Università degli Studi di Roma Tor Vergata

Aerodynamical characterization and optimization of a Velomobile

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What is a Velomobile?

The Velomobile is **closed** vehicle powered by an abundant, **sustainable** energy source: **human power**, usually, they are derived from **recumbent** bicycles or **tricycles**.

Over this structure an **aerodynamic lightweight shell** is often present to enhance the aerodynamic performances of the vehicle, to provide weather and crash **protection** and an overall practicality on a different level from a bicycle.

Why is it so special? Why not a normal bicycle?

- They are **enviromentally friendly** and **cheap to run**
- Driving a velomobile requires **three to four times less energy** in comparison to a normal bicycle.
- Velomobiles are far **more confortable** than a normal bycicle
- Allow for **storage space**
- Velomobiles are also **safer** than normal bikes
- The aerodynamic shell provides **water proofing**

Let’s look at some data!

Speed (km/h)	Flat road (250 W)	Flat road (100 W)	5% uphill (150 W)	2% downhill (100 W)	Strong wind ahead (150 W)
Neglected bicycle	23,5	15	6,5	25	3,9
Regular bicycle	29	20,5	9,7	29,5	5,5
Racing bicycle	37,5	27	11,6	38,5	9,3
Standard velomobile	41	28	8,6	50	12,1
Streamlined velomobile	50	34	9	63	17,4

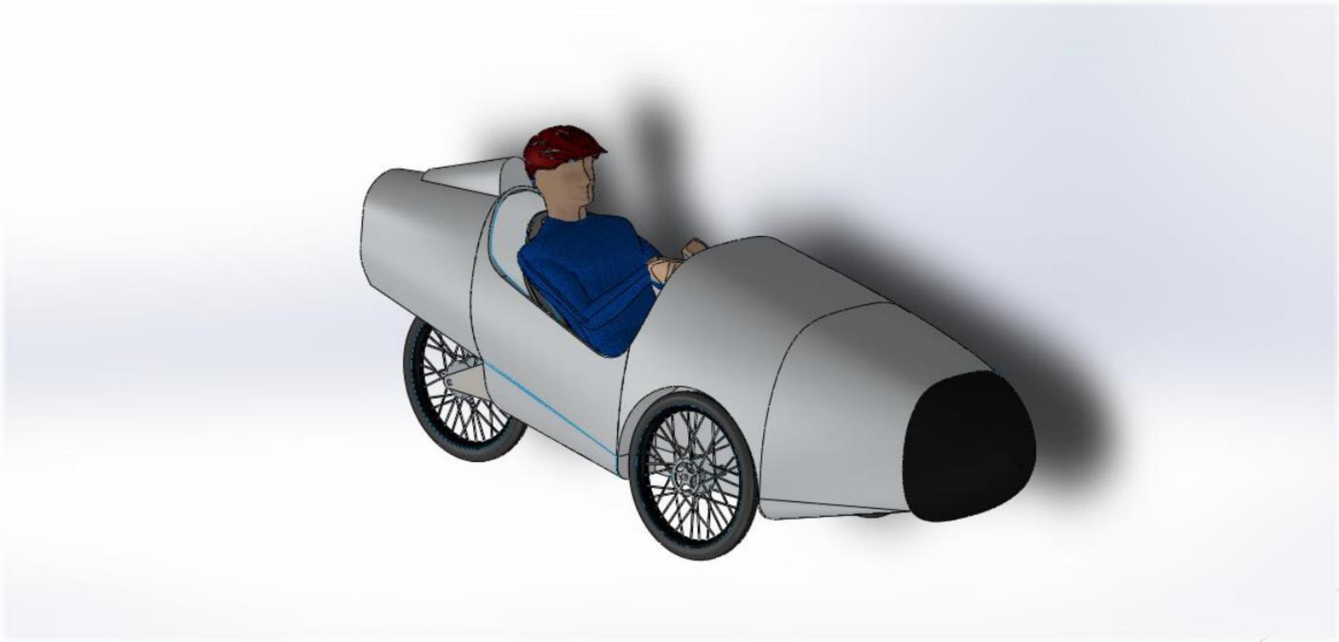
Our Experience

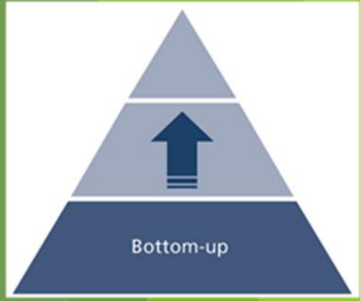
After buying the vehicle in a **kit**, a group of students from the engineering sciences Bachelor degree assembles the vehicle to its present state.

Time to make it better...

The first step of every optimization is to make the **vehicle** available **in** a **virtual enviroment.**

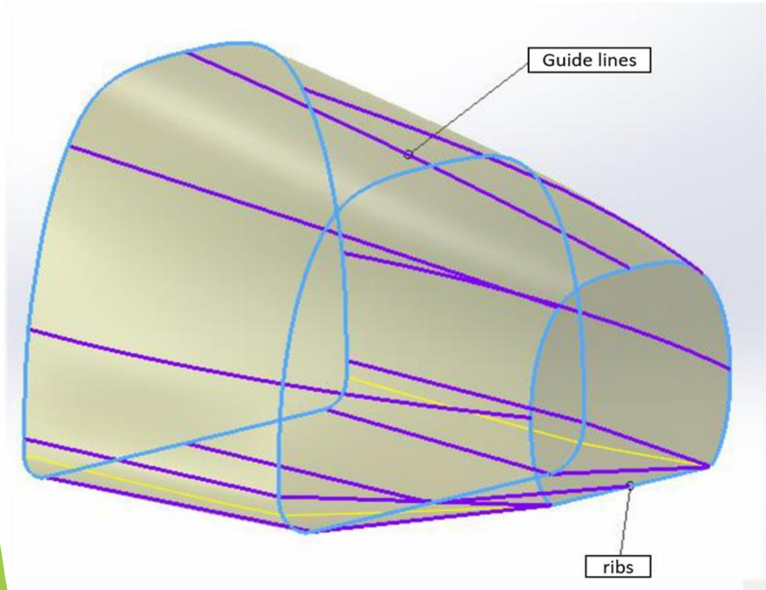
For this reason the velomobile has been modelled using Solidworks, a **CAD** tool

