Scale-Resolving Simulations in SU2

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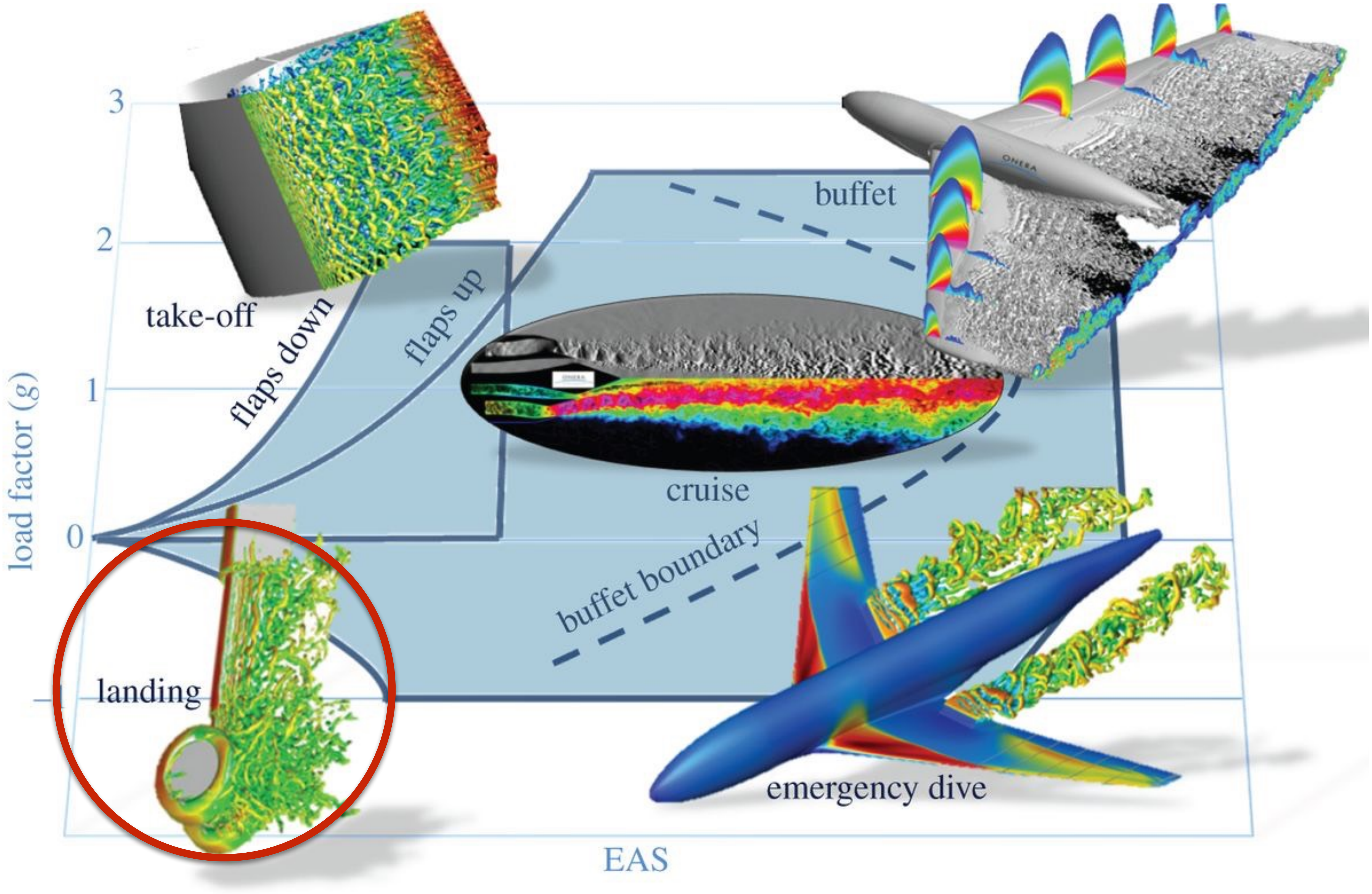
Outline

- Motivation
- Development of Hybrid RANS/LES and WMLES models
- Guidelines of Scale-Resolving Simulations in SU2
- Results
    - Turbulent Channel Flow
    - LAGOON (Landing Gear)
- Ongoing & Future work

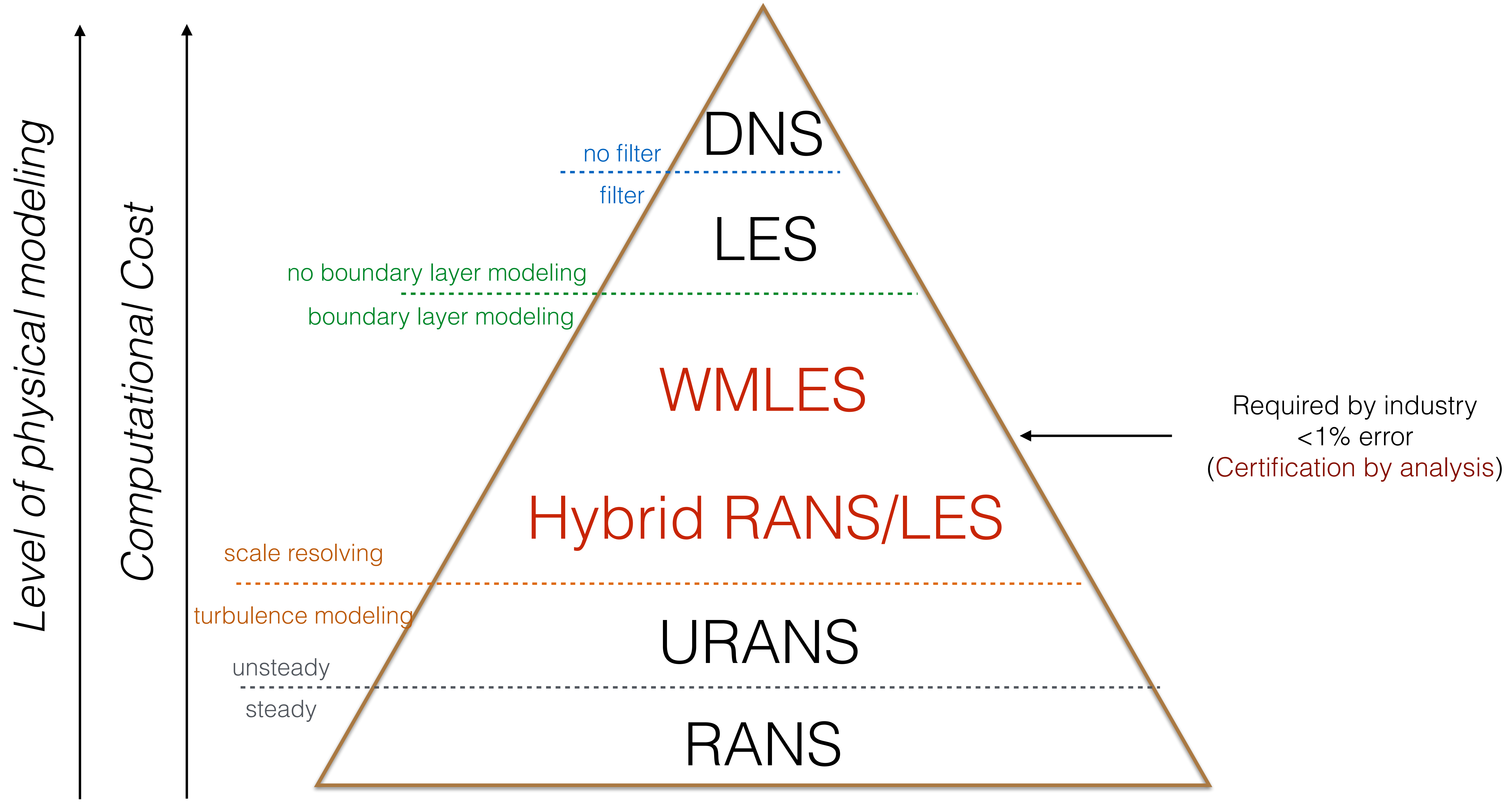
Motivation

- Standard RANS models are known to perform poorly on vortex-dominated, separated, and transitional flows.
- Increasing pressure for accurate prediction of areas at the edge of the flight envelope earlier in design process: performance, noise and safety.
- Demonstrate that scale-resolving methods can lead to high levels of confidence on design and off-design conditions.



