

# TUM Hyperloop

Building Hyperloop Pods to Revolutionize Terrestrial Transportation





The Technical University of Munich (TUM) Hyperloop team is a student organization that designs, builds, and tests Hyperloop pods for SpaceX's Hyperloop Challenge. The goal of the competition is to reach the highest possible velocity on the 1.6 km long tube without crashing the pod.

A Hyperloop is a sealed tube through which a pod travels at high speeds free of air resistance or friction, thus reducing travel times drastically. If the concept proves successful, Hyperloop will revolutionize terrestrial transportation.

In 2013, Elon Musk revived hyperloop research development with his whitepaper "Hyperloop Alpha," consisting of a low-pressure tube through which pods supported on an air cushion travel at both low and high speeds.

In research papers based on the "Hyperloop Alpha" concept, the

idea of a complete hyperloop system from Los Angeles to San Francisco was presented. Passengers would travel along the 560 km route at a speed of 1.200 km/h, allowing travel times of about 35 minutes, which is considerably faster than current rail or air travel times.

Driven by this vision, the TUM Hyperloop team followed Elon Musk's call to attend the first SpaceX Hyperloop Challenge in 2017 and has been continuously competing in the annual competition, consecutively winning and setting new speed records.

### Roadmap to Success

The rules of the SpaceX Hyperloop Challenge stipulate that a new pod must be entered into the competition each year. Therefore, all teams must develop a pod within less than a year.

Apart from the demanding timeline, the TUM Hyperloop team faced additional challenges: they had to find a way to test the pod without damaging it and without having access to the actual Hyperloop track, which is located at SpaceX's headquarters in Hawthorne, California.

To address these challenges appropriately, the team decided to use a Speedgoat real-time target machine and MathWorks® tools such as MATLAB® and Simulink®.

The TUM Hyperloop team created a detailed vehicle model in Simulink, which was then deployed on the Baseline real-time target machine, using I/O modules such as the IO613 CAN FD I/O module and the IO397 Simulink-programmable FPGA I/O module.

With this testing setup, the TUM Hyperloop team established model-based testing methods and solutions such as Hardware-in-the-Loop (HIL), verification



testing of the pods' electronics, and software testing ECU under different scenarios.

Implementing the model-based design approach was pivotal to test and emulate necessary sensors at an early stage in the development process without putting the pod in danger.

The team modeled all sensors, including the photoelectric sensors measuring the altitude of the pod by using digital outputs, the hall switch sensors measuring the velocity by generating PWM signals with varying period times, and the pressure sensors in the brake's chambers by using analog outputs. This enabled them to test all the electronic control units. These units read and process sensor data and send commands to the actuators in the pod.

Furthermore, by running their pod model in real-time on the Baseline real-time target machine and connecting their ECU to it, the TUM Hyperloop team verified the pods' control logic and various safety procedures deterministically and in real-time.

To prove full functionality of the control units, the collected data was verified and checked

“By anticipating potential failure modes through thorough testing and simulations the reliability of our Hyperloop Pod could be improved enormously. The setup was really quick and the Baseline real-time target machine was incredibly easy to use. Furthermore, connecting the Baseline real-time machine to the PC via Ethernet couldn't be easier.”



Toni Jukic, Team Manager  
TUM Hyperloop Team

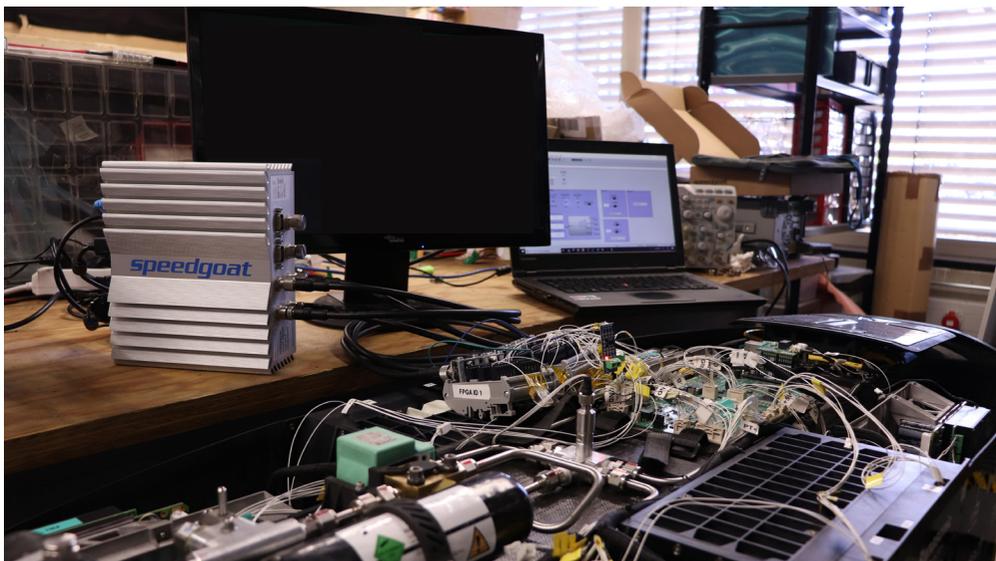
“A big plus is the integration with MATLAB.”

to determine whether the state transitions and abort criteria work correctly.

#### Future Endeavors

Hardware-in-the-Loop testing is essential in optimizing the next generation of Hyperloop pods. With pod speeds of up to 300 mph, the tube's quality has a significant influence on

the performance. Therefore, the focus is on making the pod more mechanically resilient and less sensitive to unevenness. Furthermore, the pneumatic system needs optimizing to engage the brakes even faster. Everything should fall into place for the TUM Hyperloop team to reach their goal with their next-generation pod: a velocity of half the speed of sound!



The TUM Hyperloop testing setup connecting the Baseline real-time target machine to the pod.

**Utilized Speedgoat products:**

- » Baseline-S real-time target machine
- » IO397 Simulink-programmable FPGA
- » PWM FPGA code module
- » IO613 CAN FD I/O module

**Utilized MathWorks products:**

- » MATLAB®
- » Simulink®
- » MATLAB Coder™
- » Simulink Coder™
- » Simulink Real-Time™



Speedgoat GmbH  
Waldeggstrasse 30  
3097 Liebefeld  
Switzerland  
[www.speedgoat.com](http://www.speedgoat.com)

# TUM | HYPERLOOP

TUM Hyperloop  
Lichtenbergstr. 4a  
85748 Garching bei München  
Germany  
[www.tumhyperloop.de](http://www.tumhyperloop.de)

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