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Agile component of infrastructure in New Space companies

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Abstract
Each year more and more companies are making their infrastructure that can be moved to any place, easily scaled, or quickly modified for different purposes. Łukasiewicz Research Network – Institute of Aviation (Ł-IoA) also uses, creates, and designs this type of agile infrastructure. The authors of the paper analyze existing solutions for mobile infrastructure around the world, and present future trends in the space economy. The paper also presents the design and status of the Mobile Laboratory for Rocket Propulsion (MOLAR) and lessons learned during the design and usage of the Mobile Rocket Launchpad (WR-2).

1. Introduction

Among smaller and larger companies, especially new start-ups, a growing demand for testing services can be observed. Usually design and build processes of complete test facility or launch infrastructure are very expensive [1] [2]. Consequently, a more advantageous solution is to outsource testing services to entities that already possess such infrastructure, knowledge, and experience in this field. This can significantly reduce the time between the initial project and the working solution but at the same time can increase the cost of testing part of the project. Paper presents solution that in many cases cost and time-effective and in many cases can solve scaling challenge for New Space companies.

Testing facilities are often built for specific large projects, that are meant to be developed and tested for years. Adapting such infrastructure to another project can be time-consuming and unprofitable from the perspective of the testing facility if the test object is not intended for long-term research.

Other aspects to consider include restrictions and legal requirements imposed on facilities located in densely populated areas or cities. Many test facilities handling early stage of development (TRL 3 – 6) are challenged by the higher risks of testing. Very often anomalies during testing must be taken into FMEA (Failure Mode and Effects Analysis) as probable. In such cases, testing certain solutions becomes impossible not due to technical reasons but organizational ones. Testing these types of dangerous projects typically takes place in testing ranges owned by the military or other isolated locations, where anomalies occurring during testing will result at most in prototype and/or test hardware loss.

The test infrastructure on the military test ranges often leaves much to be desired or is completely unsuited to the requirements of the project. However, to ensure an appropriate level of safety for test personnel and third parties, these inconveniences must be accepted. The natural order of things is to develop its own infrastructure, to be independent, and assure the desired quality of research.

Mobile test infrastructures

The idea of mobile test infrastructure probably was firstly adopted by universities. University campus usually is highly populated area, very often placed near the city. High risks related with testing are enforcing creative solutions like mobile test platforms – mounted on the trailers or in the shipping containers.

Even novice engineers, including university students, see the need to test their prototypes while paying attention to safety issues. Consequently, it becomes necessary to have your own mobile test stand. One such mobile test bench is Project Atlas carried out by members of the Experimental Rocket Propulsion Lab (ERPL) at Embry-Riddle Aeronautical University's Daytona Beach [3]. Atlas is a trailer-mounted mobile test stand, intended for testing rocket

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engines using liquid propellants and hybrid engines in a horizontal orientation. The maximum thrust of the tested objects can reach 22kN. A control and measurement system has been integrated at the stand. One of the main reasons for the creation of the test stand was, as the authors emphasize, the restriction issues related to Class-3 airspace and liability issues.

Another example of a mobile test bench is the Hydra project (Figure 1). Hydra was developed in the student-run Liquid Propulsion Laboratory (LPL) at the Viterbi School of Engineering at The University of Southern California (USC) [4]. Hydra was designed to be easily modified and enhanced for future uses. Hydra was designed with versatility in mind: sensors can be easily added, the software can be modified, various engines/ignition systems can be accommodated, different pressures can be set effortlessly, and various fuels (liquid) and oxidizers (pressurized gas) can be used. The main test objects are engines for liquid propellants, with a maximum thrust of 4.5 kN.

The Mobile Rocket Engine Test Stand (Figure 1) is another example of a trailer-mounted mobile test stand developed by students and staff from California State Polytechnic University Pomona [5]. MRETS can handle a thrust force of approximately 22 kN. The test stand can accommodate different liquid engine rockets, and it provides for cryogenic propellant storage and a feed system. The mobile rocket engine test stand contains a range of sensors to measure thrust, pressure, and heat generation. The structure subsystem comprises a support structure specifically designed to bear the engine's weight and withstand potential explosions. The support structure utilizes two rails, with carriages positioned on them to hold the engine mount securely.