Deck et al. 2014

Hierarchy of CFD Paradigms

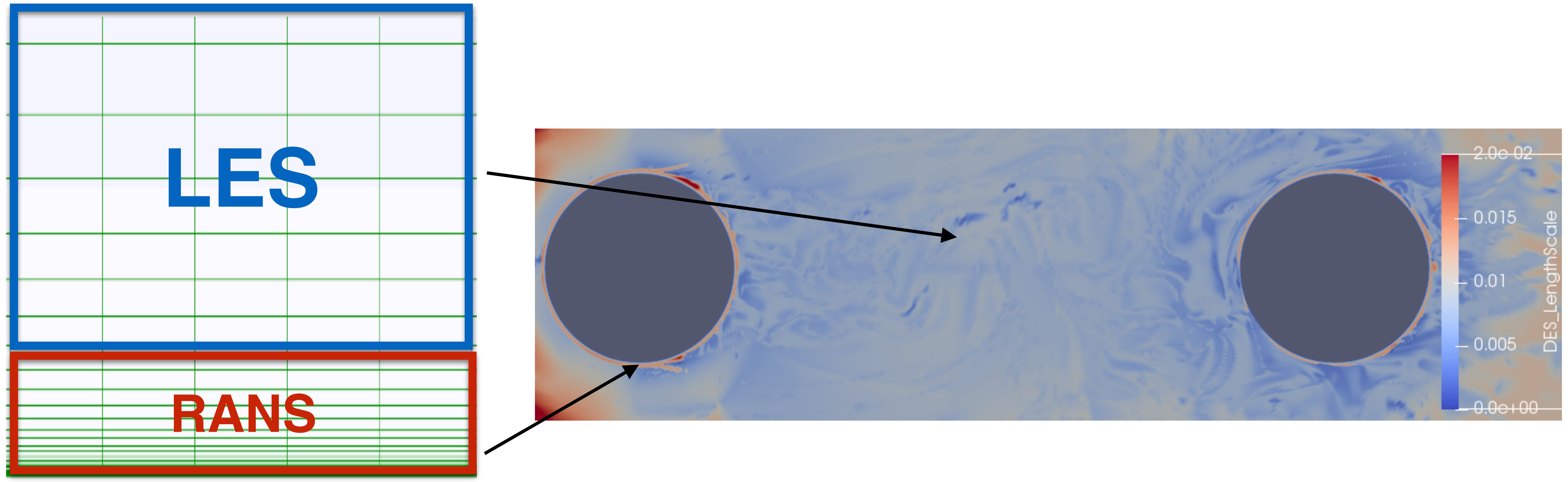


Scale-Resolving Methods in SU2

A. Non-Zonal Hybrid RANS/LES:

1. Delayed Detached Eddy Simulation (DDES) *(Spalart et al. 2006)*
2. Improved DDES (IDDES) *(Shur et al. 2008)*

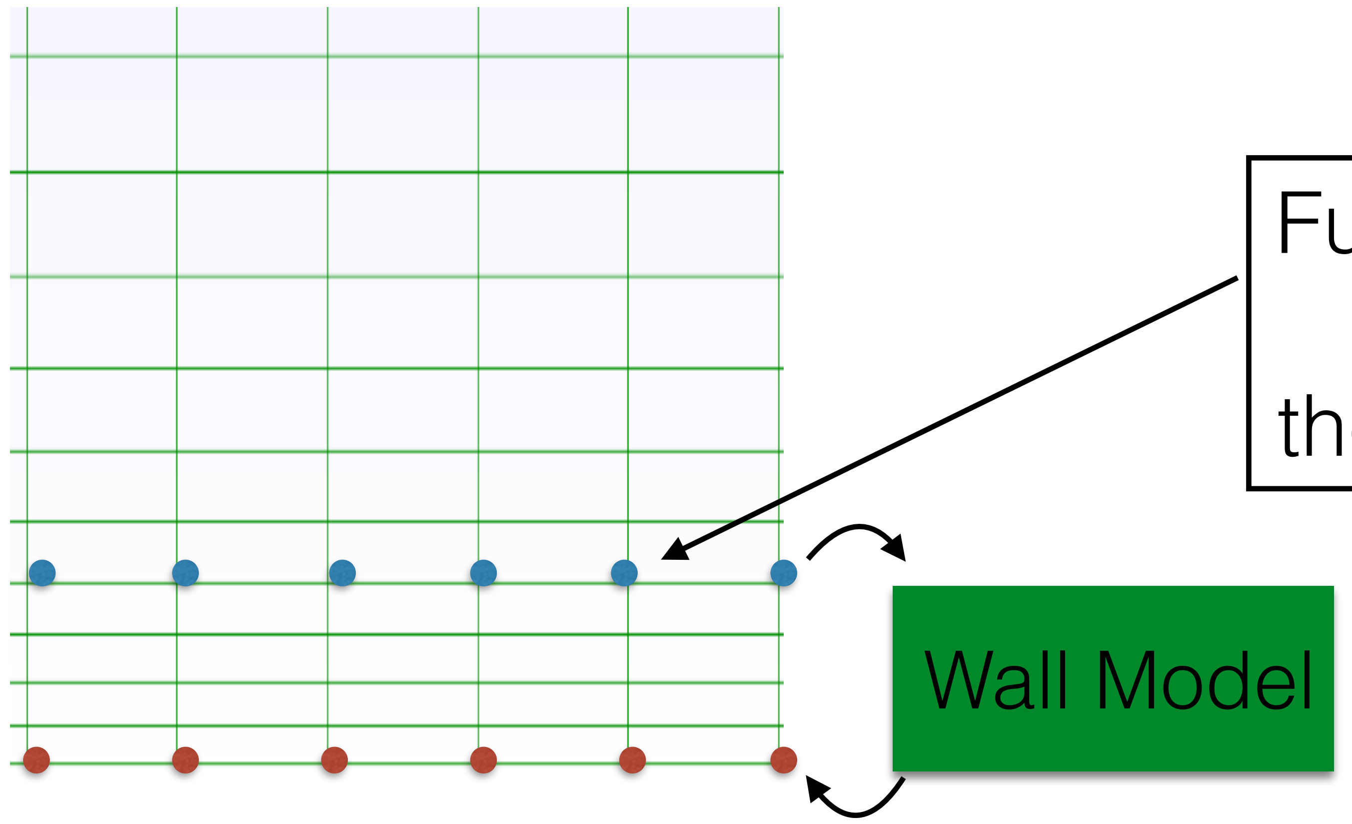
- Both approaches are based on the SA turbulence model and use the Shear-Layer Adapted SGS (SA-EDDES). *(Shur et al. 2015)*



B. Wall-modeled LES (WMLES):

1. Algebraic Wall Model *(Reichardt 1951)*
2. 1D Equilibrium Wall Model *(Kawai & Larsson 2012)*

- LES extends all the way to the wall with a separate decoupled wall-parallel grid for the WM.



Fully automated search and interpolation of the exchange locations

$$u^+ = \frac{u_\parallel}{u_\tau} = \frac{1}{\kappa}\ln(1+\kappa y^+)$$

Guidelines of Scale-Resolving Simulations

- **Numerical Method**:
  - **DDES**: Enhanced DDES based on SA turbulence model
  - **WMLES**: Logarithmic Wall Model coupled with Vreman SGS.
- **Mesh generation**:
  - Surface maximum spacing: $\Delta_{max}/l_{ref} \approx 0.005 - 0.01$
  - Focus region: $\Delta_{max}/l_{ref} \approx 0.01 - 0.02$
  - First point off the wall: DDES ($Y^+ \approx 1$) and WMLES ($Y^+ \approx 50 - 100$) with exchange location between the 3rd and 5th node.
- **Spatial Discretization**:
  - Select a low-dissipation convective scheme: Modified JST or SLAU2 are good candidates.
- **Time Discretization**:
  - Select a physical time step based on the convective time step $\Delta_{t_{max}}/T_c = 0.01$ where $T_c = l_{ref}/U_\infty$.
  - Dual-time stepping with 10 inner iterations. Expect a density residual reduction of 2-3 orders.

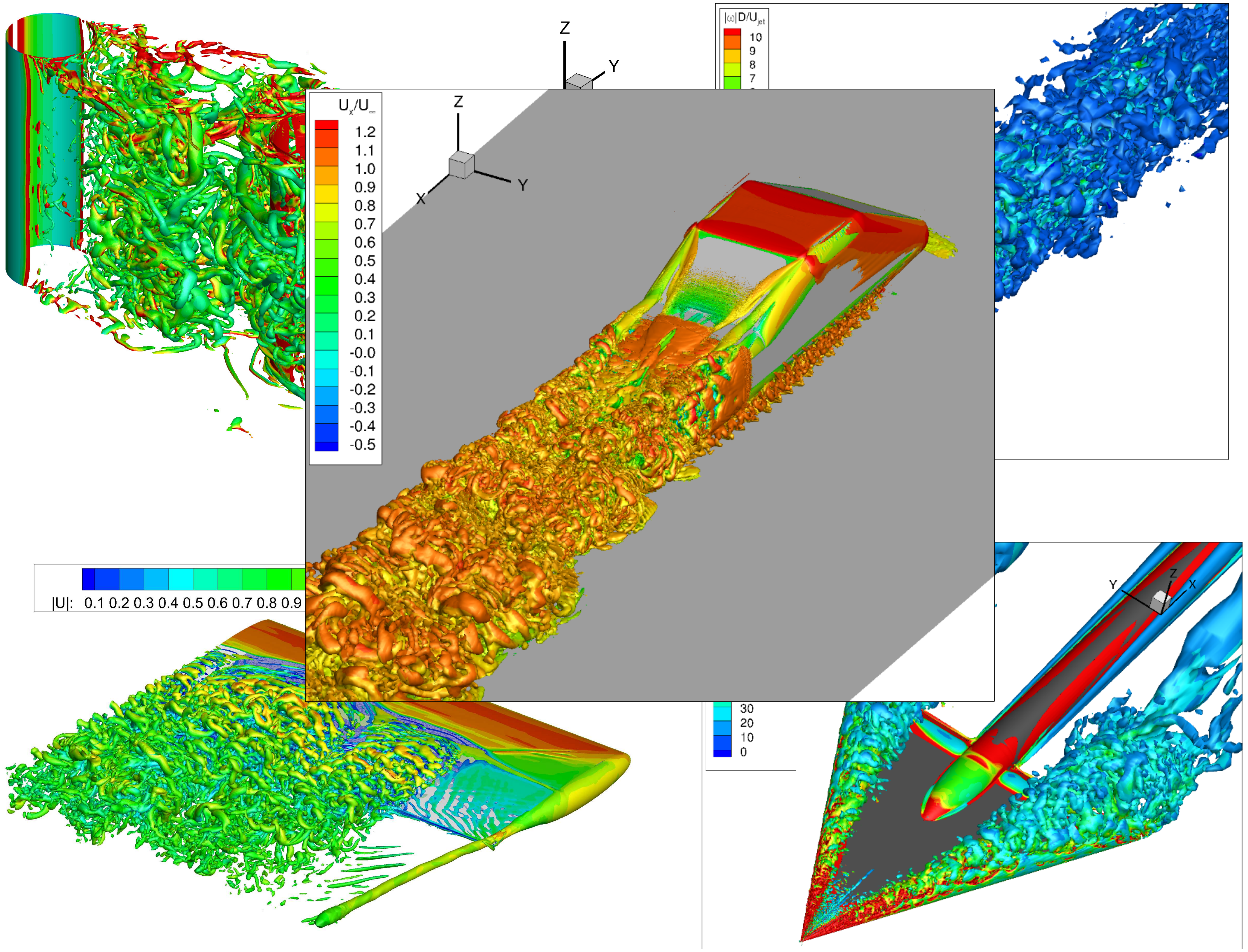
```
% DDES Config File
SOLVER= RANS
KIND_TURB_MODEL= SA
HYBRID_RANSLES= SA_EDDES

% WMLES Config File
SOLVER= NAVIER_STOKES
KIND_TURB_MODEL= NONE
KIND_SGS_MODEL= VREMAN
MARKER_WALL_FUNCTIONS= ( wall, LOGARITHMIC_WALL_MODEL, 0.1, 0.0, 0 )
VOLUME_OUTPUT= (PRIMITIVE, WALL_FUNCTION)
```

Exchange location

```
% Common settings for both DDES and WMLES
CONV_NUM_METHOD_FLOW= JST %SLAU2
JST_SENSOR_COEFF= ( 0.0, 0.0009765625 )
TIME_DOMAIN= YES
TIME_MARCHING= DUAL_TIME_STEPPING-2ND_ORDER
INNER_ITER= 10
TIME_STEP= 1.0E-5
CFL_ADAPT= YES
CFL_ADAPT_PARAM= ( 0.1, 1.2, 1.0, 20.0 )
NUM_METHOD_GRAD= GREEN_GAUSS %WEIGHTED_LEAST_SQUARES
NUM_METHOD_GRAD_RECON= LEAST_SQUARES
```

