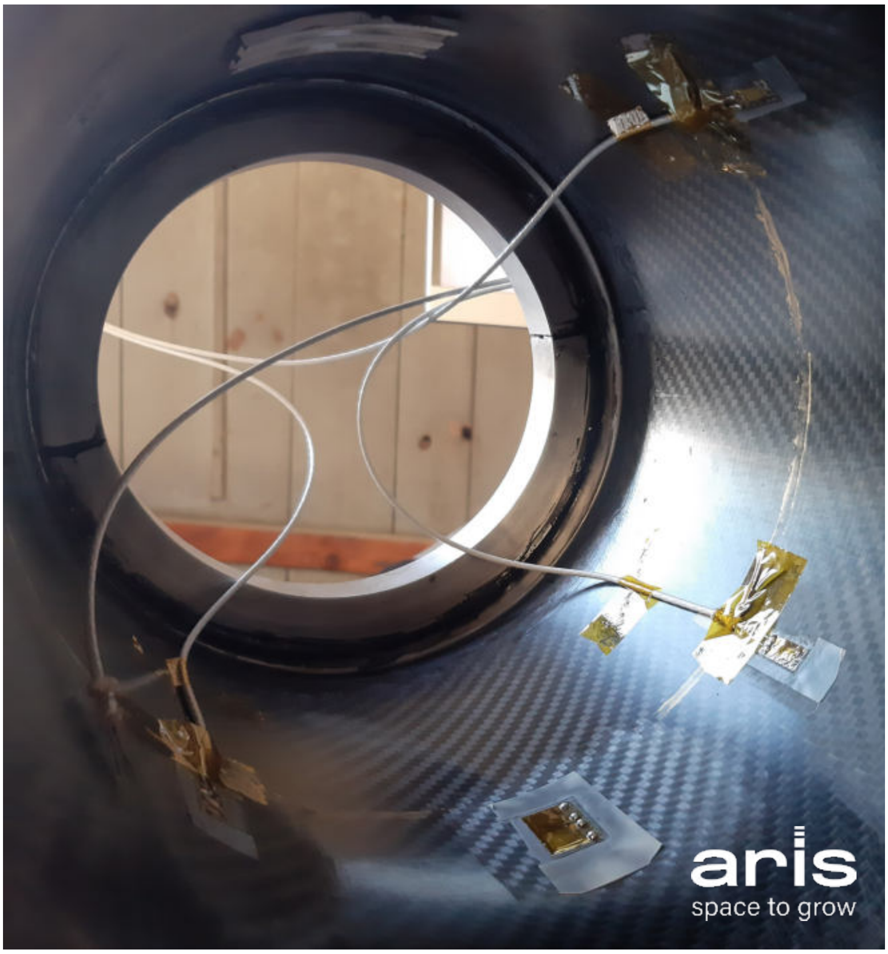
CASE STUDY

Experimental stress analysis: students conquer the outer limits of the troposphere with HBK

Students from the Academic Space Initiative Switzerland (ARIS) at the Eidgenössische Technische Hochschule Zurich (ETH Zurich) public research university have been building research rocket since 2017. In 2020/21, a team of more than 50 motivated students, studying for Bachelor, Masters or PhD degrees, produced the 4th generation of research rocket as part of the PICCARD project, and entered the European Rocketry Challenge (EuRoC) in Portugal.



CHALLENGE

A rocket's structure is exposed to considerable stress during flight. Some of this stress can be established through simulation. However, some critical influencing factors, such as wind or the shock of the drag force when the parachute opens, cannot be precisely determined in analyses.

SOLUTION

To verify the loads acting on the aerostructure of the PICCARD research rocket in flight conditions (using simulation) and to correct them if necessary, a system for monitoring actually-occurring bending moments and axial forces was incorporated in the research rocket. HBK strain gauges are at the heart of this experimental stress analysis system reliably delivering meaningful measurement results even under extreme conditions.