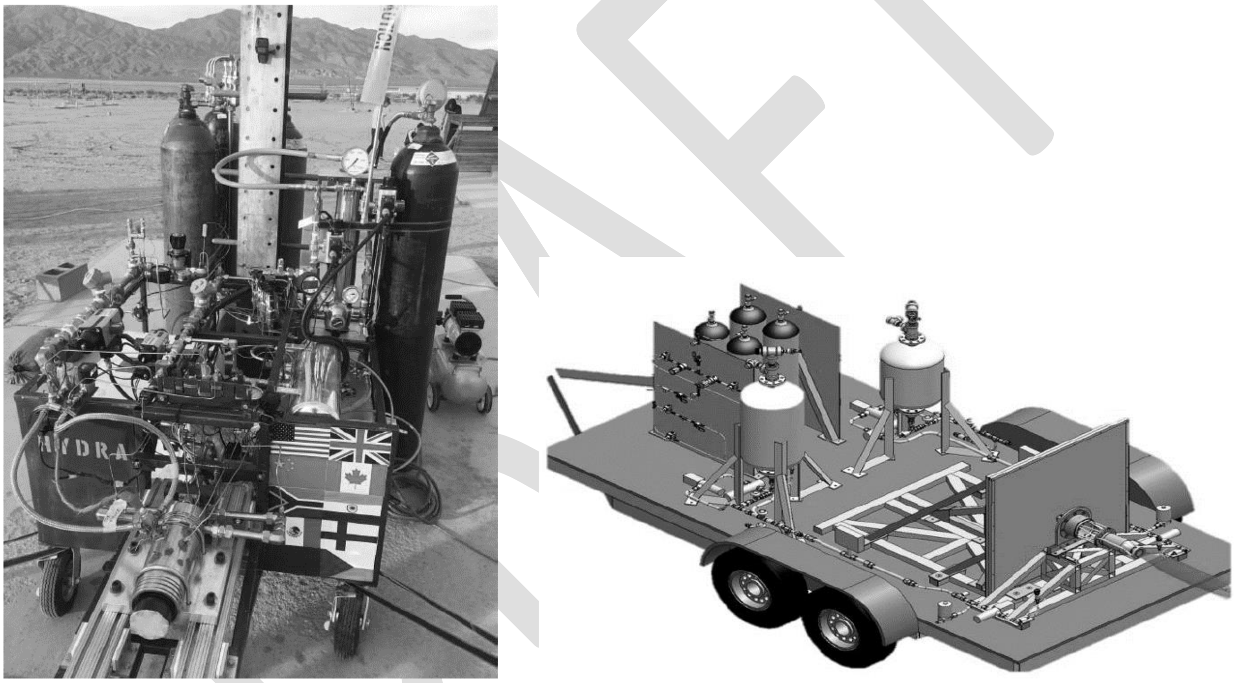

Figure 1: Hydra test bench [4] and Mobile rocket engine test stand [5]

The above examples present test stands designed by students and universities primarily for educational and scientific purposes. However, mobile test stands are also designed and constructed for commercial needs. Such test stands are often created for specific projects undertaken by a particular company. An example of this type of infrastructure is the container-based test stand for the suborbital hybrid rocket Perun [6], which can be seen in promotional materials of the domestic company SpaceForest (Figure 2). The test stand was built using a standard 20-foot container and can be used safely for testing a rocket propulsion module with a thrust of approximately 30 kN. This solution integrates propellant delivery system and (self-pressurizing N_2O) and test bench in one container.

Abyom is a company whose vision is to be India’s First Private Space Tech Company to develop Reusable Rockets with a specialization in Re-Ignitable and Throttleable Cryogenic Engines. Abyom opened an Engine Testing Facility on Wheels specially designed and developed for testing Engines capable of measuring up to 50 kN thrust force for Research & Development purposes (Figure 2). Abyom is aiming to serve with this solution on the market of new-space start up’s and universities.

