EPFLOOP

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Outline

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- The Hyperloop Concept
- The Competition 2018 – Team, Design and Achievements
- Modeling of the 2018 Design
  - CFD
  - Structural
  - Thermal
- Future – the 2019 Design

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THE HYPERLOOP CONCEPT

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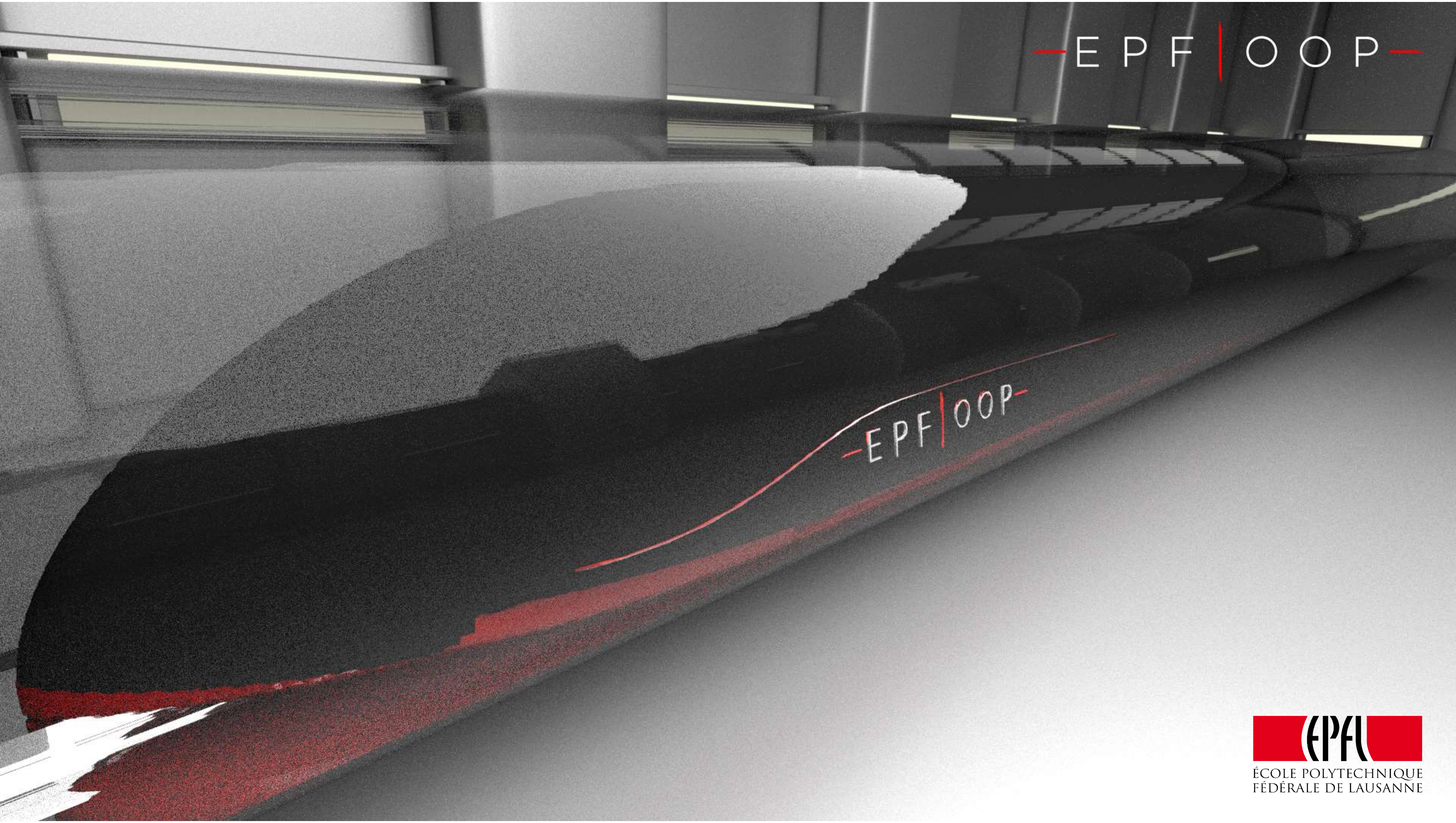
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The Hyperloop Concept

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120 km/h

320 km/h

800 km/h

1200 km/h

- Safer
- Faster
- Electric
- Autonomous
- More efficient

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The Hyperloop Concept

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Technical Challenges

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- Define a design targeting an optimal power/mass ratio

  Energy Mechanical

- Define the propulsion system capable of providing the best acceleration

  Electrical Mechanical

- Design pressurized systems capable of maintaining atmospheric pressure in the vacuum tube

  Mechanical Physics

- Optimal/safe design of a battery energy storage system operating for high current discharge

  Energy Electrical

- Design a real-time and fault-tolerant autopilot

  Control Software

- Design and manufacture all the sub-components of the vehicle

  Mechanical Aerodynamics

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THE TEAM

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logitech
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NATIONAL INSTRUMENTS
ROSAS
BRUSA
LEMO
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Team Structure

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9 different EPFL sections involved

- Electrical
- Mechanical
- Computer and Communication Sciences
- Materials Science
- Physics
- Mathematics
- Architecture, Civil and Environmental Engineering
- Microengineering
- EPFL Middle East

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THE 2018 DESIGN

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The 2018 Design

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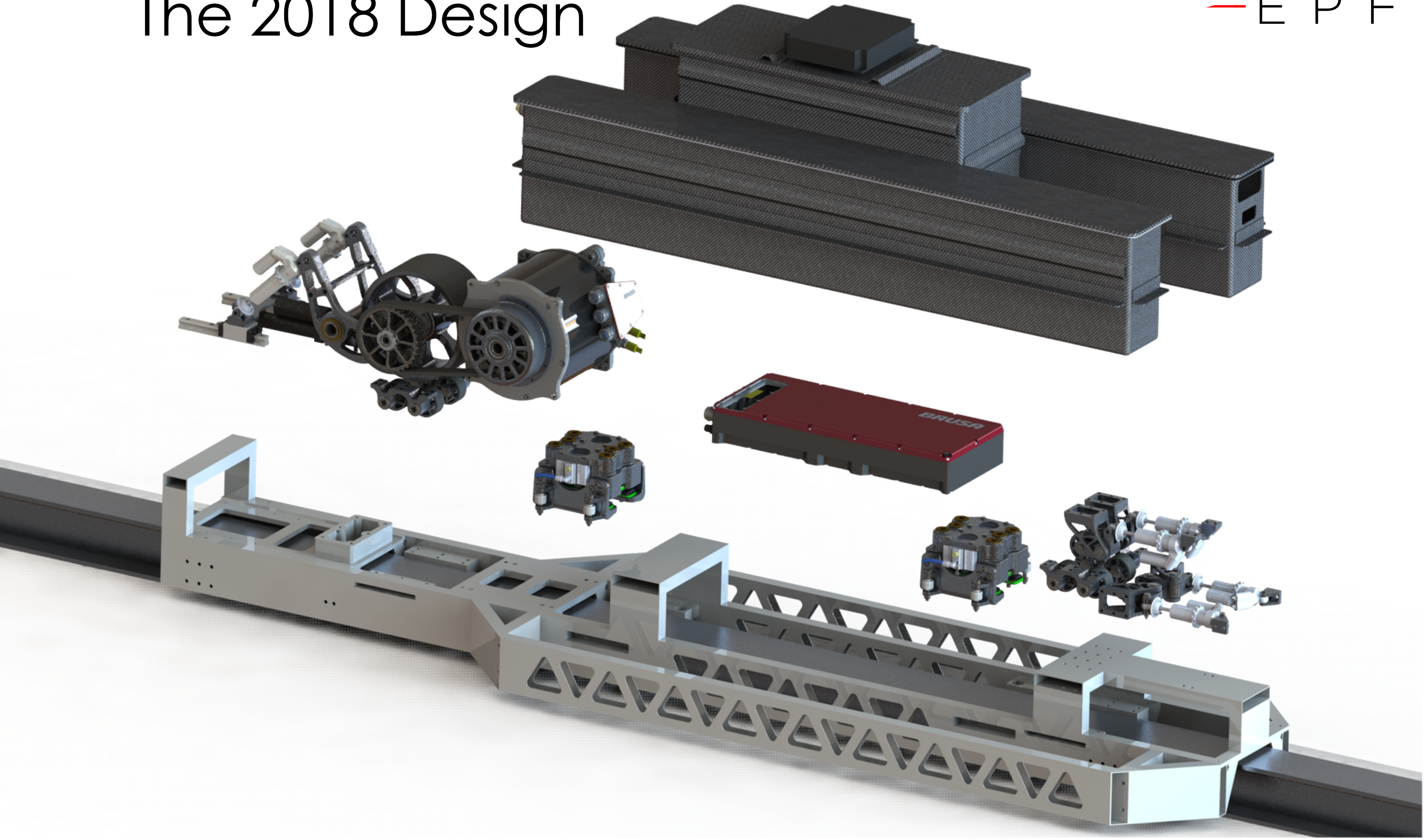