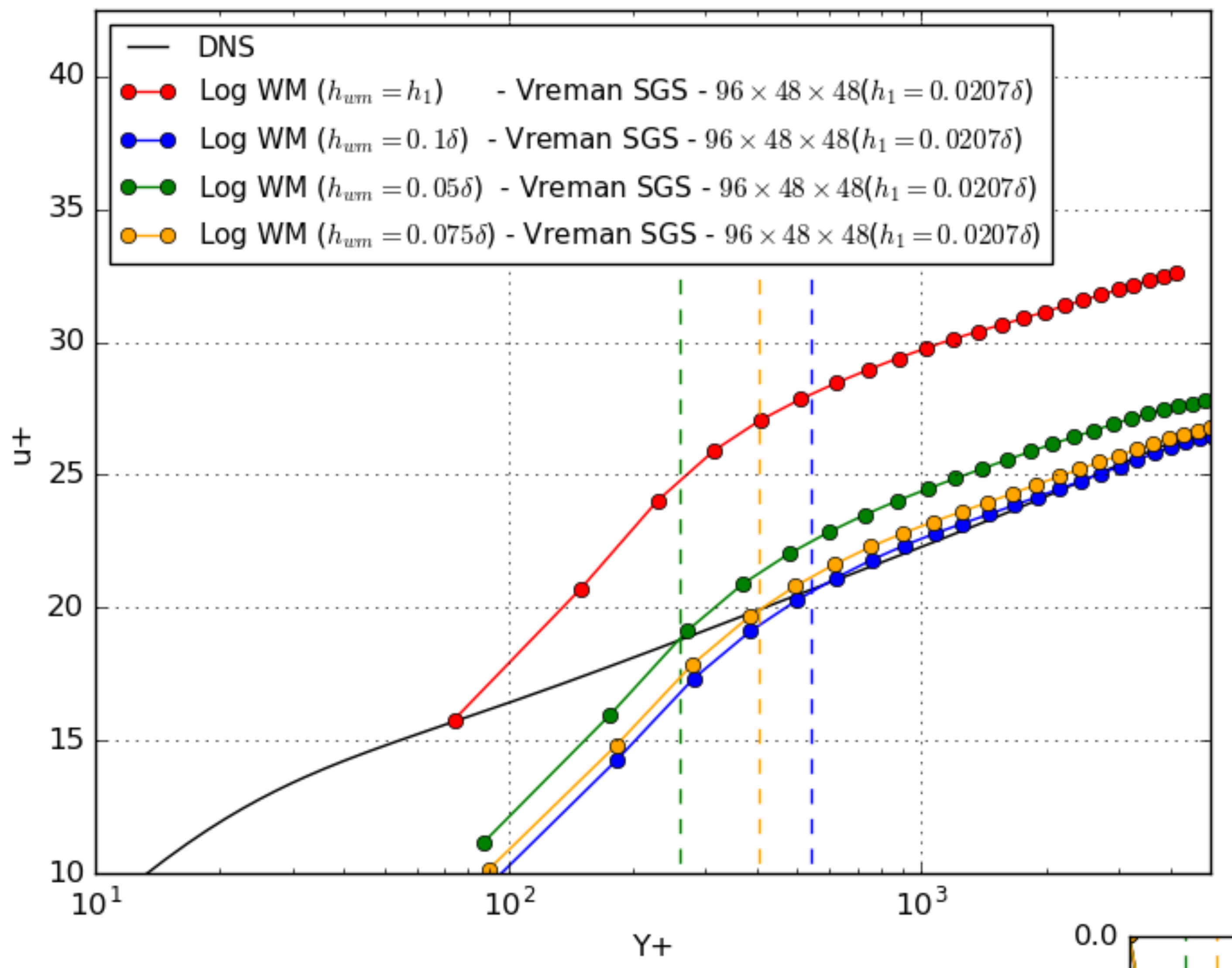
Examples of Hybrid RANS/LES Simulations in SU2

- Flow around Tandem Cylinders
  (Molina et al. 2019)
- Round jet noise *(Zhou, Tejal et al. 2021)*
- Transonic wing buffet *(Molina et al. 2018)*
- Vortex breakdown of a Delta wing
  (Zhou et al. 2019)
- Flow around automotive configurations *(Zhou et al. 2021)*

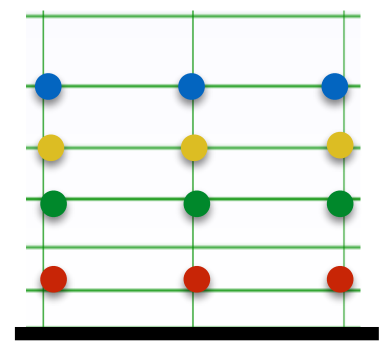


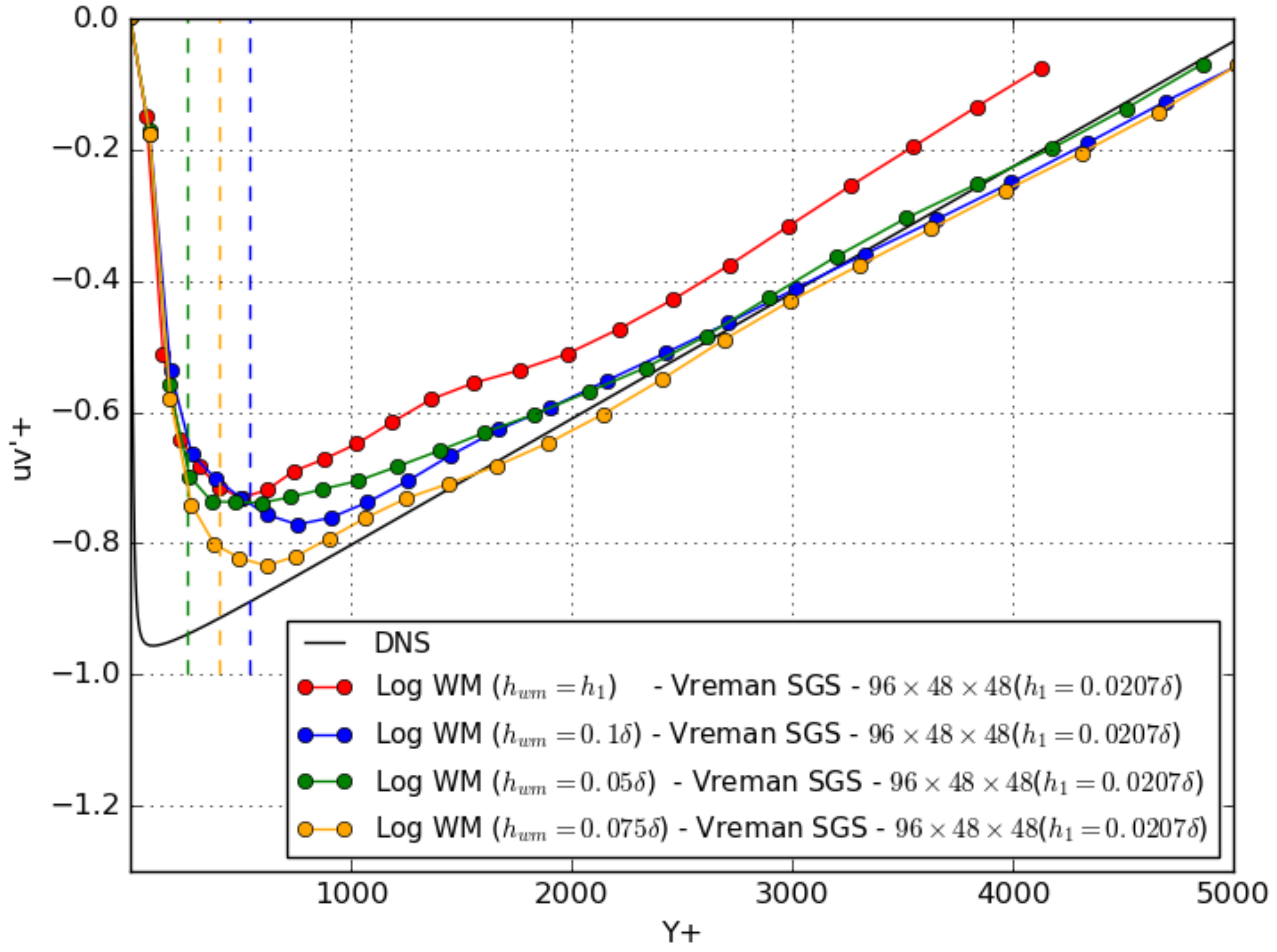
WMLES Verification and Validation

- Turbulent Channel Flow ($Re_\tau = 5200$).
- Algebraic Wall Model with Vreman SGS.
- Periodic boundary conditions in x and z-directions with a constant body force.
- Computational Domain: $L_x/\delta, L_y/\delta, L_z/\delta = (2\pi, 2, \pi)$
- Mesh Size: $96 \times 48 \times 48$ with $Y^+ \approx 100$.
- Good agreement with DNS in the outer layer for exchange locations between $h_{wm}/\delta = 0.075 - 0.1$ (top of 4th and 5th cell).
- <u>Recommendation</u>: Place the exchange location beyond the 3rd cell.



