Postprint of: Czapski M., Szulc N., Godlewska J., Lachowski W., Balogh N., Deszczyński W., Hucik K., Zieliński K., Kardaś D., Rusin A., Kaszuba M., Sieklicki W., Lessons learned during SRAD hybrid motor development.
Manuscript presented at the 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022. Copyright 2022 IAF.
Available at: https://dl.iafastro.directory/event/IAC-2022/paper/71681/

IAC-22,C4,IP,56,x71681

LESSONS LEARNED DURING SRAD HYBRID ROCKET MOTOR DEVELOPMENT

Mr. Mateusz Czapski, Gdansk University of Technology
Gdansk, Poland, mati.czapski@gmail.com

Mr. Norbert Szulc, Gdansk University of Technology
Gdansk, Poland, norbert@not7cd.net

Ms. Julia Godlewska, Gdansk University of Technology
Gdansk, Poland, julia36067@yahoo.com

Mr. Wiktor Lachowski, Gdansk University of Technology
Gdansk, Poland, w.redwind4@gmail.com

Ms. Natalia Balogh, Gdansk University of Technology
Gdansk, Poland, natbalogh1@gmail.com

Mr. Wojciech Deszczyński, WSB University Gdansk
Gdansk, Poland, w.deszczynski@wp.pl

Mr. Krzysztof Hucik, Gdansk University of Technology
Gdansk, Poland, krzysztofhucik@gmail.com

Mr. Kacper Zieliński, SpaceForest
Gdynia, Poland, kacper.zielinski@spaceforest.pl

Dr. Dariusz Kardaś, Polish Academy of Sciences
Gdansk, Poland, dariusz.kardas@imp.gda.pl

Ms. Anna Rusin
Gdansk, Poland, ania65122@gmail.com

Ms. Maja Kaszuba, Gdansk University of Technology
Gdansk, Poland, majakaszuba13@gmail.com

Dr. Wiktor Sieklicki, Gdansk University of Technology
Gdansk, Poland, wiktor.sieklicki@pg.edu.pl

Abstract

Student Researched and Developed (SRAD) hybrid rocket motor H-15 with total impulse of $15kNs$ was built. First version of the engine has average thrust of $3kN$, the second, improved one is prepared with an aim to have average thrust of $5kN$. Engine development was started from scratch and went through phases of: definition of design assumptions and constraints, numerical modelling to predict engine performance, CAD and CAM models preparation, manufacturing and static testing. Outcomes and conclusions of each phase will be presented, as well as development decisions which were the result of engine testing. H-15 employs nitrous oxide as an oxidizer and polypropylene and polyamide as fuels. This selection of materials was chosen due to their relative ease of preparation and wide availability.

The engine was built by SimLE student organisation, form Gdansk University of Technology (Gdansk, Poland). SimLE is one of the largest organisations at GUT which brings together students interested in many aspects of aerospace engineering. The reason for hybrid rocket propulsion development was participation in international rocketry competitions, such as Spaceport America Cup and European Rocketry Challenge. The goal of these contests is delivering 4 kg of payload to an altitude of 3000 m by a sounding rocket. Conclusions from the engine development process will be discussed, as well as perspectives for further development of our engine.

Acronyms/Abbreviations

EuRoC	European Rocketry Challenge
HRM	Hybrid Rocket Motor
SAC	Spaceport America Cup
SRAD	Student Researched and Developed
OBC	On-board Computer
GSE	Ground Support Equipment

1 Introduction

This paper aims to conclude nearly four years of hybrid rocket motor (HRM) development in SimLE student organisation from Gdańsk University of Technology. Our rocket propulsion project is closely related with competing in international rocketry competitions, which, in parallel with very strict regulations concering soild rocket motors in Poland, forced us to build our own, Student Researched and Developed (SRAD) motor.

Polish regulatory environment and connection with SpaceForest company paved a road to development of a HRM. Through multiple iterations we built an engine fully in-house. First by borrowing parts from SpaceForest company, and slowly building components that would fulfil Spaceport America Cup's requirements. The most important requirement, and an aim of SAC competition, is to build a rocket capable of delivering 4 kg of payload to an altitude of ca. 3 km [1].

