Modelling of porous materials

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INVENTOR example

INnoVative DEsign of INstalled Airframe ComponenTs For Aircraft NOise Reduction

Key Objectives:

- Can we understand the physics of noise reduction mechanisms for landing gears?
- Can we create a scaling for the porous fairing used for noise reduction

Aim of the project:

Decrease the external noise from business jet and short-medium range transport aircraft.

↓

Development of low-noise installed landing gears and high-lift components.



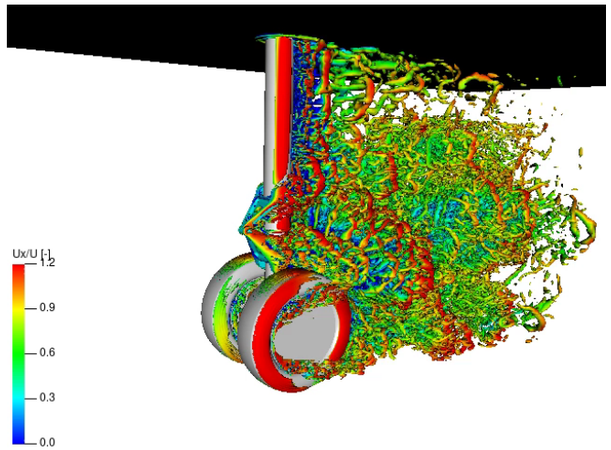
Business jet(left) and small-medium range (right) transport aircraft at approach with landing gear and high-lift devices deployed

INVENTOR example

Simplified Lagoon Model Approach

*Create a **numerical assessment** of:*

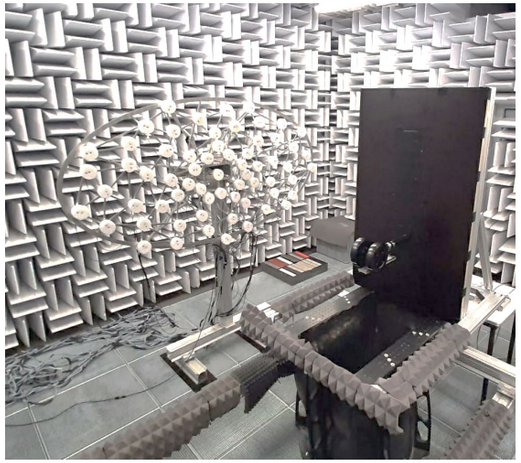
- Equivalent-fluid models for porous fairings.
- High-fidelity simulations employing a combination of fully resolved components and equivalent fluid models.
- High-fidelity simulations of fully resolved porous fairings.



Unsteady flow on Lagoon Model

*Determine an **experimental investigation** of:*

- Most promising noise reduction technologies and low-noise designs for landing gears and high lift devices.
- Turbulence interaction and mixing with porous fairings employing equivalent/full resolved models
- Extrapolation of the results from laboratory scale to full-scale components.

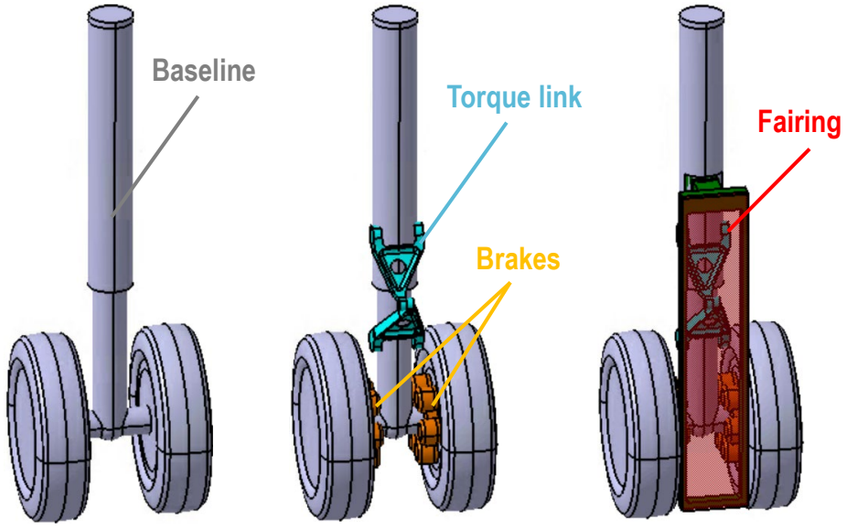


TUD A-tunnel test

INVENTOR example

Model specifications

- **Baseline model (BL)** based on original LAGOON landing gear (LG)
- Components **brakes (BK)** and **torque link (TL)**
- Upstream **fairings** fully covering LG axle, brakes and torque link

