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GAMA I – EXPERIMENTAL STUDENT HYBRID ROCKET**

Maurício Sá Gontijo
Anne Elisa Leal Caselato
Caio Henrique Franco Levi
Daniel Back da Trindade
Douglas Alves Brandão
Guilherme Portilho Ribeiro
Leonardo César Freitas
Mateus Silva Sant'ana
Priscila Yukie Yamada
Rafael Freitas de Farias da Silva
Renato de Brito do Nascimento Filho

Universidade de Brasília
mauricio.sa.gontijo@gmail.com
annelisac@gmail.com
caiohf8@gmail.com
danielback.trindade@gmail.com
douglasbbb@gmail.com
guilherme.portilho506@gmail.com
lcf250396@gmail.com
mateus.s.santana.1@gmail.com
priyamada25@gmail.com
rafa.farias@hotmail.com
renatobnf@gmail.com

Abstract. *This article presents the development of a hybrid propulsion rocket, which has as its objective to take a payload to a 3km apogee and be recovered at Centro de Lançamento Barreira do Inferno. Computational simulations were made in order to analyze the engine's internal ballistics, the structural design, and the flight trajectory. Sensors coupled to the rocket allows the collect of data, which is to be transmitted during flight. The onboard payload also captures data related to the flight, and is able to compute it in order to be flaw tolerant. After apogee is reached, a parachute is ejected to prevent the vehicle from suffering permanent plastic deformations when touching the ground, and being able to be recovered.*

Keywords: *Hybrid propulsion, Rocket trajectory, Rocket recovery, Rocket telemetry, Rocket structure*

1. INTRODUCTION

Experimental rocketry teams are growing all around the world. This kind of activity provides a large amount of experience and knowledge to graduation students who pursue the objective of becoming rocket engineers. Especially nowadays, where dozens of aerospace companies are actuating on this field and another dozens of aerospace startups are being created.

Hybrid rockets provide experience on all chemical propulsion types, because it has characteristics of both solid and liquid propulsion rockets. And at University of Brasília this experience is boosted because it has started researching this kind of propulsion since the beginning of the millennium, being the first one of the Latin America to research hybrid propelled rockets, capacitating students to work on every kind of chemical propelled rockets.

2. METHODOLOGY

The NASA systems engineering methodology was used in this project due to its high rate of success (NASA, 2007). Using this reference, the following diagram shows how the work groups were organized. These work groups were composed of aerospace and electronics engineering students.



Figure 1: Work groups diagram.

The project phases recommended at (NASA, 2007) were adapted to fulfill the project requirements and deadlines. The figure below shows the project life with phases and technical reports followed on the project.

