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Sensitive sensors for harsh environments

Rocket engine testing – students use sensors from Kistler to improve engines

space to grow

EPFL ROCKET TEAM

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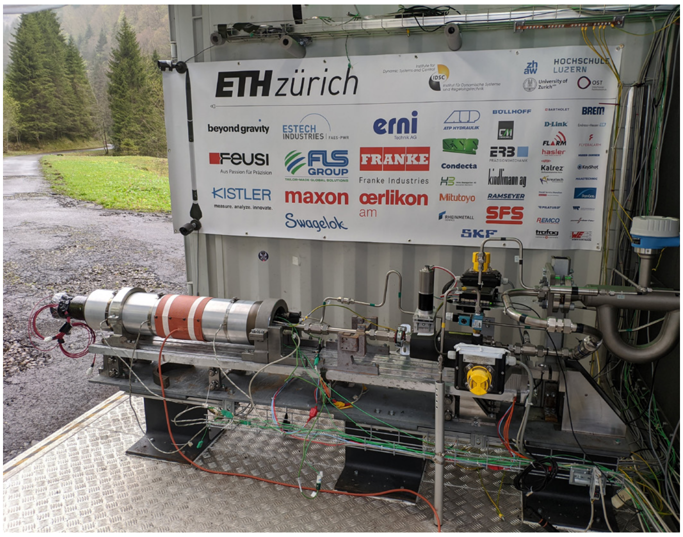
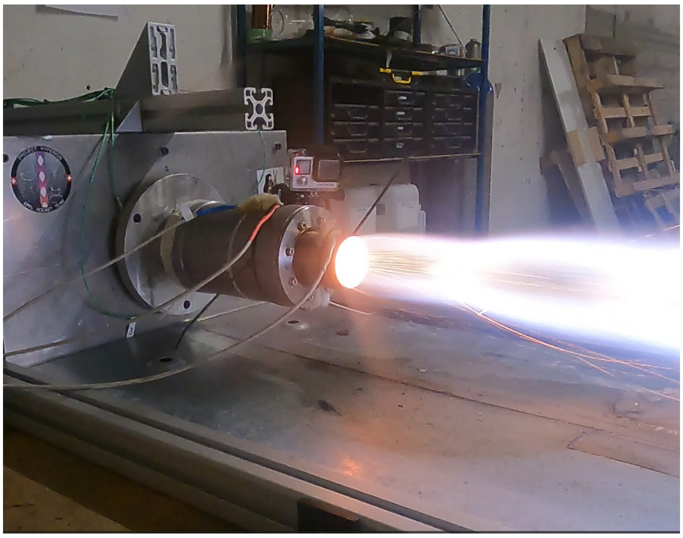


On their test stand, ARIS' hybrid rocket engine team aims at perfectly balancing the oxidizer injection. The measurements of dynamic pressure gave them the necessary insights to improve the combustion process.



The high data acquisition frequency of the piezoelectric sensors allows EPFL to gain a deep understanding of the rocket engine dynamics.

Airplane turbines and rocket engines are very powerful, hot, and noisy and yet in need of extremely sensitive measurement technology. And they have another thing in common: they are most efficient when they run on a constant and even flame. Specialized measurement technology helps aerospace engineers improve combustion chambers and fuel injectors. In Switzerland, two ambitious student organizations use iterative pressure measurements to develop and build a significantly more efficient next generation of rocket engines.

Every successful space program is the result of several years of development and countless tests. Today, engineers have a big advantage compared to the pioneers of aerospace technology, because modern test equipment enables far deeper insights even into the smallest details of functionality. The acquired data enables an in-depth understanding of the physical events and allows for a significant improvement of an aircraft's or spacecraft's efficiency and functionality.

Engines are one of the areas where detailed insights make a significant difference in research and development. Inside the combustion and ignition chambers, it is common to find instabilities causing oscillations in thrust output – an undesired effect. In rockets, combustion instabilities may lead to malfunctions or even cause severe damage to the engines. In jet engines, these imbalances also occur and lead to inefficiencies, vibration as well as increased fuel consumption. Therefore, optimizing combustion chambers to prevent these instabilities holds a lot of potential to reduce emissions. Piezoelectric pressure sensors with high temperature resistance make it possible to monitor these instabilities in both applications extremely closely.

In Switzerland, two organizations of ambitious student teams show how it is done: ARIS from the ETH Zurich (Swiss Federal Institute of Technology Zurich) and the EPFL Rocket Team (École Polytechnique Fédérale de Lausanne) compete in a literal race to the stars with rockets they developed and built themselves. Keeping their goal of reaching orbit in mind, they showcase their progress in yearly international competitions. Throughout the year, these passionate engineers in the making invest many hours and even their weekends for testing and evaluating data to improve their rocket engines. Specialized measuring equipment plays an integral part in these tests. As an expert for dynamic measurements, Kistler supports both teams with expert knowledge, high-end piezoelectric sensors, and equipment such as cables, data acquisition systems, and software for analysis.

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>
> Mathieu Sandoz, Hard- and Software engineer of the ASTREA hybrid rocket engine team

ARIS test their hybrid rocket – measuring dynamic pressure at the combustion level

In addition to a small-scale satellite, rocket recovery systems and a small underwater robot, ARIS is currently working on two different kinds of rocket engines – the bi-liquid rocket engine Prometheus and a hybrid rocket engine, ASTREA. In both engines, the students use pressure sensors to monitor and reduce the combustion instabilities.