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ACHIEVEMENTS AT THE 2018 COMPETITION

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SPACEX
SPACEX

Achievements

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- 1ST PLACE FOR THE DESIGN - HIGHEST RANKING FOR POD ENGINEERING
- 1ST PLACE IN SWITZERLAND
- TOP 3 HYPERLOOP TEAMS IN THE WORLD

Feedback from SpaceX

Very clean design. Great test data. Good answers for everything.

Incredibly well engineered, the best we have seen yet. Extreme attention to detail such as routing of battery. Very good brake design. Thorough testing before competition.

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Subsystems Modelled with COMSOL®

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Simulations by subsystem

AEROSHELL
- Aerodynamics and CFD
- Structural analysis
- Fixation on the chassis

PRESSURE VESSELS
- Structural analysis
- Temperature profile

BRAKING SYSTEM
- Temperature profile

CHASSIS
- Structural analysis
- Stability analysis

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Subsystems Modelled with COMSOL®

Modules by subsystem

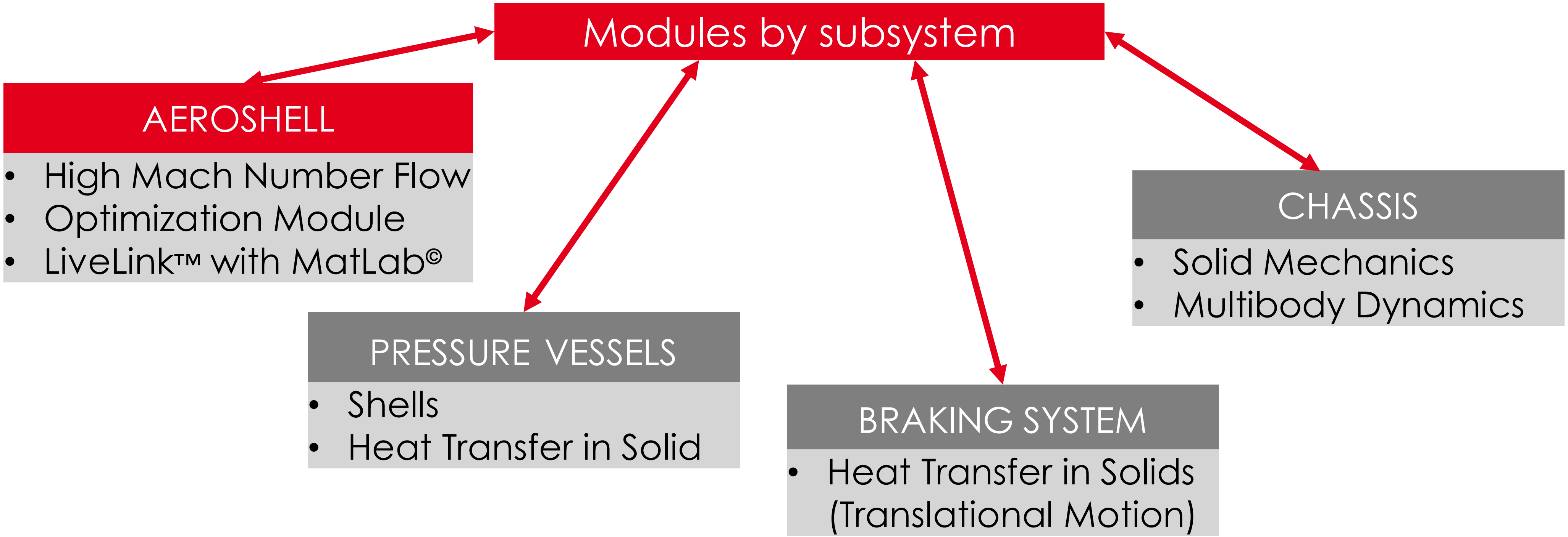
AEROSHELL
- High Mach Number Flow
- Optimization Module
- LiveLink™ with MatLab©

PRESSURE VESSELS
- Shells
- Heat Transfer in Solid

BRAKING SYSTEM
- Heat Transfer in Solids (Translational Motion)

CHASSIS
- Solid Mechanics
- Multibody Dynamics

Subsystems Modelled with COMSOL®



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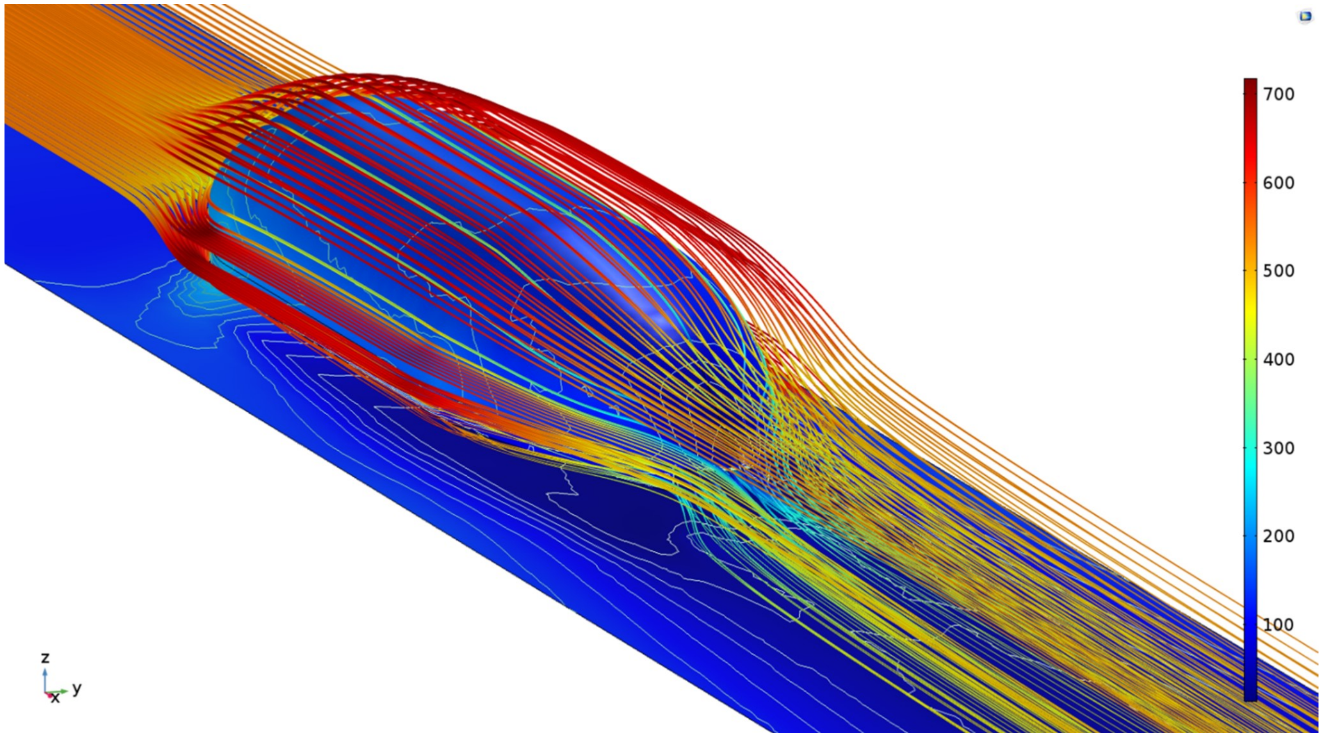
Simulations on the Aeroshell