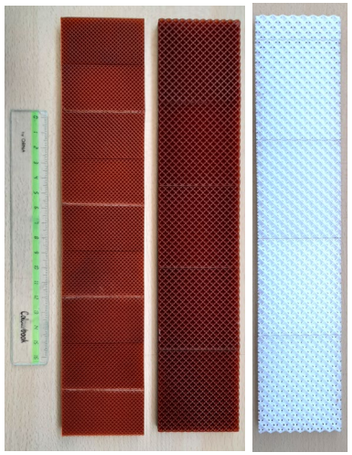


LAGOON LG configurations.

Fairing Specifications

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

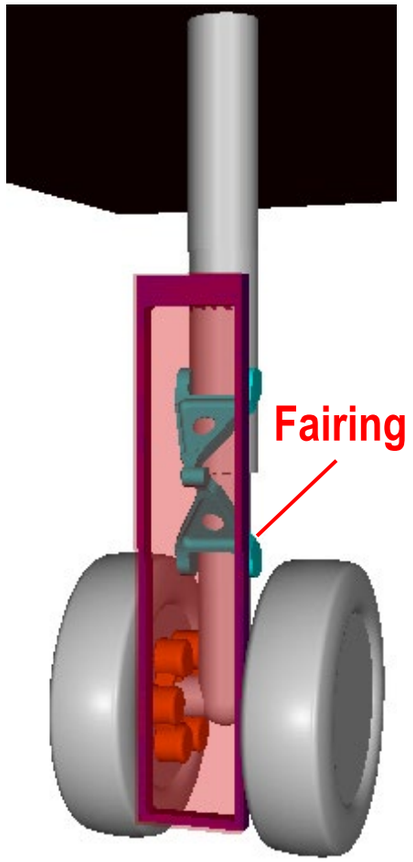
- (x12) DAv (metallic wool, straight perforations, helical perforations, oriented perforations…)
- (x2) TUD (diamond-lattice)
- (x1) ONERA (wire mesh)
- (x1) DLR (wire mesh)
- (x1) Fully solid



Porous Materials samples.

INVENTOR example

Approach on Porous Media Modelling



Diamond-fairing model, 2 approaches followed in Inventor:

1. One-to-one representation of the fairing (TUD example: diamond-cell geometry)
2. Equivalent model of the porous geometry validated by experimental/high-fidelity rig

Equivalent fluid model features:

The porous medium is modelled as an **equivalent fluid region**

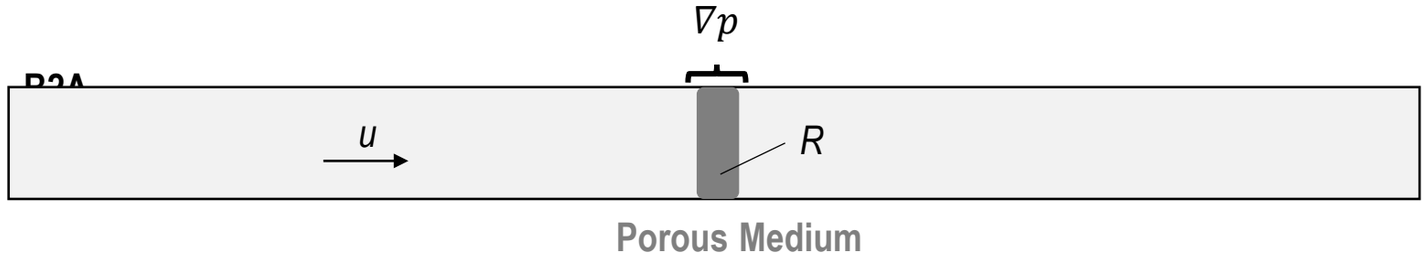
The region exerts an equivalent volume force on the flow field (**Darcy-Forcheimer Law**):

$$\nabla p = -\rho \boldsymbol{R} \cdot \boldsymbol{u} \qquad (1)$$

$$\boldsymbol{R} = \boldsymbol{R_v} + \boldsymbol{R_i}\boldsymbol{u} \qquad (2)$$

