Effect of Turbulence Modeling and Automatic Mesh Refinement on the External Aerodynamics of Automobiles

Emmanuel Guilmineau

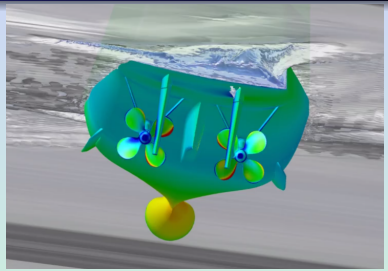


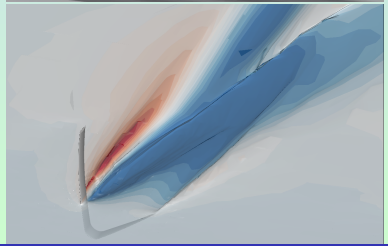
5th Automotive CFD Prediction Workshop
8-9 October 2026

ISIS-CFD flow solver

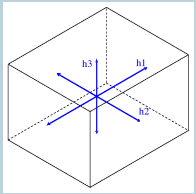
- Developed at ECN/CNRS,

- Two-fluid Navier-Stokes,
- Face-based finite-volume discretisation,
- Several RANS and hybrid RANS/LES turbulence models,
- Body motion, 6 dof,
- Mesh motion: Sliding, Overset,
- Adaptive grid refinement.





Refinement criterion



Metric-based: $\| C_i.\mathbf{h}_{i,j} \| = T_r \quad \forall$ cells $i, \forall j \in (1,2,3)$

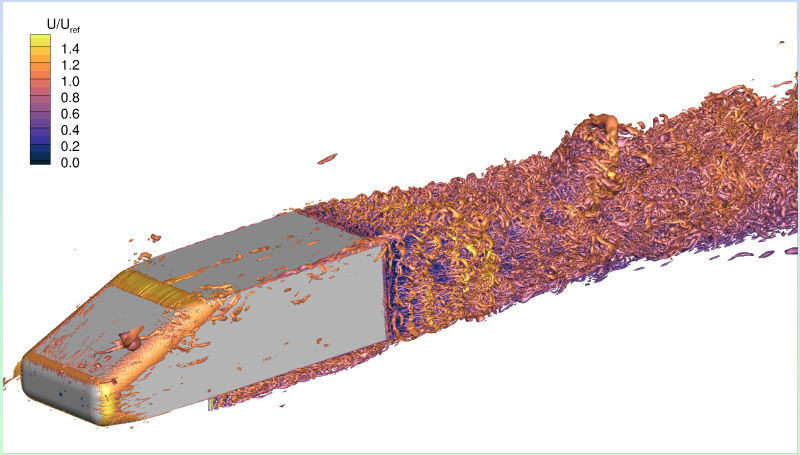
where

C_i	Criterion tensor
$\mathbf{h}_{i,j}$	Cell size vector for cell i
T_r	Threshold value (desired cell size)

Hessian criterion

- Flux-component Hessian
  $C_{FCH} = (\max(||H(p)||, \rho V||H(u)||, \rho V||H(v)||, \rho V||H(w)||))^{\frac{1}{2}}$ where p is the pressure, $V = \sqrt{u^2 + v^2 + w^2}$ the convection velocity and ρ the fluid density.
- For hybrid RANS/LES models which create locally highly unsteady flows, a temporal average of the instantaneous flux-component Hessian is used.

Windsor model



Numerical setup

Turbulence models

- RANS: k-ω SST
- Hybrid RANS/LES: DDES-SST, IDDES-SST

Time steps

- k-ω SST: Δt = 2.5e-4s, 1.0e-4 s
- DDES-SST and IDDES-SST: Δt = 5.0e-5 s

Automatic grid refinement

- Criterion: Flux component Hessian
- Threshold: 0.4L, 0.2L, 0.1L, 0.05L and 0.025L
- Minimum cell size: 1.4 mm

Meshes

Mesh AutoCFD (Committee meshes)

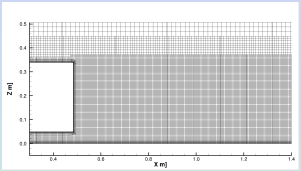
Name	Nb of nodes	Nb of cells
G1	6.5×10^6	6.3×10^6
G2	38.1×10^6	37.4×10^6
G3	200.0×10^6	197.5×10^6

