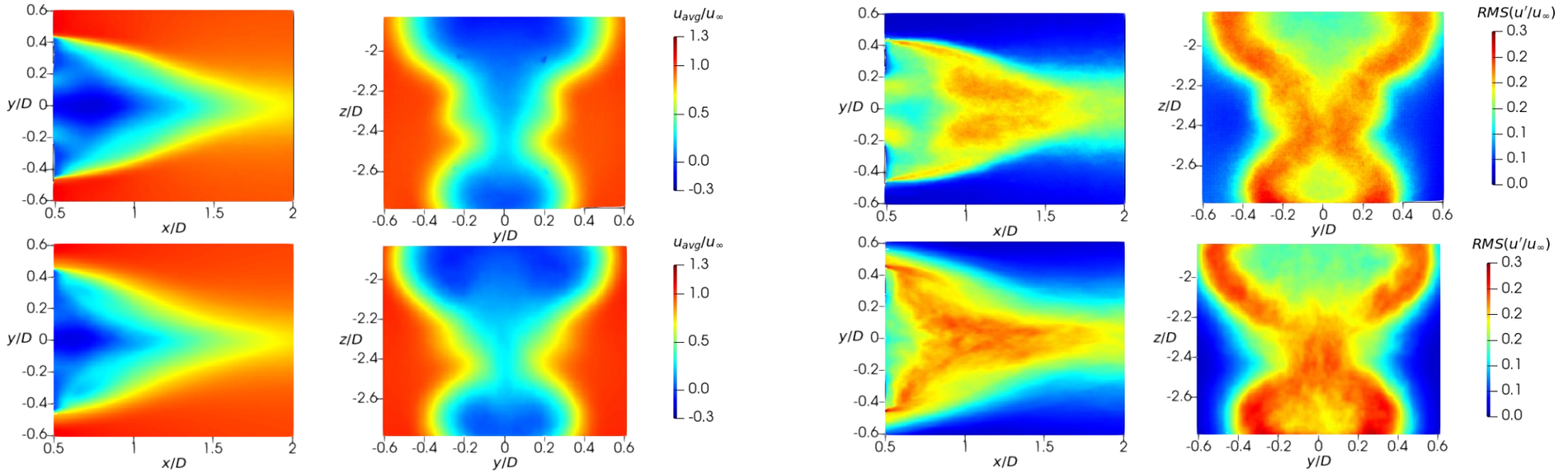
Time averaged flow field



BlBkTl

experimental

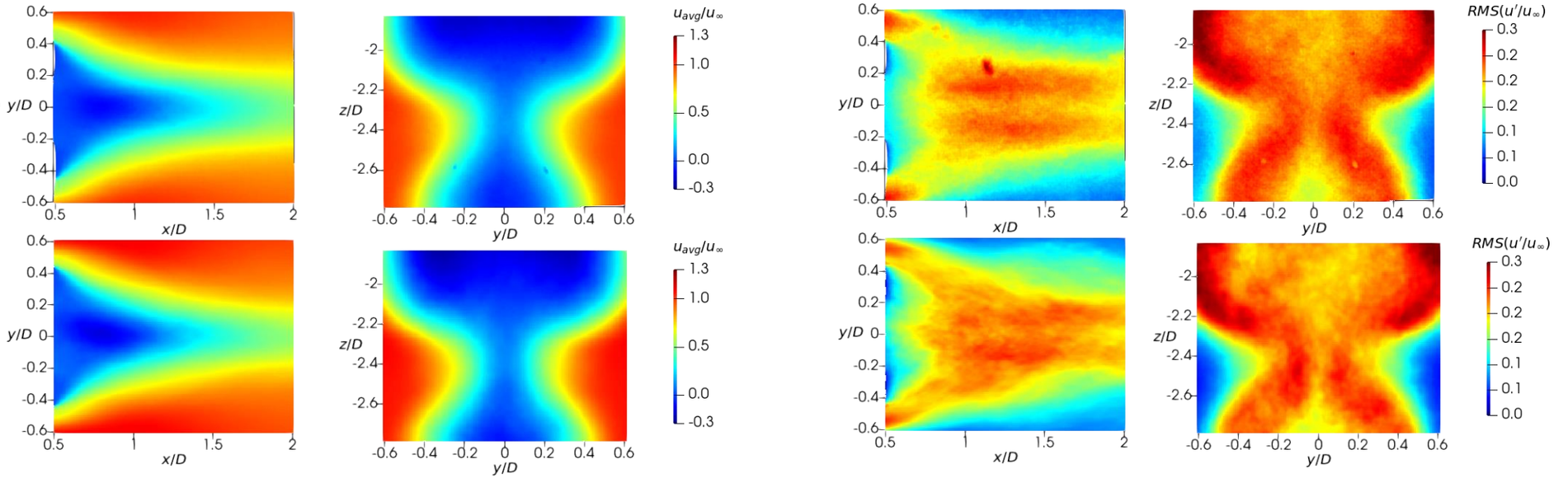
numerical



BlBkTl +solid fairing

experimental

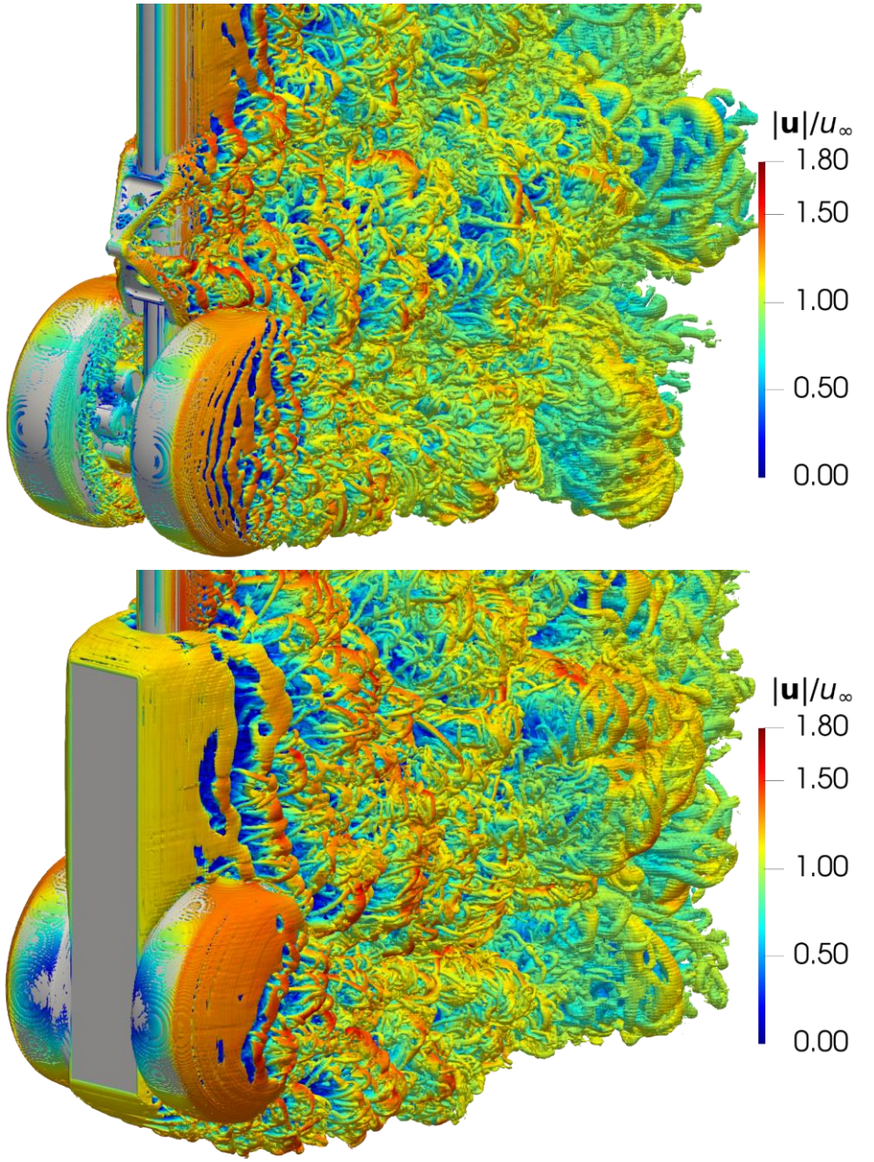
numerical



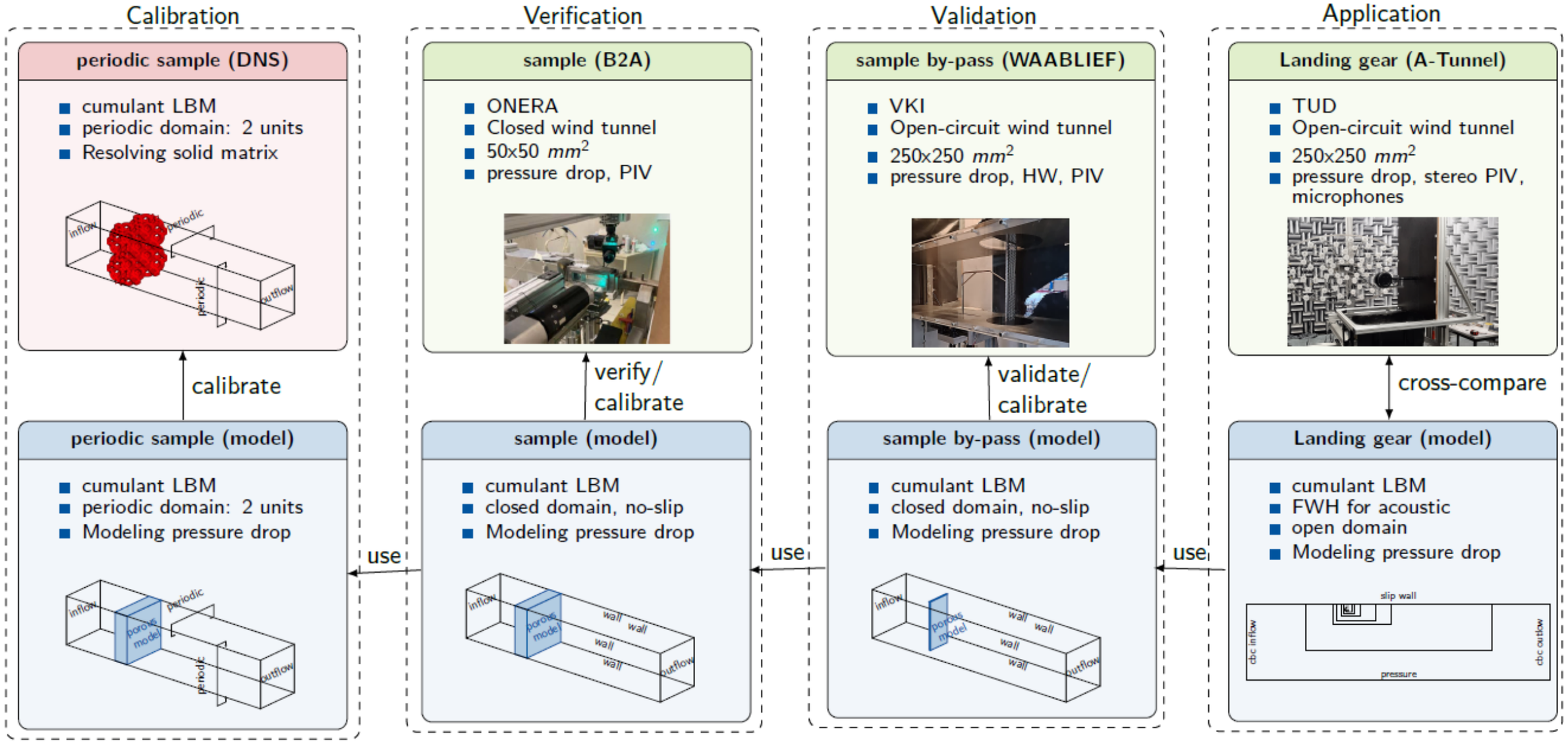
Instantaneous flow field

Upstream installed solid fairing

+ Reduction of vortex-surface interaction in the region of the torque link and the strut
+ Reduction of turbulent structures in the brake region
+ Lower noise emissions
- Stronger separation at the wheels
- Additional vortex generation at the fairing's edges
- Drag penalty



Porous fairing: workflow



Porous fairing: Darcy-Forcheimer via Guo forcing

Darcy-Forchheimer via Guo forcing

- Based on Darcy-Forchheimer relation

$$\underline{F} = -\frac{\epsilon\nu}{K}\underline{u} - \frac{\epsilon F_\epsilon}{\sqrt{K}}|\underline{u}|\underline{u}$$

- Guo2002: forcing term and corrected equilibrium distribution

Corrected equilibrium distribution

- Based on Darcy-Forchheimer relation

$$\langle f_i^{eq} \rangle = w_i \rho \left[1 + \frac{\underline{c_i} \cdot \underline{u}}{c_s^2} + \frac{\underline{uu} : \left(\underline{c_i}\underline{c_i} - c_s^2 \underline{\underline{I}} \right)}{2\epsilon c_s^4} \right]$$

