VOLKSWAGEN

AKTIENGESELLSCHAFT

GROUP INNOVATION

REDUCED ORDER MODELS FOR INTERACTIVE AERODYNAMIC VEHICLE DESIGN

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VOLKSWAGEN AG

AGENDA

1. Volkswagen as a Partner in ARIA
2. Interactive Aerodynamic Design: Pre-ARIA Status
3. The Volkswagen ARIA Test Case
4. First ARIA Results of the Hybrid Neural Network/ROM Approach

PEOPLE

- Markus Mrosek, MSc Mechan. Eng., PhD Candidate at VW since 09/2017

- Carsten Othmer, PhD in Physics, Senior Researcher and Project Lead, at Volkswagen since 2002

- Volkswagen AG, Wolfsburg, Germany
- Volkswagen Group Innovation

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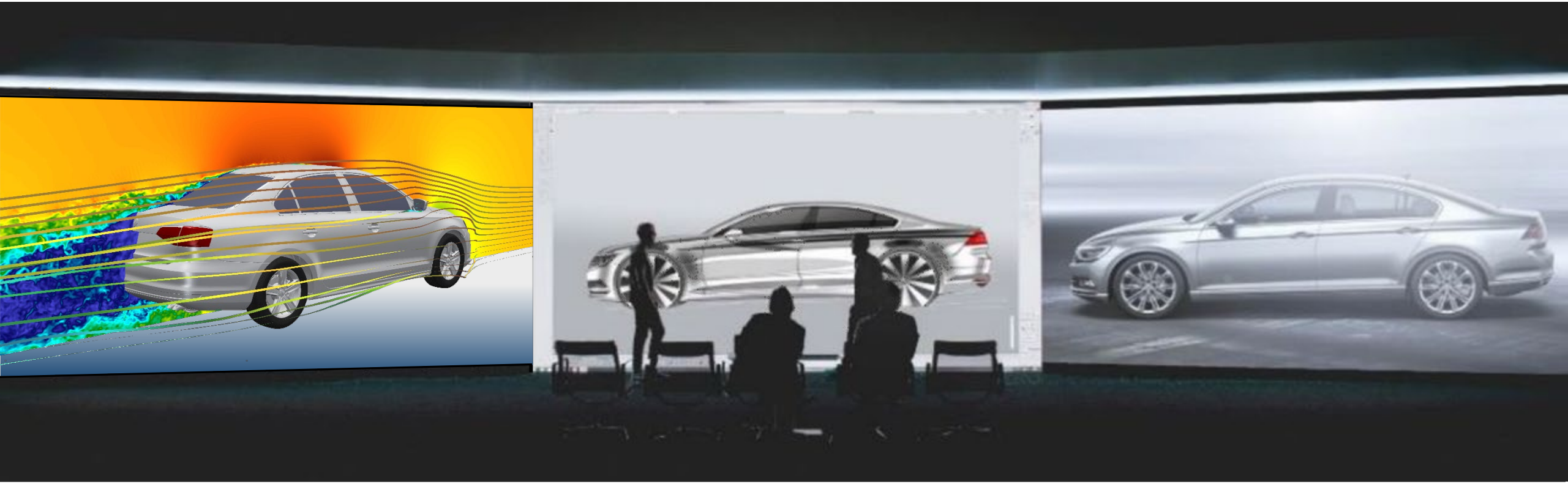
MOTIVATION

Problem: Iterative loop between aesthetic design and aerodynamic computation: 12h up to several days

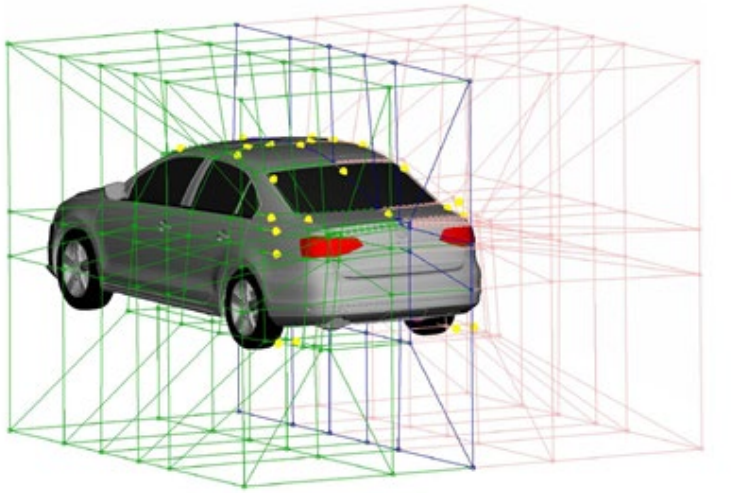
Solution: Real-time aerodynamic prediction for interactive aerodynamic design



