One Rocket Closer to Space

Team 105 Project Technical Report for the 2018 IREC

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Within the framework of AGH Space Systems student's society the project of the Turbulence rocket system is being run. Project has been started in November 2017. The idea is built around a two-stage rocket, in which both stages are propelled by single SRAD bi-liquid engine from the Zawisza series, which is one of the very first rocket-scale, bi-liquid engines in Poland. The first stage of The Turbulence is The Booster, on which this document focuses, and the second stage is The Sustainer. Each of these stages will be equipped with own propulsion, avionics, recovery, payload compartment and other elements necessary for independent operation. First milestone that was set for Turbulence project is to take part in Spaceport America Cup 2018 competition. For this purpose BS10 version of single-stage Booster is been developed. This paper reports the technical details about project progress. BS10 mission is to launch with 9 lbs payload to altitude of 30,000 feet in SRAD category. The large variety of subsystems embrace all branches of engineering, the unique features of Turbulence is innovative feed system along with unique choice of oxidizer. Apart from these, the process includes designing and building the mechanical structure, propulsion system, on-board electronics and system recovery.

Nomenclature

I_{sp} = specific impulse [s]
P_c = chamber pressure [Pa]
A_t = nozzle throat area [m^2]
C_f = thrust coefficient
$\dot{m}$ = mass flow [kg/s]
c^* = characteristic velocity [m/s]
C_d = discharge coefficient
A = area [m^2]
ρ = density [kg/m^3]

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I. Introduction

AGH Space Systems is a student-run science group affiliated with AGH University of Science and Technology in Krakow, Poland. The group was established in 2015 and its members have since been working on several space-related projects, including hybrid-powered and liquid-powered sounding rockets, planetary rovers, CanSat planetary probes and stratospheric balloons. Every group member has an opportunity to be involved in the end-to-end life cycle of a project, including conceptual design, development and subsystem integration and testing.

The idea behind the organization is to learn as much as possible about space systems while the Polish marked does not offer professional experience. We believe that only hands-on experience truly develops the intuition of the product-as-a-system approach. As pioneers in the Polish academic rocket-scale LRE, we are blazing the trail for future teams and research. Additionally, group members learn how to create product documentation and how to write various application forms. Our advancements are usually published. Furthermore, the group takes part in local science and technology festivals and conferences, and organizes classes and workshops dedicated to high school and academic students. During the three years of operation, the team has proven its worth internationally:

- 1st place – Cansat Competition 2015 USA – AAS, NASA, AIAA
- 1st place – Best Science Experiment – Global Space Balloon Challenge 2016, GSBC
- 1st place – Project of the Year 2015 in Poland – Ministry of Science and Higher Education Contest
- 1st place – Academic Project Fair 2016 – ‘Beta’ Hybrid Propulsion Rocket - EESTEC Association
- 1st place – Experimental Sounding Rocket – KOKOS Competition 2016

A. Academic Program

AGH Space Systems science group is a non-profit student organization. It operates as a part of AGH University of Science and Technology in Krakow. The University provides laboratory, workshop, storage and meeting space for the group. However, the group is not directly financed by the University. The budget consists of members’ monthly contributions, AGH University grants, Polish Ministry of Science and Higher Education grants, and money from sponsorship contracts.

Figure 1. Academic partners and affiliation of AGH Space Systems

Formally, the science group operates under The Faculty of Mechanical Engineering and Robotics, but students from other faculties are also eligible to join. A lot of group members pursue a degree in Mechanical Engineering, Automatic Control and Robotics, or Mechatronic Engineering, but this list is not exhaustive and the group is always open to accepting members studying various different branches of science and technology at AGH University.

B. Stakeholders

As part of the Polish Ministry of Science and Higher Education grant, AGH Space Systems science group is obliged to take part in several international competitions, including IREC at the Spaceport America Cup 2018. The grant was awarded as part of the program led by the Ministry which aims to support pre-eminent Polish students in participating in international conferences and competitions. Additional funds were acquired from official partners of the team. Total budget of the project for 2017/2018 academic year has not exceeded 10,000$.

Figure 2. Financial sponsors and partners of the Turbulence Project

It would be impossible to finish the project without some of the former members, whose previous research and development contributed to the success of the project. Some of them were also actively involved and assisted the team with their knowledge and proficiency during the course of the project itself.

C. Team Structure

AGH Space Systems science group is divided into teams, each of which is working on a single engineering project. Normally, new projects are proposed and approved at the beginning of each academic year. The management board is selected every year and its members are mostly responsible for administrative and organizational matters. The group is supervised by a University associate professor, who assists students in contact with University authorities and oversees group activities.

The Turbulence Rocket Team consists of 11 members who are actively working on the project. Each member has a single subsystem or part of a subsystem assigned that he or she is responsible for. The team has a single leader who is responsible for coordinating efforts of all the members. He or she should also ensure that all subsystems are properly tested and integrated. The team is not further divided into smaller groups or sub-teams.

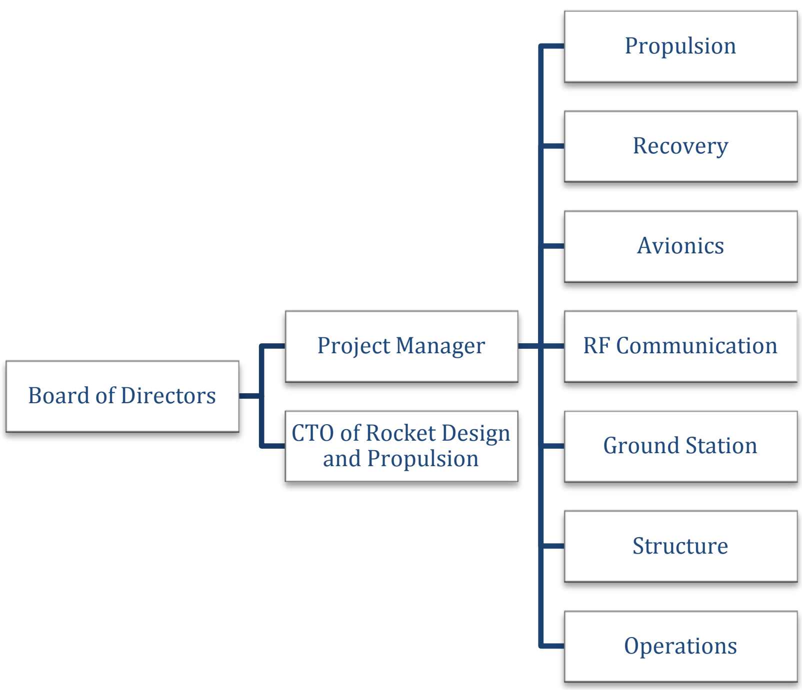

Figure 3. Turbulence Team management structure and reporting path

D. Team Management Strategy

To achieve effective communication within the team, many channels are used. For day-to-day discussion and announcements, the team uses a dedicated Facebook group. Additionally, the team takes advantage of a Trello board, where important decisions, meeting notes, general schemas and outlines are stored. All technical documentation is kept on a shared Google Drive space in the cloud.

Every week a status meeting is organized, where each member is required to present the current progress of the subsystem or part of the subsystem he or she is responsible for, including:

- highlights and lowlights of the previous week;
- list of completed tasks and tests;
- list of tests that are ready to be performed with special regard to cross-subsystem integration tests;
- potential delay concerns and schedule impact;
- plan for the upcoming weeks.

Additionally, the team leader assesses overall project progress and presents his or her conclusions to the team. Afterwards, a discussion is held where all concerns and problems are thoroughly analyzed and the team decides if any plans need to be adjusted to mitigate risks related to the schedule or the project's technical complexity. Furthermore, any tests that integrate more than one subsystem are being scheduled. Typically, decisions are made collectively by the entire team, but the team leader has a decisive vote.

Figure 4. Communication and management strategies

The decision to assign every team member a single responsibility instead of forming sub-teams was made based on the entire group's experience from previous projects. It ensures accountability – each member knows his or her particular responsibility and if any problem arises, it is clear who is obliged to manage it. Obviously, team members frequently work together on a single part or subsystem, assisting each other with their work, but it is each member's duty to assure that the subsystem or part of the subsystem he or she is responsible for is progressing according to plan.

II. System Architecture Overview

The *Turbulence* system is a modular, configurable sounding rocket system designed with phased implementation of successive versions and iterations. The ultimate design is built around a two-stage rocket, in which both stages are propelled by single SRAD bi-liquid engine from the *Zawisza* series. The first stage is *The Booster* (also called by team members as *"The Big One")*, on which this document focuses, and the second stage is *The Sustainer* (*"The Little One"*). Each of these stages will be equipped with own propulsion, avionics, recovery, payload compartment and other elements necessary for independent operation. It means that each stage can be used as a separate rocket system, launched and recovered. By exploiting such modular design, the Turbulence system permits integration of the Booster and the Sustainer with an interstage module into one rocket. Few changes are required to adapt Turbulence for two-stage flight, such as removing a module or replacing it with a different version (for example the Booster's nosecone and payload compartment is removed and the fins module in Sustainer is replaced). Moreover, both stages have similar design solutions and, when possible, use scaled modules of the other stage, like the internal structure, pressure vessel or avionics. That approach minimizes the time required to develop required technologies as well as lowers the costs and provides the team with better prediction about the possible issues and risks related to any design choice. The scaling method allows prototypes to be tested in a smaller scale. In fact, the Sustainer is a test-bed for the larger and more expensive Booster, therefore it was designed and developed first to validate as much as possible before Booster came to life.

The idea behind the Turbulence system is to set ambitious goals for the near future as AGH Space Systems has reached its saturation point running projects with a one-year development cycle. What is more, rocket propulsion is uncommon in Poland, although space industry is rapidly growing and that motivates the team to develop rocket technologies. The main engineering goal is to develop know-how in integrating and testing rocket and propulsion systems and incorporating sub-orbital grade technology as much as possible. That way, a challenge was set for the next few years for students working in AGH Space Systems. It is thought that these students and their successors will gain priceless experience and will ultimately represent technical excellence in the field, which will allow the Polish space industry to grow in branches related to the scope of this project. It will be permissible to say that the Turbulence project has been accomplished when student's grade rocket system demonstrator with integrated sub-orbital technologies is finished.

At the same time, the Turbulence system is adjusted in performance and size to the rules and requirements of Spaceport America Cup, so that AGH Space Systems' students can have the opportunity to compete with the best rocketry student teams worldwide. This event also encourages team members to further their progress, as it sets strict deadlines and requirements upon rocket design. On this occasion students also have the chance to exchange experience and gain knowledge from other competitors. The Turbulence's phased design approach takes into the account IREC events in the following years as milestones for the overall project. For this year's competition, The Booster in its simplest form, namely *BS10* configuration, is to be presented and launched in Spaceport America, New Mexico.

A. Top-level Overview

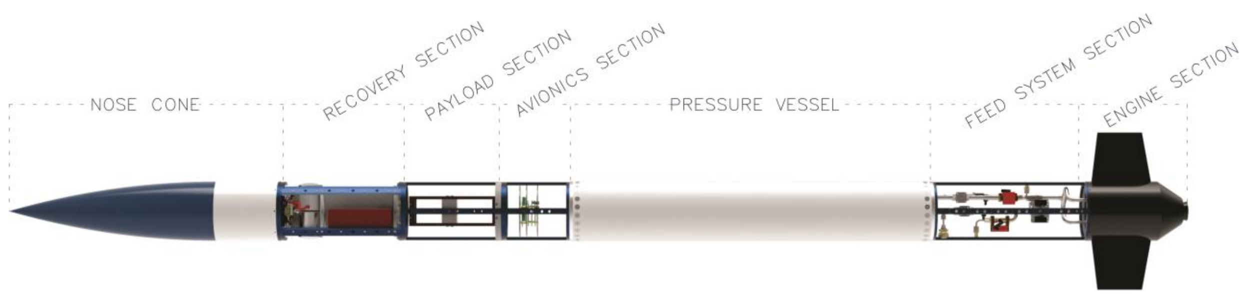

Figure 5. Turbulence rocket in BS10 configuration

B. Propulsion Subsystems

1. Overview

The Turbulence rocket in BS10 configuration is propelled by liquid rocket engine designated as *Zawisza Z3000*, which was developed, built and tested by the members of AGH Space Systems. It uses ethanol and nitrous oxide as rocket propellants in a pressure-fed cycle. For IREC 2018 flight it will generate 40200 Ns of total impulse with the nominal thrust of 2700 N.

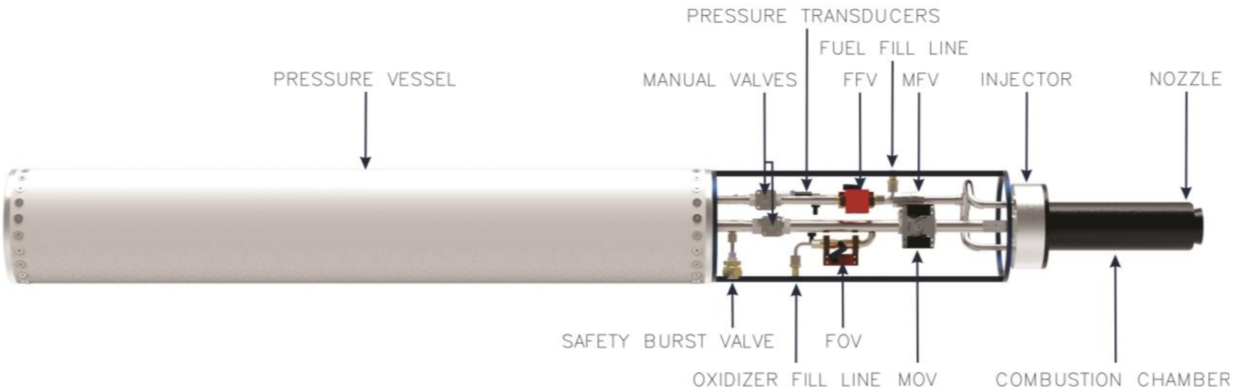

Figure 6. Zawisza 3000 propulsion subsystem for BS10

2. Propellant Combination

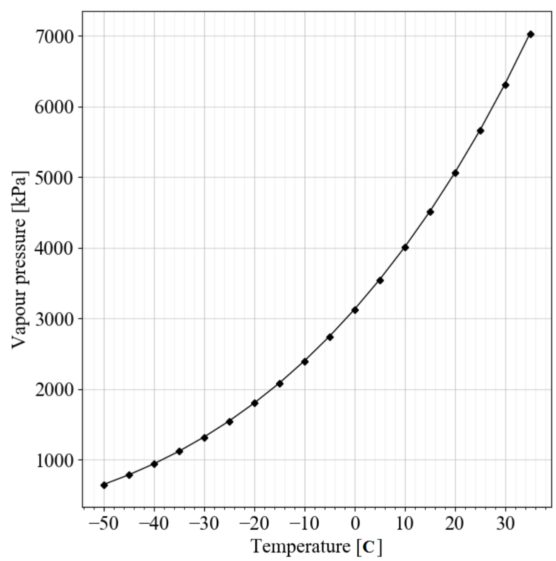

Figure 7. Vapor pressure of nitrous oxide

Due to our extensive previous experience with nitrous oxide applied in hybrid rocket engines, we decided to choose this oxidizer for Z3000 engine as well. It is easily storable and relatively safe to handle and, as such, is the only plausible option, given our limited storage capabilities and the necessity to obtain all the consumables on-site.

Nitrous oxide has a unique self-pressurizing capability, as it is easily liquefied under pressure at room temperature. The design of our pressure vessel system makes use of this oxidizer property.

The use of N_2O in liquid rocket engines is not very frequent; a more common choice of an oxidizer is liquid oxygen or hydrogen peroxide. However, theoretical considerations suggest that it could be beneficial in some systems, mostly due to its high density at lower temperatures [1]. Our use of this substance adds uniqueness to the project and helps us gain valuable experience.

The use of N_2O as an oxidizer demands oxidizer to fuel volume ratios of 4 or more. Therefore, the oxidizer mass flow accounts for most of the total mass flow, which makes the choice of the fuel less critical. According to the available data [2], various propellants paired with N_2O in LREs gave little variation in the specific impulse. For those reasons, we primarily considered factors such as price and on-site availability.

We have used isopropanol (IPA) as fuel in previous designs of bi-liquid Zawisza series engines, but encountered problems associated with its relatively low vapor pressure, causing problems with ignition and combustion instabilities. Therefore, ethanol (EtOH) was chosen for its similarity to IPA, higher vapor pressure, low toxicity, ease of handling and good availability. These two propellants were compared using NASA CEA software to validate their performance and compared their usability with N_2O.

	Ethanol	**Isopropanol**
Density	780 kg/m^3	775 kg/m^3
Theoretical specific impulse	244 s	244 s
Vapor pressure	10 kPa	7.8 kPa
Optimal OF ratio	4.2	4.8
Molar mass of gas products	25.034	25.2
Cost	Average	Good
Availability	Good	Good
Documented application	High	Low

Figure 8. Comparison of ethyl and isopropyl alcohols as fuel candidates

3. Thrust Chamber

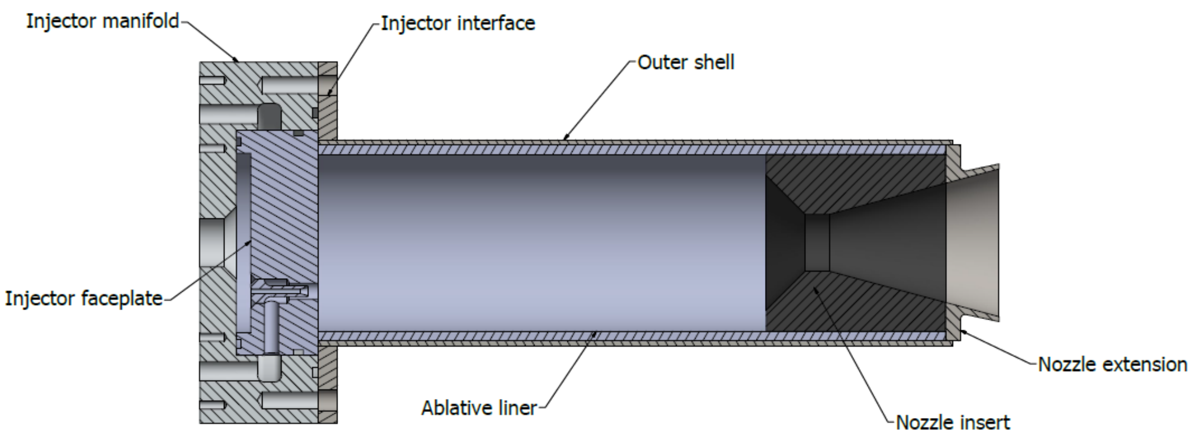

Figure 8. Z3000 Thrust Chamber overview

To provide the given thrust, the engine must operate with sufficient performance measured by specific impulse with limited amount of propellant mass flow. An analysis was performed to estimate the impact of different factors on system efficiency. NASA CEA was used to calculate combustion products and calculate the resulting performance. Two main factors that influence the specific impulse are mixture ratio and chamber pressure. Vapor pressure of nitrous oxide in the tank varies strongly with the temperature as shown in Fig. 7. Without any actual tank refrigeration system, the pressure in the tank is bound to the ambient temperature. It was assumed that the temperature in Spaceport America during IREC competition will nominally reach 30°C, based on previous years and the weather forecast, which will result in N_2O pressure of 60±3 bar that was chosen as the nominal value for the propulsion system calculations. The combustion chamber pressure of 40 bar was chosen as it was high enough to provide superior efficiency of amateur-class rocket engine and sufficient pressure drop margin for the feed system and the injector that is required for stable operation. Along with OF ratio of 4 it gives a specific impulse of 244 seconds. For such efficiency, the mass flow of 1.13 kg/s is required to attain the desired thrust. This analysis was performed iteratively and faced with the available literature and previous bi-liquid engine designs. It must be said that it does not include a variety of factors and provides only theoretical and maximum performance coefficients, whereas in real engine there are many imperfections that contribute to lowering the efficiency, such as improper mixing, incomplete combustion, flow losses, etc.

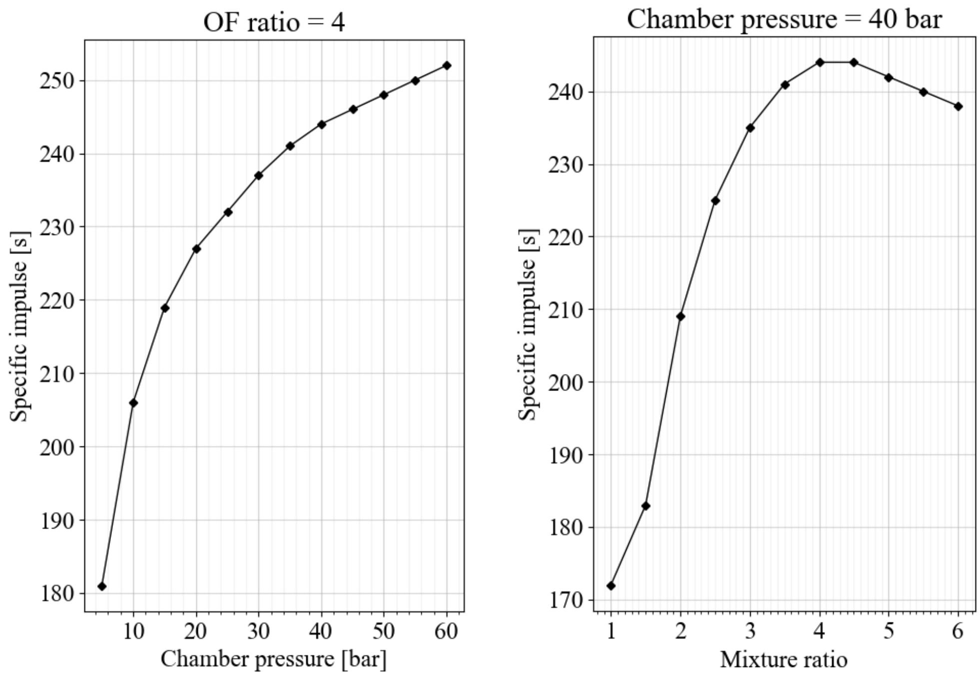

Figure 9. N_2O/EtOH combustion performance characteristics

All these defects can be included in combustion and nozzle efficiency coefficients, which can be estimated during hot-fire tests and compensated for on the fly, for example by slightly increasing the mass flow. As a starting point, an empirical performance coefficient of 0.86 was assumed, so that all calculations were performed with I_{sp} = 210 s instead of the theoretical 244 s, which translates to mass flow of 1.32 kg/s. In such a case, if the measured I_{sp} were higher, it would give an additional safety margin for the propulsion system as these calculations influence such parameters as the size of the pressure vessel in the rocket, which once fixed cannot be enlarged, but can be not fully filled, when necessary.

4. Combustion Chamber

A central element of the thrust chamber is a combustion chamber, where propellants mix together, undergo a chemical reaction and form a mixture of hot gases that is then expelled through the nozzle to produce thrust. In that process, high temperature and pressure are involved. This imposes particular demands upon the design of the chamber. It must be made of high-strength material that can withstand a given amount of time in high temperature and oxidizing environment. In order to meet that condition, chamber design is split into two elements – the outer shell and the ablative layer. The outer shell provides mechanical strength and integrity, while the ablative layer, which consists of ablative liner and nozzle insert, protects the outer shell from burn through due to exposure to hot gases.

The dimensions of the combustion chamber are estimated by the characteristic length coefficient L*, which is based on previously designed engines with the same propellant combinations. As there are few N_2O/EtOH engines built and tested with documented design parameters, we needed to estimate the proper characteristic length through our experience with previously-built prototypes and limited published data. L* was set to 1.8 m as an optimal size for performance and off-the-shelf availability of products for manufacturing.

1. Nozzle

Combustion products from the chamber are directed to the de Laval nozzle section by its converging part, passed through the nozzle throat and expelled by its diverging section. This process accounts for about 30% of overall thrust produced by the engine, the rest being accounted to 'pressure thrust'. The key feature of a de Laval nozzle is supersonic flow achieved by choked flow through the nozzle throat and conversion of pressure and temperature to kinetic energy in the diverging section. It is crucial for rocket performance to exercise this phenomenon correctly. For this reason, several different nozzle designs were considered for Zawisza 3000, two of them being 80% bell-shaped nozzle and conical nozzle. From a purely performance-focused point of view, bell-shaped nozzles are the best available solutions, but are difficult to manufacture precisely and for such a small scale it is convenient to approximate them with a conical shape. The penalty here is lowered performance, larger size and thus increased mass. Trade-off analysis has been performed to support the choice of conical nozzle.