Flow resistivity **R** is further decomposed in viscous $\mathbf{R_v}$ and inertial $\mathbf{R_i}$ terms

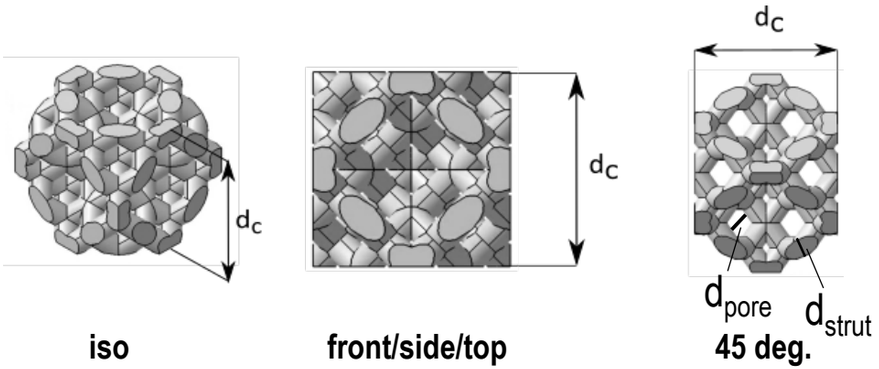
$\mathbf{R_v}$ and $\mathbf{R_i}$ are retrieved from **fit of equations (1) and (2) to experimental/high-fidelity data**