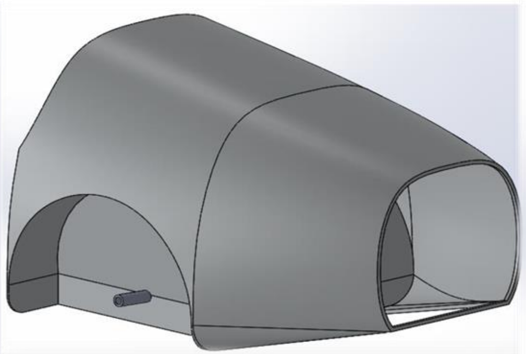


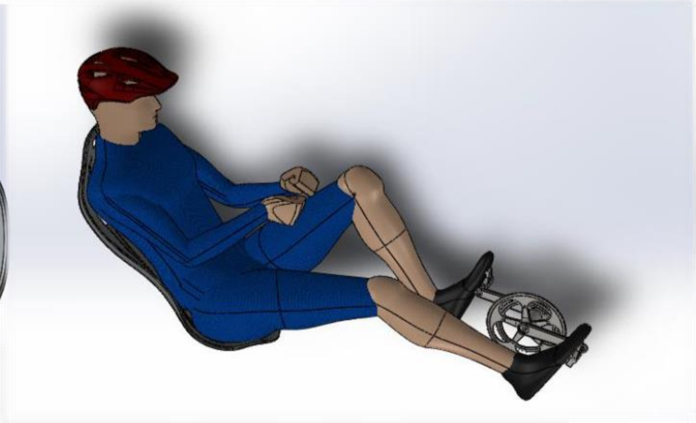


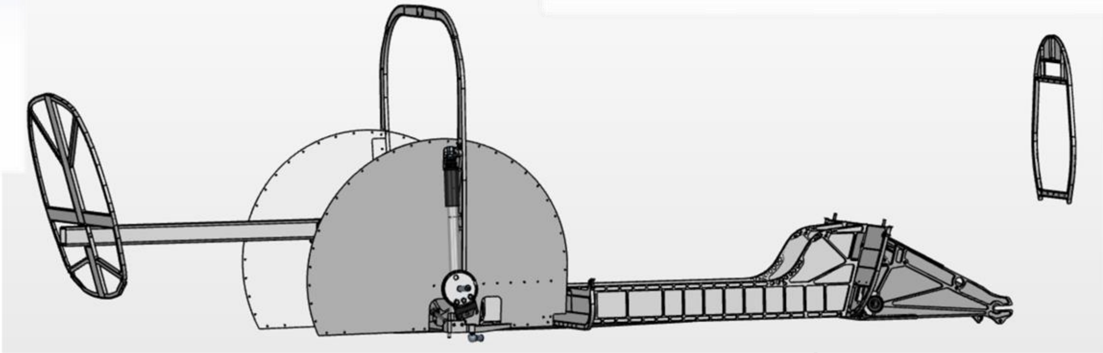
The 3D model of the velomobile was envigased after **measuring** and analysing the real **dimensions** of the vehicle.

Given the peculiar geometric characteristics of the vehicle and their **importance** concerning the **accuracy** of the CFD results, it was decided to realise the **model** in a **number** of **distinct parts** to be assembled in a subsequent step.



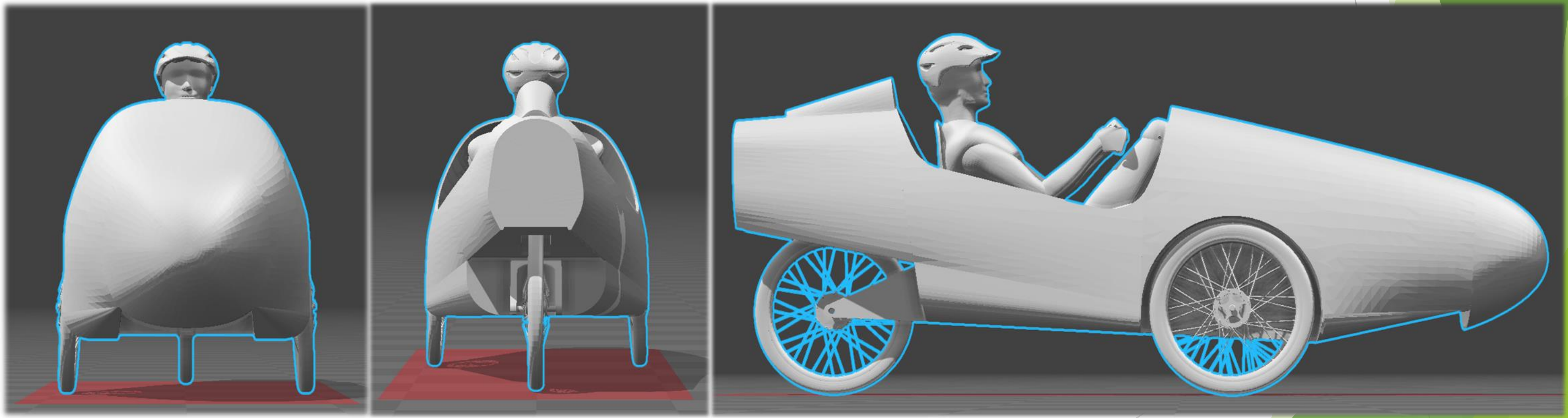






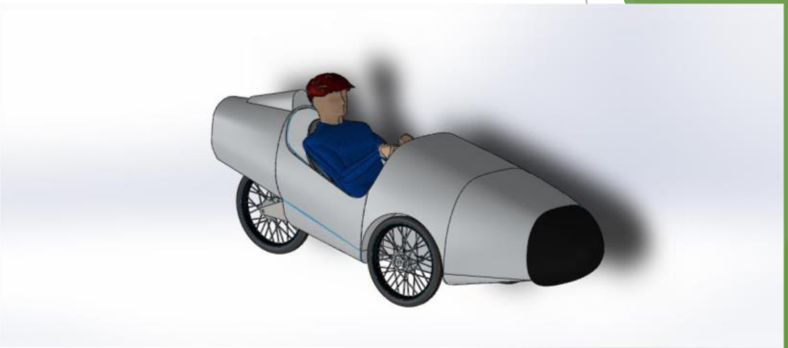
Once the parts were designed they have been brought together in an **assembly**.

Particular care has been given to replicating the **wheel-assembly geometry** so as to finely replicate the ride height and level of the vehicle.

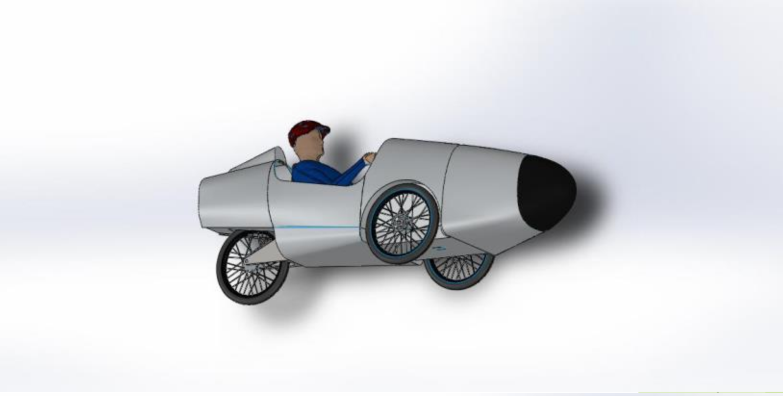


In the end there were **3 versions** of the velomobile:

- The original one



- The closed underside



- The completely optimizied vehicle

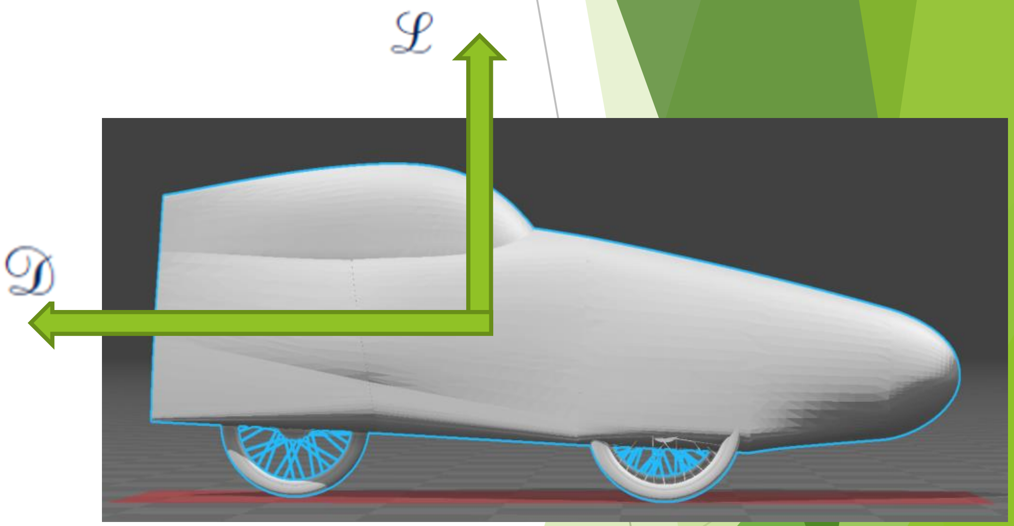
Understanding the phenomenon...

A body immersed in a moving fluid experiences a **resultant force** due to the interaction between the body and the fluid surrounding it

This effect can be described in terms of **forces** at the **fluid boundary interface**

$$\mathscr{L} = \int dF_y = -\int p \sin\theta \, dA + \int \tau_w \cos\theta \, dA$$ LIFT FORCE

$$\mathscr{D} = \int dF_x = \int p \cos\theta \, dA + \int \tau_w \sin\theta \, dA$$ DRAG FORCE



Define **dimensionless lift and drag coefficients**

$$C_L = \frac{\mathscr{L}}{\frac{1}{2}\rho U^2 A} \quad \text{and} \quad C_D = \frac{\mathscr{D}}{\frac{1}{2}\rho U^2 A}$$

Let us focus on the drag...

There are 3 causes of drag:

1. Pressure drag → drag that is due directly to the pressure on an object.
2. Friction drag → part of the drag that is due directly to the shear stress, on the object.
3. Vortex Induced Drag → is a by-product of lift or downforce.

How do we find all the quantities we need? CFD

Computational fluid dynamics (**CFD**) involves **replacing** the **partial differential equations** (in particular the Navier-Stokes equation) **with discretized algebraic** equations that approximate them.

- The CFD simulation solves for the relevant flow variables only at the **discrete points**, which make up the grid or mesh of the solution.
- **Interpolation schemes** are used to obtain values at non-grid point locations.

The CFD software used for this work is

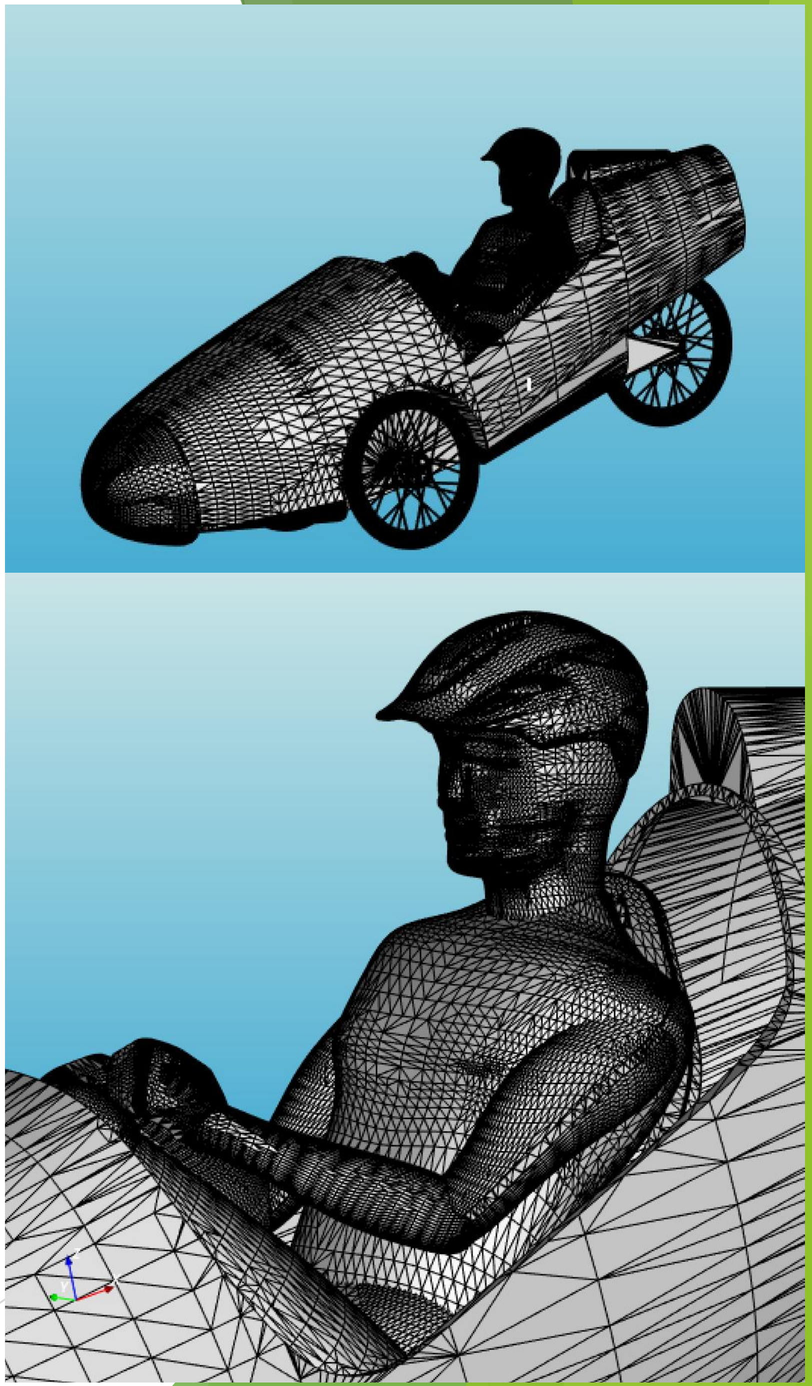
KARALIT

Simplicity without compromise

In order to analyse the vehicle with the help of CFD, the CADs need to be converted *to Stl files* *(STereo Lithography interface format)*.

In this format the geometry of every surface of the model is **discretized by means of triangles**.

Every ".stl" file contains all the **information** regarding the Cartesian **coordinates of the triangle's vertices** and those of the **normal vector** to the surface.



The succesive step is to define the **dimensions** of the virtual **wind tunnel.**

It is of pamamount importance to have dimensions **large enough** so as to **avoid** any **interaction** of the model with the top and side walls.