Determination of unknowns

- Porosity ϵ: geometric property of the given material, characterized by definition or measurements
- Permeability K and geometric function F_ϵ: Calibrated by pressure drop in permeability tube or periodic DNS

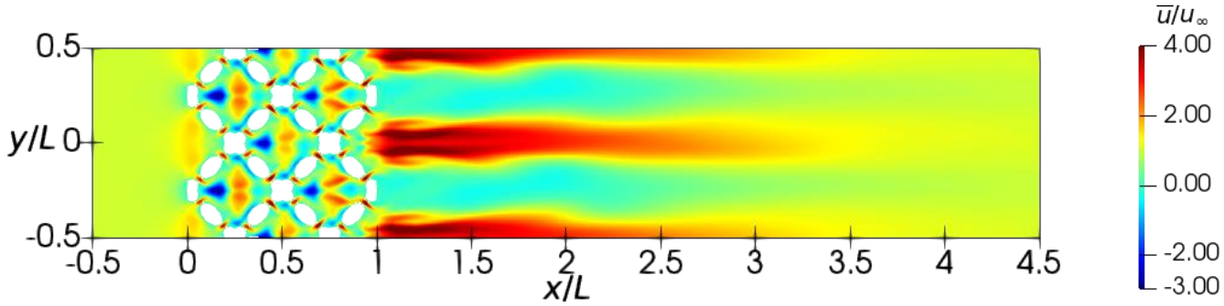
Status-Quo

- Implemented for the cumulant lattice Boltzmann method
- Validated/Calibrated for the periodic setup of permeability tube
- Application to landing gear fairing is part of ongoing simulations

Porous fairing: periodic DNS

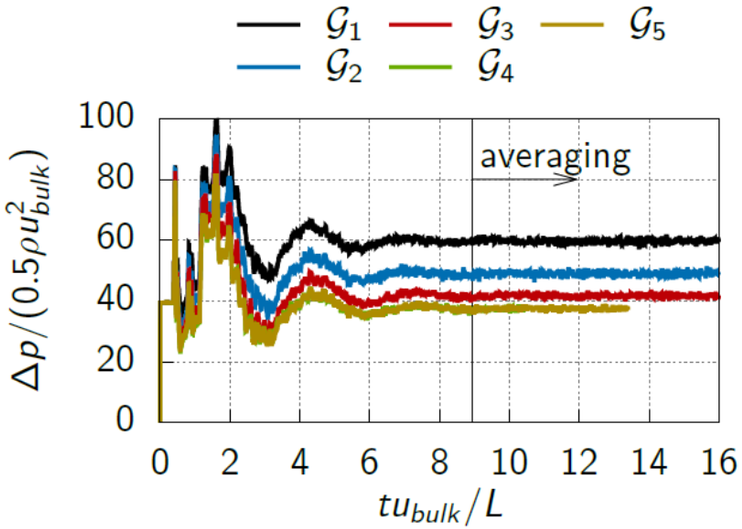
Setup parameters

- L: Thickness of the fairing (2x2.5mm)
- Re=$\frac{u_{bulk}L}{\nu}$ ~330
- Domain size: [8 x 4 x 4] L

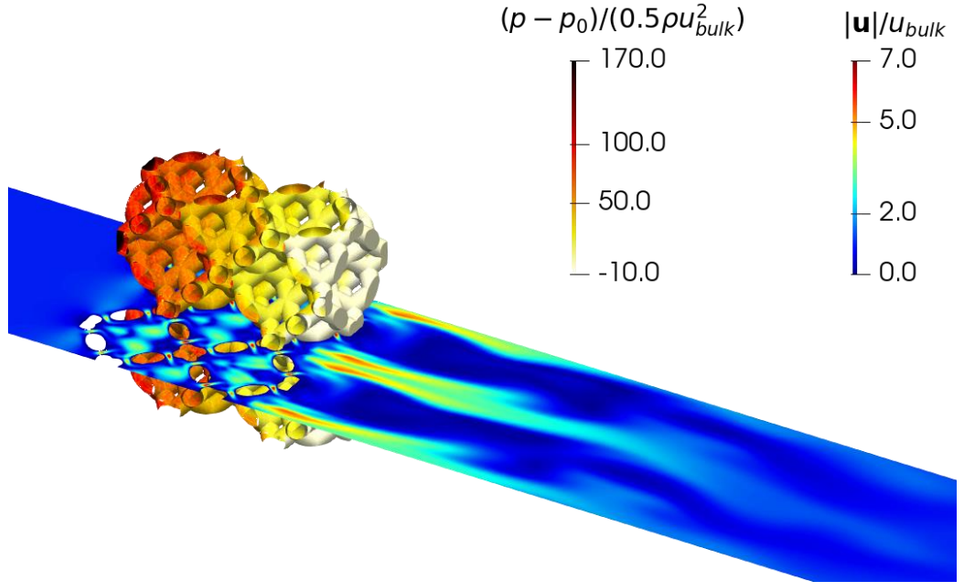


Mean velocity field in the symmetry plane.

Grid resolution study

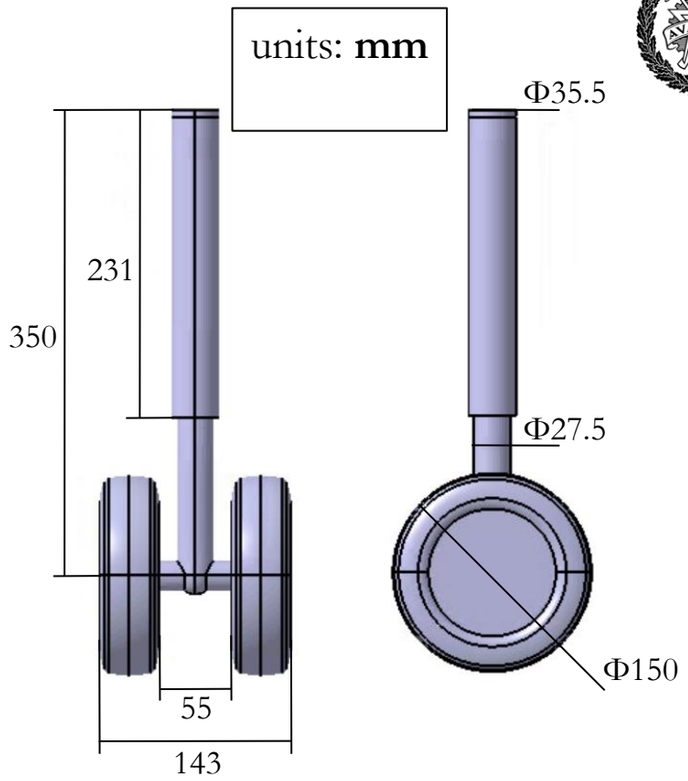


Grid	noCells/L	noCells
G_3	256	169 million
G_4	512	210 million
G_5	1024	337 million



Instantaneous velocity magnitude field and surface pressure distribution.