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Figure 2: Perun rocket test container [6] and Abyom mobile test container [7].

Above examples presents hot-fire test infrastructure that can be quickly moved from one place to another, without complicated setup operations suitable for testing propulsion in atmospheric conditions, very often with integrated setup on one platform (container). There are also existing examples of more distributed and advanced, mobile system – company called Agile Space Industries created mobile test stands. Agile Space Industries started as Advanced Mobile Propulsion Test (AMPT), on leased property from local airport in Durango, Colorado, US. From the beginning one of their goal was to create test stand that can be relocated to the other place for testing purposes [8]. Their test facility is consisted from greatly modified shipping containers that serves as propellant delivery module, control room or pumping station. As one of the few Agile Space Industries have capabilities to provide test services under vacuum conditions (under 10 mbar) for storable propellants [9]. On their smaller test stand (up to 4,5 kN) and under atmospheric conditions on the larger one (up to 26,7 kN) they are providing qualification services for flight-like thrusters. Their systems beside creating Vacuum environment can also provide propellant conditioning (from -45ºC up to 70ºC).

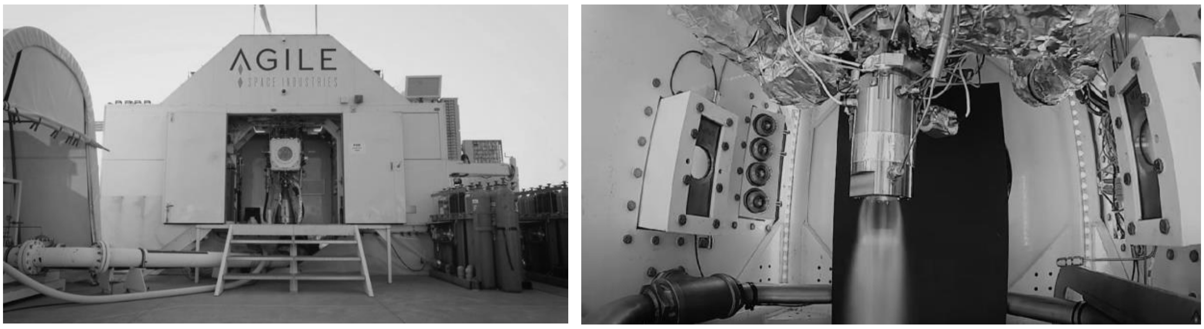

Figure 3 Agile Space Industries Vacuum Test Stand [9].

Mobile launchpads

Another problem for entities without heritage in testing are flight tests and launches of suborbital and sounding rockets. Designing and manufacturing infrastructure required to safely launch is often a task requiring additional manpower and resources which might delay project timeline. Still, some organizations, especially those planning long running programs, decide to develop their own launchers.

One of them is Copenhagen Suborbitals. This Denmark-based non-profit organization is aiming to launch a crewed suborbital rocket from an aquatic launchpad. The platform was used in many campaigns with success [10]. While seafaring craft creates great flexibility in choosing launch location and thus flexibility with launch profile, it must be noted that platform this size with fixed rail limits weather window for launching especially with unguided rockets.

Another example is TEL (Transporter Erector Launcher) developed by Space Forest company. This trailer-mounted platform allows for road transport to many launch locations available, thus providing wide variety of launch setups. So far the launcher was used in Perun rocket campaign earlier this year at Ustka military range.

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Figure 4: TEL as presented in [6]

In similar fashion operates Equatorial Space Systems from Singapore. This company aims to provide suborbital launch services based on setup consisting of two freight containers (including launcher itself), which allows for quick and easy transport [11]. First flight is planned for 2024.

Presented above examples all represent a growing trend of small scale launch philosophy. With limited access to main industry centres, more and more entities turn to modular, transportable launch systems that can be tailored to specific needs of given campaign. Securing a perimeter and preparing specific launch setup - launcher, control centre, fuelling and support systems is much easier reachable for new space companies.