INVENTOR example

Porous material characterisation

TUD example, experimental and high-fidelity variable tuning

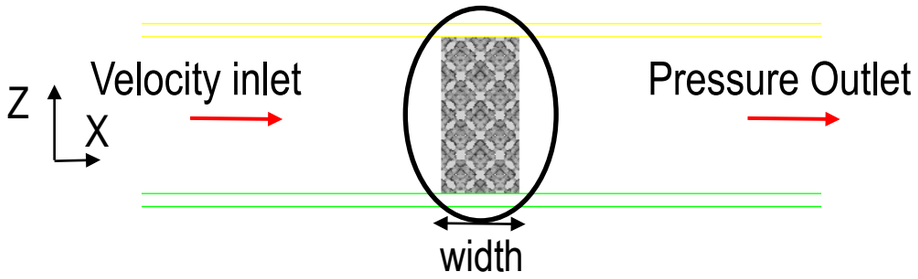


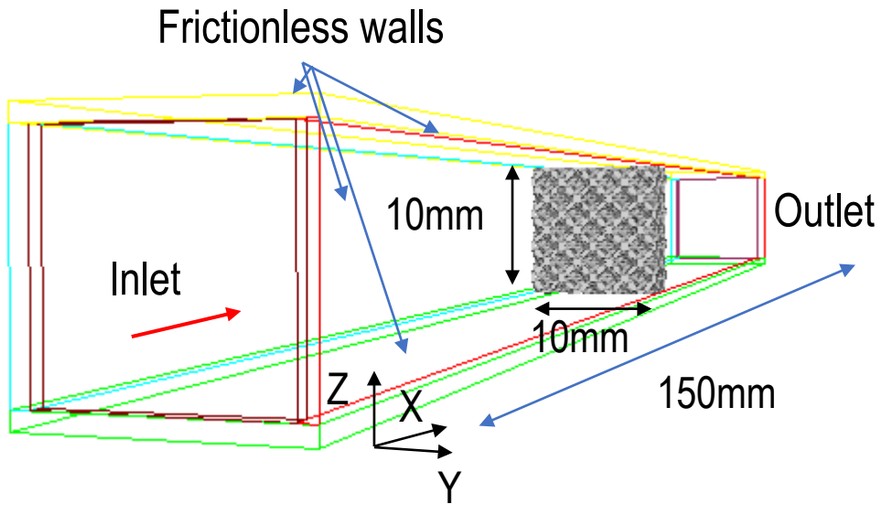
iso **front/side/top** **45 deg.**

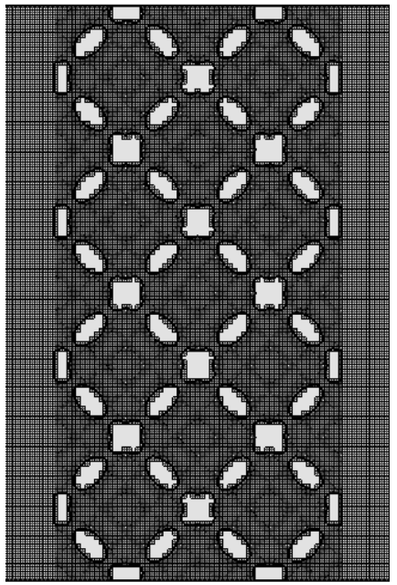
Diamond unit cell definition

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

Reproduction of numerical rig, according to experimental one:







Lattice Boltzmann Method

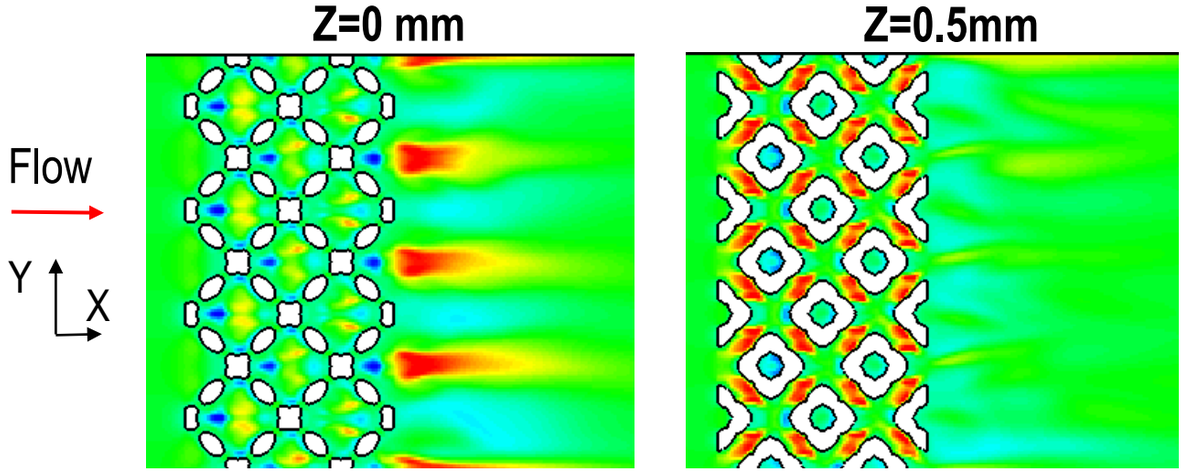
Modelling of the rig

U=35m/s + U=1m/s
P=100.7 kPa

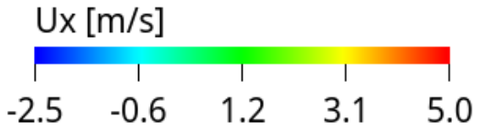
Resolution = 125 voxels along width

INVENTOR example

Porous material characterisation

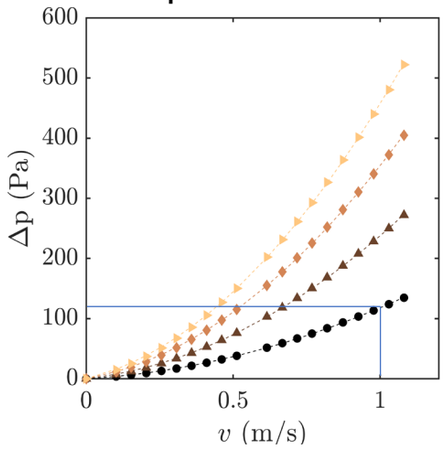


- Beside tuning of the values, the high-fidelity setup shows the flow interaction with the microstructure.
- Narrow openings lead the flow to accelerate and decelerate near the solid walls.