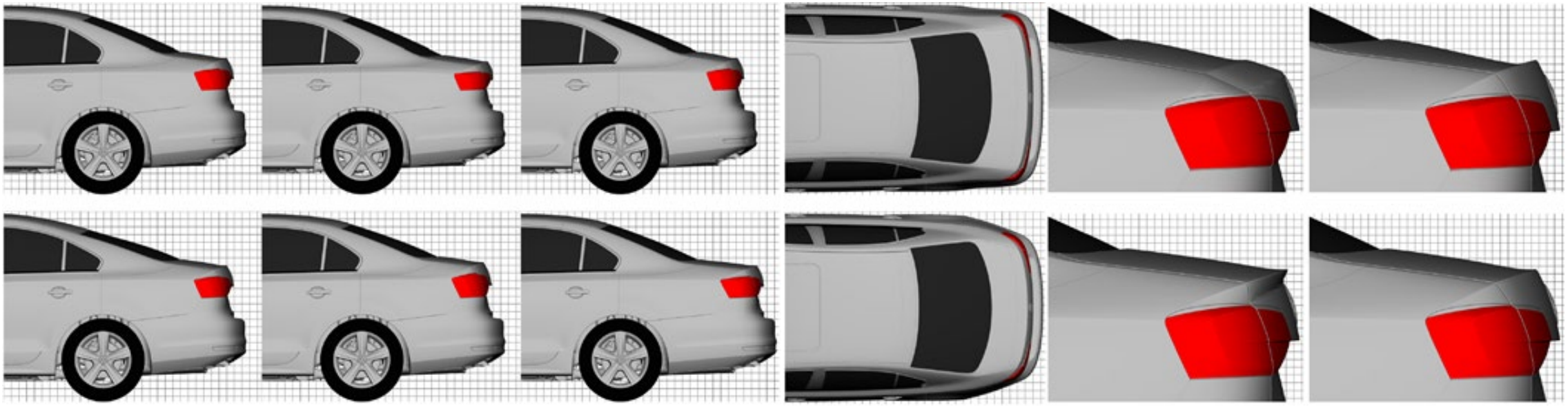
Required: Accurate Reduced Order Model (ROM)

CHARACTERISTICS OF THE REAL-LIFE APPLICATION

EXAMPLE: 6-DIMENSIONAL JETTA



- ANSA® FFD boxes, 6 parameters in the rear
- c_d and flow fields from OpenFOAM time-averaged DDES
- 103M cells, 4 sec, averaged over the last 2 (= 23,000 core-hours)
- 100 Latin Hypercube samples



a) Rear roof lowering:
0mm (top), +50mm (bottom)

b) Trunk height:
-30mm (top), +30mm (bottom)

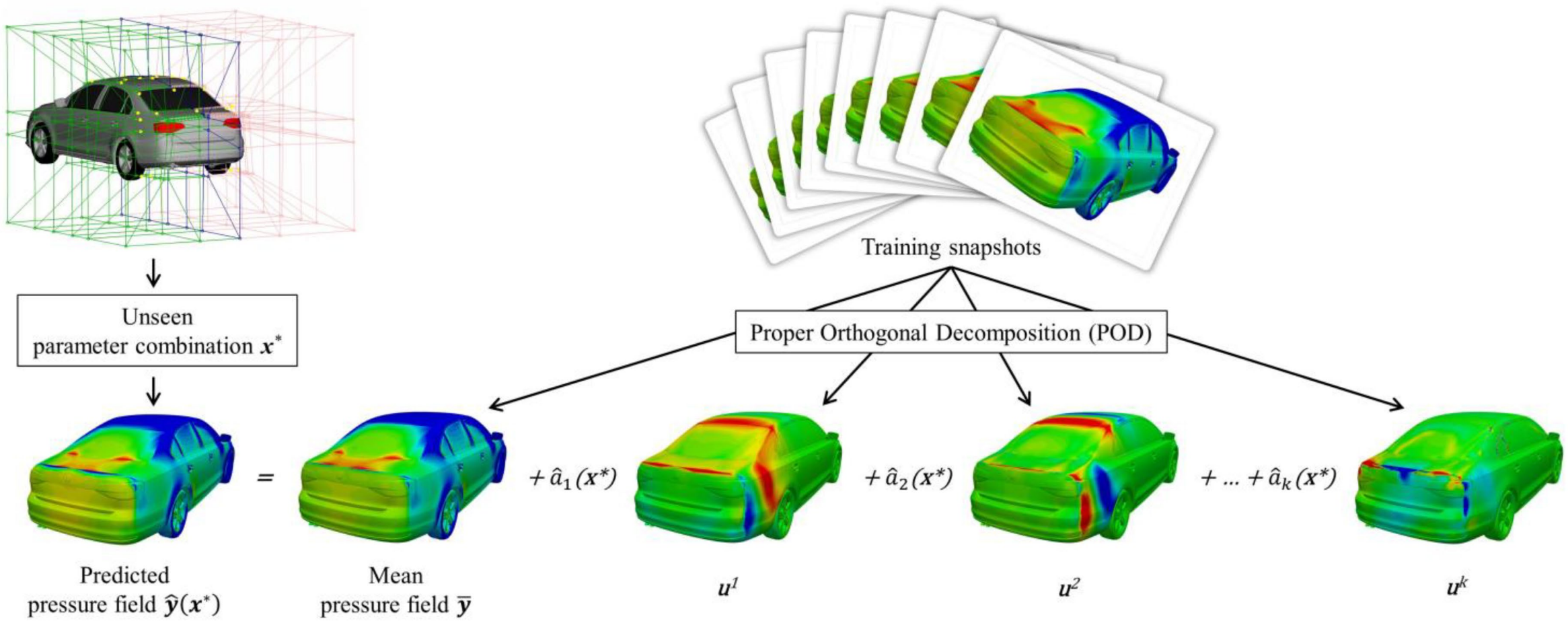
c) Trunk length:
-50mm (top), +100mm (bottom)

d) Rear lateral tapering:
-60mm (top), +50mm (bottom)

e) Rear end edge position:
-70mm (top), +30mm (bottom)

