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UNIVERSITÀ DEGLI STUDI DI ROMA

Aerodynamics optimization of a rear-camera by CFD analysis and mesh morphing

Supervisor : Prof. Marco Evangelos Biancolini

Student : Lorenzo D’Anastasio

Co-supervisor : Eng. Ubaldo Cella, Eng. Gabriele Mirasoli

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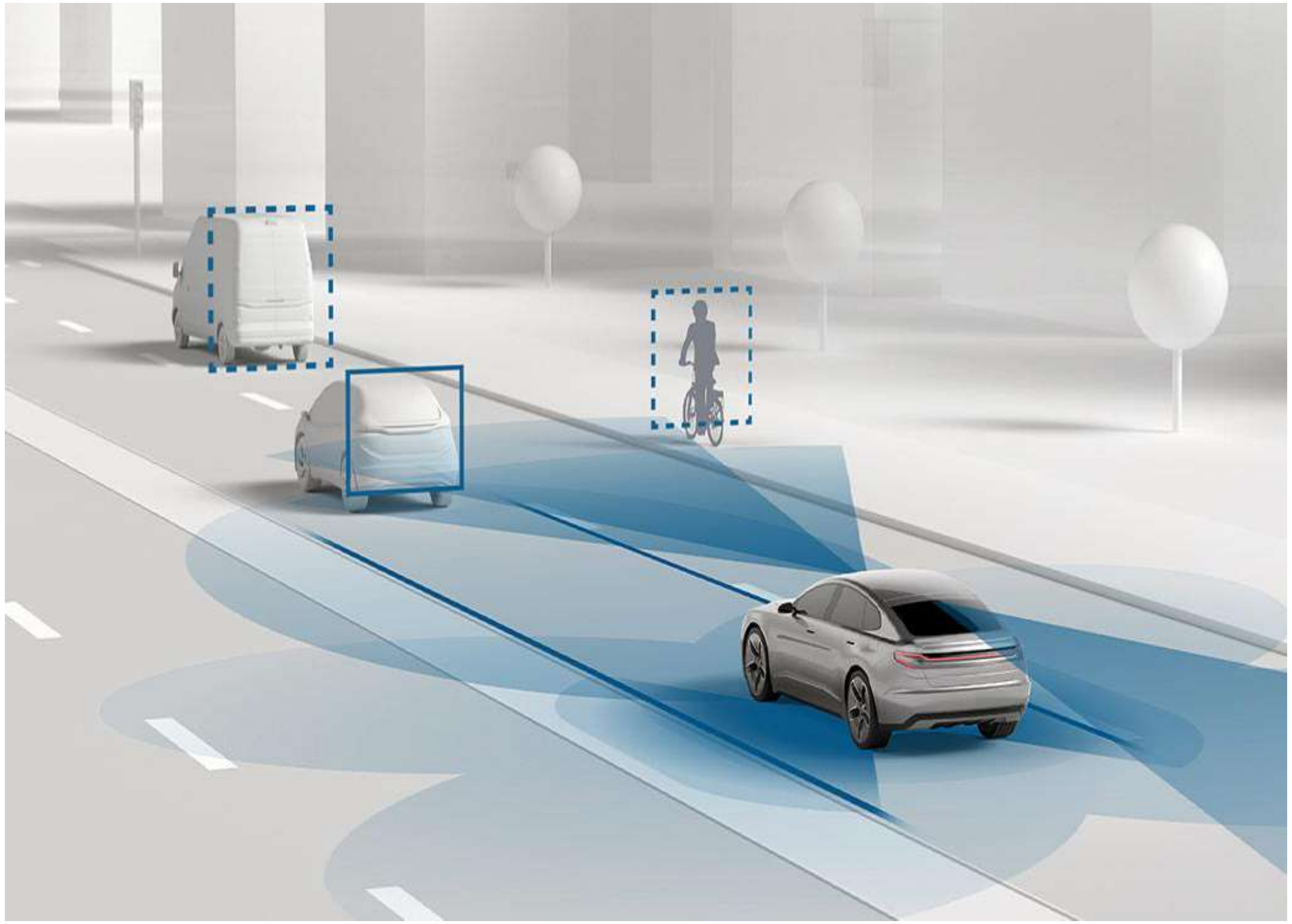
The thesis was carried out as part of a collaboration between our university, ENGYS, Volvo and RBF.

1) Introduction
2) Targets
3) Preliminary analysis on the ASMO model
4) Study of the rear-camera of a new Volvo car
5) Results and comparisons
6) Conclusions

1. Introduction

Advanced **D**river **A**ssistance **S**ystem or **ADAS**

- Automatic recognition and reading of road signs
- Automatic recognition of pedestrians
- Cameras for visual improvement



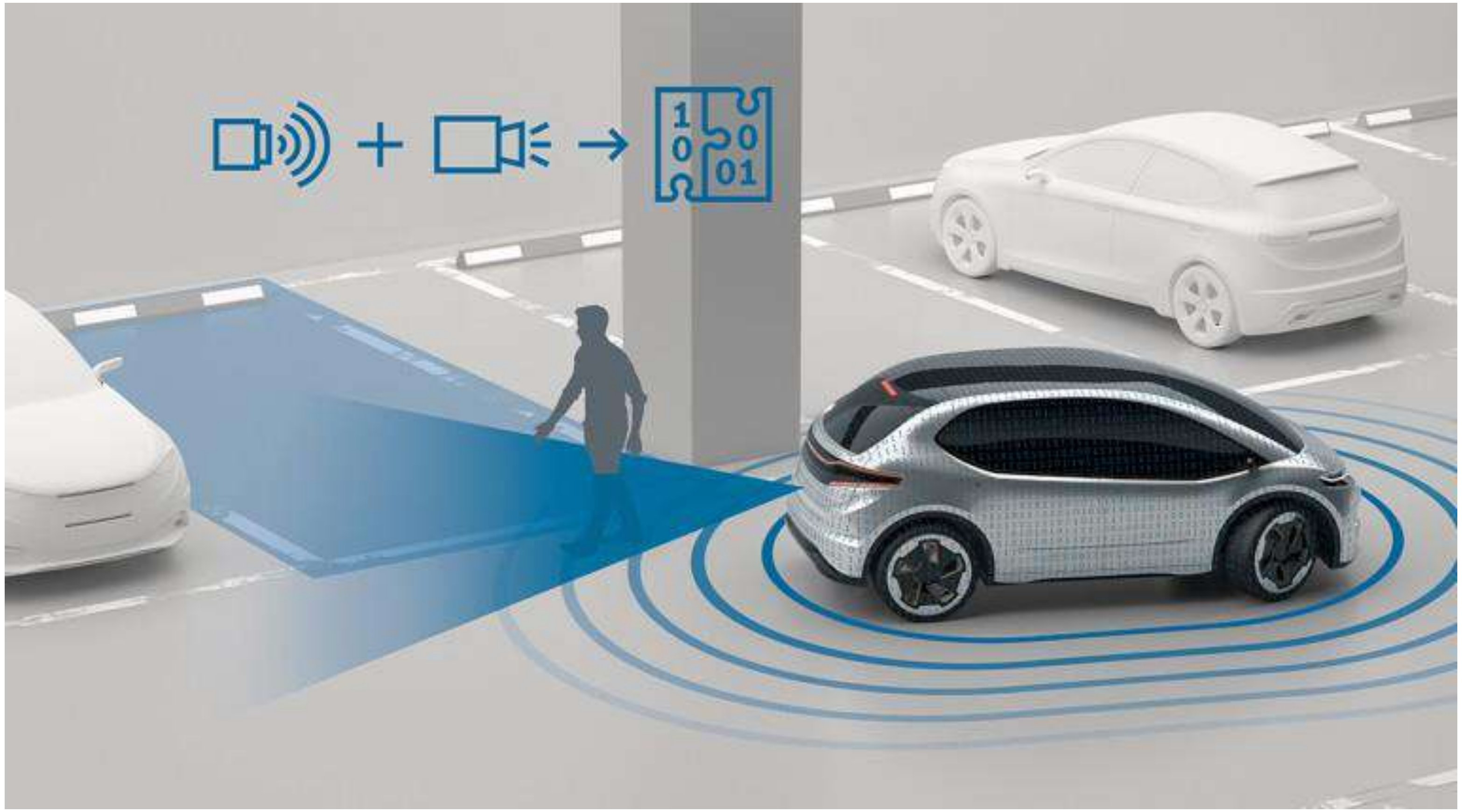
2010 Euro NCAP evaluation test for active safety technologies

- Regulation n.661/2009 CE
- Legislation n.78/2009 CE

1. Introduction

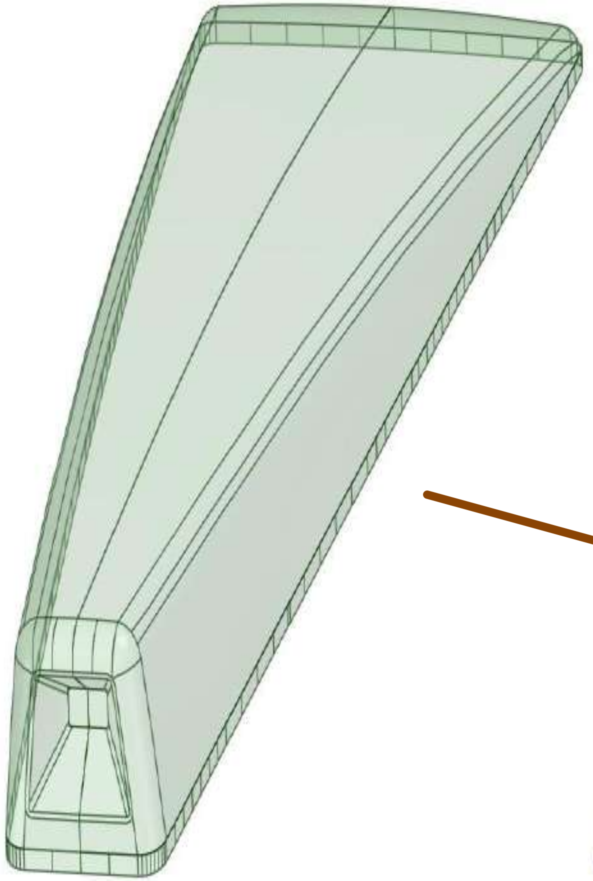
EU Regulation 2019/2144 of the European Parliament and Council Mandatory ADAS from July 2024:

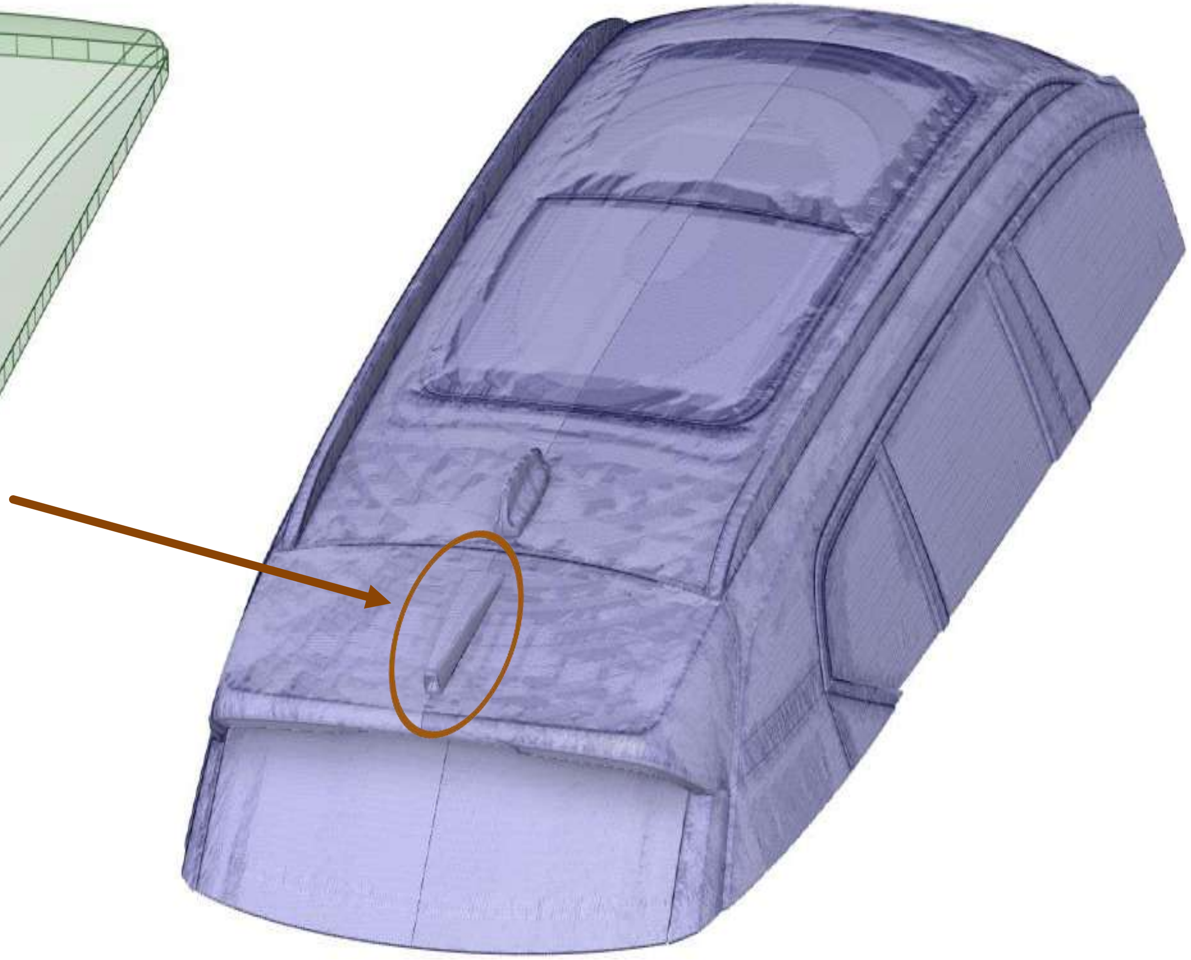
- Reverse detection
- Automatic emergency braking system
- Maintenance systems and lane warning



2. Targets

- Decrease in the accumulation of debris/dust on the section near the camera lens
- Reduction of the coefficient of aerodynamic resistance at the same cross-section of the lens



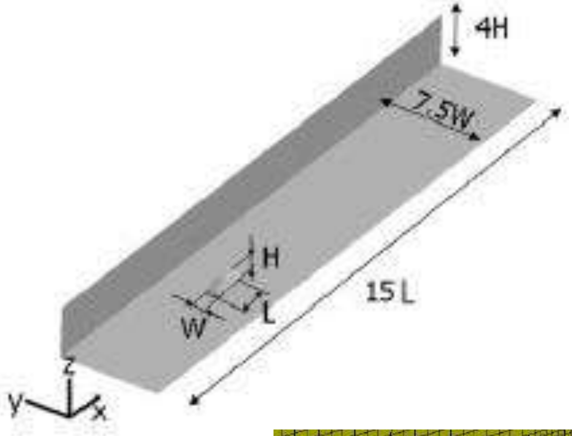


3. Preliminary analysis on the ASMO model

Article “ *Comparison of the ASMO Car Model with Experimental Data and Simulations* ”

Boundary conditions:

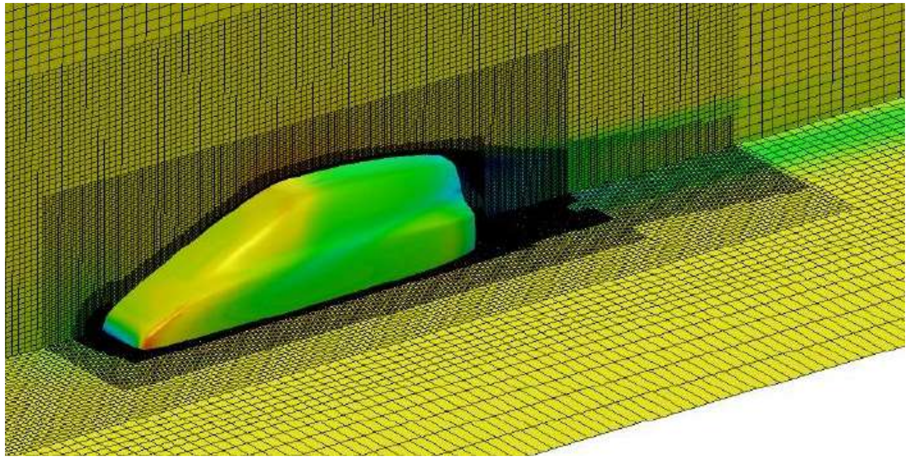
- Fixed ground
- Flow velocity 50 m/s
- Fluid air
- Temperature 20 °C
- Pressure 101 325 Pa



Asmo	Size [m]
L	0.82
W	0.29
H	0,28

Mesh :

- Rectangular cells with adaptive refinement
- 13.5 million total cells

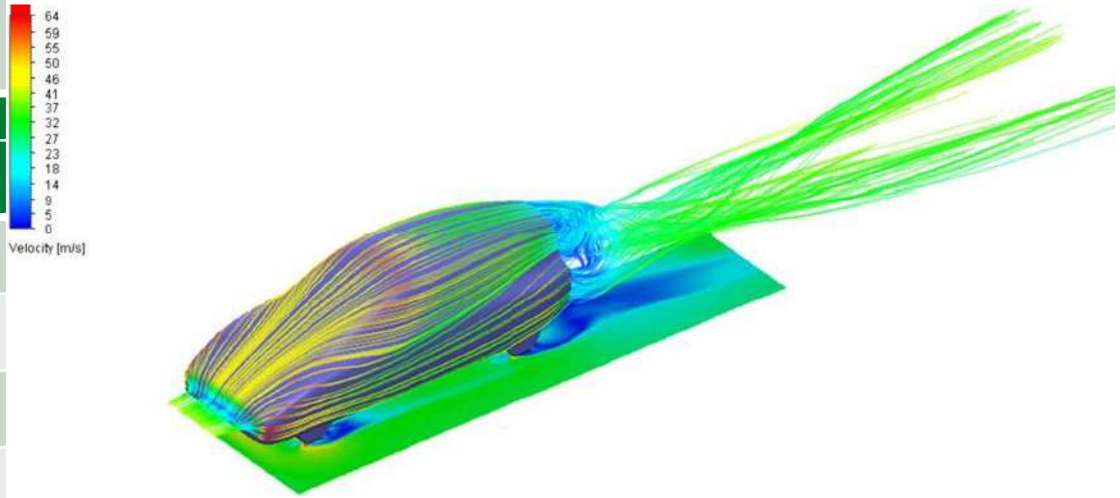


3. Preliminary analysis on the ASMO model

Article *“ Comparison of the ASMO Car Model with Experimental Data and Simulations”*

Proceedings	**Time [h]**
Case setup, pre-processing	1
Simulation	18
Analysis results and post-processing	4
Total	**23 h**

Type of analysis	**Drag coefficient**
Wind tunnel Volvo	0.158
Wind tunnel Daimler Benz	0.153
FloEFD Siemens	0.154
CFD 01 (k-ε method)	0.185
CFD 02	0.171
CFD 03	0.169
CFD 04	0.151



3. Preliminary analysis on the ASMO model

Software OpenFOAM

Workbooks:

- **0** → Initial & boundary conditions
- **constant** → Geometry, fluid properties and turbulence
- **system** → Wind tunnel, mesh, integration settings, solver type, results to be printed

