Inspiring Young Engineers to Design for the Future at EPFL

EPFLoop, one of the top three teams invited to the SpaceX Hyperloop Pod Competition, used multiphysics simulation to hit the ground running with a unique design advantage.

by BRIANNE CHRISTOPHER

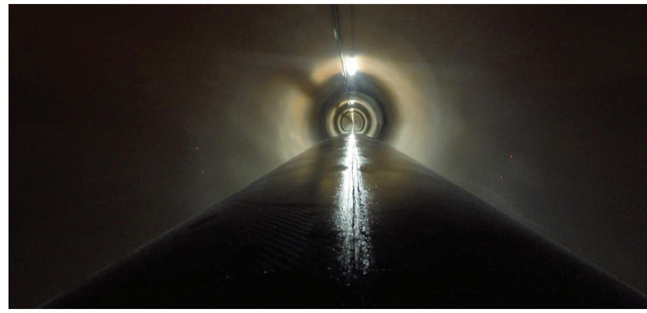

FIGURE 1. An inside view of the hyperloop test track.

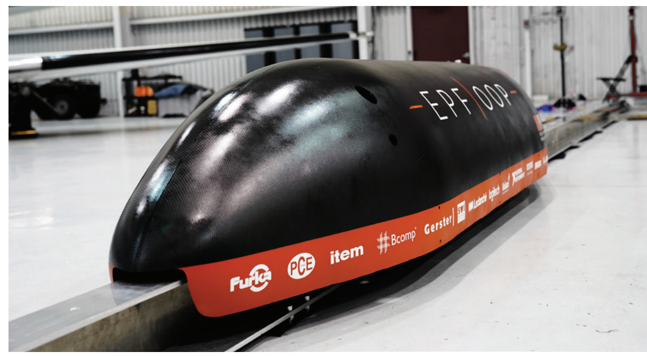

FIGURE 2. The EPFLoop hyperloop pod design.

Over the course of the annual SpaceX Hyperloop Pod Competition, engineering teams work to design and build hyperloop pods. The ultimate goal of the hyperloop concept is to achieve a mode of transportation that is high speed, intercontinental, and self-propelled. Such a system would both revolutionize the experience of transportation and offer a greener alternative to other modes of travel.

The Hyperloop Pod Competition, which started in 2015 as the brainchild of Elon Musk, culminates with a weeklong competition each summer in Hawthorne, California, located in southwestern Los Angeles. Over the course of the competition week, participants get to test their hyperloop pod designs on a mile-long track (Figure 1) at speeds of approximately 500 km per hour.

⇨ WORKING ALONGSIDE THE WORLD'S TOP ENGINEERS

Each year, the top 20 teams worldwide are invited to the California testing facility, and the top three teams can run on the track under vacuum at the final event. As a first-time competitor, EPFLoop exceeded all expectations by making a presence in the finale as one of the three teams to run in vacuum that year. Even more impressive was the fact that they classified first at the end of the testing week and were told that their pod showed the highest design reliability. Overall, the EPFLoop team ended up placing third in the high-speed run on the final day of the competition due to the unexpected presence of dust on the test track, which affected their pod's performance. Their experience at SpaceX proved to be invaluable for many reasons.

Made up of engineering students and technical advisors, the EPFLoop competition team formed at the Swiss Federal Institute of Technology Lausanne (EPFL). Dr. Mario Paolone, principal advisor of the EPFLoop team, says that the Hyperloop Pod Competition is a "chance for students and young engineers to participate in a state-of-the-art challenge, with some of the world's top engineers." Besides the chance to use high-tech testing equipment and rub elbows with professional engineers, the experience is a great opportunity for students to learn the importance of researching energy-efficient modes of transportation. It also gets students excited about research and inspires them to pursue careers in engineering.

⇨ SIMULATING THE HYPERLOOP POD

Aside from the opportunity to visit SpaceX and experience an advanced testing facility, the students who participate in EPFLoop have something more to gain: valuable experience using multiphysics simulation. Each aspect of EPFLoop's hyperloop pod design (Figure 2) involves modeling and simulation. In fact, Paolone calls simulation the "core" of their project. One obvious reason: The team's 60-meter test track is nowhere close to the mile-long test track at SpaceX. Consequently, even if their tests confirmed the results of the simulations at low speeds, they still relied on simulation software to gain insight into what will happen at very high speeds. "Every single component of the pod has to be simulated and validated," says Dr. Lorenzo Benedetti, the technical leader of EPFLoop.