RESULT

In the past, the ARIS teams had established the forces acting on the research rocket in flight purely analytically using simplified assumptions via simulation, but for the PICCARD mission a dedicated monitoring system was used for the first time. This was integrated in the rocket with the rugged strain gauges delivering useful results on the loads acting on the rocket's aerostructure.

Their aim was to win the prize in the category, 'a student researched and developed engine reaching an altitude of 30,000 feet' with their PICCARD research rocket. For the first time, the research rocket had a hybrid-propellant engine, developed by the students. The functional capabilities of the system were demonstrated by a successful launch at the EuRoC in October 2021. This success was also achieved by virtue of a new monitoring system to measure the loads on the rocket's aerostructure. The HBK strain gauges used in this system delivered valuable information about bending moments and axial forces occurring during all phases of flight.

ETH ZURICH STUDENTS REACH FOR THE STARS

The non-profit association Academic Space Initiative Switzerland was founded at the ETH Zurich public research university in August 2017. Ever since, it has encouraged students to deploy their theoretical knowledge into practical projects. So, the ARIS teams develop rockets to enter competitions around the world for young academics and ambitious non-profit organizations.

2020 saw the launch of the 4th ARIS mission with the PICCARD project. The aim of this mission is to win the Spaceport America Cup 2022 in New Mexico. For this competition, the team want their rocket to transport a payload of four kilograms to a height of 30,000 feet and then return all components safely to Earth. To achieve this, 50 motivated students developed the completely new PICCARD rocket.

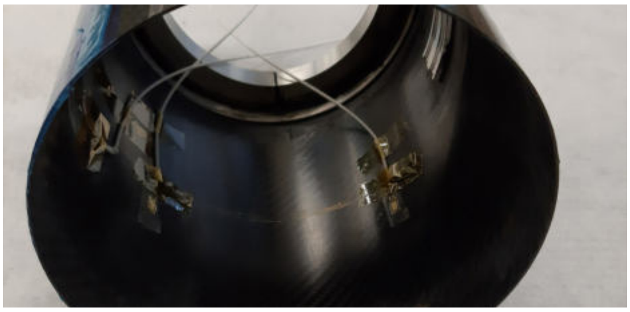
For the first time, unlike its predecessors with outsourced drive technology, the PICCARD has a student researched and developed hybrid-propellant engine. The new rocket achieved a successful first flight at the European Rocketry Challenge in Portugal, demonstrating that the system works.

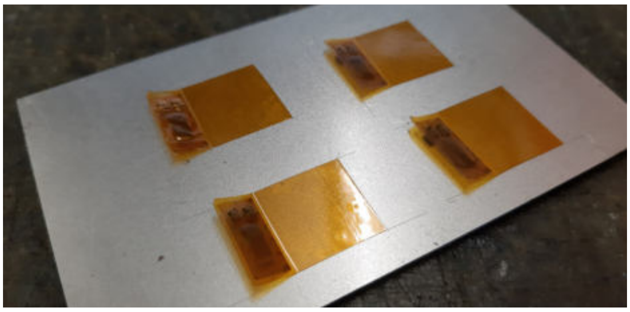
As well as the new engine, a monitoring system integrated in the rocket and based on HBK strain gauges was used for the first time. With its help, the PICCARD team were able to gather valuable data during the flight, enabling targeted optimization of the rocket for a successful launch in New Mexico.

THE STEEP ROAD TO AN OPTIMUM AEROSTRUCTURE

A sufficiently rugged aerostructure is essential for ensuring that the PICCARD rocket can successfully achieve its flight and return to Earth. It has to cope with all the forces occurring at all phases of the flight while being as lightweight as possible. That is the only way it and its payload can be self-propelled to the desired height. Therefore, the team needs precise knowledge of all possible loads acting on the structure during flight, so that the rocket can be endowed with maximum strength and minimal weight.

During the development of the PICCARD, the students used simulation to determine the most important fundamental parameters for designing the rocket's aerostructure. However, models only give an approximate idea of external influences that are difficult to predict, such as wind. By contrast, in-flight measurements deliver precise data on actually occurring forces, which in turn enables optimum design of the aerostructure.