⇩

Assignment of analysis by terminal

⇩

Post-processing on ParaView

Software HELYX

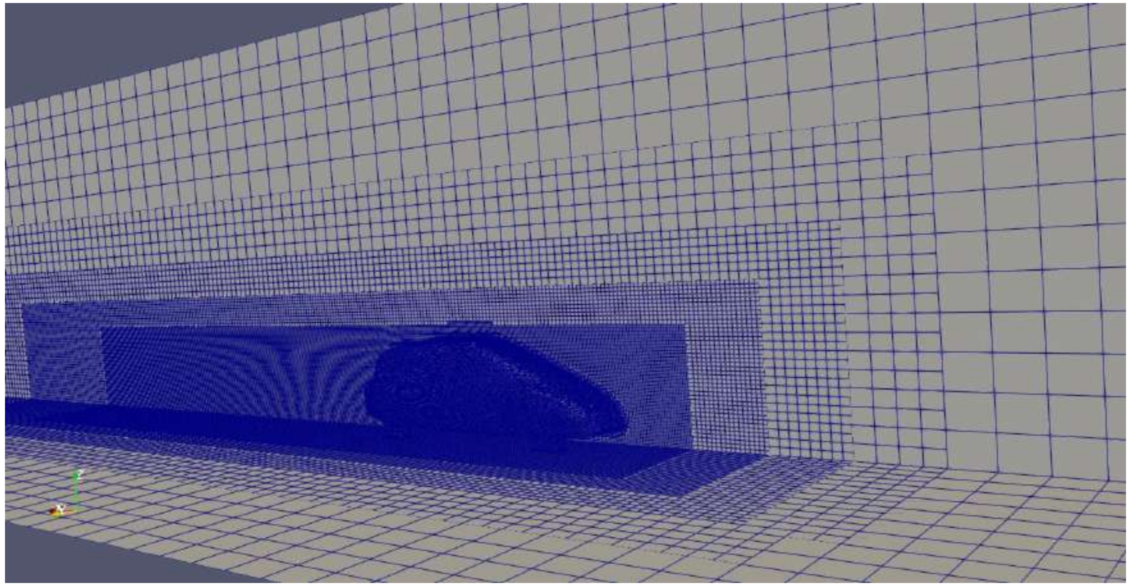
Work screen:

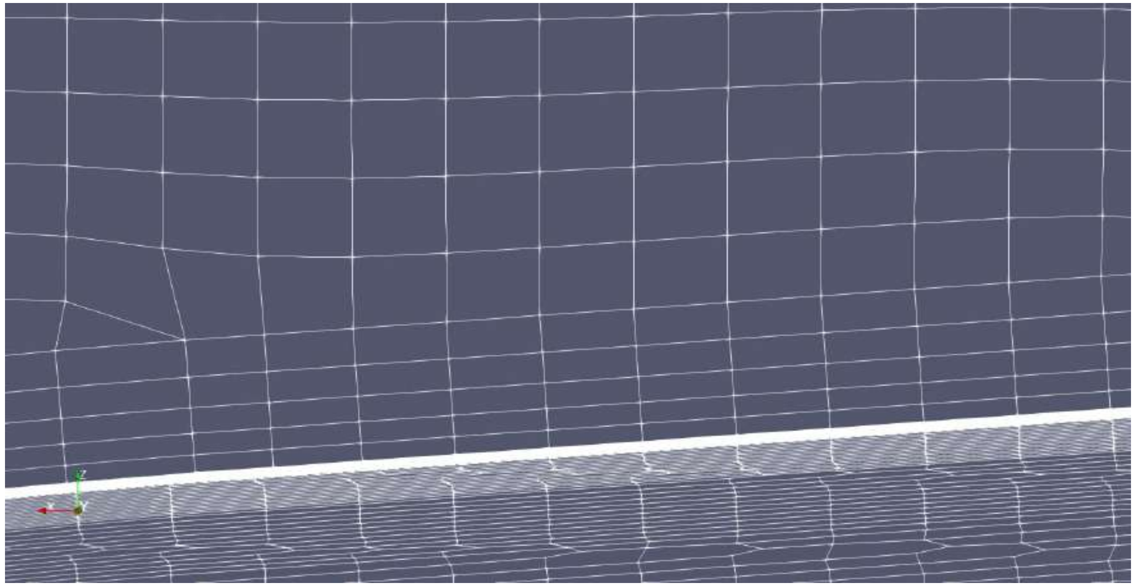
- **Mesh** → Base Mesh & Geometry
- **Setup** → Materials, Modelling, External Boundaries, Numerical Schemes, Solver Settings, Runtime Controls, Monitoring Functions and Fields Initialisation
- **Solver** → Runtime Controls, Residuals, Monitoring Functions
- **View** → Post-processing

3. Preliminary analysis on the ASMO model

Software OpenFOAM & HELYX:

- Mesh *SnappyHexMesh* and *helyxHexMesh* ⟶ 4 million cells
- # 3 Refinement Boxes in the rear of the ASMO ⟶ Cell sizes on the order of mm
- Boundary layer ⟶ 5 layers, final ratio 0.5, expansion ratio 1.2
- Turbulence ⟶ k-ω SST model

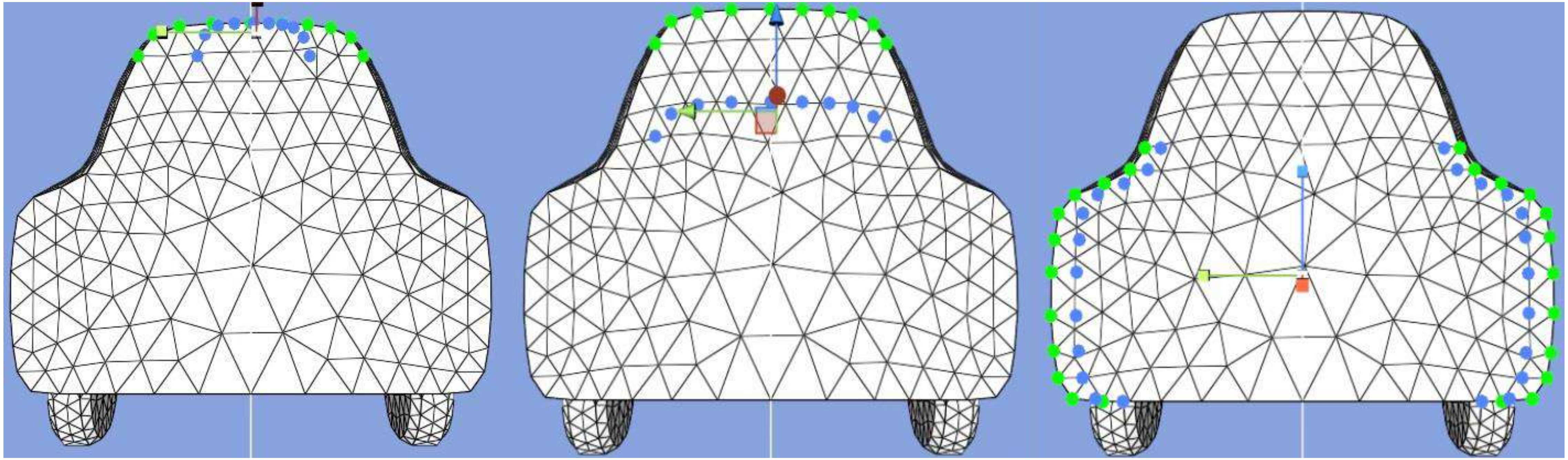




3. Preliminary analysis on the ASMO model

Morphing strategy for the ASMO:

- Scaling & Translation downward of rear roof edges
- Narrowing edges of the rear side



3. Preliminary analysis on the ASMO model

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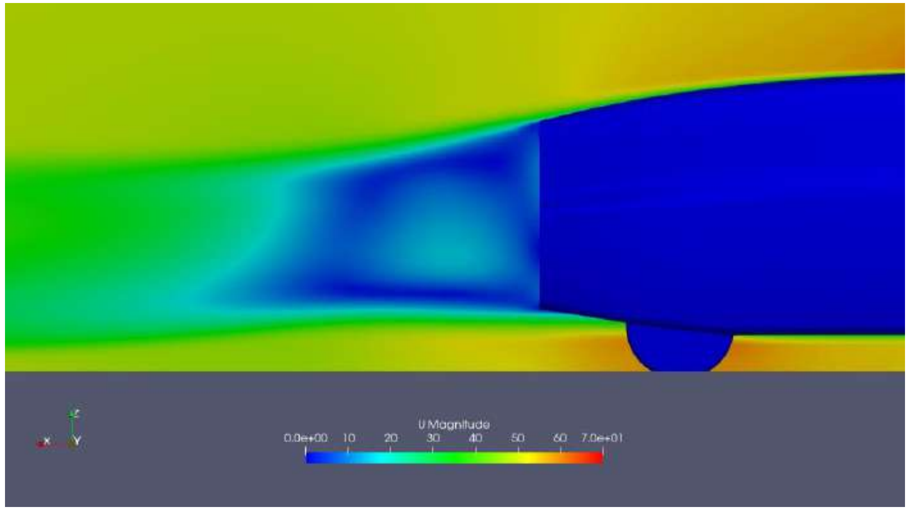
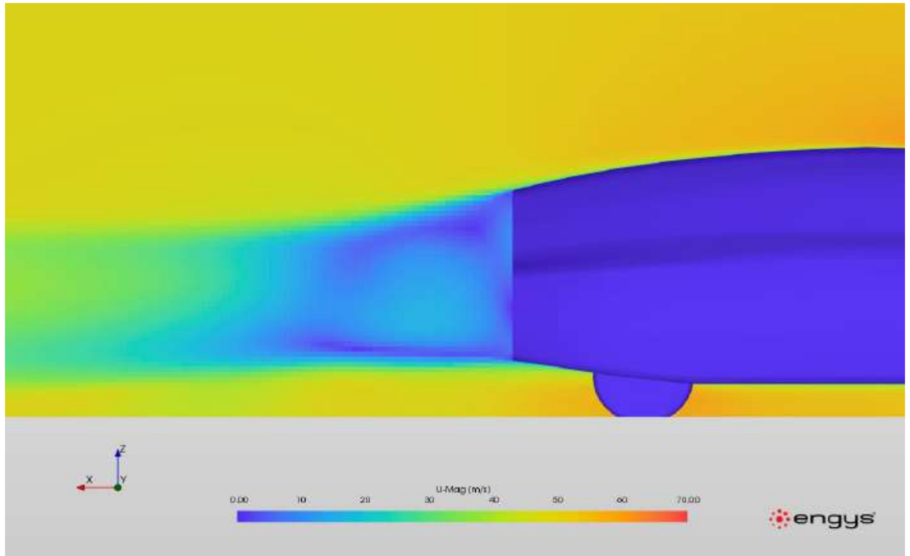
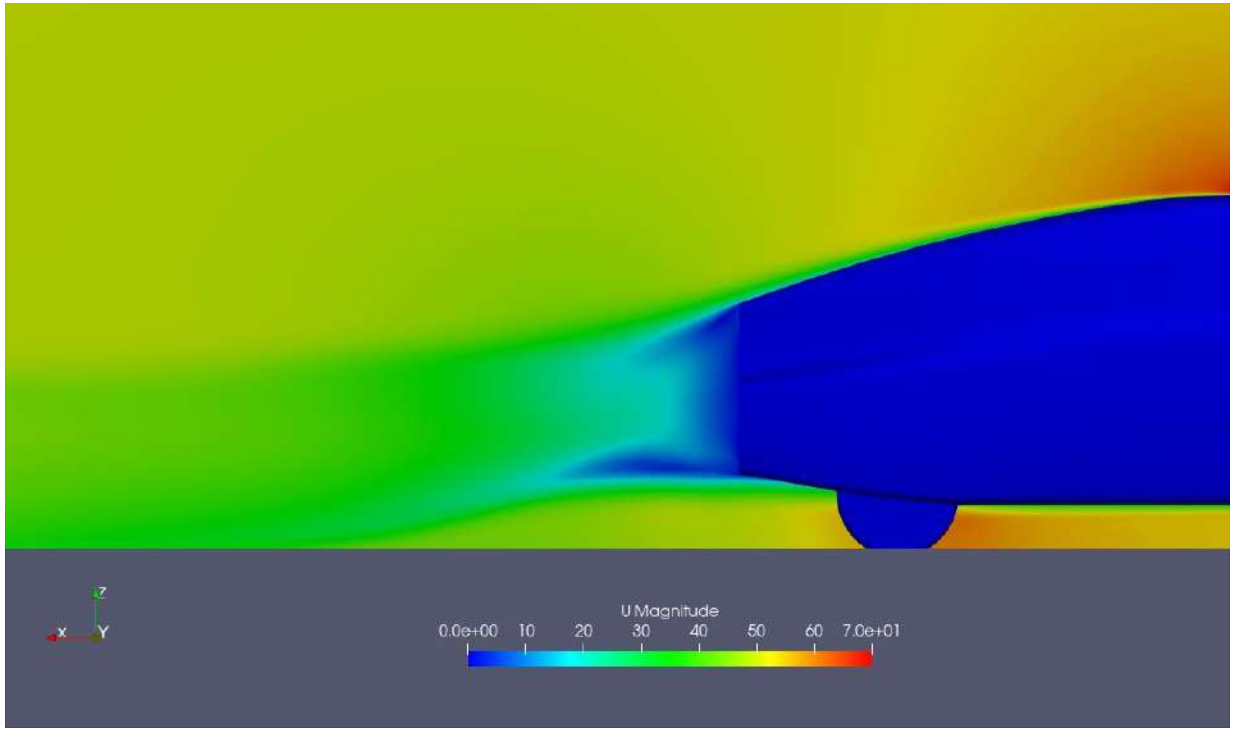
Results OpenFOAM & HELYX