Test Infrastructure Development in Łukasiewicz Research Network – Institute of Aviation

The main area of interest of Łukasiewicz Research Network – Institute of Aviation (Ł-IoA), Center of Space Technologies is aimed at the research and development of rockets and space propulsion. The vast majority of the developed solutions are utilizing Highly Concentrated Hydrogen Peroxide (>98%) and several novel non-toxic fuel formulas. Currently, almost all of the designs are verified during hot-fire test campaigns at the in-house test facility that started operations in 2011. The main atmospheric test facility is a heavily modified decommissioned jet propulsion testing facility. The unique building with a sound suppression system allows for the indoor testing whole year, regardless of weather conditions. The sound suppression system and thick concrete walls allow for safe and nearly silent operations near the airport and offices, where over 1 300 people are employed.
Hypergolic engines, hybrid motors, monopropellants, and bipropellants were tested also with throttling capabilities. Advancement of the developed engines forced constant development of the whole test facility including the control and measurement system (driven by custom-developed software). Besides engines that are using liquid propellants, there are some projects dedicated to solid rocket motors. More about current green propulsion test facility and its development can be found in [12]. Due to the age of the facility building and location some of the modifications can’t be done in cost-effective manner.
The Ł-IoA headquarters is located in the biggest city in Poland and is also in close proximity to the largest airport in Poland. In response to both internal and external demand for conducting highly experimental test campaigns, two major projects have been initiated, allowing us to perform high-quality tests as well as perform them safely. The first of these is the Mobile Rocket Launchpad WR-2, which has already completed the first successful launch of the ILR-33 AMBER rocket. The second project is the Mobile Laboratory for Rocket Propulsion (MOLAR) [13], which is in the manufacturing stage. The project is evolving, and new ideas and improvements are incorporated into the design [12]. Below, details regarding the missile launcher, as well as the concept and assumptions of the MORLAR project, will be presented. Ł-IoA is conducting analysis of mobile infrastructure since 2009, when first concept of mobile test facility, mounted on large truck was introduced [14].

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Mobile Laboratory for Rocket Propulsion – MOLAR

The demand for mobile testing infrastructure arose due to the carrying out of numerous projects. Current facility location and capacity in terms of number of testing, quantity of propellants and force introduced by the test object are at the limit of current test facility. Some of the projects must be tested at another test site of Ł-IoA partner, some test requests can't be fulfilled by Ł-IoA due to mentioned limits. Currently, various types of rocket engines using liquid propellants and hybrid engines are being tested, with a particular emphasis on HTP (high-test peroxide) as an oxidizer. For safety reasons, the maximum admissible thrust has been set at 5kN, and for hypergolic propellants, the limit is even lower. Due to the same safety considerations, the rocket propulsion laboratory does not conduct tests involving solid propellant motors on the premises. Major scaling of current test facility would introduced upgrade costs and pause the testing capabilities for a longer period.

The principle in designing MOLAR is to ensure the capability of conducting high-quality tests in facilities adapted for this purpose but utilizing its testing infrastructure. Another important aspect is to provide universality through modularity, allowing for easy adaptation of the test unit to specific test objects with minimal effort and costs. MOLAR is also designed with scalability in mind in terms of number of test benches.

Mobile Laboratory consists of several modules, some of the modules are optional, since they don't take part in every test (i.e. propellant delivery modules are not needed for every type of rocket propulsion). Modularity is key aspect of agile concept, where you don't have to use, setup, maintain or move whole laboratory for conducting test campaign. All modules will fit into standard 20-foot and 10-foot containers. Such a solution enables easy transportation and unloading of the entire infrastructure at the destination. Thanks to container standard laboratory can be transported through sea, train or road.

