Modeling The **Hyperloop** With **COMSOL®** :
On The Aerodynamics Design Of The **EPFLoop** Capsule

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INTRODUCTION

The EPFLoop team from Ecole Polytechnique Fédérale de Lausanne has developed the capsule thanks to which it won 3rd place in SpaceX's Hyperloop Pod Competition in 2018. COMSOL Multiphysics® and LiveLink™ for MATLAB® have been used to analyse and study the aerodynamic systems of the capsule. The optimization of the aeroshell's shape in order to guarantee the highest possible acceleration has been done using a CFD stationary analysis. The aeroshell should be both lightweight and withstand the maximum acceleration and deceleration during the run. Therefore, a composite aeroshell was chosen and was studied using a structural stationary analysis.

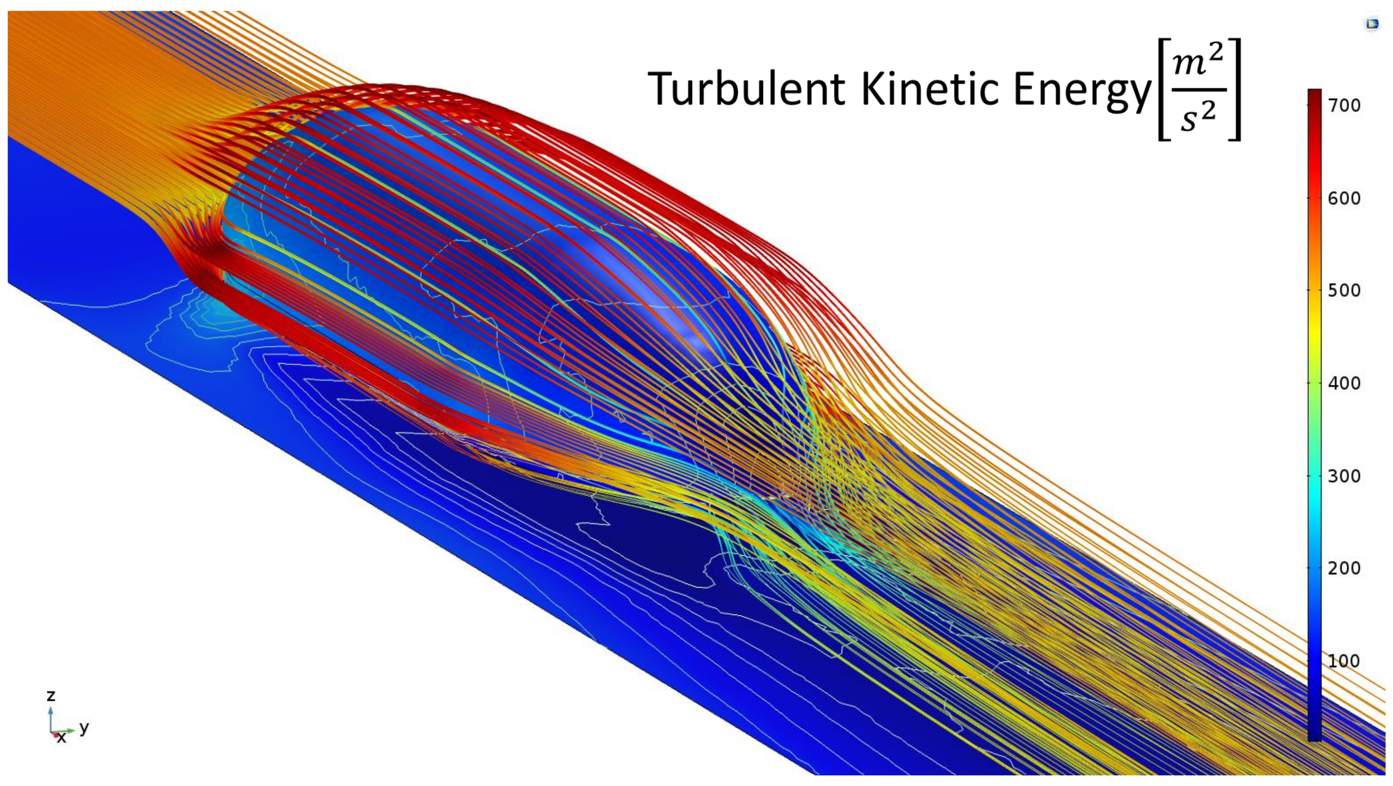

Figure 1. TKE: Turbulent Kinetic Energy.