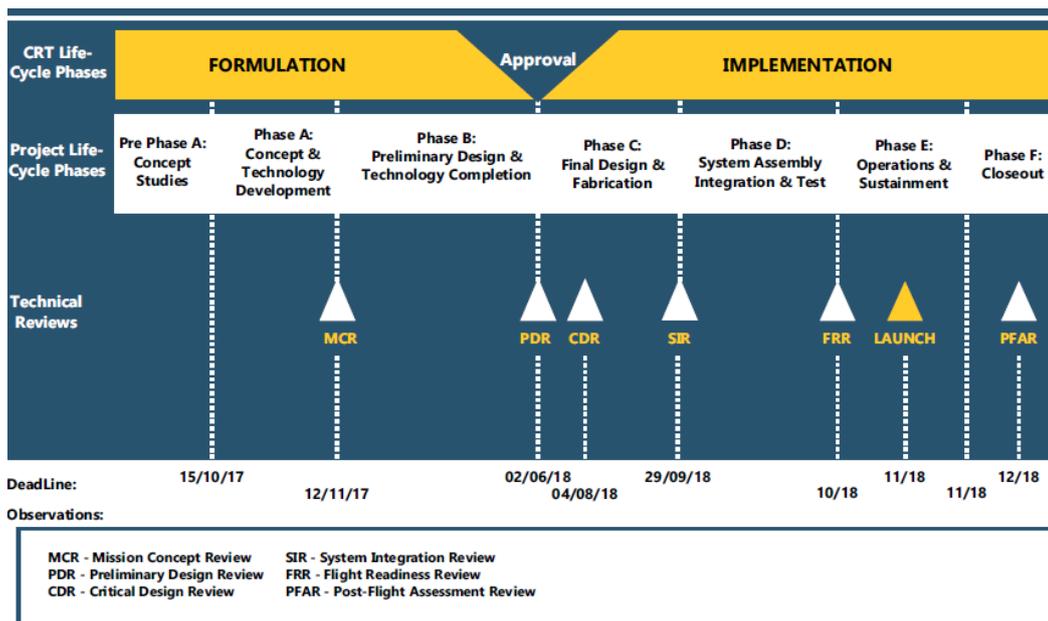


Figure 2: Project life.

2.1 Propulsion

To provide 1800N of average thrust and 6 seconds of burning time with 3000000 Pa of chamber pressure, the internal ballistics analysis was made in order to size the fuel grain, calculate the quantity of oxidant needed, set burning time, thrust, use of additives, dimension the nozzle and the combustion chamber. These calculations were made using (Sutton, 2010) and (Bertoldi, 2007) and the performance parameters calculated with the chemical equilibrium CEA NASA's software (NASA, 1996). Some of the results of the CEA analysis can be checked on Figure 3 and 4.

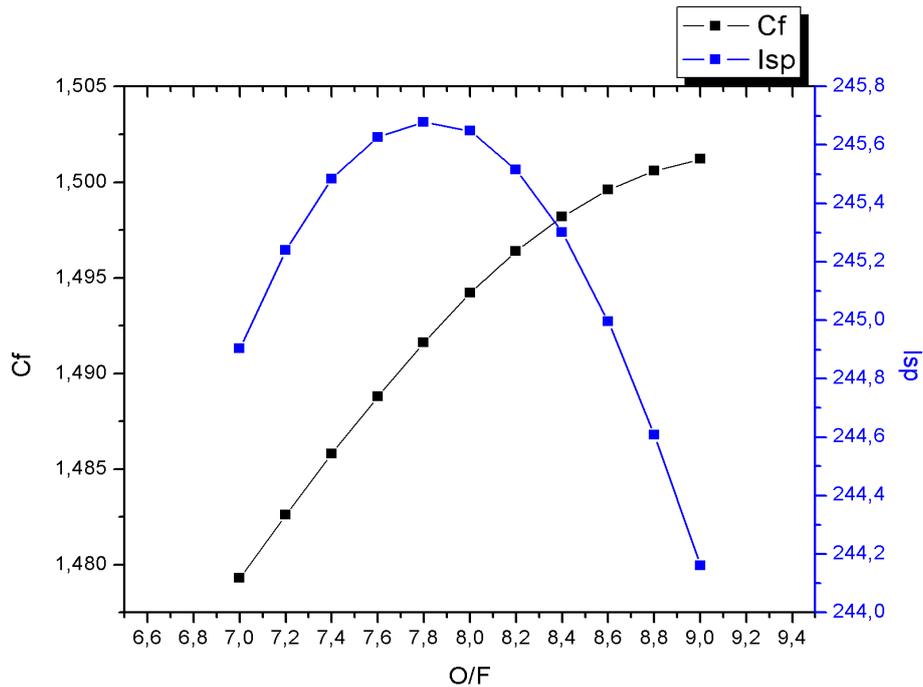


Figure 3: Thrust coefficient (Cf) vs O/F ratio vs Specific impulse (Isp) [s]

