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UNIVERSITÀ DEGLI STUDI DI ROMA

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

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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

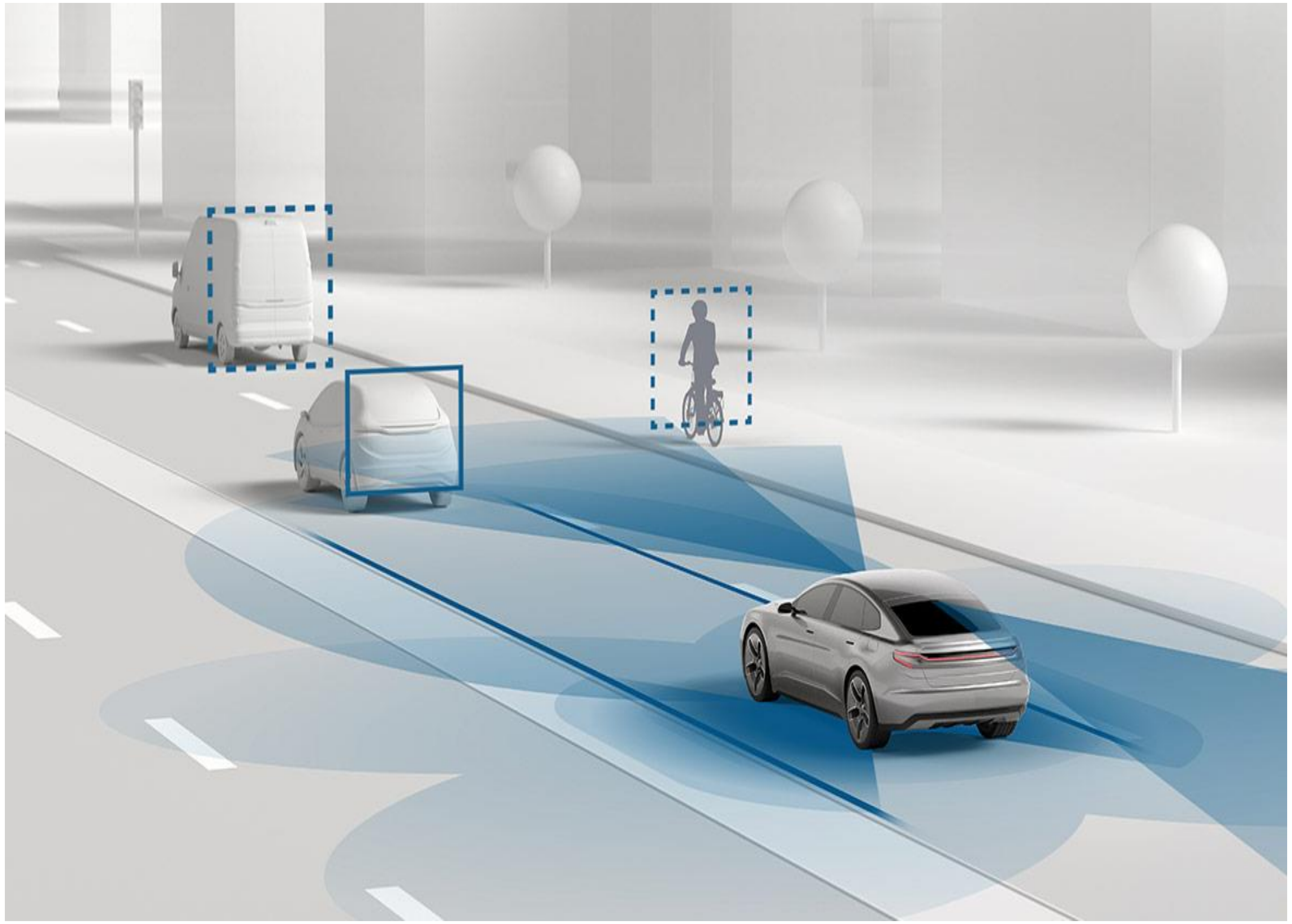
# 1. Introduction

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

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

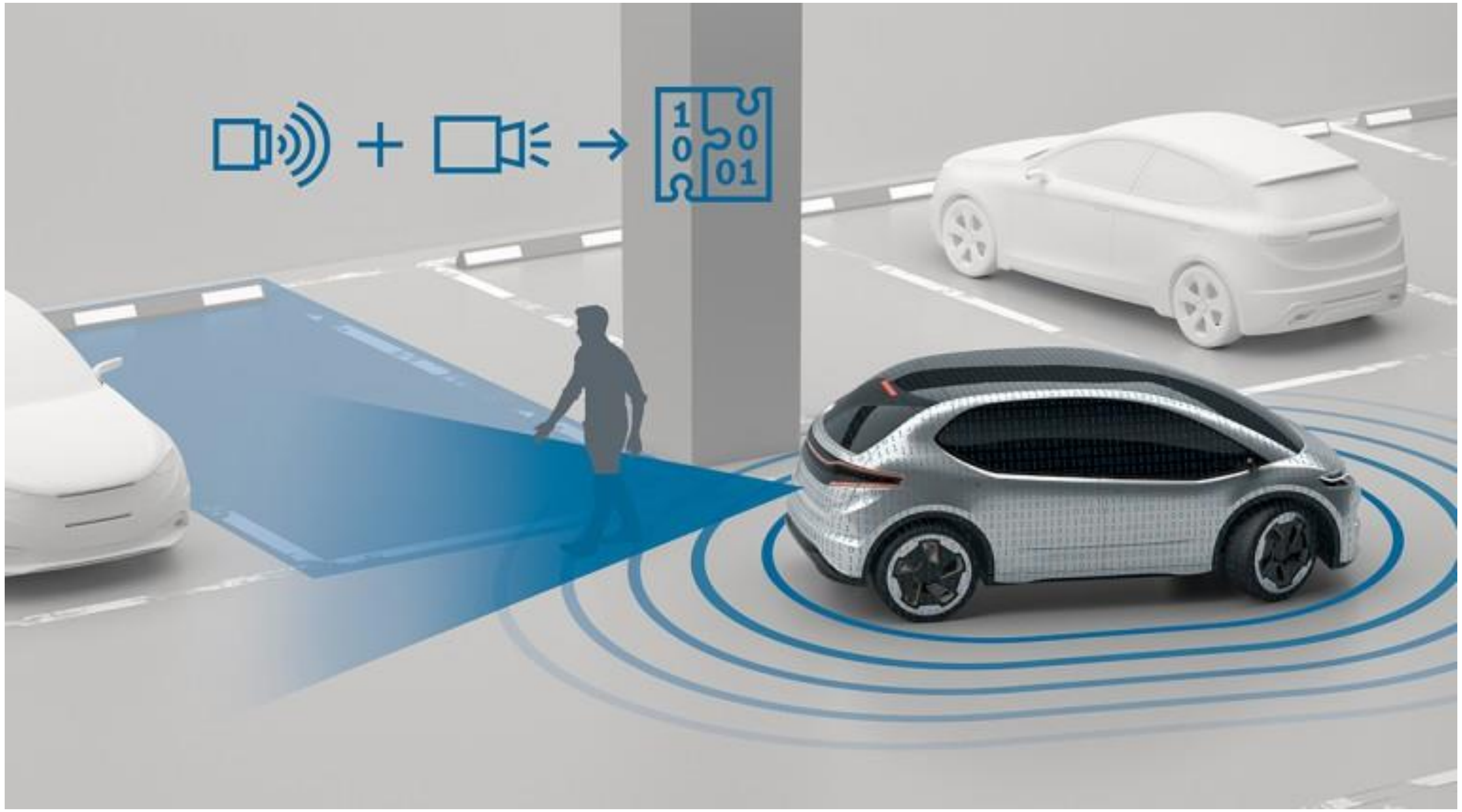
2010 Euro NCAP evaluation test for active safety technologies

- 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:

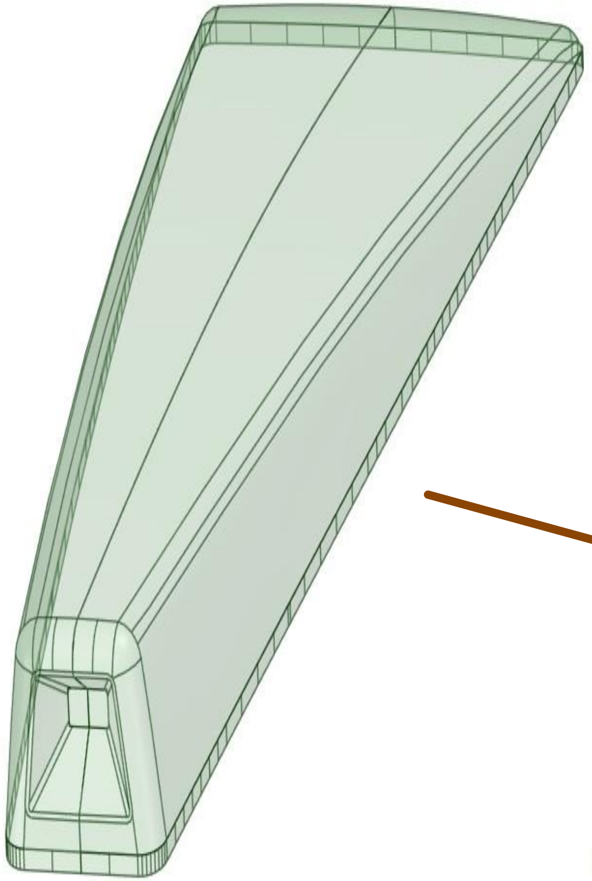


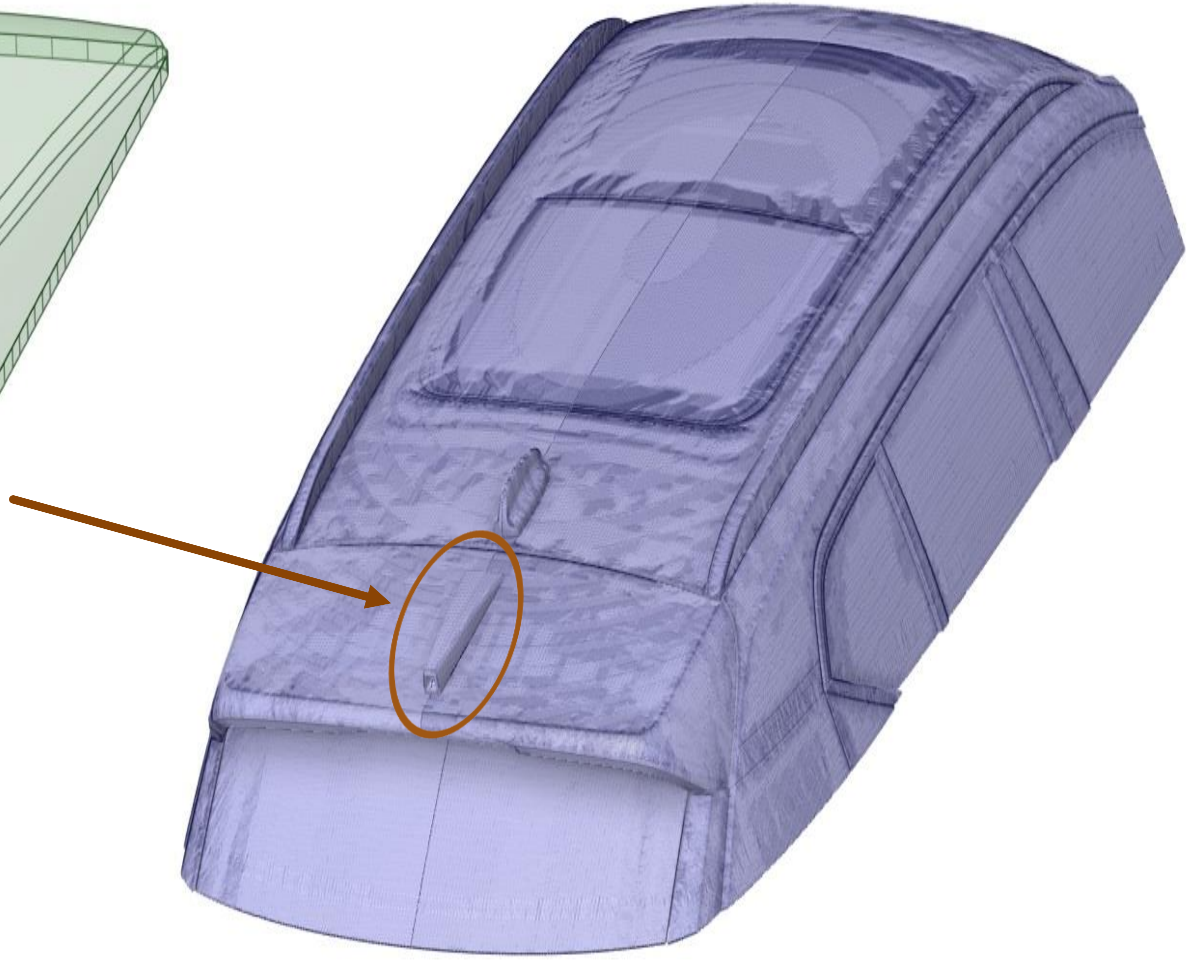
- Reverse detection
- Automatic emergency braking system
- Maintenance systems and lane warning

# 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



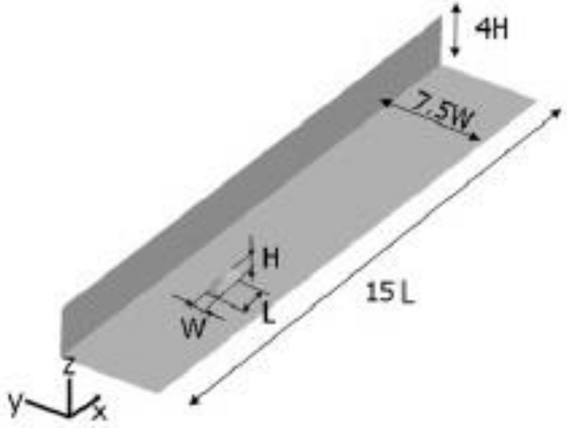


# 3. Preliminary analysis on the ASMO model

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

Boundary conditions:

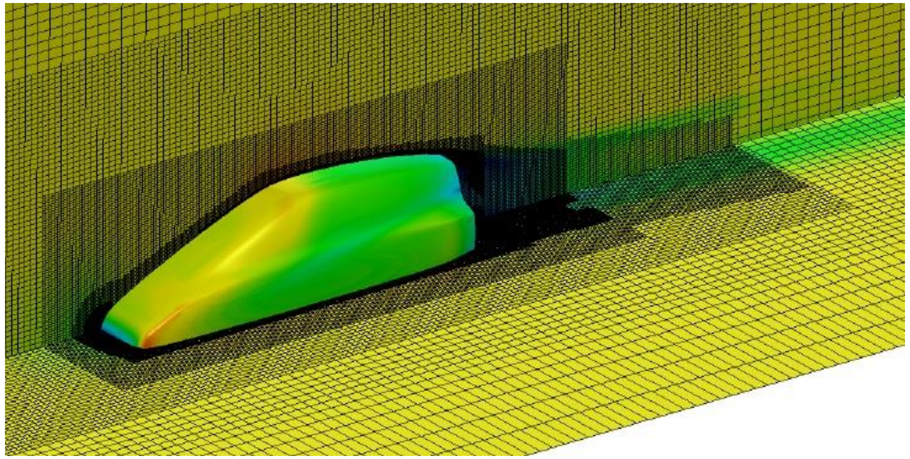
- Fixed ground
- Flow velocity 50 m/s
- Fluid air
- Temperature 20 °C
- Pressure 101 325 Pa




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

Mesh :

- Rectangular cells with adaptive refinement
- 13.5 million total cells

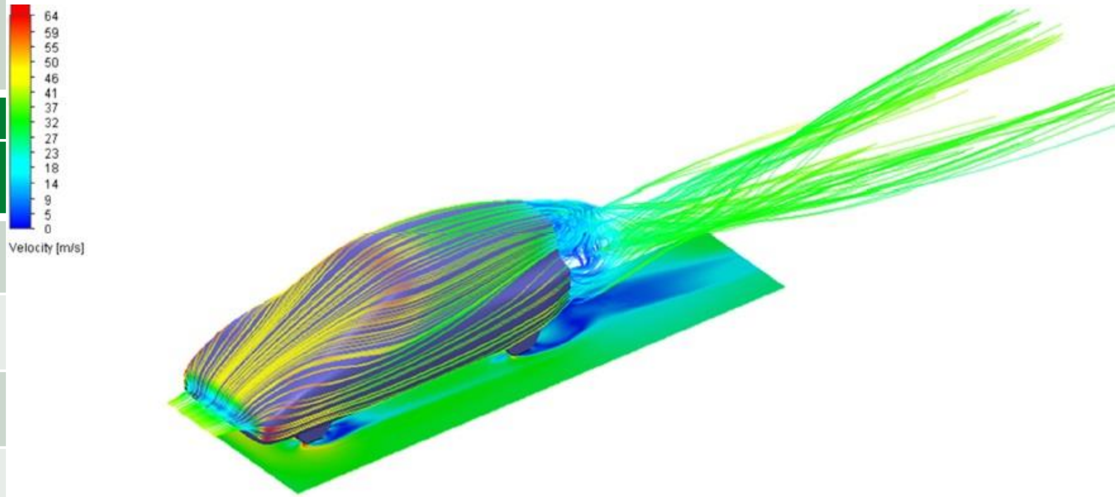


# 3. Preliminary analysis on the ASMO model

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

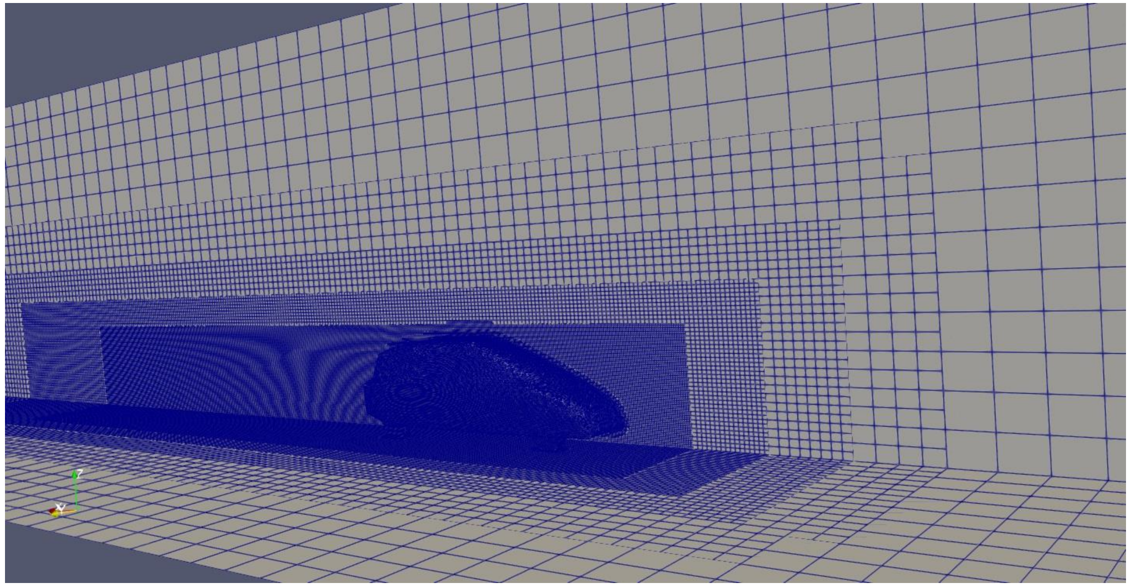
Work screen:

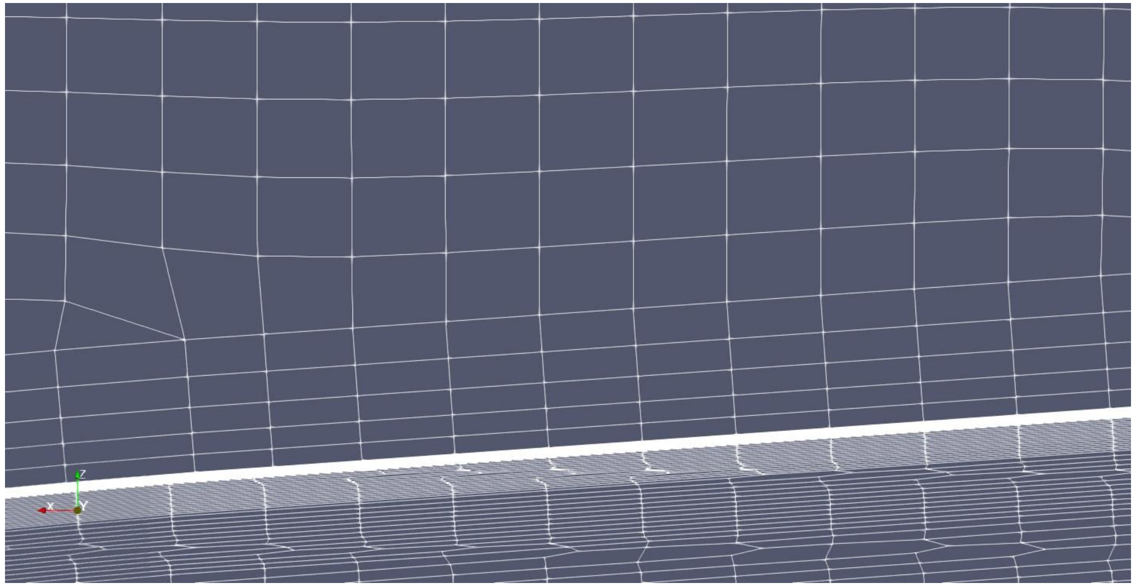
- **Mesh** → Base Mesh & Geometry
- **Setup** → Materials, Modelling, External Boundaries, Numerical Schemes, Solver Settings, Runtime Controls, Monitoring Functions and Fields Initialisation
- **Solver** → Runtime Controls, Residuals, Monitoring Functions
- **View** → Post-processing

# 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

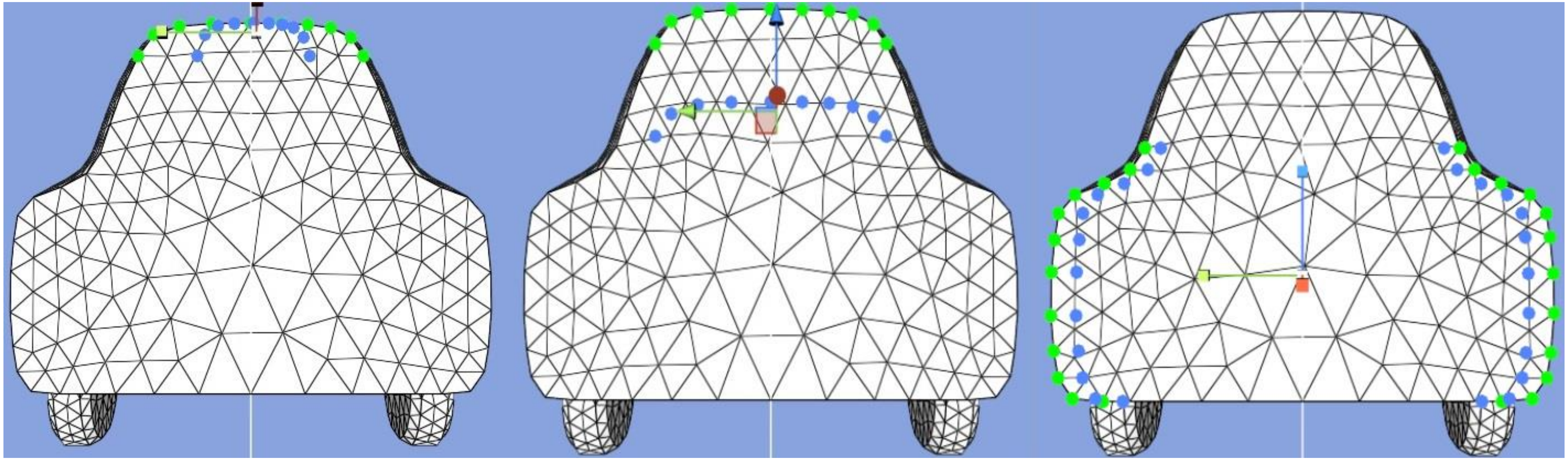




# 3. Preliminary analysis on the ASMO model

Morphing strategy for the ASMO:

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



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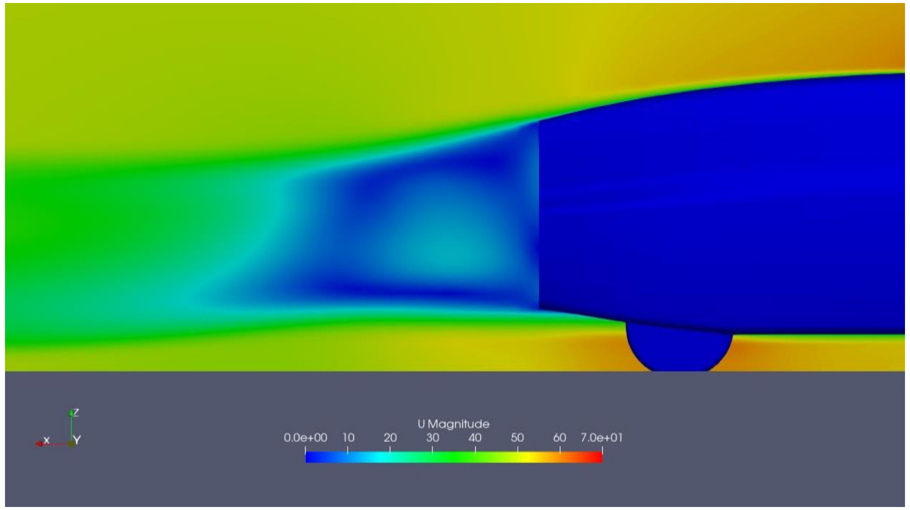
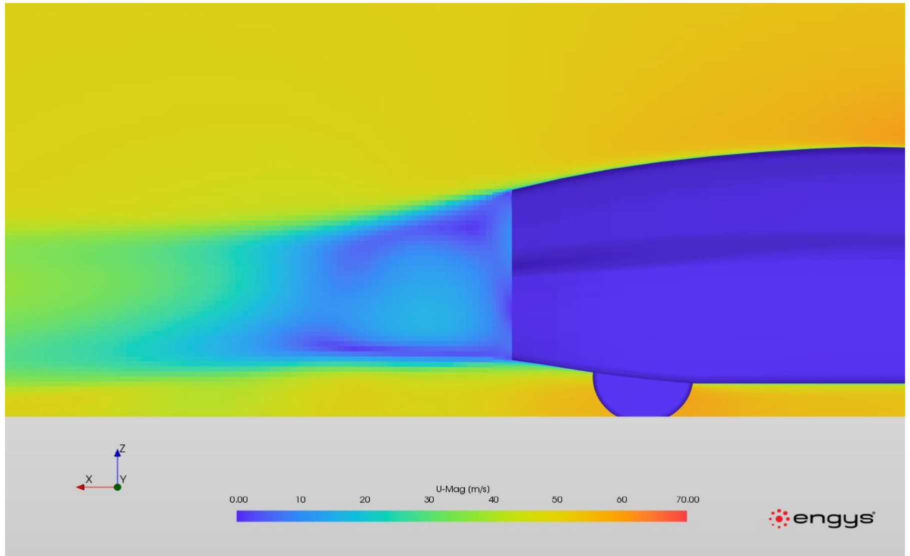
# 3. Preliminary analysis on the ASMO model