Numerical setup



Computational domain and mesh

- Wheel diameter: d_w =150 mm
- Computational domain: (130 x 65 x 32.5)d_w
- Mesh: polyhedral cell
- Number of mesh cells: 73 million for the baseline case; 89 million for the case with a solid fairing; 87 million for the case with the DLR wire-mesh fairing.

Simulation set-up

- Free-stream velocity (U_∞): **35 m/s**
- Reynolds number (based on D and U_∞): about **350,000**
- Free-stream turbulence intensity: **0.1%**
- Time step: 1×10^{-5} **s**
- Solver: IDDES with SST k-Omega turbulence model in STAR CCM+



Equivalent fluid model

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial\left(\rho u u_j\right)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j}\right) + S_i$$

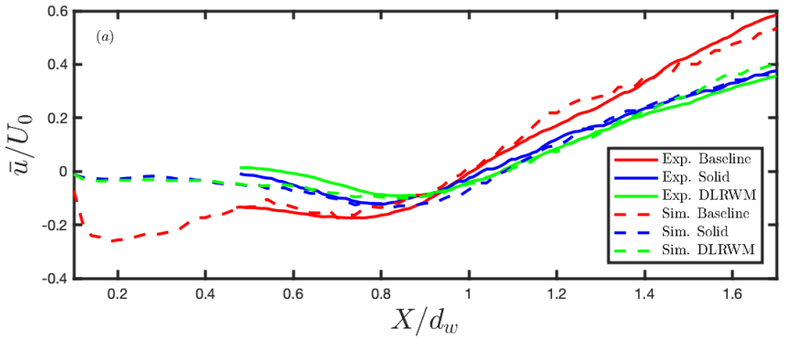
$$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} = \begin{bmatrix} -\dfrac{\mu}{\boldsymbol{K_{perm}}} u - \boldsymbol{K_0} \times \dfrac{0.5\rho|u|u}{h} \\ 0 \\ 0 \end{bmatrix}$$

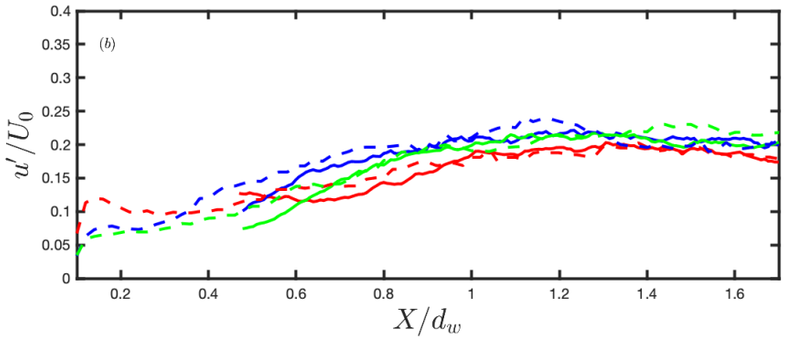
$$\boldsymbol{K_0} = \left(0.5 + \frac{26}{Re_d}\right)\left(\frac{1-\beta^2}{\beta^2}\right)$$

$$\boldsymbol{K_{perm}} = \frac{\mu U_\infty}{(K_{B2A} - K_0) \cdot 0.5\rho {U_\infty}^2 / h}$$

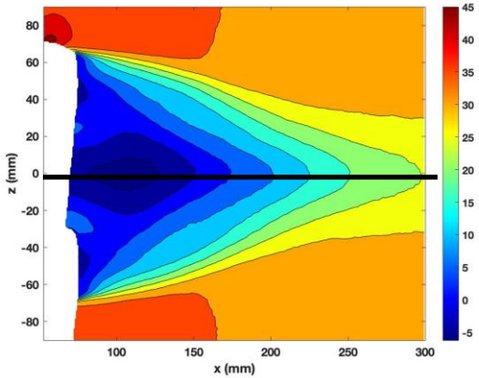
Terracol & Manoha, AIAA J., 2021, vol. 59, NO.3, and/or (2) Kurian & Fransson, Fluid Dyn. Res., 2009, vol. 41, NO.2.