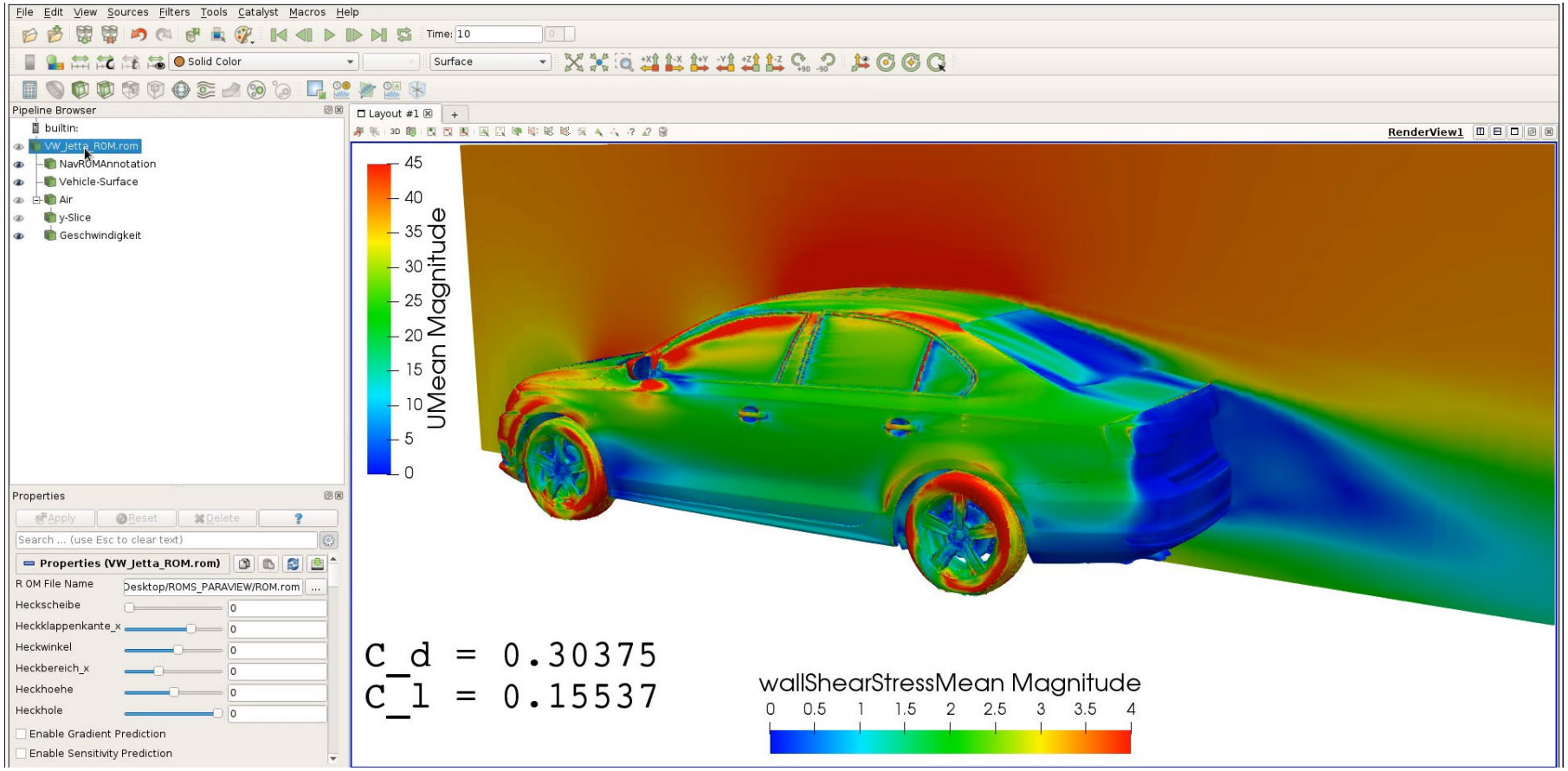
f) Rear end depression:
-15mm (top), 0mm (bottom)

CURRENT WORKHORSE: POD + I



Interpolation of base coefficients with Kriging or Thin-Plate-Splines [SAE-06-12-03-0016]

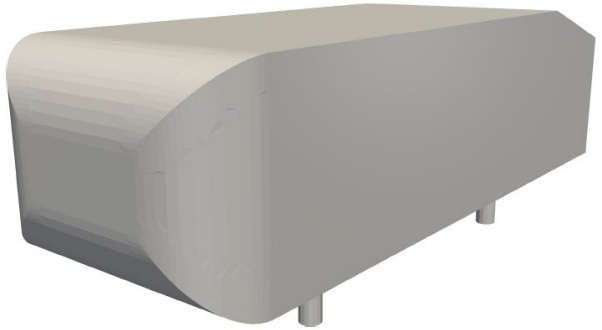
HOW IT LOOKS LIKE



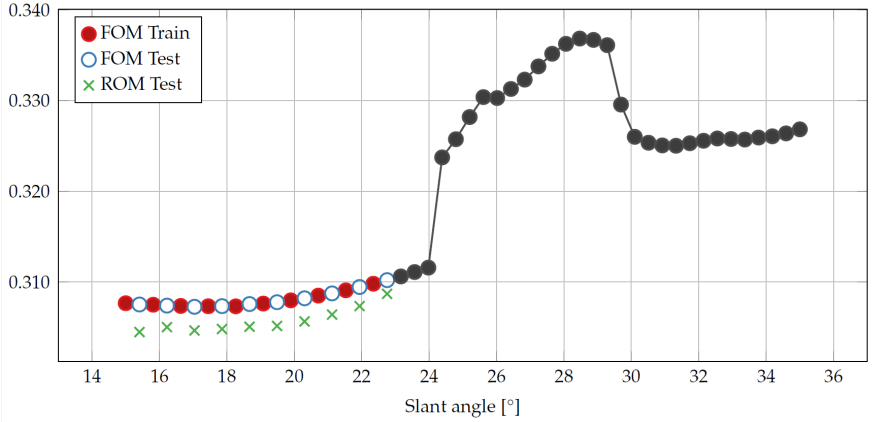
Paraview plugin for interactive visualization (by Navasto, Berlin)