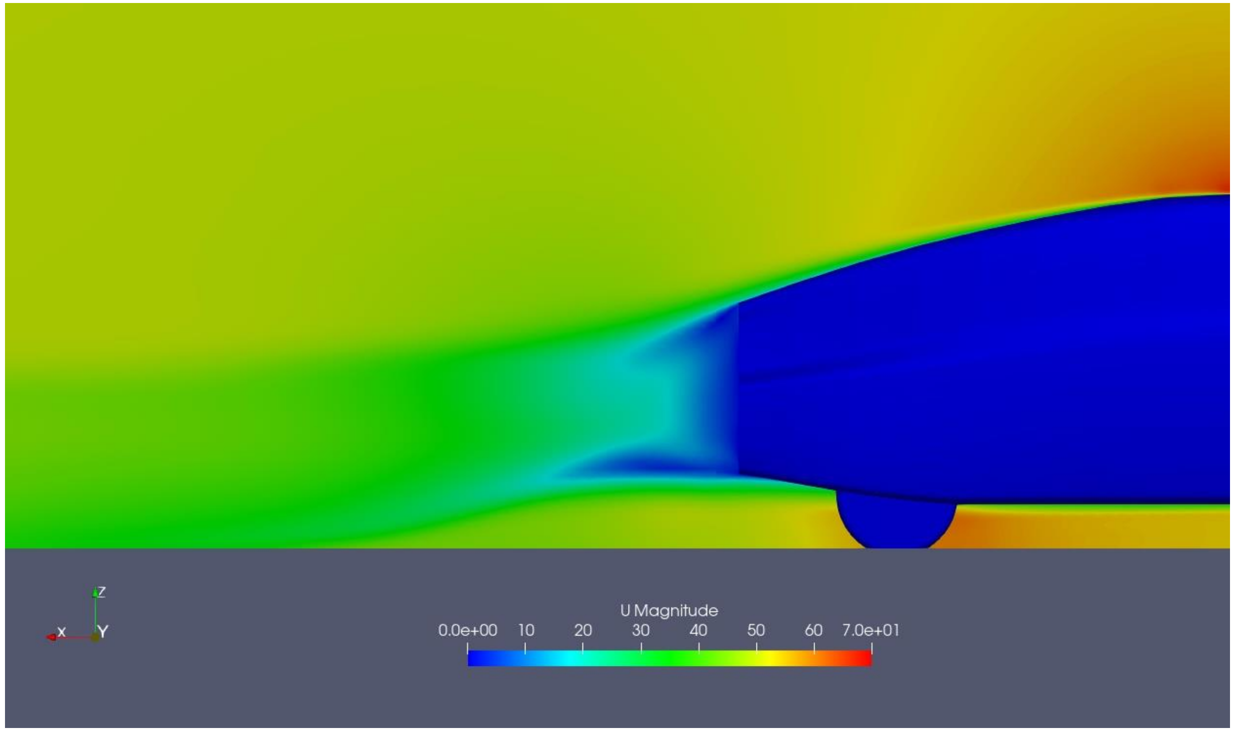
Results OpenFOAM & HELYX

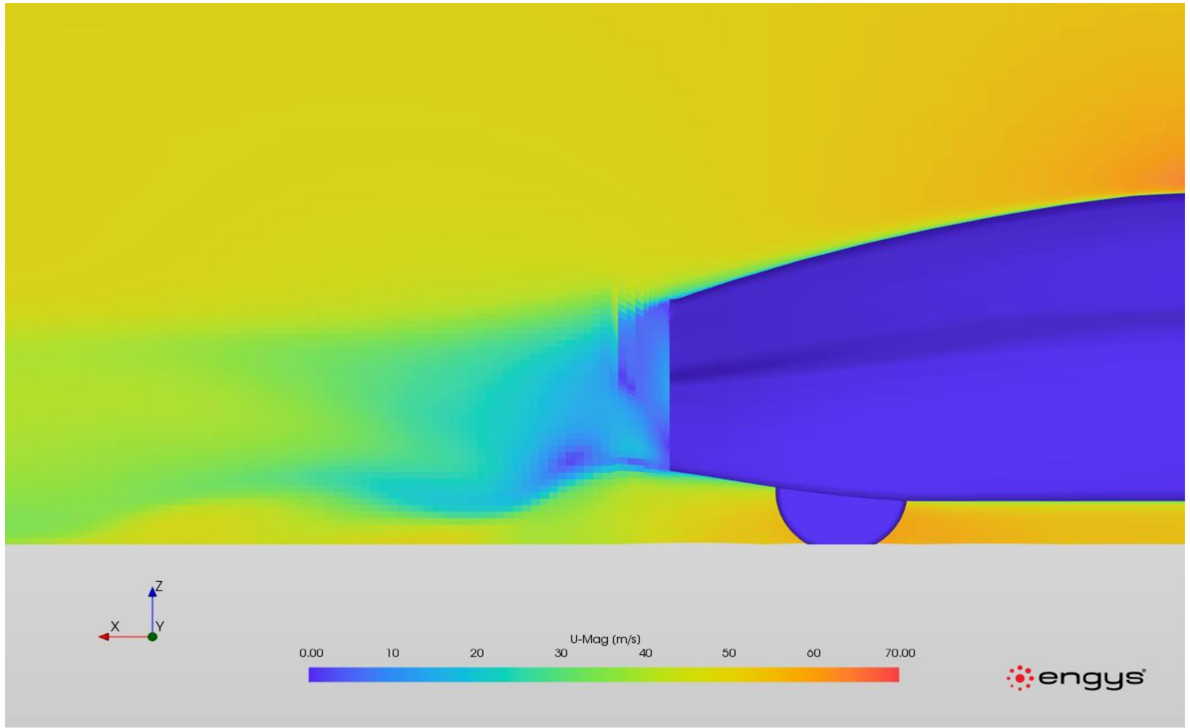
| Type of analysis | Drag coefficient |
|---|---|
| Asmo OpenFOAM standard | 0.152 |
| Asmo OpenFOAM surface morphing | 0.144 |
| Asmo OpenFOAM volume morphing | 0.146 |
| Asmo HELYX standard | 0.162 |
| Asmo HELYX surface morphing | 0.153 |
| Asmo HELYX volume morphing | 0.153 |



# 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

↓

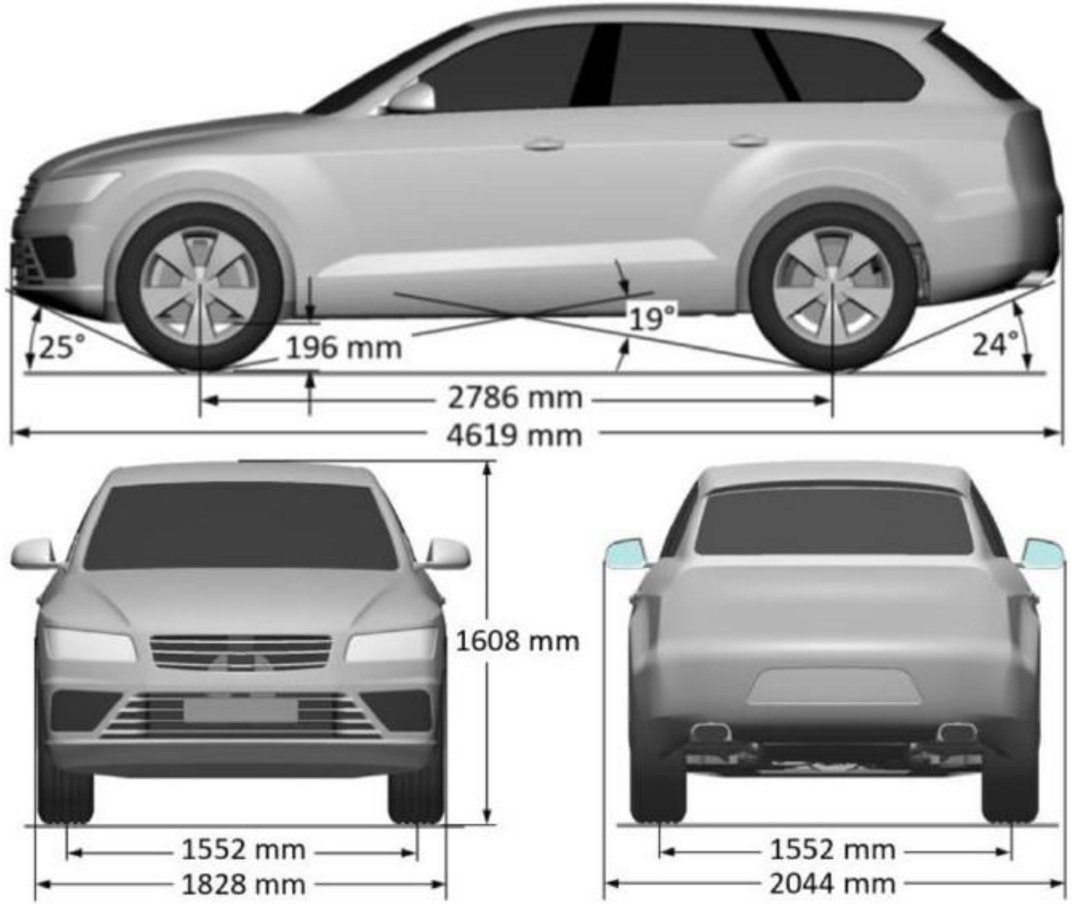
CFD with HELYX for the final AeroSUV model