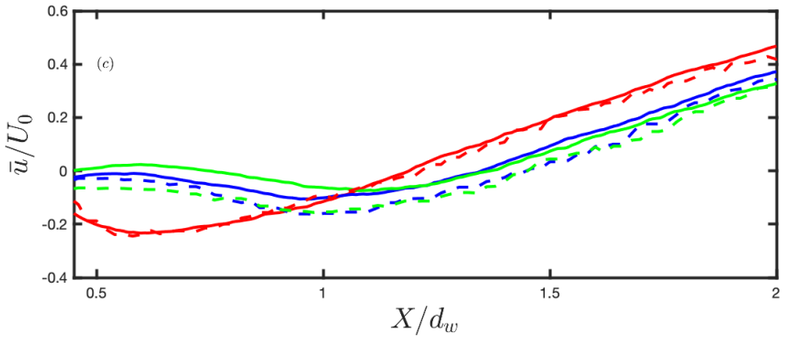
Statistics on wake centreline

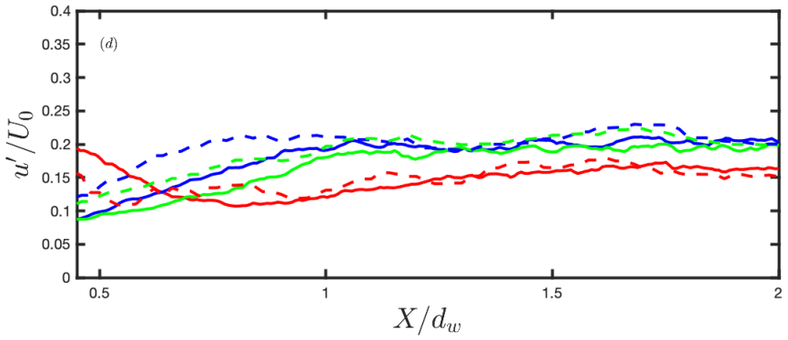




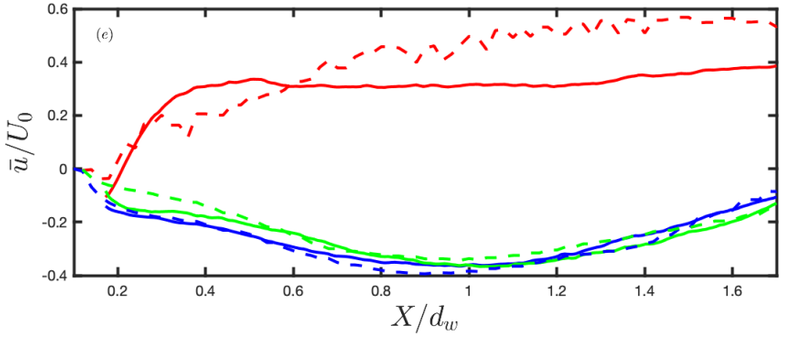
Y = 0

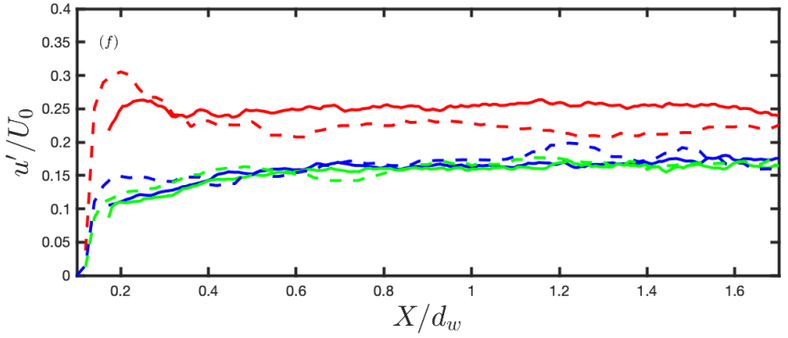






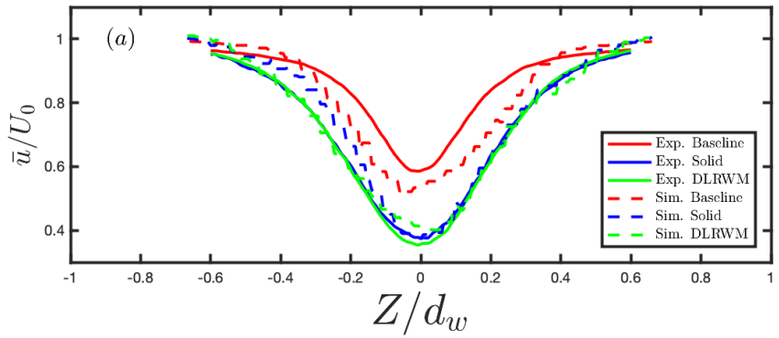
Y = 50 mm