Effect of the Exchange Location

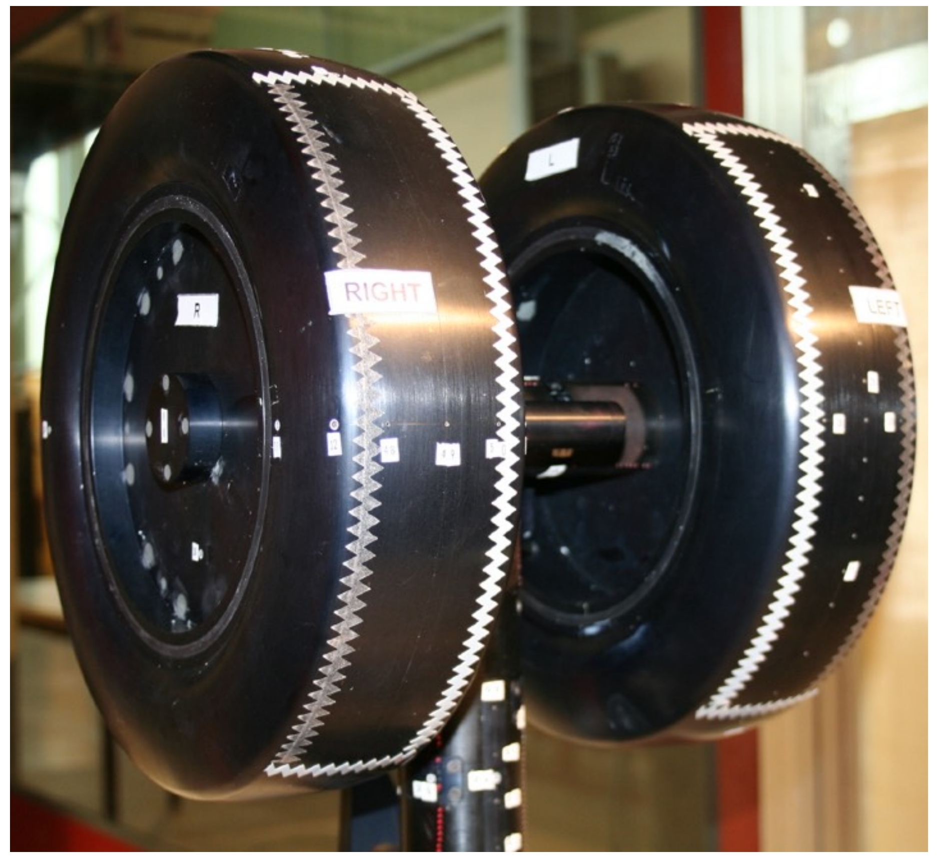


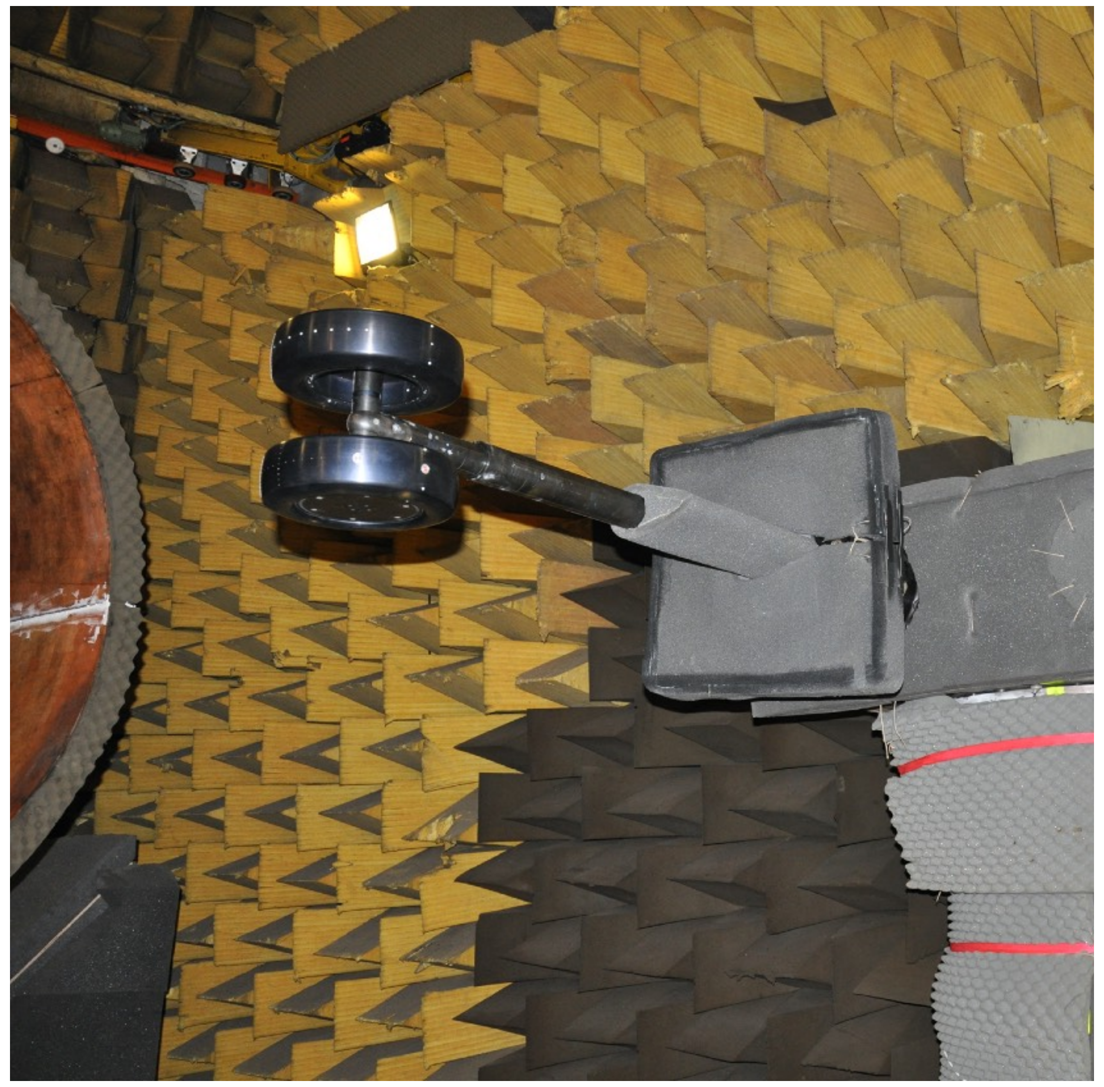


LAGOON (Nose Landing Gear Model)

- Joint project by Airbus and Onera*
- Objective: Build an aerodynamic/acoustic experimental database on a two-wheel simplified landing gear for flow and noise prediction.
- Wheel diameter: 300 mm
- 64 static pressure taps
- 27 Kulite unsteady pressure transducer
- HW, PIV and LDV measurements

F2 WT





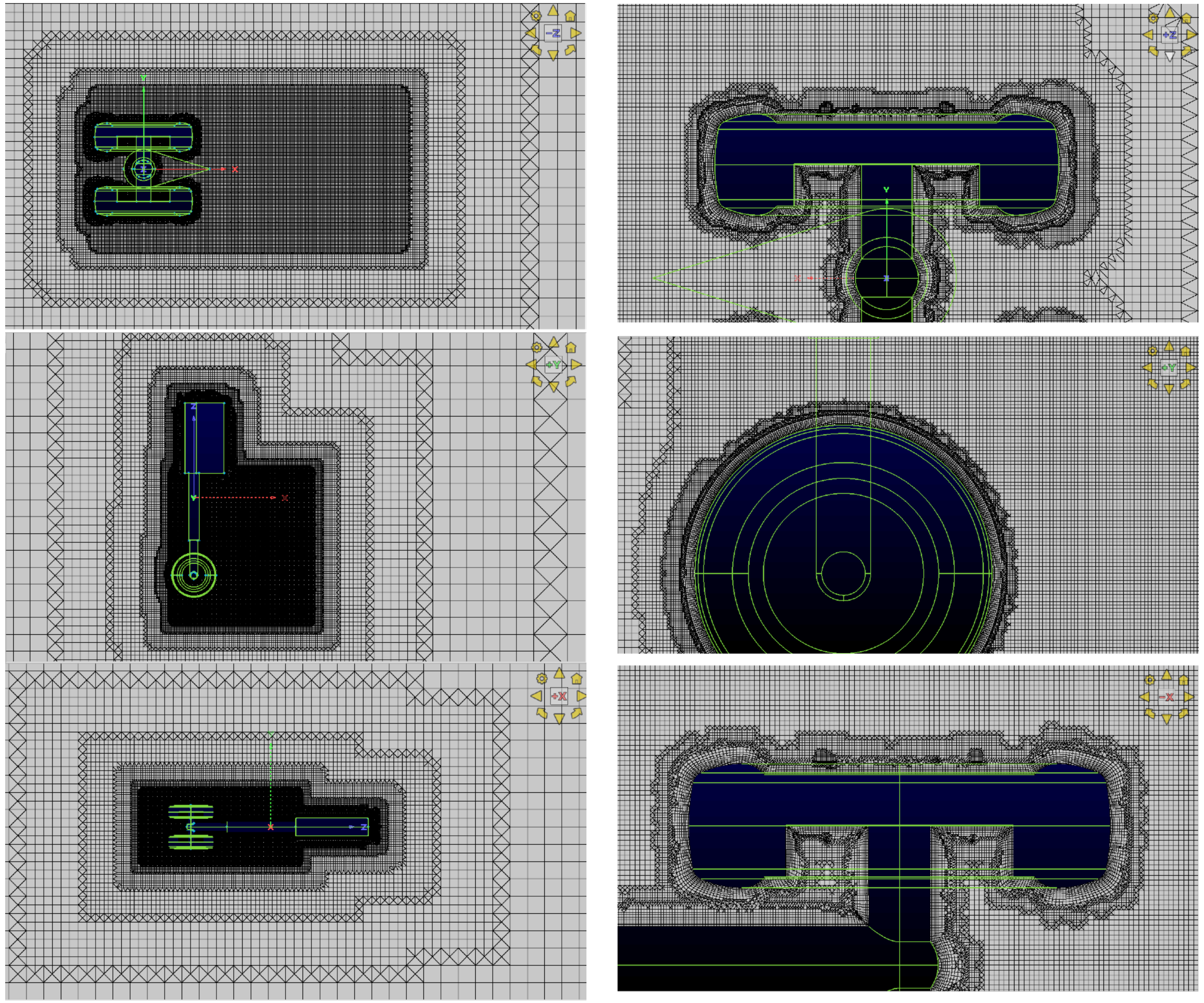
CEPRA19 WT

	F2	CEPRA19
Static pressure	99447.7 Pa	96772.3 Pa
Static temperature	293.56 °K	288.39 °K
Density	1.18 kg/m³	1.18 kg/m³
Mach	0.23	0.23

*E. Manoha, J. Bulté, and B. Caruelle, "Lagoon : An Experimental Database for the Validation of CFD/CAA Methods for Landing Gear Noise Prediction", AIAA- 2008-2816, 14th AIAA/CEAS Aeroacoustics Conference, Vancouver, May 5-7, 2008

LAGOON: Mesh Details

- Mesh generated using Pointwise's v18.3 Voxel feature.
- Maximum edge size of 0.0067D on the surface (without transition trip) and maximum edge size of 0.02D in the wake.
- Constant mesh size region 2.5D downstream of wheels added to better capture turbulent structures.
- Volume grid with 6 levels of refinement.
- Fast turnaround (CAD to final mesh).
- First point off the wall (h1 = 0.002D) with exchange location for wall model (hwm = 4.28*h1) located between the 4th and 5th element.
- During preprocessing only 2 donor elements were not found and their exchange location was set to h1.