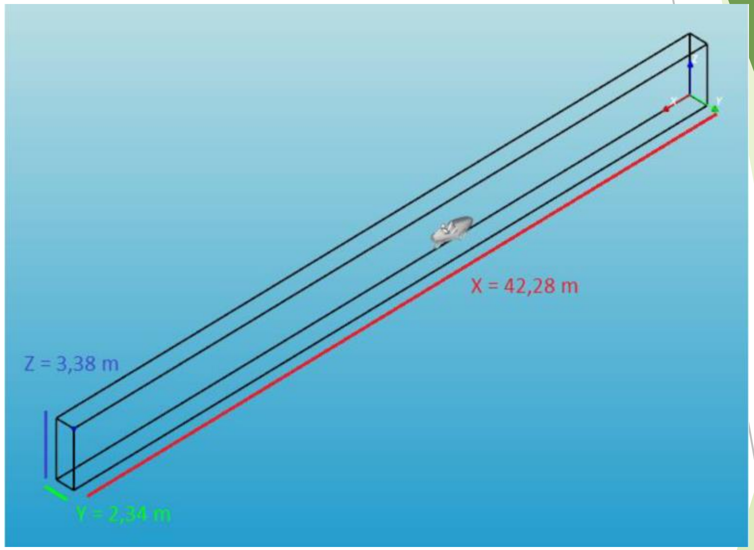
This can seriously alter the results!

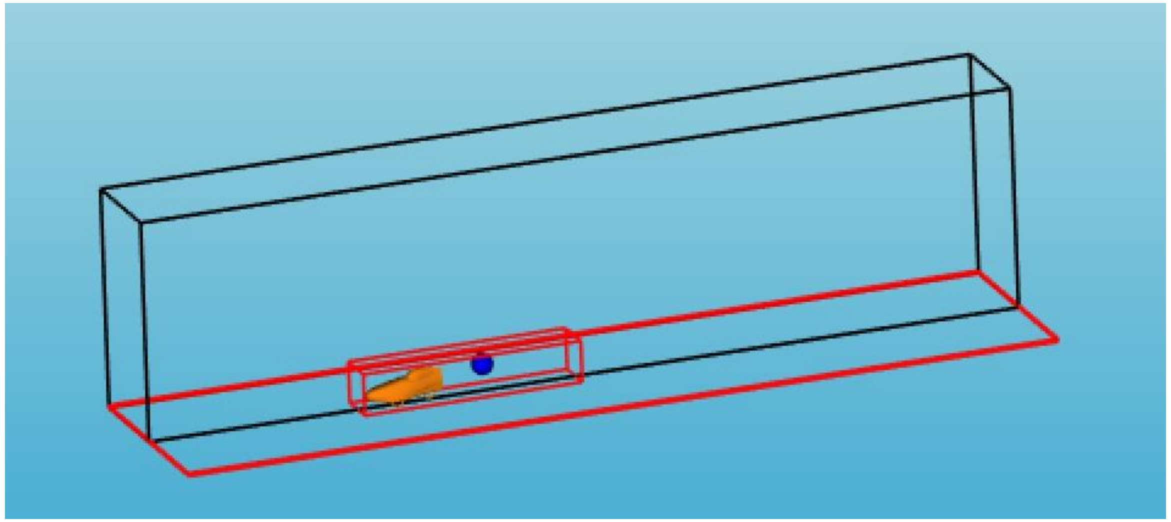
For example these 2 wind tunnels give the following

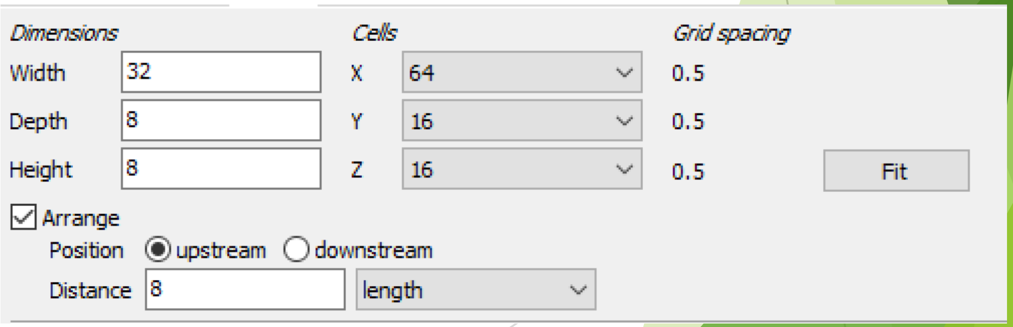
results for the drag:

19,1 N

10,7 N







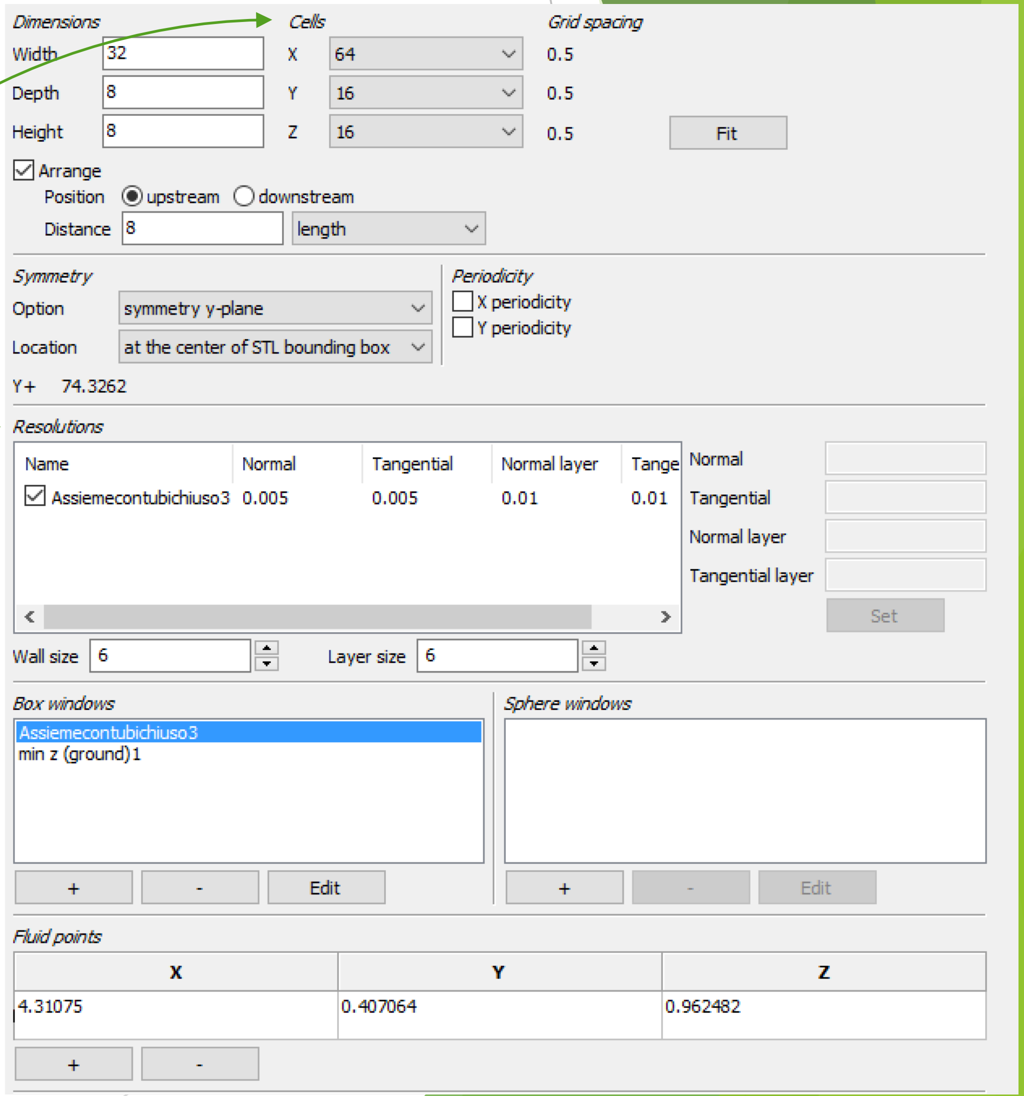
How fine the grid is is also very important