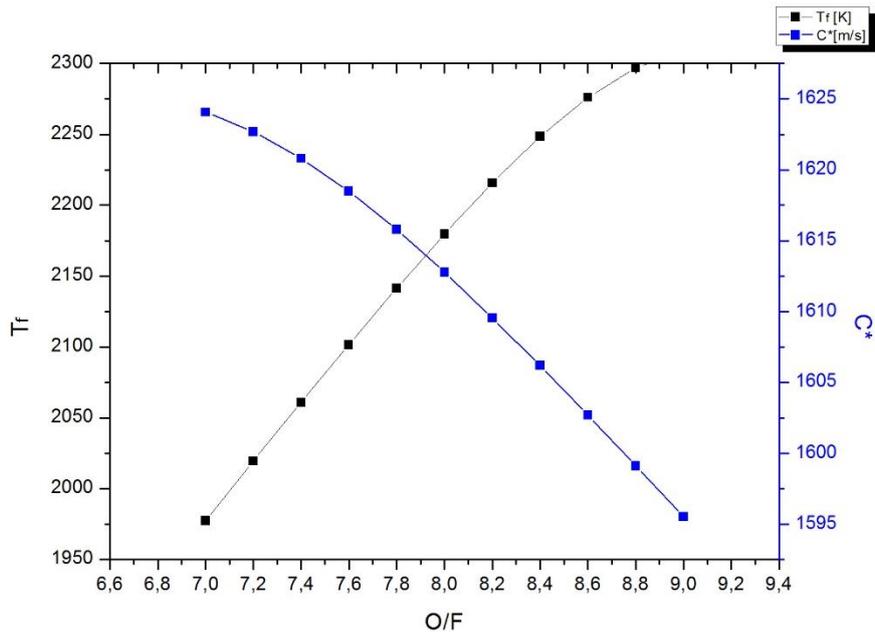


Figure 4: Flame temperature (Tf) vs O/F ratio vs Characteristic velocity (C*)

The feed system was designed to provide efficient and stable combustion and safe operation by means of remote-controlled valves. The injector design was made using (Gamper, et al, 2013) and the feeding system, considering safety, sealing, chemical compatibility and properties of the oxidizer, was designed using (Newlands, R., 2019), (Newlands, R, 2011), (Parker 2018) and (NIST, 2018).

In order to verify the data from internal ballistics, CFD simulations were performed using the ANSYS Fluent software. The 2D geometry developed contains the thrust chamber and the flame. It was considered that the motor is symmetrical with respect to the axial axis to simplify the model. Figure 5 shows the temperature profile for stationary simulation at the 3 second firing time. These simulations were made using (Matins, P.G.C., 2017) and (modern compressible flow).

The combustion chamber and the injector are made from 6351 t6 aluminum with 3.5 mm thickness radially bolted to the fuselage. The nozzle is made from graphite to support the high heat transfer, especially on the throat. The structural design and materials selection were made using (Callister, W.D., Rethwisch, D.G., 2011) and (Khurmi, 2005). The whole propulsion part was designed considering past experiences, reported on (Gontijo, M.S, et al 2018).

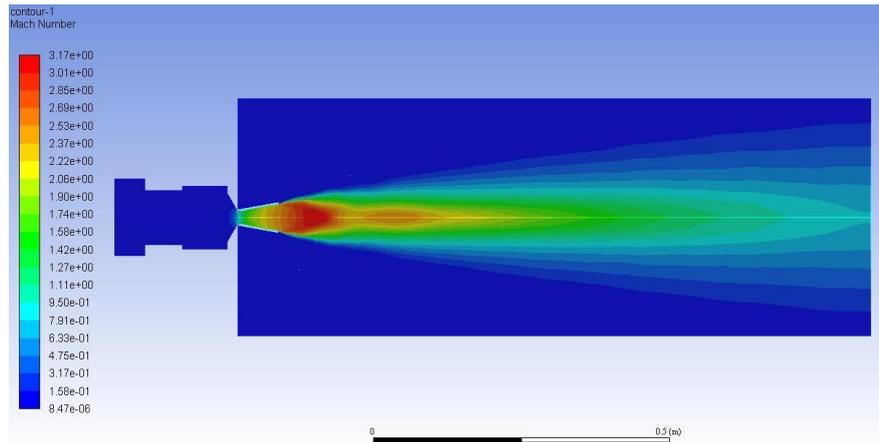


Figure 5: Mach number at t=3s.

