Development of a solid rocket motor utilizing an ammonium nitrate based propellant

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Abstract

This project aims to design and build a fully functional solid rocket motor using an aluminum and ammonium nitrate-based propellant. The purpose of this motor is to power the flight of a stratospheric sounding rocket – Bondar –, developed for peaceful applications by the Cosmic Research Association. The design of the new motor begins by examining previous research performed by amateur rocketry experts like H. Olthof [1], R. Nakka [2], and D. Clouder [2]. To mitigate the legal and safety risks associated with the tenancy and handling of the substances needed for the motor, the project is declared as a university experiment and supervised by Universitat Politècnica de Catalunya. Cosmic Research has also reached an agreement with Lleida-Alguaire Airport, where static tests take place. The design of a fully functional motor is expected to be completed before Autumn of 2019.

Keywords: rocket; motor; Cosmic Research;

I. Introduction

Cosmic Research is a student association from Universitat Politècnica de Catalunya (UPC) focused on experimental rocketry. It is formed by a multidisciplinary team of engineering students who are currently working on Bondar, a sounding rocket equipped with the most powerful solid rocket motor ever built by European students.

II. PROPELLANT DESIGN

The new propellant chemical formulation needed to fulfill the following mission requirements:

- Avoid highly energetic and sensitive components to reduce the risks of detonation or sudden ignition.
- Possess a specific impulse greater than 200 s.
- Be produced at a low cost with high availability.
- Consist of non-hazardous and environmentally friendly components and reaction products.

Careful research and study on several successful ammonium nitrate (AN) propellant formulas developed by amateur rocketeers H. Olthof [1] and R. Nakka [2] was performed at the start of the Bondar mission. This revealed AN to be a promising oxidizer for the development of a "student-friendly" propellant. It offers high specific impulse values at a low cost with good availability, despite having some drawbacks regarding its chemical properties. Aluminum was also added to the composition. The selection of an optimal binder became a challenge that was overcome through multiple tests, including some molding, mechanical and ignition tests of small samples with different binders (resins, silicones and synthetic rubbers). These tests showed that polychloroprene rubber was a very good solution for the final formula. This decision implied using high-pressure compressing for the grain production in order to ensure a good propellant density.

Theoretical performance using *Propep*, a Propellant Evaluation software widely used in amateur rocketry, showed a Theoretical Specific Impulse of 242 s.

III. GRAIN PRODUCTION

A typical BATES propellant configuration was discarded from the beginning due to the expected high temperatures and constant pressure in the chamber. These conditions were desirable for the motor operation; thus, the propulsion team developed a mold that was suitable for high pressure compressing, enabling the production of relatively long grains with complex inner core geometries. These help to obtain an almost constant thrust and pressure profiles.

With the first prototype of the mold, it was possible to manufacture 150 mm long grains with an outer diameter (OD) of 65 mm and a circular inner core. After demolding, the grains where bonded together using the same binder over the inhibitor layer, to achieve a fully monolithic behavior. With the final design of the mold, it was possible to obtain 200 mm long grains of 160 mm OD with a star-shaped inner core, reaching values between 90-95 % of the theoretical grain density (5 kg/grain):

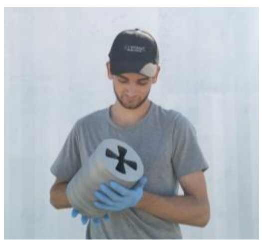

Figure 1. First demolding of a 5 Kg star-shaped propellant grain on August 12, 2019.

https://doi.org/10.29311/2020.56

IV. TEST FACILITIES

Propellant manufacture tasks and static tests demanded adequate facilities to perform these operations safely.

After exploring several options, Cosmic Research got in touch with Lleida-Alguaire's Airport Authorities, who agreed to sponsor the project. They offered Cosmic Research access to a 4700 m^2 paved surface (previously used for firefighter training) for the tests and manufacture of the propellant, as well as some safety advice.

V. TEST SETUP

The characterisation of the propellant formula was carried out using a Ballistic Evaluation Motor called Nebula-I (N-I, honouring the dense fog at Alguaire's airport during autumn seasons). The motor was designed to withstand unexpectedly high operating pressures, with 2 failure modes to avoid an explosion of the casing in case of a malfunction.

A replaceable graphite insert was used in the nozzle throat, allowing an easy modification of the throat diameter or even a complete replacement if damaged during the test campaign. This decision followed economic criteria.

The motor used a through-bulkhead initiator, developed by Cosmic Research and inspired by webpage publications of the Swiss Propulsion Laboratory [5]. It consisted of a little composite motor, with an easier to ignite formula of Potassium Nitrate + Epoxy. This mixture is ignited electrically, using a nichrome wire coated with a high temperature compound.

Figure 2. Through bulkhead initiator, showing the 4-nozzle configuration.

Threads were used for the bulkhead and nozzle holder to simplify assembly and disassembly. Sealing was achieved using aramid fibbers gaskets with an inox matrix coated with NBR elastomer (Provided by Epidor Technical Distribution).

VI. TEST STAND

For the validation of the setup, a heavy-duty test stand was designed and built by Cosmic Research in January 2019. The structure was designed to fit a wide range of motors (making minor changes) and withstand up to 20 kN of thrust.

The objective was to measure thrust and chamber pressure. A Honeywell MLH100BSB10A pressure transducer was used, as well as a 300 Kg load cell provided by Sensocar (Model S2-A). The outer chamber temperature was also measured using 3 type-K thermocouples.

Cosmic Research developed its own electronics to read, process and store data obtained from the sensors. Calibration was possible thanks to Sensocar and CCTC UPC (Heat and Mass Transfer Technological Centre).

VII. TEST RESULTS AND FURTHER DEVELOPMENT

A total of 7 N-I "less than perfect" successful motor tests were performed between February and May 2019. Solid data and valuable experience were obtained from the test campaign.

Performance data	
N-I propellant capacity	1,8 Kg
Propellant density achieved	1726 Kg/m^3
Max. Thrust delivered	1350 N
Average Total Impulse	3610 Ns
Average Specific Impulse	197 s
Burn rate coefficient "a"	2,43 mm/s/MPa^n
Pressure exponent "n"	0,43

Figure 3. N-I static test view. 02/03/2019.

Cosmic Research expects to design, build and test a solid rocket motor with a Total Impulse of 50 kNs, using the propellant formulation discussed in this document, during Autumn 2019.

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