- **Too few** cells and we **don't see** whats happening over a certain dimension
- **Too many** and the computational **time rises** too much

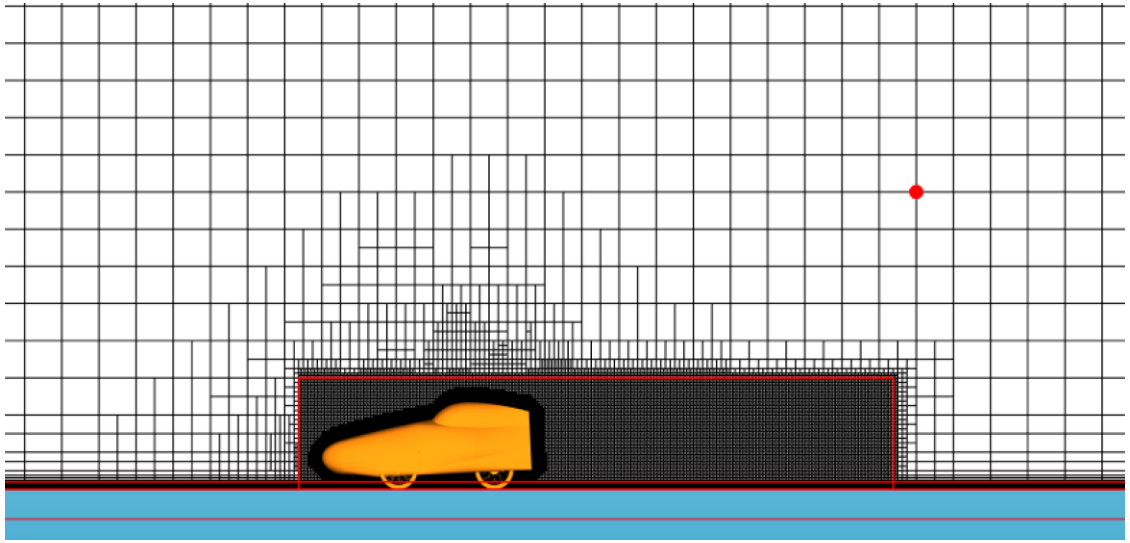
The **location** of the fluid cells is also very important

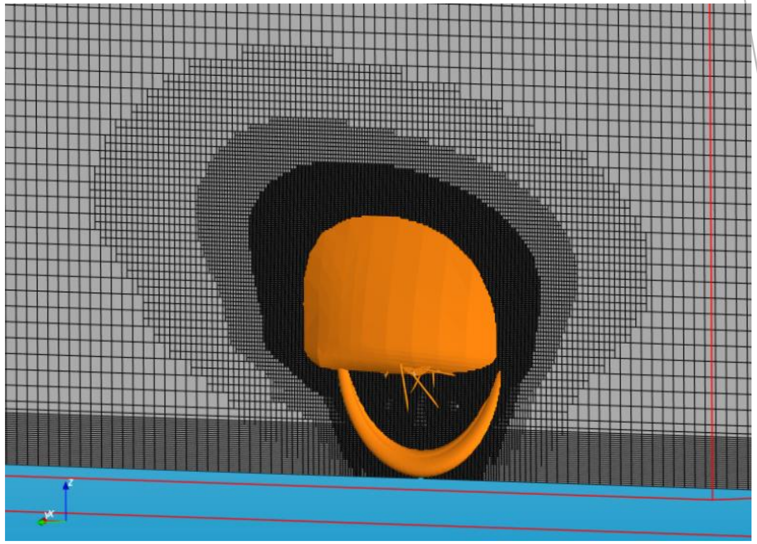
- Having too many cells were is not needed or where we dont want to investigate is a waste

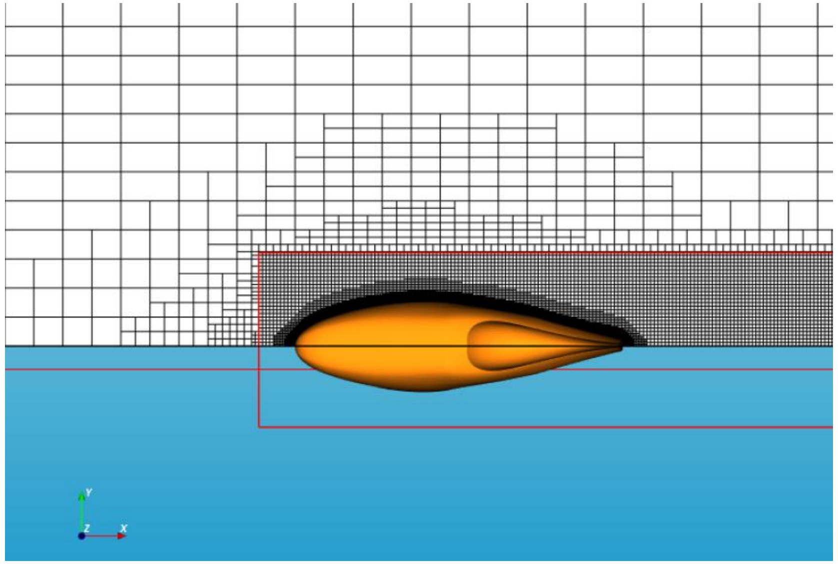
How do we set the mesh?