2.2 Payload and avionics

The payload mission is to do measurements of temperature, height, angular velocity, acceleration and speed, testing a redundancy system. The system is known as Triple Modular Redundancy (TMR), and works as a flaws tolerance for the collected data. Three are run in parallel, the controller analyzes these processes, producing only one output. The TMR system is independent of the rockets avionics, having its own feeding system and structure.

The telemetry is composed by the avionics module and a ground station, both of them having antennas and transceivers of 2.4 GHz. The avionics module measures temperature, acceleration, spin, coordinates, height and speed. The data is stored in a SD card and transmitted to the ground station independently. The ground station antenna is manually pointed at the rocket or fixed, according to the trajectory data. The avionics module is turned on as soon as it is assembled to the rocket, and the ground station should recognize it and receive data transmitted during flight.

2.3 Structure

The rocket body was designed on a modular way to allow better assembly of the internal components. There are modules for avionics and payload, recovery, oxidizer tank and combustion chamber.

The modules were built in fiber glass. They are connected with bolted internal fiber glass tubes and aluminum bulkheads that supports and fixes the internal systems.

The structure must resist the compressive load due to the launch and maximum principal tension was used to calculate the composite resistance. Static and modal structural simulations were made on Ansys to verify the rocket body resistance.

The following figures shows the simulations made on the fiber glass tubes and on the aluminum bulkheads.

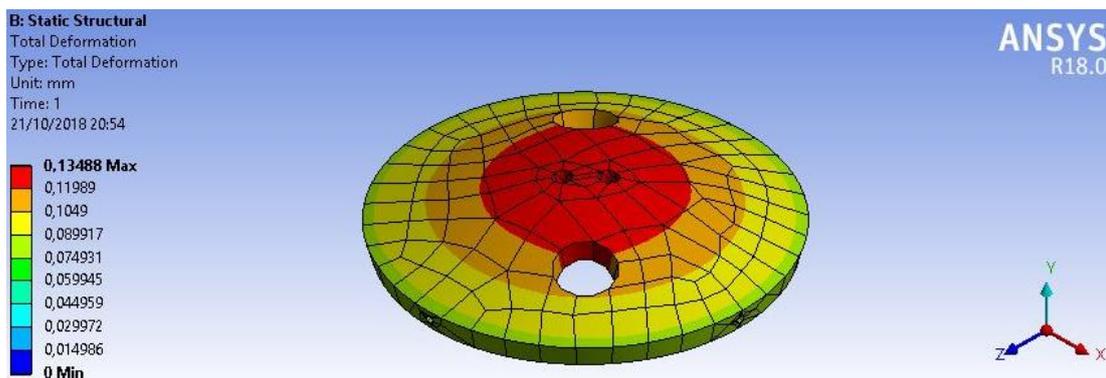


Figure 6: Bulkhead total deformation.