MOLAR is consisting of following modules (visible on Figure 7):

Test Module (mandatory)– Main module where test object is mounted. The main test container, reinforced with an additional steel structure capable of handling significant forces of normal testing and anomalies that can occur during. The structure was designed for engines capable of reaching thrust up to 60kN of nominal thrust. The entire unit will be mounted on concrete footings, ensuring stable and secure placement on the ground. Volume inside container is divided into 2 spaces – test area and DAQ area (service area). Service area is holding DAQ hardware, some of the electrical safety systems, pneumatics and hydraulics installation. Test area is safely separated from the service area. Test area provides universal thrust bed that allows for mounting solid rocket motors (longer), hybrids and Liquid Rocket Engines (LREs). Internal materials were chosen to be compatible with Hydrogen Peroxide (min. class 2).

Control Module (mandatory) – Module that hold work stations needed for controlling MOLAR. Control module is connected to the rest of the modules only with the data light fiber giving secure and reliable connection. Control module can be placed up to 500 meters from the rest of the modules giving secure spacing between experiment and operators that control the laboratory.

Fuel and Oxidizer modules (optional) – Modules that will provide propellants to the test module. In case of testing hybrid rocket motors only oxidizer delivery module will be needed. In case of testing solid rocket motor none of them will be needed. First version of the laboratory consists of the storable propellant delivery modules (Hydrogen Peroxide and storable fuels), pressure feed up to 60 bar of pressure. Future development plan involves development delivery modules for cryogenic propellants.

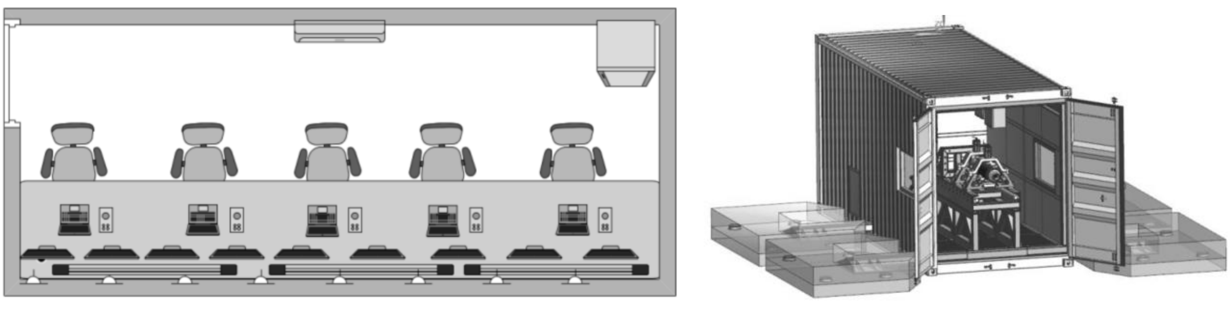

Figure 5 - Control and Test Modules, MOLAR.

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The following elements, which will be located in the test container, are listed below and depicted in Figure 6:

- test bench allowing mounting of various types of engines,
- articulated boom crane capable of operating outside and inside the test container, enabling the assembly of massive test objects,
- safety infrastructure and fire suppression systems.
- necessary measurement instrumentation and camera systems,
- air-conditioned room with control and measurement equipment.