↓

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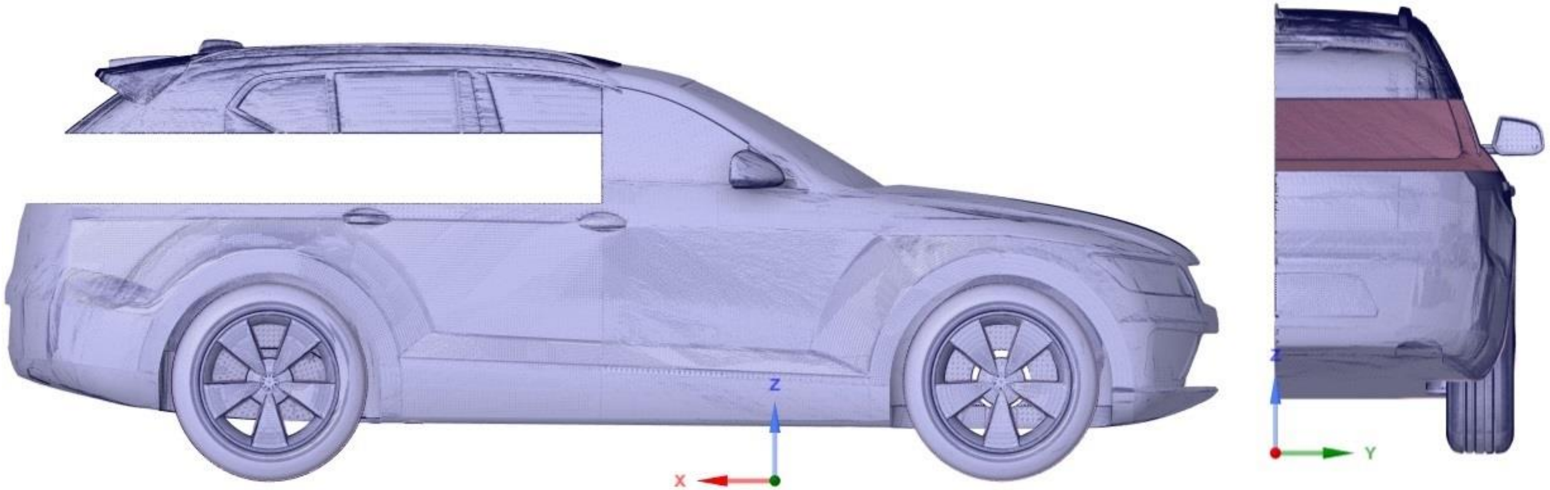
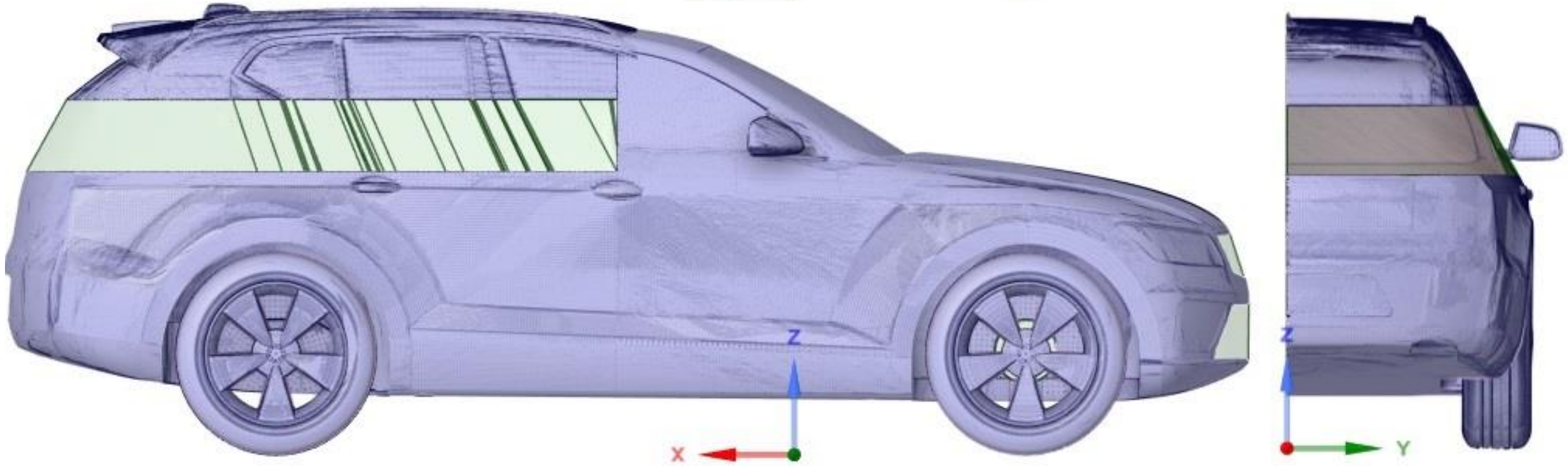
Geometric transformations with “fixed member” roof and “mobile” AeroSUV :

I. Translation of the AeroSUV body
II. Scaling of the AeroSUV body




III. Gap reconstruction by 3D sketch entities



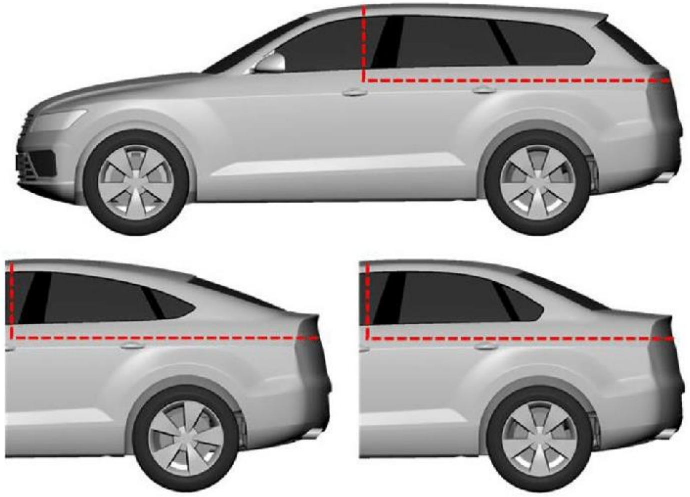
# 4. Study of the rear-camera of a new Volvo car

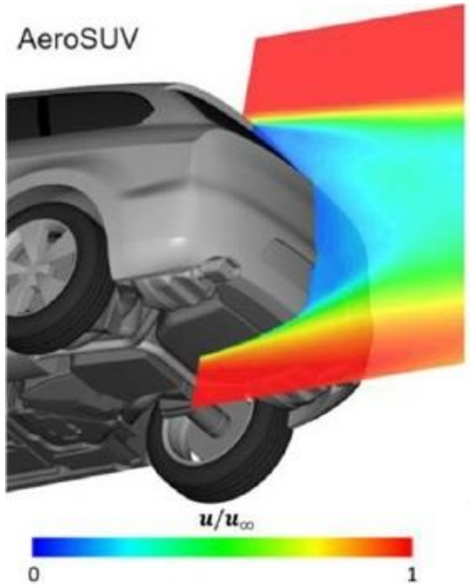
Article "*Introduction of the AeroSUV-A New Generic SUV Model for Aerodynamic Research*"

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

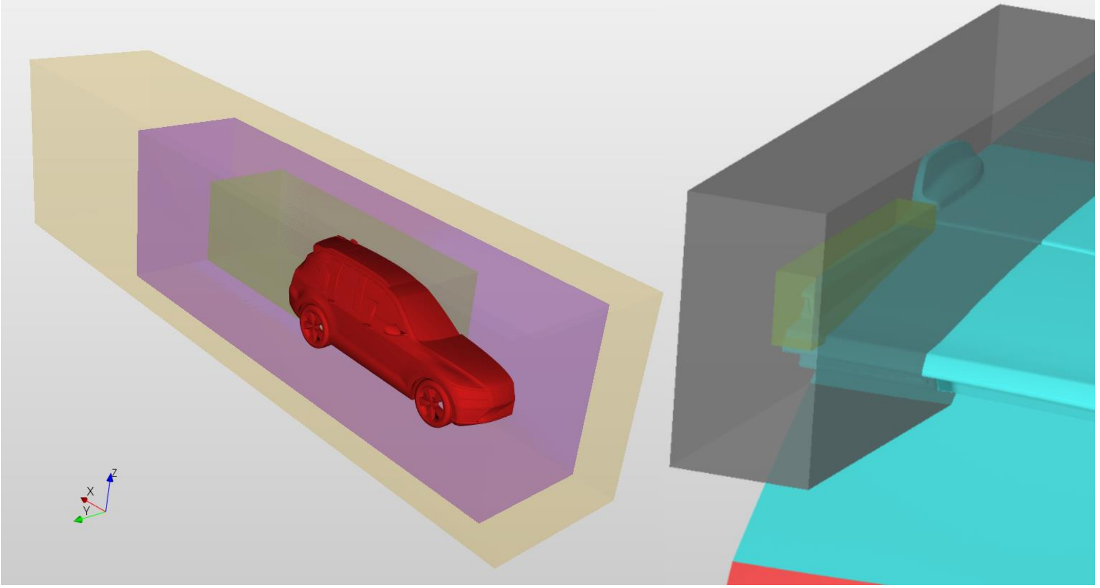
CFD software HELYX AeroSUV **Mesh**:

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

  # 3 ref.Box to AeroSUV &

  # 2 ref.Box to rear-camera

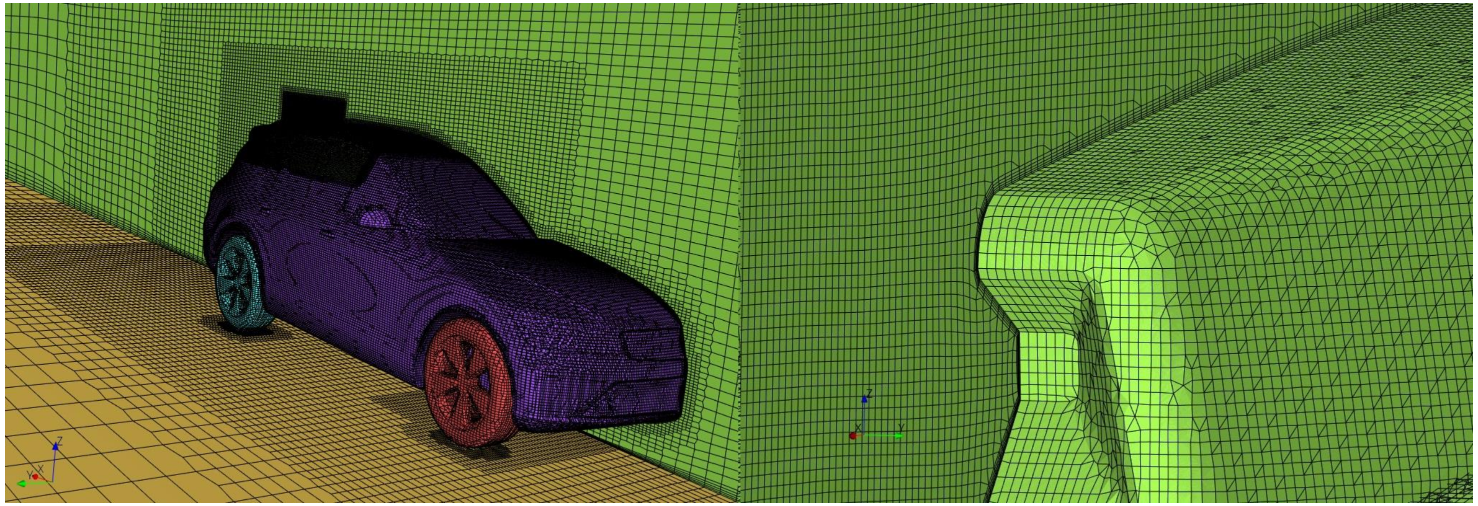
  ⮡ Cells size of rear-camera on the order of mm



- 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

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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* → $k = \frac{3}{2}(|V|I)^2$ ; $\omega = \frac{k^{0.5}}{C_\mu^{0.25} l_m}$

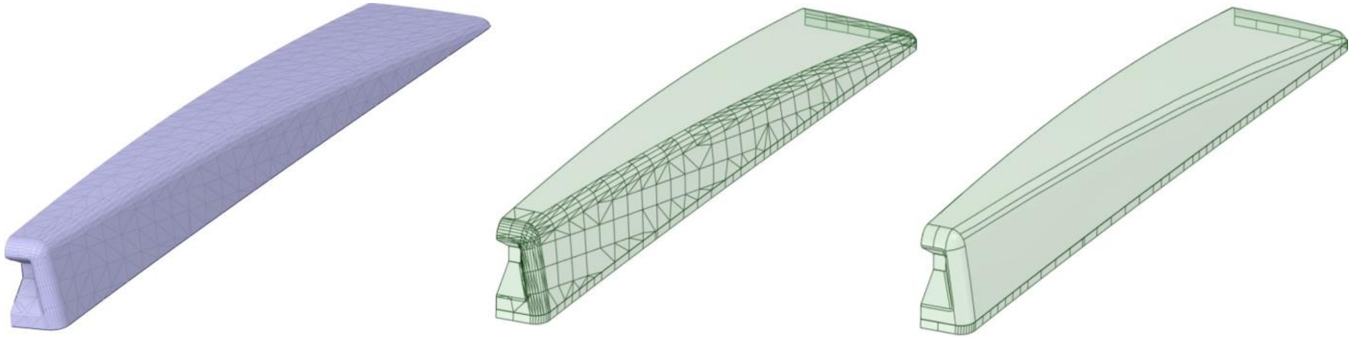
External Boundaries:

- 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

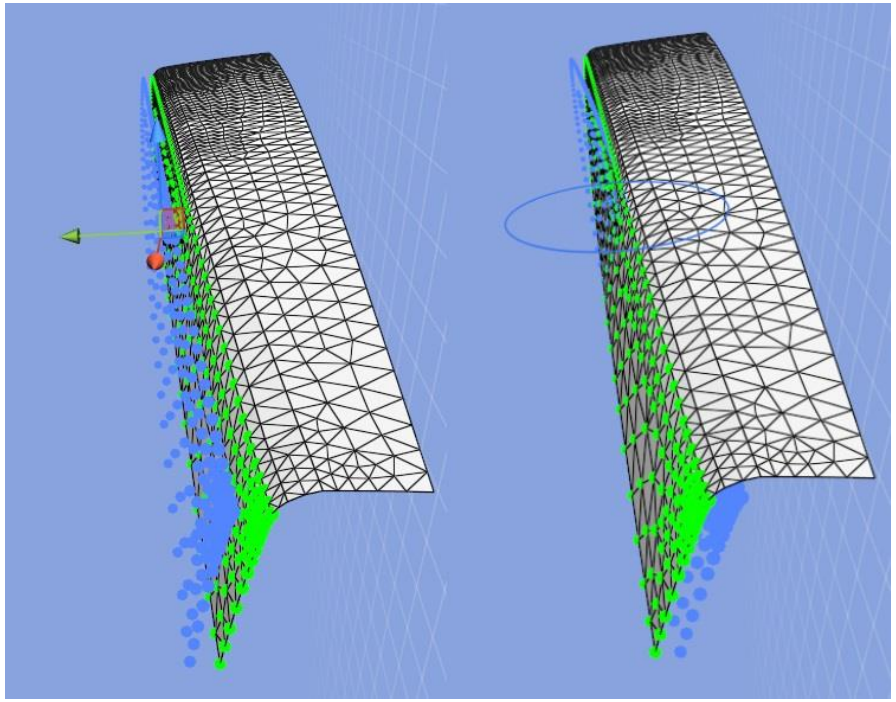
Morphing strategy for the rear-camera:

- Reconstruction of the rear-camera surface and its simplifications



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

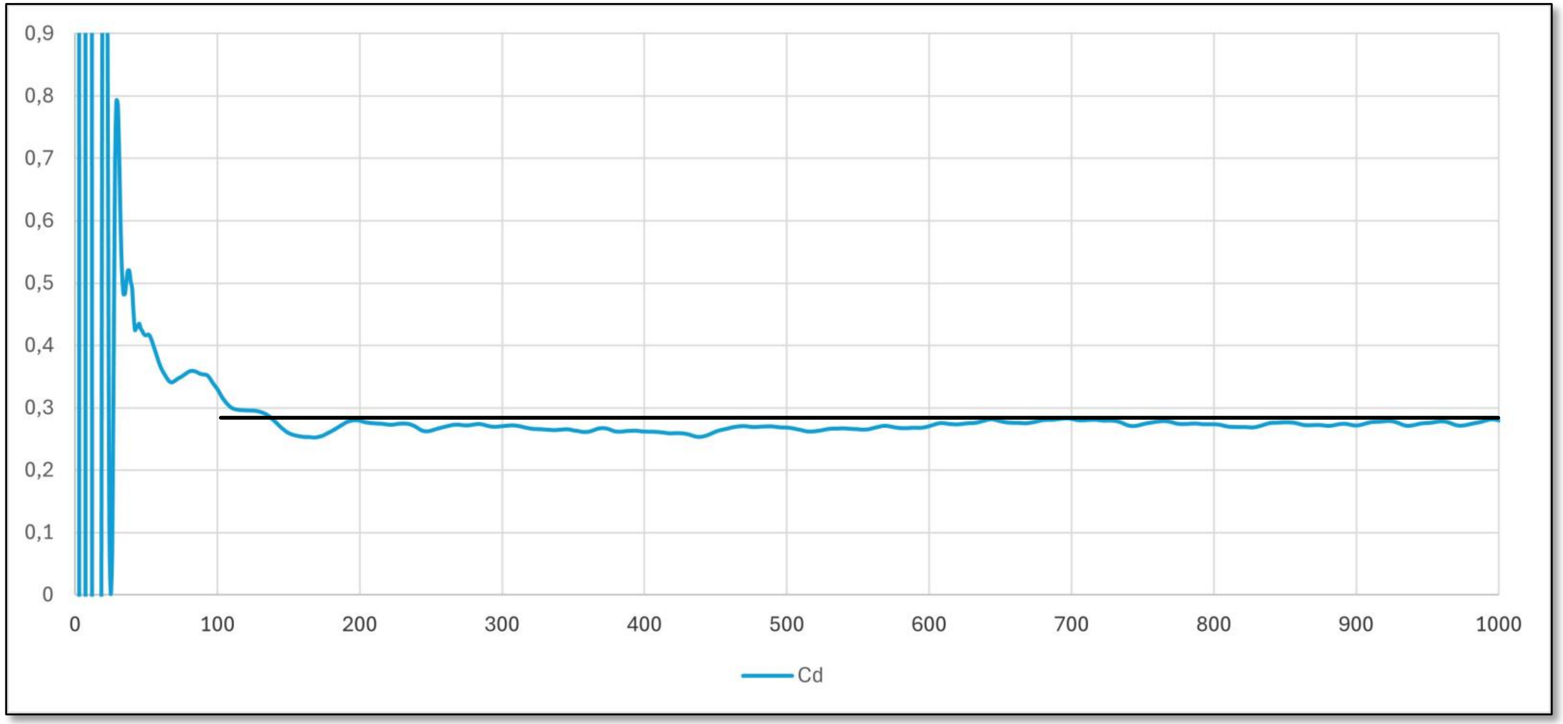
| Configurations | Rotation around Z [°] | | | |
|---|---|---|---|---|
| Translation along Y [mm] | 0.5;1 | 0.5;1.5 | 0.5;2 | 0.5;2.5 |
| | 1;1 | 1;1.5 | 1;2 | 1;2.5 |
| | 1.5;1 | 1.5;1.5 | 1.5;2 | 1.5;2.5 |
| | 2:1 | 2;1.5 | 2;2 | 2;2.5 |