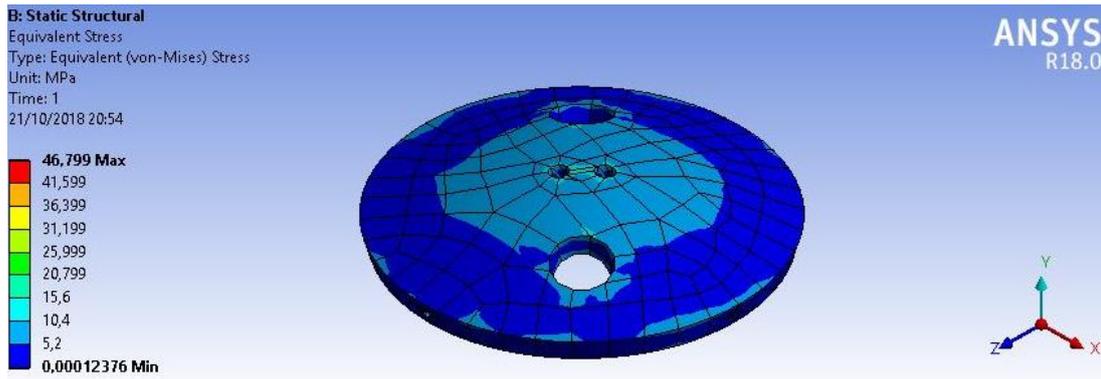


Figure 7: Bulkhead Von-Misses.

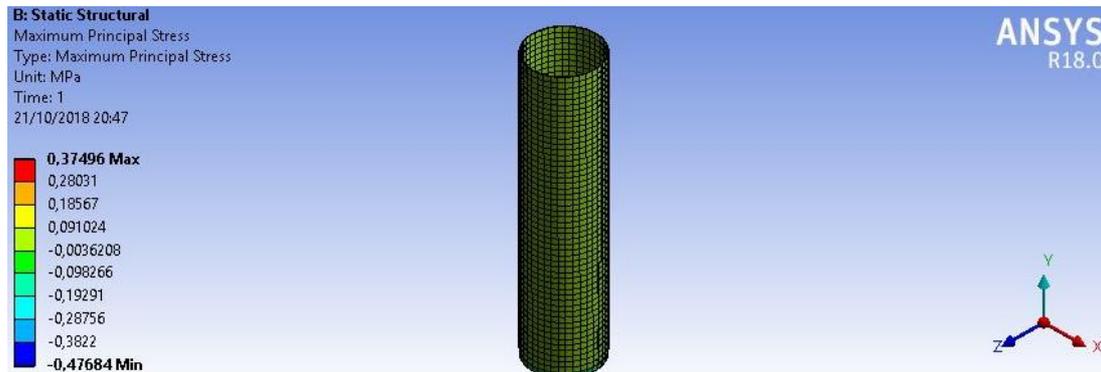


Figure 8: Tube maximum principal stress.

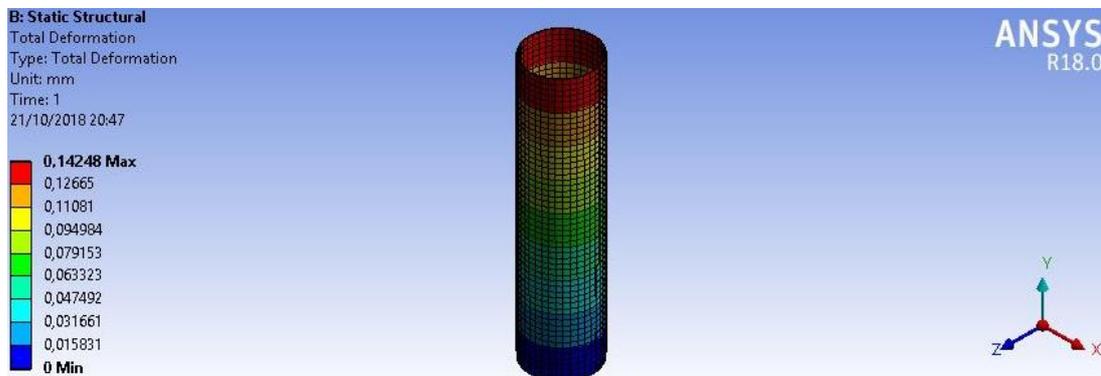


Figure 9: Tube total deformation

2.4 Recovery

The recovery system aims to ensure that the rocket will have a ground impact velocity of less than 8 m/s, in which the vehicle will not suffer high structural damages. It is composed by two subsystems: the parachute and the ejection system.