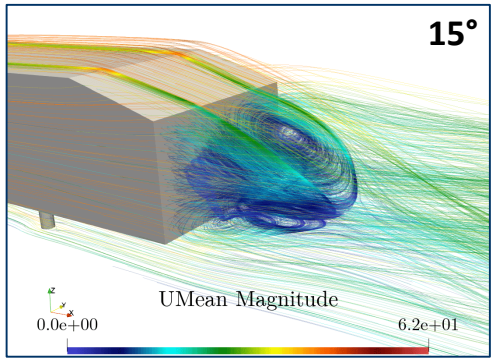
TEST CASE FOR ARIA: AHMED BODY

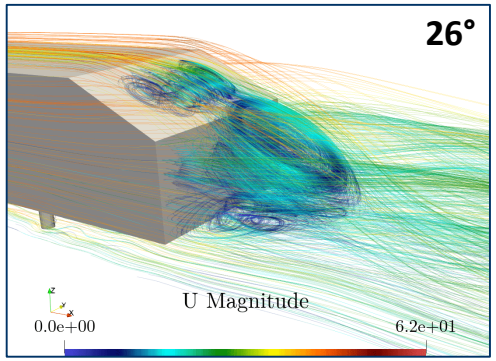
CASE CHARACTERISTICS

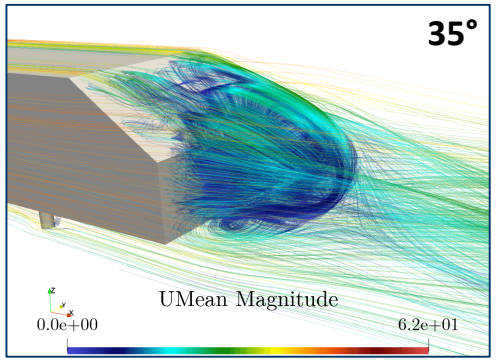


- External aero “classic“ [Ahmed et al., 1984], setup created with the SISSA team
- Very coarse on purpose; still physically sensible results

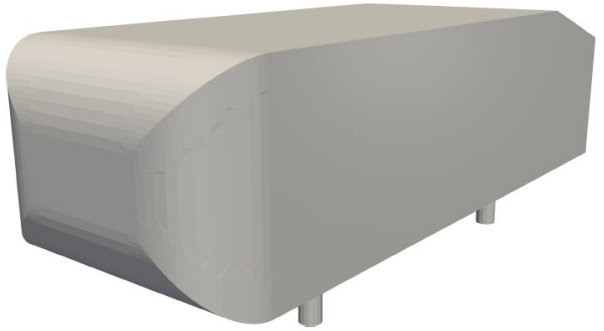








Parameters	Type of parametrisation	CFD-Model	#Cells	#Snapshots	CPU-time / snapshot [core hours]	Storage space / snapshot	Total Storage space
Slant angle: 15-35°	RBF for surface and volume mesh	DES (pimpleFoam)	0.2M	50	16	80MB (1 timestep)	4GB (1 timestep)
		RANS (simpleFoam)	0.2M	50	0.5	80MB	4GB



TEST CASE FOR ARIA: AHMED BODY

PREDICTION QUANTITIES AND ERROR METRICS

Quantities to be predicted:

- Fields:
  - Wall shear stress and pressure on Ahmed body surface
  - Pressure and vectorial velocity in the volume around the Ahmed body (whole domain)
- Coefficients:
  - Drag coefficient, lift coefficient

Error metrics:

- Fields: $\delta_y = \frac{\|y - \hat{y}\|_2}{\|y\|_2}$ (y: CFD field vector, $\hat{y}$: ROM field vector)
- Coefficients: $\delta_c = \frac{|c - \hat{c}|}{|c|}$ (c: CFD-predicted coefficient, $\hat{c}$: ROM-predicted coefficient)

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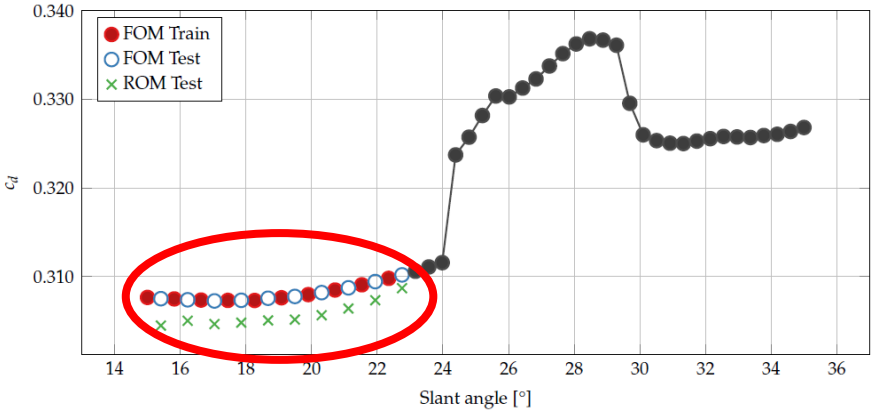
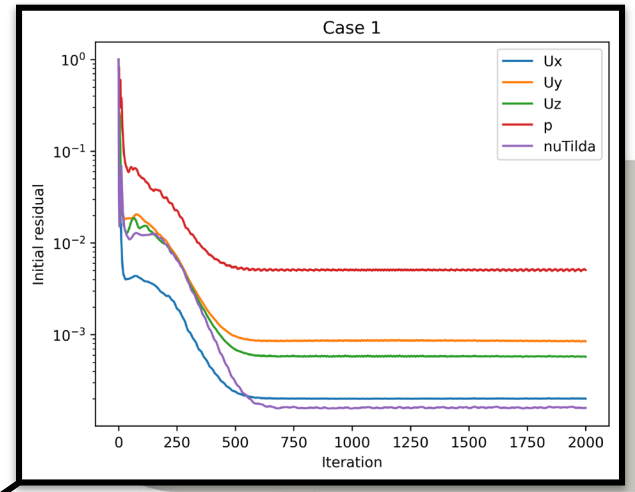
VOLKSWAGEN TEST CASE: AHMED BODY