# 5. Results and comparisons

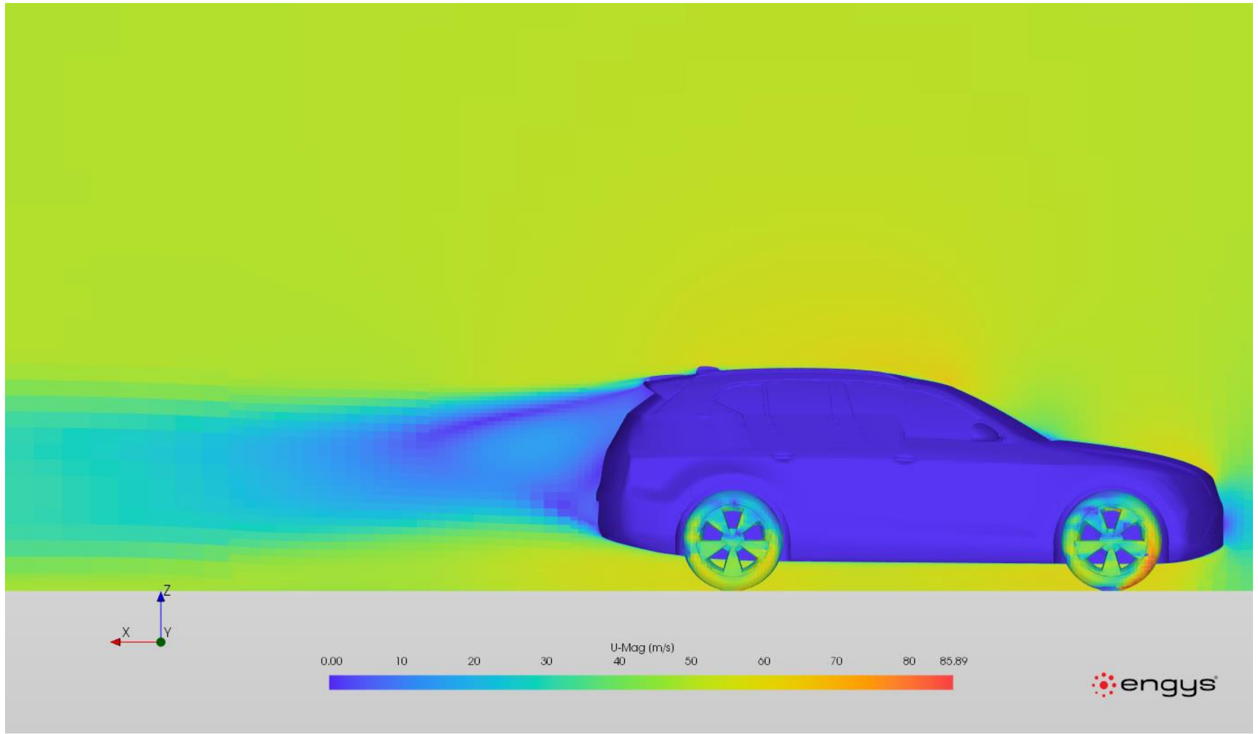
HELYX results of AeroSUV with Volvo roof

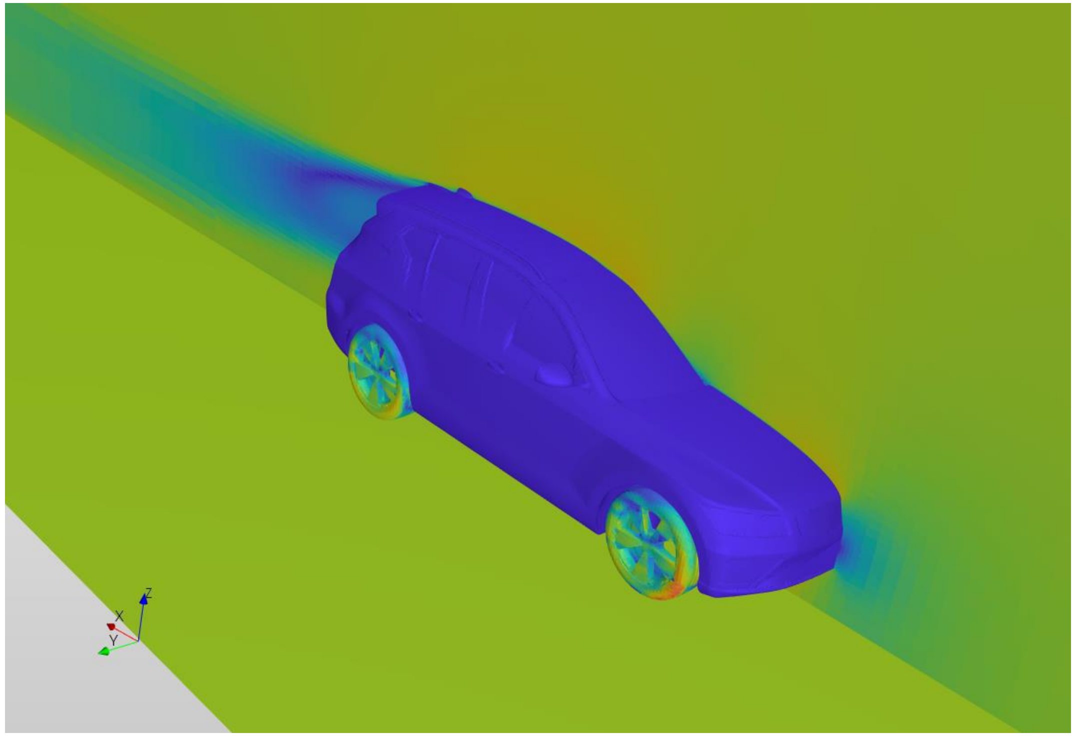
| AeroSUV style | Drag coefficient |
|---|---|
| AeroSUV station wagon | 0.314 |
| AeroSUV fastback | 0.286 |
| AeroSUV sedan | 0.286 ✓ |
| AeroSUV and Volvo roof | 0.2856 |




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

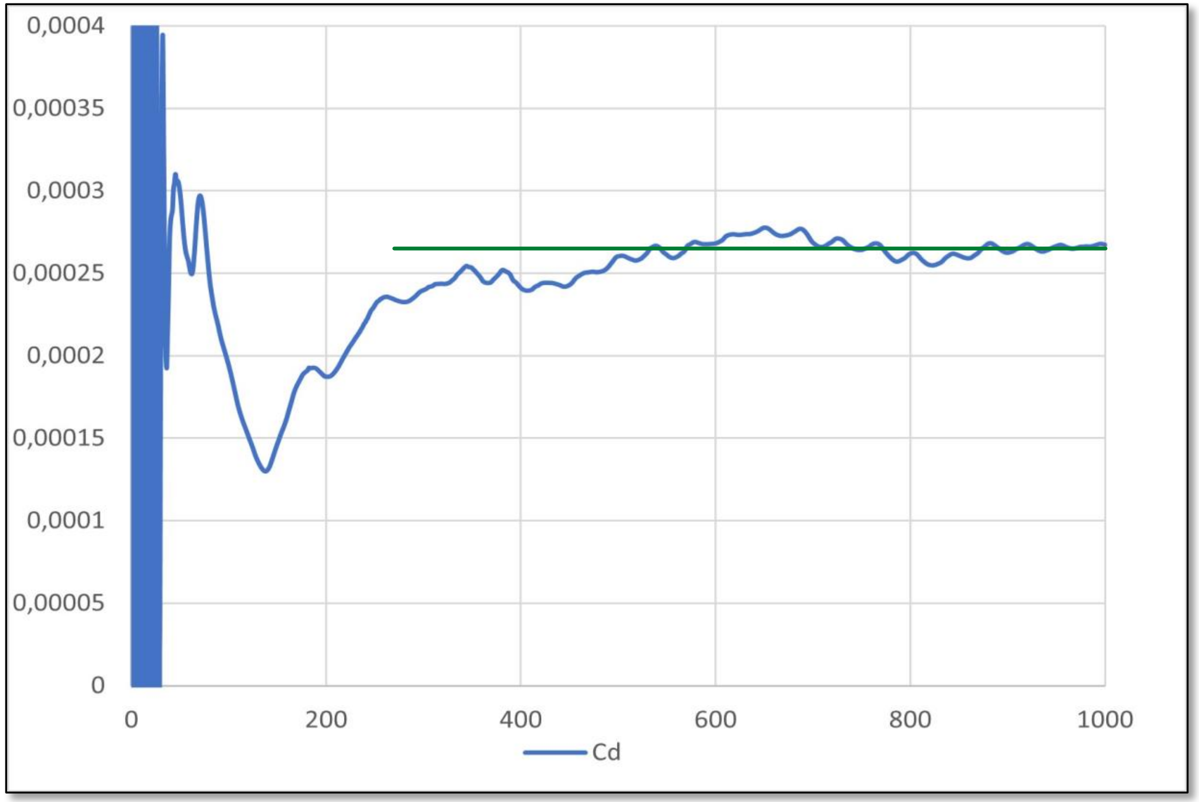
| Rear-camera configurations | Drag force[N] | Cd | ΔFd [N] | ΔCd 10^-6 | Percentage of improvement drag |
|---|---|---|---|---|---|
| Geometry standard | 0.4001 | 0.000253 | | | |
| ✓ Trasl. Y 0.5mm & Rot. Z 1° | 0.3739 | 0.000246 | -0.0262 | -7 | -7 % |
| ✓ Trasl. Y 0.5mm & Rot. Z 1.5° | 0.3741 | 0.000253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