COMPUTATIONAL METHODS

CFD Stationary Analysis

- The first step has been to perform an **optimization** on the design. The idea is to use an **Genetic Algorithm** (GA) with which the **drag and lift coefficient** is minimized (Fig. 2). The optimization was carried out in 2D with LiveLink™ for MATLAB® and the validation in 3D, using the parameters of Table 1. For sake of brevity here is presented the final design.
- The CFD analysis has been performed with the **HMNF (High Mach Number Flow)** in compressible flow regime (**M>0.3**). The **viscosity** is solved using **Sutherland**'s law[1].

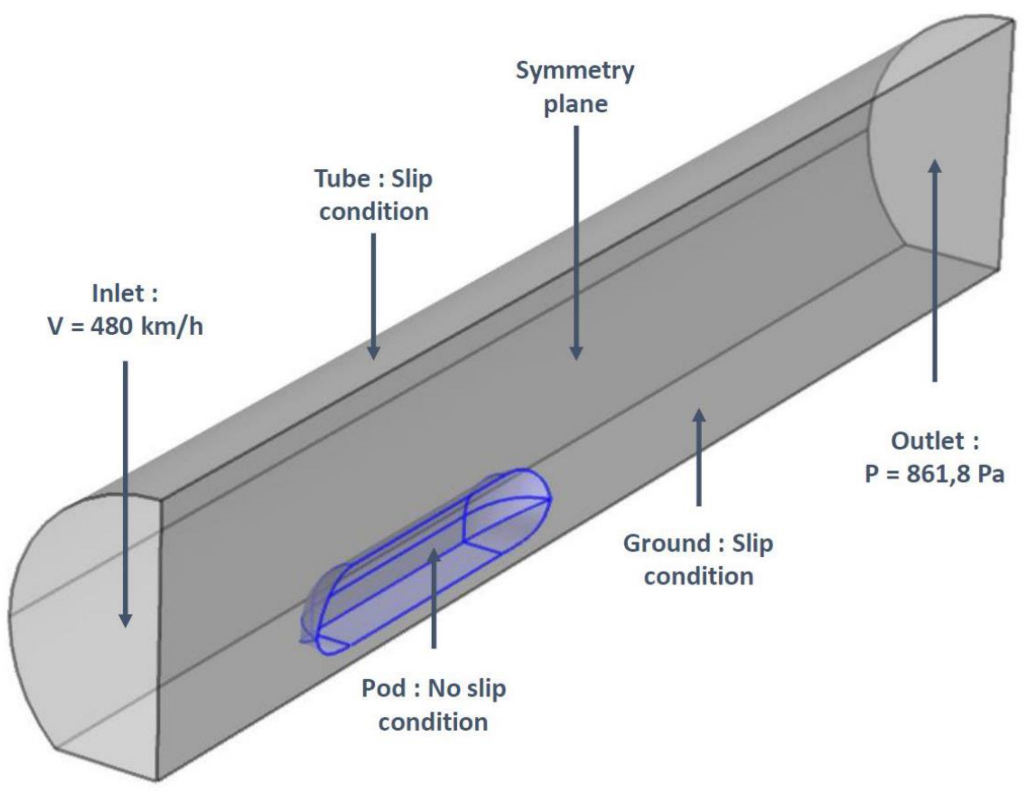

Figure 2. Overview of the computational domain.

v[m/s]	ρ(861 Pa)[kg/m³]
133	0.0103

Table 1. Simulation parameters.

Structural Stationary Analysis

- The carbon fiber composite aeroshell should withstand the load due to **acceleration and deceleration** during the run in vacuum with a safety factor of at least 2.
- The structural analysis has been performed using the **shells** module.
- The applied loads are the deceleration, weight and the pressure maps obtained by the **CFD Analysis** (Fig. 3).
- A **curvilinear coordinate interface** on each shell based on rotated coordinate systems for each boundary orientation has been used to simulate anisotropic properties on a complex geometry.