	Conical	**80% Bell shaped**
Fabrication	Easy	Complex
Cost	Low	High
Relative performance	0.98	0.99
Mass	700g	600g

Figure 10. Trade-off analysis of conical and bell shaped nozzle

Nozzle throat diameter is one of the key rocket engine parameters, bound to chamber pressure, thrust coefficient and total mass flow by the following formula:

$$I_{sp} = \frac{P_c A_t C_f}{g\dot{m}} \quad (1)$$

What is more, the characteristic velocity c* is a qualitative parameter that evaluates the performance of the combustion chamber without including the nozzle part. It can be described by:

$$c^* = \frac{P_c A_t}{g\dot{m}} \quad (2)$$

It can be assumed that to produce the required thrust from the engine, that is by summation of pressure thrust and momentum (nozzle) thrust, a given c* level is needed to be achieved. Additionally, this c* performance is then amplified by the nozzle section, which results in total engine performance measured in the previously mentioned specific impulse:

$$I_{sp} = \frac{c^* C_f}{g} \quad (3)$$

Combining Eq. (1) and Eq. (2), the required A_t can be found by substituting the chosen chamber pressure and calculated mass flow. The throat diameter is of great importance as it is a fixed design parameter, which influences chamber pressure strongly, and if chosen improperly causes the engine to work with off-design conditions. If the throat area is too large for the given mass flow, the desired chamber pressure is not achieved, thus performance is lowered. This could be compensated for by allowing more propellants to flow into the chamber, raising the pressure, but at the same time it will lower burn time due to faster consumption of propellants that are in a very limited amount on-board. If the throat area is too small, chamber pressure will rise to an excessive value and operation of all pressure-related parts would be put at risk. Obviously, there is some margin of error that is acceptable and it is a matter of compromise between the achievable chamber pressure and the use of propellants.

A conical nozzle was picked over a bell-shaped one as it is much cheaper to manufacture and the loss of performance is negligible. Typical angles of 45° for the converging and 15° for the diverging sections are chosen, following Sutton [3]. The throat diameter of 23.5 mm was calculated as a good starting point. It follows that the contraction ratio of the combustion chamber is 9.7 and combined with characteristic length of 1.8 m give the dimensions of the thrust chamber as presented on Fig. 11. The optimal altitude was set at 2,000 m AGL, as the engine will work only up to around 4,000 m. It corresponds to the ambient pressure of around 80 kPa.

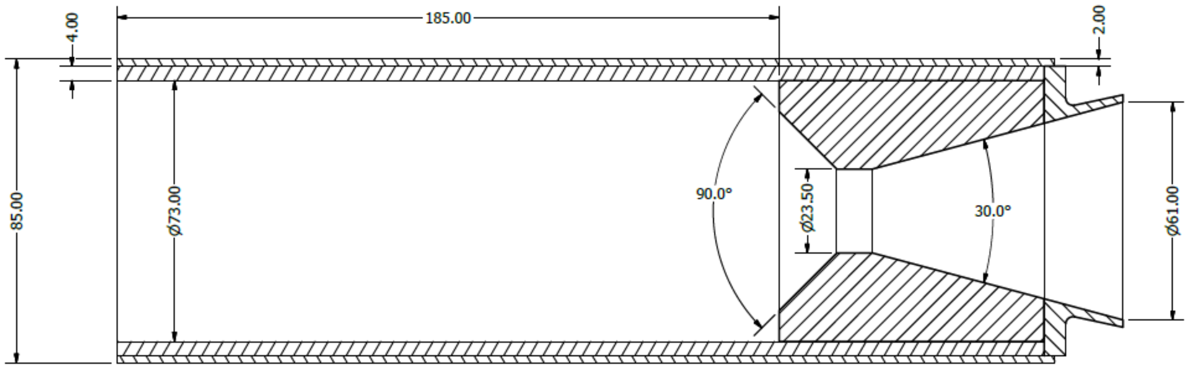

Figure 11. Dimensions of the combustion chamber and the nozzle

2. Injector

The most complex part of the thrust chamber is the injector, which allows propellants to flow into the chamber through a set of precisely manufactured orifices. The injector needs to allow the right amount of propellants to the chamber with the right OF ratio, provide sufficient mixing and vaporization, be “stiff” enough to work as an isolating element between the combustion chamber and the rest of feed system and be simple enough for ease of manufacturing. There are different approaches to designing a pattern of injecting elements as well as ways of manifolding, but each causes manufacturing and operational issues. What is more, bi-liquid engines often exhibit combustion instabilities that are feed-system-, which means that the isolation role of the injector is insufficiently accentuated. On top of that, we have to account for a two-phase, compressible flow of nitrous oxide, which complicates the design even further. Happily, team members have good experience with hybrid engines’ injectors for N_2O. However, bi-liquid injectors are governed by dissimilar design rules. Still, it is a good starting point for N_2O part of the injector.

To calculate the required mass flow of the fuel, simple Bernoulli's Law can be used given by formula:

$$\dot{m} = C_d A\sqrt{2\Delta P\rho} \tag{4}$$

The result is divided into a certain number of orifices or conduits. These orifices must follow some ground rules that are a result of empirical tests and simulation data found in literature. Over the years, some rules of thumb have been created as to these guidelines. The author of Zawisza 3000 has made extensive use of NASA archives, which, though old, provide a lot of practical advice and formulas. However, there are only recent studies that shed some light on the flow of nitrous oxide in orifices as well as ways of estimating its mass flow in the given conditions. As N2O flows in two phases and is in non-equilibrium state during its flow through orifices, it is difficult to predict its behavior without knowing the exact data upstream and downstream of the orifice. As far as upstream data can be estimated pretty accurately with pressure and temperature measurements, it is rather difficult to execute the same downstream, which is inside of the combustion chamber. Moreover, measurements alone are useless without flow models that make many assumptions on the nature of the flow. Therefore it is a rather complex problem that is far out of scope of research done by us. Nevertheless, some effort has been taken to estimate the flow of the oxidizer. Dyer et al. proposed the following mass flow formula:

$$\dot{m} = C_d A\left(\frac{1}{1+k}\dot{m}_{SPI} + (1 - (\frac{1}{1+k})\dot{m}_{HEM}\right), \tag{5}$$

which is a trade-off between two different models: Homogeneous Equilibrium Model and Single Phase Incompressible (Bernoulli's) with the weighting coefficient *k* that depends upon upstream, downstream and vapor pressure of nitrous oxide. With such approximating it is possible to achieve acceptable accuracy of mass flow estimation. Basing on available literature and experience with Zawisza 1kN engine, one of team members considered different models of nitrous oxide flow in more depth [4].

In designing fluid flow through the injector, one needs to think of the flow through a single orifice as well as the overall pattern and how it influences mixing and vaporization. To satisfy these requirements, an impinging injector design was chosen, as it was previously used in Zawisza 1kN test engine. Measurements and know-how gained through the mentioned project were used to set a pattern of 42 un-like impinging orifices. They are grouped into 6 triplets (2 oxidizer, 1 fuel) and 6 quadruplets (3 oxidizers, 1 fuel) that impinge propellants upon each other, what takes place just after their respective orifice, totaling in 30 oxidizer orifices and 12 fuel orifices. Oxidizer orifices are angled and positioned around a straight central fuel orifice, which is coaxial with the impingement axis. Both triplets and quadruplets produce axial spray direction. Additionally, the orientation of elements promotes uniform spray mixing and overall mass distribution, with the exception of outer regions where triplets produce a fuel-rich mixture to lower the heat flux to the chamber walls.

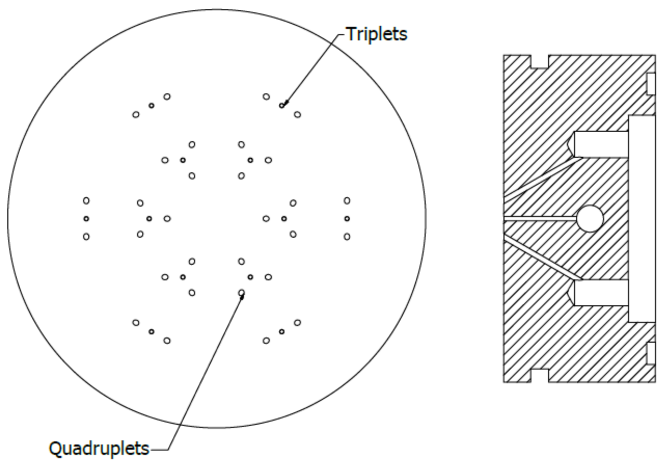

Figure 12. Un-like impinging pattern and triplet element overview

Figure 13. shows a trade-off analysis of different injector pattern designs. The un-like impinging pattern was chosen as a primary design due to its proven excellent mixing and eases of manifolding. However, angled oxidizer orifices are difficult to manufacture and even if a single orifice can be manufactured correctly, there is a strong requirement upon the alignment of all orifices with respect to each other and the axis of impingement. Such precision can be achieved with 5-axis CNC machine, although conventional manufacturing of this pattern is possible. At an early design stage, it was thought that in the case of misalignment of even a single orifice, the proper operation of the engine would be compromised. For this reason, a dissimilar pattern design was proposed as an alternative, namely the coaxial injector. This type takes the advantage of much fewer elements that are simpler to manufacture. A single element is combined out of an inner orifice and an outer annular orifice, so that their axes are coaxial, thus its name. Although with this design, precision of manufacturing is still crucial, it is much easier to do it right, because of fewer elements. Due to the much larger mass flow of the oxidizer, it is made to flow through the outer annular orifice, which must have a far larger area due to geometrical constraints.

	Like Impinging	Unlike impinging	Coaxial
Mixing	Average	Good	Good
Atomization	Good	Good	Average
Manifolding	Difficult	Simple	Simple
Pressure drop	High	High	Low
Wall compatibility	Good	Average	Good
Blowapart	N/A	May occur	N/A
Fabrication	Difficult	Difficult	Simple
Tolerances sensitivity	High	High	Average
Cost	Average	Average	Low
Previously used	No	Yes	No

Figure 13. Different design patterns for Z300 injector trade-off analysis.

3. Feed system

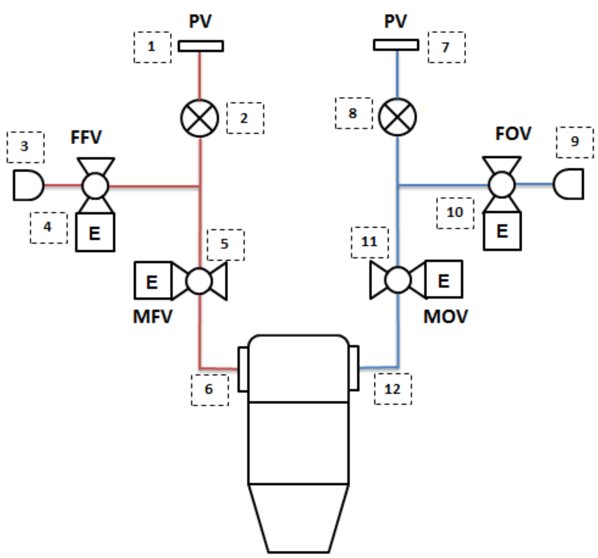

Figure 14. Feed system diagram.

The feed system is responsible for controlled delivery of propellants from the pressure vessel to the combustion chamber. Additionally, it is made to allow filling the rocket with oxidizer and fuel, provide pressure measurement points and incorporate the safety valve in case of over-pressurizing of the propulsion system. The propellants' flow is controlled by servo-valves, which consist of a servomechanism, a three-bar-linkage actuator and an off-the-shelf ball valve. There are a few servo-valves in the feed system: MOV and MFV, which control propellant flow to the thrust chamber; FFV and FOV, which control filling process. MOV is driven by two high-torque JX CLS-HV7346MG servomechanisms, MFV by the same motor, but only one, while the filling valves are driven by a standard servomechanism. The reason for different setups is that there are different torque requirements for each size of the valve with MOV being the largest and filling valves the smallest.

Element	Designation	Type
Main Oxidizer Valve	MOV	SRAD servo-valve
Main Fuel Valve	MFV	SRAD servo-valve
Manual Oxidizer Valve	-	COTS ball valve
Manual Fuel Valve	-	COTS ball valve
Oxidizer Pressure Transducer	PTO	-
Fuel Pressure Transducer	PTF	-
Safety burst valve	SBV	SRAD pressure relief valve
Fill Fuel Valve	FFV	SRAD servo-valve
Fill Oxidizer Valve	FOV	SRAD servo-valve
Fuel Fill Connector	-	-
Oxidizer Fill Connector	-	-

Figure 15. List of critical elements present in the feed system.

Designation	Valve type	Actuator	Breakaway torque	Input torque [Nm]	Output torque [Nm]
MOV	SUN WP ½”	2x JX CLS-HV7346MG	5.8	9.2	7.94
MFV	SUN WP ⅜”	JX CLS-HV7346MG	3.2	4.6	4.6
FFV, FOV	GHILUX ¼”	PowerHD LF-20MG	0.8	2	1.67

Figure 16. Operation parameters of SRAD servo-valves.

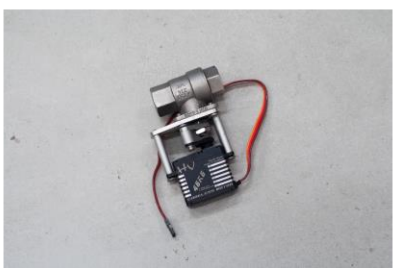

Figure 17. MFV

Figure 18. MOV

Figure 19. FFV / FOV

4. Ablation

The thrust chamber’s outer shell is protected from high temperature erosion by an ablative layer of our design. This material is easily manufactured, has no need for an extensive machining and insulates the chamber very well. Previous experience with bi-liquid engines proved that the outer shell is capable of withstanding a significantly long burn with no protection, working in radiation cooling or heat sink mode. Burn times with no damage were around a few seconds at least, as this was not pushed too far to find out the critical time, at which the combustion chamber would melt or lose its mechanical strength. However, previous designs used chamber pressure of 20 bars, and as Bartz showed with the following formula:

$$h_g = \left[\frac{0.026}{(D_t)^{0.2}}\left(\frac{\mu^{0.2}C_p}{Pr^{0.6}}\right)\left(\frac{P_c}{c^*}\right)^{0.8}\left(\frac{D_t}{r_c}\right)^{0.1}\right]\left(\frac{A_t}{A}\right)^{0.9}\sigma, \qquad (6)$$

heat flux to the wall is almost linear with chamber pressure, which means that for a 40-bar engine, the heat flux will be almost two times higher and that will significantly reduce outer shell capabilities. What is more, flame temperature will rise with higher pressure so it will further increase heat flux. Those reasons made it clear that some ablative material is mandatory for operation times over 10 seconds. Other types of cooling have not been considered, like regenerative cooling due to inefficiency related to the small scale of the engine, as shown by one of the team member [5]. An ablative layer of 5 mm thickness is considered to be more than enough to protect the outer shell for long burns of even 20 seconds.

5. Pressure vessel

Due to the unique choice of propellants for Zawisza engine series, an unusual propellant tank was proposed. In a typical pressure-fed cycle, both propellants are pushed out of their respective vessels by inert gas delivered from the third tank. Since nitrous oxide has high vapor pressure in operational temperature, it was thought that this pressure can be used to pressurize both the oxidizer and the fuel. In fact, this method of self-pressurization or vapor pressurization is widely used in hybrid propulsion and has been applied by team in previous projects.

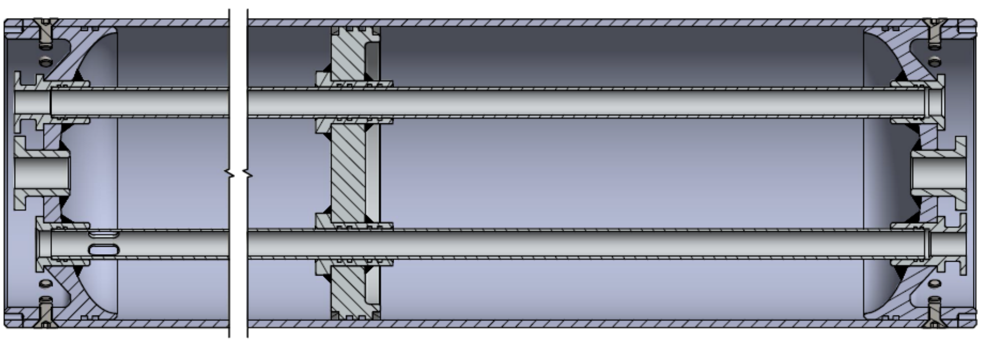

Figure 20. Self-Pressurized Pressure Vessel for Zawisza 3000.

There is only one pressure vessel in the rocket that is split into two chambers by a moving diaphragm. Nitrous oxide, located in the lower chamber serves as both oxidizer and pressurizing agent. Its vapour exerts force on the diaphragm and pushes it upwards, delivering pressure to the fuel located in the upper chamber. This diaphragm slides on two pipes that serve as guides. These pipes work also as fuel conduit and service conduit. The first one is made to allow flow of the fuel from the upper chamber into the feed system through the pressure vessel, while the latter one is used to pass all the cables and wiring from the avionics section to the feed system. This way the pressure vessel can be made as an external structure and there is no need to bypass any tubes or cables on the exterior of the rocket. Additionally, the exact position of the diaphragm can be known due to sensor array in the vessel. This is especially important in estimating the mass flow of propellants during engine burn. It is an internal feature of this design and eliminates the need of expensive mass flow meters in the system. The downsides of that setup are sealing problem due to a large number of o-ring-sealed connections and the risk of diaphragm failure due to imprecise manufacturing or assembly misalignment.

Self-pressurized	External gas	Blowdown
Constant pressure drop ratio	Difficult to control pressure drop ratio	No control over pressure drop ratio
Low pressure drop during burn	No pressure drop during burn	High pressure drop during burn
Complex	Complex	Simple
Medium weight	High weight	Low weight
Propellants usage measurements possible	Easy to control flow	Difficult control over flow

Figure 21. Trade-off analysis of different pressure-fed cycles.

This design is also justified by experience drawn from the previous Zawisza engines that were made with pressure-fed cycle. In those engines, nitrous oxide was made self-pressurized, while fuel was pressurized by external inert gas. Issues were encountered with proper operation of the feed system due to unsynchronized pressure histories in the oxidizer and fuel tanks. When oxidizer is drawn in large amounts, there is a significant pressure drop in the tank, whereas for the fuel the pressure is kept constant, which leads to shift in the OF ratio over time. An alternative would be to use a blowdown cycle for the fuel to accommodate for the pressure drop in the oxidizer tank. Obviously, there is no need to have the same pressure of the propellants, but it is crucial to have a constant pressure drop ratio (from tanks to combustion chamber) throughout the burn that will ensure a constant OF ratio even if the total mass flow drops. With the proposed solution, we eliminate the problem of different tank pressure histories. Even with variable nature of nitrous oxide, namely its dependence on temperature, this system can provide a constant pressure ratio drop for different initial conditions e.g. engine testing in winter and in summer, which results in different initial pressures in the tank. It must be mentioned that to make sure that each test of the engine is run under similar conditions, the pressure vessel is equipped with an external heater that is set to provide nitrous oxide with the initial temperature of 30°C.

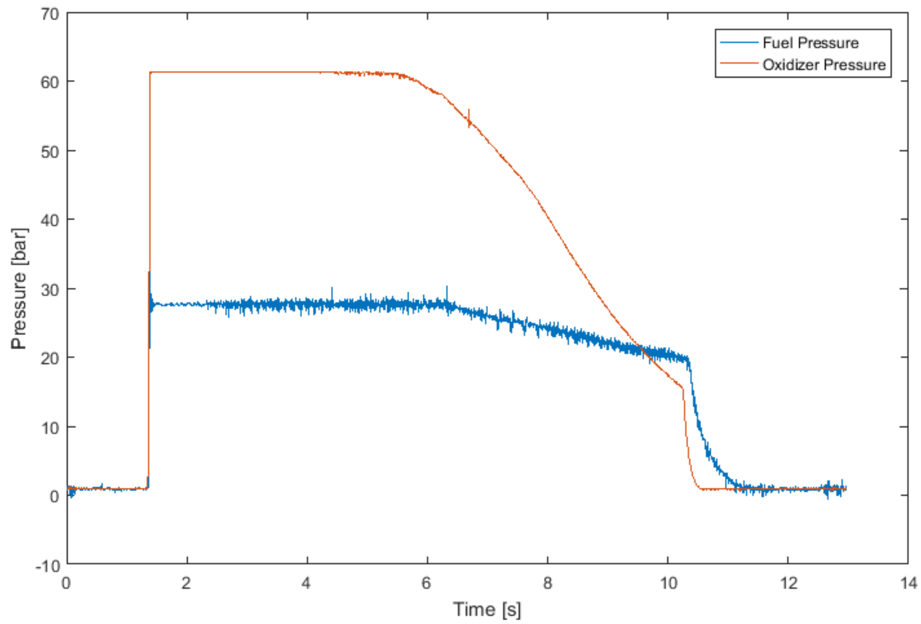

Figure 22. OF shift problem recorded during Zawisza 1kN tests as a result of different propellants pressure drop ratio

In order to accommodate 20 kg of propellants, the tank was designed to be 32 liters in volume, which translates to 30 liters of usable space due to losses in propellant extraction. The nominal pressure of 63 bar was assumed. Since the tank is made out of aluminum pipe with caps mounted with steel screws, it is possible to change the volume of a once-manufactured tank by replacing this pipe as well as internal conduits.

6. Ignition

The combustion process will be initiated by the burning of a lump of pyro-energetic material. The igniter is of a cylindrical shape with a center hole, to minimize the risk of accidental plugging of the nozzle, which is known to cause catastrophic engine failures.

Ingredient	Contribution by mass
Potassium Nitrate	68.7 %
Charcoal	3.8 %
Sulfur	3.8 %
Magnesium (100 mesh)	13.7 %
Epoxy Resin	10.0 %

Figure 23. Typical pyrotechnic igniter composition for Zawisza series.

The pyrotechnic material is custom-made with different compositions tested in order to validate versatility of the ignition technique in Zawisza 3000. It is particularly important since we cannot bring any pyrotechnic substance into USA and must rely solely on fuel grains and pyro materials available on-site, such as black powder. Other ignition sources have been considered, such as resistance wire and catalytic ignition. The former would comprise a length of nickel-based resistance wire placed inside of the combustion chamber, possibly coated with a substance known to facilitate N_2O decomposition (such as copper or nickel oxide). The temperature of the wire should allow for ignition of a small portion of propellants, kickstarting the combustion process. The main drawback of this solution is that it is power-hungry, requiring up to 100 A surge current. Another possible problem is the wire breaking, either during transport and assembly or, worse, during the ignition process, with the red-hot wire subjected to high-intensity flow of propellants. The latter (catalytic ignition) is based on a well-known exothermic N_2O decomposition reaction, which produces high-temperature gases, able to readily ignite the propellant mixture. The essential drawback of this approach is the price and availability of the catalytic material. Moreover, it is likely that implementation of this ignition system would carry with it the need for significant design alterations, such as adding a pre-combustion chamber to house the catalytic material. Finally, the catalyst would be troublesome to handle, as it might be prone to cracking or poisoning upon contact with certain chemicals or propellants of insufficient purity. We are in the process of researching these alternative ignition systems. For BS10 configuration, pyrotechnic ignition was chosen, mostly due to ease of implementation and our extensive experience with this approach.

To initiate the combustion process in a safe and repeatable manner, an ignition sequence is required. It consists of two stages: igniter phase and *prestage*. The first one comprises of pyrotechnic material ignition followed by a slight MOV opening that allows a little oxidizer vapor to fill the chamber. Next, more oxidizer and fuel are allowed into the chamber, but in a strictly prescribed ratio (oxidizer-rich) and amount (typically 10 - 25% of the nominal flow). This is where prestage starts. The combustion of oxidizer and fuel is self-sufficient in this phase, despite the presence of igniter in the chamber. This stage is held for a set amount of time, during which the pressure in the chamber is measured to check whether propellants ignition is successful. After that, MOV and MFV are opened to a set position so that propellants are allowed to flow fully through the injector. The prestage is also a safety measure against hard start as we do not ignite the whole volume of the chamber filled with propellants at once, but instead do it in stages. Fig. 23 presents typical ignition sequence in the form of MOV and MFV opening values versus time.

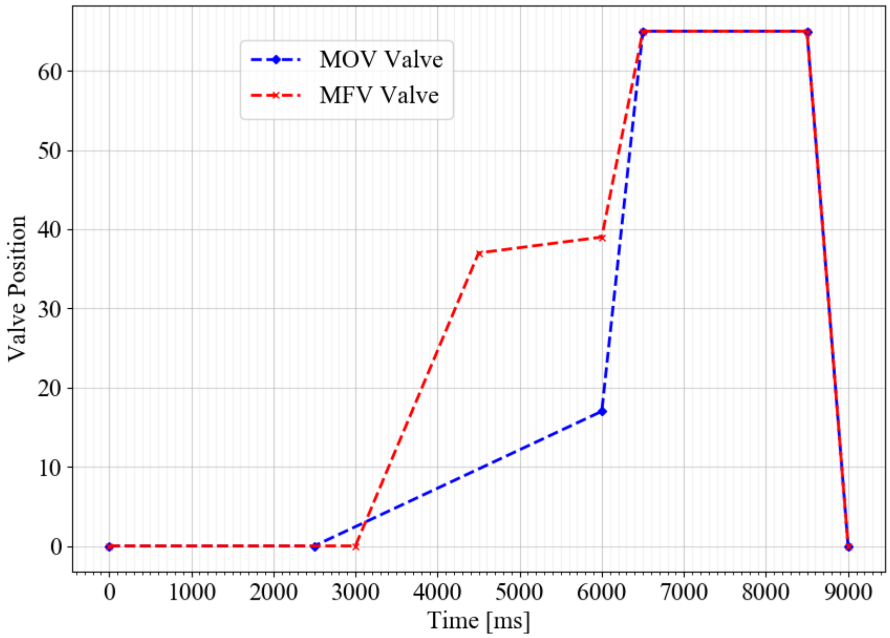

Figure 24. Typical position history of MOV and MFV during ignition sequence

7. Propulsion subsystems - manufacturing

All parts of propulsion subsystems are made SRAD with the exception of hydraulic fittings and sensors in the feed system. The thrust chamber was partially manufactured by students, but all parts were designed by the team. Only the injector manifold and the faceplate were completely manufactured by a third party, since they require good experience with milling of precise parts, most notably small orifices. The flight version of the thrust chamber is made out of aluminum: 2017A for the injector and 6082 for the combustion chamber. The first choice is dictated by its relatively low cost, exceptional machinability and high strength, while the latter is mainly chosen for its weldability and strength.