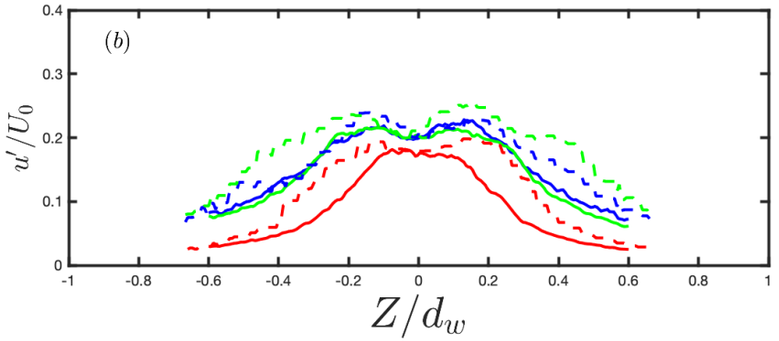


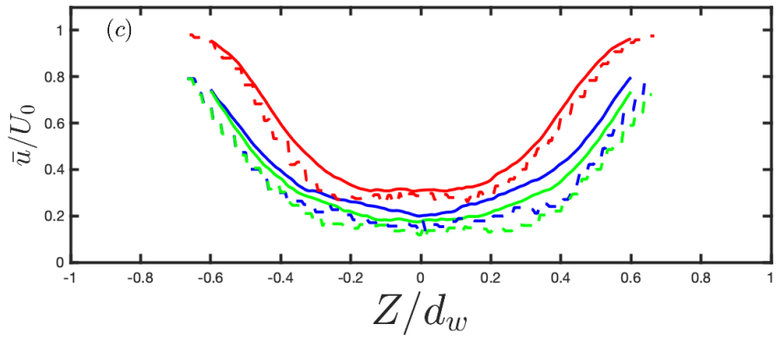


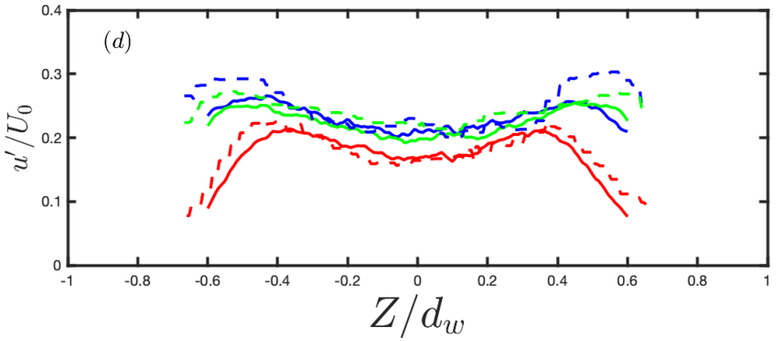
Y = 120mm

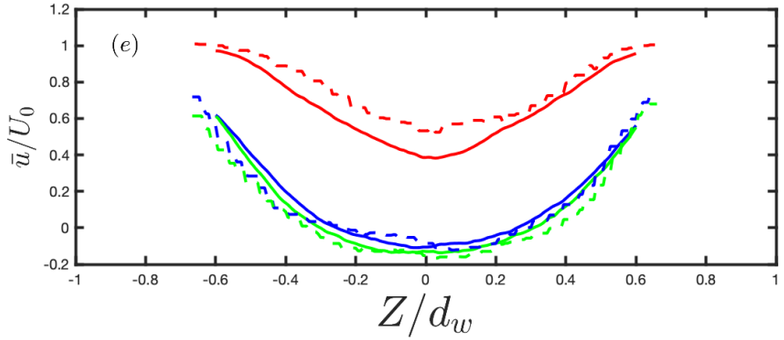
Statistics on wake centreline

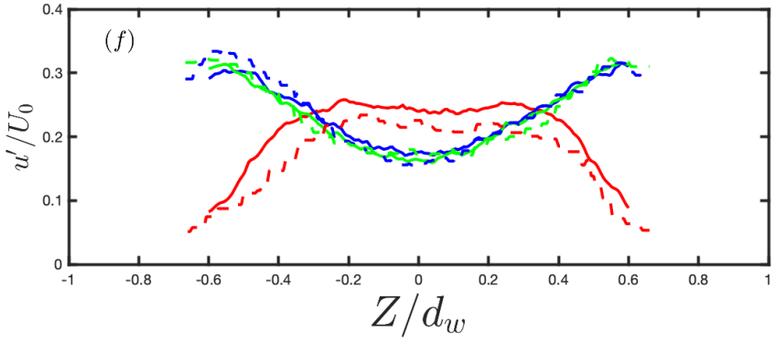