Aim of the Simulations

- The major interest in the design of the **aeroshell's shape** is to guarantee the **minimum aerodynamic resistance**
- The **optimization of the aeroshell's** shape is performed using CFD analysis
- The aeroshell should be both **lightweight** and withstand the applied loads (acceleration / deceleration and weight)
- A **composite aeroshell** was chosen and studied through structural analysis



Turbulent Kinetic Energy $\left[\frac{m^2}{s^2}\right]$

Simulations on the Aeroshell

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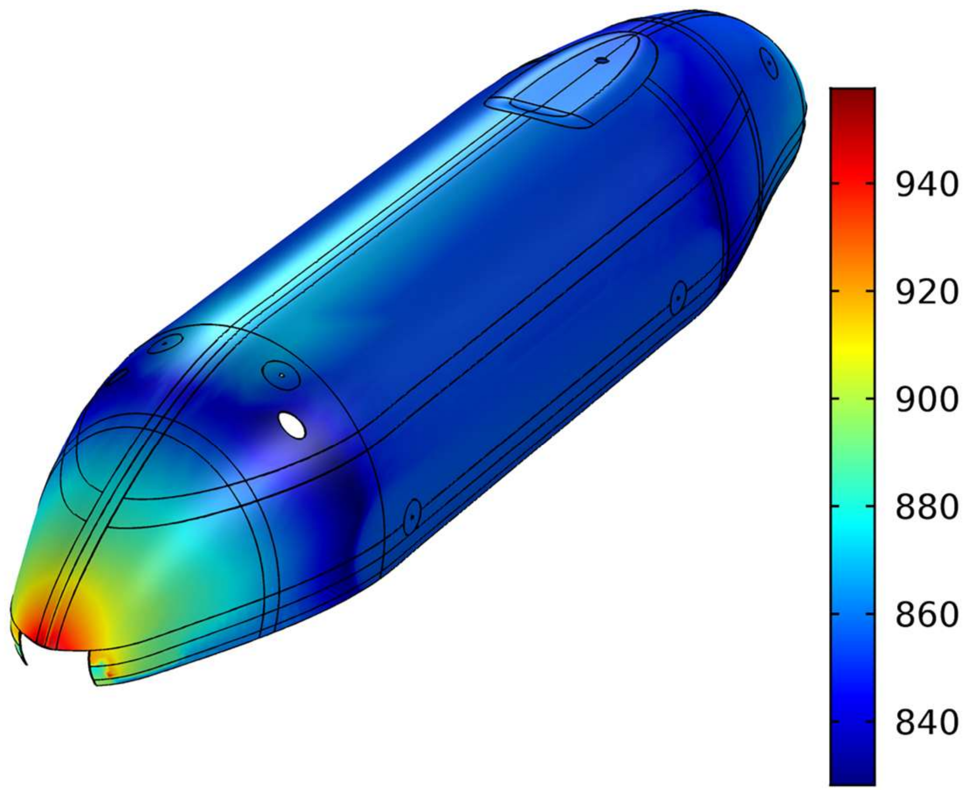
Modules, Solvers and Strategies

Modules

- CFD: The **High Mach Number Flow** functionality in stationary conditions, for evaluation of the **drag coefficient** and the **lift coefficient**
- Structural: **Shell** functionality in stationary conditions, for the arrangement of carbon fiber and epoxy, in sandwich structure with foam

Strategies

- **Optimization** through **Genetic Algorithms** and **Optimization Module** in 2D and validation in 3D
- **Pressure load** on the aeroshell surface
- Evaluation of the **safety factor**, adding more plies if needed



Pressure distribution [Pa] obtained from CFD analysis and applied as load for the structural analysis

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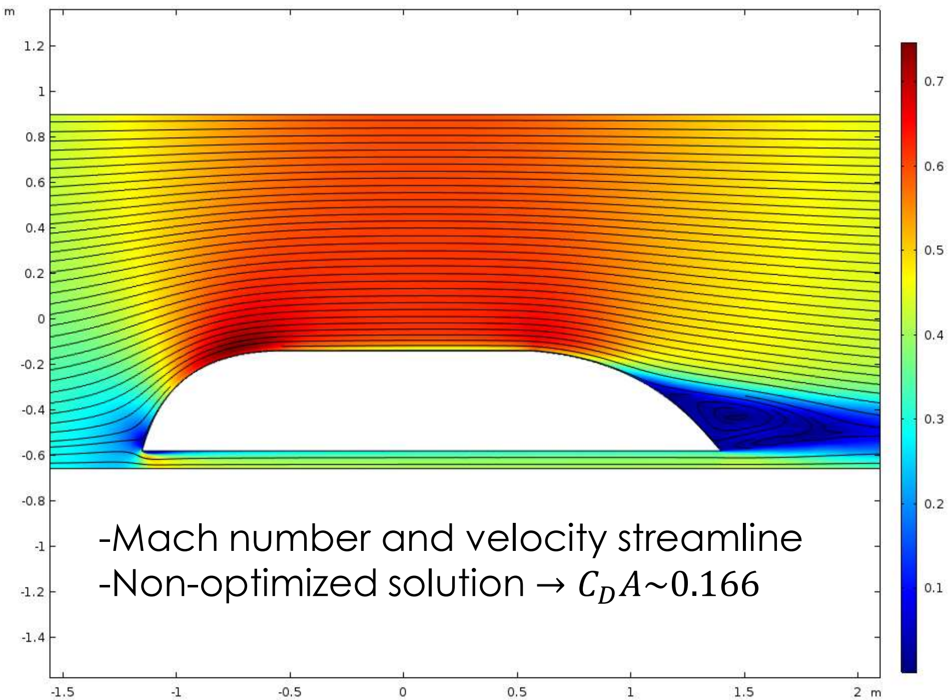
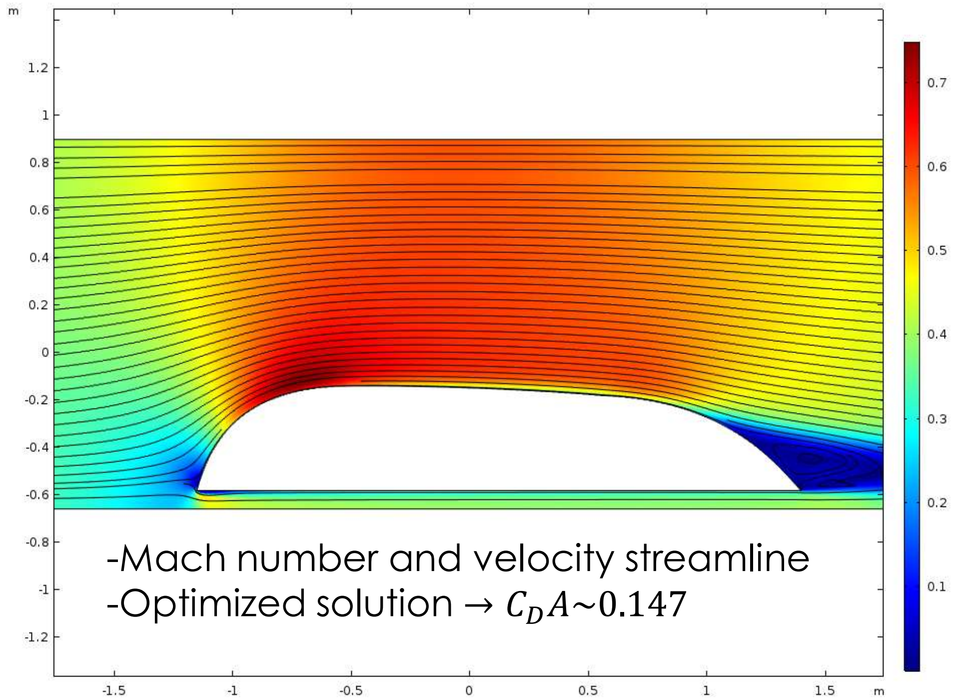
Simulations on the Aeroshell

