WARSAW UNIVERSITY OF TECHNOLOGY

DEVELOPMENT OF T800 SOUNDING ROCKET SOLID MOTOR

LESSONS LEARNED FROM THE FIGHT WITH INTERNAL BALLISTICS

AUTHORS

BARTOSZ DABROWSKI

BARTOSZ DABROWSKI, FEBRUARY 2024

This page intentionally left blank.

WARSAW UNIVERSITY OF TECHNOLOGY

DEVELOPMENT OF T800 SOUNDING ROCKET SOLID MOTOR

LESSONS LEARNED FROM THE FIGHT WITH INTERNAL BALLISTICS

AUTHORS

BARTOSZ DABROWSKI

Student No.

SUPERVISOR

BARTOSZ DABROWSKI, FEBRUARY 2024

This page intentionally left blank.

Abstract

This report outlines the development of the Ascension sounding rocket and its T800 solid rocket motor, positioned as a technology demonstrator for future atmospheric research project - GROM. The T800 project focuses on showcasing advancements in sounding rocket capabilities, with an emphasis on enhancing altitude, and overall performance for atmospheric experiments while reducing costs. The report details design and development of the T800 solid rocket motor, underscoring its role as a technological showcase. Key aspects such as composition, combustion characteristics, and performance metrics highlight the cutting-edge features incorporated into the motor.

Contents

List of Tables

This page intentionally left blank.

Abstract

This report outlines the development of the Ascension sounding rocket and its T800 solid rocket motor, positioned as a technology demonstrator for future atmospheric research project - GROM. The T800 project focuses on showcasing advancements in sounding rocket capabilities, with an emphasis on enhancing altitude, and overall performance for atmospheric experiments while reducing costs. The report details design and development of the T800 solid rocket motor, underscoring its role as a technological showcase. Key aspects such as composition, combustion characteristics, and performance metrics highlight the cutting-edge features incorporated into the motor.

1 Project overview

The primary objectives of the Ascension project are centered around achieving specific performance milestones to validate and enhance key aspects of sounding rocket technology. These objectives include reaching an altitude of 4.2 kilometers, attaining a velocity of Mach 1.5, and rigorously testing recovery, propulsion, and launch logistics. The combination of these objectives serves as a robust platform for evaluating and refining the technology for future atmospheric research applications while proving our capability to perform such tasks in safe and professional manner.

The Ascension-3 sounding rocket is meticulously designed to meet the altitude and velocity targets set for the project. A key focus is placed on the propulsion system, where the T800 solid rocket motor incorporates many technologies to ensure optimal thrust and reliability. The motor's composition and combustion characteristics are engineered to facilitate the desired performance, providing critical insights into propulsion capabilities for future projects.

The testing phase of the T800 project is a critical element in ensuring the rocket's structural integrity, aerodynamic stability, and overall functionality. A series of ground tests and multiple flight tests are conducted to validate the rocket's performance under real-world conditions. These tests allow for iterative refinements to the design based on empirical data, contributing to the overall success of the project.

A pivotal aspect of the T800 project is the testing of the recovery system. Following the rocket's ascent, the recovery system is deployed to safely return the payload to Earth. This phase is instrumental in assessing the feasibility and reliability of recovery systems for future sounding rocket missions, which often involve valuable scientific instruments.