Mesh Fidelity + AGR

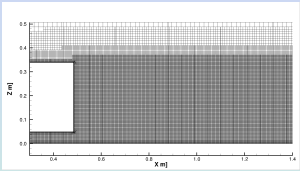
Name	Threshold	Nb of nodes			Nb of cells		
		k-ω SST	DDES-SST	IDDES-SST	k-ω SST	DDES-SST	IDDES-SST
Initial	N.A.		6.9×10^6			6.7×10^6	
0.4L	0.4176	7.3×10^6	7.5×10^6	7.6×10^6	7.0×10^6	7.1×10^6	7.2×10^6
0.2L	0.2088	9.0×10^6	25.6×10^6	29.1×10^6	8.5×10^6	24.5×10^6	27.8×10^6
0.1L	0.1044	16.6×10^6	170.3×10^6	233.8×10^6	15.1×10^6	167.2×10^6	229.4×10^6
0.05L	0.0522	47.3×10^6	N.A.	N.A.	42.1×10^6	N.A.	N.A.
0.025L	0.0261	204.8×10^6	N.A.	N.A.	181.2×10^6	N.A.	N.A.

Mesh in the symmetry plane of the model

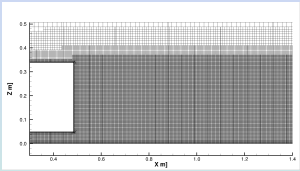
Committee



G1: $\Delta X=\Delta Z=4.8$mm

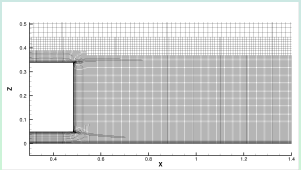


G2: $\Delta X=\Delta Z=2.4$mm

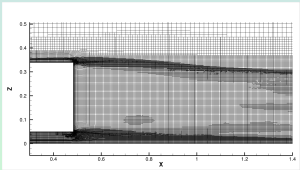


G3: $\Delta X=\Delta Z=1.3$mm

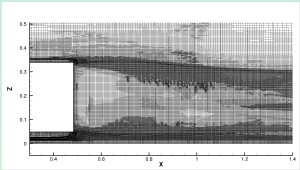
k-ω SST



Tr=0.4L: $\Delta X=\Delta Z=4.8$mm
SL: $\Delta Z=2.4$mm



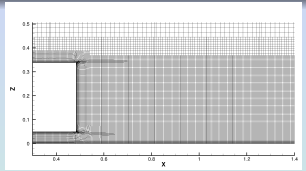
Tr=0.05L: $\Delta X=\Delta Z=4.8$mm
SL: $\Delta X=\Delta Z=1.0$mm