Results

Design Optimization

- Study of the turbulent phenomena
- Drag and lift coefficients
- Design optimization through **LiveLink™ *for* MATLAB®** and **Optimization Module**





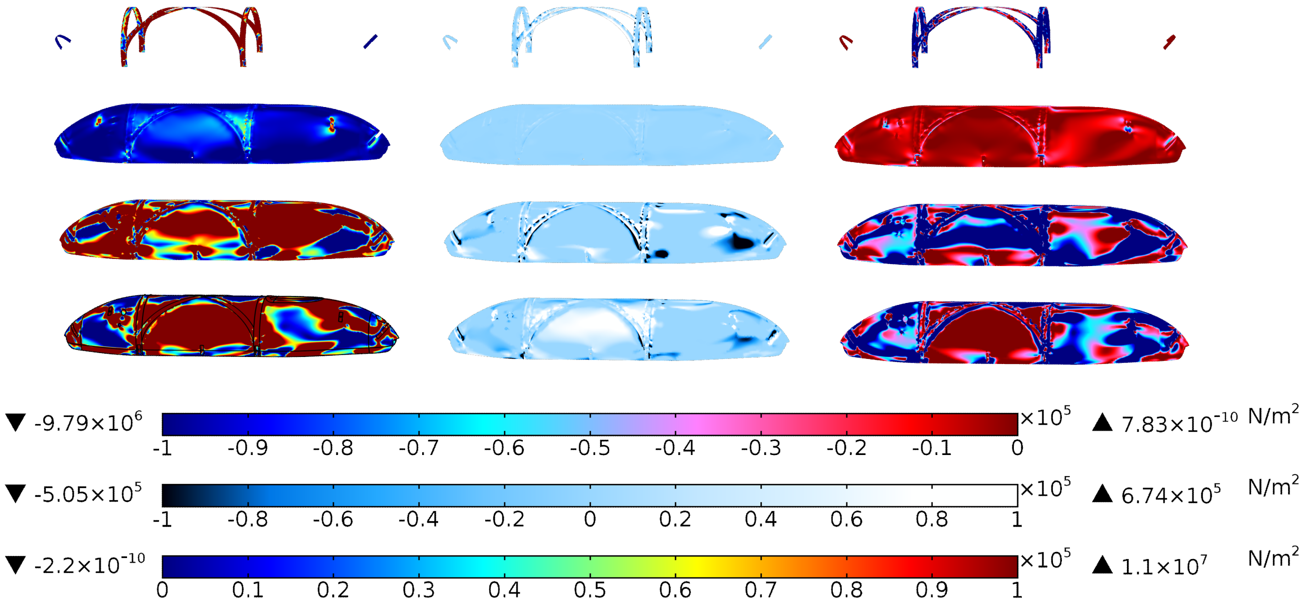
Simulations on the Aeroshell

EPF OOP

Results

Structural Analysis

- Study of the **mechanical loads** applied on the shell
- **Shells** functionality used to simulate composite behaviour
- Pressure map obtained by the CFD simulations
- Acceleration / deceleration and weight loads
- **Tsai-Wu safety factor** and **principal stresses** were studied



Principal stresses 1, 2, 3 (left to right), inside to outside layers (top to bottom) (Pa)

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Subsystems Modeled with COMSOL®

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Modules by subsystem

AEROSHELL
- High Mach Number Flow
- Optimization Module
- LiveLink™ *for* MATLAB®

PRESSURE VESSELS
- Plies
- Heat Transfer in Solid

BRAKING SYSTEM
- Heat Transfer in Solids (Translational Motion)

CHASSIS
- Solid Mechanics
- Multibody Dynamics

Simulations on the Pressure Vessels

Why Do We Need Them?

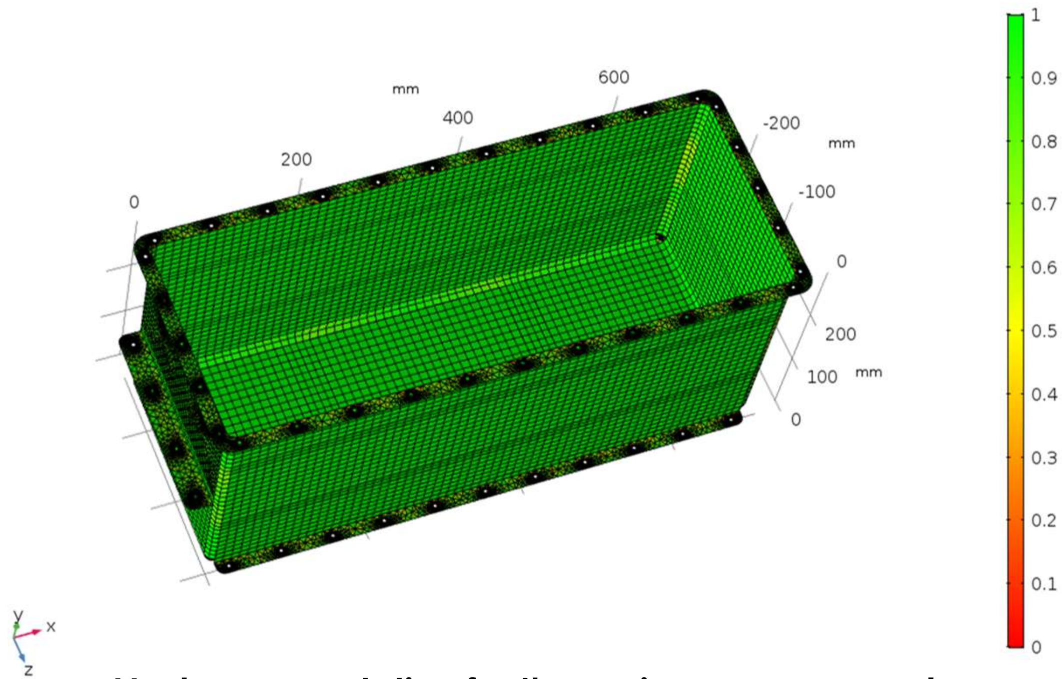
- The pressure vessels (PVs) are used to **store electrical components** in a pressurized environment (1 atm)
- The aim is to avoid a **direct exposure** of the components to the vacuum, which would be **destructive** for the batteries and the electronics inside

Simulations on the Pressure Vessels

—E P F | O O P—

Aim of the Simulations

- The **carbon fiber composite** structure of the PVs should safely resist to the conditions in vacuum during the run
- In order to find the required set of plies, a **structural analysis** was performed
- The observed quantities have been the **Tsai-Wu safety factor** and the **principal stresses distribution**
- The goal is to ensure a **safety factor of 2** everywhere for the nominal loads (inner pressure and component inertia)



Mesh representation for the main pressure vessel
Mesh quality measured by skewness
The main PV contains power and control electronics

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Simulations on the Pressure Vessels