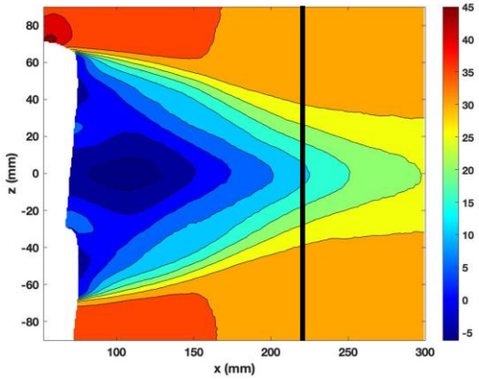








Y = 0

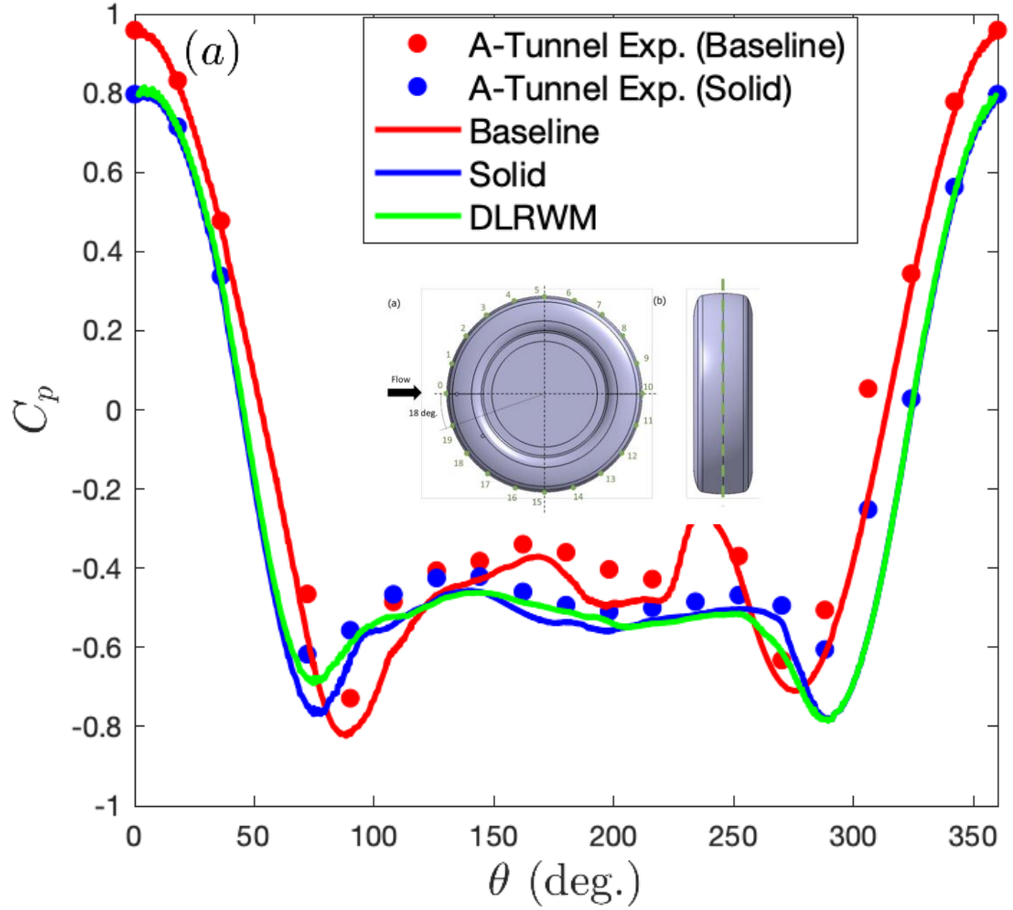


$x = 1.7d_w$

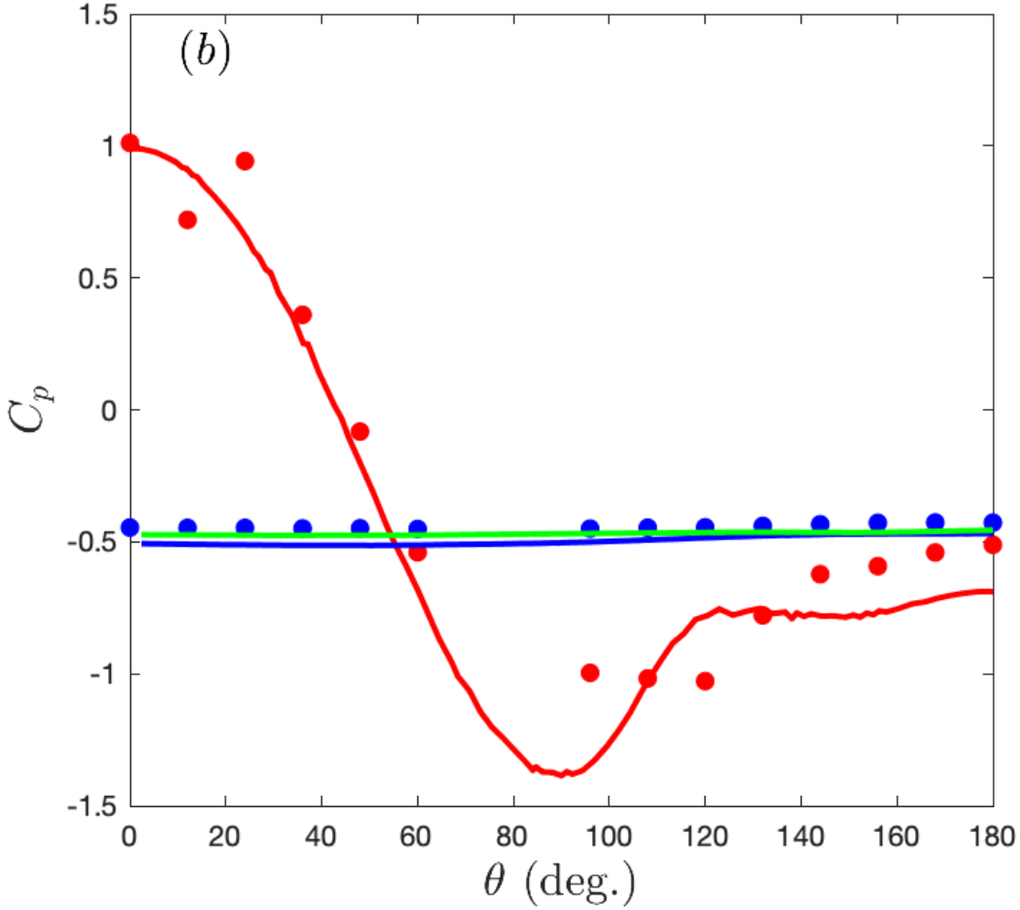
Y = 50 mm

Y = 120mm

Pressure coefficient

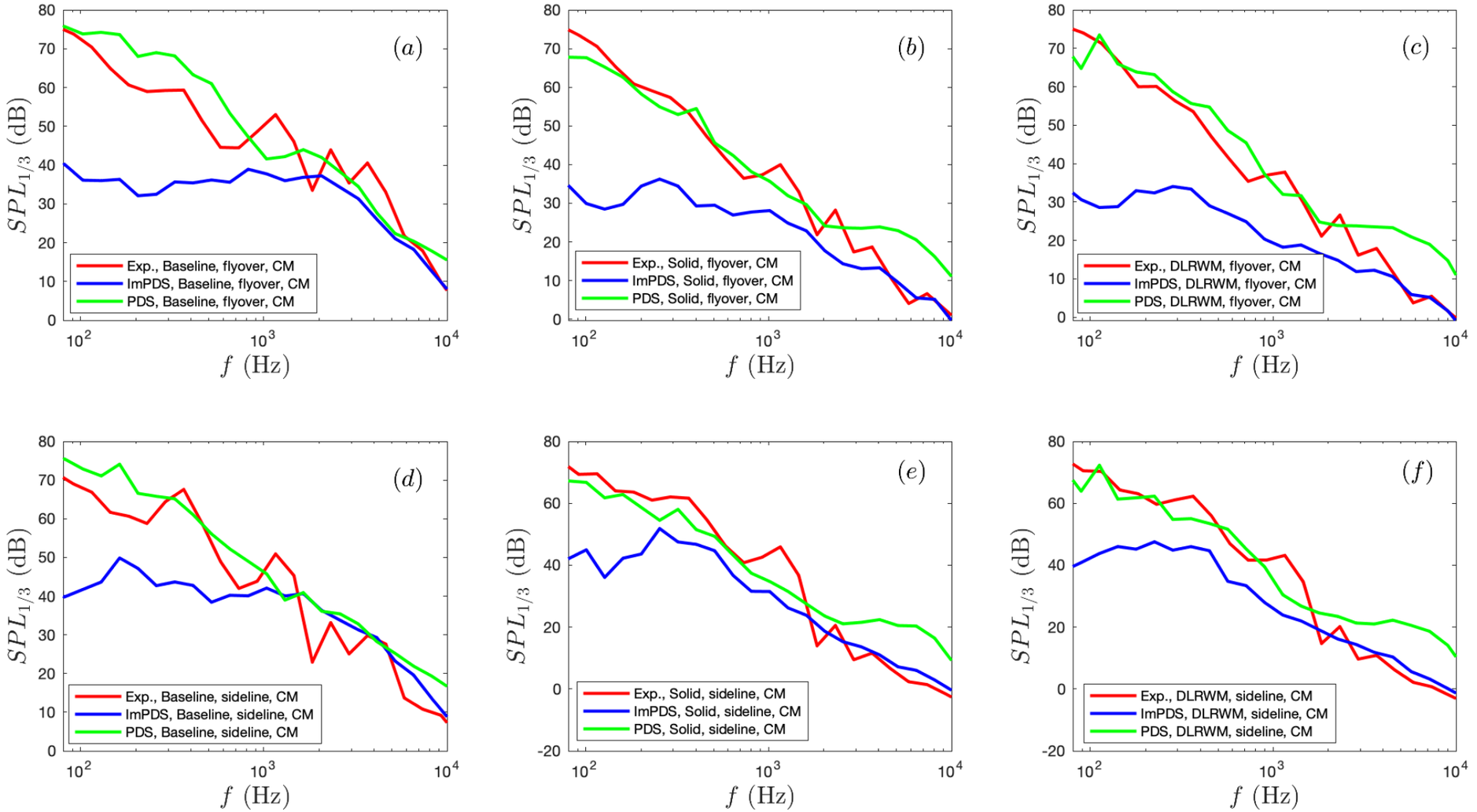


Wheel (Y=-49.5mm, STARCCM+)