Tr=0.025L: $\Delta X=\Delta Z=4.8$mm
SL: $\Delta X=\Delta Z=1.0$mm

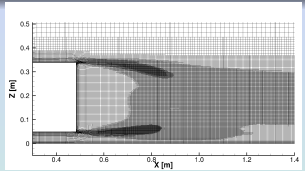
Mesh in the symmetry plane of the model

DDES-SST



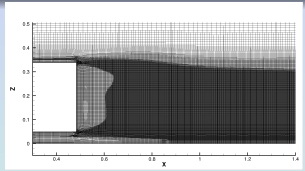
Tr=0.4L:ΔX=ΔZ=4.8mm

SL: ΔZ=2.4mm



Tr=0.05L: ΔX=ΔZ=4.8mm

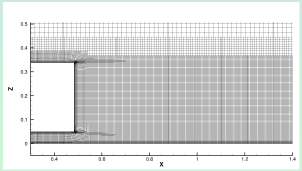
W: ΔX=ΔZ=2.4mm, SL: ΔX=ΔZ=1.0mm



Tr=0.025L: ΔX=ΔZ=4.8mm

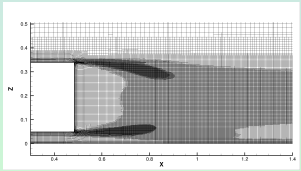
W & SL: ΔX=ΔZ=1.0mm

IDDES-SST



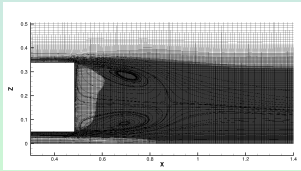
Tr=0.4L: ΔX=ΔZ=4.8mm

SL : ΔZ=2.4mm



Tr=0.05L: ΔX=ΔZ=4.8mm

W: ΔX=ΔZ=2.4mm, SL: ΔX=ΔZ=1.0mm

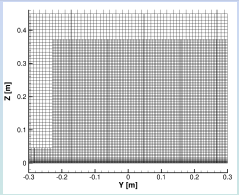


Tr=0.025L: ΔX=ΔZ=4.8mm

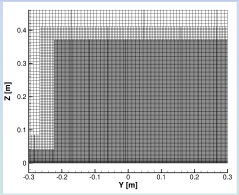
W & SL: ΔX=ΔZ=1.0mm

Mesh in the plane X = 0.922 m

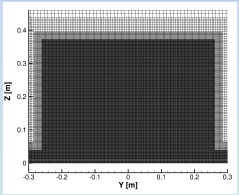
Committee



G1

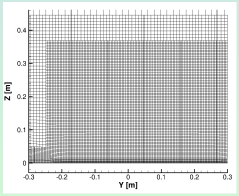


G2

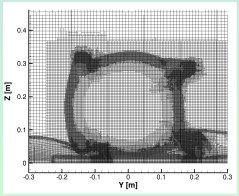


G3

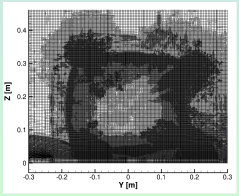
k-ω SST



Tr=0.4L



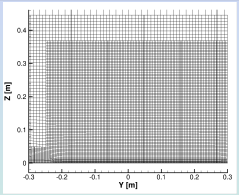
Tr=0.05L



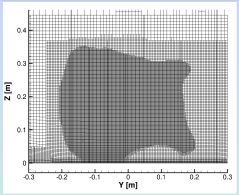
Tr=0.025L

Mesh in the plane X = 0.922 m

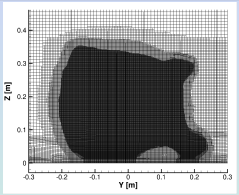
DDES-SST



Tr=0.4L

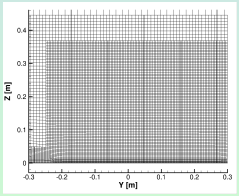


Tr=0.2L

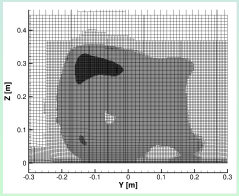


Tr=0.1L

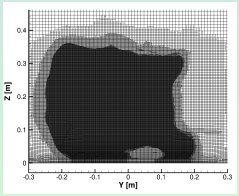
IDDES-SST



Tr=0.4L

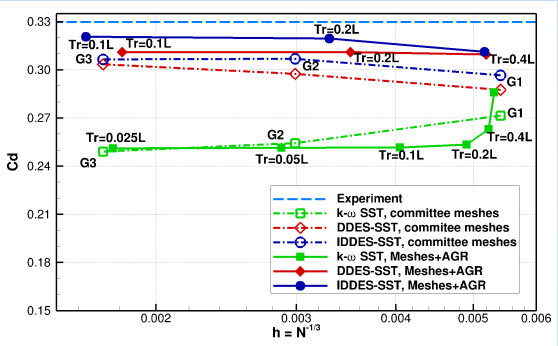


Tr=0.2L



Tr=0.1L

Grid convergence of drag coefficient



Cd drag coefficient

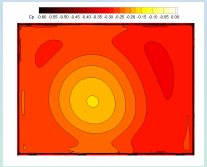
N number of cells

- The drag calculated using the k-ω SST model shows the same trend for both types of mesh, a reduction in drag as the mesh becomes finer.
- With the RANS/LES hybrid models, drag increases as the mesh becomes finer. The IDDES-SST model predicts the better drag.
- Faster mesh convergence with AGR than with committee meshes.
- With the RANS/LES hybrid models, the best results are obtained using AGR.