In the combustion chamber of ASTREA, solid polymer fuel reacts with a liquid oxidizer, which is injected as a fine mist. The pressure of this injection is a crucial parameter for achieving a constant thrust of the rocket motor. The more the young engineers understand about the relation between the oxidizer injector and the combustion, the better they can control it. "We placed one of the pressure sensors in the injector manifold chamber where the oxidizer enters the combustion chamber. Another one was placed on a test nozzle and set up to measure pressure in the combustion chamber. Because of the position of the sensors, this test setup is very demanding: the equipment needs to withstand very high temperatures," Mathieu Sandoz, hard- and software engineer of the ASTREA hybrid rocket engine team, explains. Kistler provided the team with temperature-resistant pressure sensors 601CAA, which are specifically designed for dynamic pressure measurements with high thermal shocks. Still, the student team took every precaution to make sure the valuable measurement equipment would take no harm from

The sensors used for rocket engine testing must withstand extreme conditions. Kistler provided ARIS with temperature-resistant piezoelectric pressure sensors 601CAA.

the high temperatures during the combustion and used a dummy sensor in the first tests. "To avoid direct contact with the hot gases, we installed the sensors via passage mounting. Also, we created an acoustic model of the passage to determine the natural frequency and evaluate the influence on the measurements as suggested by Kistler," Sandoz describes the precautions. This step is important because, in this case, the natural frequency of the passage has an influence on the measurements in the combustion chamber.

> "The high data acquisition frequency of the piezoelectric sensors allows us to gain a deep understanding of the dynamic of the engines."
> Florent Gaspoz, team leader propulsion at the EPFL Rocket Team

Piezoelectric sensors are particularly well suited for dynamic and quasi-static pressure measurements in harsh environments with very high temperatures. Besides their robustness, they also feature an especially high sampling frequency which allowed a detailed analysis of the acoustics in the combustion chamber and gave the students valuable insights into the combustion stability. "The sensors provided us with a high sample rate for our pressure measurements. Thanks to the data we were able to detect three different combustion instabilities during the whole duration of our test campaign. For instance, we diagnosed instabilities in the pre-combustion chamber and with the help of the gathered data, we were able to pinpoint these as the reason for an engine failure that we had experienced. After we had found the cause of the problem, a solution was quickly implemented. This allowed us to proceed with our firing campaign without too much delay," says Sandoz.

EPFL tests bi-liquid rocket engines – a balancing act

In contrast to the hybrid and solid fuel engines, bi-liquid engines use both a liquid fuel and a liquid oxidizer. Since this kind of engine is more efficient, it is also the engine type used in most commercial rockets. The development of a bi-liquid rocket however is even more challenging in some respects: The pressure of the fuel delivery system must be balanced perfectly to achieve a constant and even flame.

Not only ARIS keeps testing to find this balance, also the EPFL Rocket Team from Lausanne tests its rocket engines again and again on the institute's test bench – the heart of which consists of ten temperature-resistant piezoelectric sensors from Kistler. Three pressure sensors measure the pressure in the combustion chamber, two more monitor the pressure in the ethanol and the oxidizer injectors. Three load cells measure forces behind the thrust plate and additional pressure sensors and load cells monitor the two tanks. It is not surprising that, at full power, the test bench generates 87MB of test data per second. The KiStudio Lab software package from Kistler which includes the jBEAM post-processing software records and analyzes the data. So far, the team has performed more than 250 tests with bi-liquid engines on the test bench.

Florent Gaspoz, team leader propulsion at the EPFL Rocket Team, describes why the measurements are key to the engineering process: "The high data acquisition frequency of the piezoelectric sensors allows us to gain a deep understanding of the dynamics of the engines. This summer, for instance, we struggled with igniting the engine and could not figure out where this problem came from. That's when we zoomed in on the data and took a real close look. We found out that the oscillations in the combustion chamber preceded the oscillations in the injector minimally. We knew immediately how to solve this issue – but without the measurements we might not have found the reason for the failed ignition." A few months later, the problem came up again. Without hesitation, the team checked the data and found that this time the oxidizer was at fault. "It is an amazing experience to be able to look at data this detailed and be able to draw conclusions from it. I really felt like an engineer at that moment," Florent Gaspoz adds, laughing.

Measurement technology with implications for the whole aerospace industry

Reinhard Bosshard, sales expert at Kistler, supported the students with technical background on the correct installation of measuring chains. He is happy that the measurements provided the students with valuable insights into their projects and helped them learn. "I am amazed at the students' enthusiasm for innovation. They will learn a lot from developing test strategies themselves, interpreting the test data and drawing conclusions – these are important skills not only in the space industry, but also in many other fields of engineering. The same kind of tests, for instance, leads to very promising results in airplane turbine tests."

For the teams ARIS and EPFL Rocket Team, other challenges come first – such as winning the next European Rocketry Challenge (EUROC). Here the two Swiss teams are competitors and collaborators at the same time. While each team is competing with their own rockets, both teams help each other out in case of need and share large pieces of equipment, as, for example, the launch rail. In the end, it's the passion for aerospace engineering that counts – and the experience of designing increasingly efficient research rockets to achieve the ultimate dream: reaching the stars.

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