TRAINING DATA - RANS



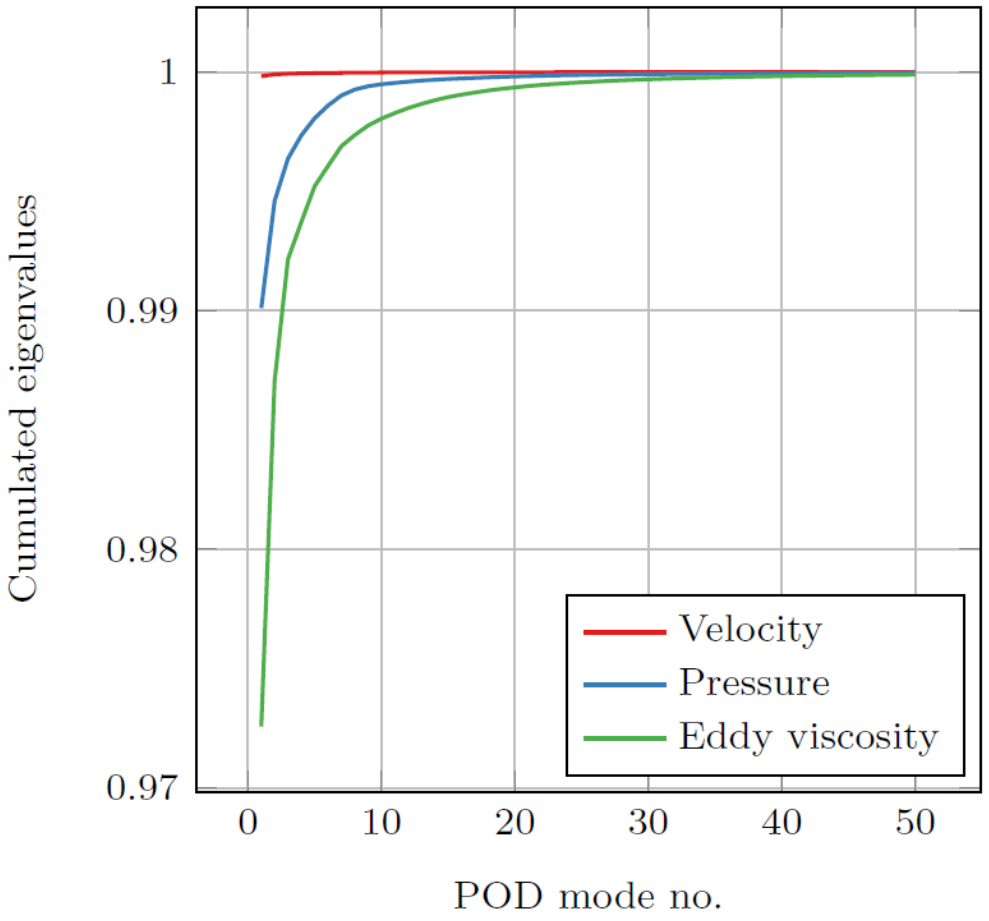


Slant angle: 15 - 22.8 degrees

- 100 snapshots saved per geometry (every 20 iterations out of 2000)➔ **1000 snapshots**
- Goal is the prediction of converged solution after 2000 iterations