2.4.1 Parachute

The parachute has the components described in the items below where it is also explained how each of them was dimensioned:

- Canopy: the inflated part made of nylon rip stop. It is composed by 20 gores cut in a triangular shape and stitched together by nylon wires. This forms a flat shape and in the top of it there is a spill hole, which increases the stability of the rocket in its descent. The size of this hole is 20% the diameter of the canopy (FRUITY CHUTES, 2019). This last size is defined according to the equation of steady descent rate, which happens when the drag force in the whole system is equal to its weight (KNACLE, 1991). Drag coefficient is equal to 0.75 for a flat canopy (KNACLE, 1991), air density was considered as an arithmetic mean of density in the altitudes of 0 m (1.223 kg/m^3) and 3000 m (0.90926 kg/m^3) (ANDERSON, 2016) and the area of the canopy surface was calculated as $9,576 \text{ m}^2$. The diameter is then calculated as being equal to 3.5 m;

- Shroud lines: the lines that connect shock cord to the canopy. They are made of Paracord 550. The number of lines chosen was 20, and the length of them are 115% the diameter of canopy, according to a standard (FRUITY CHUTES, 2019). This length is necessary to keep the canopy far away from the rocket, avoiding forebody wake effects that reduces drag force (KNACLE, 1991);
- Shock cord: is the central cord that connect all the shroud lines to the rocket. It is made of polyester.

2.4.2 Ejection system

The ejection of the parachute is produced by tensioned elastics. The folded parachute is placed between two L-shaped aluminum jaws as shown in Figure 10, which are ejected with it along with the rocket's hood. The claws are initially locked and subsequently released by means of a nylon wire, connected to them and to the axis of a servo motor. This axis rotates when driven by a commercial altimeter, which should accuse the ejection altitude, releasing the nylon wire from the shaft, developing the parachute.

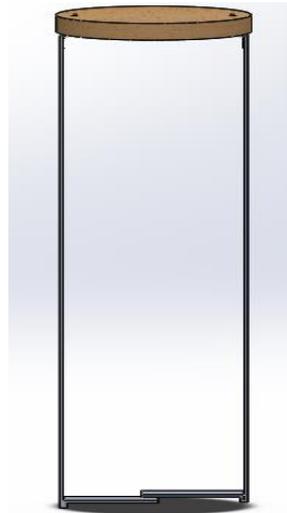


Figure 10: Parachute compartment.

2.5 Flight mechanics

The rocket was designed to have a stable trajectory. It is expected that it doesn't rotate abruptly or have an angle of attack higher than 20 degrees. In this context, the software OpenRocket was used to analyze the stability on the whole flight trajectory. Since the ambient conditions impacts directly on the trajectory simulation, those parameters are measured on the launch day at site to predict the rocket trajectory reliably. The cartesian coordinates of the rocket flight are taken from OpenRocket, exported and plotted on a 3D graphic on Matlab.