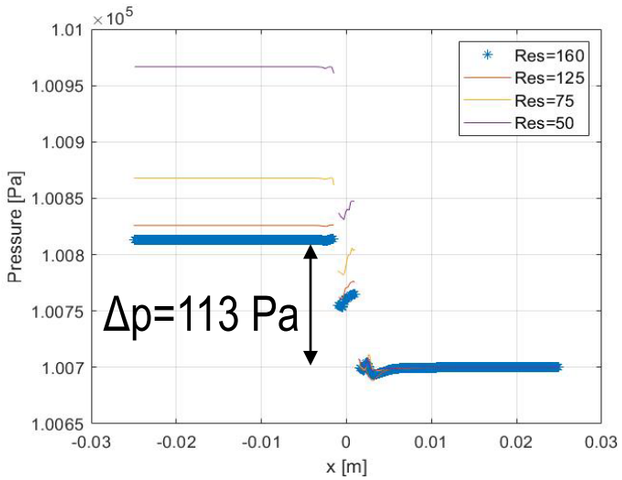


Experimental Pressure Drop

Δp = ~117 Pa



Numerical Pressure drop



Calibration and verification of the pressure drop values is possible:

Darcy law:

$$\nabla p = -\rho \boldsymbol{R} \cdot \boldsymbol{u}$$

$$\boldsymbol{R} = \boldsymbol{R_v} + \boldsymbol{R_i u}$$

Δp=119.5 Pa

INVENTOR example

LBM high-fidelity component simulation

Quick recap on Lattice Boltzmann method (LBM):

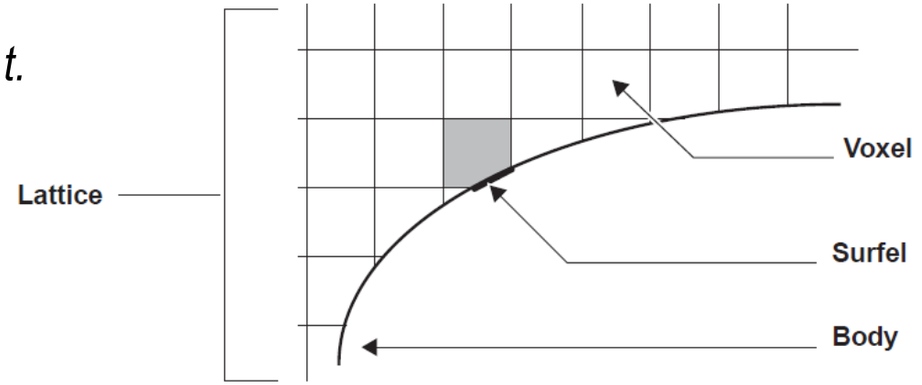
- Particle-based solver
- The macroscopic flow variables are based on the kinetic equations in the mesoscopic domain
- Software: 3DS-Simulia PowerFLOW 6.0a

Particle distribution function $f_i(x,t)$ with velocity $\boldsymbol{c}_i$ at a position $\boldsymbol{x}$ in time t.

Discrete expression of the Boltzmann equation in space x and time t :

$$f_i(x + c_i\Delta t, t + \Delta t) = f_i(x,t) + \Omega_i(x,t)$$

A lattice is used to determine the motion of the gas to discrete nodes with discrete velocities in specific directions.