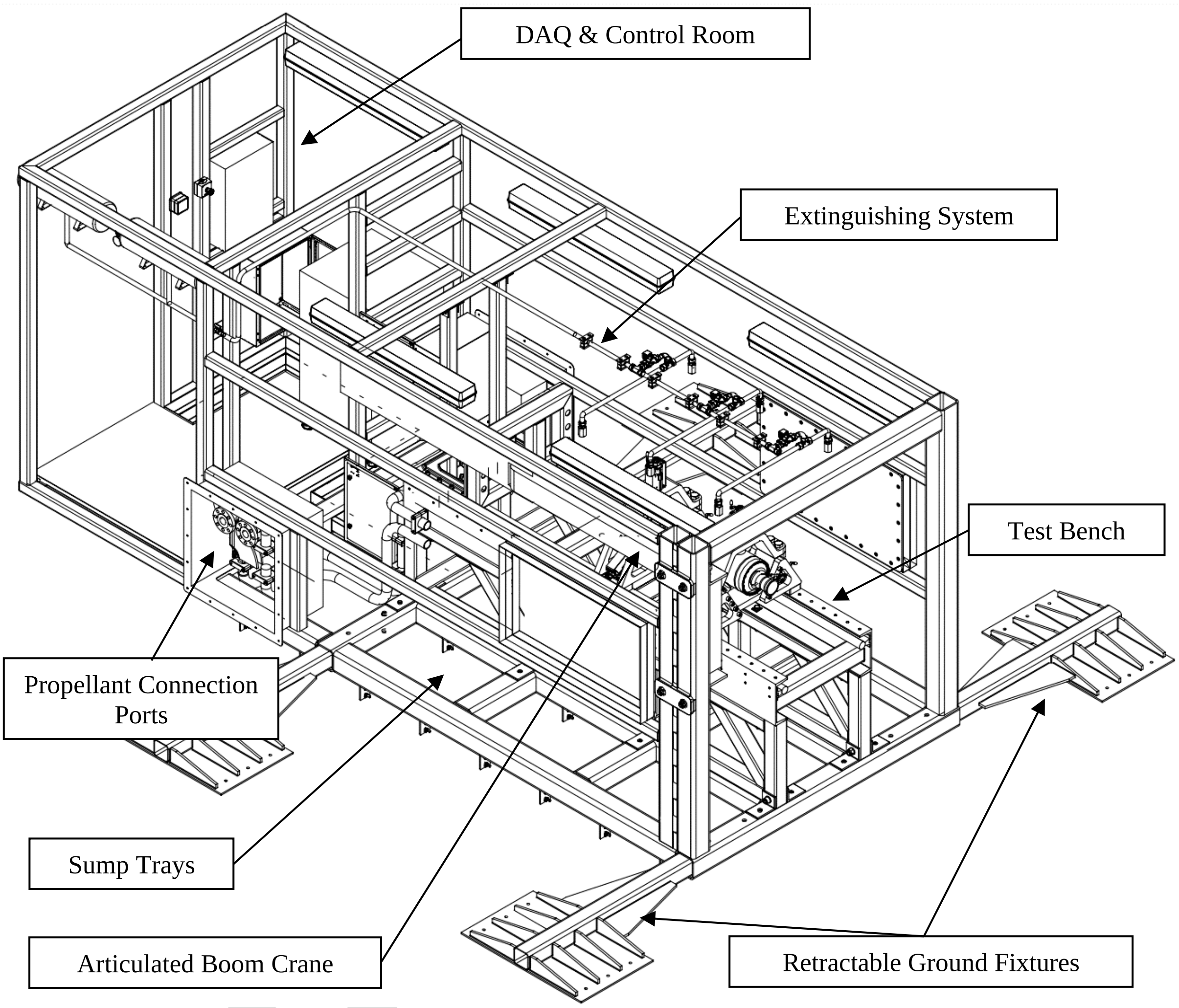

Figure 6: Test container design

Control will be performed from a separate control container connected to the test container through a fiber optic network. This solution allows for high-speed transmission of measurement data, real-time monitoring from camera systems, and high responsiveness to actions taken by the test personnel. Additional modules, such as liquid propellant feeding installations, are designed to be added as needed. Control and DAQ network will be realized in mech topology to provide redundancy and high reliability.