Base pressure coefficient

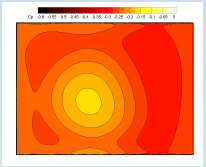
G1

Cp_B=0.2658



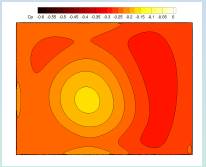
G2

Cp_B=0.2504



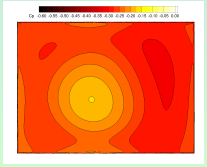
G3

Cp_B=0.2449



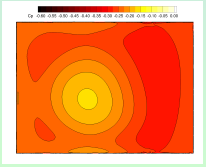
Tr=0.4L

Cp_B=0.2602



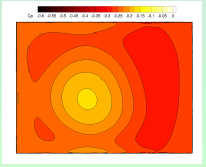
Tr=0.05L

Cp_B=0.2495



Tr=0.025L

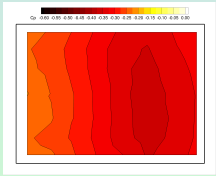
Cp_B=0.2494



k-ω SST

Experiments

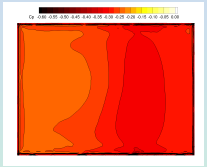
Cp_B=0.3094



Base pressure coefficient

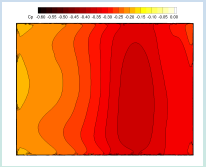
G1

Cp_B=0.2795



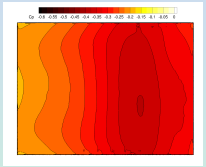
G2

Cp_B=0.2899



G3

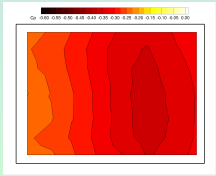
Cp_B=0.2966



DDES-SST

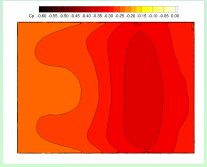
Experiments

Cp_B=0.3094



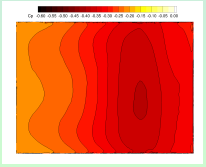
Tr=0.4L

Cp_B=0.2861



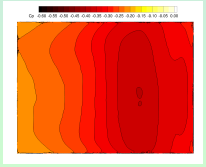
Tr=0.2L

Cp_B=0.2917



Tr=0.1L

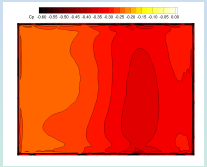
Cp_B=0.3005



Base pressure coefficient

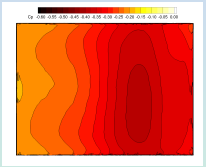
G1

Cp_B=0.2896



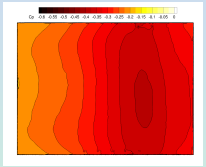
G2

Cp_B=0.2999



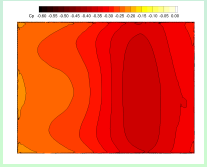
G3

Cp_B=0.3018



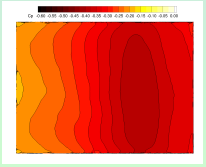
Tr=0.4L

Cp_B=0.2994



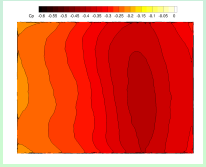
Tr=0.2L

Cp_B=0.3104



Tr=0.1L

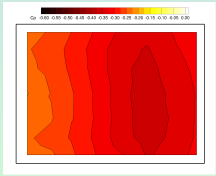
Cp_B=0.3114



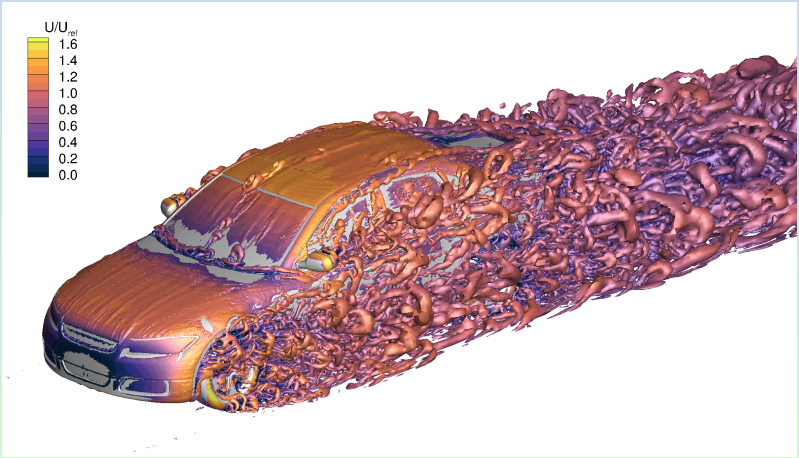
IDDES-SST

Experiments

Cp_B=0.3094



DrivAer model



Numerical setup

Turbulence models

- RANS: k-ω SST, SSGLRR (RSM)
- Hybrid RANS/LES: DDES-SST

Time steps

- k-ω SST and SSGLRR: Δt = 5e-4s
- DDES-SST: Δt = 5.0e-5 s

Automatic grid refinement

- Criterion: Flux component Hessian
- Threshold: 0.15L
- Minimum cell size: 8 mm

Meshes

Mesh AutoCFD (Committee meshes)