Lattice elements in 2D view

Collision operator

$$\Omega_i = -\frac{f_i(x,t) - f_i^{eq}(x,t)}{\tau}\Delta t \longrightarrow f_i^{eq} = w_i\rho\left(1 + \frac{u \cdot c_i}{c_s} + \frac{(u \cdot c_i)^2}{2{c_s}^4} - \frac{u \cdot u}{2{c_s}^2}\right)$$

Equilibrium state

τ: relaxation time

INVENTOR example

Numerical setup



Domain Dimensions

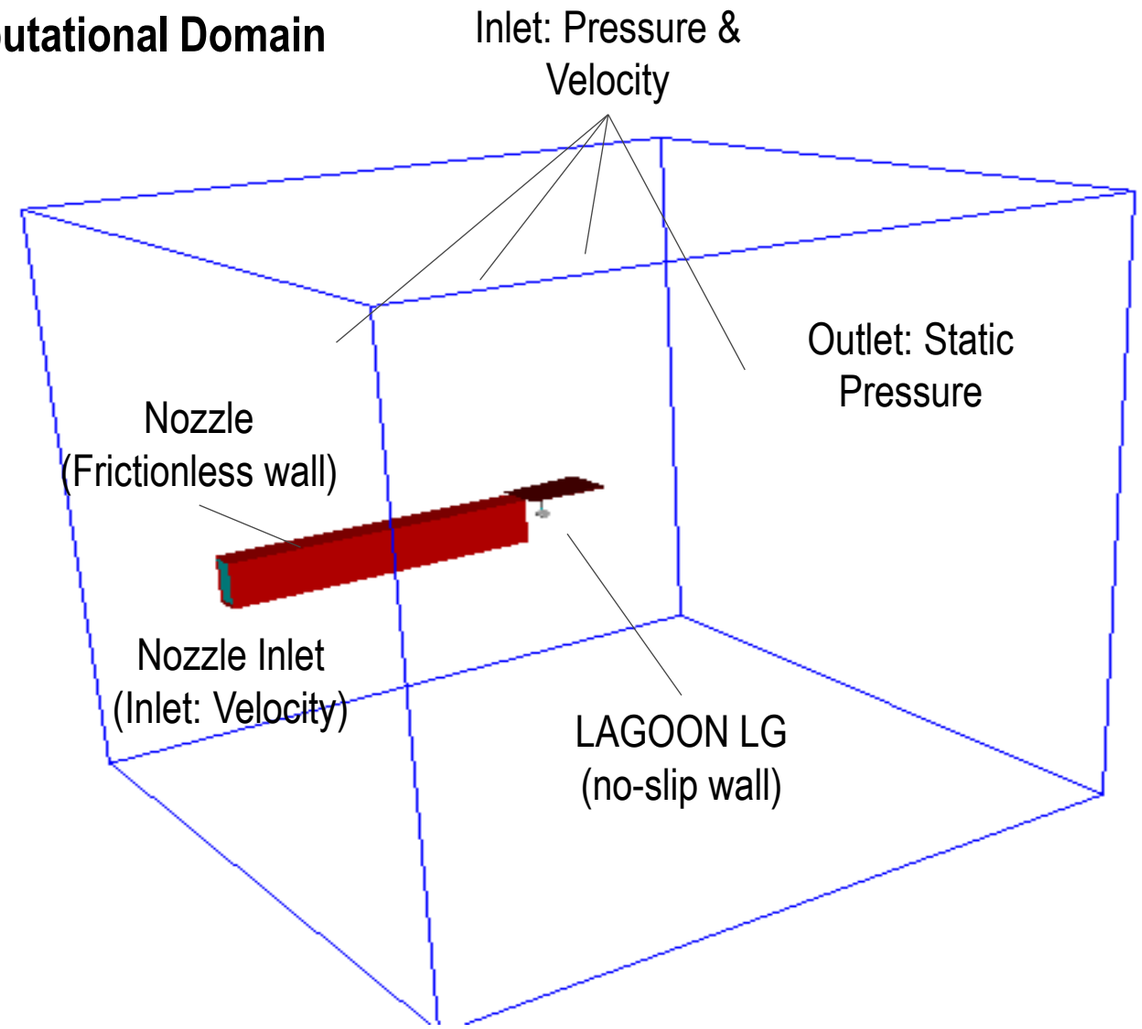
- Nozzle Length: 4.5 m
- Computational Domain: 70x70x70 m^3

Boundary Conditions

- Upstream/Top/Bottom/Front/Back Domain Boundaries: Inlet pressure (= p_{amb}) & velocity ($V_{x,y,z}$ = 0)

- Downstream Domain Boundary: Outlet static pressure (prescribed flow direction = [1, 0, 0]).