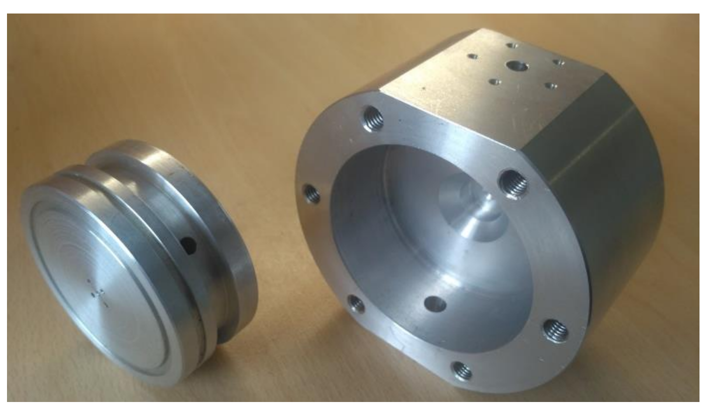

Figure 25. Zawisza series fabricated components (left – pressure vessel, right – injector assembly)

For ground testing of the engine AISI 316, stainless steel was used for the thrust chamber for its good strength and availability. Moreover, conducting many tests on aluminum flight hardware could result in lowered strength and durability over consecutive tests due to the exposure to high heat fluxes and forces. Additionally, the stainless steel version is bulkier, with a much higher safety factor and can be quickly manufactured and welded in-house by students. It is worth to mention that special care was taken when it comes to the safety of catastrophic failures due to overpressurization of the engine. When that happens, due to for example a clogged nozzle throat or a hard start, steel bolts joining the injector with the combustion chamber are ripped from the aluminum manifold, so the risk of flying debris from the combustion chamber is minimized as it simply detaches from the rest of the engine.

The ablation liner material is a paper-sodium silicate-layered composite, prepared by first impregnating paper sheets with 'water glass' and then winding them around a dowel of the appropriate diameter. After 24 hours of drying, the ablative material in the form of a tube is trimmed to the appropriate length and is ready to be placed in the combustion chamber.
The nozzle insert was fabricated out of a fine-grained graphite block, because it provides great resistance to high temperature and thermal erosion. However, it is known that there is a limited amount of hot-fire burns that this insert can withstand without significant change in dimensions, most notably nozzle throat, as there always occurs some erosion. This phenomenon is limited in bi-liquid engine for its combustion products are solely gases without any solid particles which usually contribute to high erosion.
A pressure vessel was manufactured using almost exclusively 6082 aluminum. External pipe with 200 mm in diameter and 5 mm in thickness was bought off-the-shelf as it gives the nominal design pressure rating of 65 bar with 2.5 safety factor. Smaller parts of the vessel were manufactured by students, while more complex and larger elements were necessary to be manufactured by skilled technicians with specialized machines. The precision of fabrication was crucial for mechanical integrity, sealing and diaphragm operation. As mentioned, the BS10 configuration is a scaled up version of the Sustainer stage, so first the mechanical design of the pressure vessel was verified in a smaller scale as presented in Fig. 25.

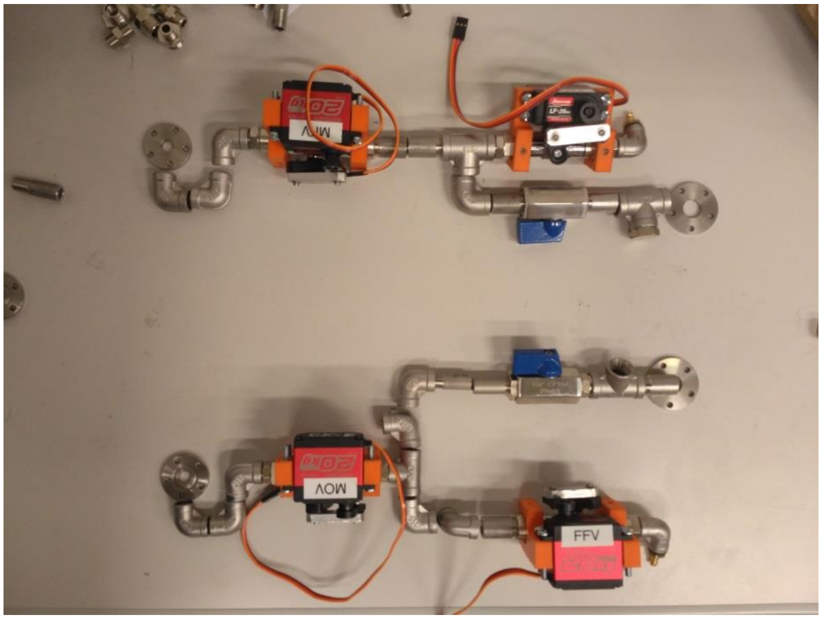

Figure 26. Feed system assembly of The Sustainer (small scale model of BS10)

The feed system was assembled from off-the-shelf hydraulic fittings, most notably DIN 2353 and weldable stainless steel piping. Connections of oxidizer and fuel lines with injector as well as pressure vessel were secured using custom made flanges with o-ring sealing. All threaded connections were sealed with Teflon tape or Loctite 543 glue. Initially, the structure of the servo valves was entirely made of aluminum. After the first recognition, the decision was made to replace aluminum fitting in the third servo valve type with a 3D-printed one in favor of the mass budget. Successful tests confirmed the validity of this decision. 3D-printed PLA fittings were strong enough to hold the construction of the servo valves. Bar-linkage between the servo motor and the ball valve is made of aluminum and plastics and also confirmed its durability during the tests.

A. Aerostructures

1. Nose cone

The nose cone is hand-manufactured by students. The composite material was developed by AGH Space Systems and perfected in three flight-tested models. Our rocket is intended to exceed Mach 1, thus the design of the nose cone will be determined by aerodynamic properties over a wide range of velocities, its machinability and total cost. The nose shape is accompanied with a shoulder to provide a structural interface. The length of the shoulder should be at least one cone diameter. During the design of the nose cone, an important aspect was to determine its dimensions so as to balance the drag, weight and the nose cone manufacturing costs in a reasonable way. To ease the task, the focus was put on tangent ogive type. Simulations of the nose cone drag coefficient were performed depending on its length. Results showed that lengthening of the nose cone above 700 mm does not bring any significant reduction in the drag, but increases the mass of the structure and is consequently related to the costs of materials and manufacturing.

Shape	Tangent ogive
Length	600 mm
Base Diameter	200 mm
Wall Thickness	3 mm
Component Material	Composite
Component Finish	Smooth paint
Shoulder Length	200 mm

Figure 27. BS10 Nosecone configuration

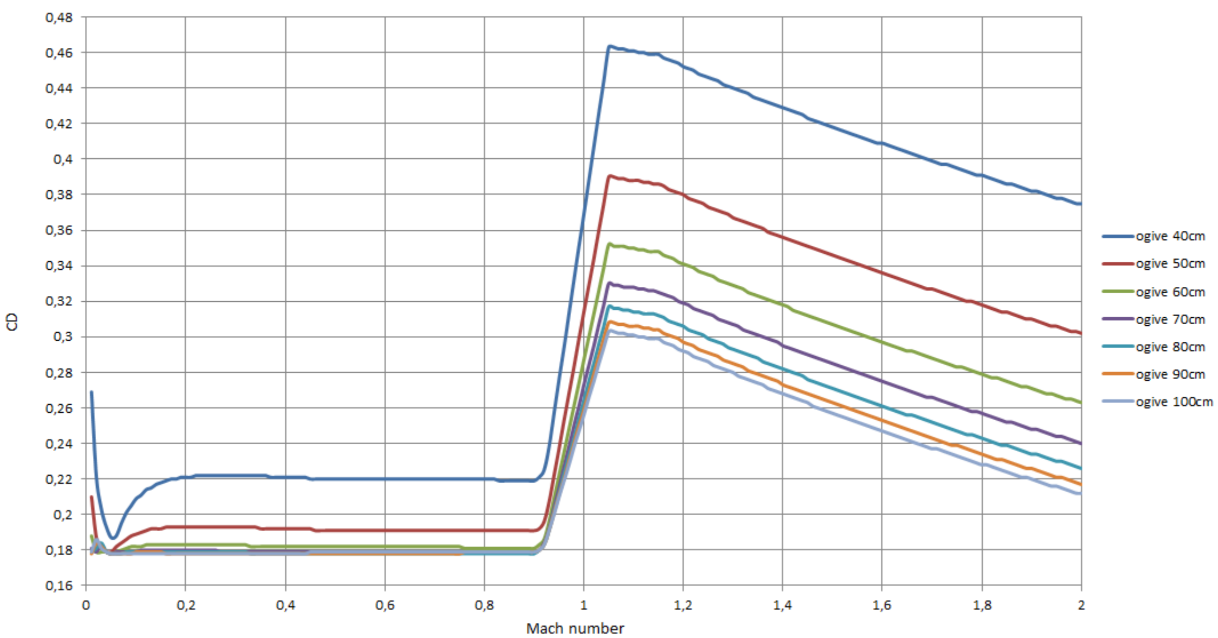

Figure 28. Cd for Mach number and different lengths of nose cone

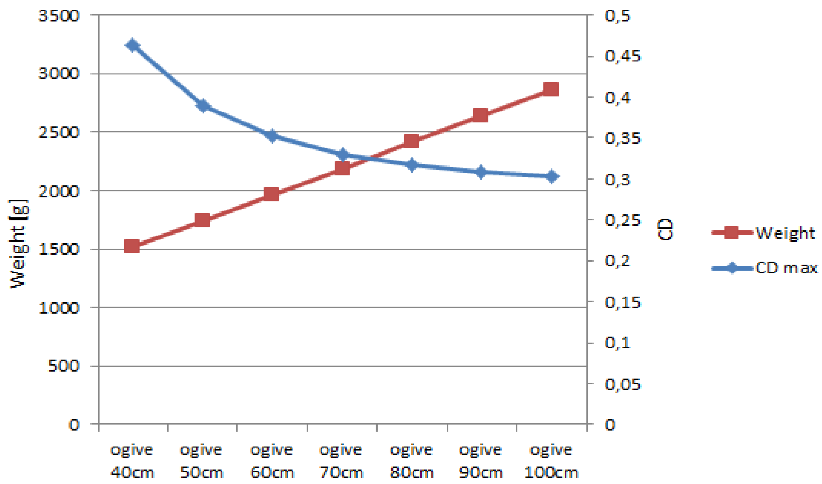

Figure 29. Maximum Cd and weight dependence

The nose cone was made on a foam core that was protected against sticking to the nose cone with the use of stretch film. Then, pieces of previously cut out glass fabric saturated with epoxy resin were laid on the core and then secured against sticking with stretch foil. After the resin cured, the laminate was milled to give the nose cone the desired shape and dimensions. The last step was filling, painting and removing the core.

Figure 30. Fabrication of the nosecone (left – foam core, right - fiberglass pieces)

Figure 31. Curing of laminate on foam core

2. *Fins*

The fins provide the stabilizing force to keep the rocket moving along a safe trajectory. The fins should be positioned at the back of the rocket for maximum efficiency. The fins of the rocket are considered separately from the body. The shape of fins comes from stability caliber calculations of the whole rocket structure. The construction includes the production of a planar sheet of composite material made usually from sandwiched structural foam core covered with fiberglass from both sides. The final treatment includes edge smoothing and polishing.

Shape	Trapezoidal
Wall Thickness	3 mm
Component material	Composite 0.25g/cm^3
Component finish	Polished
Number of fins	4
Cross-section	Square

Figure 32. Fins configuration for BS10

3. *Internal Structure*

One of the major design considerations of the Turbulence rocket was to create a structural frame. This is a result of the constraints of the tube based structure. Such construction allows for greater flexibility in design of the rocket subsystems. Internal structure major functions are:

- transfer all loads,
- define the available space and be the basis for further design
- be easy to assemble and easy to change as a module

	Internal structure	**Tube based structure**
Fabrication	Simple	Moderate
Costs	Average	Low
Mass	Average	Low
Previously used	No	Yes
Complexity	High	Low
Adaptability	High	Very Low

Figure 33. Fins configuration for BS10

Such a modular structure allows quickly adjustment of the dimensions of each section. In the Turbulence rocket, aluminum 2017A rings with a thickness of 8 mm and 20x10 flat bars were used.

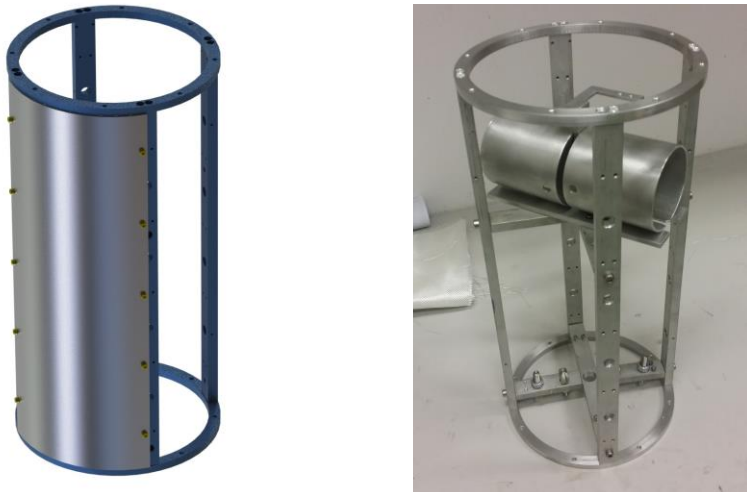

Figure 34. Internal structure (left – with fairing panel, right – recovery section assembly)

4. Fairing

Due to use of the structural cage as a "skeleton" of the rocket, fairings do not transfer significant forces. Their role is limited to the aerodynamic and aesthetic functions. This allowed great flexibility in choosing the type of material which they will be manufactured from and their design.

To reduce the mass as much as possible, it was decided to use a fiberglass laminate and an epoxy resin in the Glass Fiber-Foam sandwich configuration. The composite consists of 2 mm PU foam with the density of 60 kg / m3 and two layers of glass mat with a surface mass of 160 g / m2 on each side.

Such a material is more rigid, durable and resistant to damage than aluminum. This is associated with a longer production time, but the AGH Space Systems team has experience in laminates production. To improve the appearance of the Turbulence, resin dyes were tested. In the end, it was decided to use white resin dye and then paint the rocket a desired color.

A composite pipe was made on the matrix. The pipe was cut to the appropriate elements and assembly holes were made. Edge processing was carried out for aesthetic purposes. To facilitate fairings assembly, they were mounted to the structural cage with M3x12 screws.

Figure 35. Dyed epoxy during test

5. Aerobrake - optional

The aerobrake system was developed to decrease the speed of the vehicle in the late stage of the flight and improve accuracy of the altitude at apogee. Initially, it was planned to operate at The Sustainer of a two-stage rocket. What is presented below is a model of the device and the working prototype. However, aerobrake *will not be* used in the BS10 developed for the competition.

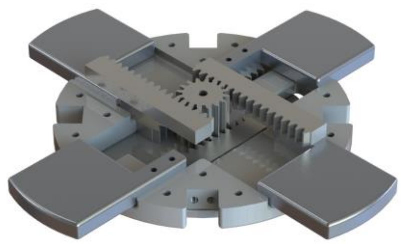

Figure 36. Aerobrake internal mechanism

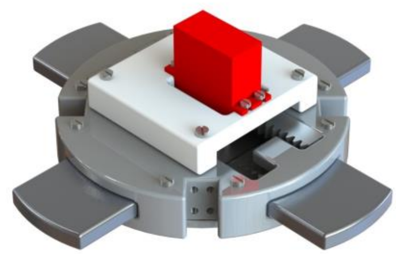

Figure 37. Aerobrake assembly

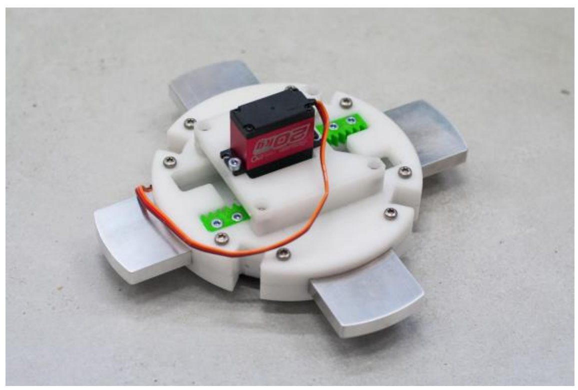

Figure 38. Aerobrake assembly

The mechanism consists of four braking planes driven by a servomechanism. Transmission is carried out using a gear and gear racks. Such solution ensures symmetrical extension of the braking planes guaranteed by the construction of the mechanism, precise control of the extension range and reduction of the entire module weight. These parameters play a key role in the aerospace industry in terms of reliability, precision of operation and mass budget.

D. Recovery Subsystems

The recovery system enables the recovery of an undamaged rocket and its payload and its reuse as a new object. In addition, it provides safety for the launch site and the surrounding areas.

The use of a two-stage recovery system allows limiting the area onto which the rocket will fall to the launch site. The pilot chute is thrown at the apogee and at a predetermined altitude, the main parachute is deployed. The rocket descends with a lower touchdown speed. The main parachute deployment allows a gentle landing. When descending under the pilot chute, the rocket descends faster in the upper layers of the atmosphere, which allows reducing the impact of the wind that could significantly drift the rocket off the launch site. At an altitude of 10 km, as meteorological data shows, we can expect winds blowing at around 30 m/s. If such a wind blew, the entire radius of the rocket search would be about 10 km. It would make it difficult for the rocket to be found, and we could even risk losing it due to the breakdown of communication with Ground station.

The recovery system must be designed so as to:

- Stabilize the rocket while descending under the pilot chute that the main parachute can be properly released
- The difference in speed between descending under the pilot chute and the main parachute have to be small enough that during the filling of the main parachute canopy no overload on the object occurs

To stabilize the fall as much as possible, it was decided to put the recovery sections as close as possible to the front of the rocket, and thus just behind the nose cone. Due to the relatively large dry mass of the rocket, a redundant system was chosen: two pairs of main-pilot parachutes.

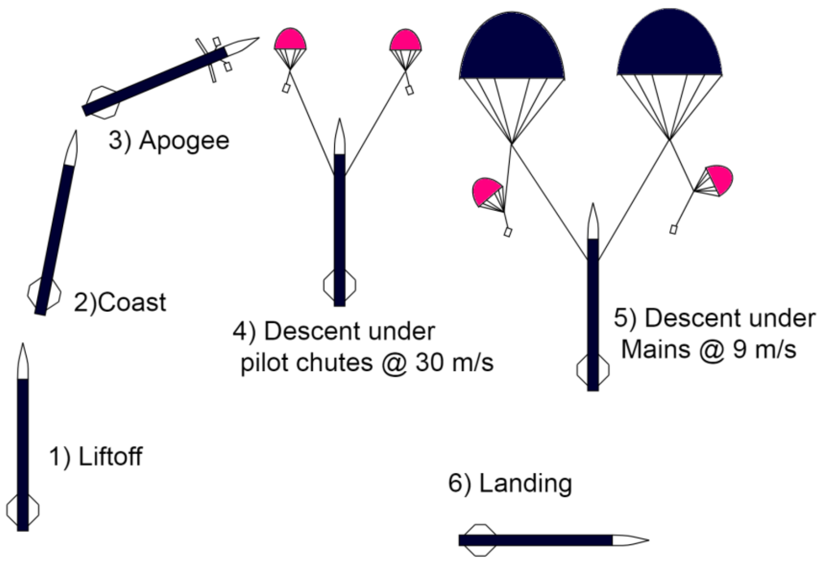

Figure 39. Recovery system concept of operations

The operation of recovery system occurs as follows:

1. Apogee is detected.
2. Command is sent by recovery avionics to deploy drogue chutes. Pneumatic system is activated. Drogues are ejected from the compartments out of the rocket.
3. Drogue chutes inflate and begins to stabilize the rocket.
4. On 500 m command is sent by recovery avionics to deploy main chutes. Heat-resistant wire is powered with current. Holding cord is cut and main chutes are released and pulled out of the rocket by drogue chutes.
5. During inflating of the main parachutes an force impulse is generated. Shock cords minimizes the effect.
6. With all parachutes inflated rocket descents with vertical velocity of 9 m/s.
7. The rocket impacts the ground and awaits retrieval.

1. Parachutes

Starting our considerations with Newton's laws, we assume that the force of gravity must be balanced by the drag force generated on the parachute.

$$\frac{1}{2}\rho v^2 C_d A = mg, \quad (7)$$

where
C_d = drag coefficient
ρ = density of fluid (1.2 kg/m^3 for air at NTP)
v = flow velocity (m/s)
A = characteristic frontal area of the body (m^2)

In our case "A" is the 2D projection of the parachute area, so we find:

$$d = \sqrt{\frac{8mg}{\pi \rho v^2 C_d}} \quad (8)$$

In our case, we substitute half the mass of the rocket for the mass of the object. Figure 40 gives input data for parachute calculations. The hemispherical shape was chosen for both due to an easy fabrication process that allowed in-house production. Air density is given for the end phases of descent on each parachute. Only these moments are critical: 500 m for the pilot chute and 0 m for the main parachute.

	Dry mass [kg]	**Air density (for terminal phase) [kg/m^3]**	**Descent velocity [m/s]**	**Coefficient of drag (hemispherical)**	**Calculated diameter [m]**	**Planned diameter [m]**
Main parachute	17	1,2	9	0,95	2,145	2,1
Pilot chute	17	1,13	30	0,95	0,663	0,6

Figure 41. Input parameters for parachutes sizing

Differences in velocities for planned and for calculated diameters are negligibly small and for better calculations, the values of 9 and 30 were assumed. Then, for selected sizes of parachutes, the characteristic descent velocity as a function of the mass of the falling object was found. Evidently, the redundant structure of the system allows that in the event of the failure of one set, the falling rocket only once gets a touchdown speed of about 20 m/s. This is the speed at which serious damage may occur, but it still allows for emergency touchdown.

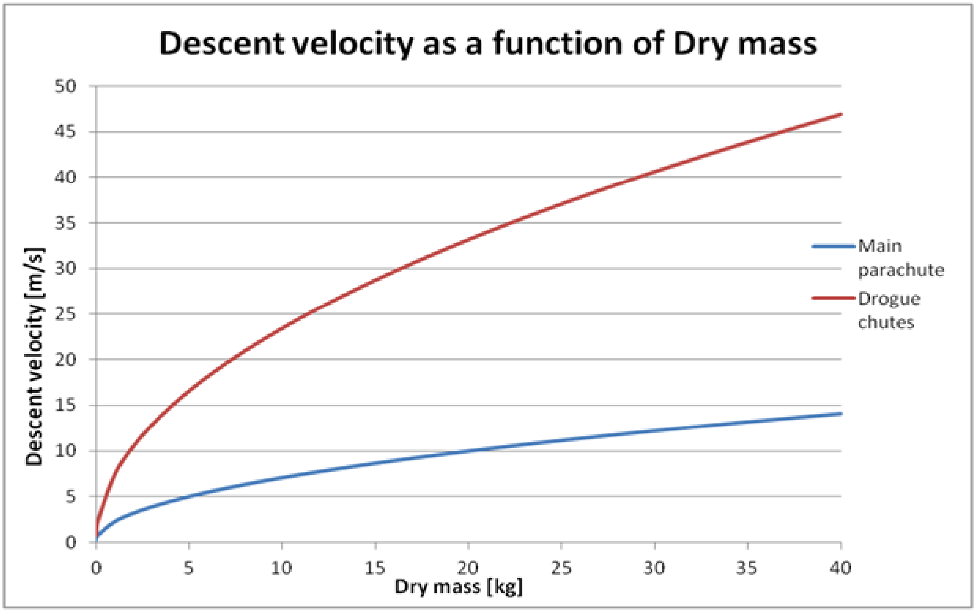

Figure 42. Descent velocity as a function of the dry mass of the rocket

	Main Parachute	Pilot Chute
Manufacturer	AGH Space Systems	AGH Space Systems
Type/Shape	hemispherical	hemispherical
Material	Ripstop Nylon + Aramid threads	Ripstop Nylon + Aramid threads
Dimensions (diameter x height) [cm]	210x149	60x43
Weight of the dome [g]	310	30
Colour	navy blue	dark pink

Figure 43. Final design parameters of the parachutes

From own practice, the length of shroud lines and main lines was chosen. To minimize the jerk during main canopy inflation, a shock cord was added. Chosen main rope is made from PP material, not Kevlar, due to much greater stretch of 17% instead of 4%.