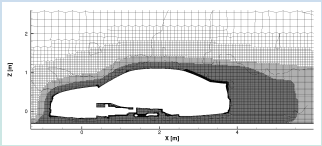
Name	Nb of nodes	Nb of cells
Coarse	72.1×10^6	66.2×10^6
Medium	133.4×10^6	123.4×10^6

Mesh Fidelity + AGR

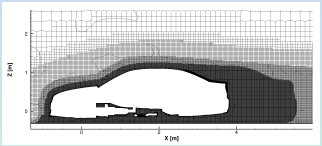
Name	Threshold	Nb of nodes			Nb of cells		
		k-ω SST	SSGLRR	DDES-SST	k-ω SST	SSGLRR	DDES-SST
Initial	N.A.		93.0×10^6			82.6×10^6	
0.15L	0.008	100.6×10^6	105.0×10^6	116.9×10^6	89.6×10^6	93.8×10^6	105.5×10^6

Mesh in the symmetry plane of the model

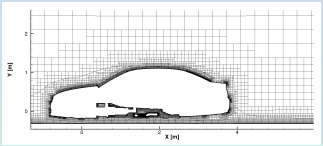
Committe: Coarse



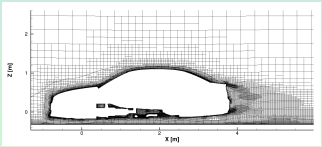
Committe: Medium



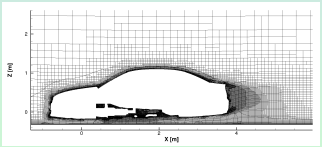
Fidelity: Initial mesh



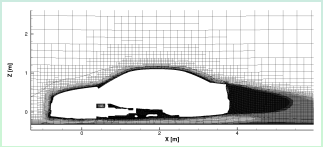
Fidelity+AGR: k-ω SST



Fidelity+AGR: SSGLRR

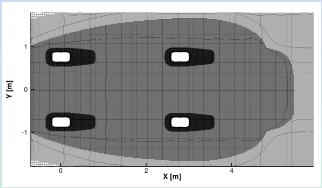


Fidelity+AGR: DDES-SST

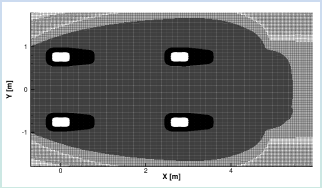


Mesh in the underbody plane Z = -0.2376 m

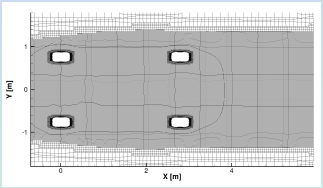
Committe: Coarse



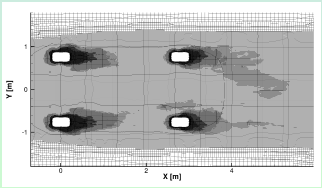
Committe: Medium



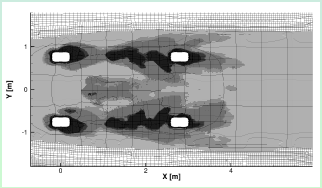
Fidelity: Initial mesh



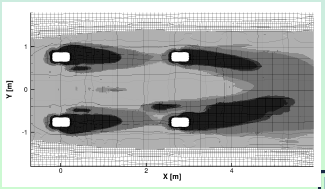
Fidelity+AGR: k-ω SST



Fidelity+AGR: SSGLRR

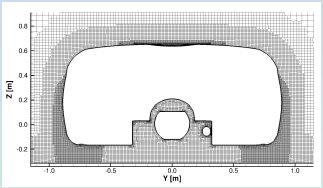


Fidelity+AGR: DDES-SST

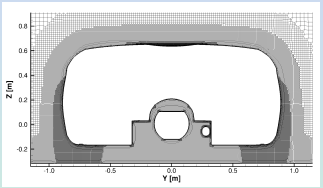


Mesh in the plane X = 0.4070 m

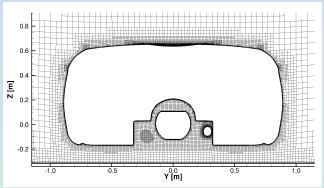
Committe: Coarse



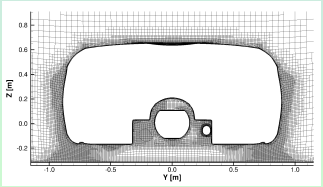
Committe: Medium



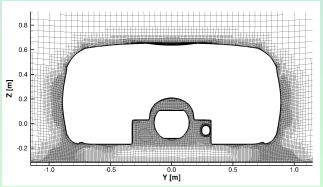
Fidelity: Iniitil mesh