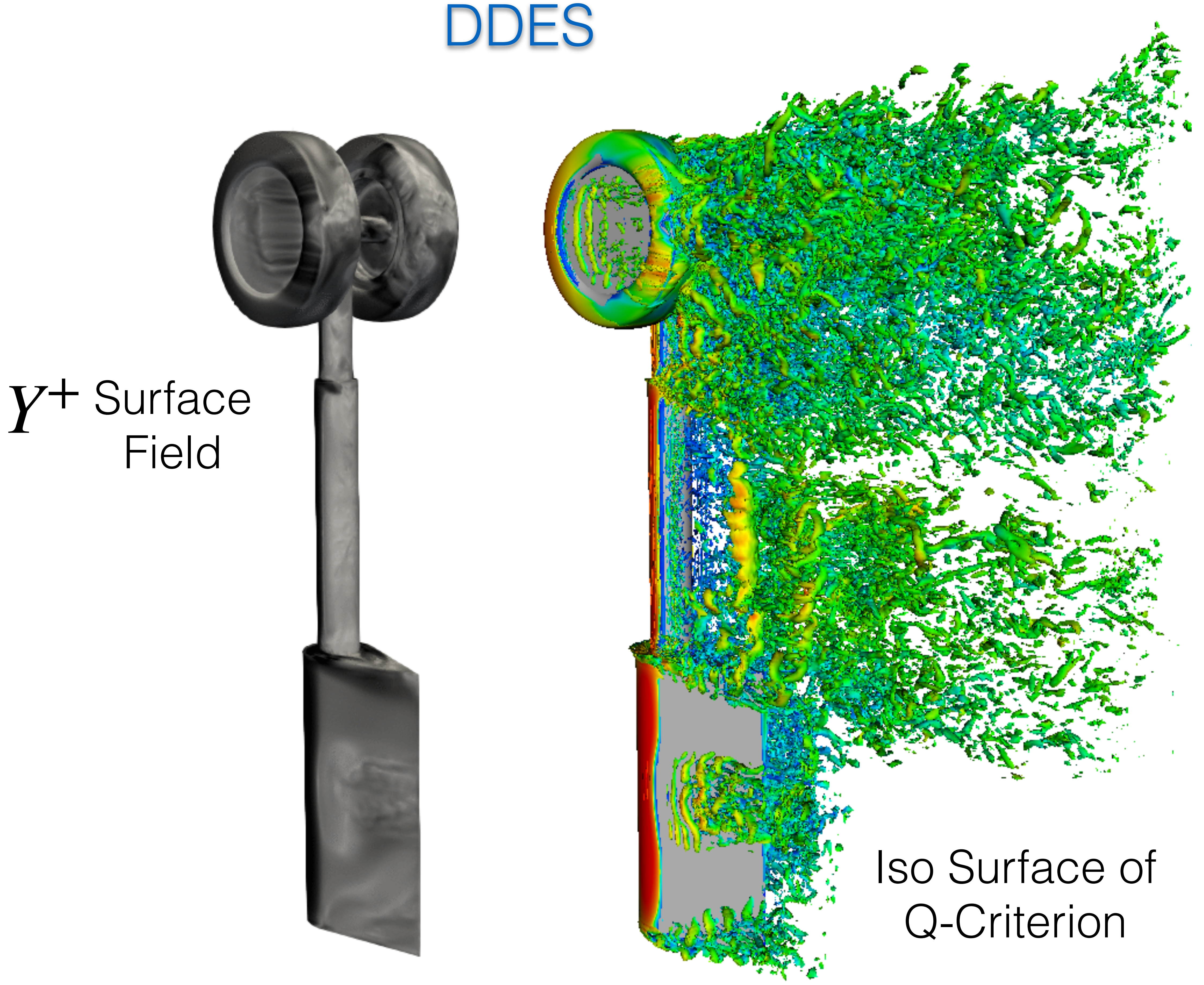


LAGOON: Computational Details

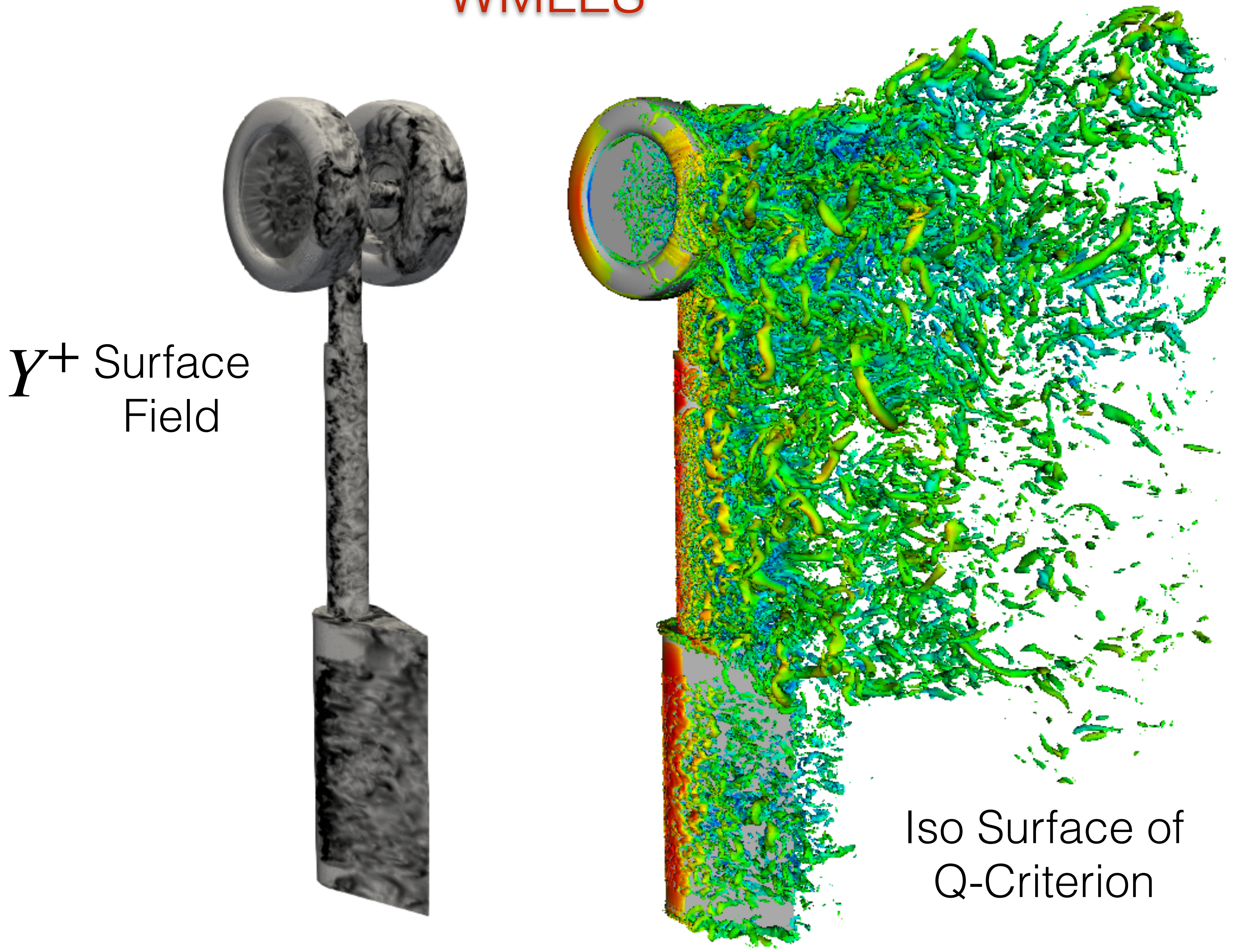
Method	WMLES	DDES
Turbulence Model / Subgrid Scale	Vreman SGS	SA EDDES
Spatial / Time Discretization	JST ($k^4 = 1/1024$) with implicit dual-time stepping (10 inner iterations)	
Number of Elements (1e6)	27	34
First grid off the wall (mm)	0.01	0.6
Time Step (1e-6 s)	38	
Wall Time for 200 CTUs (hours)	29,094	43,480 (~1.5x)