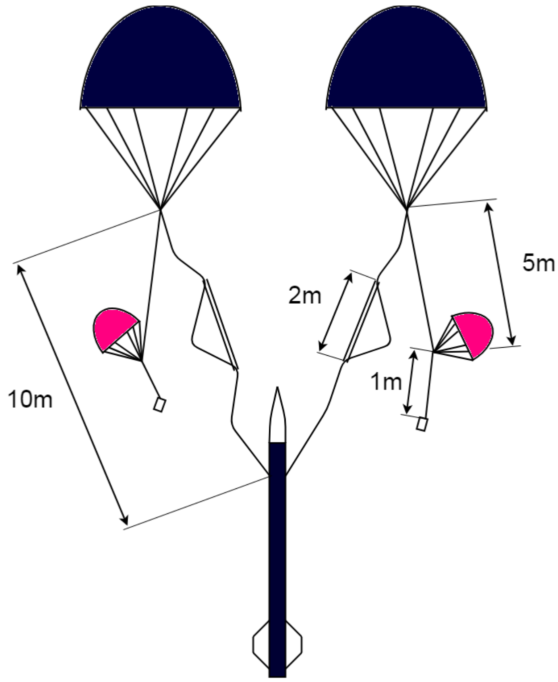

Figure 44. Lines and shock cords length for the recovery system

Component	Material	Maximum load [kN]
3mm Line	polypropylene silk	1,71
Dyneema® 1.0MM Line	ultra high molecular weight polyethylene	1,57
Dyneema® 1.5MM Line	ultra high molecular weight polyethylene	2,94
Swivel	stainless steel	0,98

Figure 45. Parachute system available loads

Clearly, there is a large safety margin. The literature shows that for hemispherical shape the Opening-Force coefficient is 1.7, thus no element is overloaded.

2. Deployment system

From several possible means of storing the energy needed to eject the parachutes, the chosen solution consists of liquefied gas under pressure. For this purpose, a small-sized pressure vessel up to 60 bar with a safety factor of 4 was designed. In the available space, a pneumatic system was placed that provides gas to containers in which the pilots are located.

Two sets of stationary and mobile containers work like a piston and a cylinder. After high pressure is delivered, the deployment of the drogue compartment occurs. A few seconds before servo valve opens, the locking bolts of the door are unlocked. Deployed containers throw out the unrestricted doors. After drogues inflate, main parachutes are blocked from ejection by the blocking rope. This line is routed to the assembly points via a tube. At this point, the rope is hold with the resistance wire. On 500m, the wire gets hot and cuts the holding rope and the force generated by the pilot chute pulls out the main parachute from the parachute bay.

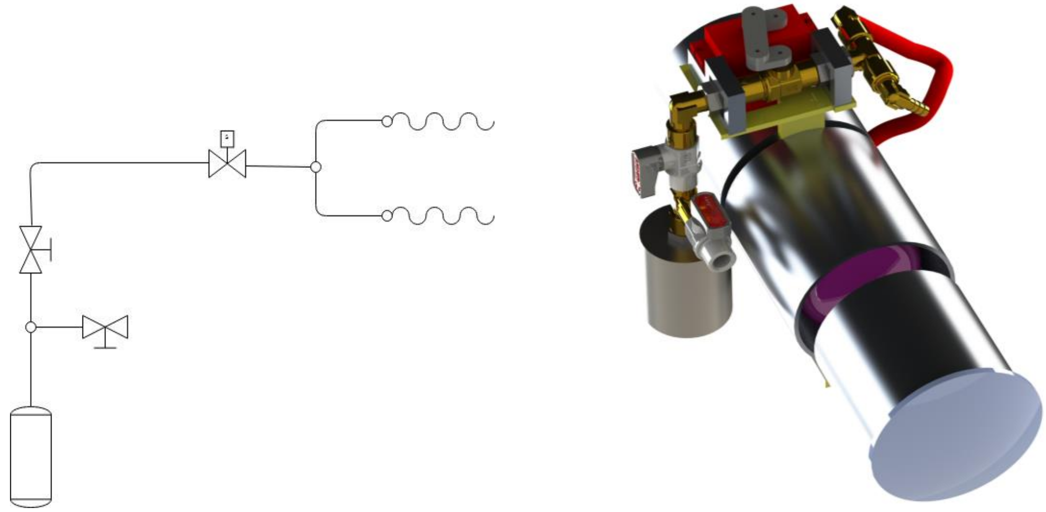

Figure 46. Pneumatic deployment system (left – fluid diagram, right – assembly)

This type of recovery system was pioneering and there was no certainty as to its correct functioning. However, successful tests were carried out. The test confirmed a correct design of the pneumatic system and the validity of assumptions.

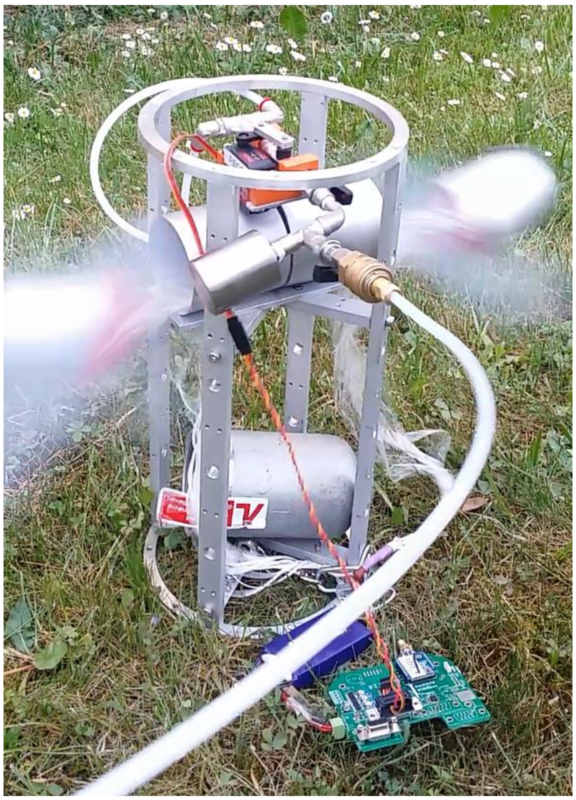

Figure 47. Pneumatic deployment system during ground test.

E. Payload Subsystems

The payload compartment is the part of the vehicle that contains possible experiments which can be conducted during the mission. The modularity of the compartment allows us to meet many expectations regarding the type and size of the payload. Universal mounting between the payload and the vehicle allows development of different kinds of payloads that can be easily integrated within the vehicle.

Figure 48. Payload section with 3U adapter and boiler plate payload.

The launch vehicle will carry 9 lbs of inert payload. The payload will consist of two main parts: a steel boiler plate, which constitutes the most of the payload mass, around 6.6 lbs, and an aluminum cuboid (U3 standard size). Assembly holes along the cuboid allow changing the position of the steel boiler plate. Position of the steel mass can differ up to 11 inches. The payload is not functional in terms of scientific experiments and technology demonstrations; however, this setup gives us the possibility of adjusting the position of the center of mass of the vehicle. This kind of functionality helps in improving the stability of the launch vehicle and allows gathering data about the influence of the position of the center of mass on the vehicle's flight parameters.

F. Avionics Subsystems

1. System design

Experience gathered over the years in our group made us consider many high-level design ideas while designing the subsystem architecture. There were many factors taken into account during the preliminary engineering phase. Given a very short project period, which lasted for 8 months, here are some points we considered:

- reliability
- cost
- development and concept variability
- team management and work management

- universality for further projects
- soft and hard ideas connectivity
- potential failures

During the work on previous projects: hybrid-powered sounding rockets, planetary rovers, CanSat planetary probes and liquid engine test stand with data acquisition devices – we developed solutions that imposed the following technical requirements:

- software and hardware decentralization
- fast prototype versions
- common sensors in the entire assembly
- multiplication of sensors in different boards
- dissimilar design for redundant boards – made by a different people

The requirements dictated by the construction of the rocket, type of engine, competition requirements and the above considerations determined the structure of a multi-level distributed electronic system capable of handling the entire mission of our rocket. This solution generated a number of electronic circuits further referred to as modules. Advantages of multiple MCU network are many, and some of them are:

- every microcontroller has a strictly defined task while other threads have a lower priority
- vote implementation
- simple redundancy
- operative for group work
- small conception change - small board change
- simple software

The decentralized sensing and executive system solves the problem of redundancy required in the rocket system. It allows us to carry out voting for each decision and software stage change by assigning weights to each module and making several types of conditions available for presentation in a vote. A steady and reliable connection between each module was obtained by using the almost failure-free CAN protocol. This standardized communication system in terms of physical and protocol layer allows for flexible adjustment of the number and type of sensors needed in the sensory network. Each board has a layout compatible with the other modules making stackable configuration possible.

Each module is based on Cortex M0-M7 core family. STM32 processors were selected due to their wide spectrum of capabilities, reliability and good support of programming environments / software.

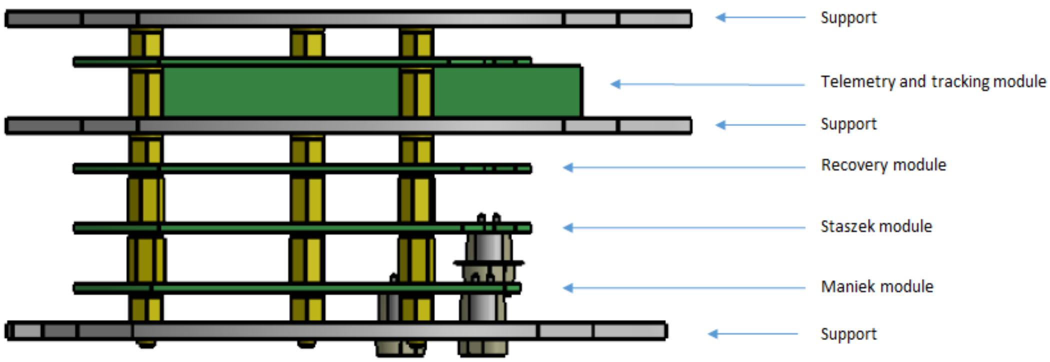

Figure 49. On-board Flight Computers assembly

	Tasks	Priority	Implementation	Stored data	Power supply
Staszek parent	data acquisition	low, redundant	ADC pressure vessel measurements, IMUs, barometer, thermometer	orientation, acceleration, angular rate, pressure, vessel pressure, temperature, velocity	3s li-po 11.1V
	cutoff algorithm	high, main	ARM-CMSIS hardware support		
	ignition system	high, main	high power FETs, high power supply		
	AHRS algorithm	high, main	3x MPU9250 with Kalman filter and sensor fusion algorithm		
Staszek redundant	data acquisition	high, main	IMUs, barometer, CAN messages	orientation, acceleration, angular rate, pressure, temperature, velocity, longitude, latitude, altitude	2s li-fe 6.6V
	cutoff algorithm	low, redundant	ARM-CMSIS hardware support		
	AHRS algorithm	low, redundant	3x MPU9250 with AHRS Madgwick algorithm as filtering and fusion algorithm		
Maniek	power distribution	high, main	D-sub connectors, ACS712 hall current sensors	servos current, CAN messages	2s li-fe 6.6V
	feed system control	high, main	4x servo controlled valves		
	ignition system	low, redundant	high power FETs		
	short range telemetry	low, main	Xbee, Grażyna as ground station		
	aero-break	high, main	servo controlled aero-breaking mechanism		

Czapla	long range telemetry	high, main	Baofeng and each avionics module	longitude, latitude, altitude on Staszek's flash memory	2s li-po 7.4V
	tracker GSM	high, main	Sim800c, ublox-cam8c, Baofeng		
	antenna tracker	high, main	Baofeng		
Baofeng	long range telemetry	high, main	Using Czapla as message modulator sends telemetry to Grażyna where it is demodulated by another Czapla/Baofeng	---	2s li-po 7.4V
Romek	fueling	high, main	relays array connected with electromagnetic valves	----	3s li-po 7.4V
Magneto	official altimeter	high, main		----	
	pressure vessel separator positioner	high, main	Maniek, MLX hall sensors		3v3

Figure 50. Control avionics datasheet

	Tasks	Priority	Implementation	Stored data	Power supply
SS Jajo	servo controller	high, main	cortex m0 with pwm outputs, redundant power supply	----	2s li-fe 6.6V
	battery backup management	high	redundant power supply		2s li-fe 6.6V
Recotta	recovery	high, redundant	accelerometer, barometer, SD card	altitude, acceleration, pressure, temperature	2s li-fe 6.6V
Sravery	recovery	high, main	barometer, IMU, AHRS, SS Jajo	angels, acceleration, angular rate, pressure, temperature, velocity	2s li-fe 6.6V
	altimeter	high, redundant	barometer, accelerometer		

Figure 51. Recovery avionics datasheet

2. *Staszek*

Component	Qty	Function
STM32f446RCT6	1	microcontroller
AD7194	3	ADC converter
AD8227	7	precision instrumentation amplifier
MPU9250	3	9 DOF IMU
MS5607	1	barometer and thermometer
S25FL256	1	flash memory

Figure 52. Staszek's onboard components.

During the flight Staszek is gathering flight parameters such as atmospheric pressure, acceleration, angular speed, magnetic intensity, temperature, stores it on flash memory and runs an algorithm liable for the decision about turning off the engine. It contains an ignition system capable of providing up to 450W power signal. Its shape, layout and design allow it to provide redundancy by stacking multiple Staszeks in assembly. In BS10 flight configuration two Staszeks are mounted with parent one.

This module is also responsible for measuring engine parameters upon static fire. Pressure transmitters provide 4-20mA output signal indicating two pressures in a vessel, two before the injector and one in the engine chamber. Those can process pressures up to 100 bar with 1% accuracy. The thrust generated by static fire is measured by shear beam load cell with a maximum load of 500 kg. For reading the amount of fueled propellant with the whole rocket mass we used a smaller, 200 kg shear-beam load cell. A thermocouple reading was implemented for verification efficiency of ablation located in the engine combustion chamber. Each signal is amplified by a precision instrumentation amplifier for reducing temperature variation, common-mode rejection ratio, and to use maximum available 24-bit of ADC converter. The use of 3 same ADC converters was necessary for minimum sampling frequency.

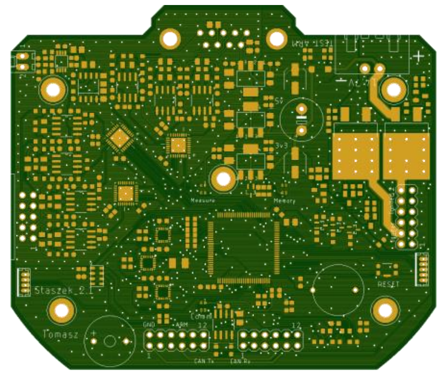

Figure 53. Staszek's PCB.

3. *Maniek*

Component	Qty	Function
STM32f413RCT6	1	microcontroller
ACS712	5	HALL current sensor
SN65HVD	2	CAN controller
P82B715TD	1	I2C bus extender
XBEE S2C PRO	1	low range telemetry

Figure 54. Maniek's onboard components.

The Maniek electronic module was designed as the lowest-located PCB, which determines that all connectors must be placed on it. As the most reliable solution, D-Sub connectors were chosen. There are three 9-pin and one 15-pin D-subs. A solution like this ensures balance between robustness and lightness. The module is based on STM32F413 MCU and is responsible mainly for operation and control liquid engine feed system. Each of the five high-current servo outputs is secured and measured by Hall current sensors. Data from these measurements can be used for monitoring servo-valves work. Moreover, through the I2C protocol, Maniek module communicates and reads data from a magnetometer mesh system. A special algorithm computes this data and returns precise position of the pressure vessel's diaphragm. Because of I2C bus, the length limit there uses I2C bus extender. In response to the requirements, an additional engine ignition system is included. As low-range high transmission speed telemetry radio, 2.4Ghz XBee Pro module was chosen to be installed on Maniek. It provides 115200 baud rate and a range up to 1,600 ft. This communication is used during static tests and just before our rocket flight.

4. Magneto

Due to the atypical pressure vessel structure, it was necessary to design a system for diaphragm position measurement. We could not place any electronic instruments inside the vessel, so we decided to use magnetic field measure. Inside a service pipe, 1.77 x 0.5 inches PCBs were mounted in an interval of 3.93 inches. 3D printed holders were used to set them in parallel. Each module contains Hall-sensor MLX90393 and I2C bus extender P82B715.

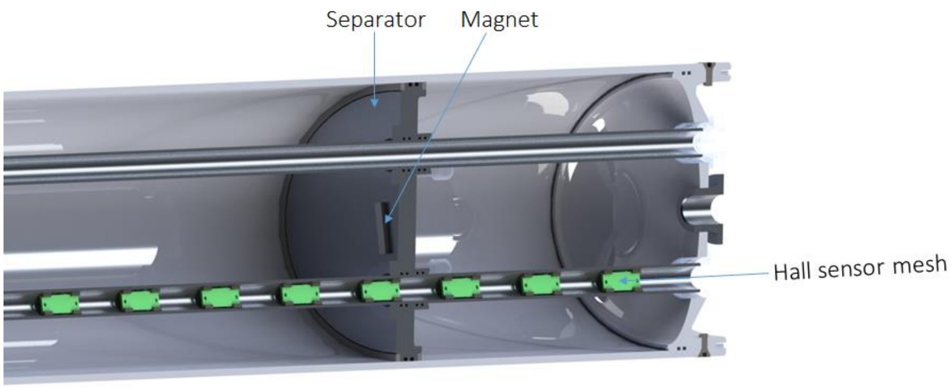

Figure 55. Hall sensor mesh location in the service conduit of the pressure vessel.

5. Sravery

Component	Qty	Function
STM32f446RCT6	1	microcontroller
MS5607	3	barometer and thermometer
MPU9250	1	9DOF IMU
S25FL256	1	flash memory
SN65HVD	1	CAN controller

Figure 56. Sravery's onboard components.

Sravery is a SRAD recovery module that releases pilot and main parachutes at the right time. Its 180MHz microcontroller runs the Kalman algorithm and the sensor fusion algorithm for orientation and altitude. It is supported with CMSIS - hardware floating point unit. It stores every parameter and voting result on flash memory.
Since voting was used as a mechanism for making decisions, it was necessary to use state weights described in Figure 55. Sravery's votes are counted times two; votes from the two Staszeks are counted normally. If voting results exceeds 4 then voting conclusion is to deploy recovery. In case CAN communication is lost, Sravery performs a single vote with threshold value 2.

Action	Factor	Weight
Lift-off	above specified altitude and acceleration - latch	-2
Velocity	above specified velocity	-2
Apogee	at maximum altitude - latch	+2
Acceleration	above specified acceleration	-2
Engine valves opened	Maniek's message	-2
Engine cut-off	acceleration apogee, velocity decreasing	+2

Figure 57. Voting table for recovery deployment.

6. SS Jajo

This small board designed as simply as possible has one main task - it is a servo controller with a separate supply. It is used to open servos in the recovery section while reading readiness from two modules – Sravery and Recotta. Its layout is compatible with the Sravery pinout and dimensions, so it is possible to stack Jajo with the other boards. It provides 3 power outputs, 6 logical inputs, 2 timer outputs for servos and 2 separate supply inputs for power redundancy. Therefore, it is supplied with two 2S Li-Fe batteries connected parallelly and secured with Schottky diodes. It also has additional connectors for power distribution.

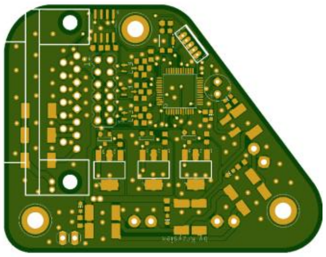

Figure 58. Staszek's PCB.

7. Recotta

Figure 59. Arecorder. COTS recovery computer.

Recotta is a dual deployment of the shelf recovery module. It is called Arecorder by its creator. 3 power outputs are programmable for altitude or apogee deployment. It uses accelerometers and a barometer to compute altitude with Kalman filter correction and stores all data on a SD card. After landing, it uses a buzzer for position indication. It has been extensively used by AGH Space Systems.

8. Power management

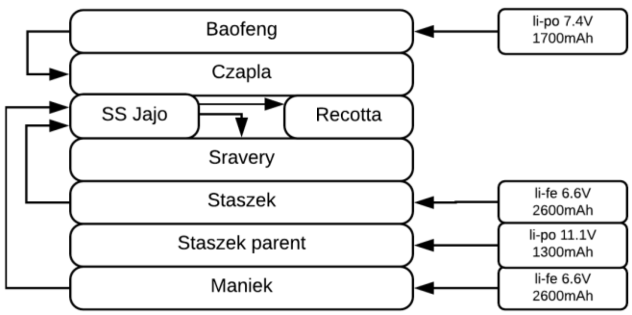

Figure 60. Power supply and management diagram.

9. Recovery redundancy

SRAD recovery module - Sravery - is primary initiator. It detects an apogee of the rocket with checking severals condition - whether the engine is still working or velocity is above safe for chute to be released. In case of wrong algorithm implementation or MCU hung up, COTS recovery module - Recotta - makes final decision. To provide dual redundancy for low cost servomechanism, SS Jajo module has been designed. Apart from its function as servo controller, it provides power lines to control solenoids and hot wires. Based on cortex M0 core, MCU has only two functions - generate PWM signals for servos and latch signals for power outputs. Such minimalistic design makes Jajo very reliable and makes signals from Sravery and Recotta sure to be executed. It has implemented hardware watchdog - periphery which resets core if no action occurred for programed period. Because its software is not time dependant, resetting the MCU forces the return of full functionality of the module in recovery subsystem.

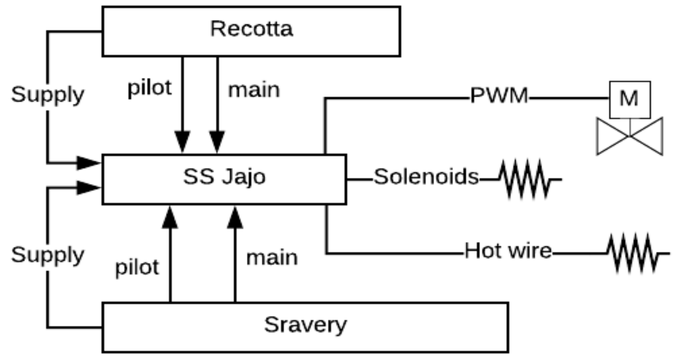

Figure 61. Redundancy diagram for recovery electronics.

Such minimalistic design makes Jajo very reliable and makes signals from Sravery and Recotta sure to be executed. It has implemented hardware watchdog - periphery which resets core if no action occurred for programed period. Because its software is not time dependant, resetting the MCU forces the return of full functionality of the module in recovery subsystem.

G. Telemetry and tracking

The Turbulence rocket incorporates a telemetry module that is able to transmit data with 700 bps of speed, allowing it to constantly broadcast information collected from the rocket's sensors, which include, but are not limited to: altitude (calculated from the barometer), GPS position (longitude, latitude, height), voltages of particular modules. Apart from that, it incorporates a GSM module allowing it to send its position after the rocket lands. By doing so, we have two ways to determine the rocket's landing site. Should something go wrong with GSM/GPS module, or when there is no cellular network in the vicinity, we are able to determine a rough position of the rocket while it is falling, head in the direction of the landing site, and determine the exact location with a directional antenna.

Both the transceiver and the receiver use BaoFeng UV-5R radios paired with custom-made modems and protocols allowing them to communicate with minimum lag and maximum speed. We've chosen those radios due to their unbeatable price-to-power ratio, which is very desirable while testing rockets. Additionally, they are able to transmit on amateur frequencies, which is legal provided the operator has a ham radio license.

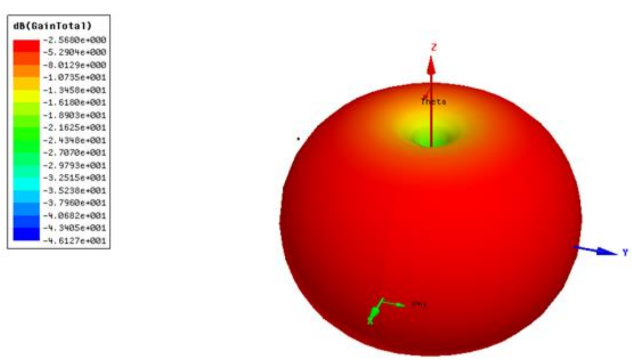

Figure 62. Antenna radiation pattern.

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The transmitter's antenna was simulated in HFSS software to ensure its maximum performance for this specific application. During the design process we found out that metal rods supporting the rocket's structure cause significant losses and that is why we are planning to replace them with non-metallic structure in the next iteration. However, there it has been proposed to locate the antenna in the nosecone section. Figure 58 presents the radiation pattern of the whole system, which is omnidirectional as desired.

Because of the radio's transmitting power, it is bound to produce unwanted electromagnetic field. It would be very undesirable to have such a device in the avionics section, which could potentially lead to a system malfunction due to electromagnetic interference with other electronics in that section. That is why we decided to mill an aluminum case that also serves as a heat sink. The radio and transmitter are connected with single IDC ribbon cable and D-SUB screwed connectors providing both power and modulated signal to and from the radio.