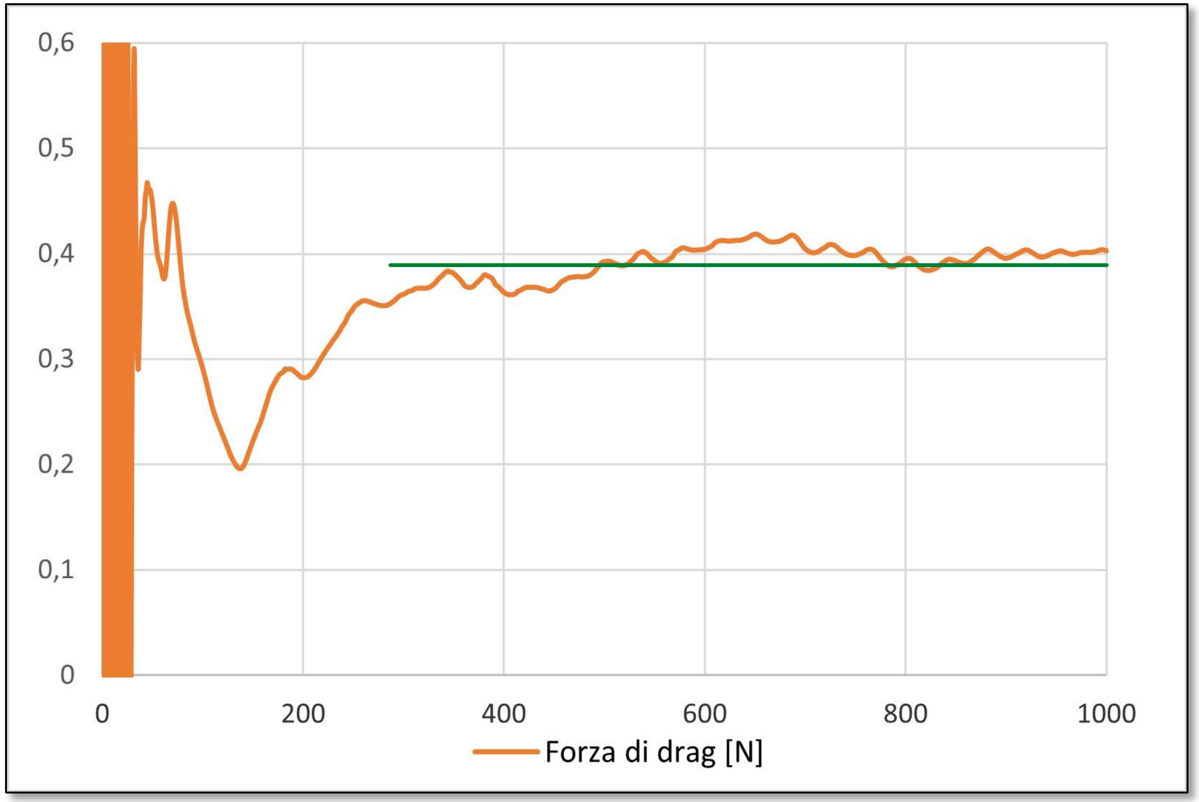
Th

predetermined targets prior to the work.

# 5. Results and comparisons

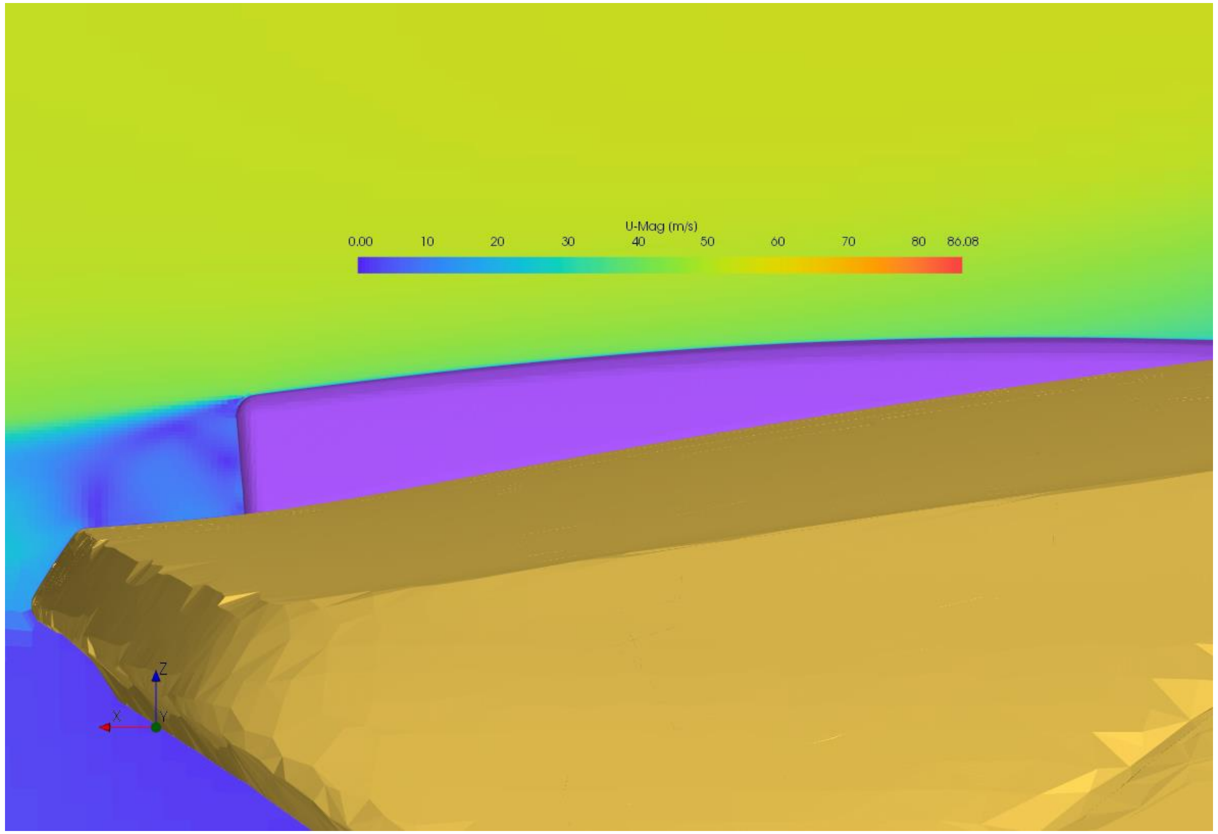
HELYX results of AeroSUV with Volvo roof and morphing of the rear-camera **best case**

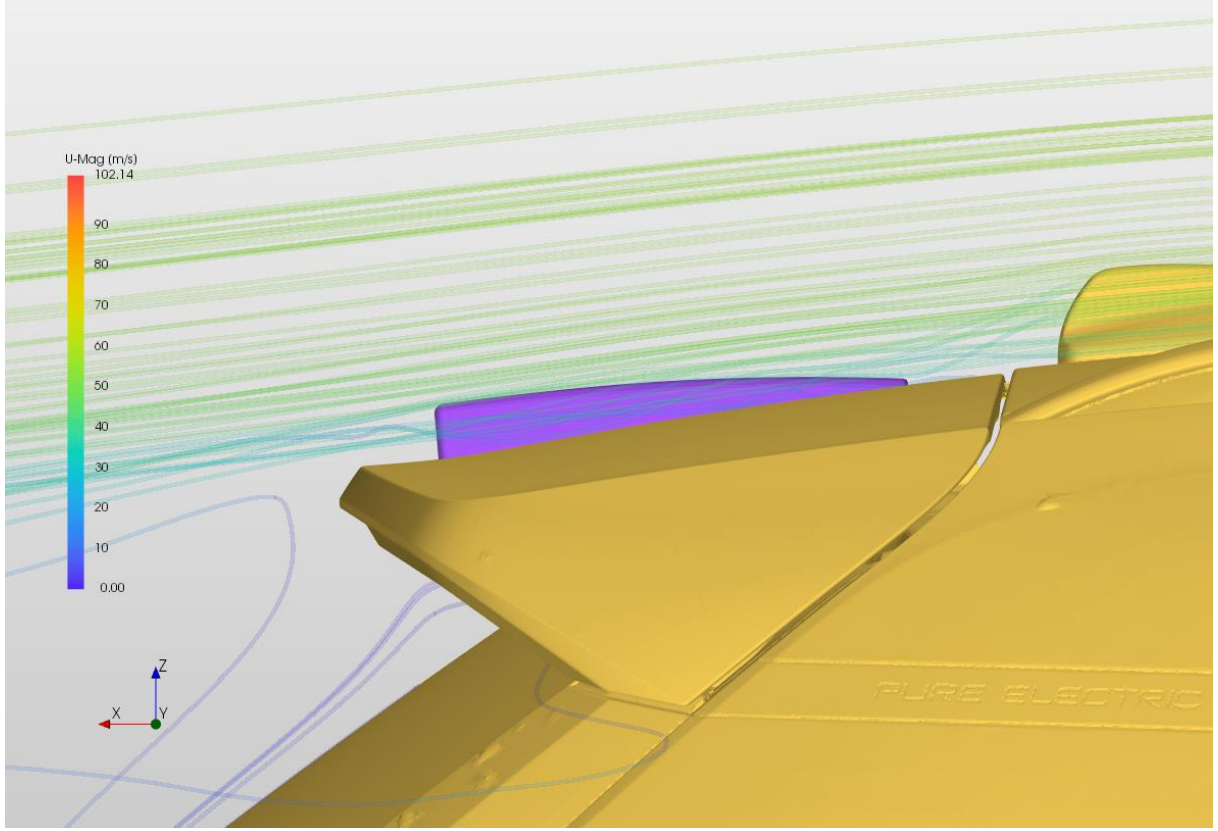


# 5. Results and comparisons

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



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

Supervisor : Prof. Marco Evangelos Biancolini

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

Student : Lorenzo D'Anastasio

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