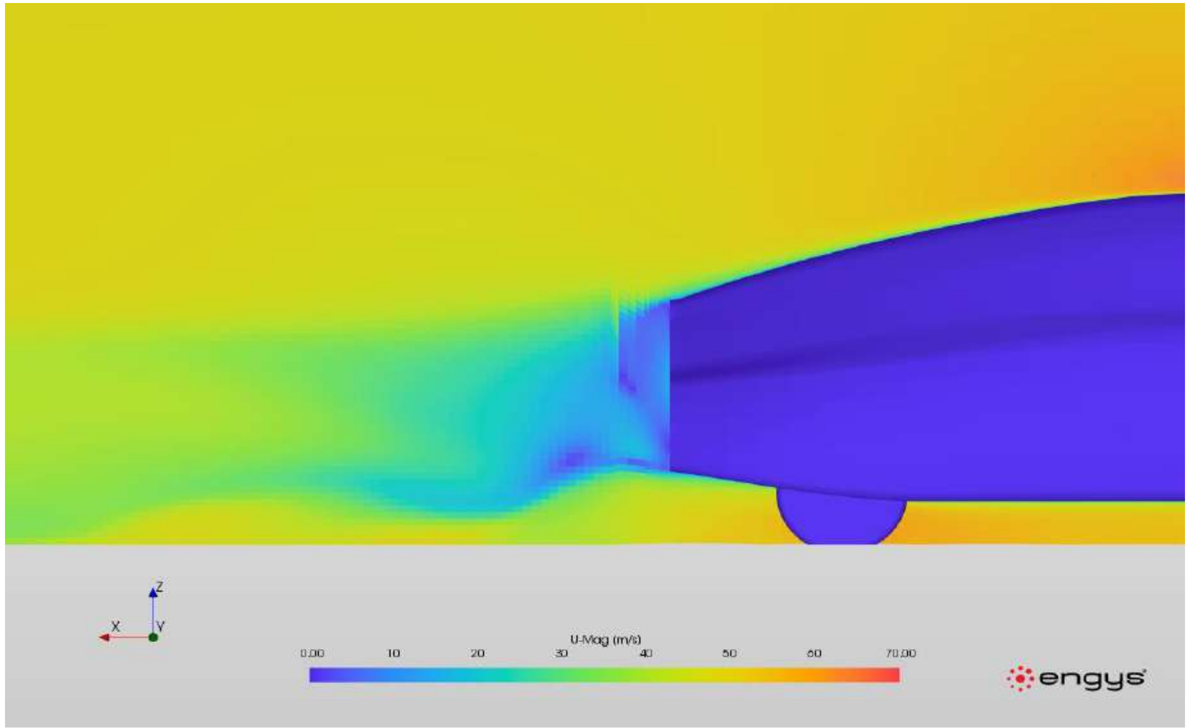
Type of analysis	Drag coefficient
Asmo OpenFOAM standard	0.152
Asmo OpenFOAM surface morphing	0.144
Asmo OpenFOAM volume morphing	0.146
Asmo HELYX standard	0.162
Asmo HELYX surface morphing	0.153
Asmo HELYX volume morphing	0.153





3. Preliminary analysis on the ASMO model

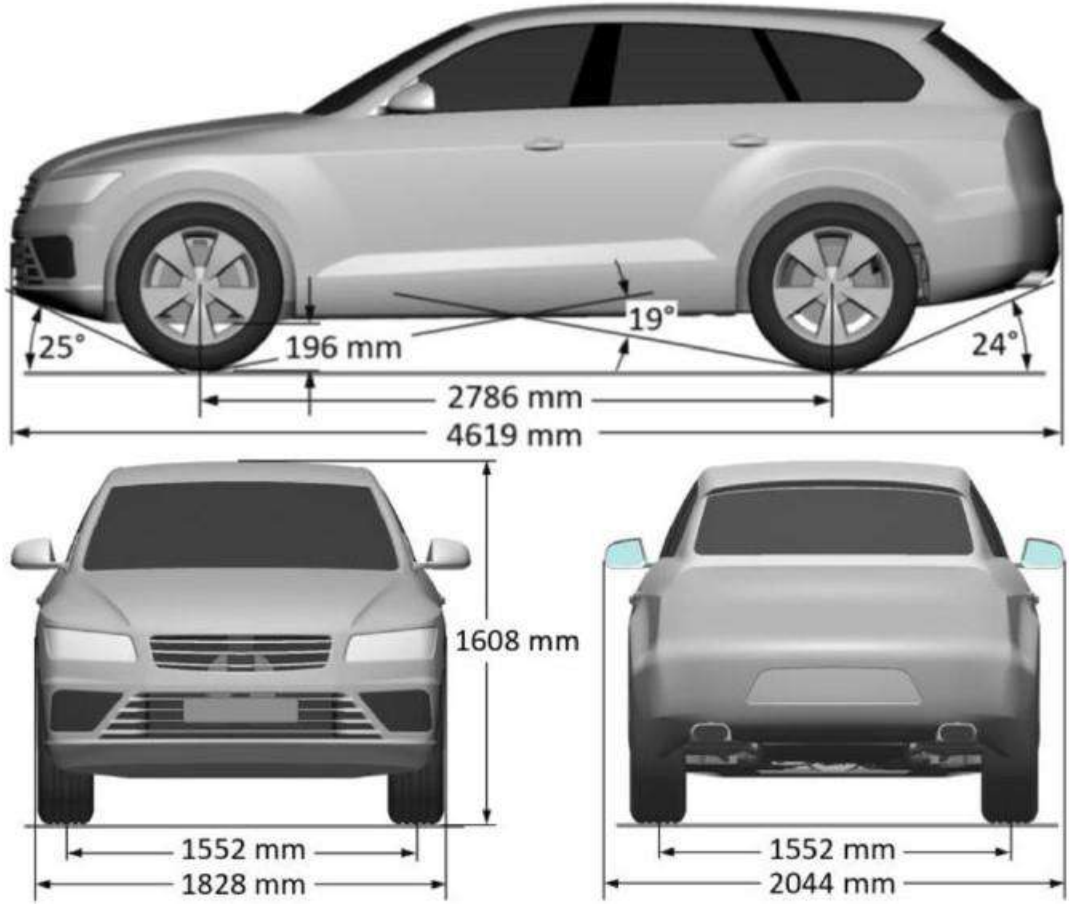




4. Study of the rear-camera of a new Volvo car

For reasons of secrecy the study is conducted with only the roof of the Volvo, because the car isn't yet on the market

- AeroSUV model standard
- Case simplifications
  - Symmetry
  - Flat underbody
  - Chassis and wheels
- Geometric transformations to adapt AeroSUV to Volvo roof with rear-camera
  - Translation
  - Scaling
  - Gap reconstruction
- Final AeroSUV model
- CFD with HELYX for the final AeroSUV model
- Comparison with «*Introduction of the AeroSUV-A New Generic SUV Model for Aerodynamic Research*»
- CFD with HELYX for the final AeroSUV with morphed rear-camera