H. Communication and Ground Station Subsystems

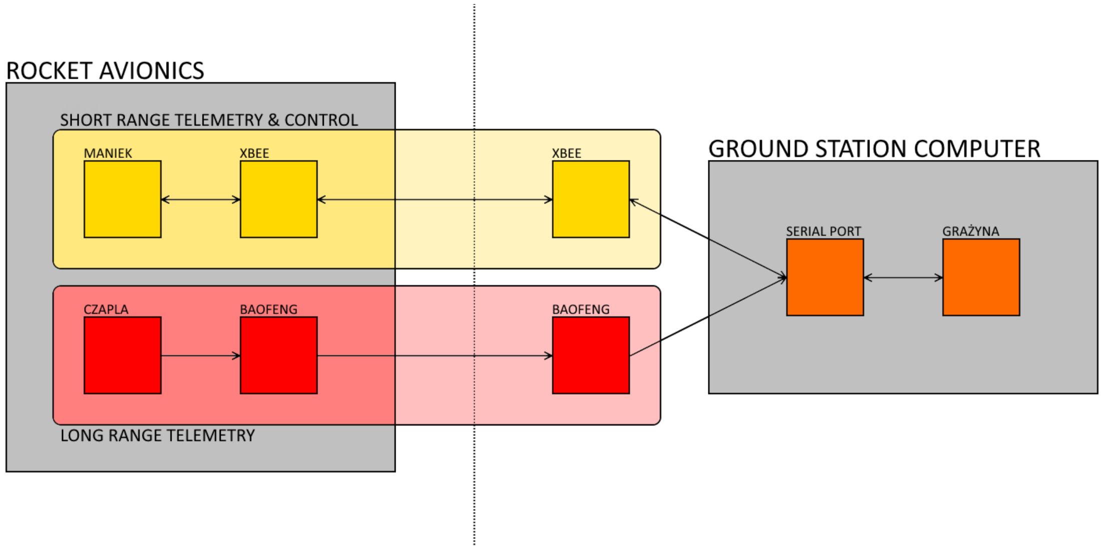


Figure 63. Communication diagram for BS10.

The Ground Station software was created in order to reinforce the remote control over the engine, internal subsystems and the rocket itself. The main purpose of its existence is to provide remote access to all data gathered from rocket telemetry. It also provides support for crucial stages of pre-launch activities, e.g. fueling and engine tests.

The application uses serial port communication as the main communication layer. It allows an operator to choose an available port, baud rate, and also set the serial port delay and the timeout if needed as shown on Figure 59.

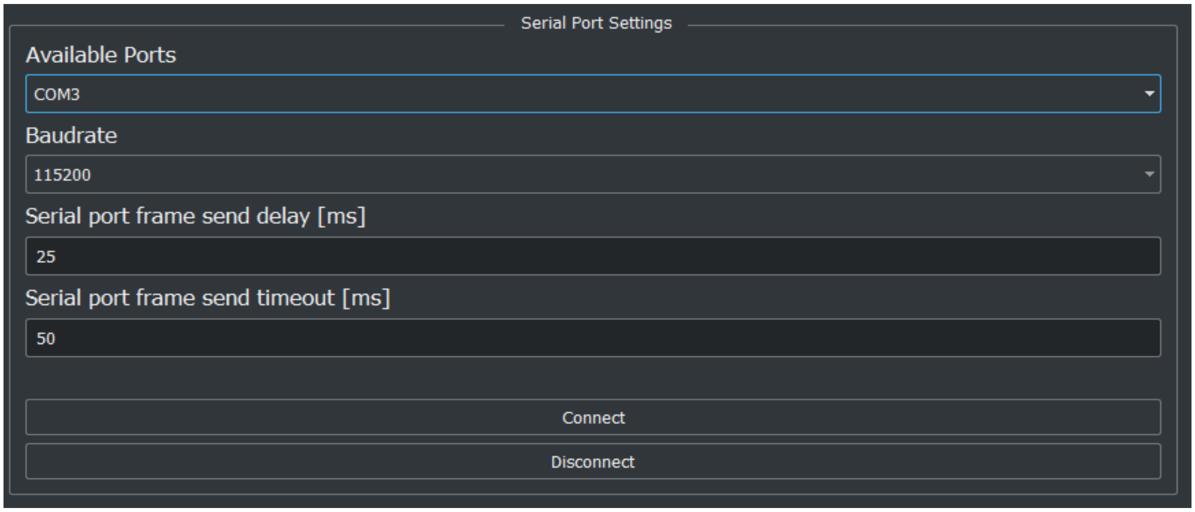


Figure 64. Serial port connection menu.

Apart from the connection module, the application supports four dedicated modes for different scenarios:
- hybrid fuel engine test
- liquid fuel engine test
- fueling
- launch

1. Engine Test

The first two modes were created to cover hot-fire tests of hybrid-powered and liquid-powered engines developed by the group. In this mode, two steps shall be performed. The first one is the preparation, where the test operator shall provide the following values for both the fuel and the oxidizer valve servo motors:
- initial position
- open position
- closed position

There is also a possibility to test minimum and maximum valve position (open and close position) and visually confirm that servo motors are performing nominally. The preparation step tab is shown on Figure 60.

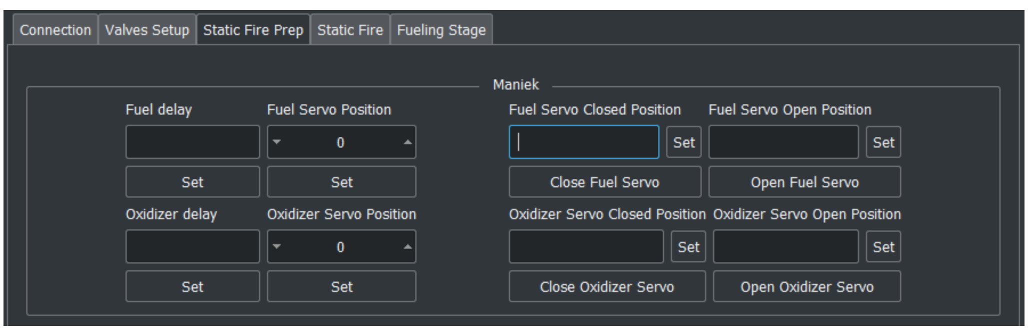


Figure 65. Engine test preparation tab.

The next tab is dedicated to running the test and provides the following data:
- Staszek's and Maniek's hardware:
  - voltage [V]
  - servomechanisms' current [A]
  - sent packages (frames)
  - SD flash drive availability

    ○ IGN and ARM statuses
- Measurements:
    ○ oxidizer/fuel vessel pressure
    ○ oxidizer/fuel pressure
    ○ combustion chamber pressure
    ○ current mass
    ○ thrust

Thrust value is obtained from the tensometer, which is built-in into the testing platform. There is also a control panel for both Staszek's and Maniek's hardware, which allows an operator to:
- start writing data to SD card
- start writing ADC data to flash
- start/stop ADC measurements
- delete all flash data
- tare tensometer
- trigger ignition
- initiate ignition sequence
- abort the test

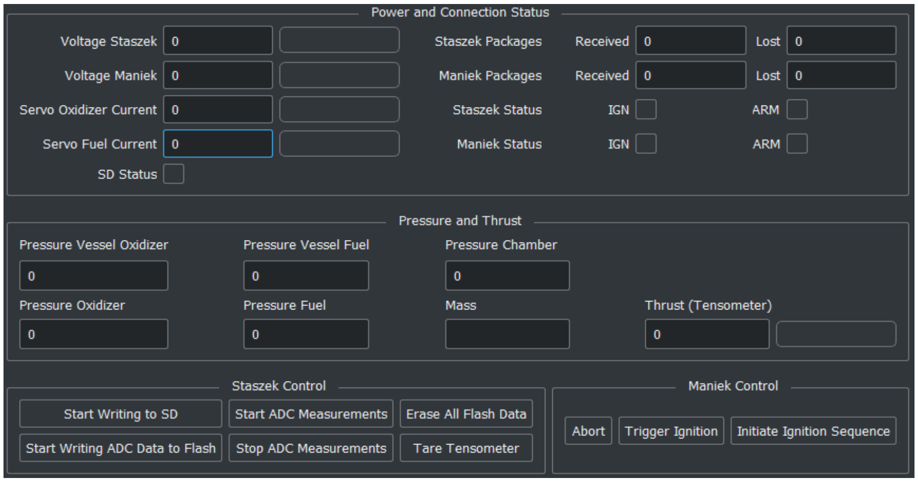


Figure 66. Static test fire tab.

2. Fueling

The fueling mode is dedicated to performing the rocket fueling process, without forcing the operator to stay close to the fueling stand. The fueling tab displays the most important values related to this process:
- fuel/oxidizer piston position [mm]
- fuel and oxidizer pressure [bar]
- current mass [kg]

The operator shall be able to load and unload both the fuel and the oxidizer by using manual loading or toggle controls. The toggle can be triggered and causes a continuous propellant flow. The manual loading button, on the other hand, allows more precise control and propellant flows only during the time when the button is pressed. There is also the possibility to use the tare button to scale the mass properly before the process.

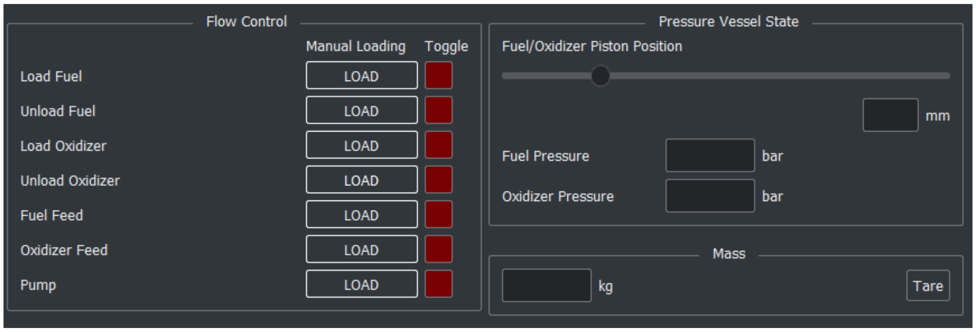


Figure 67. Filling tab.

3. Launch Mode

This is the most important mode provided by the ground station software. It allows the operator to perform the entire rocket launch procedure. The procedure itself is composed of connection, preparation, and fueling tabs, which are mentioned in the previous subsections, but it also contains additional tabs for valves settings and launch.

The valve settings tab is responsible for determining the valves' opening sequence, which has a huge impact on the rocket engine's performance, especially during ignition phase. The operator should be able to provide values for valve delays for both fuel and oxidizer and set the valves' opening percentage and time. Furthermore, the settings will be visible in built-in charts.

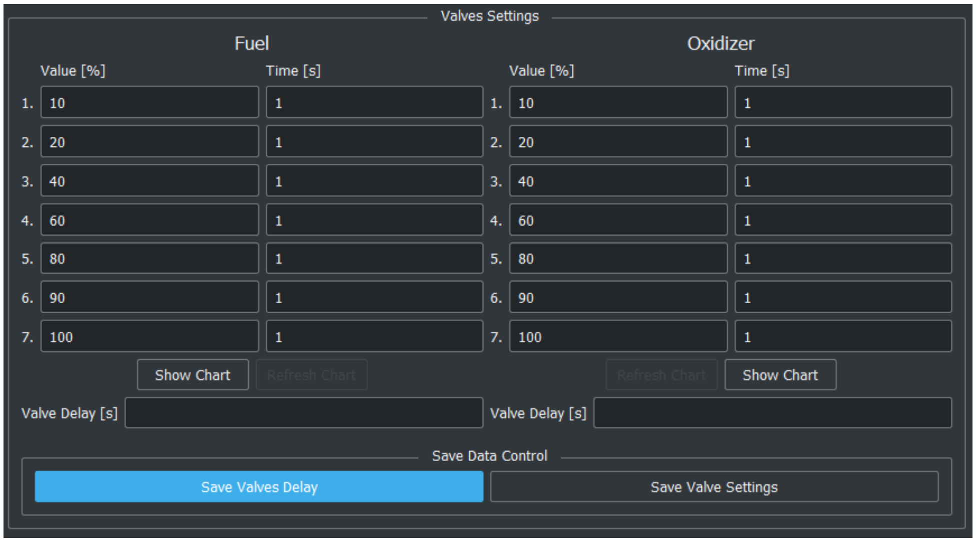


Figure 68. Ignition sequence tab.

The launch tab should give the operator an insight into the live status of the rocket. Moreover, all its parameters should be received during pre-launch, launch, powered flight, ballistic flight and recovery. It is the most complex tab available in the entire application and displays the following data:

- atmospheric conditions:
  - altitude [m]
  - pressure [hPa]
  - reference pressure [hPa]
- hardware status:
  - ARM and IGN statuses for Staszek, Maniek and Sravery microcontrollers
  - voltage for all available hardware modules [V]

    - received frames for all available modules
- rocket status:
    - pitch|roll|yaw
    - velocity [m/s]
    - acceleration [m/s2]
    - current mass [kg]
- vessel pressure state:
    - fuel/oxidizer piston position [mm]
    - fuel pressure [bar]
    - oxidizer pressure [bar]

Additionally, a GO/NO-GO section was added. These indicators provide information on the most crucial steps which should be finished/fulfilled in order to perform the rocket launch. The operator will be informed in which stage the process currently is, how many frames have been sent and received throughout the flight, and will be able to start writing data to an SD card by clicking the Start Writing Data button. The launch procedure functionality shall be triggered from the Launch button. Launch can also be terminated by using the Abort button, which will stop all ongoing procedures.

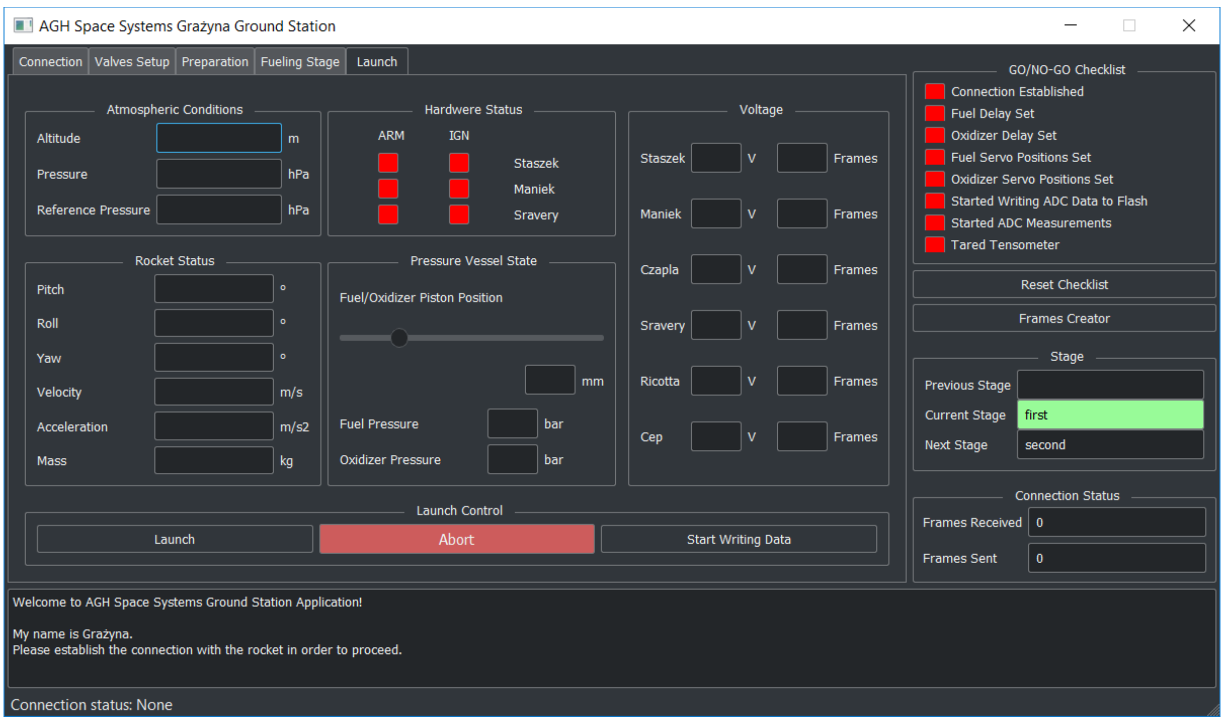


Figure 69. Launch control tab.

III. Mission Concept of Operations Overview

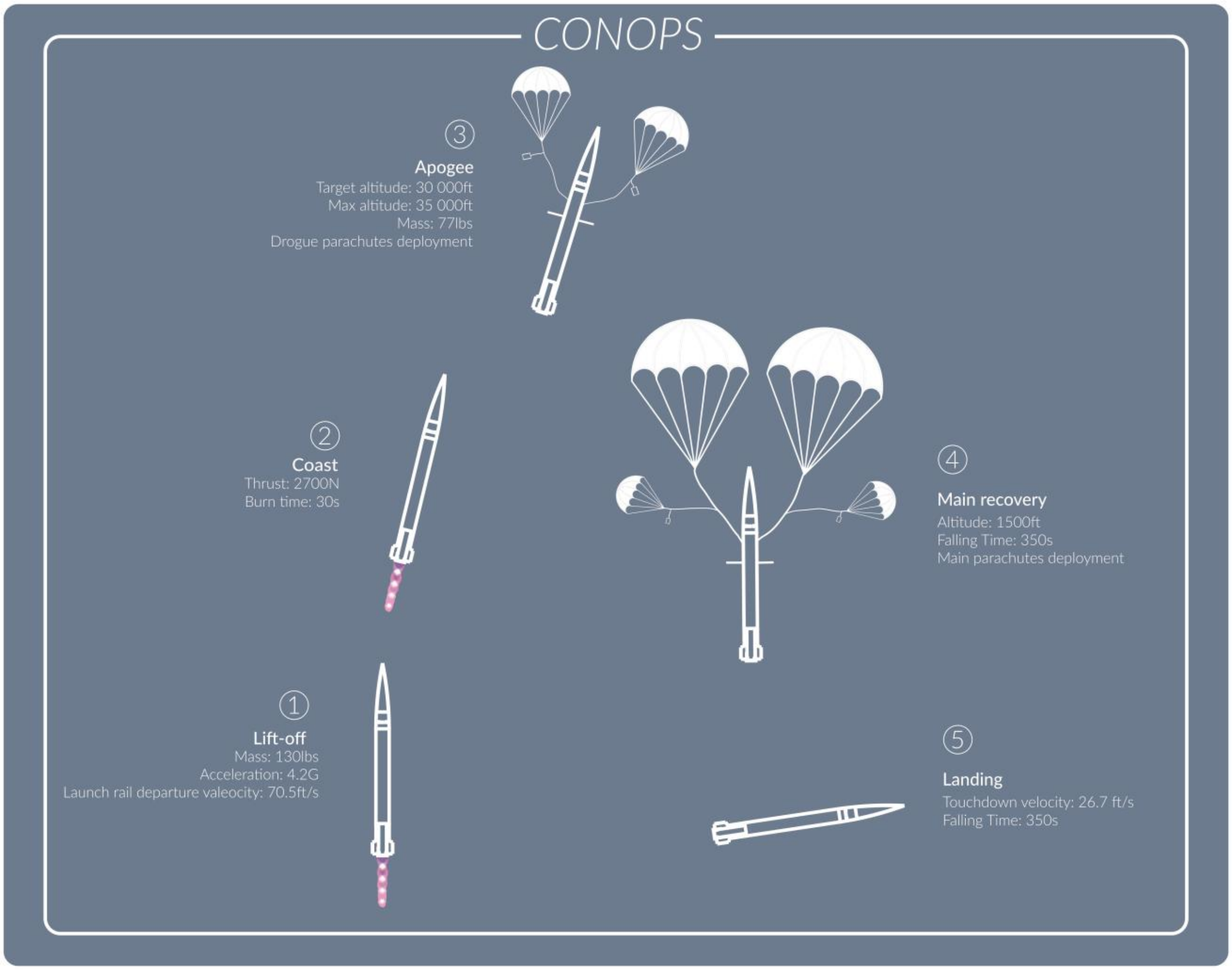


Figure 70. BS10 IREC 2018 Mission concept of operations

A. At launchpad

Mission event: Power provided to the rocket systems
Visual identification: Rocket vertical on the rail

Propulsion Subsystems	Pressure Vessel	empty, opened
	FOV, FFV	connected, open
	MOV, MFV	depressurized, opened
	Thrust Chamber	depressurized
	Igniter	SAFED
Recovery Subsystems	Drogues	internal
	Mains	internal
	Pneumatic Ejection System	ARMED
	Heat-resistant Wire	ARMED
Control Avionics		communication OFF, telemetry ON, DAQ ON, GPS OFF
Recovery Avionics		standing by

B. Filling

Mission event: First fill command sent from Ground Station fueling tab
Visual identification: Rocket vertical on the rail

Propulsion Subsystems	Pressure Vessel	full, opened
	FOV, FFV	connected, open
	MOV, MFV	depressurized, opened
	Thrust Chamber	depressurized
	Igniter	SAFED
Recovery Subsystems	Drogues	internal
	Mains	internal
	Pneumatic Ejection System	ARMED
	Heat-resistant Wire	ARMED
Control Avionics		communication OFF, telemetry ON, DAQ ON, GPS OFF
Recovery Avionics		standing by

C. Ignition

Mission event: Launch command sent from Ground Station Launch tab, ignition sequence begins
Visual identification: Rocket vertical on the rail, flames out of the nozzle

Propulsion Subsystems	Pressure Vessel	full, opened
	FOV, FFV	disconnected, closed
	MOV, MFV	pressurized, opened
	Thrust Chamber	pressurized
	Igniter	ACTIVATED
Recovery Subsystems	Drogues	internal
	Mains	internal
	Pneumatic Ejection System	ARMED
	Heat-resistant Wire	ARMED
Control Avionics		communication OFF, telemetry ON, DAQ ON, GPS OFF
Recovery Avionics		standing by

D. Lift-off

Mission event: Ignition sequence has been completed
Visual identification: Rocket clears the launch rail, exhaust gases from the nozzle

Propulsion Subsystems	Pressure Vessel	full, opened
	FOV, FFV	disconnected, closed
	MOV, MFV	pressurized, opened
	Thrust Chamber	pressurized
	Igniter	ACTIVATED
Recovery Subsystems	Drogues	internal
	Mains	internal
	Pneumatic Ejection System	ARMED
	Heat-resistant Wire	ARMED
Control Avionics		communication OFF, telemetry ON, DAQ ON, GPS OFF
Recovery Avionics		recording

E. Burnout

Mission event: Pressure Vessel depressurizes, out of propellants
Visual identification: Rocket starts to decelerate, no exhaust gases from the nozzle

Propulsion Subsystems	Pressure Vessel	empty, opened
	FOV, FFV	disconnected, closed
	MOV, MFV	depressurized, opened
	Thrust Chamber	depressurized
	Igniter	ACTIVATED
Recovery Subsystems	Drogues	internal
	Mains	internal
	Pneumatic Ejection System	ARMED
	Heat-resistant Wire	ARMED
Control Avionics		communication OFF, telemetry ON, DAQ ON, GPS OFF
Recovery Avionics		recording

F. Apogee

Mission event: Apogee latch on control avionics, voting successful
Visual identification: Rocket starts to fall down, chutes deployed

Propulsion Subsystems	Pressure Vessel	empty, opened
	FOV, FFV	disconnected, closed
	MOV, MFV	depressurized, opened
	Thrust Chamber	depressurized
	Igniter	ACTIVATED
Recovery Subsystems	Drogues	external
	Mains	internal
	Pneumatic Ejection System	ACTIVATED
	Heat-resistant Wire	ARMED
Control Avionics		communication OFF, telemetry ON, DAQ ON, GPS ON
Recovery Avionics		drogue deployment command sent

G. Main Parachutes Deployment

Mission event: Command sent to Recovery Avionics
Visual identification: Rocket descents on chutes, main parachutes deployed

Propulsion Subsystems	Pressure Vessel	empty, opened
	FOV, FFV	disconnected, closed
	MOV, MFV	depressurized, opened
	Thrust Chamber	depressurized
	Igniter	ACTIVATED
Recovery Subsystems	Drogues	external
	Mains	external
	Pneumatic Ejection System	ACTIVATED
	Heat-resistant Wire	ACTIVATED
Control Avionics		communication OFF, telemetry ON, DAQ ON, GPS ON
Recovery Avionics		main deployment command sent

H. Touchdown

Mission event: Command sent to Recovery Avionics
Visual identification: Rocket descents on chutes, main parachutes deployed

Propulsion Subsystems	Pressure Vessel	empty, opened
	FOV, FFV	disconnected, closed
	MOV, MFV	depressurized, opened
	Thrust Chamber	depressurized
	Igniter	ACTIVATED
Recovery Subsystems	Drogues	external
	Mains	external
	Pneumatic Ejection System	ACTIVATED
	Heat-resistant Wire	ACTIVATED
Control Avionics		communication OFF, telemetry ON, DAQ ON, GPS ON
Recovery Avionics		standing by

IV. Conclusions and Lessons Learned

For our team, it was the first end-to-end project of the liquid-powered rocket. We have encountered many problems for the first time and we have had to learn how to solve them. Therefore, the project was a big challenge for the team, but, at the same time, it allowed the entire team to gain a lot of knowledge that will certainly pay off in the future.

A. Lessons Learned During Design

- Project design and development should start from the minimum working version, especially when the team has no extensive previous experience in the subject. It is usually impossible to avoid all the delays when most of the subsystems contain solutions that have not been approached by the team before. Adjusting the design for the delays and issues to ensure that the system still reaches desired goals is very time-consuming and forces the team to make many difficult decisions. It is much easier to first develop a more simple system leaving the door open for further development and, after proving it works as intended, to incrementally improve the system by implementing more complex and advanced subsystems. If any new solution or subsystem does not meet expectations or is delayed, there is already an existing system that is tested and ready for operation.
- The team should be prepared that the first prototypes are likely to fail and should include this fact in the schedule. Usually, early subsystem tests unveil issues that were not included in the design and, often, at least a partial redesign is required. It is especially valid in case when the team aims to make use of any particular solution or technology for the first time.