Computational Domain

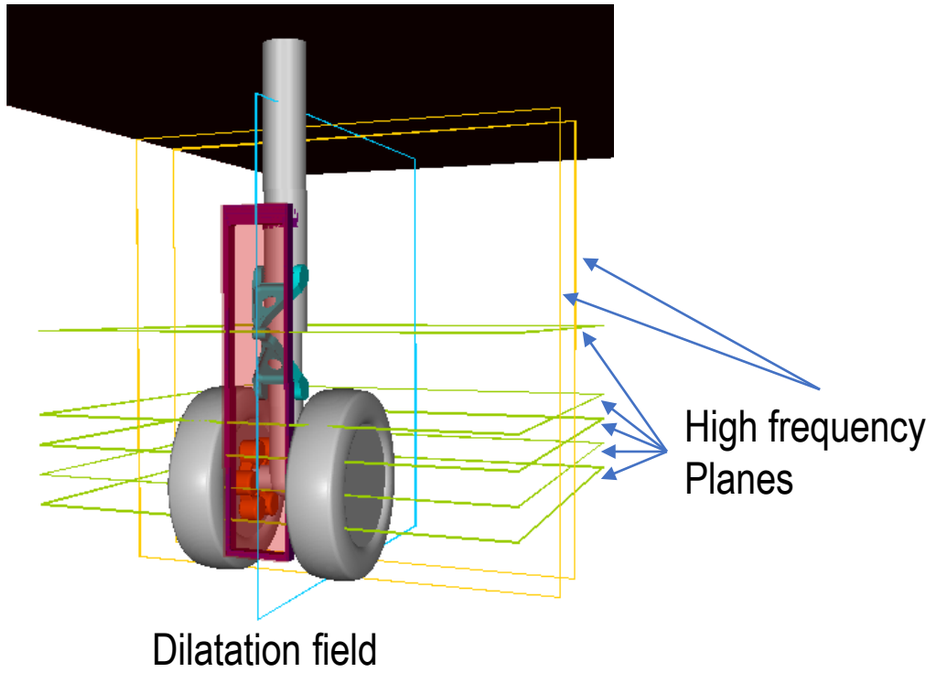


INVENTOR example

Flow conditions and numerical sampling

p_∞ [Pa]	ρ_∞ [kg/m3]	U_∞ [m/s]	Turb. length [m]	Turb. Int. [%]	M_∞	ReD (10^5)	$\mu(10^{-5})$ [Pa s]
100,700	1.21	34.7	0.0001	0.1	0.1019	3.56	1.791

Start of measurements: 170 flow passes over the wheel (d_w=0.15m) with velocity 35m/s.
End of measurements: 95 flow passes over the wheel after start.
Duration of measurements: ~0.49 s



Transient solution	Sampling frequency [kHz]
Volume	3.5
High frequency Planes	46.66
Plane for dilatation field	29.17
FWH-Surfaces	
Permeable surface	46.66
Solids (BK, TL, Axle+Wheels, Fairing+Support)	46.66