By sharing lessons learned to date we want to push this process to next generation of our rocket. Those lessons mainly cover the process of development and testing rather than performance metrics. As proper environment in which the propulsion subsystem is developed is necessary for achieving good results, as bulk of know-how is acquired in an experimental fashion.

2 Developed motors

In this section a brief summary of hybrid rocket motors developed in our project will be presented. Each of the presented motors was a lesson on its own, and main characterising descriptions will be provided in this section. Different motors were developed with different aims, which are provided in subsection referring to them.

To provide clear overview, SimLE's rocket motors parameters are aggregated in the Table 1.

Table 1: Comparison of presented rocket motors parameters

Motor	SF-4	H-15	H-15v2
Total impulse	7,5 kNs	13 kNs	
Peak thrust	TBF	2,8 kN	4,7 kN
Burn time	TBF	5,0 s	3,5 s
Chamber pressure	TBF	30 bar	
Oxidizer	Nitrous oxide		
Fuel	Polypropylene and polyamide		

2.1 SF-4 Hybrid Rocket Engine

This HRM was developed for fourth rocket of SimLE's "R" rocket family in close cooperation with SpaceForest company. Combustion chamber was developed by them, while oxidizer tank and plumbing were prepared by SimLE. This experience allowed us to kickstart our developement processes.

Main structural material of the whole SF-4 are various aluminium alloys. Sealing of the end cap in the combustion chamber was provided by a threaded connection, which was one of the biggest drawbacks of this construction, while oxidizer tank end cap retention varied. In our first attempt to manufacture this oxidizer tank, we decided to weld our end caps in. While this type of connection is quite strong, it proved to be really hard to keep both end caps in parallel to each other. The second attempt, connected with enlargement the oxidizer tank volume, was a bolted connection, which we use in all constructions that follow.

Second major drawback of this engine was its ignition system, which relied on pyrotechnic mass manufactured out of black-powder fuse and hot glue, and needed to be precisely carved to fit in its designed place in the engine.

2.2 H-15 Hybrid Rocket Engine

The need for an engine with higher total impulse and peak thrust emerged, when our team decided to greatly increase rocket diameter, to fit inside it a scientific payload with a form-factor of 3U cubesat. To propel this vehicle, and to gain experience with construction of our own hybrid rocket motors combustion chamber, we have decided to construct our second engine from scratch.

Initial design calculations placed desired total impulse at a level of 15 kNs, hence the name H-15 for the motor. This was later revised to be slightly lower, at ca. 13 kNs, but left us with energy margin. To take advantage of experimental data gained from experiments with SF-4 HRM, fuel and oxidizer combination was not changed, as was the overall fuel grain layout.

Main challenges when designing this engine were: assembly simplification, flow calculations of oxidizer

MOST WIEDZY Downloaded from mostwiedzy.pl

out of tank, combustion simulation and nozzle design. To achieve latter two, we have established a cooperation with the Institute of Fluid-flow Machinery of Polish Academy of Sciences.

H-15 rocket motor was test flown during European Rocketry Competition (EuRoC) 2021, but it has not completed its full burn due to release of deadman switch by the rocket operator which caused flight abort.

2.3 H-15v2 Hybrid Rocket Engine

The hybrid rocket motor of the R6 rocket, codenamed H-15v2, is an improved version of the H-15 hybrid rocket motor. Four components may be distinguished within the motor, from the top to the bottom:

- venting lines with sensor bay
- oxidizer tank
- main oxidizer lines
- combustion chamber

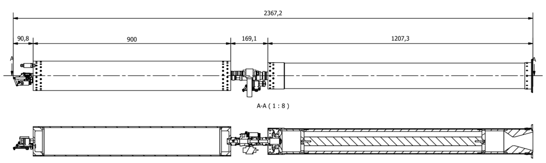

Figure 1: Simplified technical drawing of H-15v2 engine

The propulsion subsystem interfaces with three other subsystems of the rocket, which are: the ground support equipment, electronics subsystem and aerostructures. Main parameters of the H-15v2 engine are summarized in the table below.

Many parameters of this rocket motor are shared with previous designs used by SimBa rocketry team. This allowed us to greatly simplify development process, as we had experimental data from previous instalments available.

The main design challenges for this version of our engine were increasing the peak thrust and simplifying the engine assembly, which was problematic mainly because of plumbing complexity. Additionally, along with development of ground support equipment for our engine, we have designed novel system to measure the oxidizer level in a tank.