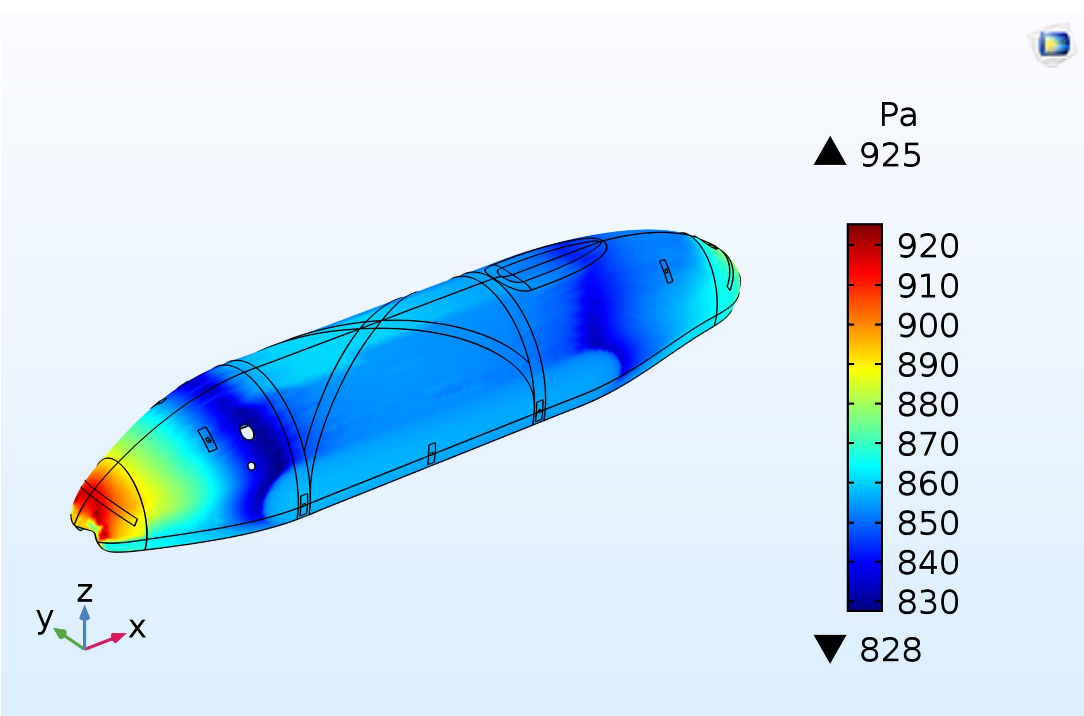

Figure 3. Pressure loads applied on the aeroshell.

RESULTS

CFD Stationary Analysis

- To validate the **aerodynamics coefficient** obtained in the simulations, a grid sensitivity analysis has been performed (Table 2).

	0.5 ·10⁶ Elem.	10⁶ Elem.	2.3 ·10⁶ Elem.
Lift [N]	0.356	0.362	0.335
Drag [N]	4.335	4.3803	4.254
C_L	0.023	0.223	0.021
C_D	0.265	0.269	0.261

Table 2. Grid sensitivity results.

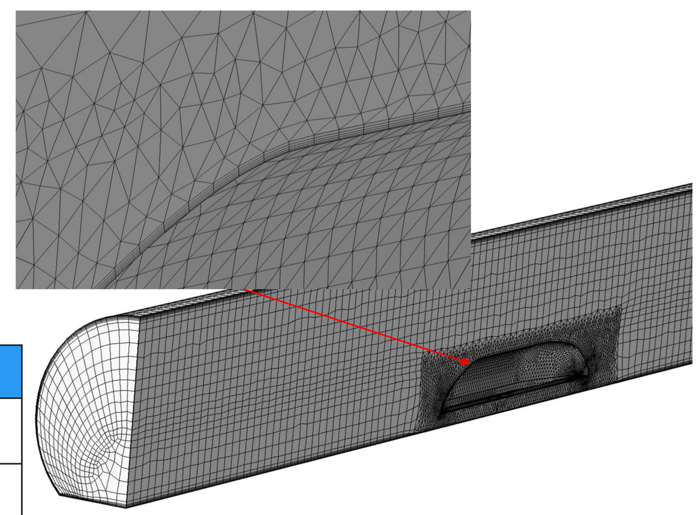

Figure 4. Example of mesh.

