Modeling The **Hyperloop** With **COMSOL®** :
On the Design Of The **EPFLoop** Pressurized Systems

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Introduction

The **EPFLoop** student team from **Ecole Polytechnique Fédérale de Lausanne** developed a capsule thanks to which it won third place at the SpaceX Hyperloop Pod competition in 2018. During the development of the EPFLoop pod, COMSOL Multiphysics® was used to study the design of composite pressurised subsystems. 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 electronics inside. The composite structure of the PVs should safely resist to the conditions in vacuum during the run while being light. In order to find such an arrangement, a **structural analysis** was done. To ensure the safe functioning of the electronics inside the PVs (Fig. 1 and 2), the temperature must not exceed 50°C. A **thermal analysis** has been done to ensure that the PV will not overheat due to power losses at full power.

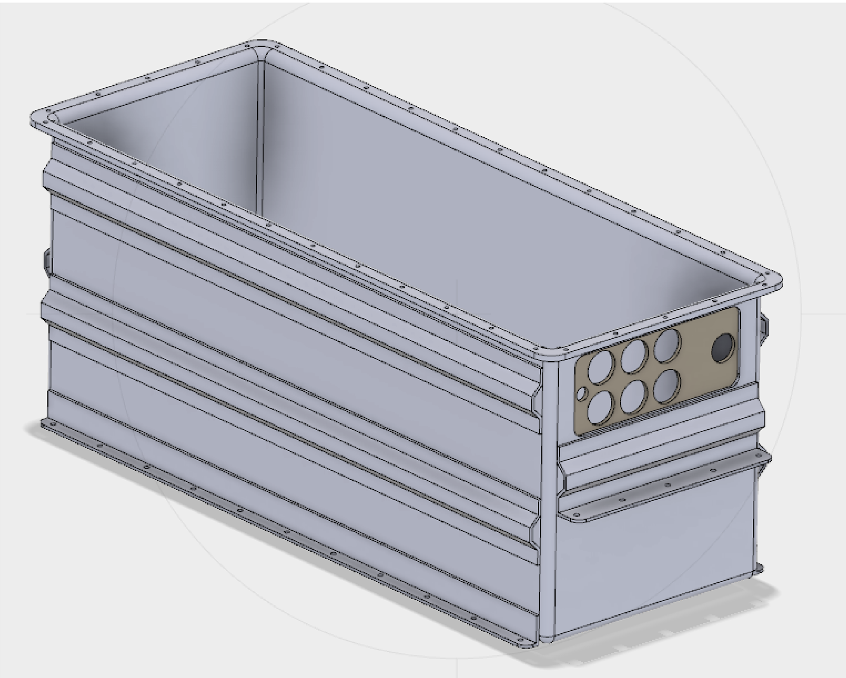


Figure 1. Main pressure vessel (MPV).

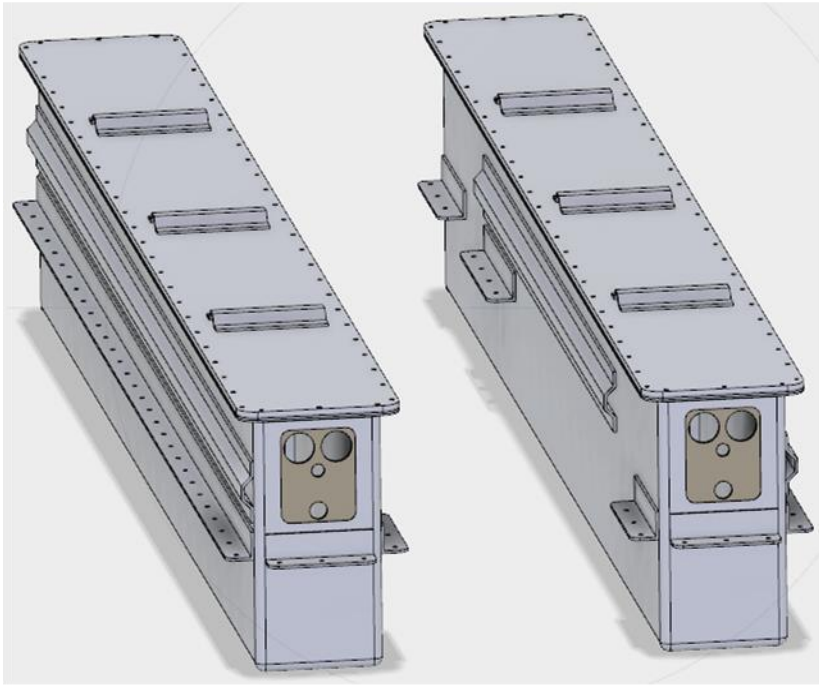


Figure 2. Lateral pressure vessel (LPV)

Thermal Analysis

The functioning of the **electronic components** in the **MPV** is guaranteed as long as the **temperature inside** of the MPV does not exceed 50 °C.