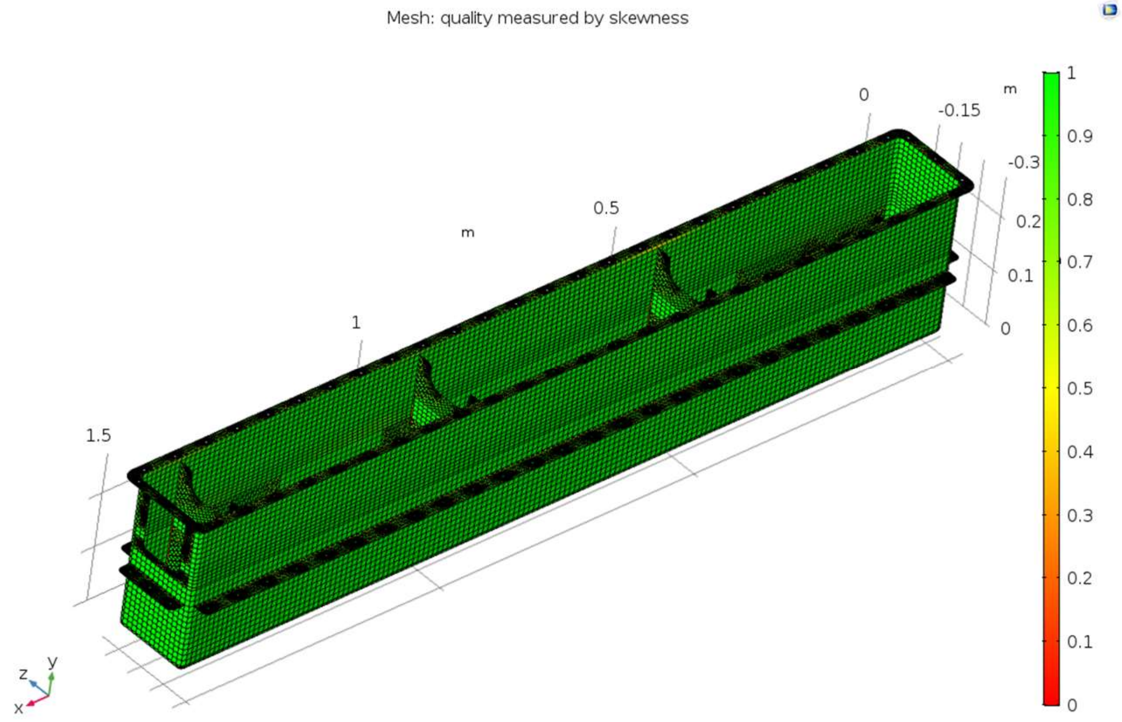
Modules, Solvers and Strategies

Module

- The **Shells** functionality has been used to simulate in **stationary conditions** the arrangement of plies of carbon fiber and epoxy composite, in sandwich structure with foam

Strategies

- A **parametric sweep** has been performed, varying the pressure load on the inner surfaces, in order to evaluate the safety factor for a range of pressures



Mesh representation for the lateral pressure vessel
Mesh quality measured by skewness
The lateral PVs contain mainly batteries

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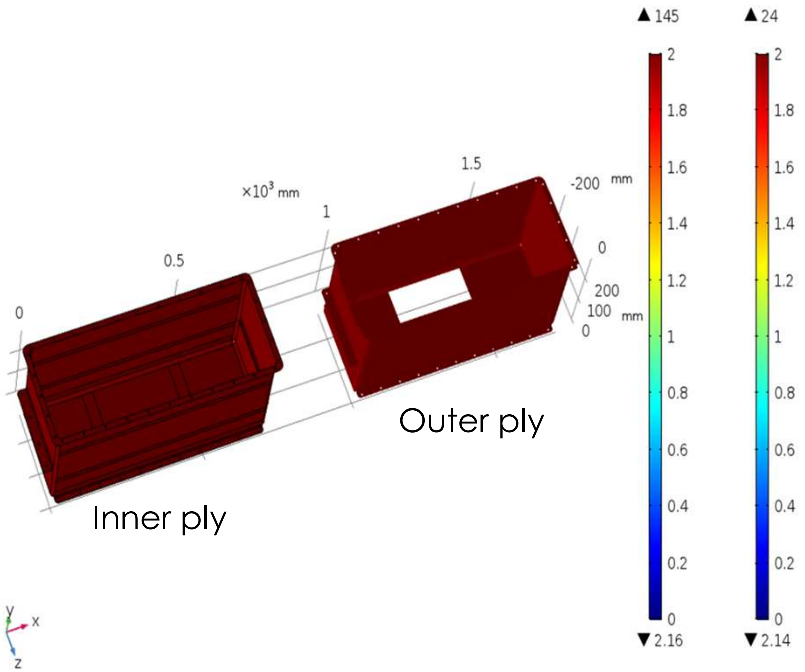
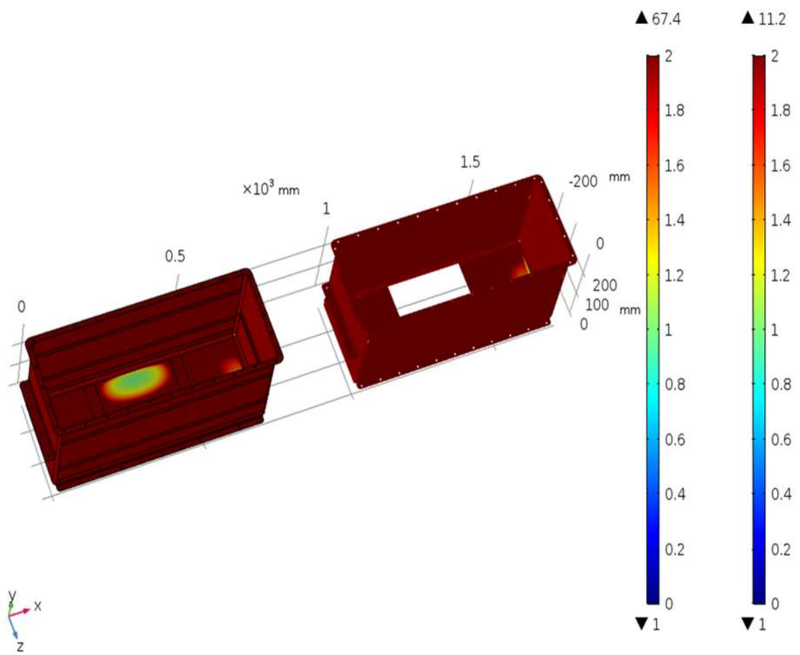
Simulations on the Pressure Vessels

Results

- **Iterative process:** Reinforcing with more plies the areas with the highest stress
- **SpaceX parameters**:
  MAWP (Maximum Allowable Working Pressure – safety factor>2)
  BURST (safety factor<1)



Tsai-Wu safety factor for MAWP (1.2 bar)



Tsai-Wu safety factor for BURST (2.6 bar)

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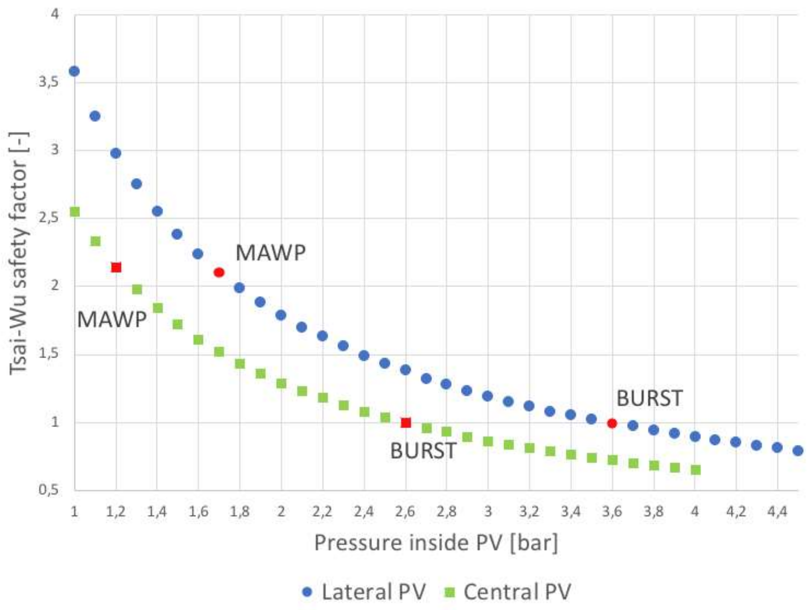
Simulations on the Pressure Vessels