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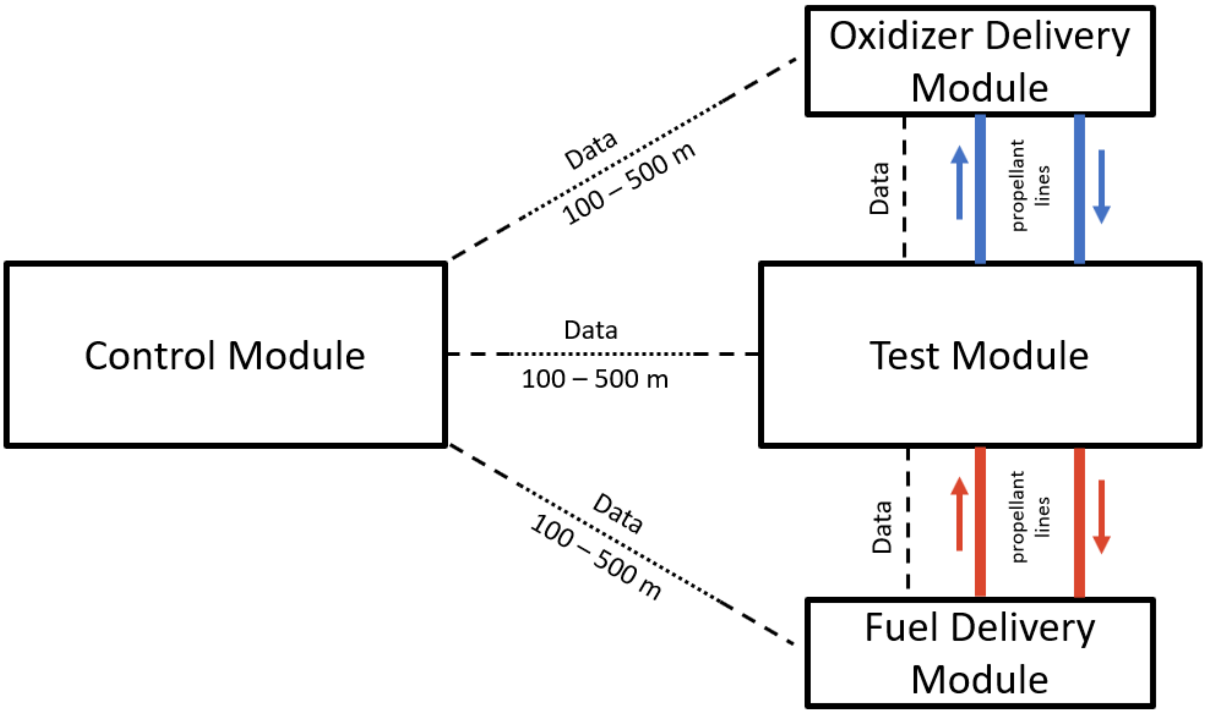

Figure 7: Connections between separate modules

Scaling number of the test benches is possible with multiplication of the Test Modules. Control module due to the ethernet network infrastructure and developed software can provide control to the multiple test benches. In that case cost of enlarging test capabilities of the laboratory are minimal because just the essential hardware is multiplicated and there is no need for large infrastructure investments.

Mobile Rocket Launchpad – WR-2

Simultaneously with the continuous development of rocket technology in Ł-IoA, there was a natural demand for a new version of the mobile rocket launcher. The new device should ensure adjustment of the growing requirements and additional functionalities to improve the operation and safety of the event service on external places dedicated for this type of tests.
The new launcher was named WR2. WR2 is a prototype of independent mobile device for launching suborbital rockets. All conceptual and design work was done from scratch by a team of Ł-IoA engineers from the ESG department. Despite the single production, this construction was implemented taking into account the best technical knowledge in terms of functionality, reliability and safety of its use.
The purpose of the launcher is to give the rocket the direction of the intended shot. The WR2 is designed to support single or multi-stage suborbital rockets with parallel or serial stages, with a mass up to 3000 kg and a maximum thrust of 60 kN.
WR2 is in the form of a cuboid with overall dimensions of 11.62 x 2.24 x 2.1 m^3 (length x width x height) and a gross weight approx. 11.5 tons (with flooded hydraulic and fuel systems) operating condition. In the transport version, the weight of the set is approx. 13 tons. This set includes additional WR2 equipment packed and transported on it. WR2 is adapted for truck transport. Thanks to the system of hydraulic legs, it is possible to independently raise the frame to a height enabling loading on a semi-trailer. This is how it was transported in Poland. The shape of the cuboid allows the WR2 to be loaded into a standard 40 ft container. This solution enables easy transport to any place in the world with a developed port infrastructure.
For the transport and extended parking the WR2 is protected by a full transport roofing – effective protection from weather conditions. In addition the WR2 is equipped with a partial roofing, which enables comfortable work of the rocket's crew in unfavorable weather.