Heat transfer in solid coupled with **laminar flow**, during **idle mode** and **full power** functioning has been done in order to ensure that the dissipated power will not heat the MPV, which would lead to possible malfunctioning of the electronics (Fig. 3).

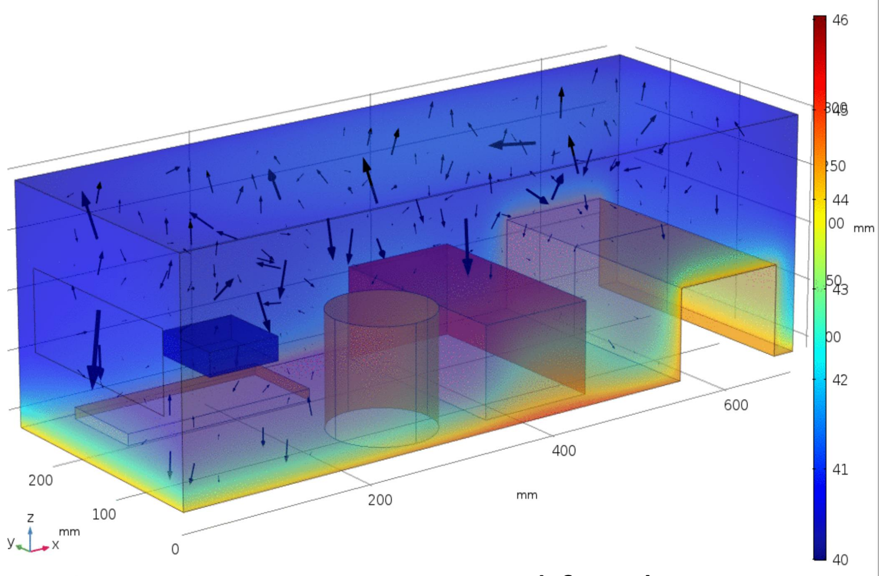


Figure 3. Temperature and free buoyancy during 1 hour.

The **heat load** is the heat dissipated via Joule effect, emitted by surfaces. The simulations, showing an upper temperature of 47 °C, have been **validated** through measurements.

Structural Stationary Analysis

The **PV's failure** under load was studied using a **stationary simulation** with the **Shells** module, where shells represent the plies of the carbon fiber-epoxy and foam sandwich structure.

The applied loads are given by the deceleration, the weight of the components inside the PV and a **constant and uniform pressure** of **1 atm** applied on the inner surfaces.
A free triangular mesh was applied on the PVs. Its quality was measured by skewness (Fig. 4).
A curvilinear coordinate interface on each layer has been used to simulate the **anisotropic properties** and the **irregular geometry**.

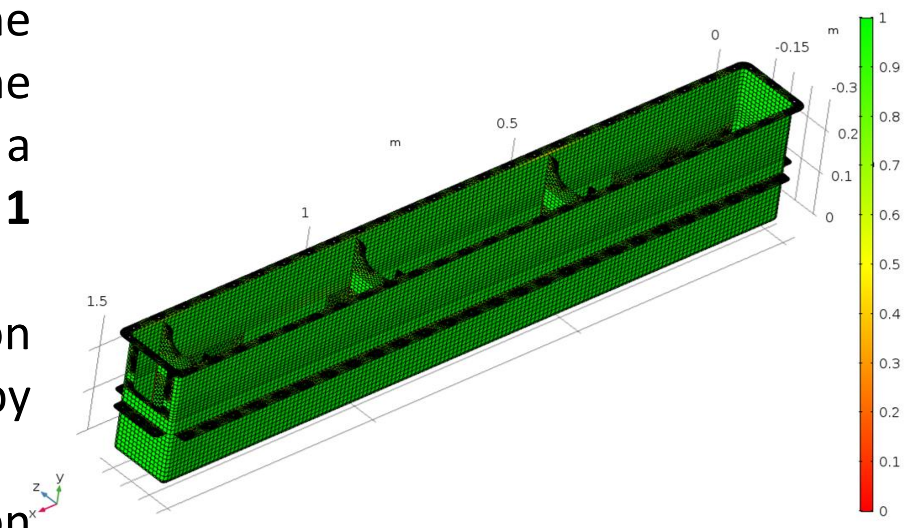


Figure 4. LPV quad mesh.