4. Study of the rear-camera of a new Volvo car

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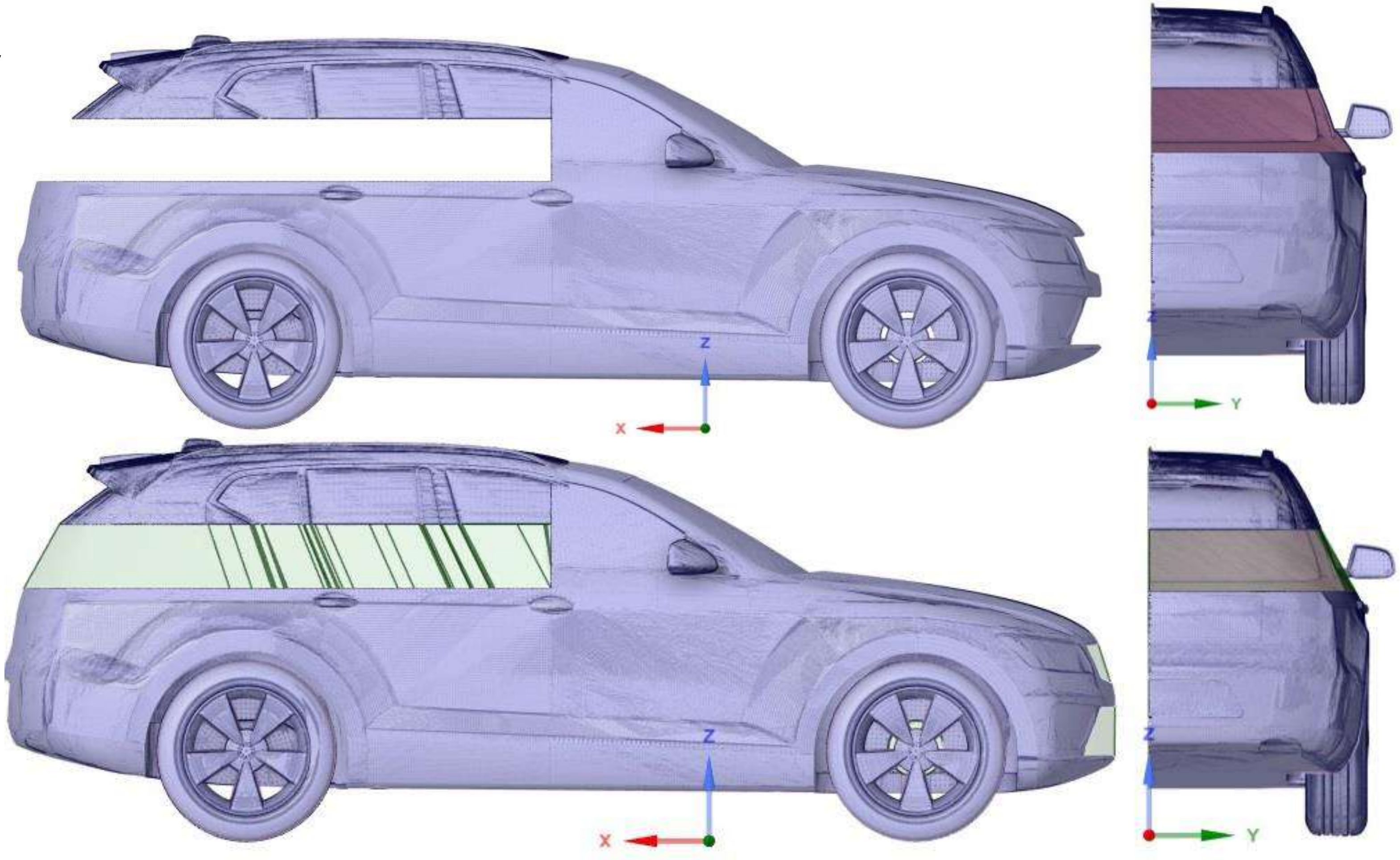
Geometric transformations with “fixed member” roof and “mobile” AeroSUV :

I. Translation of the AeroSUV body
II. Scaling of the AeroSUV body
III. Gap reconstruction by 3D sketch entities



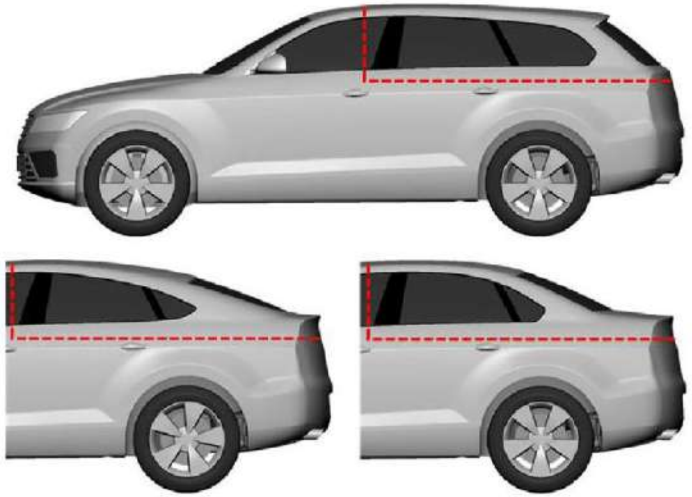
4. Study of the rear-camera of a new Volvo car

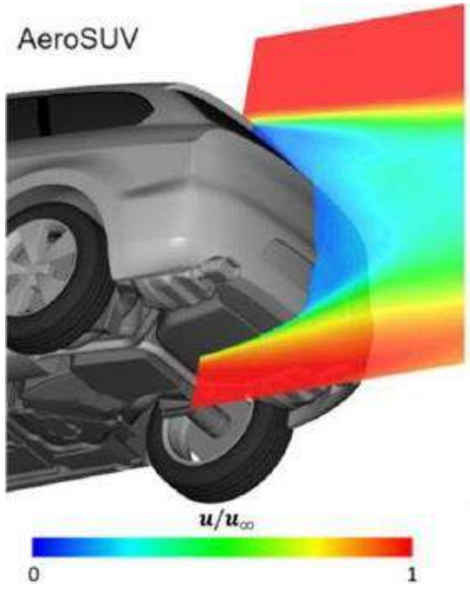
Article “*Introduction of the AeroSUV-A New Generic SUV Model for Aerodynamic Research*”

Wind tunnel boundary conditions :

- Type Station wagon, fastback and sedan in 1:4 scale
- Ground flow 50 m/s
- Velocity flow 50 m/s
- Fluid air

AeroSUV style	Drag coefficient
AeroSUV station wagon	0.314
AeroSUV fastback	0.286
AeroSUV sedan	0.286





4. Study of the rear-camera of a new Volvo car

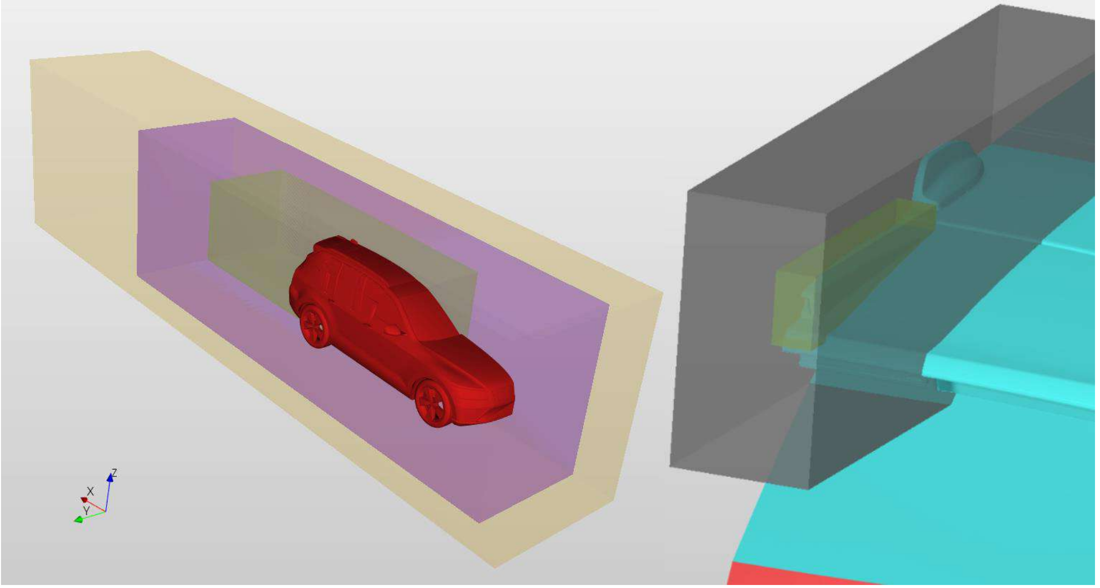
CFD software HELYX AeroSUV **Mesh**:

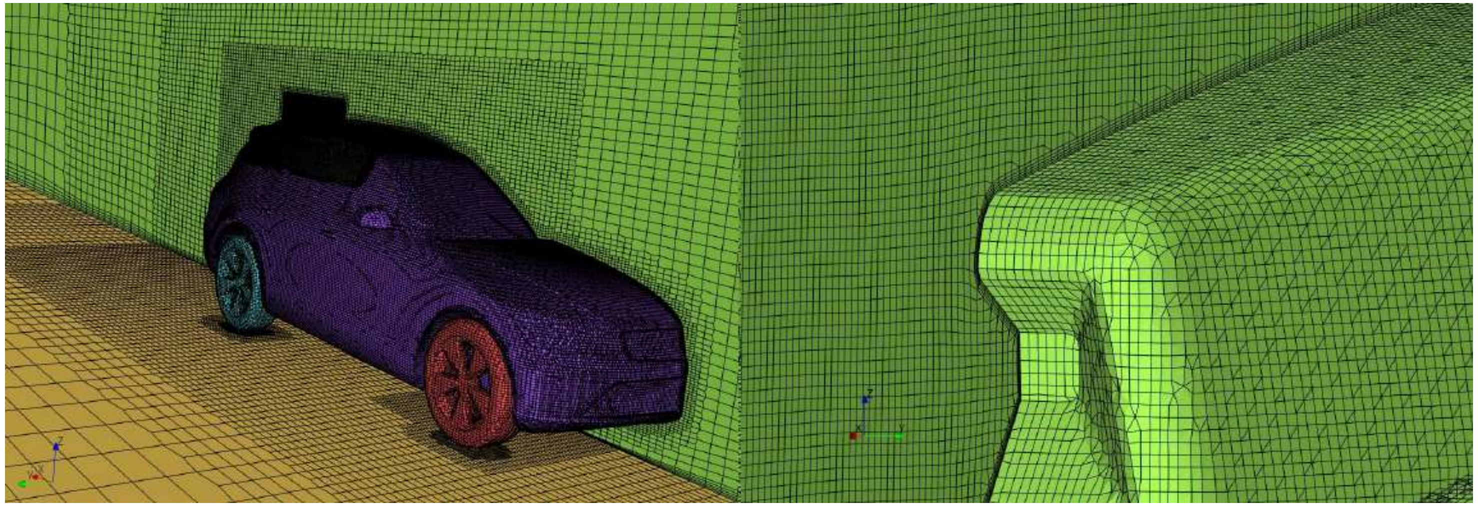
- Wind tunnel 25m along X, 3m along Y and 5m along Z