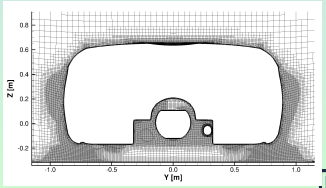
Fidelity+AGR: k-ω SST



Fidelity+AGR: SSGLRR

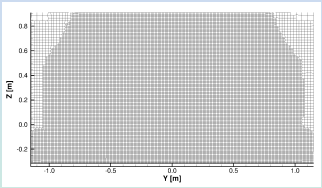


Fidelity+AGR: DDES-SST

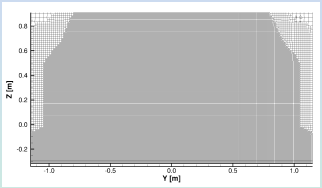


Mesh in the plane X = 4.0070 m

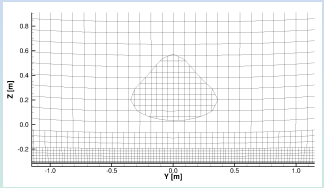
Committe: Coarse



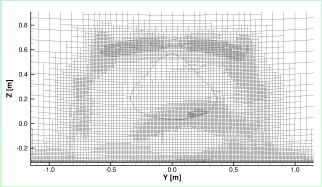
Committe: Medium



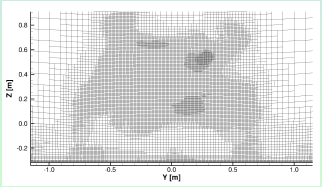
Fidelity: Initial mesh



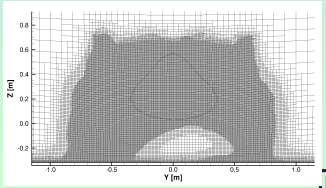
Fidelity+AGR: k-ω SST



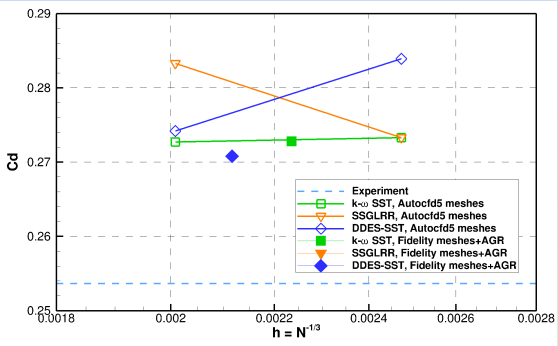
Fidelity+AGR: SSGLRR



Fidelity+AGR: DDES-SST



Grid convergence of drag coefficient



Cd drag coefficient

N number of cells

- With the committe meshes, the drag decreases as the mesh becomes finer, except for the SSGLRR model.
- The solution obtained with k-ω SST model is consistent regardless of the type of mesh.
- DDES-SST+AGR gives the better result.

Conclusions and future work

- Conclusions
  - Thanks to AGR, mesh convergence is faster than with static meshes
    $\Longrightarrow$ Less energy consumption
  - Forces and moments:
    - RANS (k-ω SST) is nowhere as good as DDES in this flow.
    - DDES-SST: It provides a prediction at 6% of the drag (-6% Windsor, +6% DrivAer).
    - IDDES-SST: Windsor: It is the best model for predicting drag (underestimation by 2.4%)
- Future work
  - Use the IDDES-SST model for the DrivAer model,
  - Use different threshold values for refinement to perform a mesh convergence study.