During the design, the assessment of the **MAWP** (Maximum Allowable Working Pressure, where the safety factor is >2 everywhere) and the **BURST** pressure (safety factor <1 in some areas) was required [REF SpaceX]
In order to assess these values, a parametric sweep varying the inside pressure has been performed, during which the changing of the **Tsai-Wu safety factor** and the **principal stresses** were studied.

The plies were arranged in order to ensure a **safety factor of 2** with a pressure of **1.2 bar (MAWP)**. After several iterations, the safety factor is of 2 everywhere on the PVs. The performance of the composite pressure vessels is determined using the Tsai-Wu model (Fig. 5) .

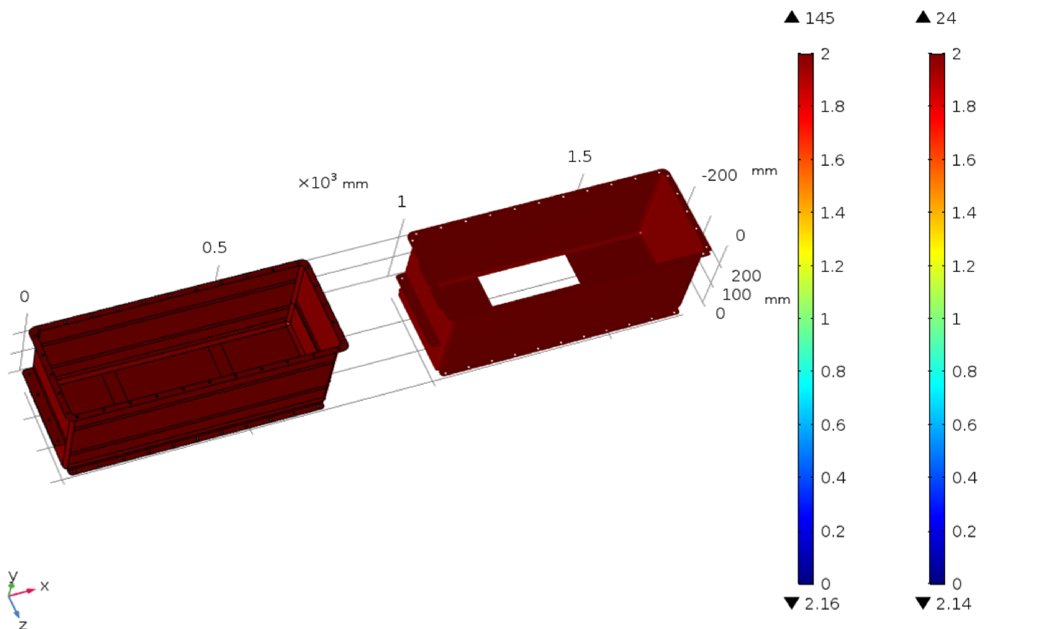


Figure 5. MPV inner and outer ply (L to R) Tsai-Wu safety factor at MAWP.

The analysis of the distribution of **principal stresses** (Fig. 6) made it possible to **localize** the direction of stress and the areas where the structure needed to be reinforced.