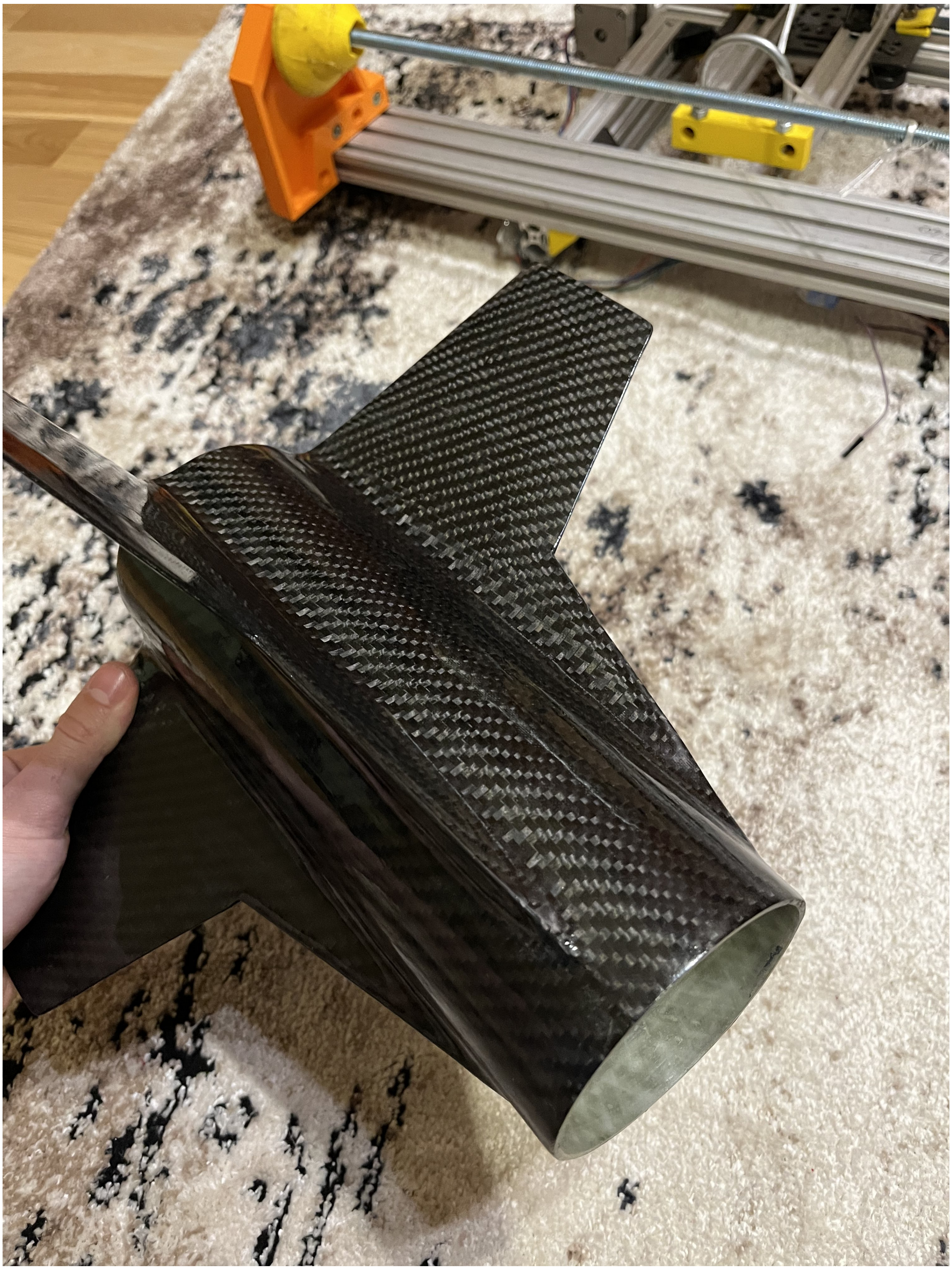
2

Structural design

The structural design of our rocket was tied to the motor casing already in our possession, leading us to opt for an 85x2.5mm fiberglass filament wound tubing for the airframe. To accommodate all the necessary electronics for a safe flight and successful recovery, the nosecone was made mostly to fit payload, not for performance. Ogive shape, featuring a 6:1 L/D ratio, was chosen.

In a nod to a previous rocket project where this motor was intended to be a part of, the fins were designed in the distinctive LERX-delta shape. Although this design excels in high Angle of Attack (AoA) scenarios, it's worth noting that such performance attributes hold less relevance in the context of sounding rocketry.