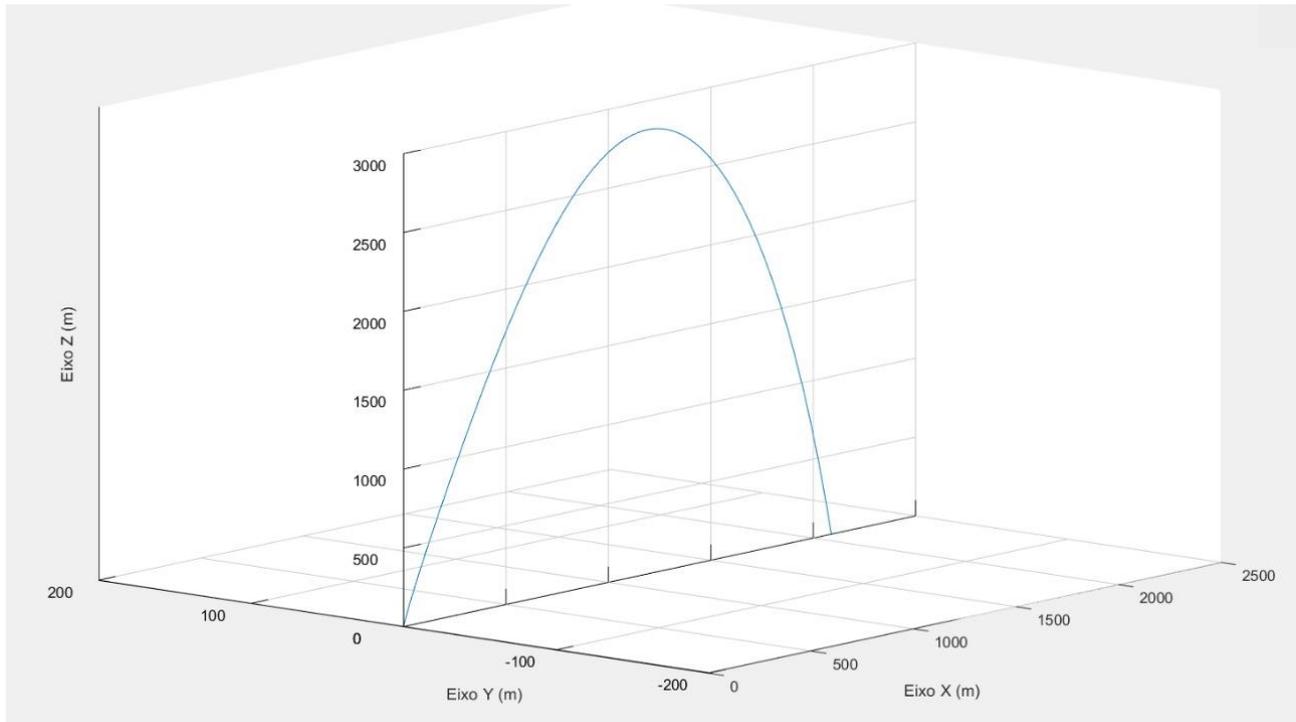


Figure 11: Rocket flight trajectory for 80° of launch angle

The flow simulation was made on software Ansys, on which the pressure, temperature and velocity gradients along the rocket body were taken. Simulations were made on the higher velocity expected of 0.87 Mach. The four fins have rectangular profile with rounded edges and trapezoidal Clipped Delta shape, built with balsa wood and fiber glass with 5 mm thickness. The nose is ogival built in fiber glass.

The following figures shows the 3D trajectory plot and the velocity distribution along the rocket external surface.

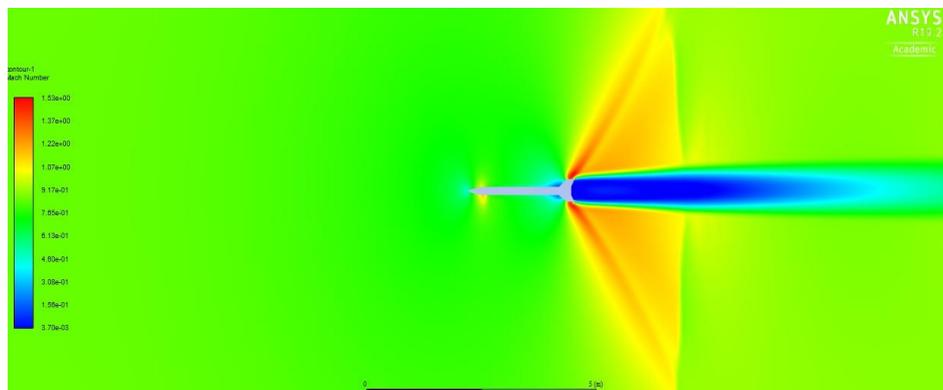


Figure 12: Flow simulation

The launch rail needs to be long enough to guarantee stable lift off, enabling the rocket to reach stabilization velocity. Using trigonometric relations between rocket velocity, wind velocity and angle of attack, it is possible to determine the maximum wind velocity and the launch rail length.