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Figure 8 – WR2 Mobile Rocket Launcher during transport and preparation.

The WR2 structure consists of 7 main modules, which include:
1) a frame with service platforms,
2) a 10.98 [m] long starting arm,
3) a hydraulic system,
4) an electrical system with a control system,
5) a roofing,
6) an anchoring system and
7) a deflector.

The WR2 is adapted for use on paved ground, with a small slope angle which is compensated by leveling on hydraulic legs, in the temperature range: -30 °C to + 50 °C. WR2 is adapted to be equipped with a chassis module enabling entry / exit from the transport container and allows to move over short distances within the launch area. GPS antennas and a movable arm (rotation and tilt) makes it possible to take the exact position for the direction of the shot - with an accuracy of 0.1°. Essential function of the launcher is an ability to make corrections to these values during the preparation process of the rocket start. After taking into account volatile atmospheric conditions, azimuth and elevation angle adjustments can be easily, quickly and safely made using the remote control panel. WR2 has two control modes - local control using the HMI panel and remote control via GSIA-L applications.
The WR2 has the option of using two alternative power sources: self-powered by a power generator or mains power from a three-phase source (400AC [V]z, 50 [Hz]). As part of its electrical system, it has 12 single-phase sockets (230 [V]) for general use for additional research infrastructure. In addition, WR2 has a guaranteed UPS power supply, sufficient for approx. 10 [min] operation.

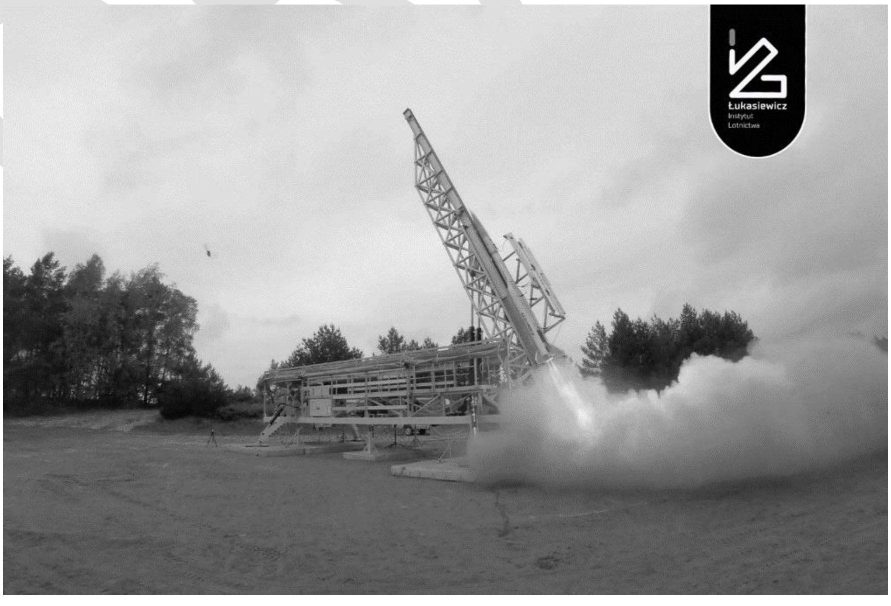

Figure 9 - WR2 during launch of ILR-33 Amber 2K suborbital rocket.

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The control system of the mobile rocket launcher is equipped with a security system responsible for monitoring critical process and test parameters. If a dangerous state is detected or the alarm value of a parameter is exceeded, the safety system is responsible for performing an emergency stop according to a defined algorithm.

The flight test confirmed the efficient operation of all components of the WR2 Launcher, which enabled the launch of the ILR-33 Amber 2K rocket in accordance with the test program.

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