  # 3 ref.Box to AeroSUV &

  # 2 ref.Box to rear-camera

  ⮡ Cells size of rear-camera on the order of mm





- AeroSUV, wheels level mesh 4

  and roof level 5

  ⮡ Cells size on the order of cm

<u>Total grid of about 4.5 million cells</u>

4. Study of the rear-camera of a new Volvo car

CFD software HELYX AeroSUV **Setup**:

- Tyre rolling using 2 *Reference Frames*
- Turbulence *RANS* method with *k-ω SST* model
- *External Boundaries* #6 tunnel surfaces, #4 of AeroSUV
- *Numerical Schemes* → *U, p, k, ω* with Gauss linearization
- *Solver Settings* → *Residual Control U, p, k, ω* 0.00001
- *Runtime Controls* → 1000 s with time-step 1 s
- *Field Initialisation* → $k = \frac{3}{2}(|V|I)^2$; $\omega = \frac{k^{0.5}}{C_\mu^{0.25} l_m}$

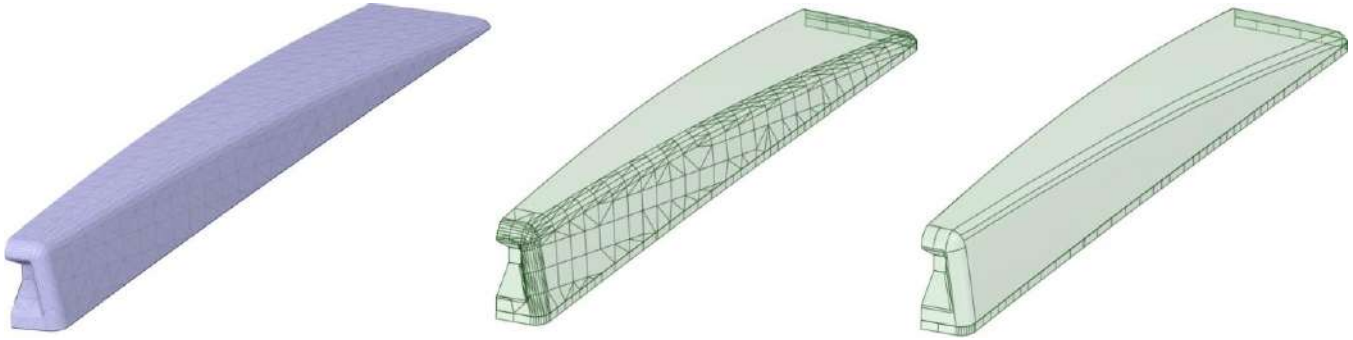
External Boundaries:

- Chassis, roof and wheels *Wall, No-slip*
- front *Symmetry Plane*
- inlet constant *Velocity profile* 50 m/s in X
- outlet *Fixed Pressure* 0 Pa
- lowerWall *Moving Wall* 50 m/s in X
- upperWall *Wall, Slip*

4. Study of the rear-camera of a new Volvo car

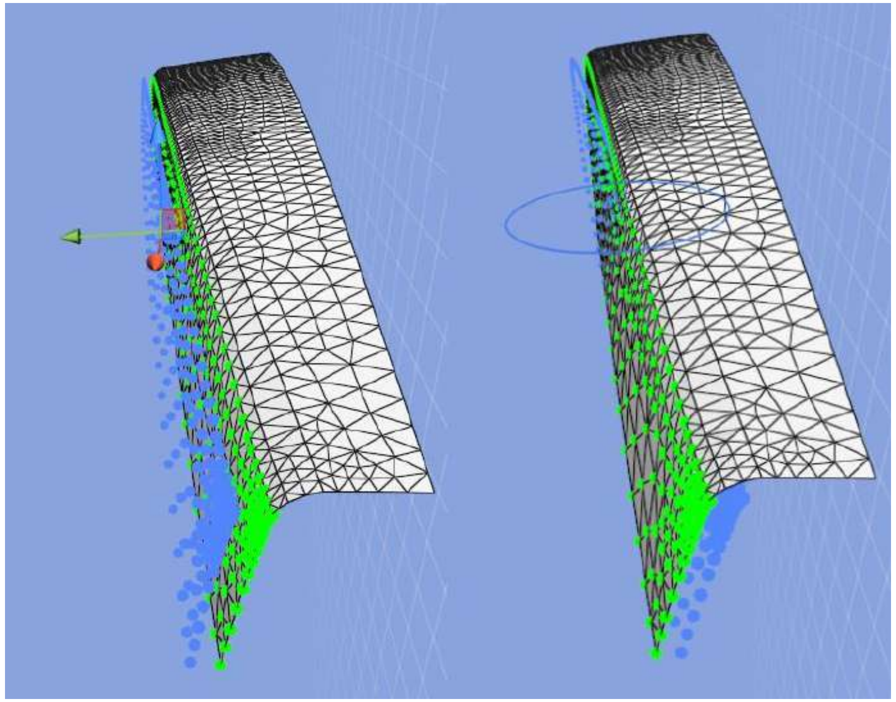
Morphing strategy for the rear-camera:

- Reconstruction of the rear-camera surface and its simplifications



- Translation & Rotation of the side surfaces with 4x4 distribution for the two parameters

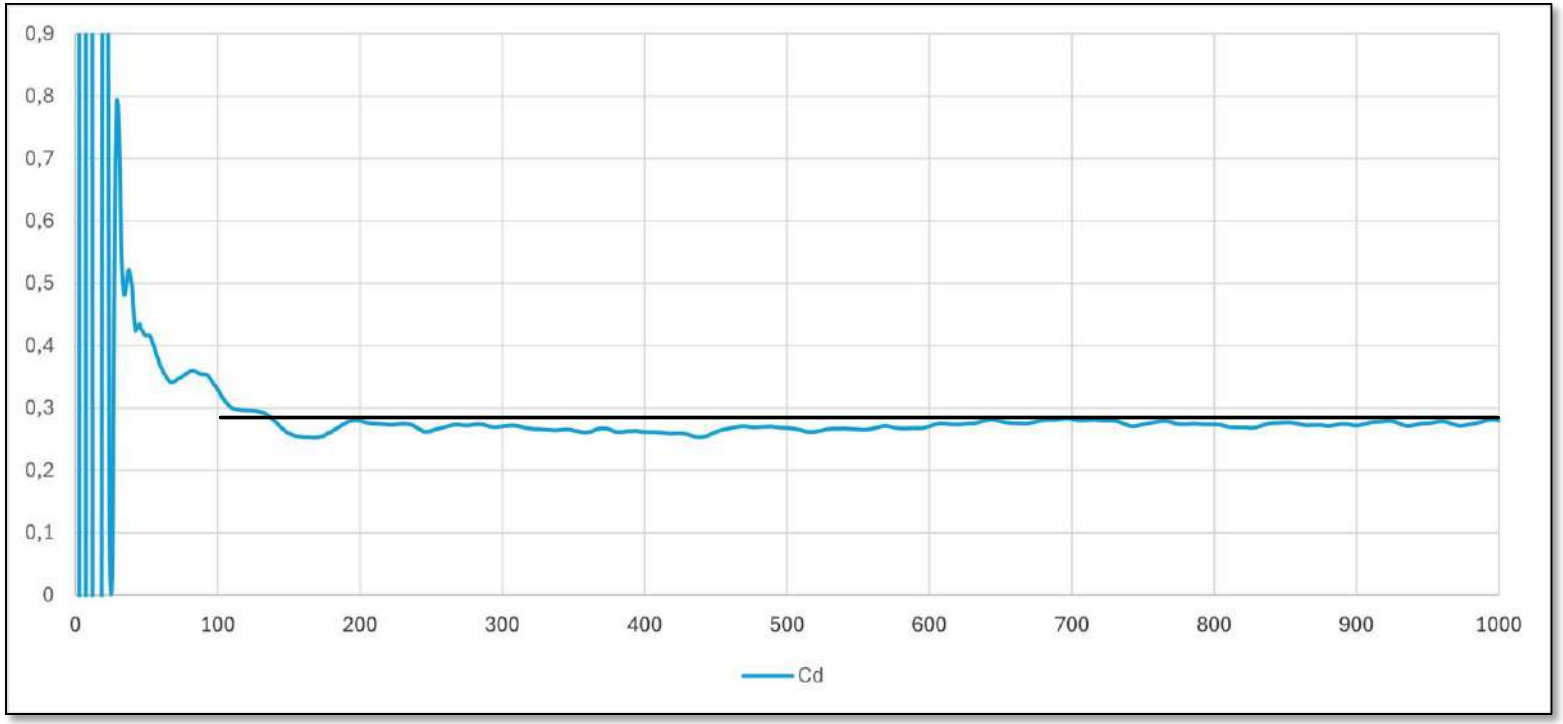
Configurations	Rotation around Z [°]			
Translation along Y [mm]	0.5;1	0.5;1.5	0.5;2	0.5;2.5
	1;1	1;1.5	1;2	1;2.5
	1.5;1	1.5;1.5	1.5;2	1.5;2.5
	2:1	2;1.5	2;2	2;2.5