B. Lessons Learned During Manufacturing

- Manufacturing has to be planned carefully, as it tends to take more time than estimated, especially when relying on external suppliers. Parts ordered from suppliers or manufactured in-house do not always meet the precision criteria and some issues can only be discovered after a part manufacturing is complete. Therefore, manufacturing schedule should always be prepared with an assumption that many parts may require to be manufactured again. It turned out that manufacturing caused most of the project schedule bottlenecks.

C. Lessons Learned During Testing

- Even if any particular test passes many times, it should not be taken for granted that it will pass the next time. Testing conditions should be as close to the operational ones as possible ("test as you fly, fly as you test" principle), because many external conditions may often influence a test in a way that could not be easily predicted. Additionally, any small change to the subsystem should also trigger additional tests, because it may cause some effects not predicted by the theoretical analysis.
- Cross-subsystem integration tests are usually much more valuable than single subsystem tests. Even if every subsystem is tested thoroughly by itself, integration tests often reveal issues that were not encountered earlier. We have observed at least two causes of this fact. The first one is that mocks of the other subsystems always differ from the real ones. The other one is that it is impossible to predict and test every behavior of every subsystem, especially in case of negative paths and failure modes.
- Frequent testing (including cross-subsystem testing) during development is very important and, somehow counter-intuitively, reduces overall development time. When a specific component is not tested for a long time, it may eventually happen that the requirements were misunderstood and the component has to be at least partially redeveloped. Frequent tests help to avoid such issues and to ensure that development of all the components follows the right direction.

V. SYSTEM WEIGHTS, MEASURES, AND PERFORMANCE DATA APPENDIX

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	155	
Airframe Diameter (inches):	7.87	
Fin-span (inches):	20.47	18.89 for 1st stage, 14.56 for 2nd stage
Vehicle weight (pounds):	71,6	
Propellent weight (pounds):	44	
Payload weight (pounds):	8,8	
Liftoff weight (pounds):	124,4	
Number of stages:	1	
Strap-on Booster Cluster:	No	
Propulsion Type:	Liquid	
Propulsion Manufacturer:	Student-built	
Kinetic Energy Dart:	No	

Propulsion Systems: (Stage: Manufacturer, Motor, Letter Class, Total Impulse)

1st Stage: SRAD Liquid, 11 pounds of ethanol propellant and 36 pounds of Nitrous Oxide, O Class, 40200 Ns

Total Impulse of all Motors: 40200 (Ns)

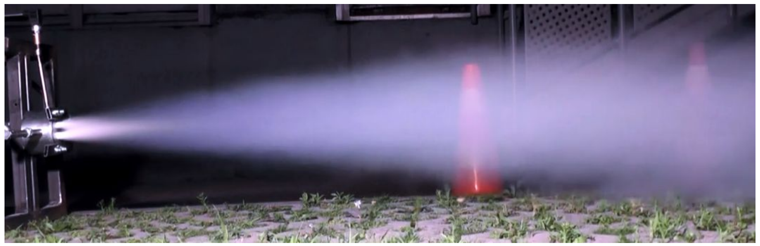
Predicted Flight Data and Analysis

The following stats should be calculated using rocket trajectory software or by hand.

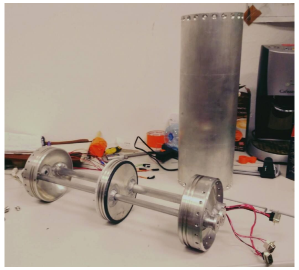
Pro Tip: Reference the Barrowman Equations, know what they are, and know how to use them.

	Measurement	Additional Comments (Optional)
Launch Rail:	ESRA Provide Rail	
Rail Length (feet):	17	
Liftoff Thrust-Weight Ratio:	4.7	
Launch Rail Departure Velocity (feet/second):	68.8	
Minimum Static Margin During Boost:	1.03	*Between rail departure and burnout
Maximum Acceleration (G):	4	
Maximum Velocity (feet/second):	1407	
Target Apogee (feet AGL):	30K	
Predicted Apogee (feet AGL):	30K	

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 10.02.2018**
Test Name	**Propulsion System Testing - 2nd Stage Pressure Vessel Test**		
Objective	Checking that the pressure vessel is working properly. Functional project verification.		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)	• Pressure measurement, • visual inspection of leaks and damage • touch-screening	**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	Preparation of the research area. Closed test performed in a safety room. Safety measures shall be taken to ensure that nobody is on the test site. We prepare firefighting and rescue equipment. 2 employees wear protective clothing. The tank is mounted on a special stand. Connection of the set to a hydraulic equipment with a pressure of at least 60 bar.
Test results (analysis, importance of the results for the design)	The tank was tested in 3 stages: 1. Maximum strength was tested on 130 bar. 2. The leak test at 60 bar for 20 minutes was successful and no pressure drop was noted. 3. The filling and emptying test was carried out in 50 cycles. We achieved up to 60 bar (working pressure) per cycle. This successful test confirms the component's performance and gives us the opportunity to perform more complex tests in the future. 		
Rating	**SUCCESSFUL**		
Conclusions and recommendations	As a result of the successful test, we can go further in integrating this subsystem into the propulsion system. This is an extremely important test because the tank is our own design. The innovative design saves space and weight. We have high hopes for development and scaling with this concept.		

<table>
<tr><td colspan="4">Test Report</td></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 24.03.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Propulsion System Testing - 2nd Stage Propulsion Integration and Cold Flow Tests</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of the title components.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td>● checking the connections,
● checking the tightness of the system,
● testing the fit of the subsystems,
● visual inspection,
● photos for integration purposes
● Recording of sensor data.
● touch-screening</td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td>Preparation of the test space. Security measures shall be taken to ensure that nobody is present on the test site. We prepare firefighting and rescue equipment. 3 staff members wear protective clothing. The feed system is integrated. Subsequent preparation of subsystems for integration. Overview of interface matching. Preparation of a stand for a cold-flow test. Pressure vessel integration. Integration of final components such as nozzle and combustion chamber. Startup of the test electronics. Vessel is filled and prepared for propellant delivery. The flow of fluids through the system is started and the flow parameters are measured simultaneously. End of test. Data logging.</td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3"> </td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3">As a result of the successful test, we can go further in integrating this propulsion subsystem into the rocket system.</td></tr>
</table>

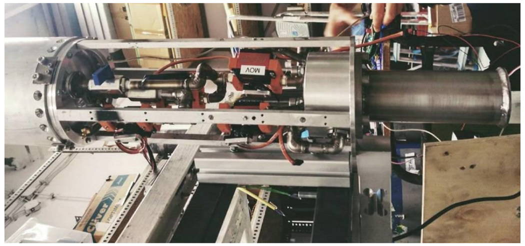
<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 02.04.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Propulsion System Testing - 1st Stage Pressure Vessel Test</td></tr>
<tr><td>Objective</td><td colspan="3">Checking that the pressure vessel is working properly. Functional project verification.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td>● Pressure measurement,
● visual inspection of leaks and damage
● touch-screening</td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td>Preparation of the research area. Closed test in a safety room. Safety measures shall be taken to ensure that nobody is on the test site. We prepare firefighting and rescue equipment. 2 employees wear protective clothing. The tank is mounted on a special stand. Connection of the set to a hydraulic equipment with a pressure of at least 60 bar.</td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">The tank was tested in 3 stages:
1. Maximum strength was tested on 130 bar.
2. The leak test at 60 bar for 20 minutes was successful and no pressure drop was noted.
3. The filling and emptying test was carried out in 50 cycles.

We achieved up to 60 bar (working pressure) per cycle. This successful test confirms the component's performance and gives us the opportunity to perform more complex tests in the future.
</td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3">The conclusion is similar to that of the 2nd Stage Pressure Vessel Test. As a result of the successful test, we can go further in integrating this subsystem into the propulsion system. This is an extremely important test because the tank is our own design. The innovative design saves space and weight. We have high hopes for development and scaling with this concept.</td></tr>
</table>

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 03.04.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Propulsion System Testing - 2nd Stage Propulsion Hot-fire Tests no. 1</td></tr>
<tr><td>Objective</td><td colspan="3"></td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">Due to critical delays and schedule adjustments test has been postponed indefinitely.</td></tr>
<tr><td>Rating</td><td colspan="3">xxx</td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td colspan="4">Test Report</td></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 14.04.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Propulsion System Testing - 2nd Stage Propulsion Hot-fire Tests no. 2</td></tr>
<tr><td>Objective</td><td colspan="3"></td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">Due to critical delays and schedule adjustments test has been postponed indefinitely.</td></tr>
<tr><td>Rating</td><td colspan="3"><u>xxx</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

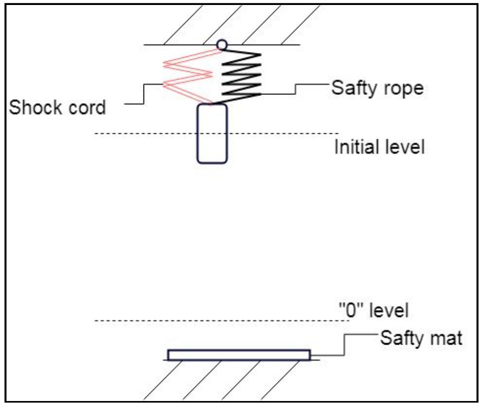
<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 21.04.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Propulsion System Testing - 1st Stage Propulsion Integration</td></tr>
<tr><td>Objective</td><td colspan="3">In-depth verification of the integration of the entire system before the hot-fire test.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td>● recording of sensor data
● video
● visual inspection
● checking the connections
● checking the tightness of the system
● testing the fit of the subsystems
● photos for reference
● touch-screening</td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td>Preparation of the test space. Security measures shall be taken to ensure that nobody is present on the test site. We prepare firefighting and rescue equipment. 3 staff members wear protective clothing. Subsequent preparation of subsystems for integration. Overview of interface matching. Preparation of a stand for a cold-flow test. The feed system is integrated. Pressure vessel integration. Integration of final components such as nozzle and combustion chamber. Startup of the test electronics. Vessel is filled and prepared for propellant delivery. The flow of fluids through the system is started and the flow parameters are measured simultaneously. End of test. Data logging.</td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">All interfaces have been tested and successfully connected. The new test rig was used and proved to be an excellent one. The feed system has been effective in providing a fuel supply. No leaks were noted. We integrated our tank, which was initially a source of uncertainty. The combustion chamber and engine nozzle were successfully connected. The refueling process went smoothly and successfully, without major leaks.

Then we successfully passed the propellant through the system. No anomalies were noted. In addition, a data acquisition system for the propulsion system has been tested.
</td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3">System integration was extremely important for us. Liquid fuel propulsion is an extremely complex component of a rocket. This allows us to gain experience and improve the order of work.

We should pay more attention to holding the integration tools together.</td></tr>
</table>

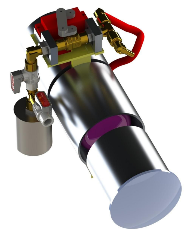
Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 01.06.2018**
Test Name	**Propulsion System Testing - 1st Stage Propulsion Hot-fire Tests no. 1**		
Objective	Validation of the title components.		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	
Test results (analysis, importance of the results for the design)	**This test is scheduled to be conducted soon.** **Its results will be evaluated prior to the event and brought to the Flight Safety and Launch Operations Teams to review on request.**		
Rating	**SUCCESSFUL**		
Conclusions and recommendations			

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 01.05.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Propulsion System Testing - 1st Stage Propulsion Hot-fire Tests no. 2</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of the title components.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">This test is scheduled to be conducted soon.
Its results will be evaluated prior to the event and brought to the Flight Safety and Launch Operations Teams to review on request.</td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 27.03.2018**
Test Name	**Recovery System Testing - Recovery Shock Cord Test**		
Objective	Verification of the shock resistance of parachute cords.		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)	● visual inspection ● controlled load	**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	Preparation of the stand for the drop of the device from a height. Preparation of the load, which will be increased accordingly and will simulate the forces exerted on the parachute cord. Different shock variants have been tested for comparison. We use a safety rope to secure the test. The test is performed from a designated level described as initial level. An additional protection is provided by a mat absorbing the impact, which is laid out under the stand.
Test results (analysis, importance of the results for the design)	We have tested a number of construction proposals for cords. The position has been helpful and effective. Simplicity has prevailed.The test showed that for a heavy load the best results are obtained by shock cord consisting of tubular tape sewn twice with a straight seam along the axis of the tape and elastic rope 8mm. The test was carried out by dropping 20 kg from a height of 2.5m. Corresponding to similar in-flight conditions. This is a very important test because we have very little space for potentially thicker cords. This saves space and ensures that the design will withstand a shock.  		
Rating	<u>**SUCCESSFUL**</u>		
Conclusions and recommendations	Simple yet critical test. This successful experiment confirms the component's performance and gives us the opportunity to perform more complex tests in the future.		

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 02.05.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Recovery System Testing - Recovery Pneumatics Test</td></tr>
<tr><td>Objective</td><td colspan="3">Verification of the functionality of a high pressure system for recovery firing.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td>● visual inspection
● touch-screening</td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td>Preparation of the test space. Security measures shall be taken to ensure that nobody is present on the test site. Assembling the entire pneumatic system. Setting the test safety cover. Personnel putting on protective equipment. Filling the pressure vessel with gas. Check for tightness in the gaseous phase. Carry out a liquid phase test. Execution of the test sequence of gas batch firing.</td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">We were preparing for the test longer than we had expected. Due to its high energy content, we have made this test a priority.

1. The entire pneumatic system was successfully assembled.
2. Successful filling of the pressure vessel with gas.
3. The gas tightness test was successful and no major leakages were noted. We have written down recommendations for the future.
4. The liquid phase test was successful. There were no problems.
5. Successful execution of a test gas batch firing sequence. Sensor electronics was included in the test.

All components have withstood the above test.
</td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3">Special attention should be paid to the precise sealing of the threaded connections. Due to the very low NO_2 temperature, connections tend to leak. This successful test confirms the component's performance and gives us the opportunity to perform more complex tests in the future.</td></tr>
</table>

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 16.05.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Recovery System Testing - Ground Test Demonstration</td></tr>
<tr><td>Objective</td><td colspan="3">Verification of the parachute ejection system.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td>● Video footage.
● Visual inspection.</td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td>Completion of the entire recovery system. Practice the sequence for folding and stacking parachutes. A system of parachutes, such as in flight. Perform strength test. After the pilots were thrown away, the force on them was generated manually.</td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">Recovery system mechanisms were tested successfully. Test carried out correctly and effectively. Efficient assembly of the entire recovery system was not a problem. Skillful practicing the sequence of assembling and stacking parachutes requires skill, but it was successful. Building a system of parachutes as successful and trouble free as in flight.

Successful endurance test. After the pilots were thrown away, the force generated on them was manually generated and did not damage the devices.
</td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3">Special attention should be paid to correct folding and laying of parachutes and ropes in order to minimize the possibility of entanglement.
It would be useful to confirm empirically the value of the force generated on the pilot in order to confirm the correctness of the assumptions.
Therefore, the next test is planned: Empirical parachute drag force designation. This successful test confirms the component's performance and gives us the opportunity to perform more complex tests in the future.</td></tr>
</table>

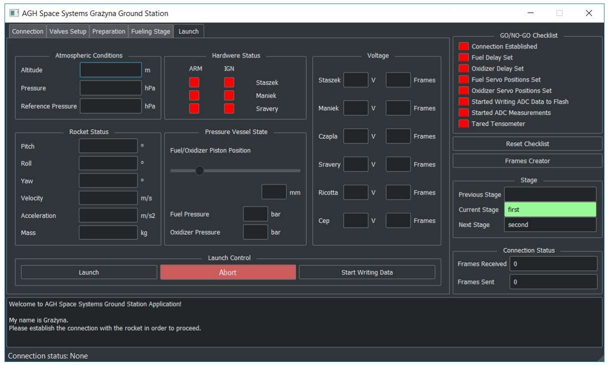
<table>
<tr><td colspan="4">Test Report</td></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 08.06.2018 (planned)</td></tr>
<tr><td>Test Name</td><td colspan="2">Recovery System Testing - Empirical parachute Drag force designation</td></tr>
<tr><td>Objective</td><td colspan="3"></td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">This test is scheduled to be conducted soon.
Its results will be evaluated prior to the event and brought to the Flight Safety and Launch Operations Teams to review on request.</td></tr>
<tr><td>Rating</td><td colspan="3"><u>xxx</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td colspan="4">Test Report</td></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 30.03.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Recovery System Testing - 2nd Recovery Nosecone and Pilot Test</td></tr>
<tr><td>Objective</td><td colspan="3"></td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">Due to critical delays and schedule adjustments test has been postponed indefinitely.</td></tr>
<tr><td>Rating</td><td colspan="3"><u>XXX</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 30.03.2018**
Test Name	**Recovery System Testing - 2nd Stage Recovery Main Parachute Release Test**		
Objective			
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	
Test results (analysis, importance of the results for the design)	**Due to critical delays and schedule adjustments test has been postponed indefinitely.**		
Rating	**XXX**		
Conclusions and recommendations			

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 18.03.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Avionics System Testing - DAQ Electronic Unit Test</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of DAQ electronics functionalities.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td>● Processor readings.
● Visual inspection.
● Performance in other tests</td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td>Preparation of DAQ tests. Cylinder filling test. First fill command sent from Ground Station fuelling. Ignition test. Simulated rocket launch. Burnout of the engine. Achievement of the apogee. The parachutes were thrown out. Landing and recovery.</td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">We have prepared parts of the tests using DAQ electronics. We have performed a successful bottle filling test. Ignition tests have been carried out. We threw out the parachutes during the test.

Our experience so far gives us all the certainty of the proper functioning of DAQ electronics.</td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3">Ready for further testing.</td></tr>
</table>

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 20.03.2018**
Test Name	**Avionics System Testing - Ground Station Integration and Communication Test**		
Objective	Validation of Ground Station Integration and Communication.		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)	• Processor readings. • Visual inspection. • Performance in other tests	**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	Test four dedicated modes for different events. Establish connection with rocket.
Test results (analysis, importance of the results for the design)	A communication test was successfully carried out. The range is described in another report. A number of tests were performed by issuing commands to a simulated rocket system. No anomalies were found. • hybrid fuel engine test • liquid fuel engine test • fueling • launch 		
Rating	**SUCCESSFUL**		
Conclusions and recommendations	A ground station is the legacy of many years of work and we can count on this software, specially adapted to the needs of the competition.		

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 20.03.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Avionics System Testing - CAN Communication Test</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of CAN avionics modules communication.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td>● Processor readings.
● Visual inspection.
● Performance in other tests</td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td>Testing the CAN bus during all possible experiments.</td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">We carried out the following tests using CAN:

● MANIEK - power distribution, feed control system, ignition system, short range telemetry
● STASZEK - data acquisition
● Sravery - SRAD recovery module

CAN is standardized communication system in terms of physical and protocol layer allows for flexible adjustment of the number and type of sensors needed in the sensory network. Each board has a layout compatible with the other modules making stackable configuration possible.</td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3">CAN has proved to be a good communication standard. As a key element, it has proved its worth quickly and can be used for further testing. Changing this standard in the future will involve a lot of work.</td></tr>
</table>

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 22.03.2018**
Test Name	**Avionics System Testing - Fueling System Test**		
Objective	Validation of...		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	
Test results (analysis, importance of the results for the design)			
Rating	**SUCCESSFUL**		
Conclusions and recommendations			

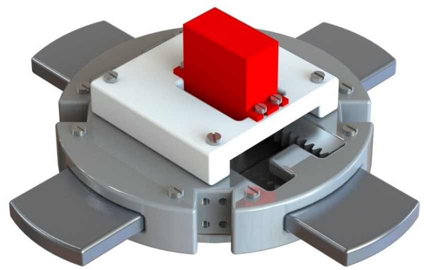
Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 31.03.2018**
Test Name	**Avionics System Testing - Telemetry and GPS Positioning**		
Objective	Validation of...		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	
Test results (analysis, importance of the results for the design)			
Rating	**SUCCESSFUL**		
Conclusions and recommendations			

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 31.03.2018**
Test Name	**Avionics System Testing - AHRS Algorithm and Hardware Test**		
Objective	Validation of...		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	
Test results (analysis, importance of the results for the design)			
Rating	**SUCCESSFUL**		
Conclusions and recommendations			

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 31.03.2018**
Test Name	**Avionics System Testing - Recovery Electronics Test**		
Objective	Validation of...		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	
Test results (analysis, importance of the results for the design)			
Rating	**SUCCESSFUL**		
Conclusions and recommendations			

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 31.03.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Avionics System Testing - Altitude Algorithm and Hardware Test</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of...</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3"></td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

Test Report

Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 20.04.2018**
Test Name	**Aerobrake System Testing - 2nd Stage Aerobrake Mechanical Performance Test**		
Objective	Validation of the Aerobrake mechanical performance and reliability under load.		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)	● visual inspection ● touch-screening	**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	Preparation of the research area. For the test, a working Aerobrake prototype was used as well as a servomechanism which controls the length of the extension of the braking planes.
Test results (analysis, importance of the results for the design)	During the test it was found that the mechanism has no backlashes and the braking planes extend at the same distance. During work under load no abnormalities were observed. The drive torque of the servomechanism proved to be sufficient, the drive transmission system was working properly, the braking planes were not deformed. The above factors play a key role in the stability of the vehicle's flight during the aerodynamic braking procedure.		
Rating	**<u>SUCCESSFUL</u>**		
Conclusions and recommendations	This test confirms the component's performance and reliability under load.		

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 21.04.2018**
Test Name	**Aerobrake System Testing - Aerobrake In-flight Performance Test**		
Objective			
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	
Test results (analysis, importance of the results for the design)			
Rating	<u>xxx</u>		
Conclusions and recommendations			

Test Report

<table>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 18.04.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Integrated Rocket System Testing - 2nd Stage Flight Acceptance</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of...</td></tr>
<tr><td>Evaluation methods
(e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results
(analysis, importance of the results for the design)</td><td colspan="3"></td></tr>
<tr><td>Rating</td><td colspan="3"><u>xxx</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 30.04.2018**
Test Name	**Avionics System Testing -Long-term High Altitude Test in Balloon**		
Objective	Altitude determine algorithm, low temperature and low pressure measurements, long-term storing test.		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)	● pressure, ● temperature, ● altitude, ● UV-radiation, ● Time measurements stored on flash memory	**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	We have been granted permits to fly legally with a balloon. Preparation of the start position. Flight in a balloon at an altitude of 16km. The on-board computer is located on board. Operation of electronics under changing environmental conditions. Fall of the cargo to the ground. Test of strength of equipment. Recovery of equipment from the place of landing.
Test results (analysis, importance of the results for the design)	Measurements below 0 degrees of Celsius induced variable overflow in pressure temperature compensation algorithm. Previous barometer module was tested in lower temperature, however indywidual calibration parameters made the compensating value lower, determining algorithm work correctly. The balloon flight took place without any disruptions. The on-board computer, placed on board, operated for the expected time. The weather conditions have changed considerably. The electronics survived the fall of the load to the ground. The recovery of equipment from the point of landing and the recovery of data have been successful. Whole flight parameters successfully stored on flash memory. 		
Rating	**<u>SUCCESSFUL/FAILED</u>**		
Conclusions and recommendations	The flight made it possible to test the key electronic and communication components. In the future, we will certainly be doing more of these tests.		

Test Report			
Team ID: 105	AGH Space Systems Turbulence Project		Date: 21.04.2018
Test Name	Integrated Rocket System Testing - 2nd Stage Test Flight no. 1		
Objective			
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)	
Test results (analysis, importance of the results for the design)	Abandoned		
Rating	xxx		
Conclusions and recommendations			

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 04.05.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Integrated Rocket System Testing - 1st Stage Flight Acceptance</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of...</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3"></td></tr>
<tr><td>Rating</td><td colspan="3"><u>xxx</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 09.05.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Integrated Rocket System Testing - 1st Stage Test Flight no. 1</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of...</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3"></td></tr>
<tr><td>Rating</td><td colspan="3"><u>xxxx</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 28.04.2018**
Test Name	**Overall Rocket System Testing - 2nd Stage Test Flight no. 2**		
Objective			
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	
Test results (analysis, importance of the results for the design)	Abandoned		
Rating	xxx		
Conclusions and recommendations			

<table>
<tr><th colspan="4">Test Report</th></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: 15.05.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Overall Rocket System Testing - 1st Stage Test Flight no. 2</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of...</td></tr>
<tr><td>Evaluation methods
(e.g. visual inspection, slo-mo footage, pressure measurements)</td><td></td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td></td></tr>
<tr><td>Test results
(analysis, importance of the results for the design)</td><td colspan="3"></td></tr>
<tr><td>Rating</td><td colspan="3"><u>xxx</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3"></td></tr>
</table>

<table>
<tr><td colspan="4">Test Report</td></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date: XX.XX.2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Feed System Testing - Servo-Valves Leakage Test</td></tr>
<tr><td>Objective</td><td colspan="3">Validation of the servo-valve performance under high pressure.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td>● visual inspection
● touch-screening</td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td>Preparation of the research area. Closed test performed in a safety room. Safety measures shall be taken to ensure that nobody is on the test site. Servo valves, safety valves and compressed nitrous oxide cylinders were used for the test. Compressed nitrous oxide is introduced into the closed servo valve via a safety valve. The servo valve was then checked for leaks.</td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">During the leak test of the servo valves, no leaks were detected. The equipment worked very well. There was no problem with operating the servo valves. The safety valves are tight and impermeable to nitrous oxide. A cylinder of compressed nitrous oxide was sufficient for the test, although in the event of failure, we considered using compressed air.