For the recovery system, we implemented a drougue-main architecture. The drougue parachute was deployed at apogee, ensuring stability during the descent. At a specified altitude Above Ground Level (AGL), the main parachute was released, facilitated by a in-house developed pyrotechnical cable cutter. This recovery setup was designed to enhance safety and precision throughout the entire flight and landing sequence.



LERX delta fincan

3

Motor design

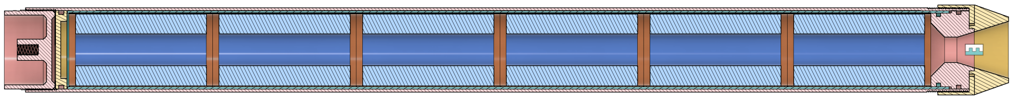
Main goals of this motor development was to find best processes regarding motor manufacturing and put our hardware design rules to the test. Design phase started as early as January 2023 with first small scale static fire in June. Testing campaign consisted of 2 T300 (shorter version of T800 with impulse of 1500NS) test fires, 1 flight test. Then we moved to full scale test in December 2023 and after a successful firing we are prepared to cast and fly at LRE 2024.

3.0.1 Casing

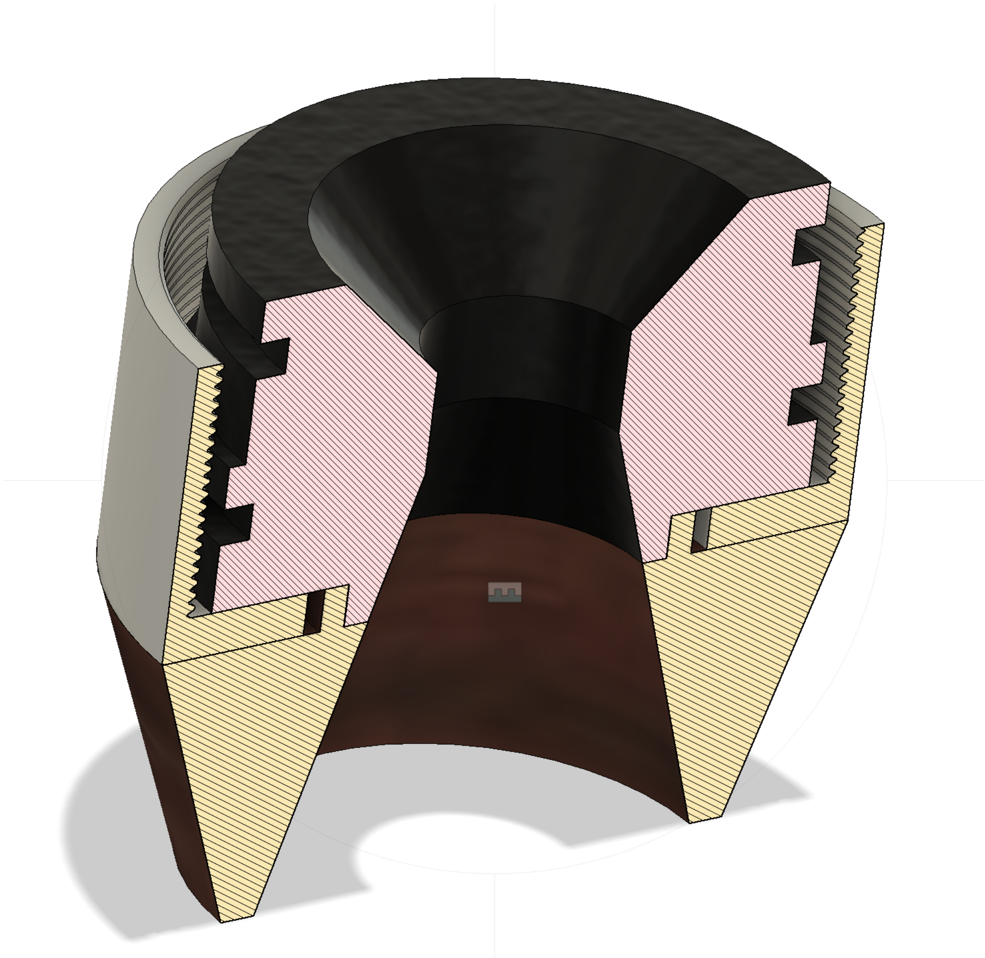
The casing, already machined with 80x3 PA38 tubing and a threaded closures, provided a sturdy foundation for our motor development. In our structural simulations, we ensured a safety factor of 2 for a simulated Maximum Expected Operating Pressure (MEOP) of 6 MPa, offering us ample room for experimenting with propellant geometry and throat sizes.