5. Results and comparisons

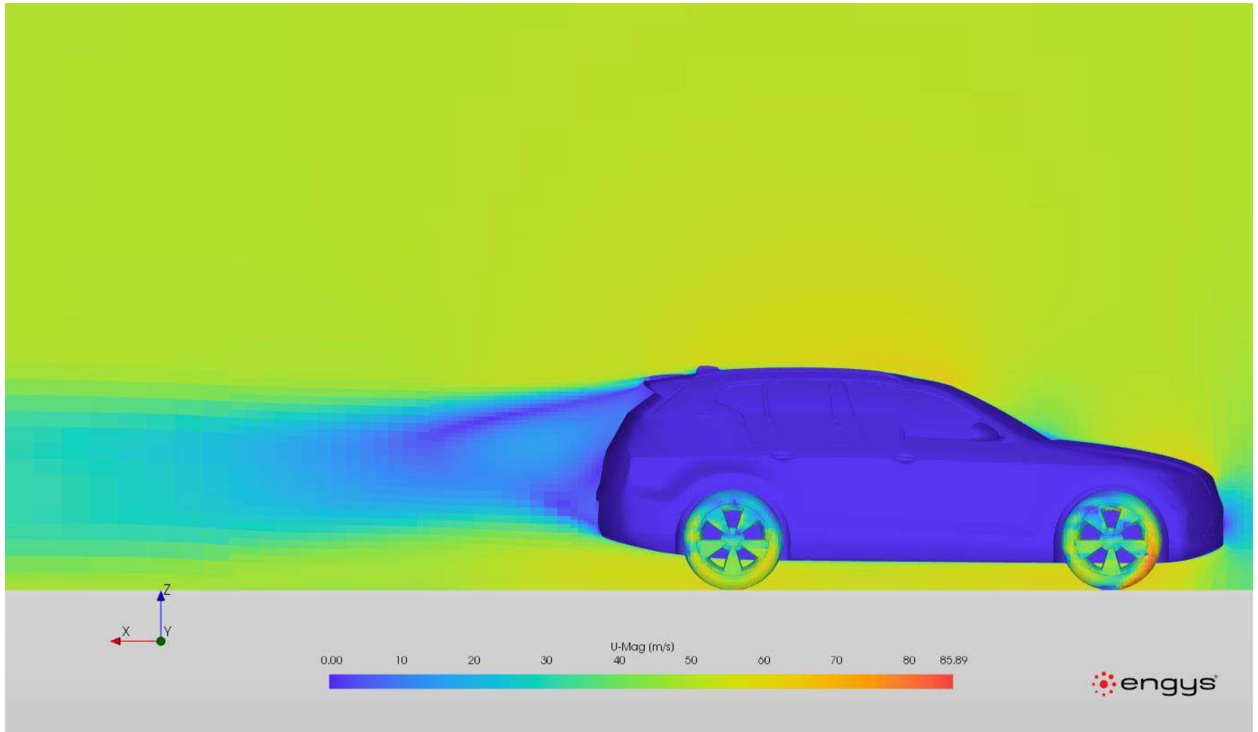
HELYX results of AeroSUV with Volvo roof

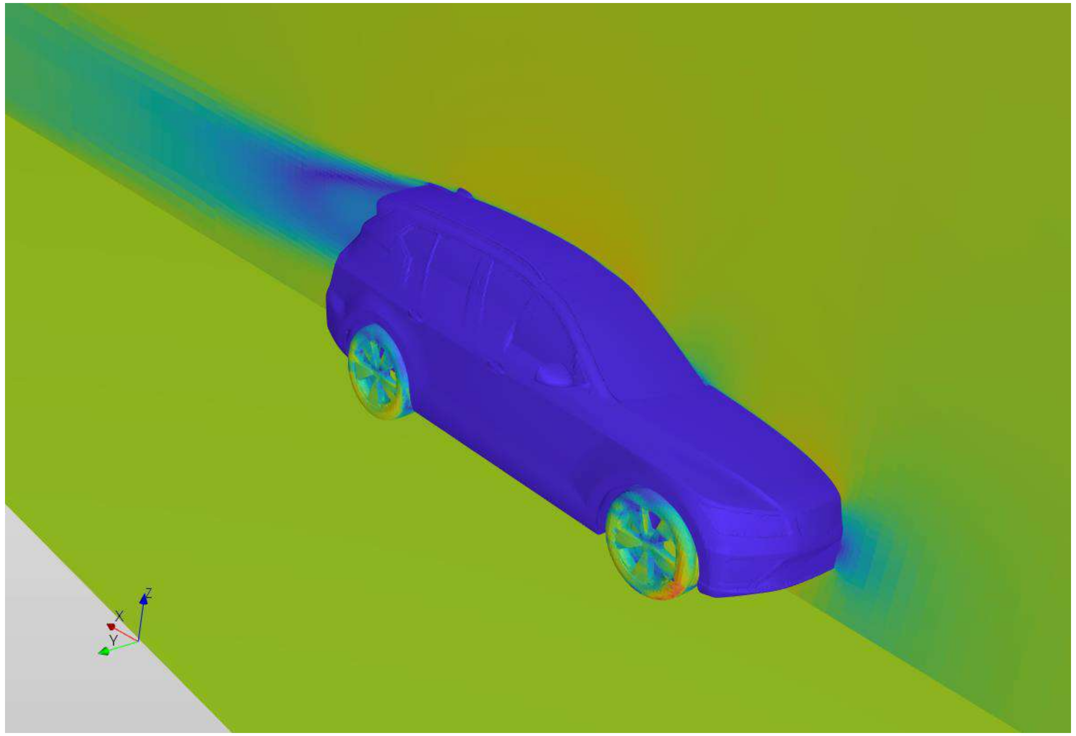
AeroSUV style	Drag coefficient
AeroSUV station wagon	0.314
AeroSUV fastback	0.286
AeroSUV sedan	0.286 ✓
AeroSUV and Volvo roof	0.2856



Initial fluctuations due to the phenomenon and the RANS, the initial values are neglected for the calculation of the Cd

5. Results and comparisons





5. Results and comparisons

HELYX results of AeroSUV with Volvo roof and morphing of the rear-camera

	Rear-camera configurations	Drag force [N]	Cd
	Geometry standard	0.4001	0.000253
✓	Trasl. Y 0.5mm & Rot. Z 1°	0.3739	0.000246
✓ ✓	Trasl. Y 0.5mm & Rot. Z 1.5°	0.3741	0.000253
	Trasl. Y 0.5mm & Rot. Z 2°	0.374	0.000251
	Trasl. Y 0.5mm & Rot. Z 2.5°	0.405	0.00027
	Trasl. Y 1 mm & Rot. Z 1°	0.3931	0.000261
	Trasl. Y 1 mm & Rot. Z 1.5°	0.3814	0.000252

Rear-camera configurations	Drag force [N]	Cd
Geometry standard	0.4001	0.000253
Trasl. Y 1.5mm & Rot. Z 1°	0.4121	0.000274
Trasl. Y 1.5mm & Rot. Z 1.5°	0.4107	0.000273
Trasl. Y 1.5mm & Rot. Z 2°	0.4352	0.000286
Trasl. Y 1.5mm & Rot. Z 2.5°	0.4154	0.000273
Trasl. Y 2mm & Rot. Z 1°	0.4194	0.000275
Trasl. Y 2mm & Rot. Z 1.5°	0.4011	0.000264
Trasl. Y 2mm & Rot. Z 2°	[illegible]	[illegible]

5. Results and comparisons

Comparisons between the three best morphing configurations and standard geometry

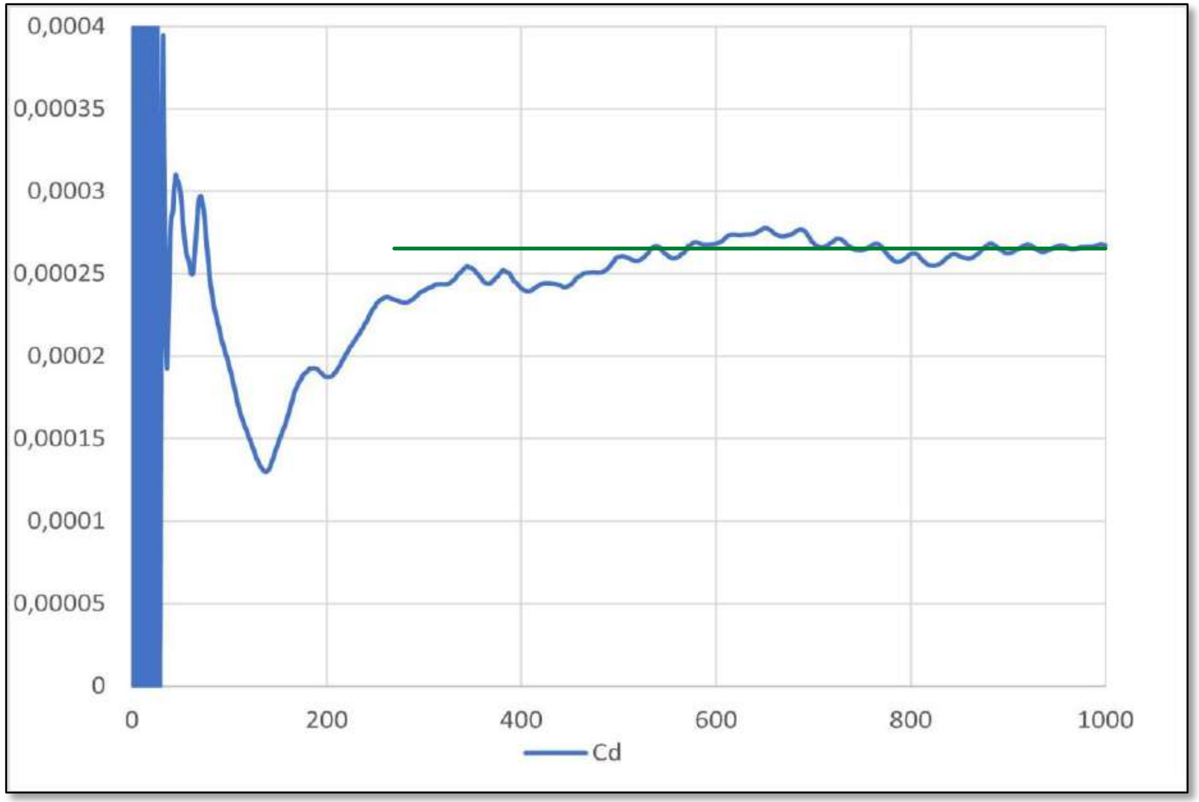
Rear-camera configurations	Drag force[N]	Cd	ΔFd [N]	ΔCd 10^-6	Percentage of improvement drag
Geometry standard	0.4001	0.000253			
✓ Trasl. Y 0.5mm & Rot. Z 1°	0.3739	0.000246	-0.0262	-7	-7 %
✓ Trasl. Y 0.5mm & Rot. Z 1.5°	0.3741	0.000253	-0.026	0	-6.5 %
✓ Trasl. Y 0.5mm & Rot. Z 2°	0.374	0.000251	-0.0261	-2	-6.5 %