The absence of leaks is a key component in maintaining safety and proper operation of propulsion systems. The test is important because the entire flow system is designed and developed by our team. All threaded and welded joints have been made by our members. It was extremely valuable to confirm its functionality and to detect hidden defects of the project.
</td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3">Check the pre-flight sealing of the servomotors as the seals are subject to damage at low temperatures. This will be analysed in the next test. This test confirms the component's performance under high pressure. We can use small servos to save space, weight and money.</td></tr>
</table>

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: 04.05.2018**
Test Name	**Feed System Testing - Frozen Servo-Valve Flow Control Test**		
Objective	Validation of the servo-valve performance at low temperatures.		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)	• visual inspection • touch-screening	**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	Safety measures shall be taken to ensure that nobody is on the test site. Servo valves, safety valves and compressed liquid nitrous oxide cylinders were used for the test. The servo valve was then checked for freezing. Compressed nitrous oxide is introduced into the closed servo valve via a half-open servo valve. We did it until the servo valve was frozen. The possibility of controlling the degree of opening / closing of the servo valve was then checked.
Test results (analysis, importance of the results for the design)	After complete freezing, the servo valves did not present any problems with the possibility of controlling the degree of opening / closing of the servo valves. Our previous designs have not been able to function after freezing. This is a critical factor for the correct operation of the feed system, as failure to control the degree of opening/closing of the servo valves would result in a lack of control over the rocket motor. The successful freezing test has been the result of work on this issue over the past two years. It will no longer cause us any worries. 		
Rating	**<u>SUCCESSFUL</u>**		
Conclusions and recommendations	Check the pre-flight sealing of the servomotors as the seals are subject to damage at low temperatures. This test confirms the component's performance at low temperatures.		

Test Report			
Team ID: 105	**AGH Space Systems Turbulence Project**		**Date: XX.XX.2018**
Test Name	**2nd Recovery Nosecone and Pilot Test**		
Objective	Validation of...		
Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)		**Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)**	
Test results (analysis, importance of the results for the design)			
Rating	**SUCCESSFUL**		
Conclusions and recommendations			

<table>
<tr><td colspan="4">Test Report</td></tr>
<tr><td>Team ID: 105</td><td colspan="2">AGH Space Systems Turbulence Project</td><td rowspan="2">Date:12.04..2018</td></tr>
<tr><td>Test Name</td><td colspan="2">Telemetry and Tracking Test</td></tr>
<tr><td>Objective</td><td colspan="3">Measure the range of telemetry transmitter.</td></tr>
<tr><td>Evaluation methods (e.g. visual inspection, slo-mo footage, pressure measurements)</td><td>● GPS location measurement.
● Evaluation of the signal strength on the receiver.</td><td>Preparation, test setup, course of action (activities done prior to the test, step by step procedure etc.)</td><td>We used a transmitter to evaluate the transmission range. We moved away from the transmitter waiting for the connection to be disconnected. Evaluation of the distance between transmitter and receiver by means of GPS transmitter. Transmitter has been broadcasting current position in intervals of 10s. After the connection has been lost we were able to assess the range.</td></tr>
<tr><td>Test results (analysis, importance of the results for the design)</td><td colspan="3">We have successfully used the transmitter to evaluate the transmission range. The evaluation of the distance between the transmitter and the receiver was successful and should not cause any problems during the flight. We have experienced minor losses what is noted below.

This is very important because we managed to test the receiving system and data decoding system, which was created by our students. The transmission distance is satisfactory and equals 10 km.

Both the transceiver and the receiver use BaoFeng UV-5R radios paired with custom-made modems and protocols allowing them to communicate with minimum lag and maximum speed.</td></tr>
<tr><td>Rating</td><td colspan="3"><u>SUCCESSFUL</u></td></tr>
<tr><td>Conclusions and recommendations</td><td colspan="3">During the test process we found out that metal rods supporting the rocket’s structure cause significant losses and that is why we are planning to replace them with non-metallic structure in the next iteration. Recommended tests of the transmitter inside the rocket. This test confirms the component's performance and gives us the opportunity to perform more complex tests in the future.</td></tr>
</table>

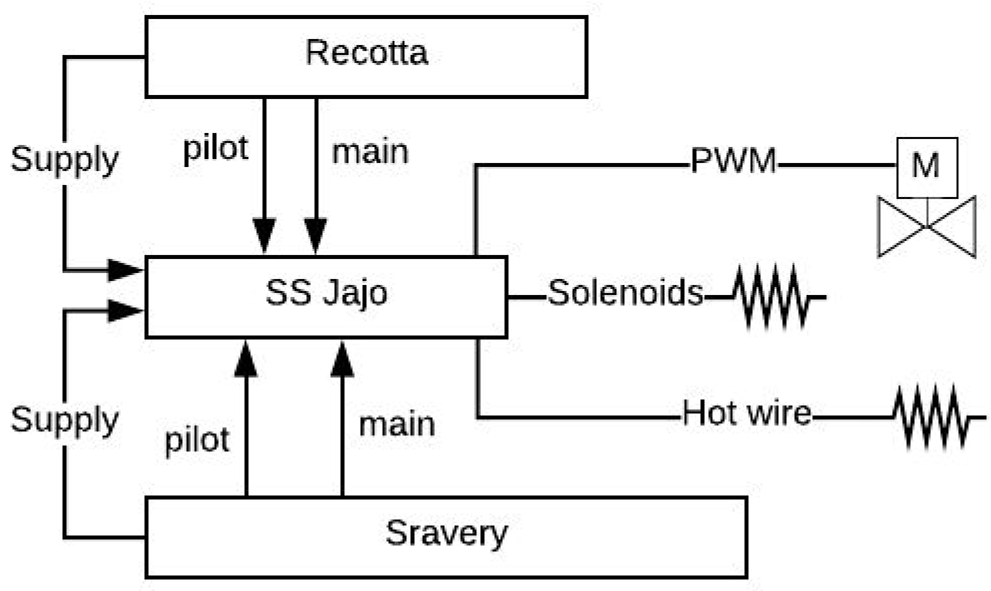
Recovery System Testing

SRAD recovery module - Sravery - is primary initiator. It detects an apogee of the rocket with checking severals condition - whether the engine is still working or velocity is above safe for chute to be released.

In case of wrong algorithm implementation or MCU hung up, COTS recovery module - Recotta - makes final decision. To provide dual redundancy for low cost servomechanism, SS Jajo module has been designed.

Apart from its function as servo controller, it provides power lines to control solenoids and hot wires. Based on cortex M0 core, MCU has only two functions - generate PWM signals for servos and latch signals for power outputs.

Such minimalistic design makes Jajo very reliable and makes signals from Sravery and Recotta sure to be executed. It has implemented hardware watchdog - periphery which resets core if no action occurred for programed period. Because its software is not time dependant, resetting the MCU forces the return of full functionality of the module in recovery subsystem.



Team 105	AGH Space Systems	14.05.2018

Hazard	Possible Causes	Risk of Mishap and Rationale	Mitigation Approach	Risk of Injury after Mitigation
Explosion of liquid a fuel or an oxidizer during fueling procedure	Leaky pipes, or valves	Low; student-built fueling unit	Smell and sound inspection (pipes and valves)	Low
	Open fire, cigarettes, lighters close to the fueling point		Fueling operator shall not be in possession of any devices generating flame	
	Damaged hose		Fueling process run remotely using dedicated application	
			Actual pressure and piston position live values visible in the app	
			Launch crew 10 meters from the fueling point	
Explosion of liquid-propellant rocket engine during launch with blast or flying debris causing injury		Medium, student-built pressure vessel and feed system unit	Check for lickage	Medium
	Engine end closures fail to hold		Check for maximum pressure	
	Engine case unable to contain normal operating pressure			
Black powder ignition out of control	Exposure to fire	low	Storing away from heat sources	Close to none
Parachute deployment during rocket assembly	Electronics problems		Pretrained rocket's assembly personnel	Low
			Plugging electronic system at the end of assembly	

Igniter malfunctioning during start	Improper placement of eMatch in the igniter	Low	Proper placement of eMatch in the igniter	Low
	Wire discontinuity		Wire continuity verification	
	Electronics problems		Multiple electronic tests	
			Disarming system before coming to proximity of the rocket	
Not opening of the main fuel valve	Frozen valve	Medium, student made pressure vessel and feed system	Multiple tests of servovalves	Low
	Electronics problems		**Previous remote defueling of the vessel**	
Not opening of the relief valve	Pressure vessel damage	Low, the design is to prevent failure	check proper operations prior flight	Low
Rocket falls without parachute	Recovery system fail	Low, we use redundancy for recovery deployment system	Make sure the electronics is supplied with power and operational. Check connections.	Low

Team 105	**AGH Space Systems**	**14.05.2018**		
Risk	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Recovery system fails to deploy, rocket or payload comes in contact with personnel	Unsealing of the pneumatic system before the moment of action	Low; student-built system with redundancy and COTS	Double check of tightness in preflight phase	Low
Recovery system partially deploys, rocket or payload comes in contact with personnel	Hot wire string cutter fail to cut string and prevents main chute deployment	Low; student-built system with redundancy and COTS	Hot wire string cutter tests	Low
	Parachute shroud lines tanglement		Parachute folding procedure development	
	Main Parachute line tearing during inflation phase		Shock cord application	
	Main Parachute tearing during inflation phase		Aramid sewing thread.usage.	
Main parachute deploys at or near apogee, rocket or payload drifts to highway(s)	Flight controller malfunction	Low; student-built parachute and calculations	Check parachute folding, check redundancy of deploy electronics, check aerodynamics and structural integrity	Low
	String to be cut with a hot wire not strong enough			
	String to be cut with a hot wire improperly attached			
Propellants leak from the servovalves	Lack of proper sealing of the pneumatic system	Low; tested prior to flight tests	Double check of tightness in the preflight phase	Low
	sealing wear-off		check o-rings when appropriate and possible	

Frozen ball-valve makes it impossible to control the flow of the propellants in servovalves	Servomechanism with torque not high enough to counteract the resistance of the frozen ball-valve		Application of the high torque servomechanism	Low
			Tests of the flow control with a frozen ball-valve	
The igniter does not start the engine.	inadequate fuel mix	Medium: student-made igniter and fuel mix and feed system	Multiple tests of engine ignition	Low
	insufficient temperature			
	insufficient pressure in the chamber			
The igniter falls out of the engine.	incorrect attachment of the igniter	Medium: student-made igniter and attachment, it happened before	Parts well-prepared for assembly. Done only by qualified crew	Low
	damaged igniter		Ignition system redundancy	
Loss of communication during the start procedure.	signal interference	Medium: student-made electronics and radio, it happened before	Multiple check and test the connection link	Low
	loss of power in the rocket		use redundant power supply	
Loss of communication while searching for a rocket.	signal interference	Medium: student-made components	Multiple check and test the connection link	Low
	loss of power in the rocket		use redundant power supply	
Highly disrupted flight path.	unequal lift-off from the launcher pad	Medium: student-made structure and fins, students design, calculations and testing of subsystems	Multiple flight tests of the system and experience gained during previous projects	Medium

	damaged fins		Rocket is put together according to design	
	strong wind		Special caution during transportation of structure	
	Too low launch rail departure velocity			
	Problems with rocket weight distribution			
	Aerodynamics misbehaviour			
Disintegration of a rocket on the fly.	damaged external or internal structure	Low: student-made and designed structure and integration procedure	Special caution during transportation of structure	Low
	failure of the propulsion system			
	structural integration failure			

AGH Space Systems Turbulence Rocket
Team 105 Assembly, Preflight and Launch Checklist APPENDIX
for the 2018 IREC

AGH Space Systems Turbulence Rocket Team
The Faculty of Mechanical Engineering and Robotics
AGH University of Science and Technology, Krakow, Poland

ASSEMBLY CHECKLISTS

This list is made to ensure that critical steps are not overlooked. You are not allowed to skip any point mentioned in this document.

Propulsion Subsystems

- ❏ Assemble flight cylinder
- ❏ Assemble feed system section
- ❏ Connect injector assembly with feed system section
- ❏ Mount feed system - oxidizer
- ❏ Mount feed system - fuel
- ❏ Check if all servo valves are closed
- ❏ Check if all manual valves are closed
- ❏ Seal engine
- ❏ Insert ablation and nozzle into the combustion chamber
- ❏ Insert igniter into the combustion chamber
- ❏ Joint combustion chamber to the injector
- ❏ Connect servos to the servo supply bus

Payload Subsystems

- ❏ Assemble Payload: Payload Cage, Boilerplate Payload
- ❏ Mount Payload on Payload Interface
- ❏ Partly assemble Payload Compartment
- ❏ Insert Payload Interface with Payload into Payload Compartment and slide it down to desired position
- ❏ Mount Payload Interface with Payload on Payload Compartment
- ❏ Finish assemble of the Payload Compartment

Recovery Subsystems

- ❏ Assemble Structural_Cage
- ❏ Mount X_bar_Top and X_bar_Bottom
- ❏ Assemble Pilot_Cage with Pilot_Can1 and Pilot_Can 2
- ❏ Mount Pilot_Cage_Assy on X_bar_Top
- ❏ Mount Servo_Valve_1/8_Assy on Pilot_Cage, be careful not to damage wiring
- ❏ Assemble Pneumatic_System and fit it in Pilot_Cage; make sure that joint is well sealed with teflon tape and that you tape thread in a correct direction
- ❏ Arrange the Main_Parachute bay
- ❏ Mount four sets of Eye_screw_M8x35, Spring washer M8, nut M8) and PrzepalinkaTube
- ❏ Begin the Main Parachute Folding Procedure
- ❏ Put folded Main_Parachutes into Main parachute bay
- ❏ Mount Doors_Frames in Structural_Cage
- ❏ Assemble PilotCans
- ❏ Seal joint between 6mmPipe and PilotCan.
- ❏ Begin the Pilot Chutes Folding Procedure
- ❏ Put folded Pilot Chutes into Pilot Cans_S
- ❏ Tie Pilot_Can_S Lines to Pilot Cans_S
- ❏ Mount CabinetBoltLocks
- ❏ Tie Lines to mouting point in Doors
- ❏ Mount Doors into Doors_Frame, adjust the position of CabinetBoltLock x4 and tie another end of Line to Eye screws
- ❏ Mount First Fairing on Struktural_Cage
- ❏ Lead the wiring
- ❏ Check if servo works properly

Avionics Subsystems

- ❏ Stack together all PCBs
- ❏ Make sure arm key is turned off

  Romek
  - ❏ Make sure all valves are closed
  - ❏ Connect all solenoid valves
  - ❏ Make sure arm key is opened
  - ❏ Connect arm key
  - ❏ Power on with battery
  - ❏ Connect D-sub to rocket structure

  Maniek
  - ❏ Connect Xbee
  - ❏ Connect each bottom D-sub
  - ❏ Plug external D-sub from Romek

  Staszek
  - ❏ Connect D-sub to Staszek

  SS Jajo

        - [ ] Connect solenoids
        - [ ] Connect servomechanism
        - [ ] Connect hot wire
        - [ ] Check solenoid and hot wire continuity test

    Recotta

        - [ ] Make sure SD card is inserted
        - [ ] Insert plugs to SS Jajo

    Czapla

        - [ ] Connect D-sub to Baofeng

- [ ] Connect batteries to each module
- [ ] Make sure Maniek and Staszek are unarmed (LED indicator)
- [ ] Reset Maniek
- [ ] Check for CAN activity on Staszek
- [ ] Check igniter continuity

Grażyna - the Ground Station

- [ ] Connect with virtual port
- [ ] Check for connection activity (frames sent & received)
- [ ] Check all voltage readings determining connectivity
- [ ] Check whether NO2 and fuel pressure level are close to zero (unfueled vessel)
- [ ] Check mass beam readings
- [ ] Check for separator positioning validity
- [ ] Make sure valves from supply vessels are closed
- [ ] Check proper work of servos:
    - [ ] MOV
    - [ ] FOV
    - [ ] MFV
    - [ ] FFV
- [ ] Check proper work of solenoids:
    - [ ] Loading fuel
    - [ ] Unloading fuel
    - [ ] Loading oxidizer
    - [ ] Unloading oxidizer
    - [ ] Fuel feed
    - [ ] Oxidizer feed
- [ ] Check if pump works properly
- [ ] Check orientation readings
- [ ] Check barometer readings
- [ ] Reset all Flash memories
- [ ] Zero mass readings

Ready for fueling

Aerostructures

- [ ] Mount Nosecone
- [ ] Mount fairings
- [ ] Mount fins section to engine structural cage

PREFLIGHT CHECKLISTS

This list is made to ensure that critical steps are not overlooked. You are not allowed to skip any point mentioned in this document.

Propulsion Subsystems

- ❏ Using Ground Station application prepare and make servo valves movement test

Payload Subsystems

- ❏ Check proper and stable position of payload

Recovery Subsystems

- ❏ Connect Parachutes lines
- ❏ Seal connection between Pilot Can_Secondary and Pilot Can with teflon tape if needed
- ❏ Ensure that Pilot Can_Secondary x2 is sliding smoothly in Pilot Can x2 until it reaches teflon sealing
- ❏ Make sure that any lines are tangled and they are free to go in case of ejection
- ❏ Check connections and signals in avionics checklist
- ❏ Mount Filling Nippel on FillingValve, close Safety Valve
- ❏ Start Filling Pressure Tank
- ❏ Make sure that no leakage occurred
- ❏ Open Safety Valve
- ❏ Mount Second Fairing on Structural_Cage

Avionics, Communication & Ground Station Subsystems

- ❏ Check pressures readings
- ❏ Set ground level (zero the altitude)
- ❏ Zero the velocity readings
- ❏ Calibrate the AHRS algorithm
- ❏ Check igniters continuity
- ❏ Check CAN proper work
- ❏ Connect both rocket's and ground station's modules to power
- ❏ Connect receiver to the computer
- ❏ Check Czapla telemetry
- ❏ Check all batteries level

LAUNCH CHECKLISTS

This list is made to ensure that critical steps are not overlooked. You are not allowed to skip any point mentioned in this document.

- ❑ Wind at launch (less than 5 mph recommended)
- ❑ Provide minimum clear distance
- ❑ Provide minimum spectators and participant distance

Propulsion Subsystems

- ❑ Connect fuel and oxidizer refueling conduit through quick couplers
- ❑ Close all servo valves with Grażyna
- ❑ Open manual valves
- ❑ Clear the launchpad area
- ❑ Start remote filling process
- ❑ Depressurize filling lines
- ❑ Disconnect fuel and oxidizer filing lines
- ❑ Connect igniters to the connector
- ❑ Remove 'remove before flight key'
- ❑ Go fo launch

Recovery Subsystems

- ❑ Check CAN connection with Sravery
- ❑ Check batteries level for both Recotta and Sravery
- ❑ Go for launch

Avionics Subsystems and communication (using Ground Stations)

- ❑ Check communication responsibility (packages sent and received)
- ❑ Check for igniters continuity (Staszek and Maniek)
- ❑ Check arm status - need to be armed! (Staszek and Maniek)
- ❑ Check altitude readings, should be near zero
- ❑ Start writing data to Flash
- ❑ Check proper stage - Flight Ready Stage
- ❑ Ready for counting down

4 3 2 1

F

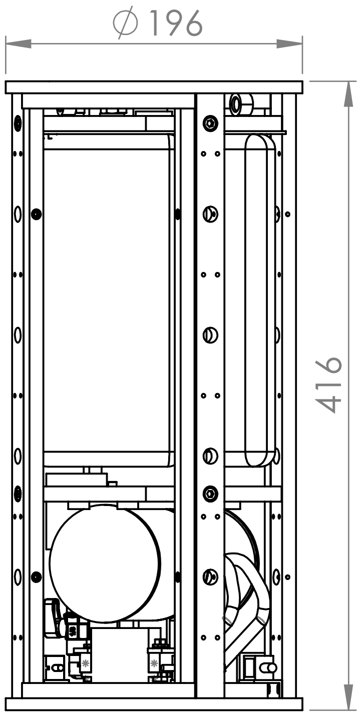
E

D

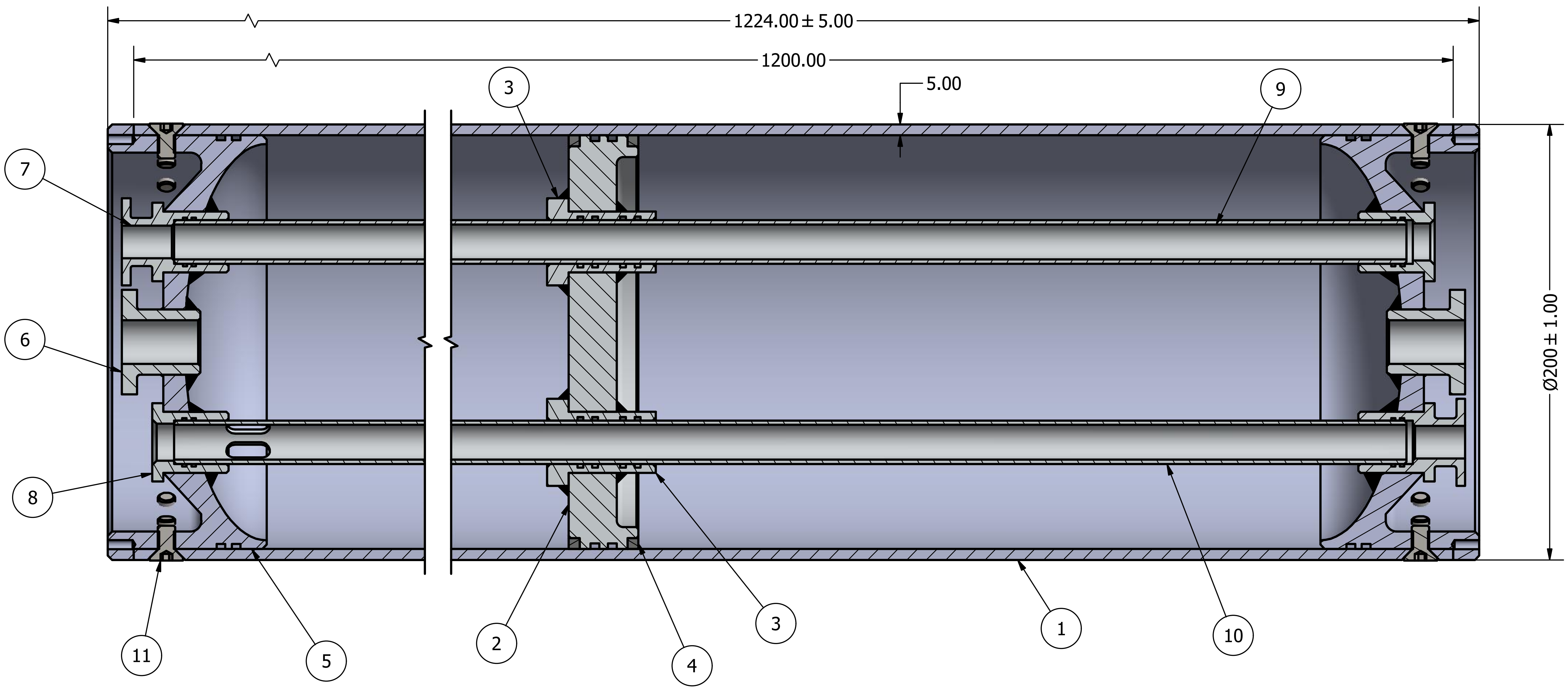
C

B

A



CHYBA ŻE OKREŚLONO INACZEJ: WYMIARY SĄ W MILIMETRACH WYKOŃCZENIE POWIERZCHNI: TOLERANCJE: LINIOWA: KĄTOWA:			WYKOŃCZENIE:		STĘP OSTRE KRAWĘDZIE	NIE SKALUJ RYSUNKU / POPRAWKA
	IMIĘ I NAZWISKO	PODPIS	DATA			TYTUŁ:
NARYS.						
SPRAWDZ.						
ZATWIER.						
WYPROD.						
Z.JAKOŚCI				MATERIAŁ:		NR RYSUNKU FirstStage_Recovery_Assy A4
				WAGA:		SKALA:1:10 ARKUSZ 1 Z 1



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Pipe	2007/PA6/PA4
2	1	Piston	PA4
3	2	Piston Bushing	PA4
4	2	Piston Slider	PA4
5	2	Cap	PA4
6	2	Oxidizer Connector	PA4
7	2	Fuel Connector	PA4
8	2	Service Connector	PA4
9	1	Service Conduit	PA4
10	1	Fuel Conduit	PA4
11	44	M8 x 16	PN-EN ISO 10642