LAGOON: Instantaneous Flow

DDES

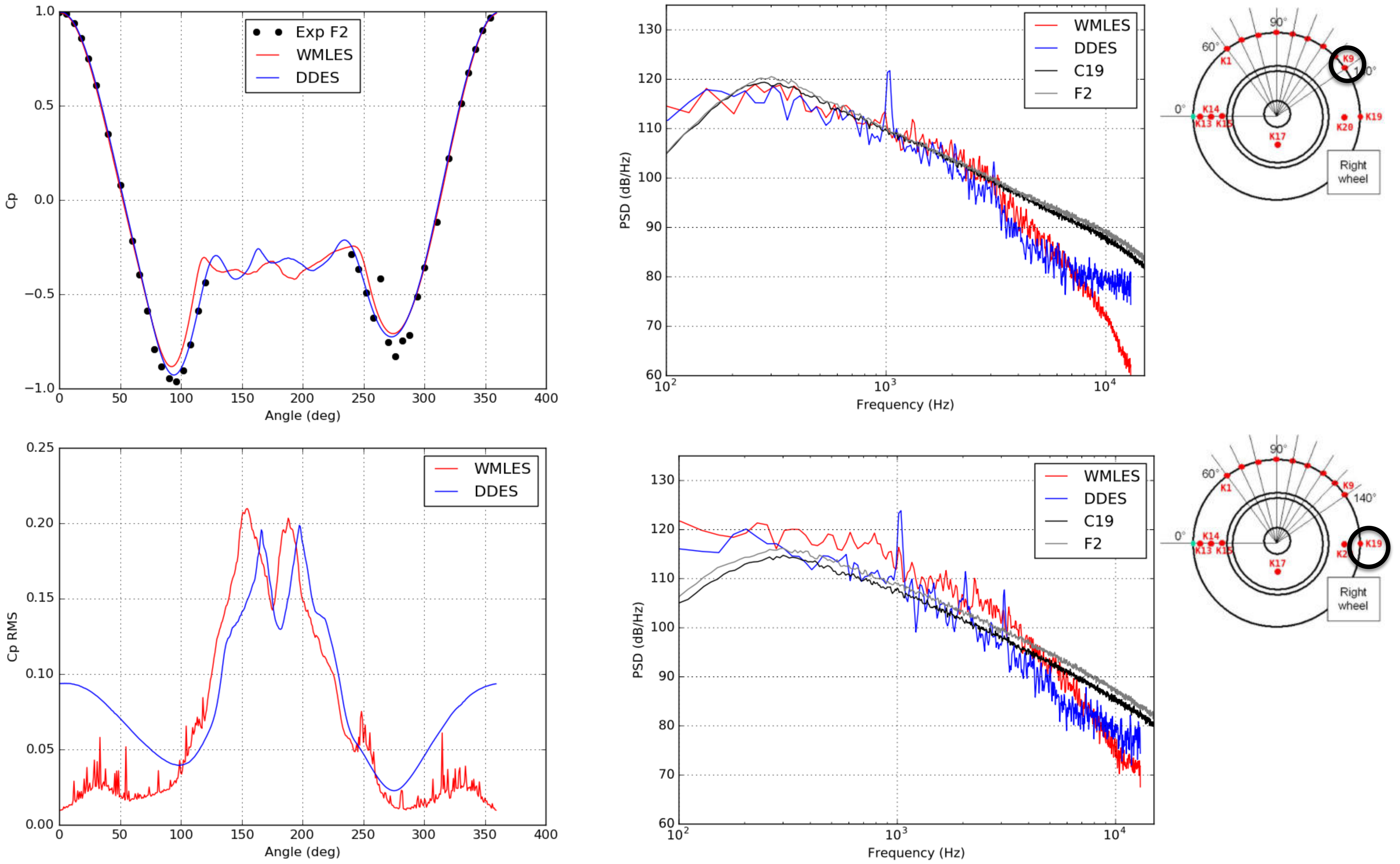


WMLES

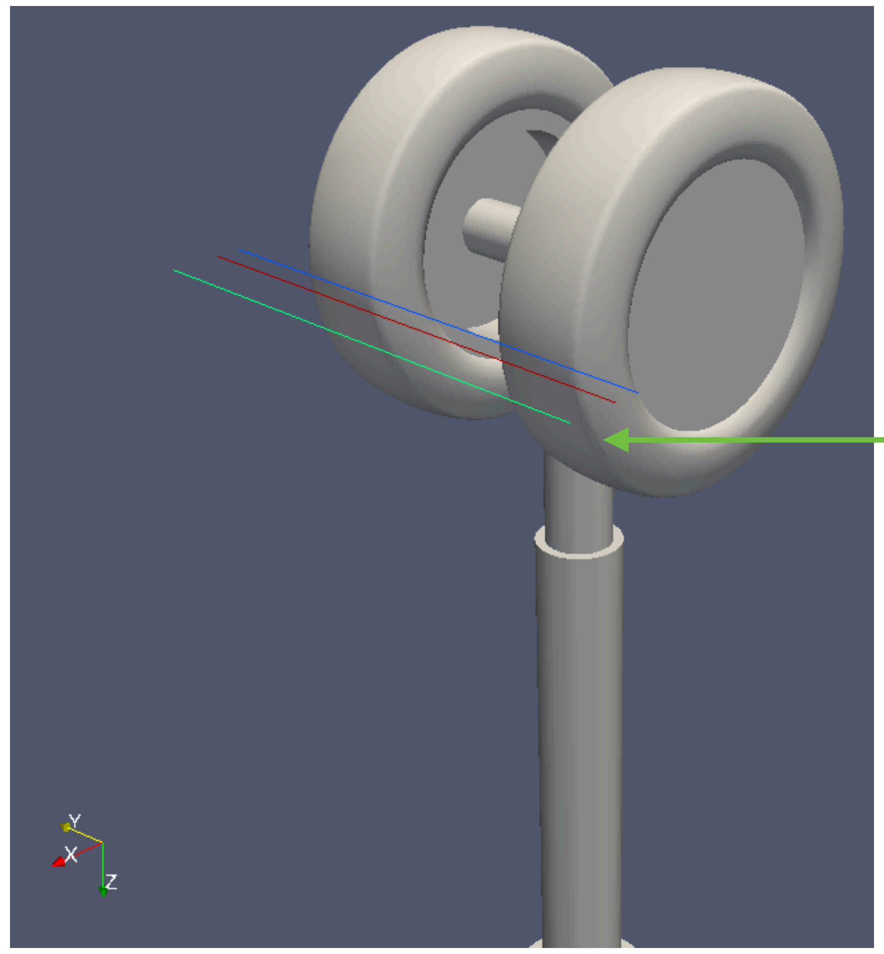


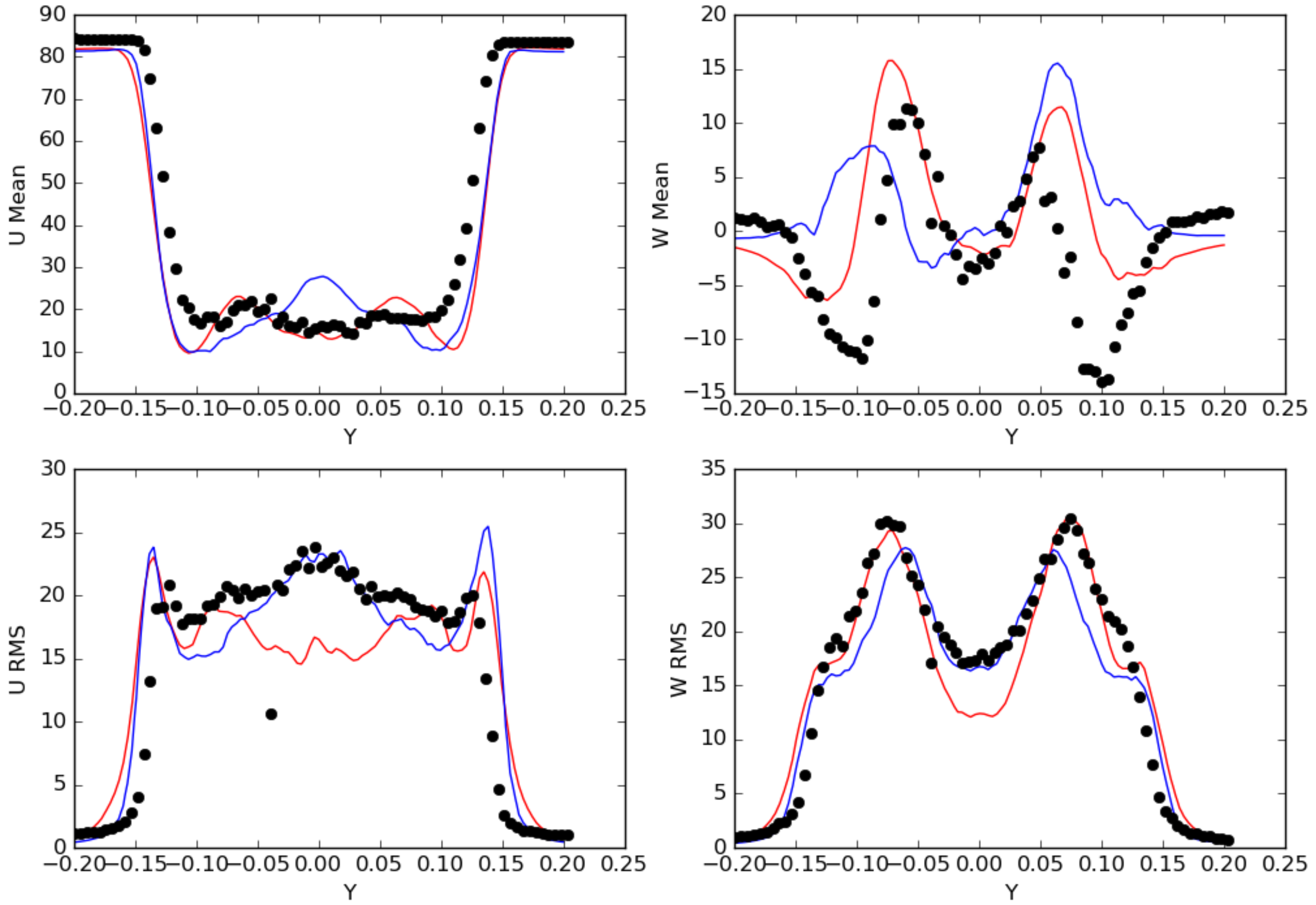
LAGOON: Surface Pressures

- Mean and RMS pressure on the wheel perimeter.
- Effect of not tripping the boundary layer on WMLES.
- Ongoing investigation of the difference in RMS levels between DDES and WMLES.
- PSD comparison on 2 regions of separated flow behind the wheel.



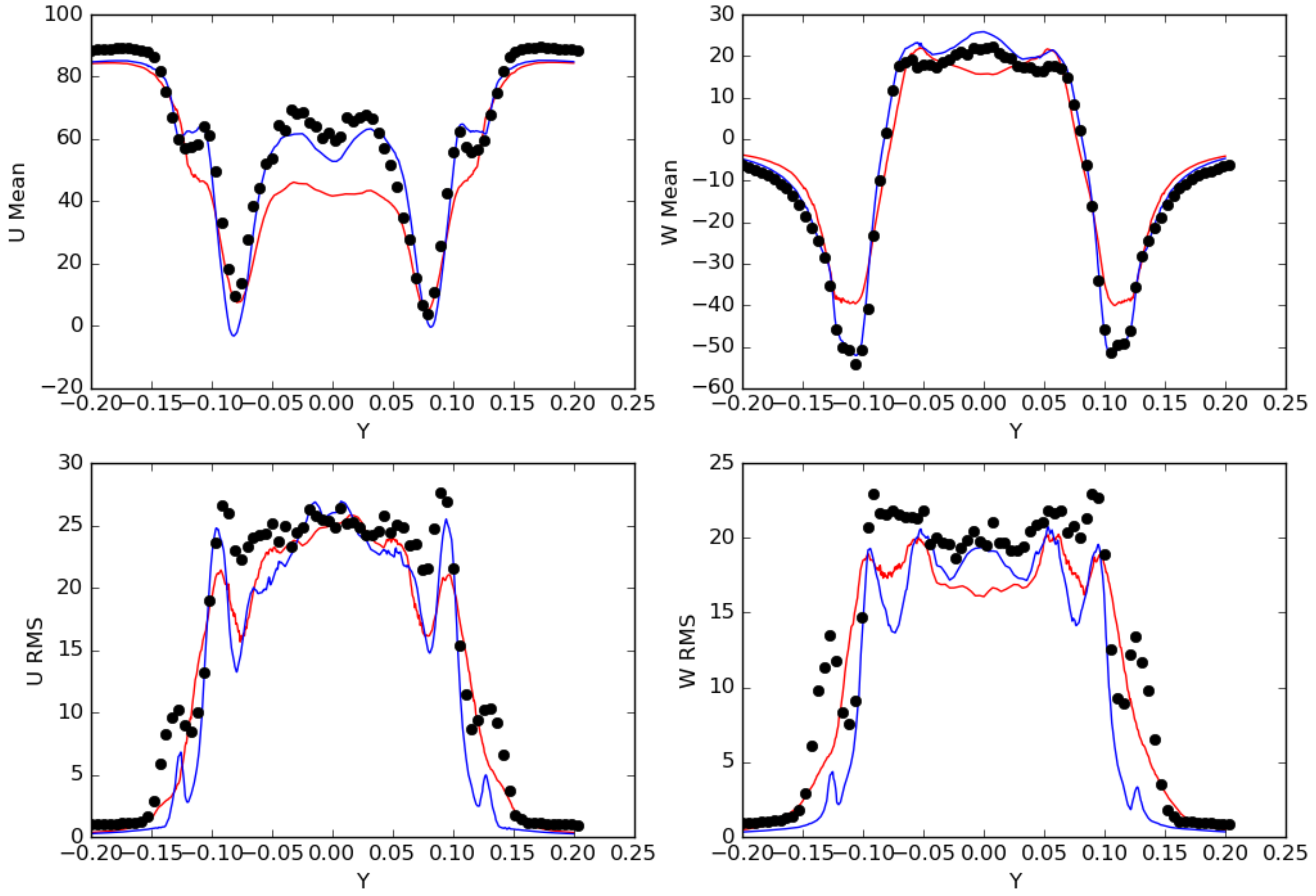
LAGOON: Velocity Profiles



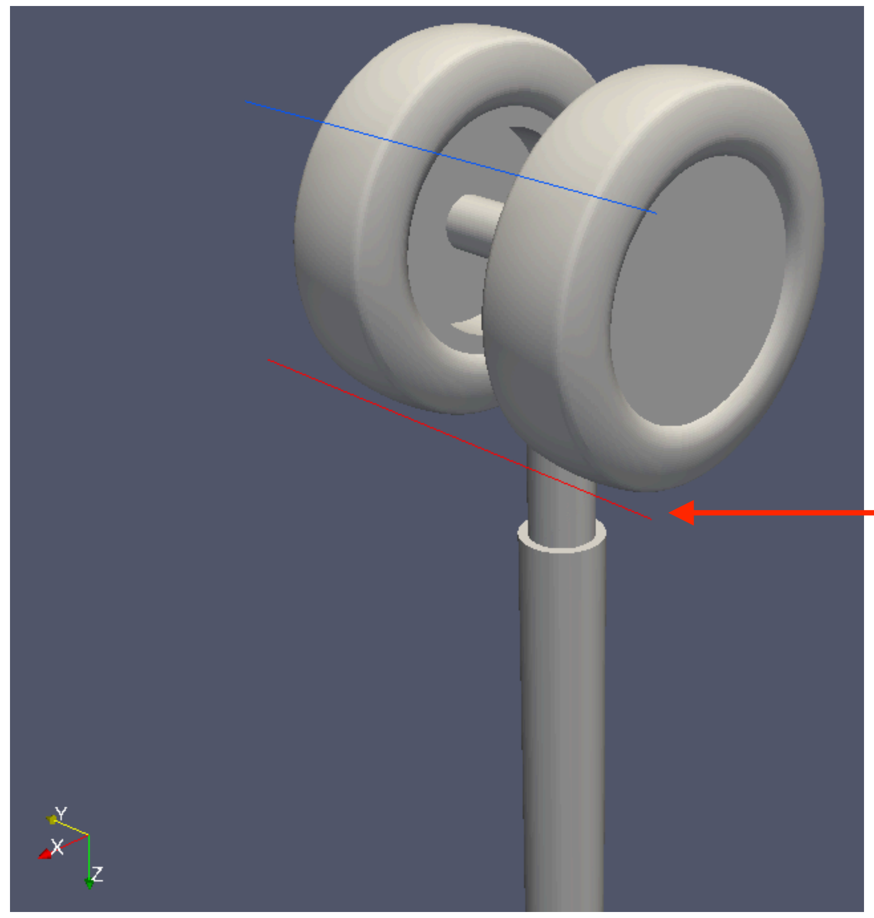


Experiments include mean and RMS data generated by laser Doppler velocimetry (LDV).

DDES - Blue line
WMLES - Red line

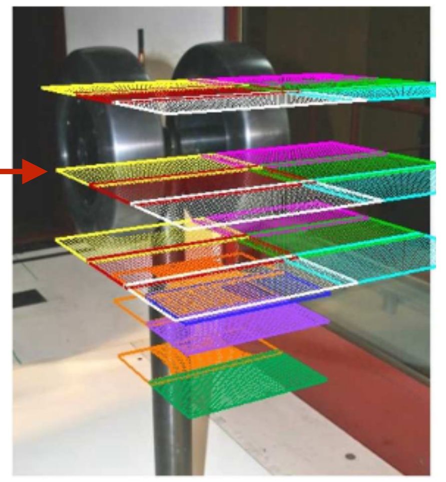


WMLES and DDES results show good agreement with exp. data near the wheel.