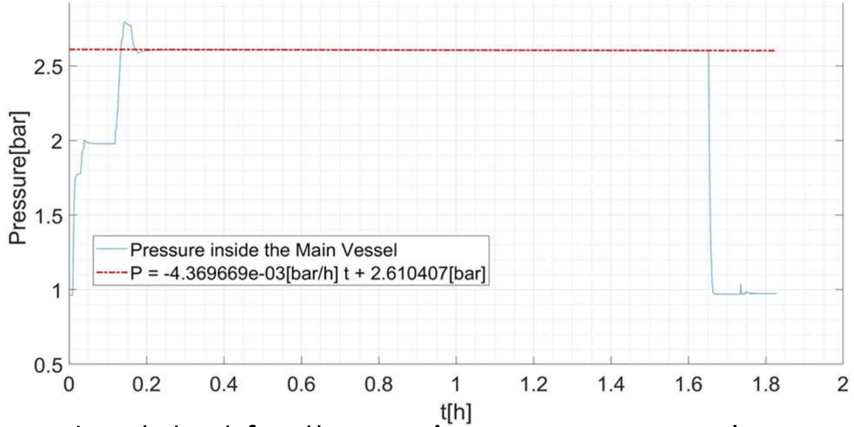
—E P F | O O P—

Experimental Validation

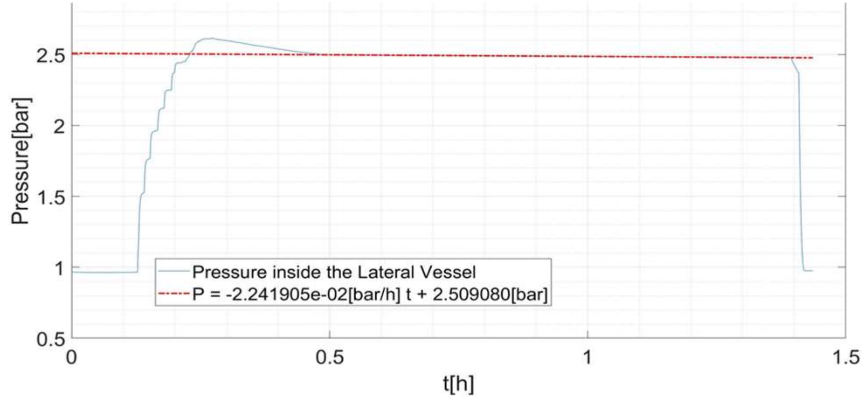
- Compressed air was injected up to **1.6 bar**, to check the presence of leaks near **MAWP**
- Remarkably low leakages were observed (<20 mbar/h for all the PVs)



Parametric sweep on internal pressure



Leak test for the main pressure vessel



Leak test for the lateral pressure vessel

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Subsystems Modeled with COMSOL®

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Modules by subsystem

AEROSHELL
- High Mach Number Flow
- Optimization Module
- LiveLink™ *for* MATLAB®

PRESSURE VESSELS
- Shells
- Heat Transfer in Solid

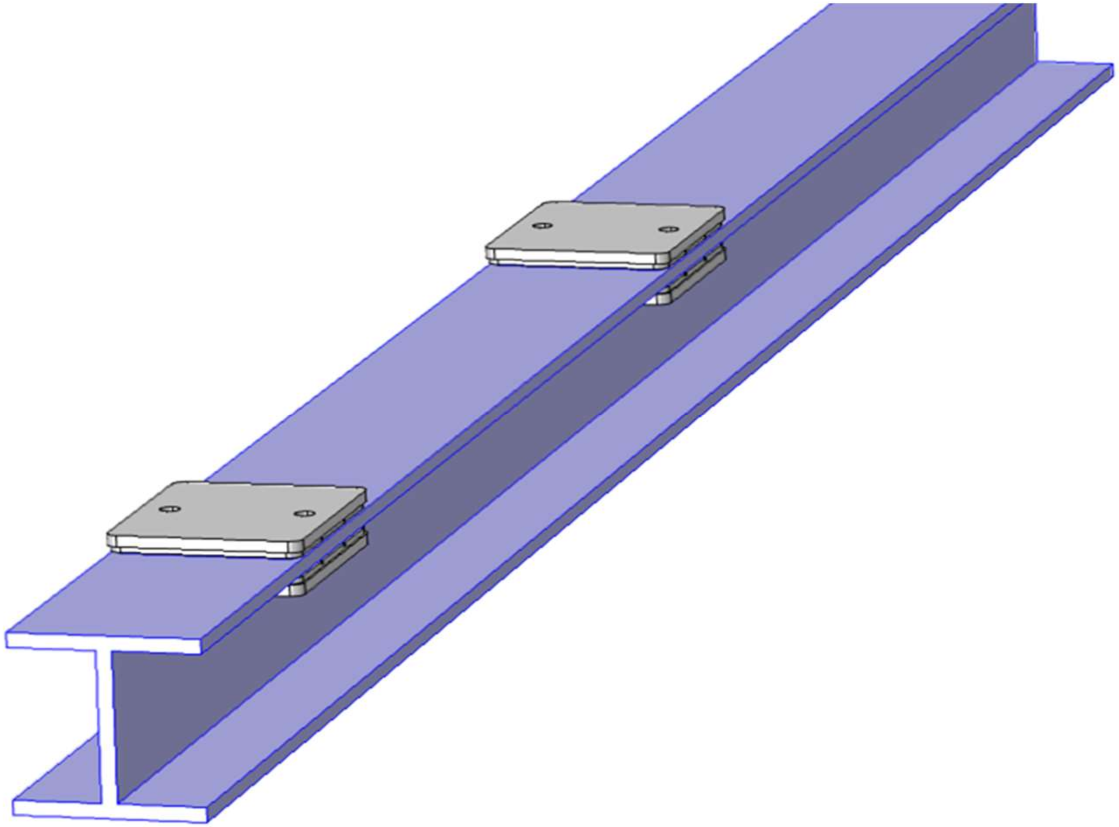
BRAKING SYSTEM
- Heat Transfer in Solids (Translational Motion)

CHASSIS
- Solid Mechanics
- Multibody Dynamics

Simulations on the Braking System

Aim of the Simulations

- In order to stop safely after having reached top speed, it is required to have an **efficient braking system**
- The amount of **kinetic energy** carried by the pod can create an excessive **increase of temperature** in the brakes
- In order to **choose the material** constituting the brakes in order to **avoid reaching problematic temperatures**, simulations with heat transfer and frictional effects were performed



