Development of a test stand for experimental rocket engines

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The development of innovative engines and rocket propellants requires adequate infrastructure for testing and verification of design assumptions. As part of the scientific and research activities in the AGH Space Systems Student Association, such projects are being developed and compete with student designs from around the world. The opportunity to verify the solutions used and to translate theory and calculations into practice is therefore essential for further research progress. With these requirements in mind, a rocket engine test stand was designed and constructed. A truss structure favorably distributing the pressure generated by the running engine is connected through linear guides to the carriage, interacting with the strain gauge sensor. The fabricated prototype of the test stand makes it possible to assemble motors, diversified both in terms of construction and size, which does not limit the possibilities of rocket propulsion development.[1]

2022 engineers from AGH Space Systems set themselves the goal of creating their own static engine test stand equipped with a proprietary measurement system, allowing, among other things, to determine engine thrust, pressure or fuel level in the rocket. The device was also intended to enable remote control of the cylinder refueling process and the ignition sequence. Due to the high forces generated by the rocket engines during operation, the created structure had to feature high strength, ensuring its stability and safety. Since the team is constantly developing further propulsion unit designs, as well as researching new types of propellants, the developed structure was to be used for both static testing of small-scale demonstration engines and for small-scale testing of new design solutions different types of propellants, as well as the team's flagship designs with a maximum thrust of 3-4 kN. It was also supposed to be used to evaluate a new series of propulsion systems, with a target thrust of up to 30 kN. For this reason, it was necessary to adapt the stand to suitably accommodate motors of varying design and size and to ensure the structure's ability to withstand the impact of thrust forces of varying courses.

After preparing the preliminary design of the test stand, the team faced a challenging task: choosing the right construction material and verifying that its frame would not deform during engine operation, which could prevent full use of the stand. Therefore, the most optimal solution turned out to be to test the test stand in advance through computer simulation. The AGH Space Systems team used the Ansys Mechanical package, which enables Finite Element Method (FEM) simulations, for this purpose. Due to positive simulation results indicating adequate resistance of the frame, the design was accepted and moved to the manufacturing stage.

After conducting a few series of testing rocket engines at the stand, it was decided to use innovative technical solutions to improve the reliability of the design and adapt it to the requirements of the team's next projects.

In particular, the changes involved the test stand's electronic control and measurement system. The activities were aimed at both adapting the construction to the new engine architecture and enabling the handling of new data sources as well as quantitative improvements, increasing the accuracy of measurement range and reducing the negative impact of the presence of noise, nonlinearities and disturbances due to environmental influences. This resulted in increased measurement precision and the ability to perform more extensive analysis of test objects.

Sensor networks were integrated with additional "S" type strain gauge cells with measurement ranges of 2500 kg and 1000 kg. This increased the measurement range and configurability of the system as well as gave us a more advanced insight into the engine's operating characteristics, allowing us to measure values such as thrust, vibration, oscillation, parameters of the fuel used, pressure in designated areas and the quality of the combustion chamber's thermal protection components. The hydraulic system of the test stand was expanded to include low-noise pressure transducers and servos for valve control. Valve control system is responsible for oxidizer flow, which is a fundamental part of the drive system. The efficiency of the hydraulics also affects the performance of the propulsion system and the safety of its operation, as it directly affects the flow of propellants and thus, the performance characteristics of the engine.

Control and electronic systems responsible for measuring the level of fuel in the rocket using magnetic sensors were created. As electronic components were updated, it is possible to take measurements aimed at designing the device's control algorithm. The sensors used in the development of the test stand were characterized by substantial sensitivity and reliability, so that the performed tests are marked by high precision.

The electronic apparatus operating the test stand's sensors and mechanisms was improved. The production of the necessary control and measurement systems involved the design and manufacture of suitably adapted PCBs using an advanced technological process to achieve satisfactory signal integrity. It was necessary to purchase analog-to-digital converters with high resolution, signal-to-noise ratio and sufficiently high sampling frequency, as well as microprocessors and memory modules capable of handling the assumed data stream throughput.

Radio modules were also introduced, allowing remote control of the test stand. Thanks to the cameras used, an observation of the propulsion system testing from a safe distance is possible. This allows the realization of one of the most important stages of the rocket construction process – the testing of the propulsion system together with electronic systems, taking into account factors whose occurrence is impossible to simulate within the framework of available tools. In addition, it makes it possible to check the operation and compatibility of components in real environmental conditions, while protecting the overall design.

The implementation of this project has positively influenced the work on projects developing rocket technology. Rocket engines, as one of its most important parts, can be now thoroughly tested under all possible conditions. They were checked not only for the performance of their design and the fit of individual components for engine operation, but also for the safety of operators.

The test stand, located in one of the University's out-of-town laboratories, significantly improved the engineering team's performance of all tests and inspections. The construction is characterized by a high degree of innovation on a national scale. Currently, there are only a few such structures in Poland, owned by space companies and scientific institutions such as the Łukasiewicz Research Network – Institute of Aviation.
Earlier, the test stands on which the team had conducted tests of propulsion units were not equipped with electronics enabling sufficiently precise measurement of engine performance parameters, which made it impossible to conduct advanced analysis of test data. The implementation of the project has made it possible to improve the quality of the data obtained, and to adapt the design to new types of engine architecture and support diverse data sources.