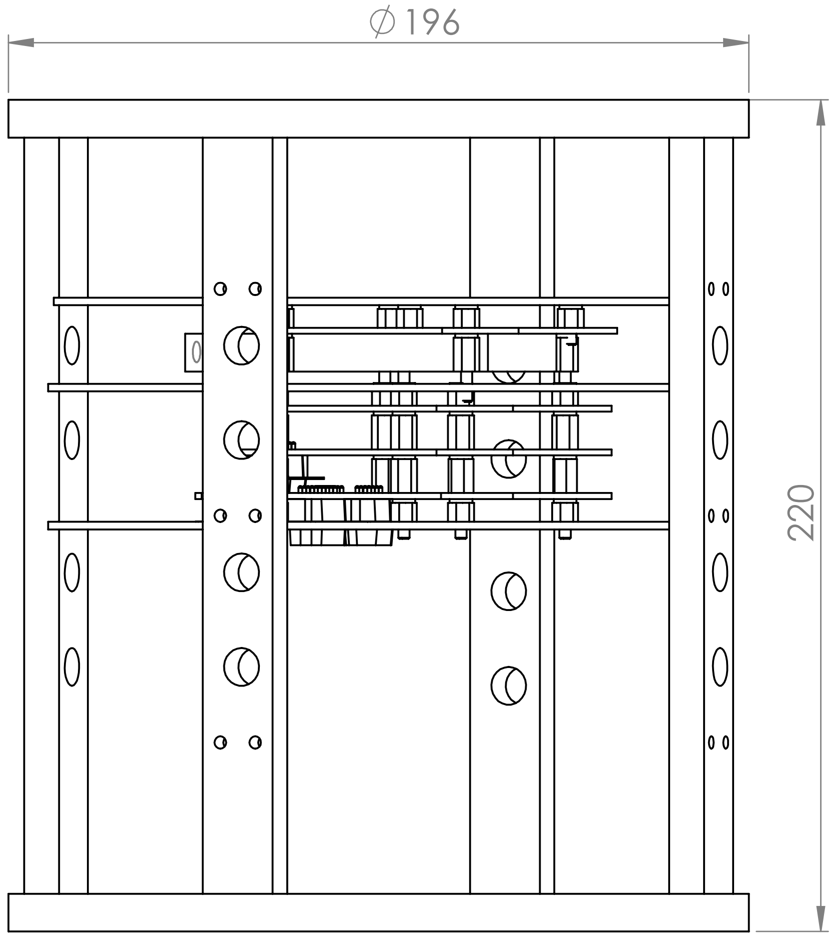
DESIGNED BY Tomasz Palacz	ID MKX_1_PV_Assembly	2018-01-31	Booster Stage
AGH Space Systems	Pressure Vessel		
	Turbulence Rocket	ISSUE 1	SHEET 1 / 1

Parametry techniczne:

Ciśnienie robocze: 63bar
Współczynnik bezpieczeństwa: 3
Pojemność użyteczna: 30L ± 0.1L
Pojemność całkowita: 32L ± 0.2L
Masa zbiornika: 16.2kg ± 0.4kg
Ciśnienie próbne butli: 120 bar

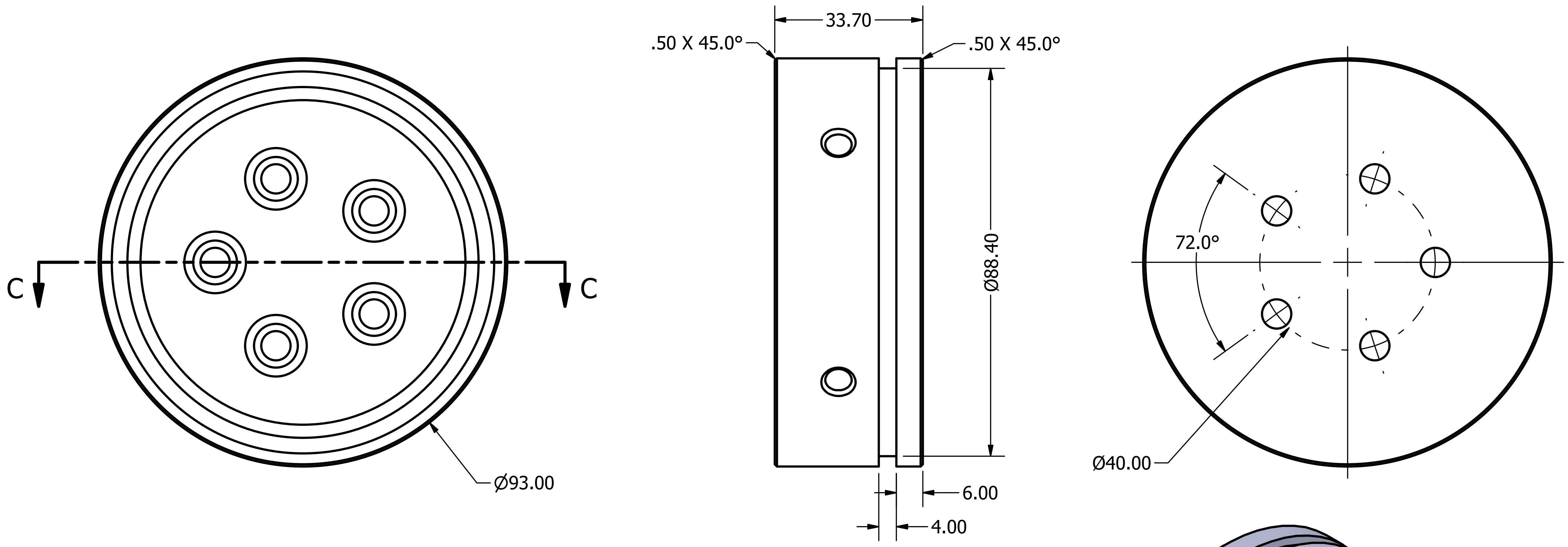
Uwagi:

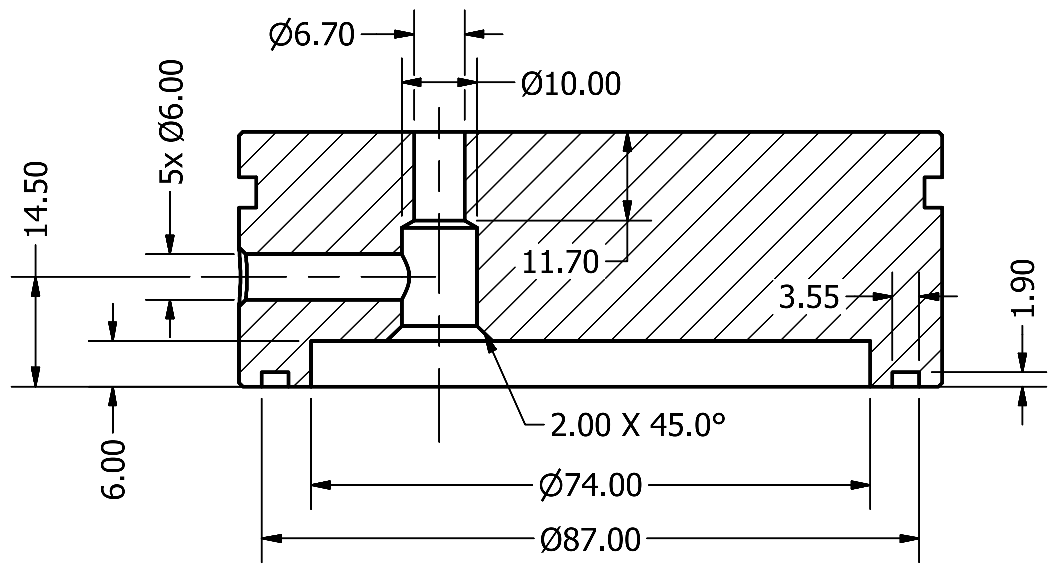
Dokładne wymiary połączeń spawanych dobrać na podstawie wymiarów wykonanych elementów.
Prostoliniowość butli powinna zawierać się w tolerancji średnicy butli.



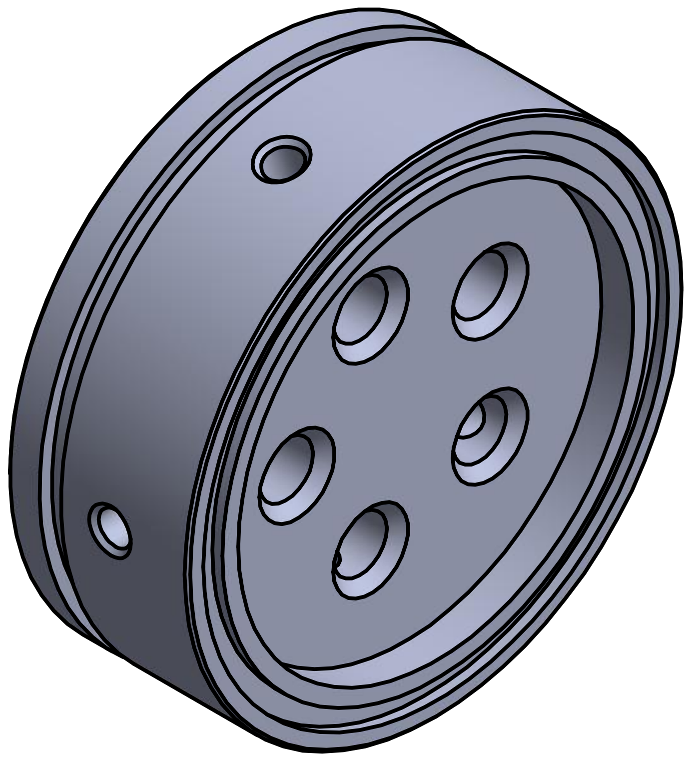
CHYBA ŻE OKREŚLONO INACZEJ: WYMIARY SĄ W MILIMETRACH WYKOŃCZENIE POWIERZCHNI: TOLERANCJE: LINIOWA: KĄTOWA:	WYKOŃCZENIE:	STĘP OSTRE KRAWĘDZIE	NIE SKALUJ RYSUNKU	POPRAWKA	

	IMIĘ I NAZWISKO	PODPIS	DATA				TYTUŁ:
NARYS.							
SPRAWDZ.							
ZATWIER.							
WYPROD.							
Z.JAKOŚCI				MATERIAŁ:			NR RYSUNKU
							MKX_AvioS_StructureAsm
							A4
				WAGA:			SKALA:1:5 ARKUSZ 1 Z 1





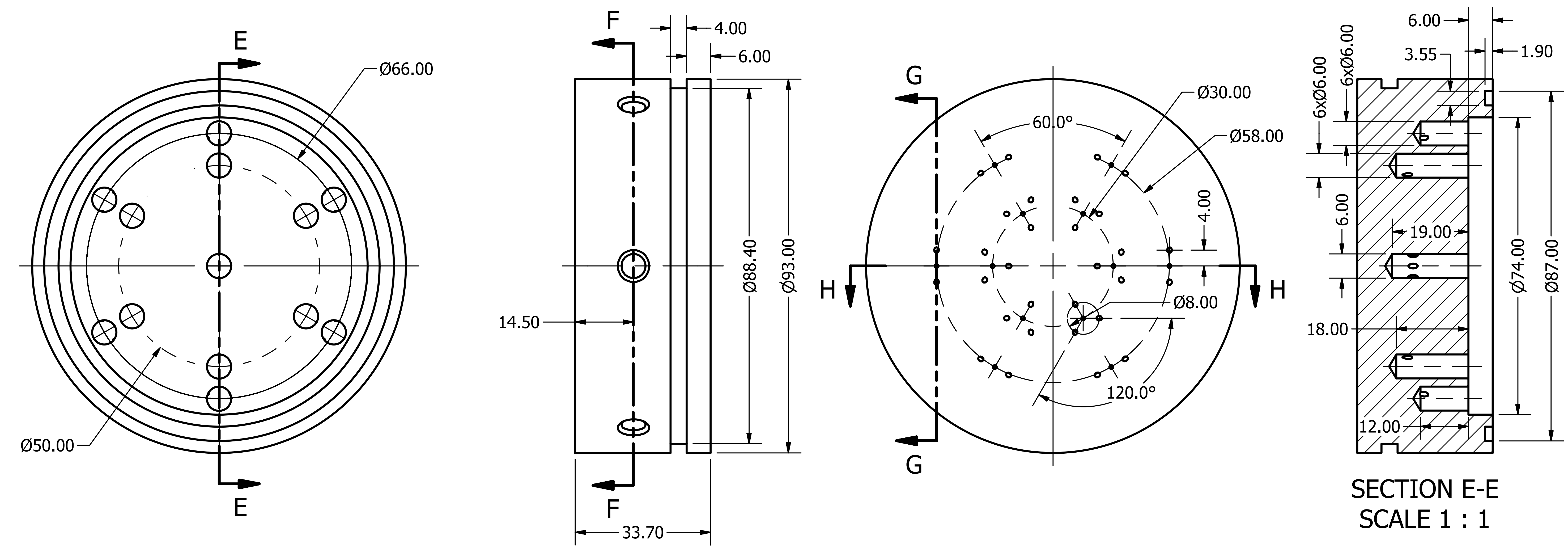
SECTION C-C
SCALE 1 : 1



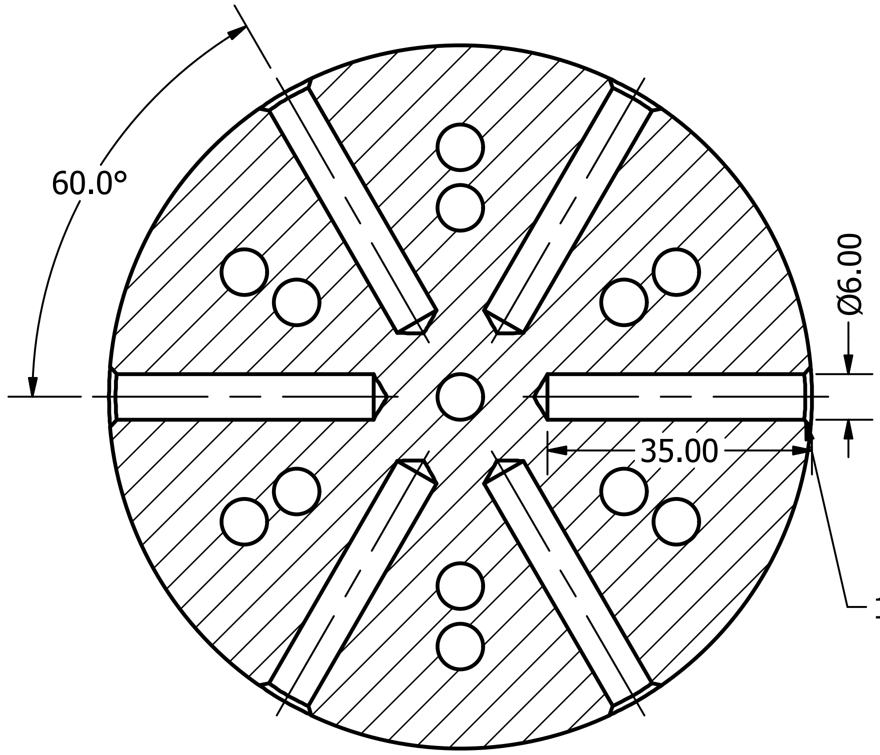
Ostre krawędzie stępić
Dla wymiarów nietolerowanych przyjąć standardową tolerancję ±0.10
Otwory Ø6.00 fazować 1.00 X 45.0°

Ra10

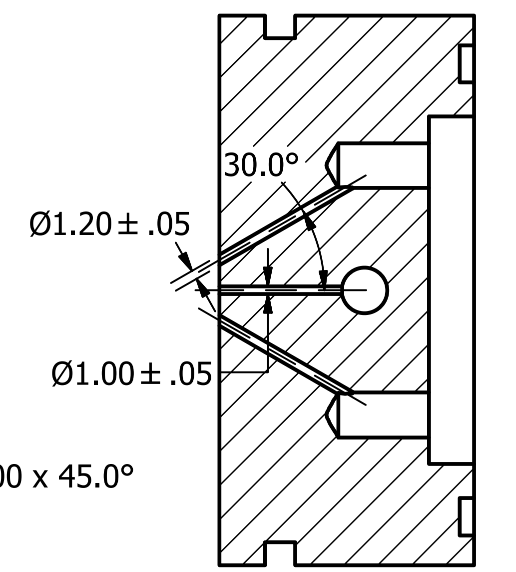
DESIGNED BY Tomasz Palacz	ID Z3000_Faceplate_Coaxial	2018-01-31	Aluminium (PA9/PA6/PA4)
AGH Space Systems	Injector Faceplate Coaxial		
	Zawisza 3000	ISSUE 1	SHEET 1 / 1



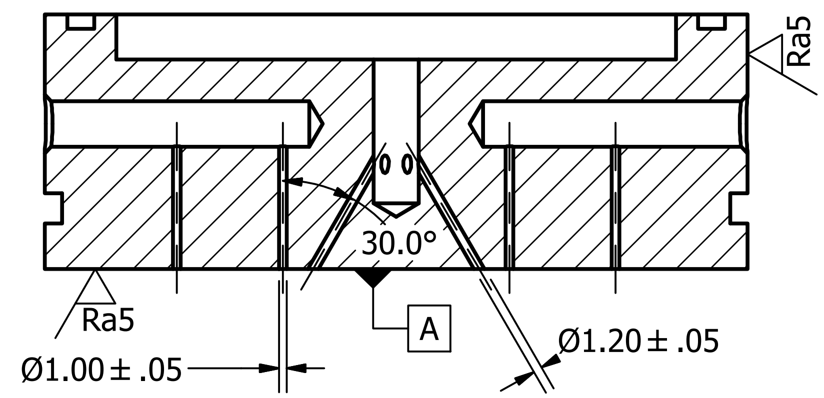
SECTION E-E
SCALE 1 : 1



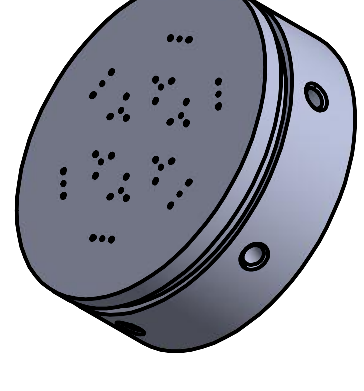
SECTION F-F
SCALE 1 : 1



SECTION G-G
SCALE 1 : 1



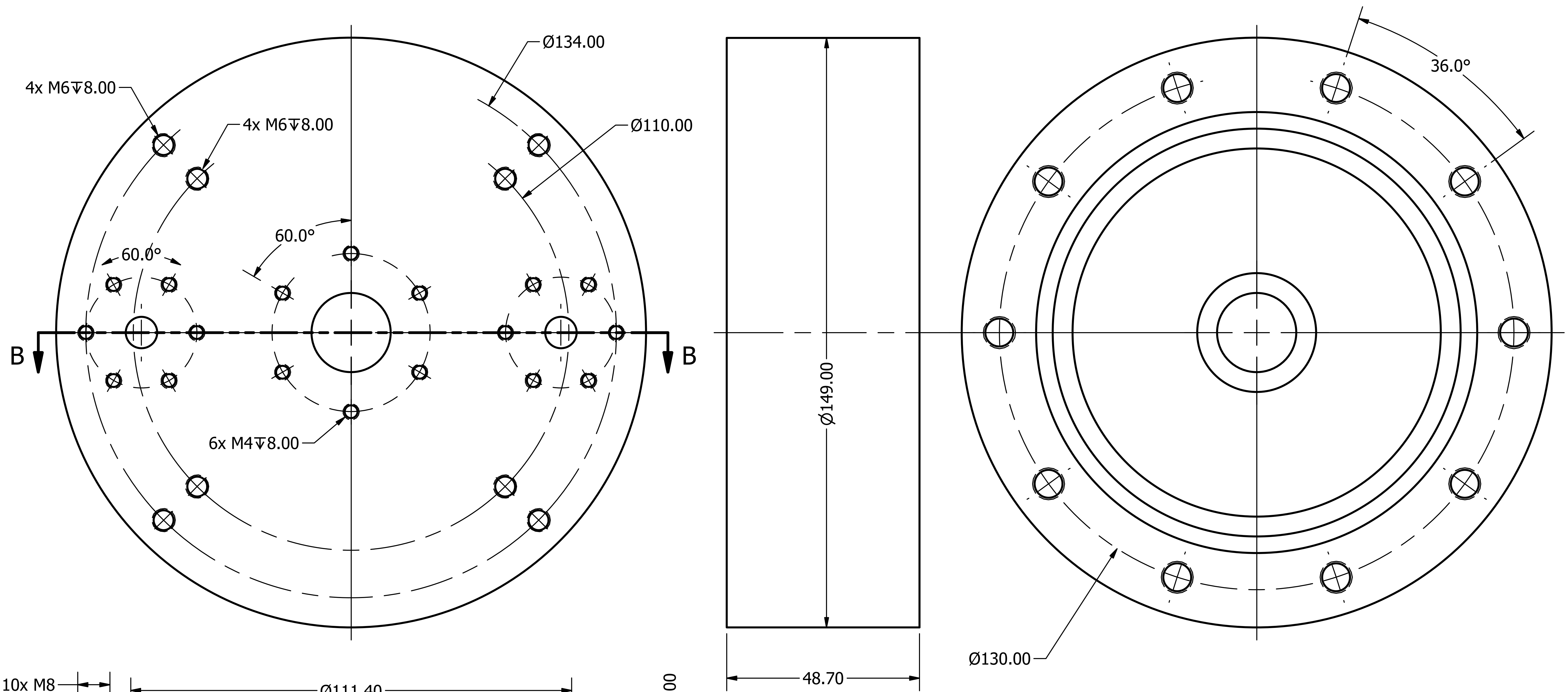
SECTION H-H
SCALE 1 : 1

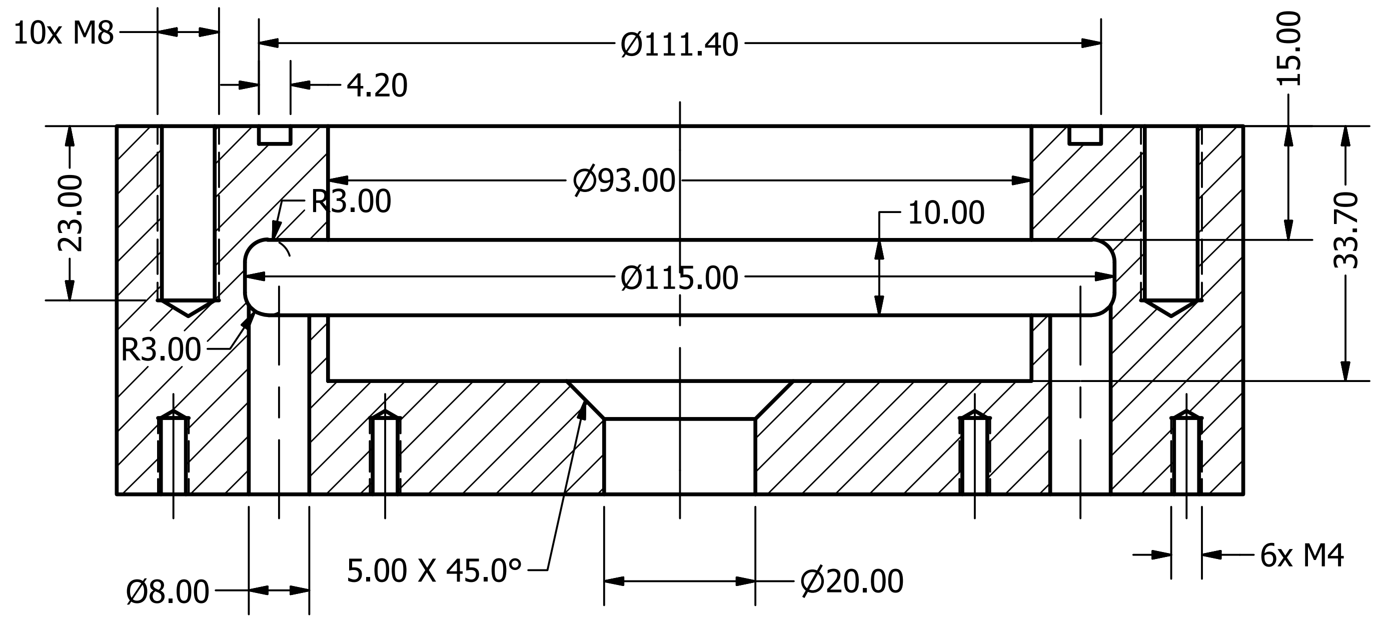


Ostre krawędzie stępić
Dla wymiarów nietolerowanych przyjąć standardową tolerancję ±0.10
Otwory Ø1.00 oraz Ø1.20 wykonywać przed wykonaniem otworów Ø6.00.
Następnie powierzchnię A splanować.

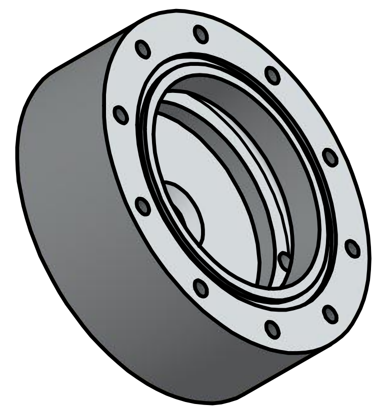
Ra10 √ (√)

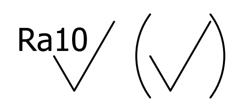
DESIGNED BY Tomasz Palacz	ID Z3000_Injector_FaceplateV2	2018-01-31	Aluminium (PA9/PA6/PA4)
AGH Space Systems	Injector Faceplate V2		
	Zawisza 3000	ISSUE 2	SHEET 1 / 1





SECTION B-B
SCALE 1





Ostre krawędzie stępić
Dla wymiarów nietolerowanych przyjąć standardową tolerancję ±0.10

DESIGNED BY Tomasz Palacz	ID Z3000_Injector_Manifold_v2	2018-01-31	Aluminium (PA9/PA6/PA4)
AGH Space Systems	Injector Manifold V2		
	Zawisza 3000	ISSUE 2	SHEET 1 / 1