Using the COMSOL Multiphysics® software, the EPFLoop team was able to analyze the complex components of their hyperloop pod and predict its performance before ever setting foot on the SpaceX premises. Furthermore, the team needed to be able to look at multiple physical effects at once, including mechanical, fluid, electrical, and materials science phenomena. "This project is inherently multidisciplinary," says Benedetti. For example, the design team wanted

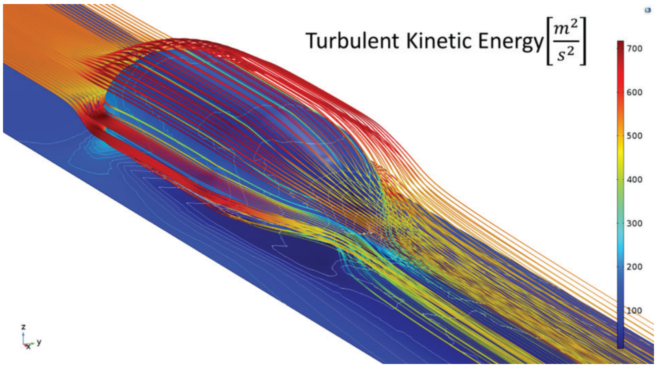

FIGURE 3. The turbulent kinetic energy around the hyperloop's composite aeroshell structure.

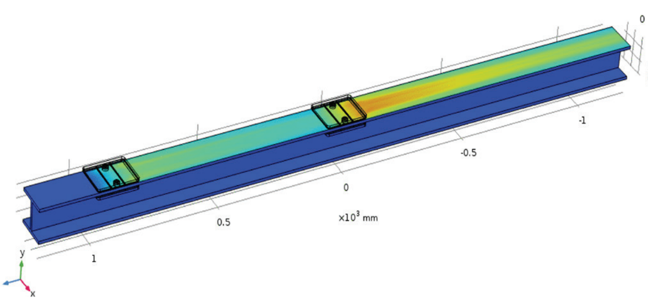

FIGURE 4. The temperature profile in the hyperloop's braking system.

to see how the pod's aeroshell, made out of a lightweight composite carbon fiber, would fare on the test track. To minimize the aerodynamic resistance of the shell, they performed a computational fluid dynamics (CFD) analysis coupled with shape optimization and mechanical stress studies (Figure 3).

The aeroshell had to be both lightweight and able to withstand aerodynamic forces during acceleration and deceleration. The team used the High Mach Number Flow interface to find the lift and drag coefficients of the pod. The pressure distribution results from the CFD analysis were then used to find an optimized aerodynamic shape via the LiveLink™ *for* MATLAB® interfacing product.

The team also needed to see how the pod's pressure vessel would perform in the tube, under vacuum, during the high-speed run. They designed vacuum-proof enclosures, which are responsible for storing the batteries and electrical components of the pod. In fact, some electronics cannot sustain vacuum conditions, and a subpar design could cause the inner components to be directly exposed to the track — which is essentially a vacuum tube — and destruct. The team performed a structural analysis of the vessel's design, a composite pressure vessel, using the Shell interface in the COMSOL® software to account for the superposition of layers. They then optimized the structural response to be able to have the minimum weight possible. The Tsai–Wu safety factor and principal stresses were then studied in the optimized pod design.

⇨ SLIDING TO A STOP

The hyperloop's braking system is another example of multiphysics design. The brakes need to be able to safely slow the pod down after it has reached its top speed. However, there is an extreme temperature increase in the braking system due to the vacuum conditions in the tube: Without air, there is no convective dissipation of heat to the air and the heat remains stored in the brake pads. To ensure that the braking components would perform as expected, the EPFLoop team coupled heat transfer and mechanical simulations for their brake system design (Figure 4).

Using the Heat Transfer in Solids interface, the team analyzed the temperature profile in the brake system during and after braking to ensure that it would not become hot enough to cause damage to the hyperloop pod. They then used the Translational Motion feature to estimate the power dissipation caused by the friction, and therefore, the temperature rise in the brakes. Using this information, the team performed a material sweep of the different brake pad options, including ones made out of leather, thermoplastic polyurethane, plaster, and some more classical braking pad materials used in the automotive industry. The simulation analysis helped the team to identify that a customized material created for them by an external company was the best material option for the brake pads because it kept the braking system within the desired temperature range.

The team's detailed simulation work paid off: "One of the judges called our approach 'extremely compelling'," says Benedetti.

⇨ LIFE-SHAPING EXPERIENCES

The most impressive aspect of EPFLoop is not their pod design or competition ranking, but the project's impact on the students who participated. Nicolò Riva, a PhD student at EPFL who also heads the team's aerodynamics group, said that the experience made him "want to stay in academia and participate in similar projects." Zsófia Sajó, another student involved in the 2018 competition team, said that EPFLoop inspired her to "do something about solar power and clean energy for transportation."

Paolone's impression of the project echoes the takeaways of his team members. He said that students set aside their personal and free time to participate in EPFLoop with motivation, drive, and commitment. "We need these kinds of people," he said, to be engaged in designing clean modes of transportation for the future. ❖

The EPFLoop team.