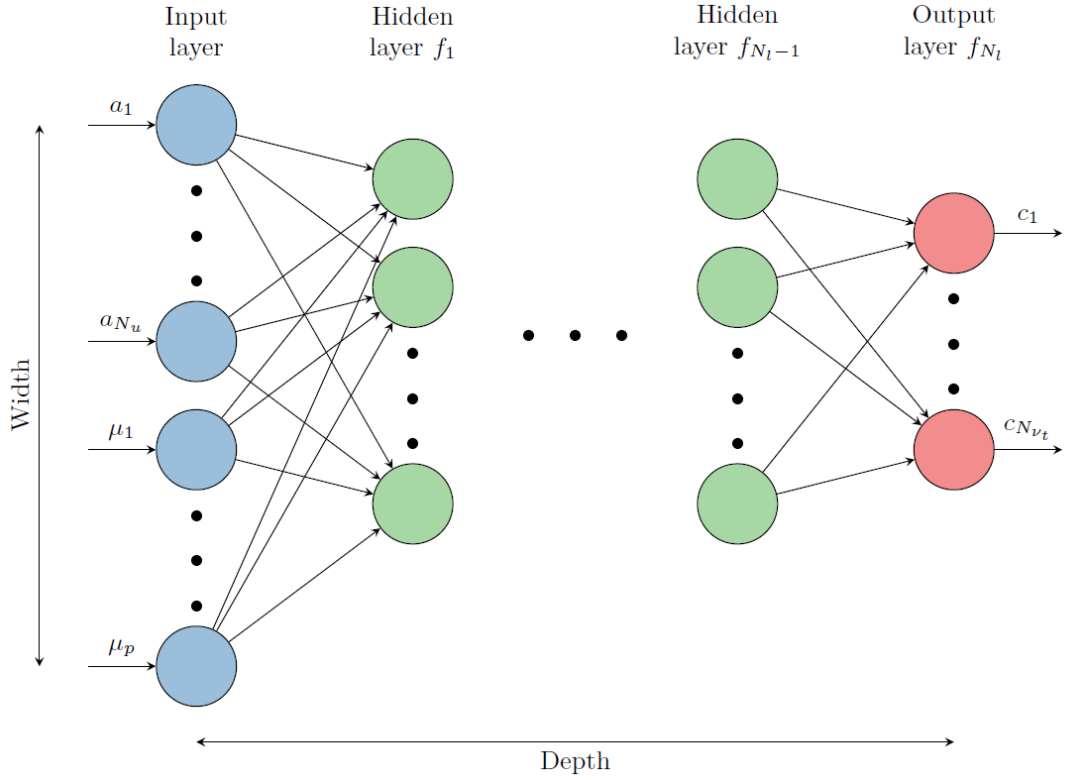
POD EIGENVALUES

- Separate POD for velocity, pressure and eddy viscosity based on 1000 snapshots
- 30 modes kept for all three fields



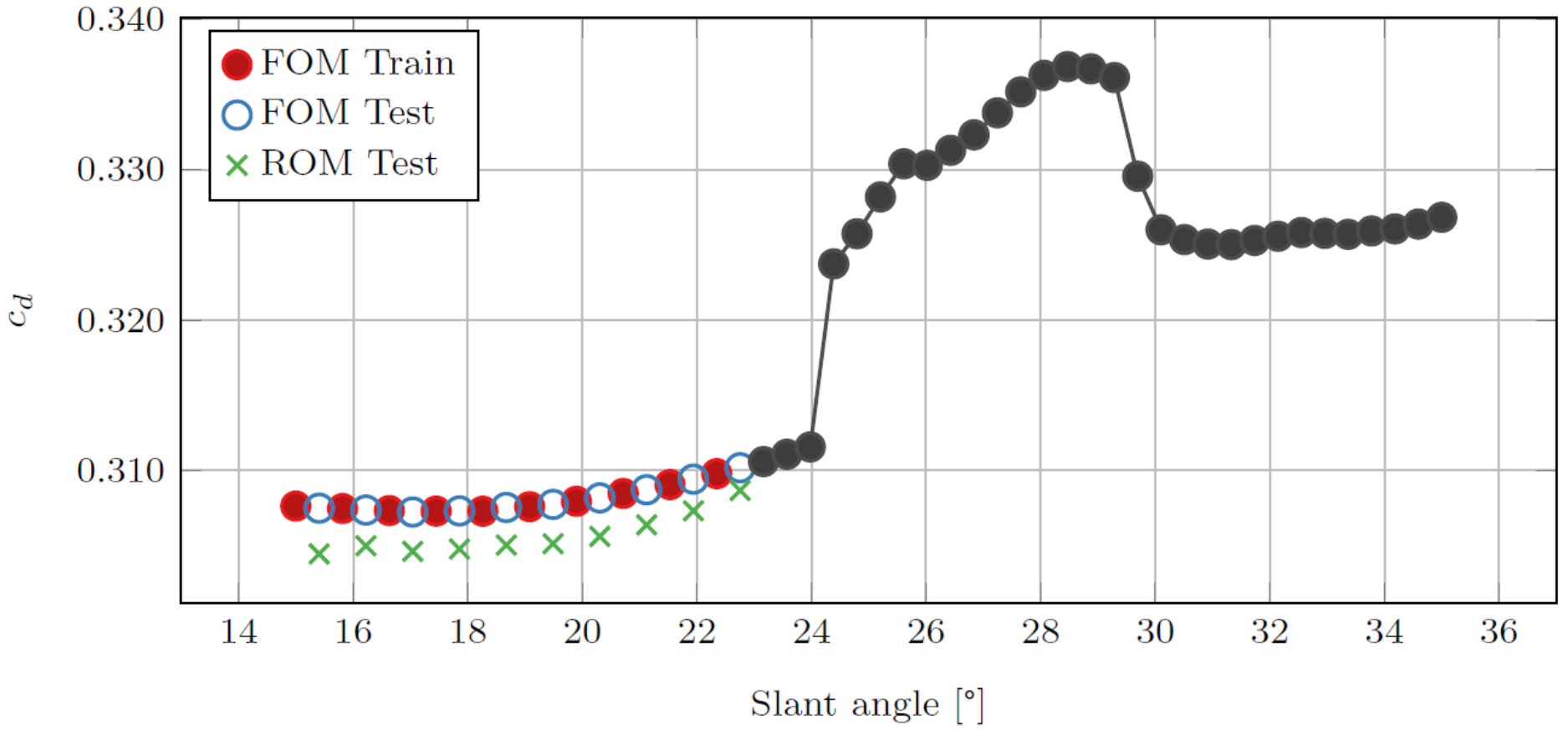
HYBRID NEURAL NETWORK REDUCED ORDER MODEL

- SIMPLE algorithm for full order model (FOM) and ROM
- Equations for **velocity** and **pressure** are Galerkin projected and then solved
- **Eddy viscosity** modeled by Neural Network
  - Inputs: Slant angle, POD coeffs velocity
  - Outputs: POD coeffs eddy viscosity