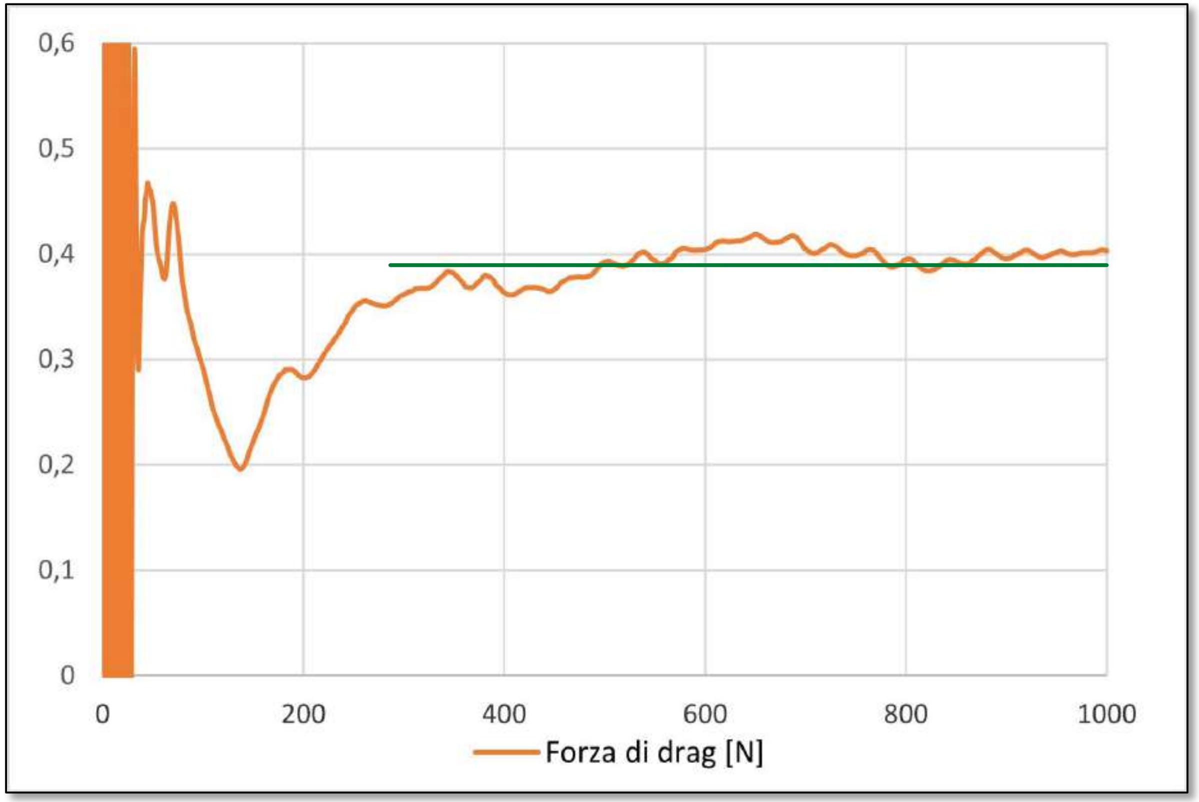
Th

predetermined targets prior to the work.

5. Results and comparisons

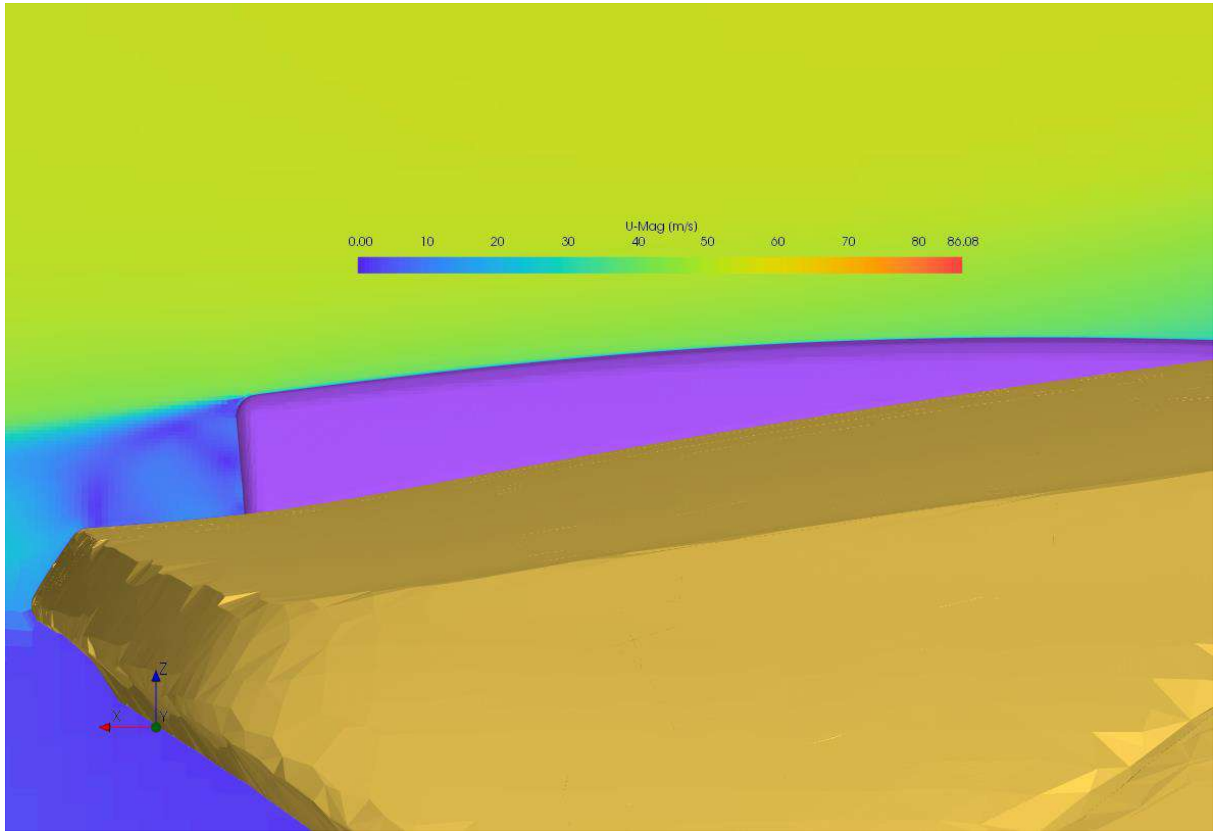
HELYX results of AeroSUV with Volvo roof and morphing of the rear-camera **best case**

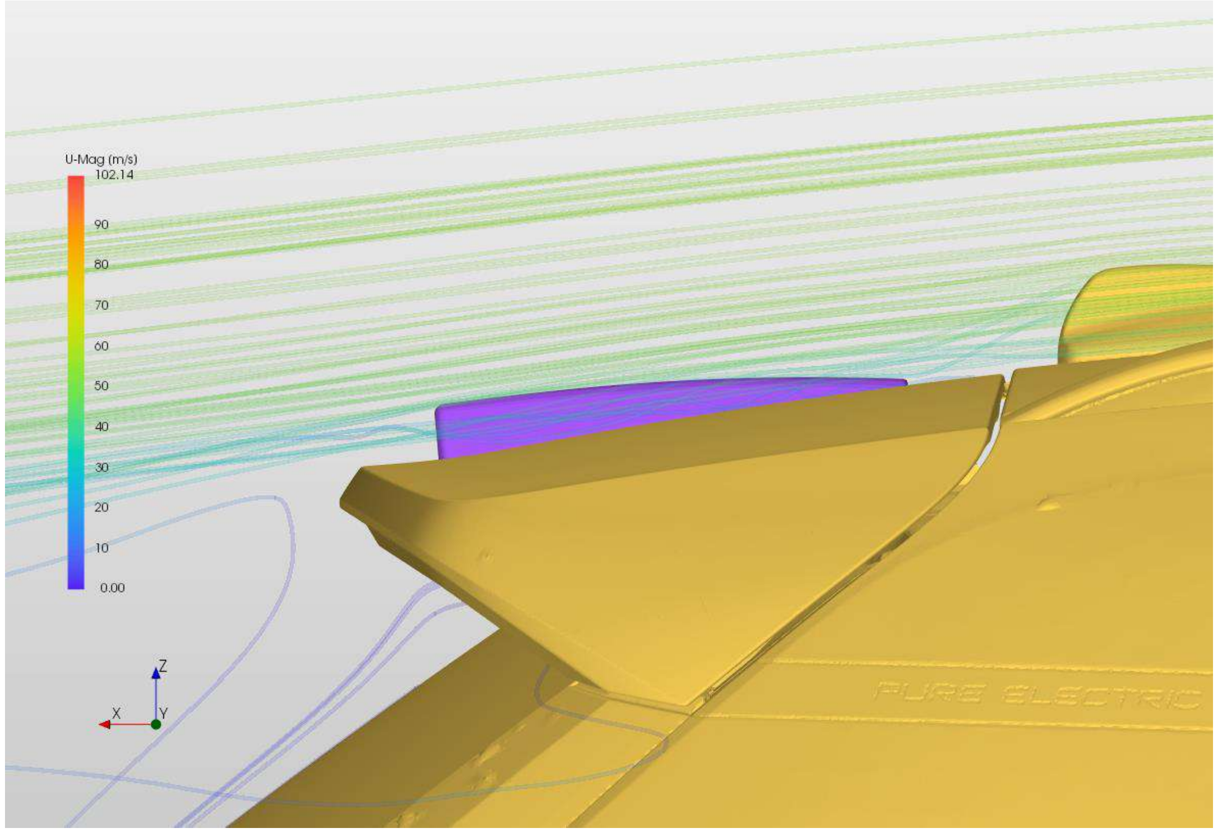




5. Results and comparisons

HELYX results of AeroSUV with Volvo roof and morphing of the rear-camera **best case**





6. Conclusions

The **contributions** of the work carried out can be summarized as follows:

- Use of models for "light" CFDs, through rigorous choices and simplifications that have significantly reduced the computational burden (symmetry, targeted refinementBox, geometric simplifications), while maintaining a high level of fidelity to the problem.
- Calibration and derivation of methods for industrial cases, validated by comparing them to studies involving computing centers and wind tunnels.
- Drastic reduction in geometric parameterization time trough a mesh morphing-based approach, rather than laborious and heavy re-meshing.
- Use of the generic and highly specialized AeroSUV geometry, valid for many SUV vehicles, tailored to the industrial case through its adaptation to the Volvo roof with rear-camera.

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