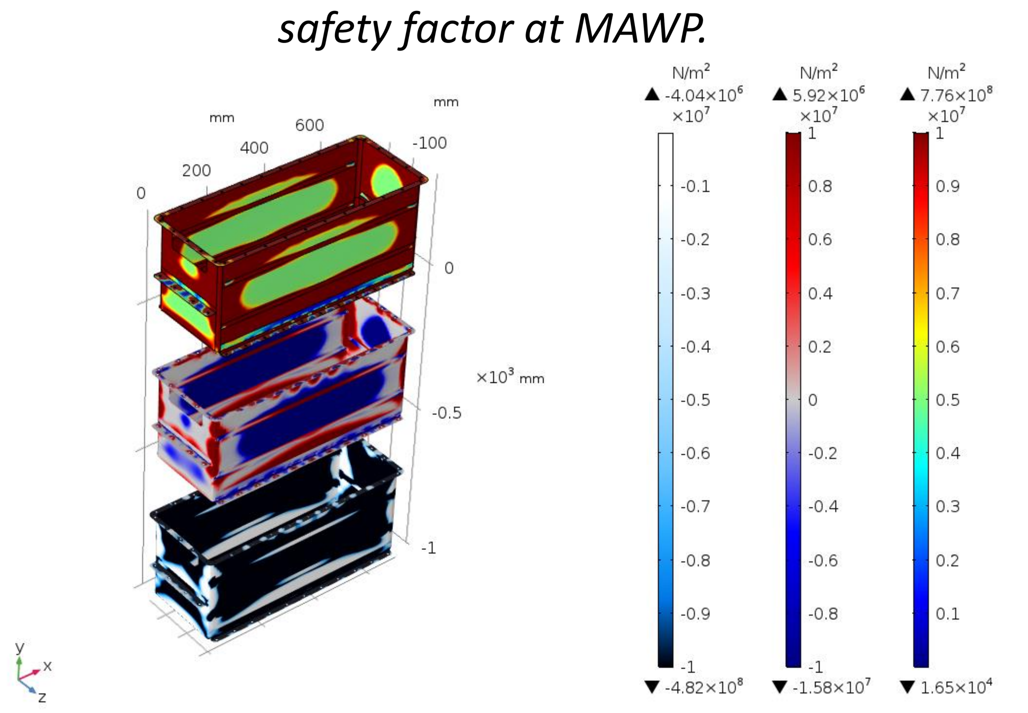


Figure 6. MPV inner shell principal stresses 1, 2, 3 (L to R) at BURST.

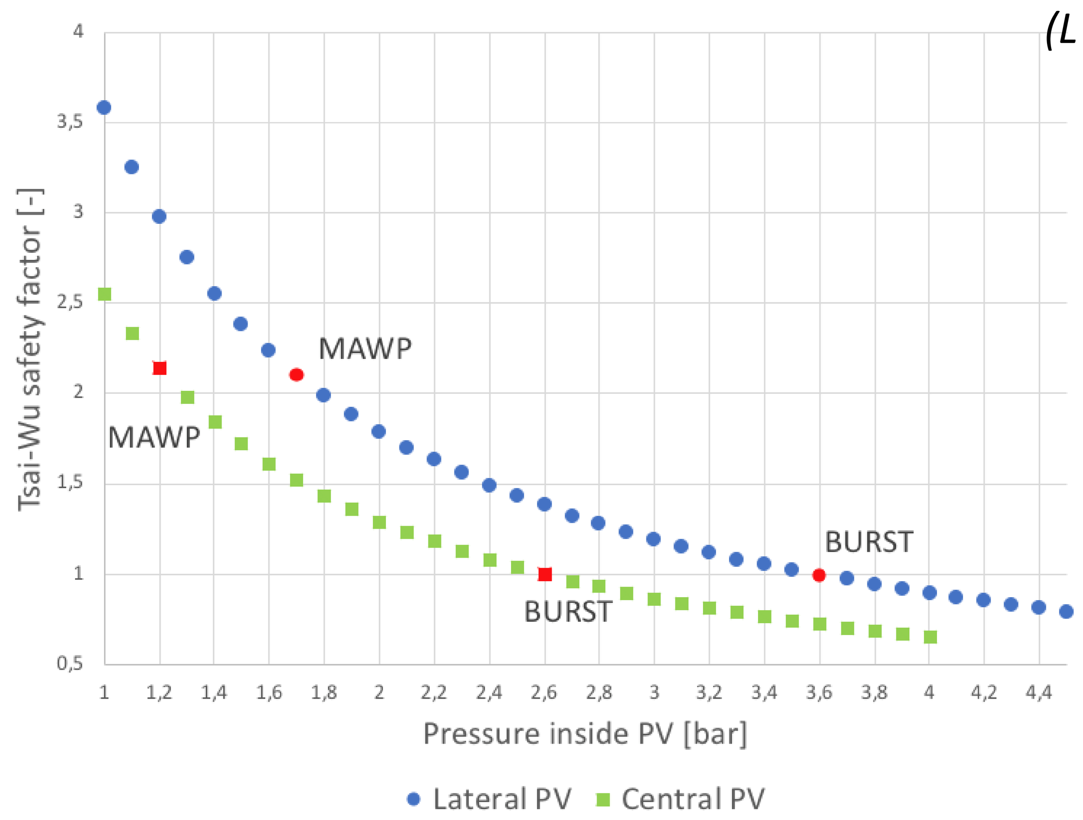


Figure 7. Minimum Tsai-Wu safety factor vs inner pressure.

To evaluate the **BURST** and **MAWP** pressures, a of **pressure** sweep from 1 bar to 10 bars inside the PVs has been carried out (Fig. 7). Additional loads were the weight of the components during acceleration and deceleration.