Opting for cost-effectiveness, we selected PFCP21 phenolic-paper composite tubing for the thermal insulation of the motor. This choice not only proved economical but also delivered state of the art thermal protection. The aft closure and nozzle retainer were machined from PA38 aluminum, ensuring durability and reliability. The T800's nozzle extension was a unique feature, made from a linen-phenolic composite. While it was non-reusable, the nozzle insert, made from graphite, showed exceptional heat resistance.

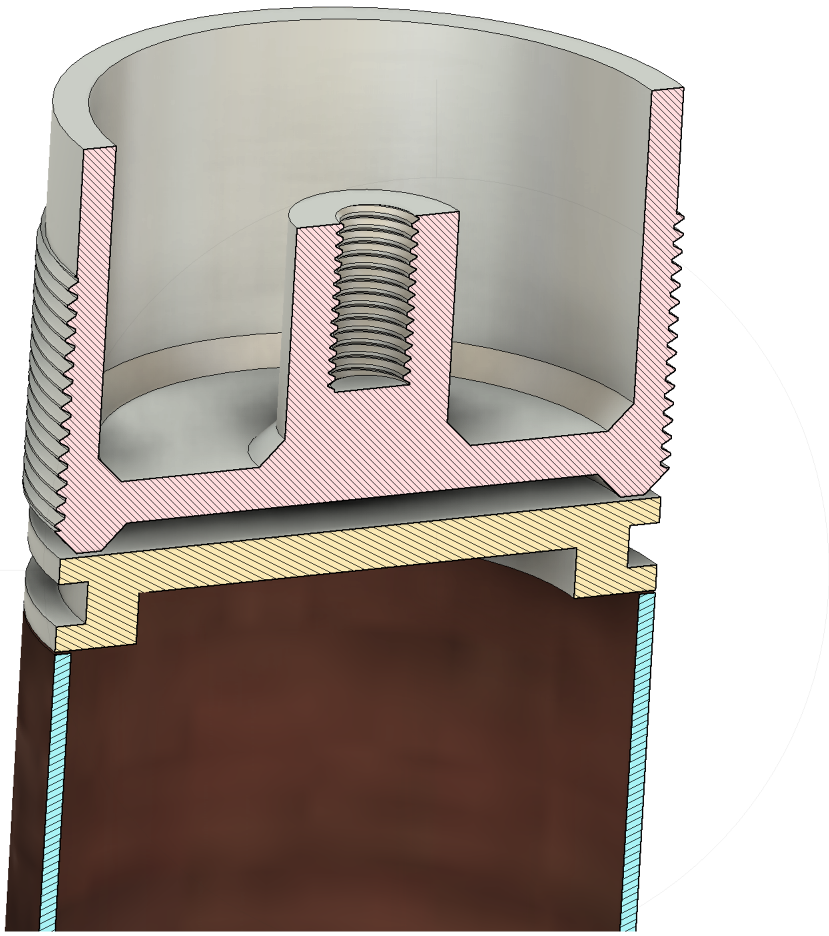
After conducting numerous static firings, we made a strategic decision to leave the top of the liner unsealed. This design choice facilitated pressure equalization, preventing liner cracking. This approach, with the top chosen for its higher static pressure, lower mass flux, and longer path to the aft seals, ultimately maximized the overall safety of the motor.