Simulations on the Braking System

—E P F | O O P—

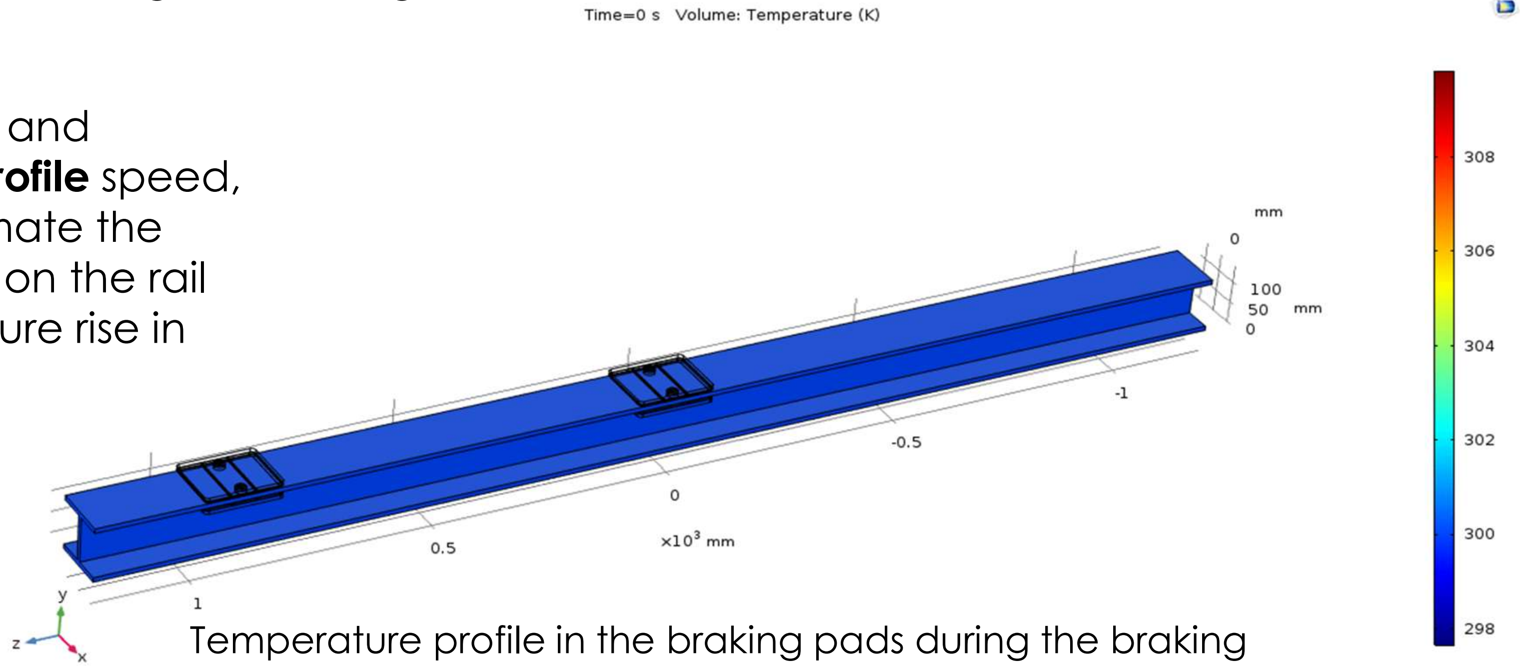
Modules, Solvers and Strategies

Module

- The **Heat Transfer in Solid** module has been used to simulate the temperature profile behavior of the brakes during the braking at the end of the run

Strategies

- Using the **Translation Motion** and inserting the **deceleration profile** speed, it has been possible to estimate the **power dissipated by friction** on the rail and therefore the temperature rise in the pad volume



Temperature profile in the braking pads during the braking

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Simulations on the Braking System

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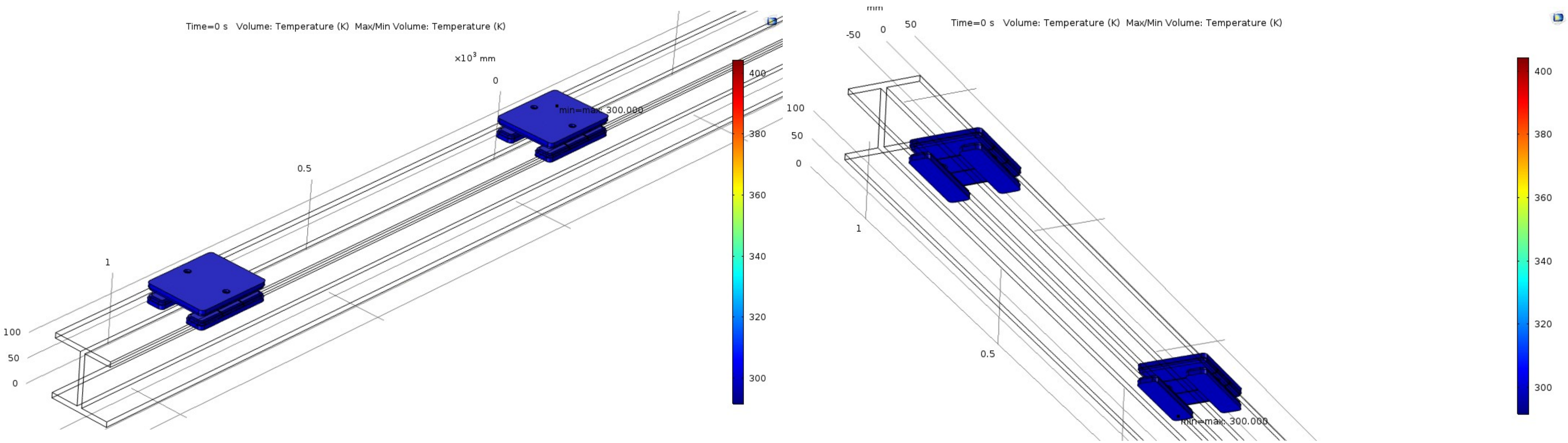
Results



Temperature profile in the braking pads during the braking : material sweep

Simulations on the Braking System

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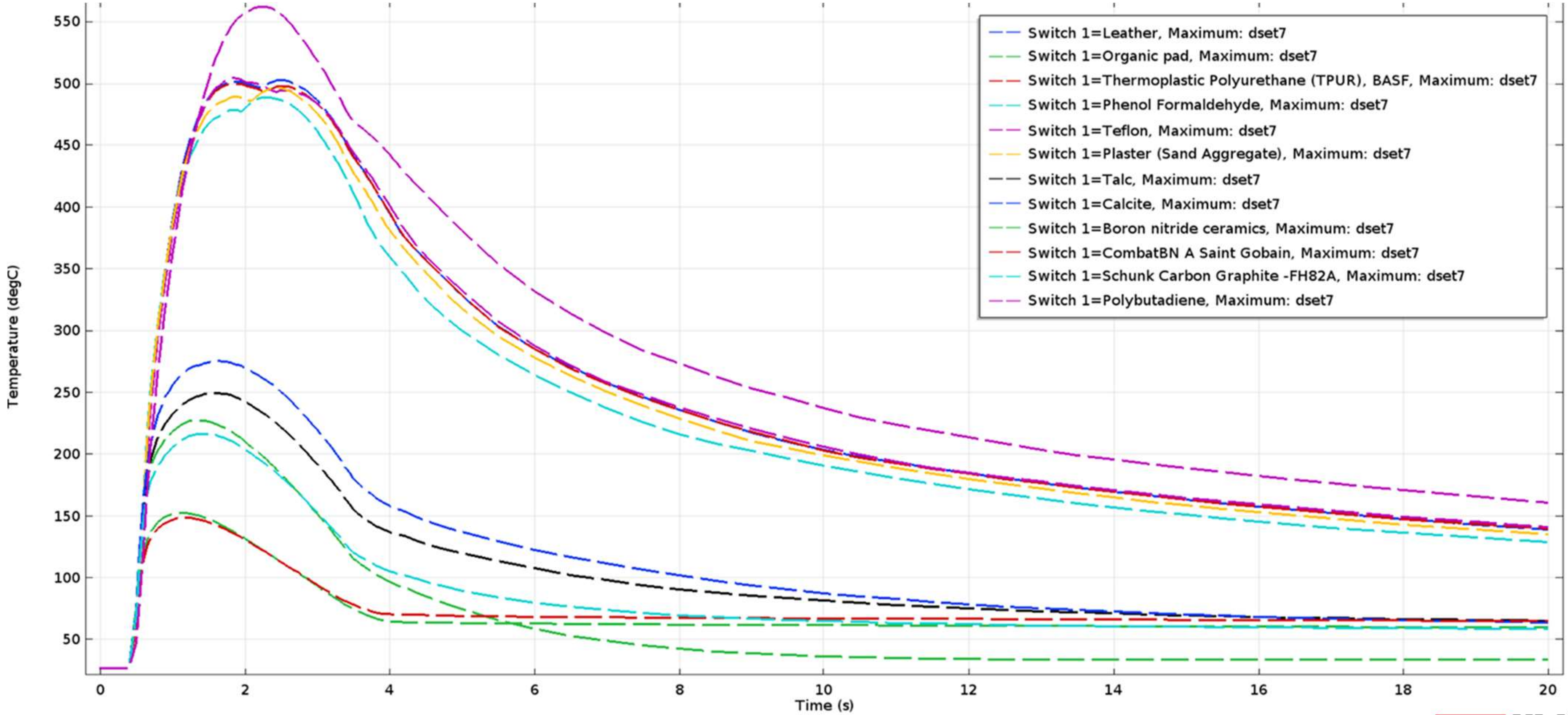
Results