The created test stand formed the basis for the development of the 3-TTK hybrid rocket and contributed to the development of its second iteration, the 3-TTK+. The engine of this rocket was checked for consistency in simulating the behavior of its various systems under specific environmental conditions during a series of tests. The tests addressed both the performance and stability of the engine, as well as the efficiency of the entire test stand and its compatibility with electronic systems.

Thanks to that, the 3-TTK rocket won third place in its category at the prestigious Spaceport America Cup 2022 competition. The rocket engine test stand also became the basis for scientific papers, including the engineering paper "Design and construction of a rocket engine test stand". In addition, the work on the project was presented as part of the paper "Design process of complex and reliable testing equipment for experimental rocket engines" at the 25th ESA Symposium on European Rocket & Balloon Programs and Related Research conference. The team also presented the results of the test stand development at the 2022 Space Mining Conference. In 2023, the 3-TTK+ rocket took 4th place at the Spaceport America Cup 2023.


Figure 1. First test stands for rocket motors manufactured by AGH Space Systems.


Figure 2. N-class motor during a test on the old equipment adapted to large motors.

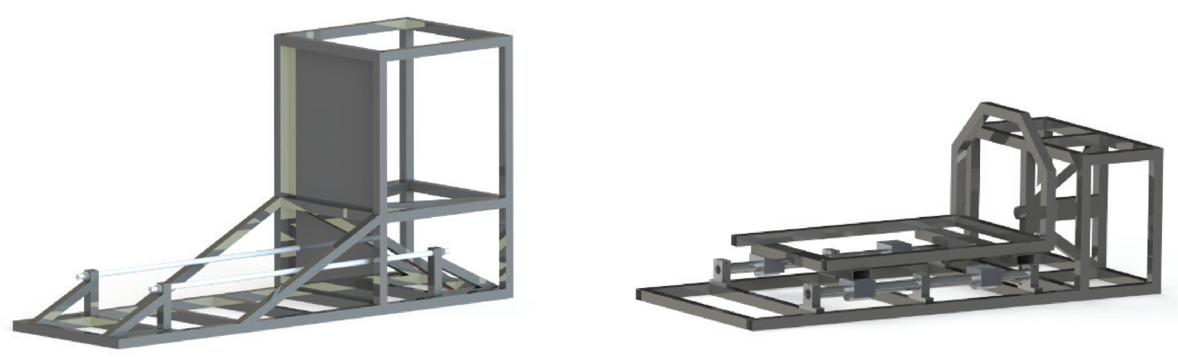
Figure 3. First iterations of the new test stand.


Figure 4. Final design of the new testing equipment with application example for liquid propellant motor.

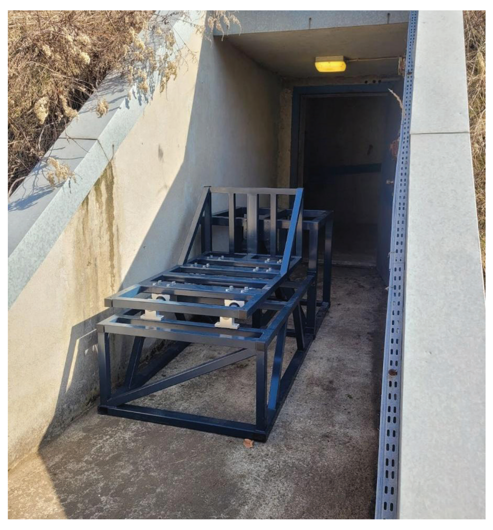
Figure 5. Manufactured test stand at its final location provided by AGH UST.


Figure 6. B3 AGH Space Systems developed motor mounted to the test bench.

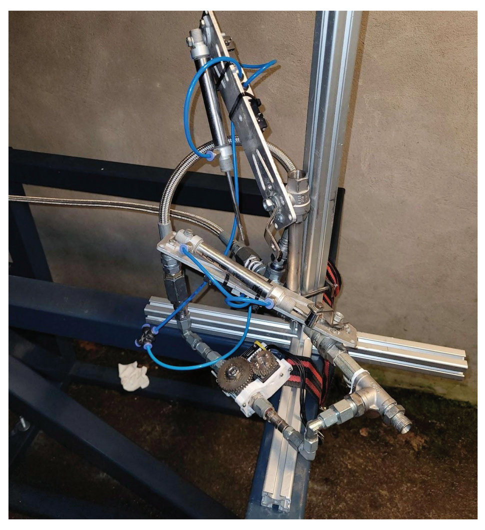
Figure 7. Picture of the test setup.

Figure 8. Frames from the IP cameras – idle test setup (left), engine during test (right).

1. Korczyński, R., (2022), Design and construction of a test stand for rocket engines.