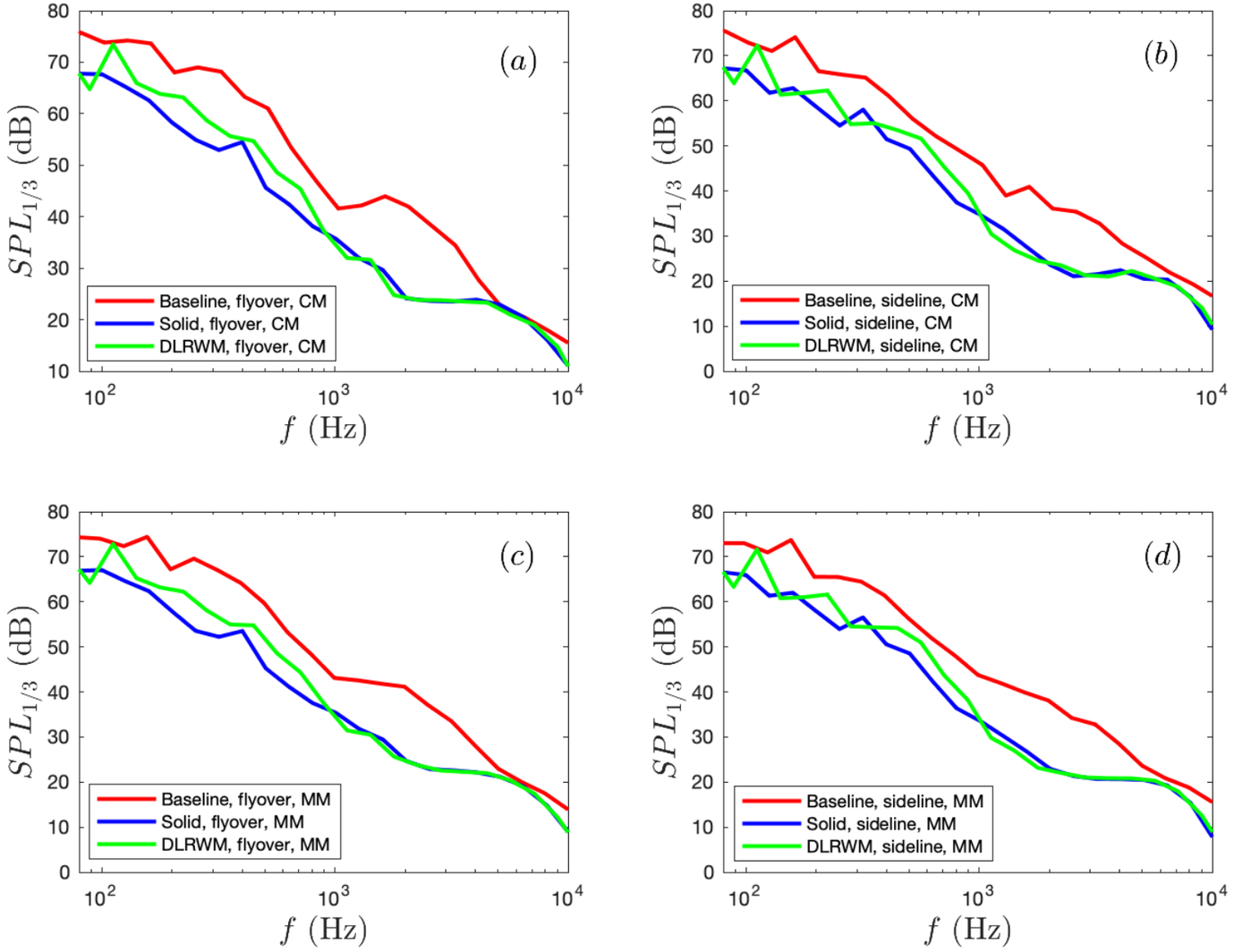
Rod (Z=50mm, STARCCM+)

Sound Pressure Level



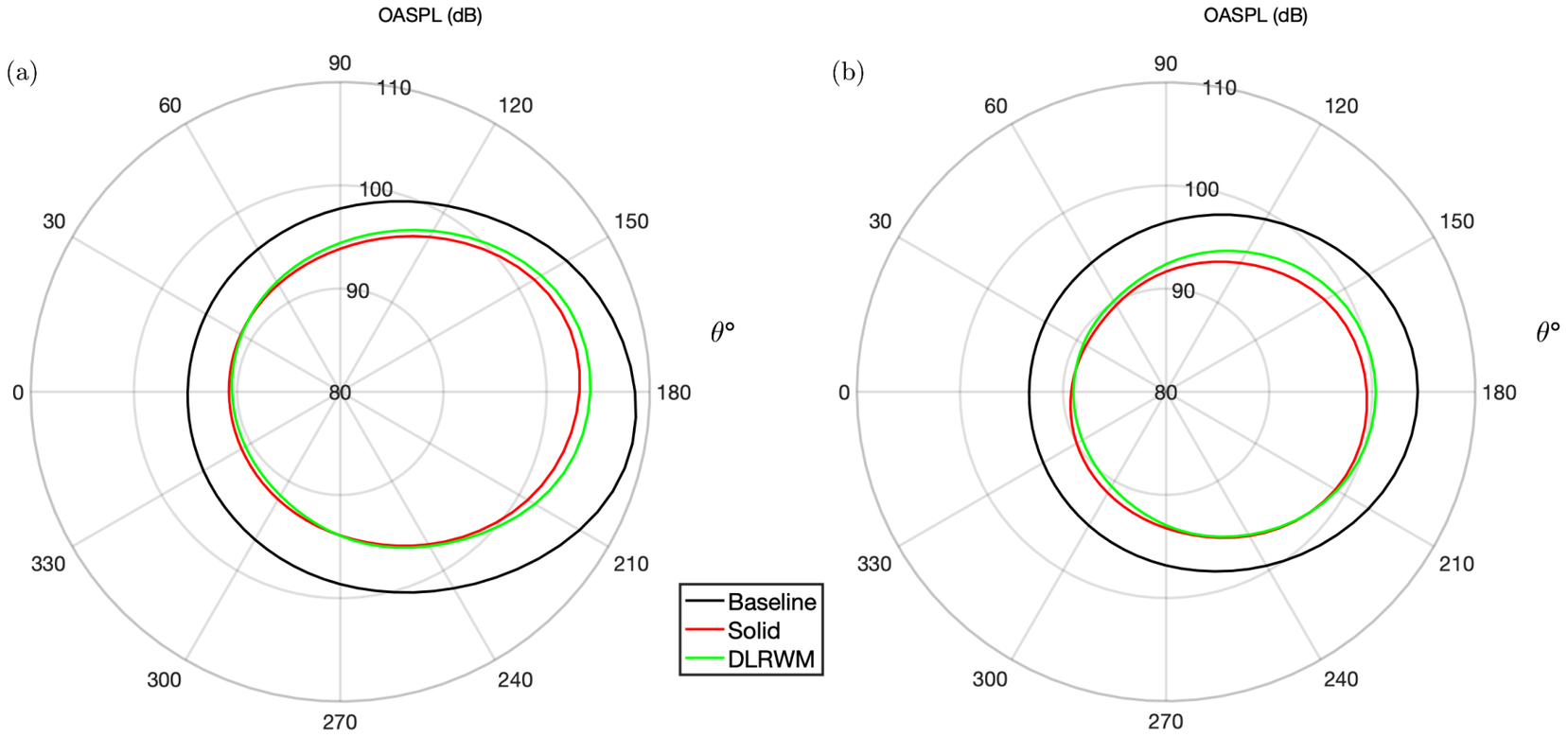
Reasonable agreement with measurements using FW-H analogy with permeable integral surfaces .

Sound Pressure Level



Noise mitigation observed with both fairings compared to the baseline case!

Sound Pressure Level



Noise reduction of 3-6 dB is achieved in all directions with both fairings compared to the baseline case!

Conclusions

- A simplified LAGOON model has been investigated both numerically and experimentally
- Several numerical methods or different implementations have been applied
- All the numerical methods used show reasonable agreement with the numerical results

Open Questions

- Are porous fairings a design tool to obtain a low noise landing gear with an acceptable drag penalty?
- Can we find an optimum between noise reduction and drag penalties?

Questions?

Flow permeable materials for landing gear noise reduction

Francesco Avallone
Delft University of Technology

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The INVENTOR project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 860538