Temperature profile in the braking pads during the braking : material sweep

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The Manufacturing of the Pod

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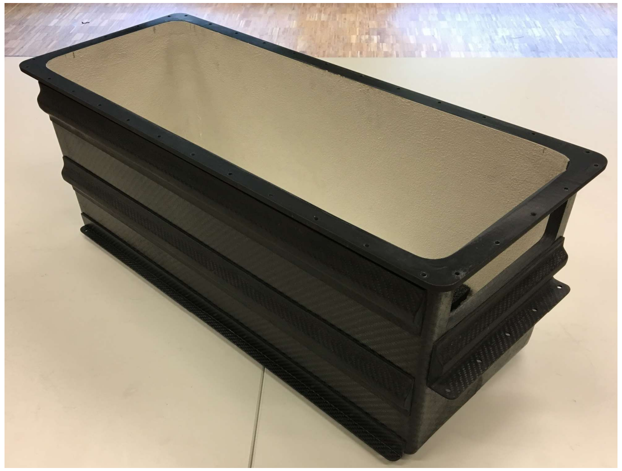

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Simulations on the Braking System

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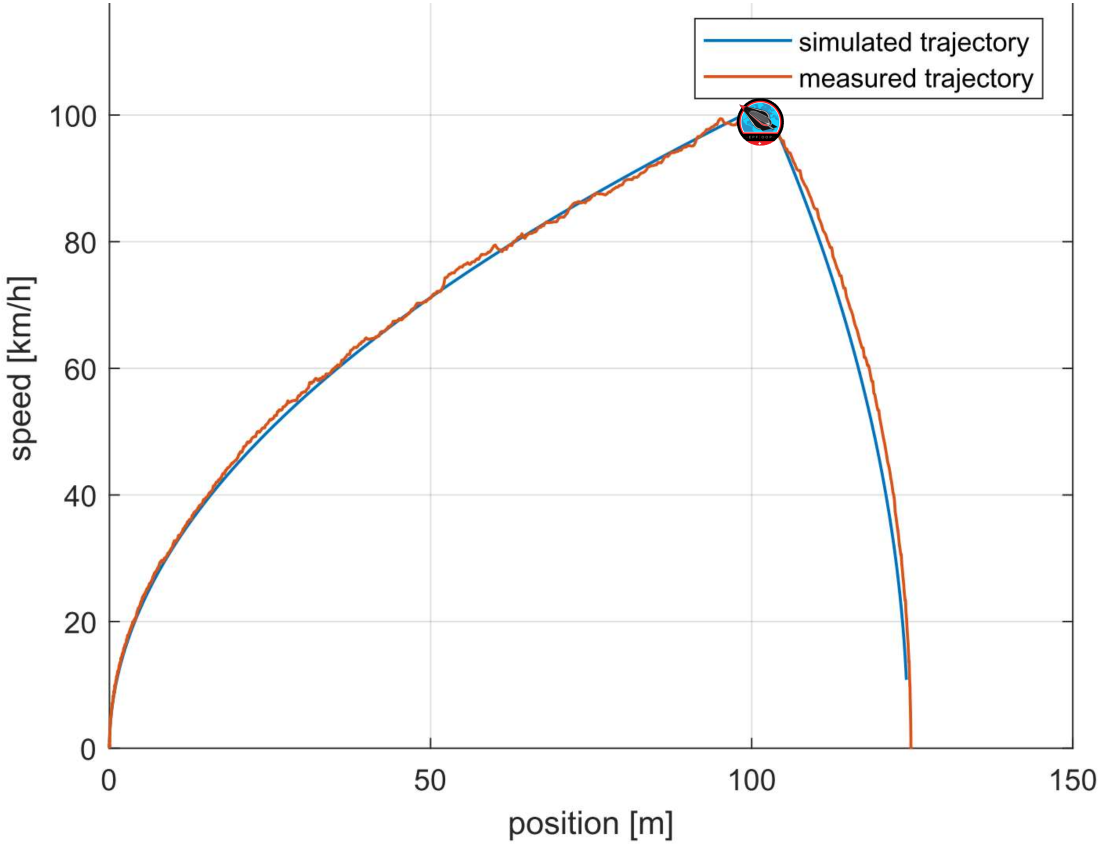
Validation 0-100 km/h run used for the pod kinetic model validation

Pod Performances Validation



Kinematics model validation: 150 Nm, 305 kg

- Comparison between the **kinematics model** developed by EPFLoop and **measurements during the run**

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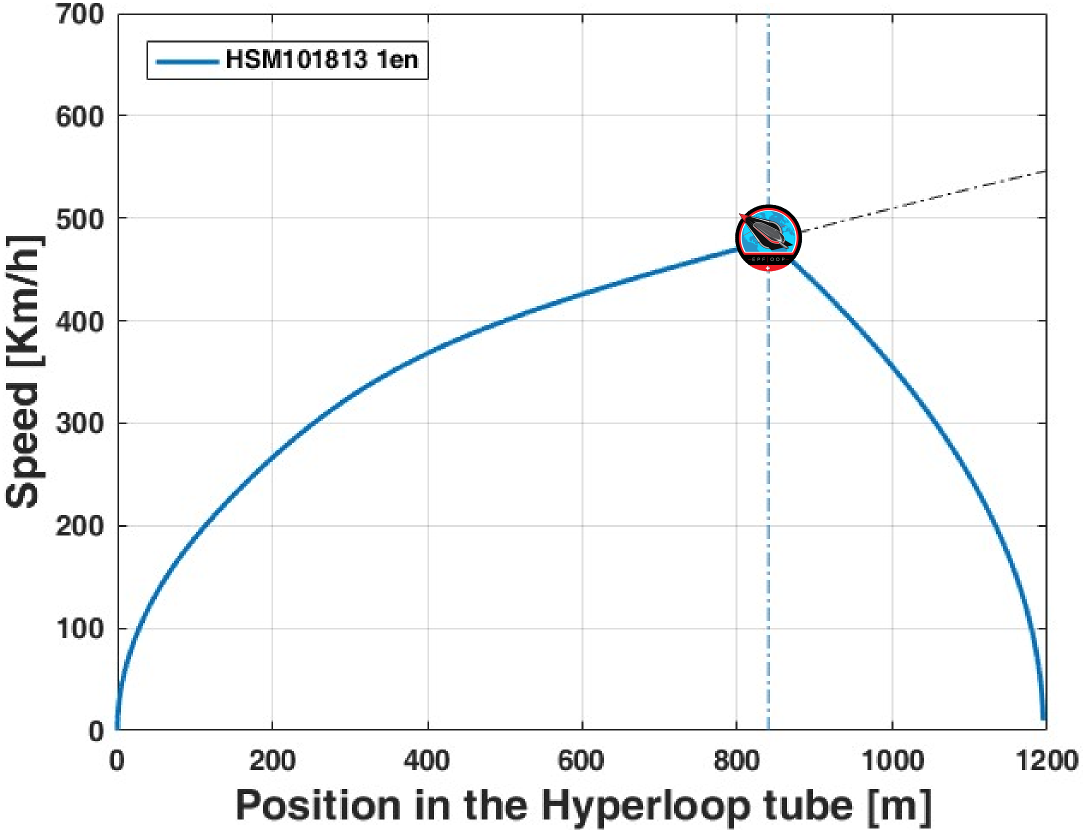
Pod Performances Prediction



Kinematics model for the EPFLoop pod

Mass	295 kg
Max requested power	178 kW
Max torque	385 Nm
Total capacity	15 Ah
Estimated max speed	470 km/h

THE 2019 HYPERLOOP COMPETITION

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The 2019 Hyperloop Competition

- Increase maximum speed
- Scalable prototype
- New approach inspired by Swissmetro
- Optimal design
- Collaboration with partners such as COMSOL
- New involved students


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Special Thanks

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Sven Friedel
Alyona Friedel
Thierry Luthy
COMSOL (amazing!) Support

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