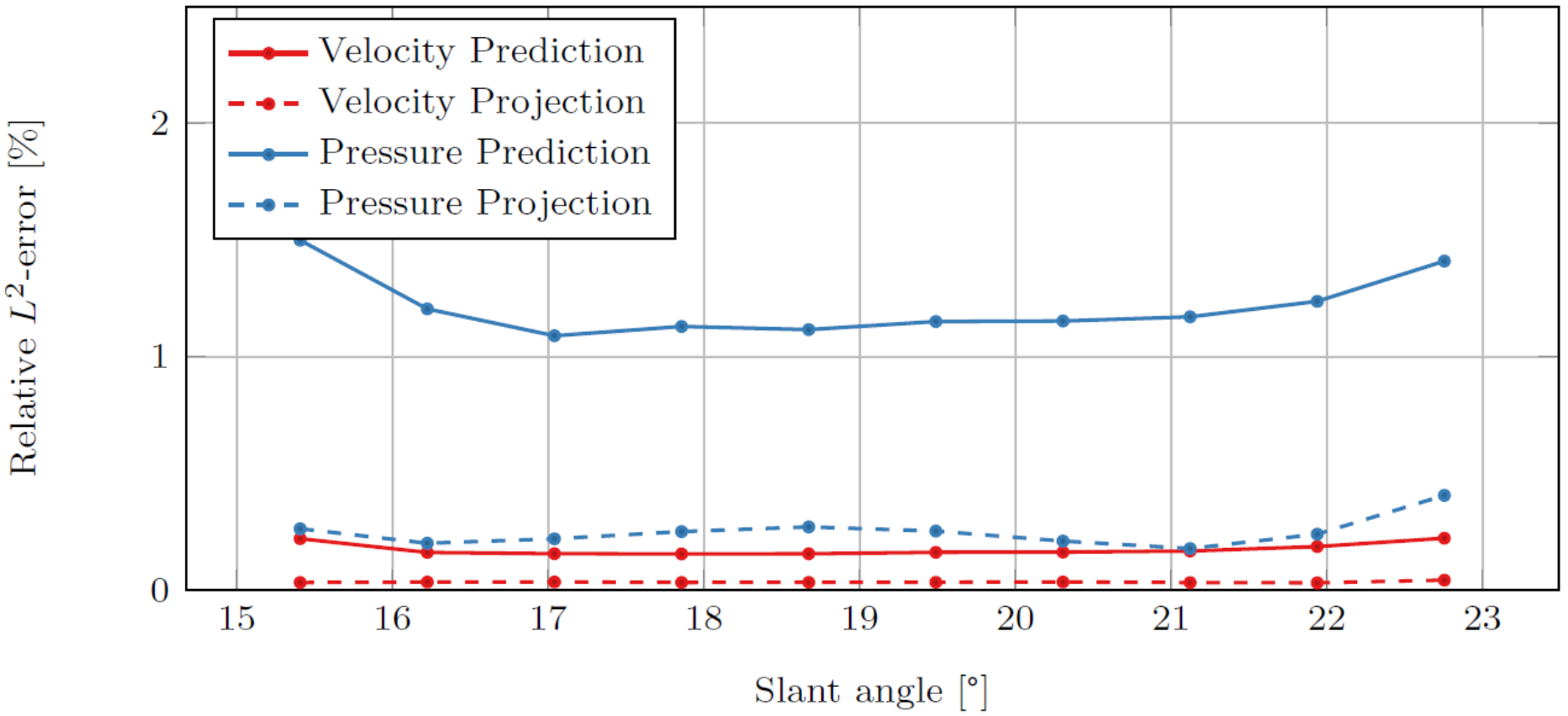


- For details, see Zancanaro et al., Hybrid Neural Network Reduced Order Modelling for Turbulent Flows with Geometric Parameters, Fluids 2021