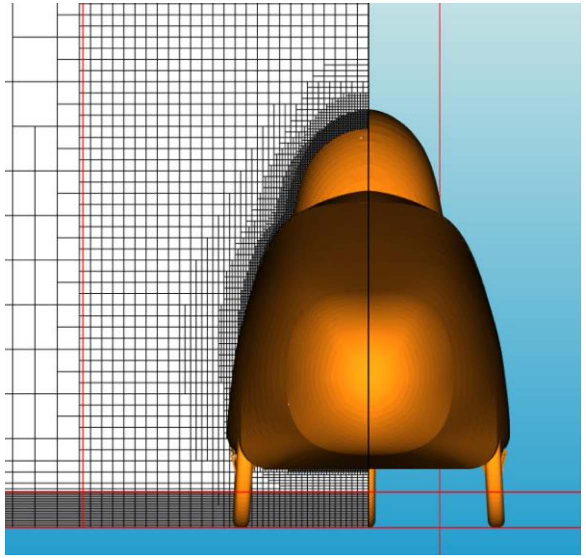


The grid









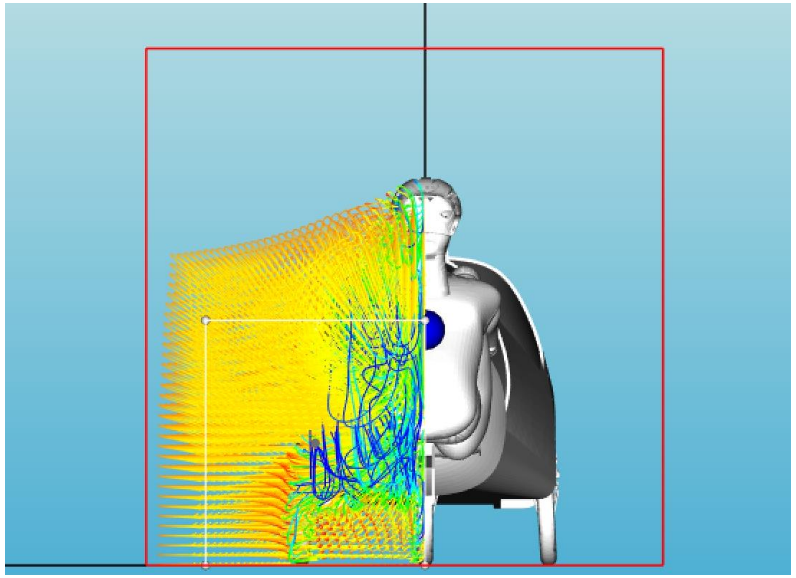
Results

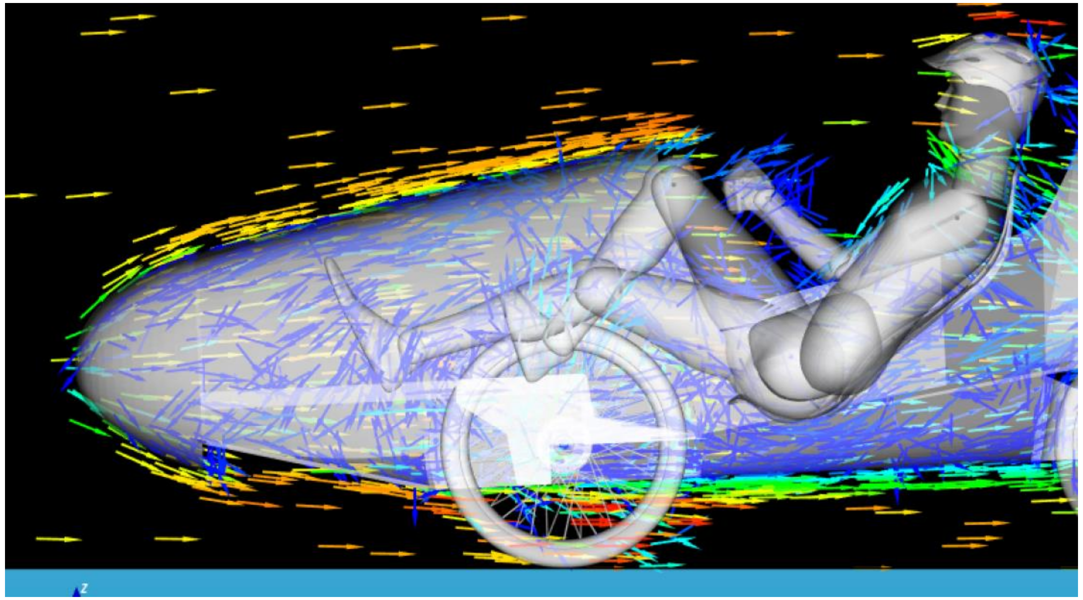
Geometry	Vx	Fx	Fz	Cd
Original	10 m/s	10.1 N	-4.7 N	0.35
	15 m/s	23.1 N	-10.8 N	
Streamlined	10 m/s	4.8 N	-3.6 N	0.16
	15 m/s	10.7 N	-7,1 N	