3. RESULTS

Hydrostatic, cold flow and hot fire tests were conducted to validate the design and guarantee the motor safety, repeatability and reliability. The graph on Figure 14 shows one of the hot fire tests conducted, it shows lower chamber pressure and thrust due to the ambient conditions and the elevation that are very different from expected at launch site on CLBI (Barreira do Inferno Launch Center – in portuguese), at sea level. Figure 13 shows the cold test conducted to check the feeding system and the injector.

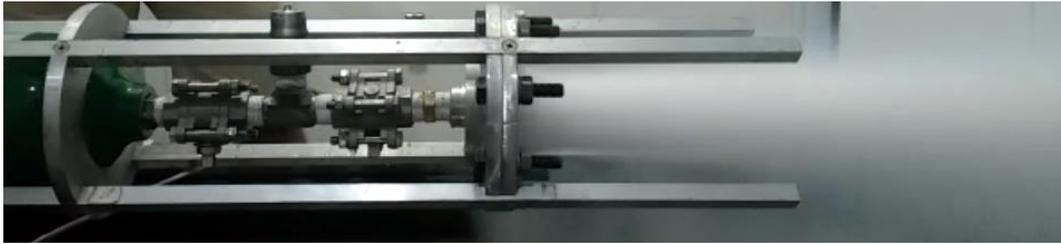


Figure 13: Cold flow test

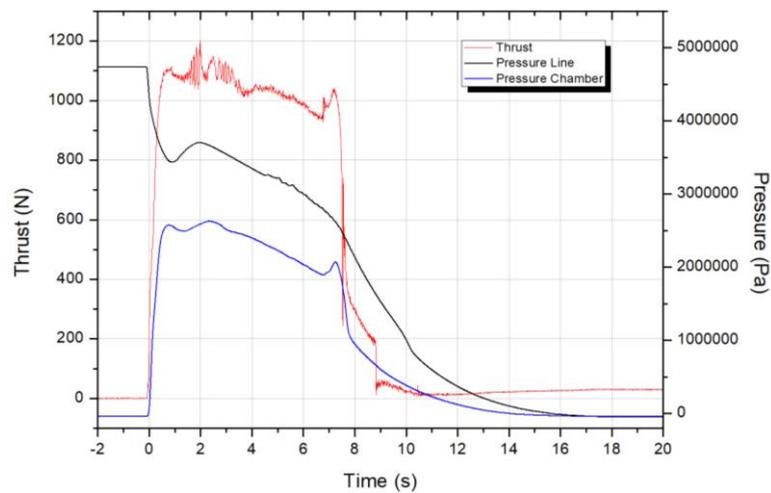


Figure 14: Thrust and pressure curves.

A stable and safe flight with professional operation and reliable measurements are expected for the rocket. And the flight trajectory can be double checked with the CLBI's radar. With this design, the rocket should reach 3km apogee (with 80-degree launch angle) and a successful recovery and data transmission.

The following figure displays the shape of the rocket and how the internal systems are organized, and the next one shows the real rocket built.

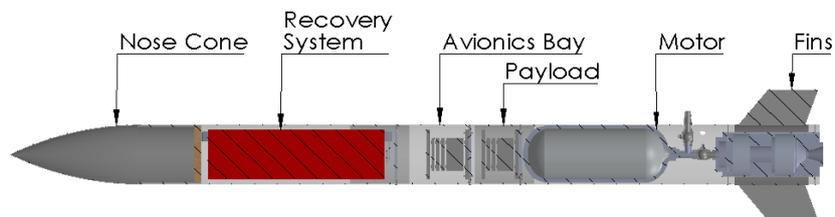


Figure 15: Rocket schematics.



Figure 16: Real Rocket

Two tests have been made in the recovery system: a parachute deployment test, as shown in Figure 17 and an opening test on high speed;



Figure 17: Parachute ejection test

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5. RESPONSIBILITY NOTICE

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