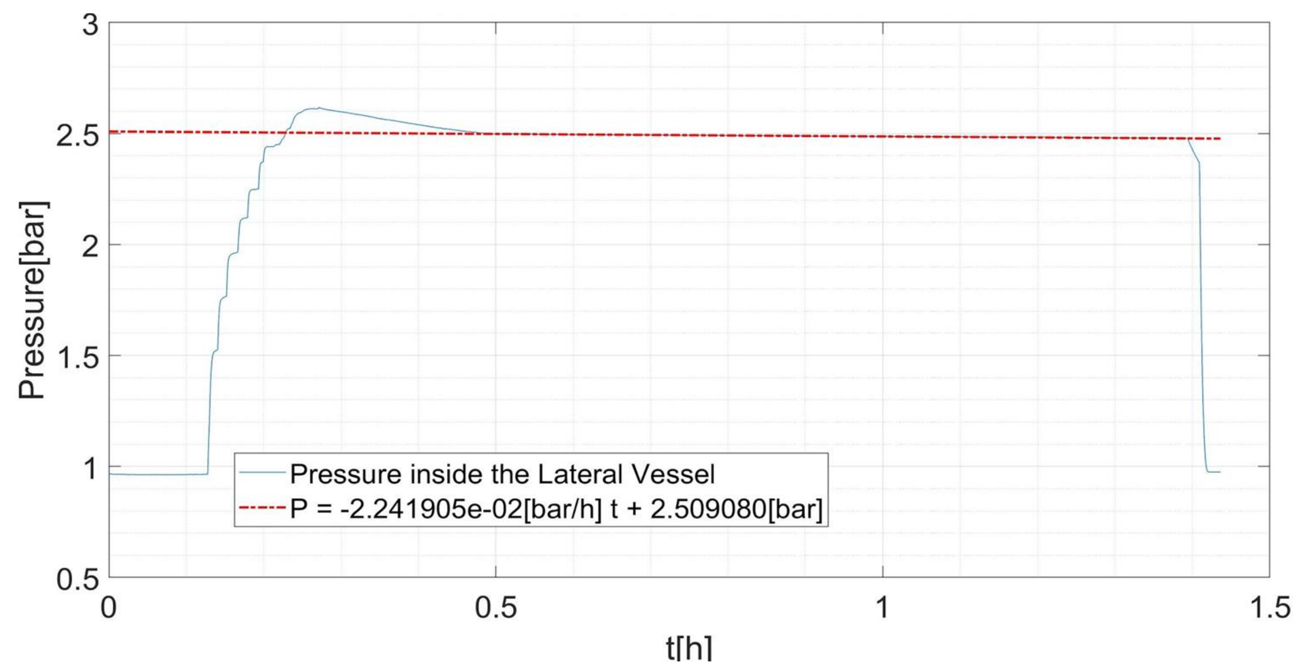
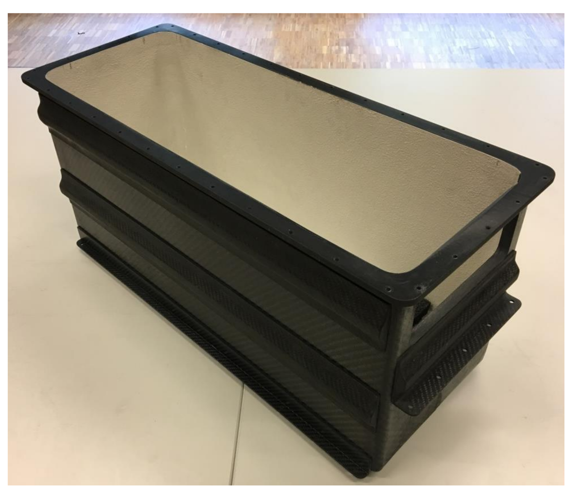


Figure 8. Leak test (LPV).

To **validate** the FEA, the pressure vessels have been tested: **compressed air** was injected up to **1.5 bar**, to check the presence of leaks at **MAWP** (Fig. 8). Remarkably low leakages were observed (**<20 mbar/h** for all the PVs).

Conclusion

The structural analyses have resulted in a safe design of the PVs, which has been confirmed by the thermal analysis. The PVs have been successfully **tested at nominal pressure (1 atm)**. This work pointed out how **interdisciplinary** and **polyhedral skills** can lead to new solutions in engineering. EPFLoop, thanks to **COMSOL** and others partners, will participate at the 2019 SpaceX Competition.



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1. Gay D. (2015). *Composite Materials Design and Applications*, Boca Raton, FL, CRC Press
2. SpaceX 2018 Competition Safety document