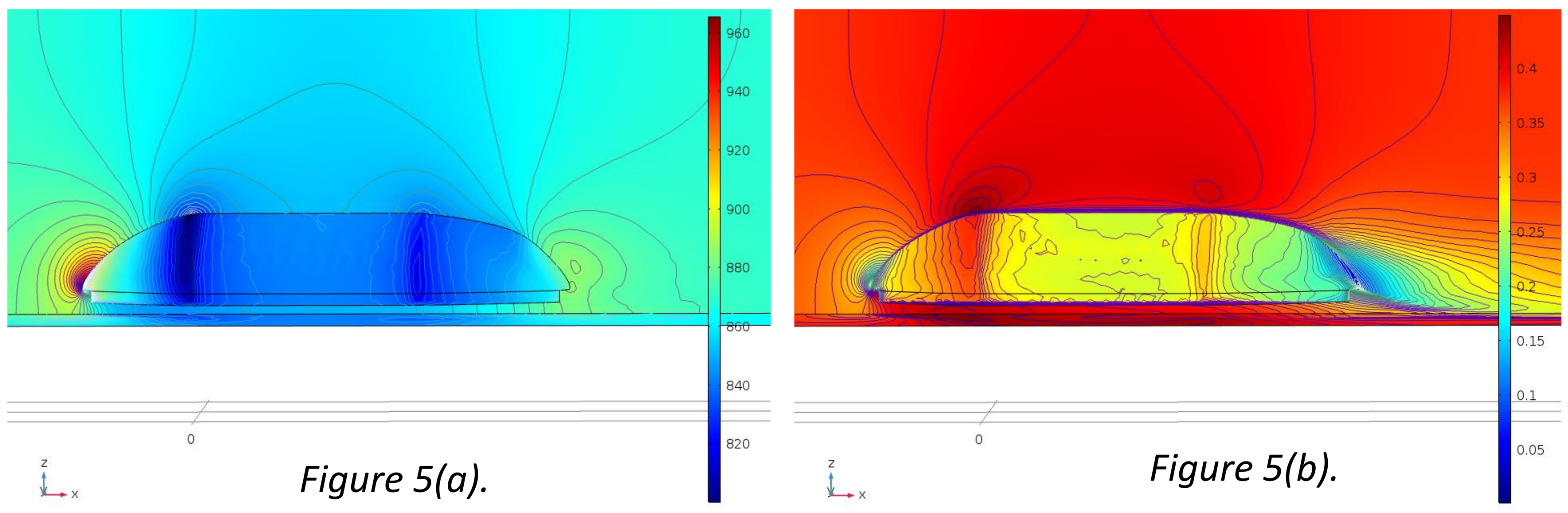

Figure 5(a). *Figure 5(b).*

Figure 5. (a) Pressure map and (b) Speed profile around the pod.

Structural Stationary Analysis

- The **structural behavior** of the aeroshell was validated through the study of the **principal stresses** (fig.6), and the **Tsai-Wu safety factor** (fig. 7), used for anisotropic materials. At each iteration, carbon fiber-epoxy, flax fiber or foam shells were added in a **sandwich structure** to reinforce the aeroshell at its weakest points.