LAGOON: Velocity Flow Field

Z = 0.0m



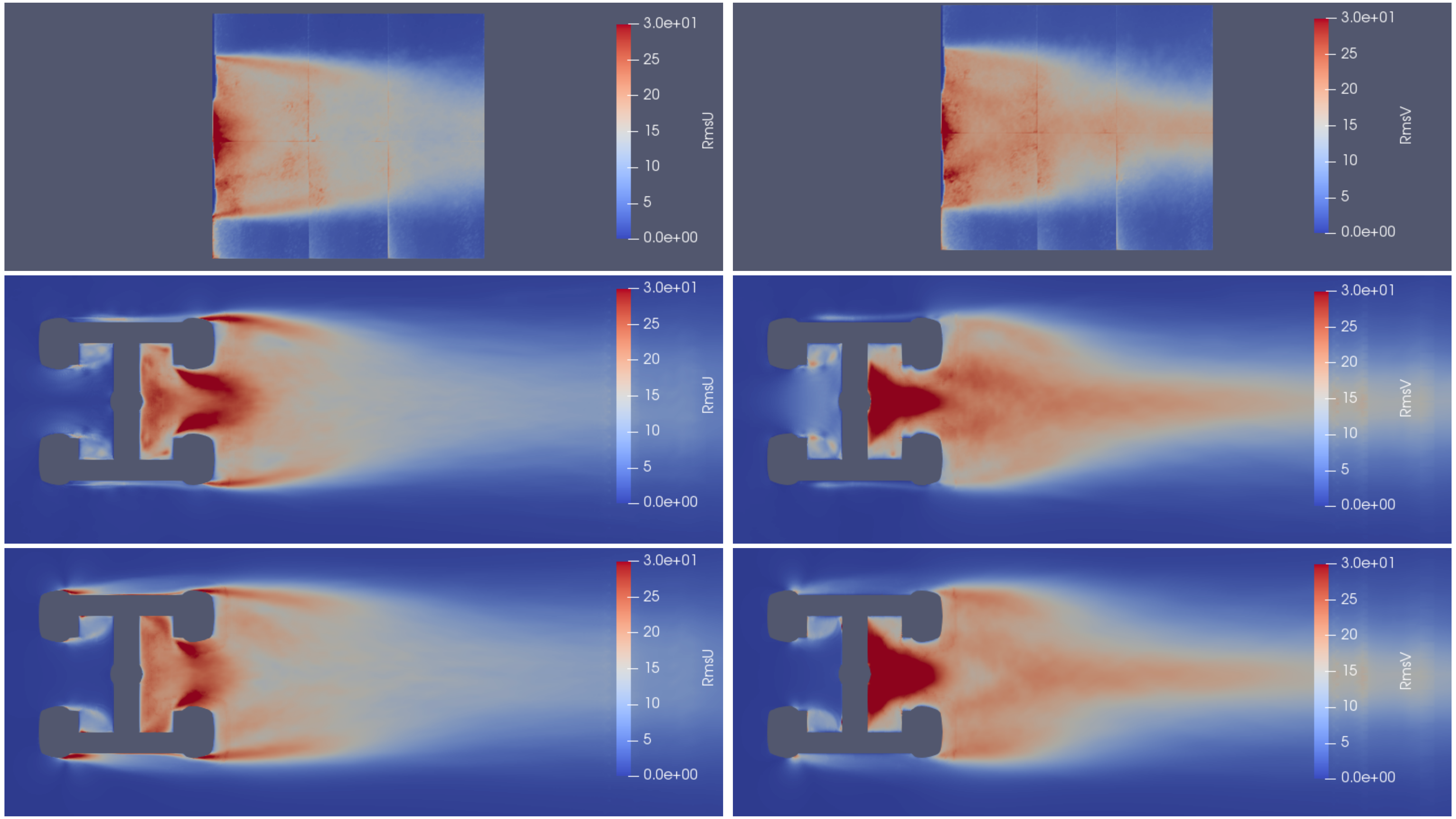
Streamwise RMS Velocity

Spanwise RMS Velocity

Experimental Data

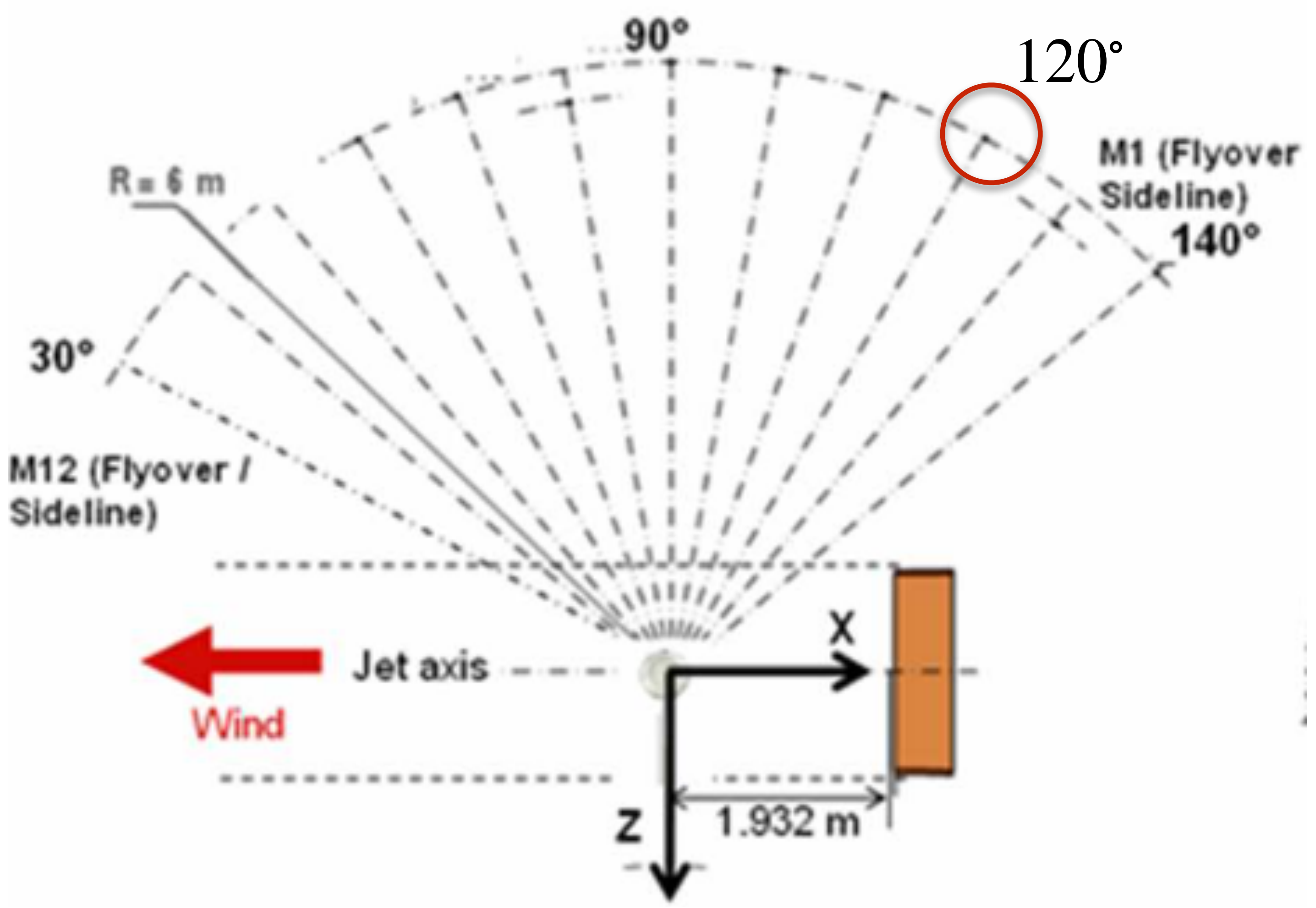
DDES

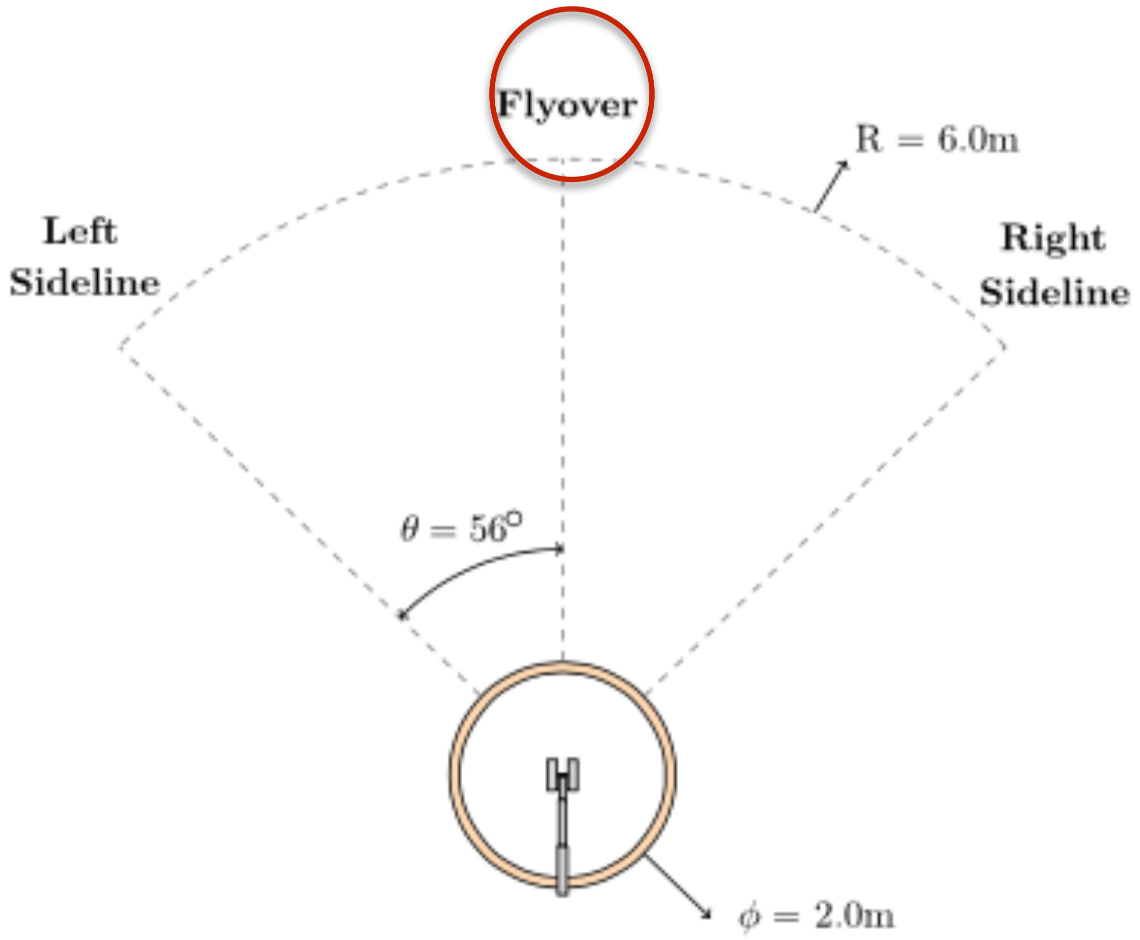
WMLES

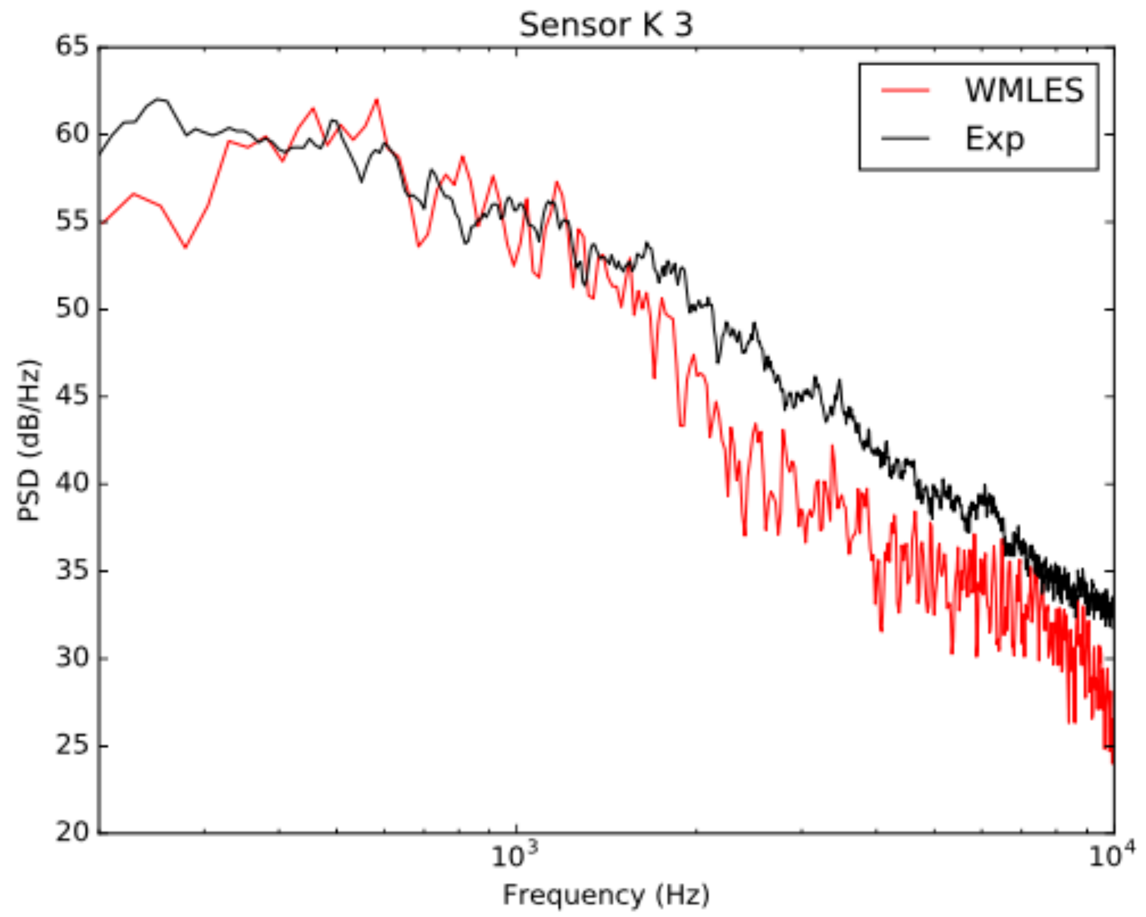


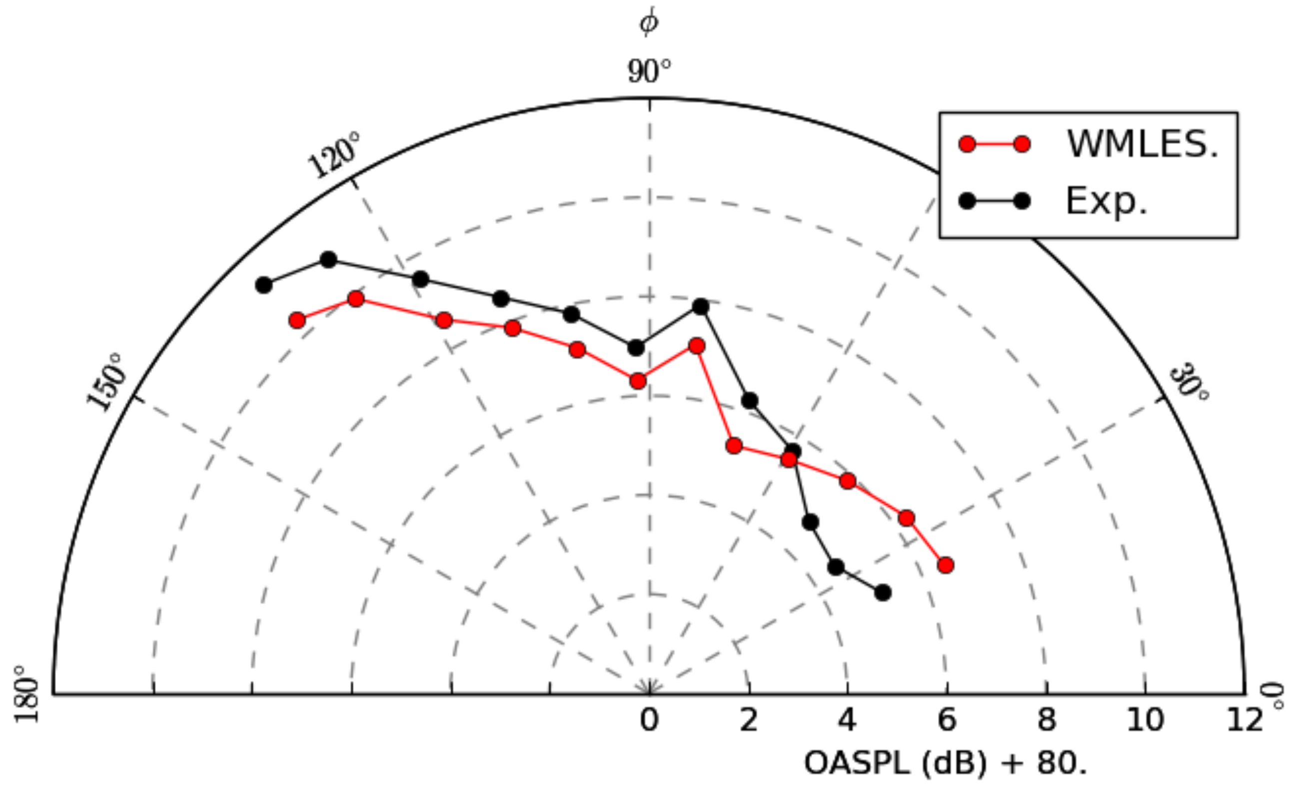
LAGOON: Farfield Acoustics

- PSDs are corrected for background noise, atmospheric absorption, and the effects of refraction through the open-jet wind tunnel.
- Good agreement with experiments up to 1.5kHz.
- OASPL (200Hz - 10kHz) directivity noise PSD (Flyover position) computed with solid-surface FWH formulation.





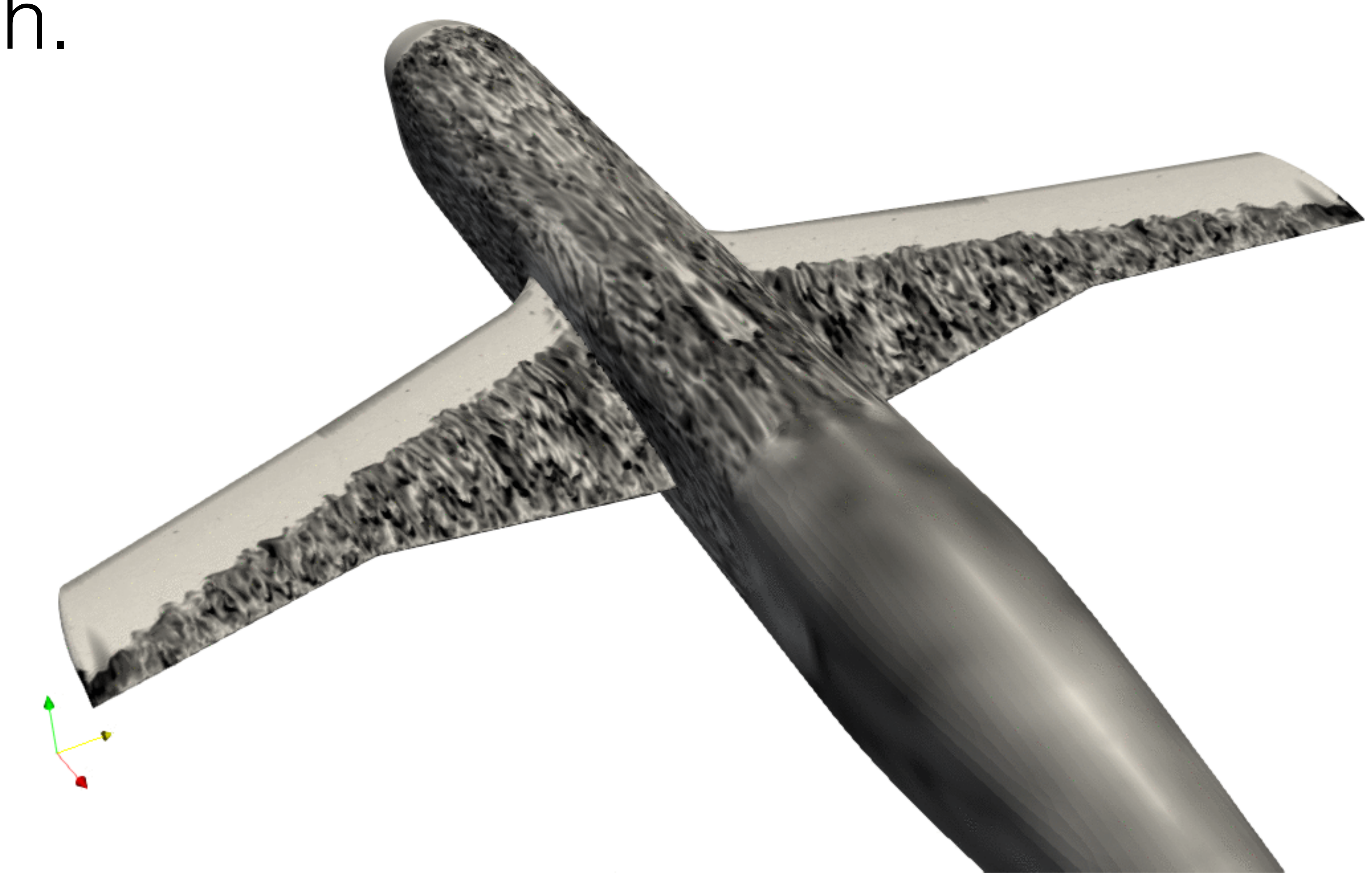




Conclusions and Future Work