SUCCESSFUL LAUNCH OF MISSION MONITORING SYSTEM

In a separate sub-project, the students developed a lightweight, easy-to-implement and yet precise monitoring system for the PICCARD mission. The finished system was installed above the tank of the rocket, allowing the bending moments and axial forces occurring during the rocket's flight to be recorded. This data now forms the basis for further optimization of the design of the rocket's structural parts, in the hope of taking first place in the 2022 Spaceport America Cup.

A total of three Wheatstone bridges, two for moments in the x and y directions and one for axial forces in the z direction, each with two HBK strain gauges, were installed in the monitoring system for measuring loads. The strain gauges were attached to the inside of the rocket's carbon-fiber shell. 350Ω strain gauges were used and supplied with a high-precision voltage of 3.3 V. All signal cables were shielded to ensure optimum signal quality and grounded on the circuit board. Previous tests showed that the module generated very little noise. The sensors were calibrated by means of a 3-point bending test. To demonstrate bending load, loads up to three quarters of the maximum were introduced.

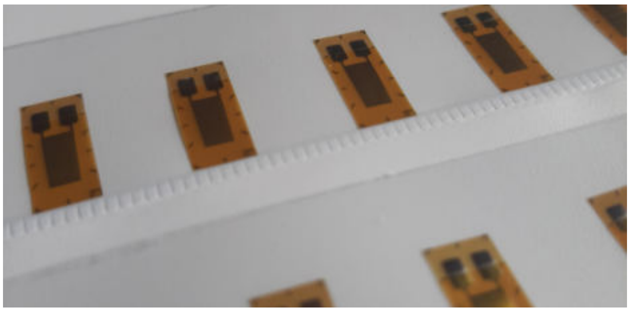
The strain gauge setup for the bending moments enabled the deformations to be compensated by axial forces and temperatures. On the other hand, the setup for axial forces measured force components caused by bending and normal forces, and only compensated for temperature-induced deformations. To gain direct information on axial forces, further processing of this measured data is required.

PRECISE DATA ENABLES OPTIMIZED STRUCTURAL PARTS

The new monitoring system demonstrated its capabilities during its first use in Portugal. It reliably measured loads during the flight and delivered most of the hoped-for data. The axial forces and bending moments in the x and y directions could be precisely determined from the rocket's launch to the apogee (highest point) of its flight.

Unfortunately, it was not possible to collect meaningful data during the return to Earth: the parachutes did not deploy as planned at the apogee due to a technical fault in the parachute system. They opened only during the descent, when the rocket was falling at a speed of 240 m/s. The shock forces this caused were so great that the rocket broke apart.

Despite the lack of measured values for the descent, the data still enables a better understanding of the system. This way, the aerostructure of the PICCARD rocket can be further optimized, raising the possibility of victory at the 2022 Spaceport America Cup.



HBK DELIVERING THE BEST RESULTS

When choosing the measurement technology to be employed in the newly developed monitoring system, strain gauges from HBK were the obvious choice. The decision was based on positive experiences in the past, coupled with the company's international reputation as a supplier of measurement technology that delivers precise results even under the most demanding environmental conditions. Another advantage was the ease with which the strain gauges could be integrated, living up to HBK's promise of 'plug and measure'. In addition, the HBK team were dedicated to supporting the PICCARD project with help and advice. This, plus HBK's identification with the mission's goals, are convincing arguments in favour of future collaboration and further successful projects.

ABOUT ARIS AND ETH ZURICH

At the Academic Space Initiative Switzerland, motivated students at the ETH Zurich public research university have been working intensively on building rockets since 2017. Their goal is to apply and deepen their theoretical knowledge to successfully take part in various aerospace competitions. ETH Zurich is a university specializing in technology and the natural sciences. It was established in 1855 and is today one of the world's best-known universities. Around 23,000 undergraduates and postgraduates are enrolled in 16 departments.

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