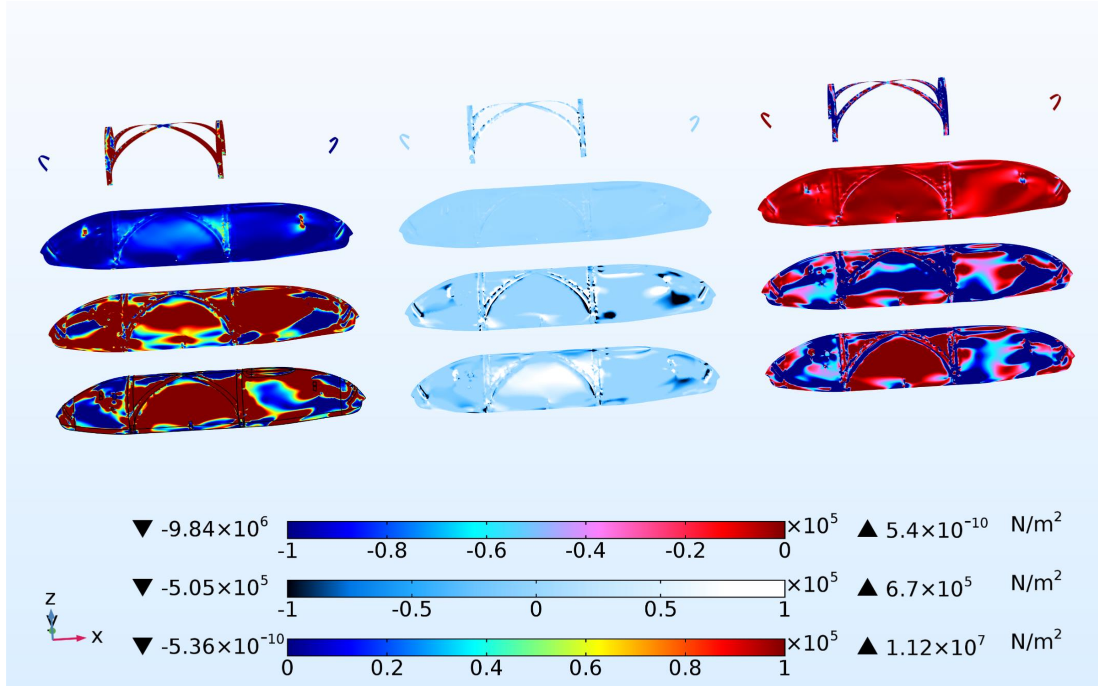

Figure 6. Principal stresses 1, 2, 3 (L to R).

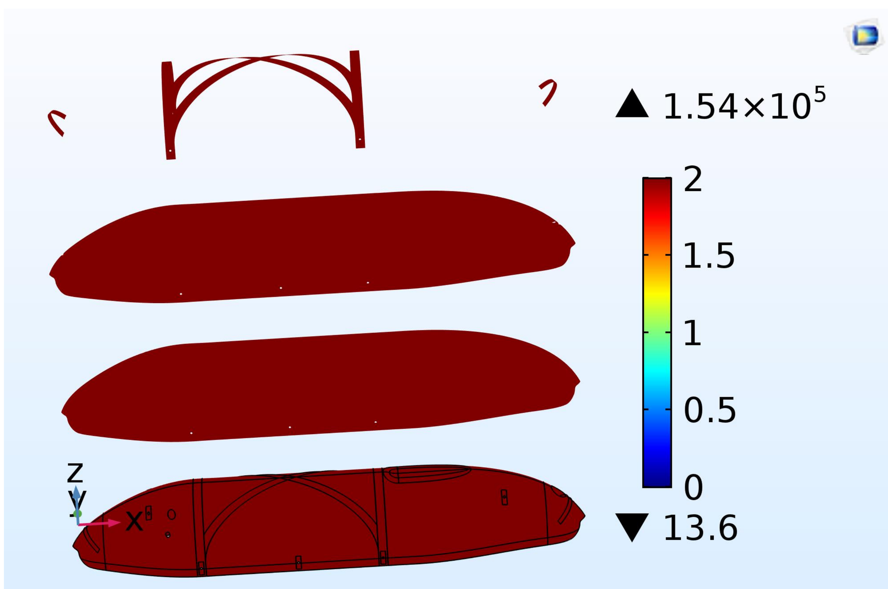

Figure 7. Tsai Wu safety factor.

- In the resulting structure, the Tsai-Wu safety factor is of 2 at every point, as required.
- The weight of the aeroshell is approximately **8 kg.** The aeroshell has been manufactured by the **LPAC** laboratory at EPFL.

CONCLUSION

The EPFLoop team succeeded in studying and developing the optimal shape and composite structure of the aeroshell using CFD and structural stationary analyses. This work pointed out how interdisciplinary and polyhedral skills can lead to new solutions in science and engineering. EPFLoop, thanks to COMSOL and other partners, will continue its work for the 2019 SpaceX Competition.

We thank **EPFL**, **EE**, **COMSOL**, **LPAC** and **Cyril Dénéréaz** for their support.

REFERENCES:

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