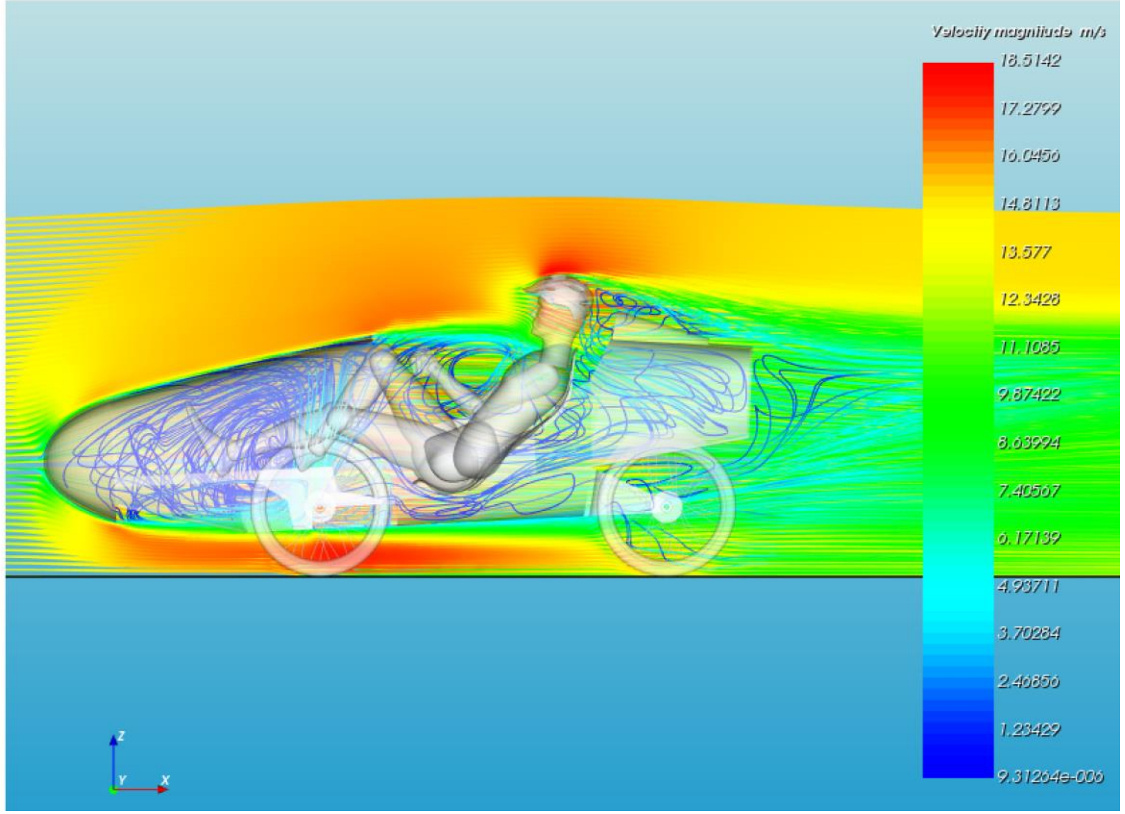
Improvement:56%

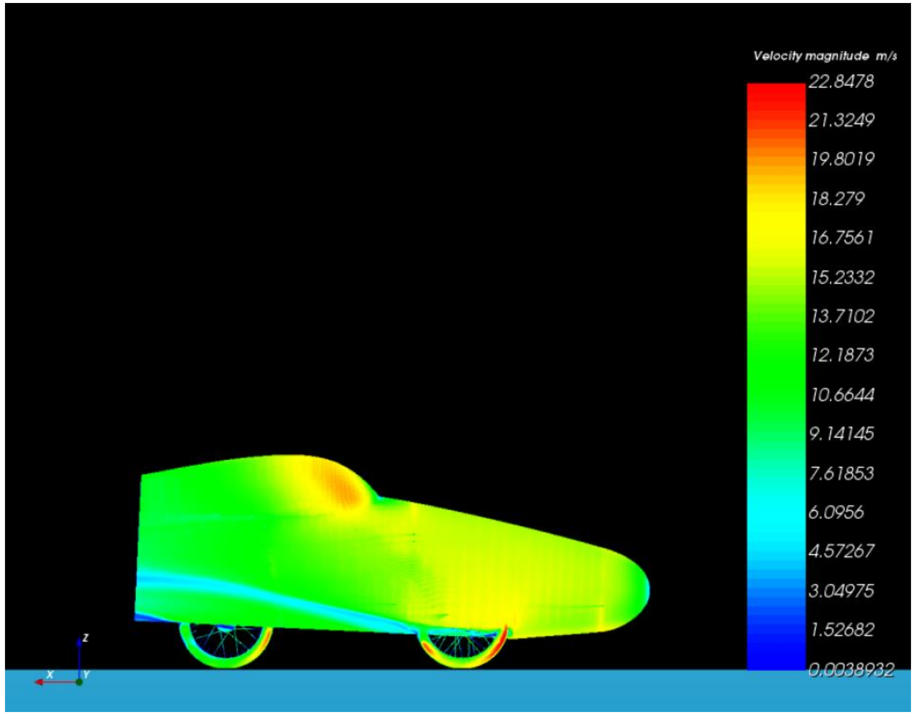
Critical areas:

1) The recirculation zone inside the vehicle
2) The open cockpit that expose the cyclist to the flow
3) The flow detachment with consequent generation of vortices in the back section of the velomobile
4) Turbulent zone in the wheel area