3 Lesson 1: Static test mishap

During a test for a 3 kNs engine, we failed to mount the combustion chamber to the test bed properly. The tested engine was resting in one place on mounting bold. This resulted in not having the full force registered by the load cell. It introduced a systematic error that didn't allow us to estimate available ΔV. We also weren't able to filter out this error.

What we got was a thrust characteristic that showed us quite stable and long enough operation. With reassurance from SpaceForest, we proceeded with the test flight and succeeded in reaching the goal altitude.

Later we were able to extract the thrust curve from the flight telemetry, by filtering out air resistance and gravity through estimates. Although not a perfect method to obtain the thrust curve of the rocket engine, it allowed us to verify if our simulation was close to the experimental data.

Takeaway

It was an obvious operational mistake which could be avoided by a check just before the static test.

4 Lesson 2: Faulty electronics save the day

For H15v1 a test setup consisted of the propulsion subsystem mounted to the test bed and OBC, our flight hardware, on its side. The mode of nominal engine operation is as follows:

- Igniter fires pyrotechnic charge in the nozzle.
- After approx. 3 seconds the main valve opens.
- With the pyrotechnic charge properly ignited oxidizer rushes to it and starts combustion of the propellant.

Because of the required time gap between ignition and opening of the main valve we need a control system which in our case is the main OBC based on pixhawk hardware.

Even in static environment combustion is a violent reaction that generates a lot of vibrations. These vibrations led to the interruption of the power supply to OBC and directly led to the closing of the main valve as OBC booted into the initial state. This shut down the test prematurely as we tested only 2 seconds out of desired 7 seconds of operation.

MOST WIEDZY Downloaded from mostwiedzy.pl

Outcome

At first, the test looked like a failure and a waste of materials. With proper securing of OBC and power supply we would have a full test. During the engine inspection, another picture emerged, as thermal insulation within the engine burned very quickly during those first seconds. In essence, if the engine operated for longer it would lead to self-destruction as fire would start to melt the combustion chamber itself.

Takeaway

In a way, our team got a free "out of jail" card, as destruction of the engine would set us back few weeks in development.

It was also a clear sign, that partial tests of a new engine version are necessary, and going for full burn time test for the first time, should be preceded with shorter tests connected with system examination.

5 Lesson 3: Highly coupled subsystems slow development

We envision our rocket as highly coupled with OBC based on PixHawk hardware. We wanted to take advantage of this powerful platform. This meant that our development efforts were highly dependent on it. Each test of recovery subsystem or propulsion subsystem required OBC to be working in some state. It never allowed us to develop subsystems truly independently. This led to delays and a lot of crunch withing electronics department of the team. For R6 rocket we started moving away from this model for more decentralized approach. Now a system bus runs along whole rocket connecting controller nodes of each subsystem. We use use OpenCyphal standard as a basis of interoperability between subsystem nodes.

Takeaway

By build high dependence on single component, we couldn't test the whole system until the end.By creating independent nodes within each subsystem, one could create dedicated GSE that would test, operate, and validate interoperability. The desirable outcome would be that, each subsystem would be tested against specification long before system integration.

6 Conclusion

Developing a propulsion subsystem for a rocket within constraints of a student group is no easy task. We accumulated a lot of operational and technical know-how. On this foundation we will be building next generation of hybrid engines and teams of people who will develop them. The hardest challenge is ability to retain this know-how within organisation.

Acknowledgements

Authors of this paper thanks the Gdańsk University of Technology Student Council for obtaining the financial support necessary to carry out our project. Moreover, we thank the Polish Rocketry Association and the SpaceForest Company for their technical and material support.

We heartily thank His Excellence, the Dean of Faculty of Mechanical Engineering and Ship Technology, Gdańsk University of Technology for his support and ability to provide us with the legal personality of the Faculty.

References

[1] Intercollegiate Rocket Engineering Competition. *Rules and Requirements Document.* 2022. URL: `https://www.soundingrocket.org/uploads/9/0/6/4/9064598/sa_cup_irec_rules___requirements_document_20210927_rev_j.pdf`.

MOST WIEDZY Downloaded from mostwiedzy.pl