T800 motor cross section



T800 nozzle assembly



T800 forward closure assembly

3.0.2 Simulation

To simulate the motor's performance, I developed an in-house internal ballistics simulator, drawing inspiration from Richard's Nakka SRM spreadsheet with a few tailored modifications addressing erosive burning. All the software mentioned is openly available as Open Source and can be accessed, along with the source codes and equation sources, on my GitHub page.

When it came to the motor itself, we opted for the Bates geometry not just for its commendably flat burn rate curve, but also for its simplicity in manufacturing. Initially, we experimented with Aft Finocyl geometry. However, due to the propensity for fracturing in sugar propellants, we encountered setbacks, leading us to discard this geometry.

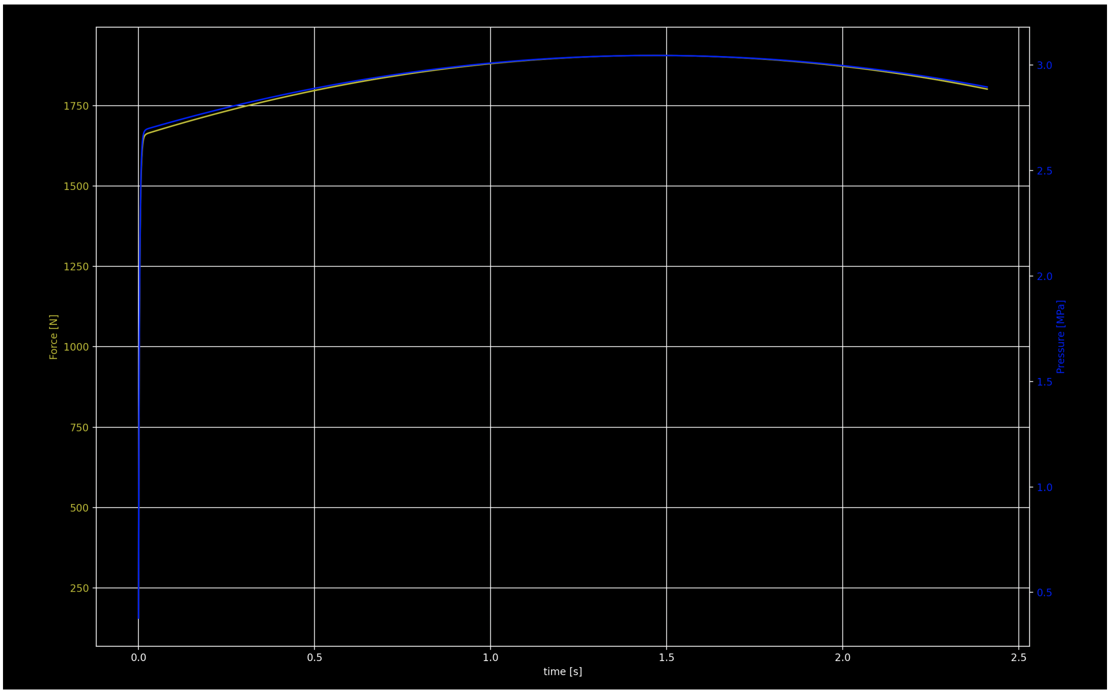
The final simulated motor geometry showcased six 125x68mm bates grains with a bore diameter of 29mm. This configuration proved to be optimal for our objectives.

For all our tests, we utilized KNSB propellant with a specific composition. This propellant choice was crucial for achieving consistent and reliable results throughout the testing phase.

After simulating the motor we came to the following time-thrust curve:

Table 3.1: *KNSB propellant composition*

Sorbitol	35	%
KNO_3 400um	32,5	%
KNO_3 90um	32,5	%



And performance results were as follows:

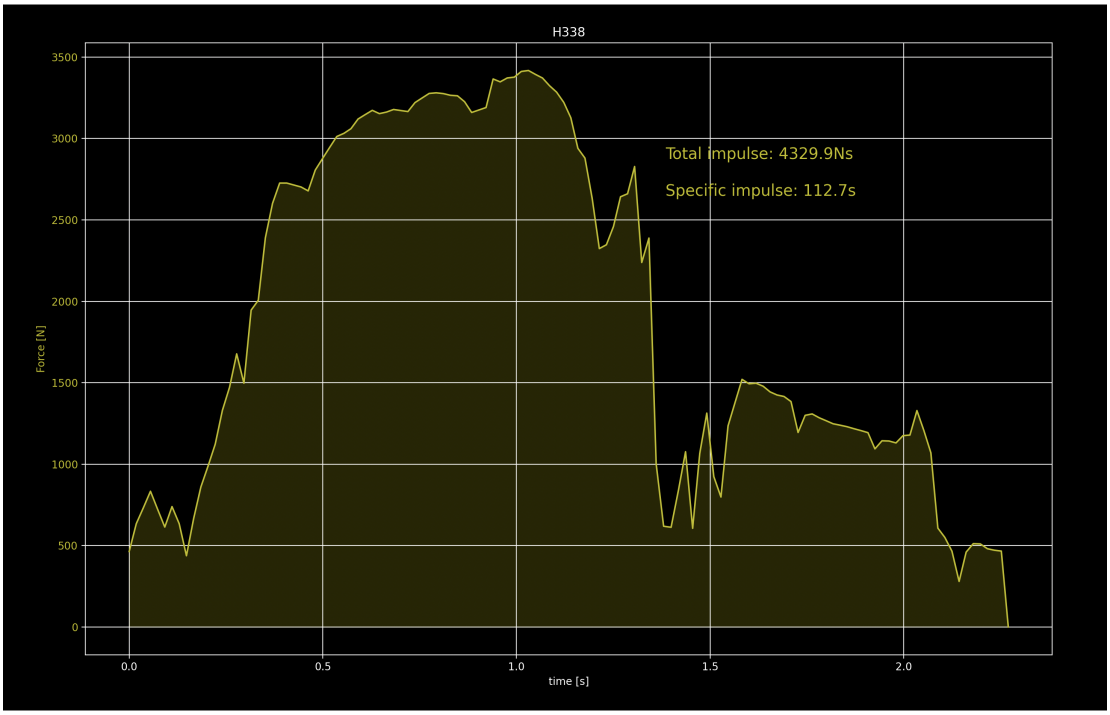
Table 3.2: *T800 simulated performance*

Impulse	4431 Ns
Peak pressure	3,05 MPa
Peak mass flux	2628,24 $\frac{kg}{m^2 * s}$
Propellant mass	3,82 kg
ISP	118 s

3.0.3 Testing

Throughout the meticulous testing phase of the small-scale motor, we encountered and systematically addressed a series of challenges, resolving each one until we achieved the desired outcome. The utilization of the T300 motor in the final stages closely aligned with our simulation, with the only notable exception being a sluggish ignition process. To address this concern for the T800 motor, we introduced an ignition compound called TADEX, which proved to be a viable solution.

However, as with any ambitious project, full-scale testing presented unforeseen hurdles. During one of the tests, two aft grains unexpectedly debonded from their respective casting tubes, causing a significant increase in burn rate. While the casing withstood the trial, the nozzle sustained major damage, resulting in a time-thrust graph that deviated from our simulated expectations. Subsequently, we promptly implemented corrective measures to prevent such rapid burn scenarios in future flight tests. The learning and refinement process during testing has been instrumental in steering the project towards greater success and reliability.



T800 thrust curve recorded during testing

Liners after the test showing major burn marks near the nozzle

4 Conclusion

Embarking on the development of the T800 sounding rocket motor proved to be a challenging yet profoundly rewarding journey. The experience enriched our understanding of the intricate workings within solid rocket motors, offering invaluable insights that surpassed our initial expectations. It served as a masterclass in iteratively solving complex engineering problems, refining our approach at each turn.

While the motor's performance may not have reached stellar heights, the wealth of knowledge gained positions us confidently for the final flight. The T800 project has not only advanced our technical expertise but has also instilled a deep sense of readiness and anticipation for the culmination of this remarkable endeavor.

This page intentionally left blank.