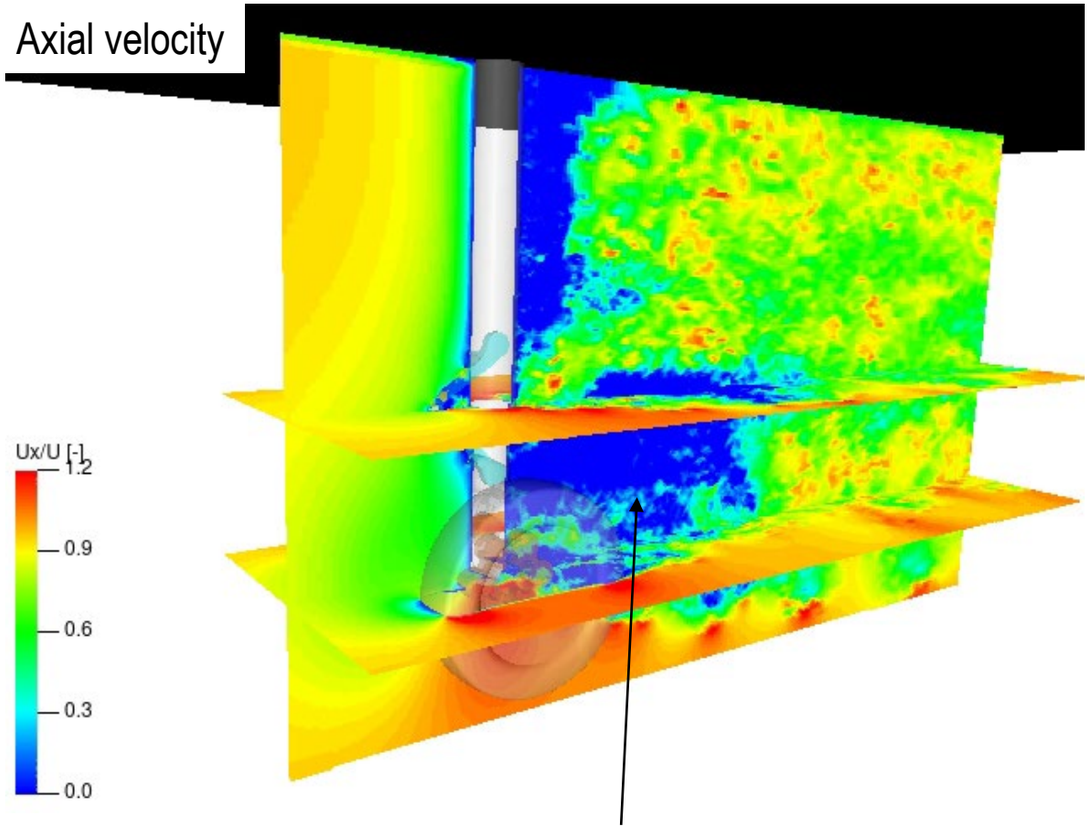
INVENTOR example

Flow solution examples

Flow features being validated in the project:

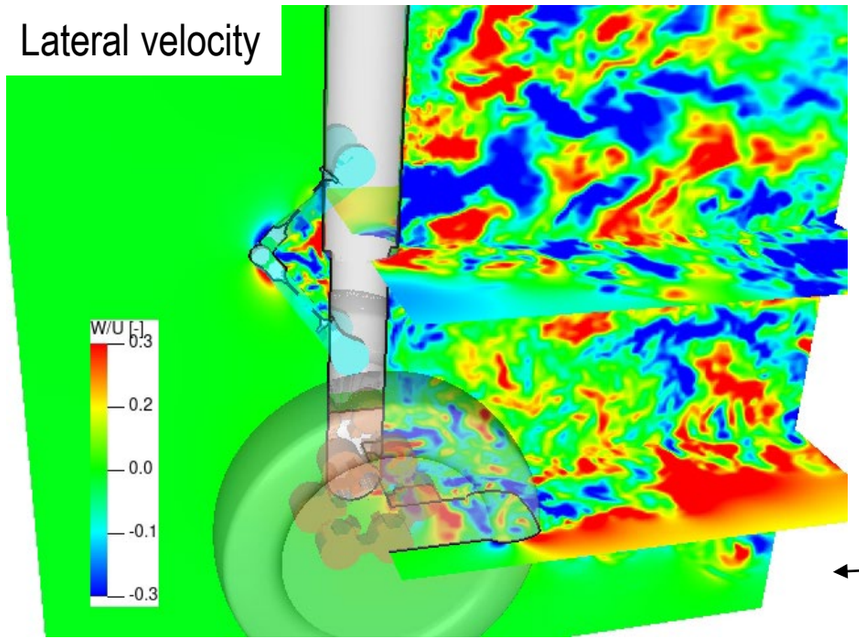
- Flow recirculation downstream of the axle
- Smaller recirculation region downstream the rod and the axle
- Increased mixing at the wheels and at the main rod

Axial velocity



Flow mixing downstream the torque link and brakes

Lateral velocity



Detachment of shear layers on the side wheels