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21.3249
19.8019
18.279
16.7561
15.2332
13.7102
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10.6644
9.14145
7.61853
6.0956
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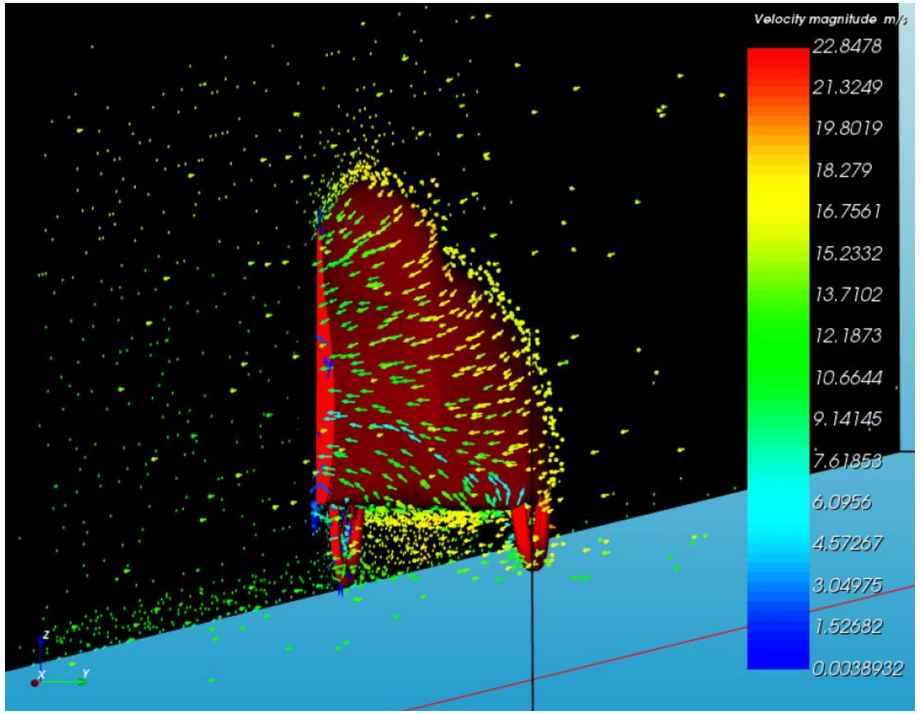
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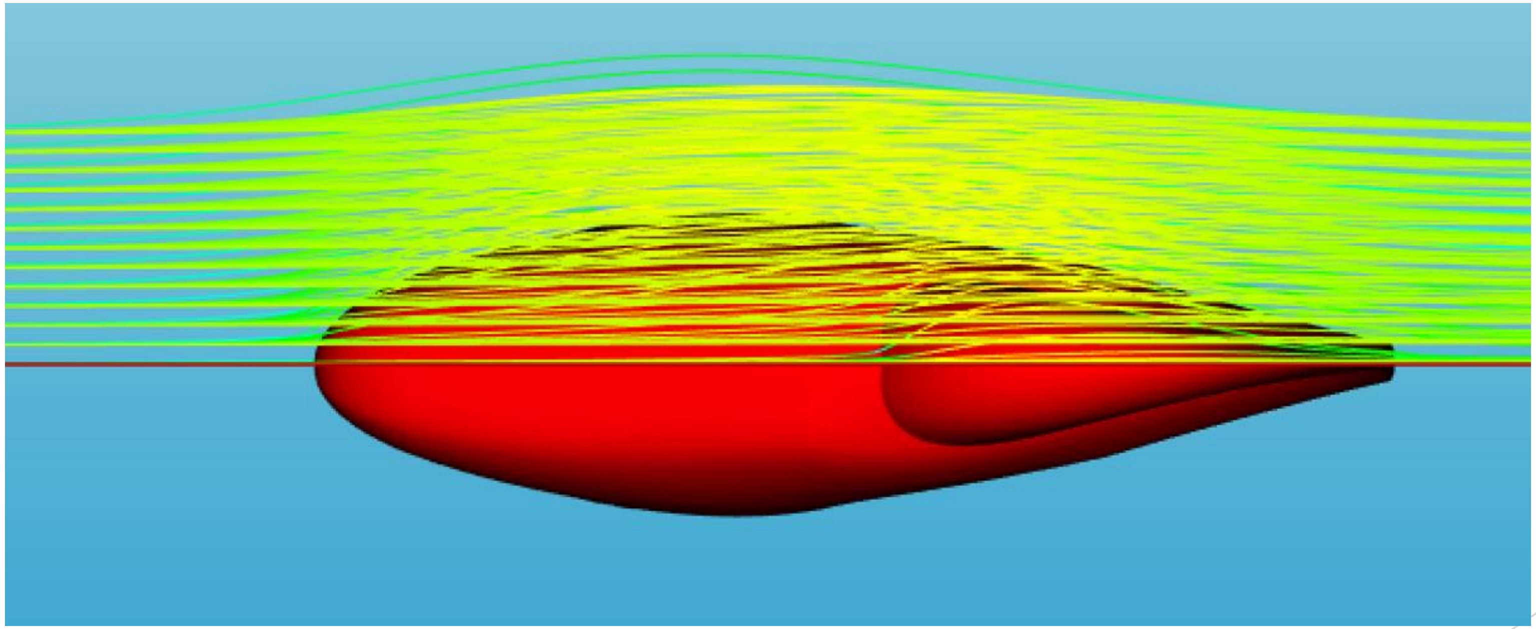
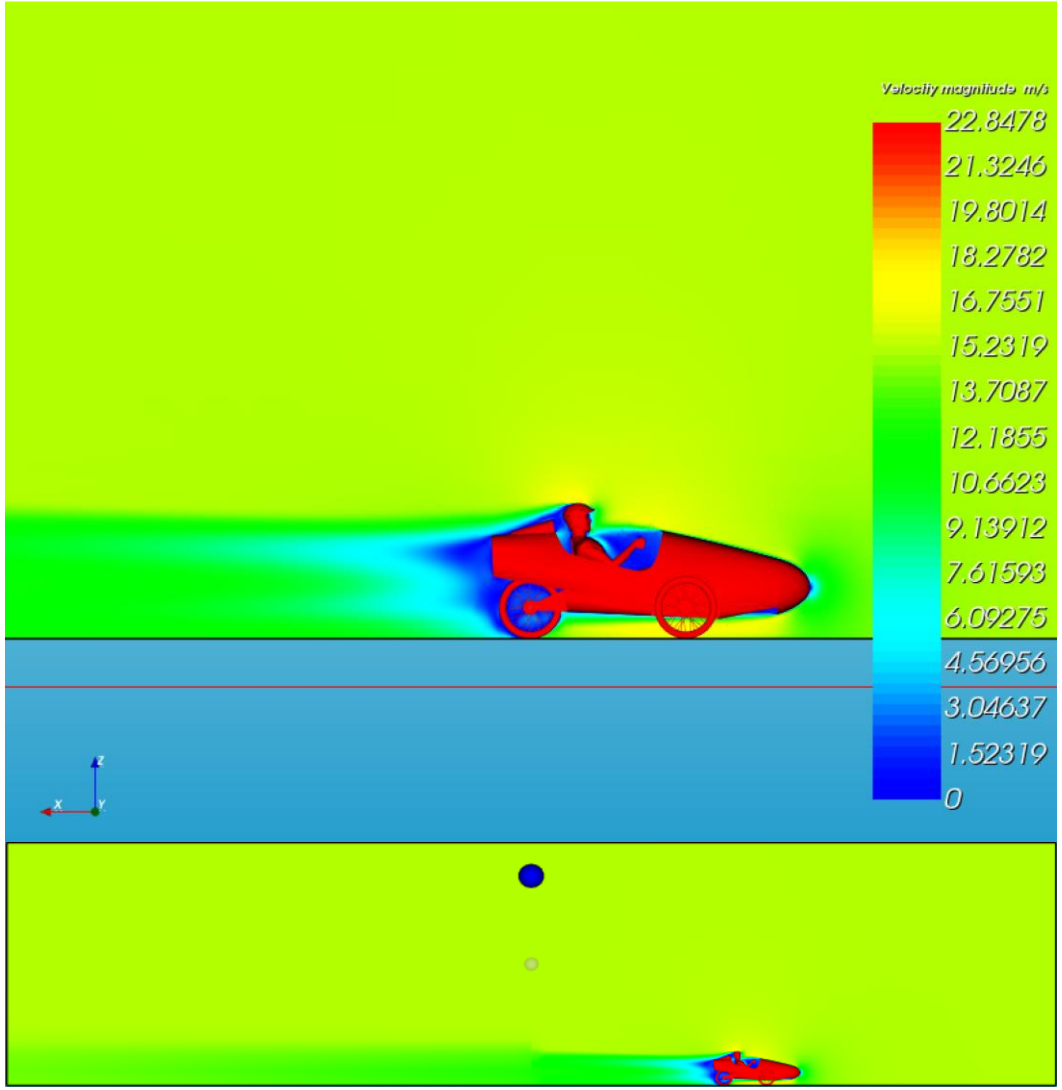
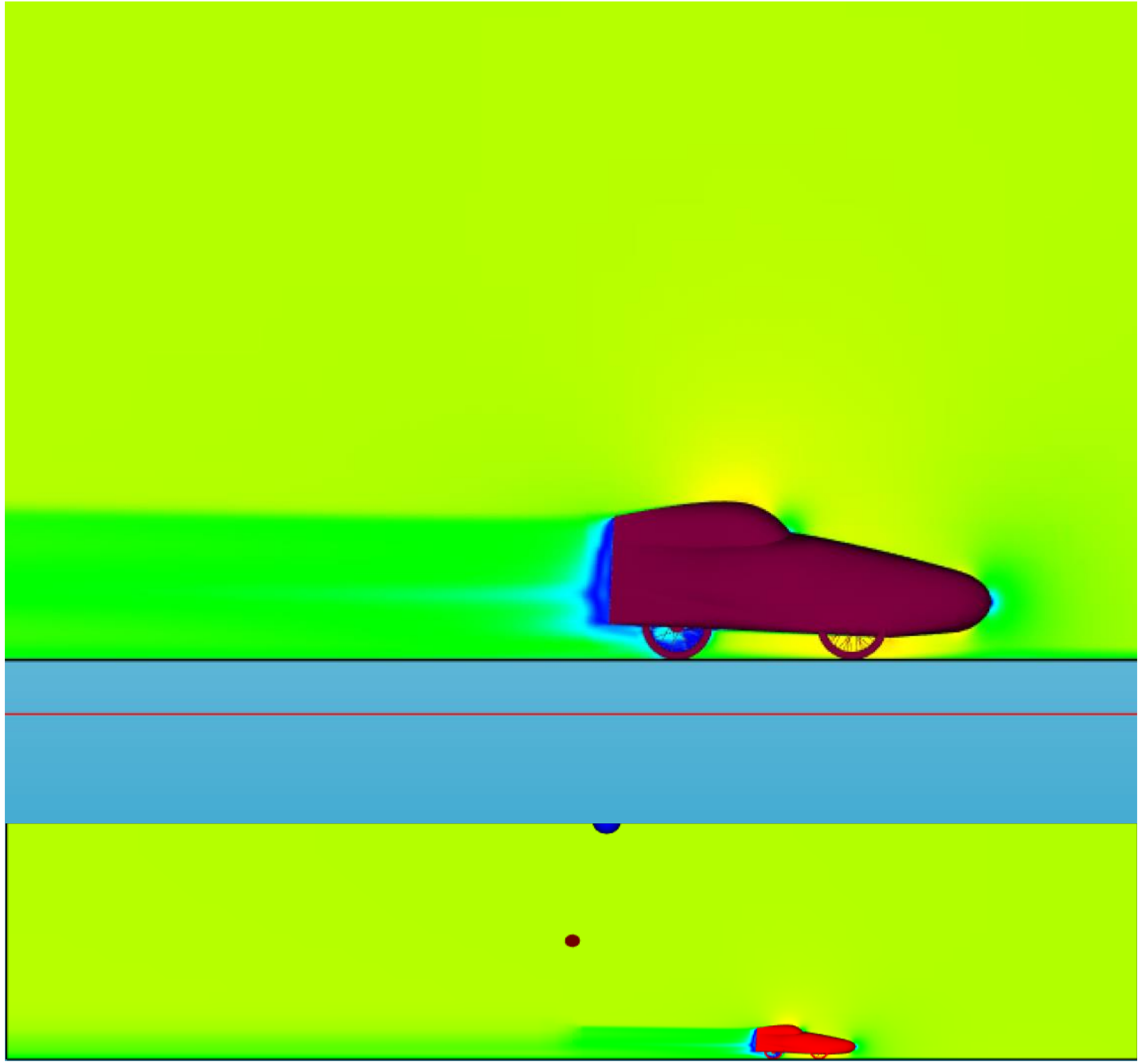


Wake comparison





Thank you for your attention!