DRAG COEFFICIENT PREDICTIONS



FIELD PREDICTIONS

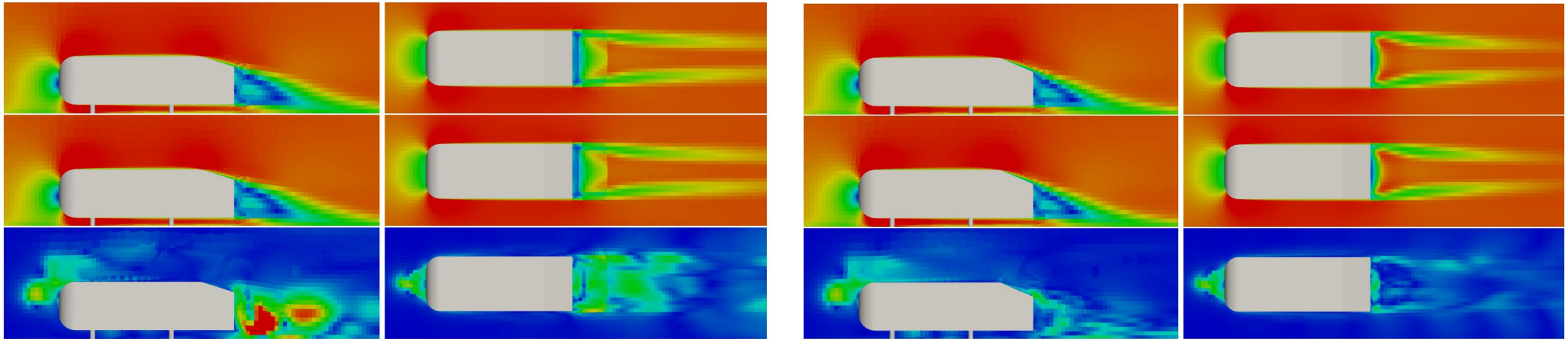


VELOCITY FIELD PREDICTIONS

FOM

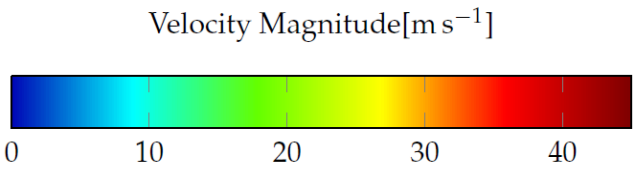
ROM

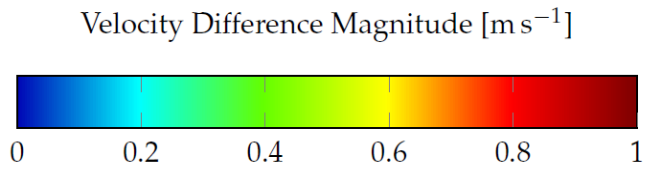
ROM - FOM



(a) Test sample with slant angle 15.4°

(b) Test sample with slant angle 22.8°



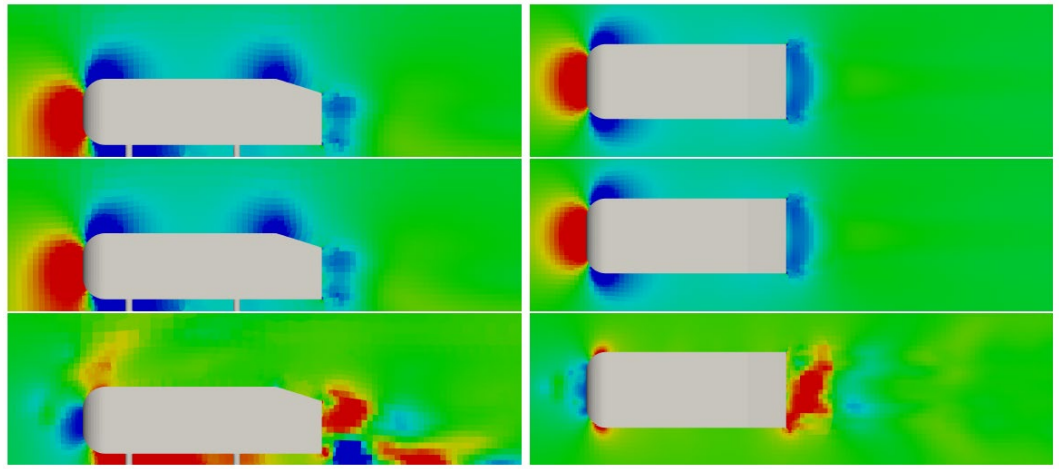


PRESSURE FIELD PREDICTIONS

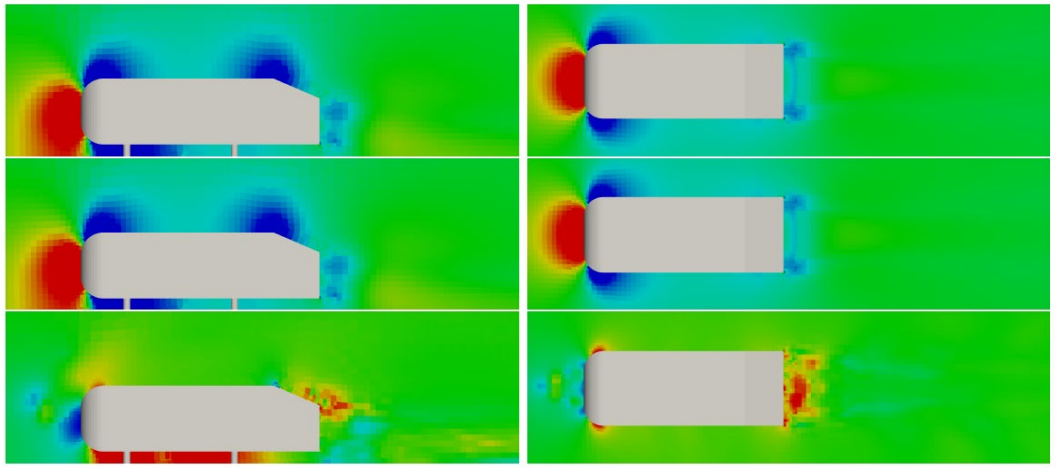
FOM

ROM

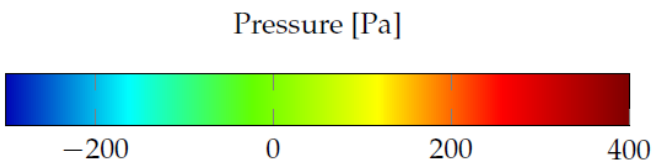
ROM - FOM

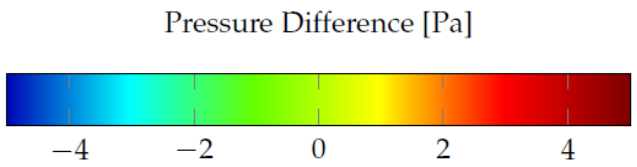


(**a**) Test sample with slant angle 15.4°.



(**b**) Test sample with slant angle 22.8°.





SUMMARY AND FUTURE WORK

Summary:

- Hybrid Neural Network Reduced Order Model successfully applied to Ahmed body test case
- Accurate predictions for velocity and eddy viscosity, while pressure field predictions still show deficiencies

Future work:

- Improve accuracy of pressure field predictions
- Hyper reduction to decrease prediction times
- Move from RANS to DES