- DDES and WMLES scale resolving simulations are now available in SU2. Feedback appreciated!
- Source code available in ***feature_WallModelLES*** branch.
- Complete set of WMLES validation test cases include: turbulent channel, turbulent duct, NASA Hump and LAGOON.
- Future work:
  - Merge with ***develop*** branch for future release.
  - Ongoing simulations of the NASA Juncture Flow.

NASA Juncture Flow Experiment



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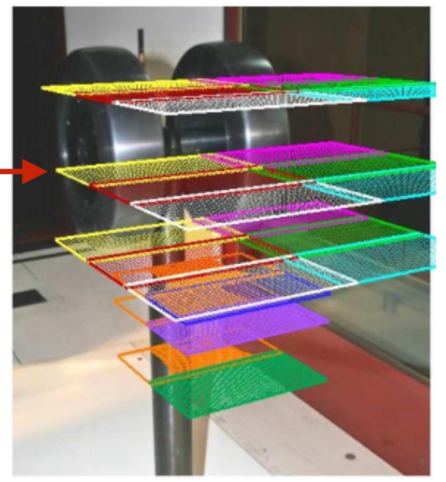
- Embraer SA
- Boeing Brazil
- Dr. Eric Manoha (Onera) for providing the geometry and experimental data of the LAGOON case.

Backup slides

LAGOON: Velocity Flow Field

Z = 0.0m



Experimental Data

DDES

WMLES