GFRJ – Canalle Platinado IV Project

Team 50 Project Technical Report for the 2022 LASC

Igor S. Procopiak[1], Giulia F. Santos[2], Renan L. A. Mourão[3], Mylena C. P. B. N. Candido[4], Marcus V. A. Ribeiro[5], Matheus R. Fernandes[6], Igor F. S. R. Lopes[7], Lucas C. R. Fraga[8], Lucas J. Carneiro[9], Caio M. G. Burlini[10], Gabriel M. O. de A. Bastos[11]

Rio de Janeiro State University, Rio de Janeiro, Rio de Janeiro, 20550-900

This report presents the technical aspects of the GFRJ's project for 2022 Latin American Space Challenge that is competing in the 1km AGL apogee with solid rocket propulsion system category. *Canalle Platinado IV,* the launch vehicle, has a J-class solid motor that uses potassium nitrate and dextrose as its propellant. Its structure is made of fiberglass and aluminum, with its aerodynamics calculations made with *OpenRocket*.

I. Nomenclature

V_{ms}	=	main stage velocity
v_{ds}	=	drogue stage velocity
C_d	=	drag coefficient
m_t	=	total mass
g	=	gravity
ρ	=	air density
C_s	=	safety factor
A	=	area
A_{main}	=	area of main parachute
f	=	safety margin
σ	=	allowable yield stress of the material
t	=	casing thickness
P	=	pressure
d	=	average diameter
Fp	=	strength weight
h_{alt}	=	altitude

[1] Undergraduate Student, FEN/MECAN, igorsatopvg@gmail.com
[2] Undergraduate Student, FEN/MECAN, fferreiragiulia@gmail.com
[3] Undergraduate Student, FEN/ELE, renanlarrieu@gmail.com.
[4] Undergraduate Student, FEN/MECAN, mylenaaapimentel@gmail.com
[5] Undergraduate Student, FEN/MECAN, marcusalves740@gmail.com
[6] Undergraduate Student, FEN/MECAN, rod_matheus2012@hotmail.com
[7] Undergraduate Student, FEN/MECAN, igorfelipe201615@gmail.com
[8] Undergraduate Student, FEN/MECAN, lucas.castro.fraga@gmail.com
[9] Undergraduate Student, FEN/DESC, ljunqueiracarneiro@gmail.com
[10] Undergraduate Student, FEN/ELE, caiomgb2@gmail.com
[11] Undergraduate Student, FEN/ELE, gabrielmaximus80@gmail.com

II. Introduction

Grupo de Foguetes do Rio de Janeiro (GFRJ) is a student-run organization of Rio de Janeiro State University (UERJ) dedicated to developing the aerospace science in the state of Rio de Janeiro through the development of our members' technical and professionally, by doing projects and science events all over the state. Every GFRJ's member can earn lots of knowledge and experience for a lifetime, either by participating in the management team or in the technical team. The main mission of the group is related to scientific education, trying a simple and enthusiastic approach on rockets, astronomy and space related content, working together with OBA (Brazilian Astronomy and Astrophysics Olympics) on events and workshops, to basic and high school students. This is a way the group found to contribute to the university, to science, and to the society at large.

The rocket team was founded in 2016 and it is the oldest group of the state, that is why the name makes a reference to the Rio de Janeiro. The GFRJ has a large historic of rockets and motors of your own authorship, that was only possible because the UERJ community always support the group, either for the academic support or the money donated from the students and teachers. Besides the financial help of the general people of the university, the team counts on the sponsorships of companies who want to contribute to science and the development of the members of the group.

GFRJ team is organized by the following organizational chart.

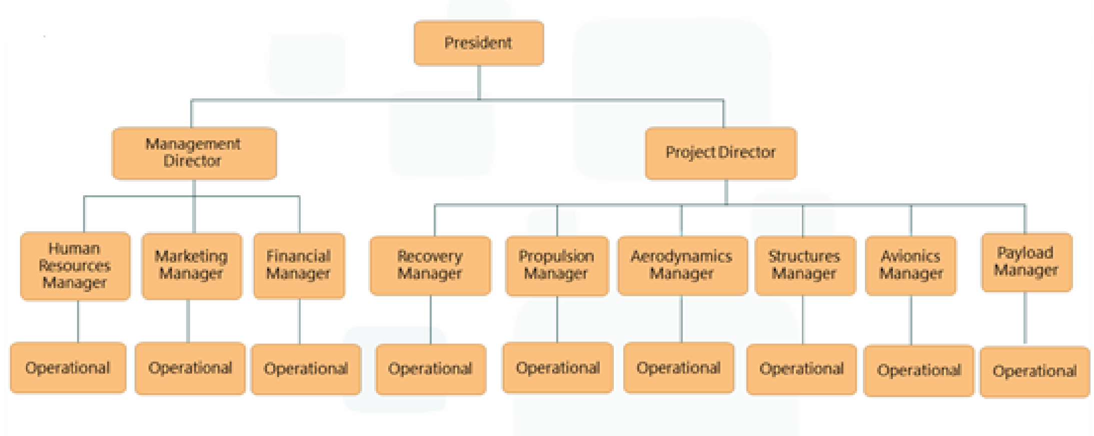


Fig. 1 GFRJ's organization chart.

The rocket team decided to organize itself that way because of the new strategic planning. The Objective and Key Results (OKR) was adopted as a form to accomplish every goal planned by the directory.

The management team is responsible to earn and manage the resources of the group. The main idea is making GFRJ have exponential results with its own forces and for that it counts on with a Management Director and 3 managers: Financial, Marketing and Human Resources.

The project team is responsible to study, plan and execute everything related to the maintenance and development of the rockets for the competitions and events. For that it counts on a Project Director and 6 managers: Recovery, Propulsion, Aerodynamics, Structures, Avionics and Payload.

The President is responsible to represent GFRJ's meanings inside and outside the group, to the meanings and to make the action plan works integrated with all team.

The GFRJ has its organization on 3 levels: strategic, tactical and operational. On the strategical level, the directory has the role to decide the objectives to be fulfilled and think all the action plan, considering only the goals wanted by the group. The tactical level is formed by the managers, and they are responsible to lead the operational level to realize every action in the action plan. The operational level is responsible to execute every action demanded by the managers. Worth mentioning that this is the way of strategy that every action is planned to achieve the goals thought by the directory.

III. System Architecture Overview

Canalle Platinado IV is a 1566 mm length and 79 mm diameter launch vehicle designed to reach 1km AGL, divided into three modules and equipped with a solid propelled student-built motor, a recovery system by CO_2 ejection systems, a 3-ring mechanism, a COTS altimeter and a student-developed embedded system. The Payload is a dead weight to ensure the stability of the rocket. The *Canalle Platinado IV*'s rocket design and its internal subsystems can be seen in Fig. 2 and Fig. 3, respectively.

Fig. 2 *Canalle Platinado IV*'s.rocket design.

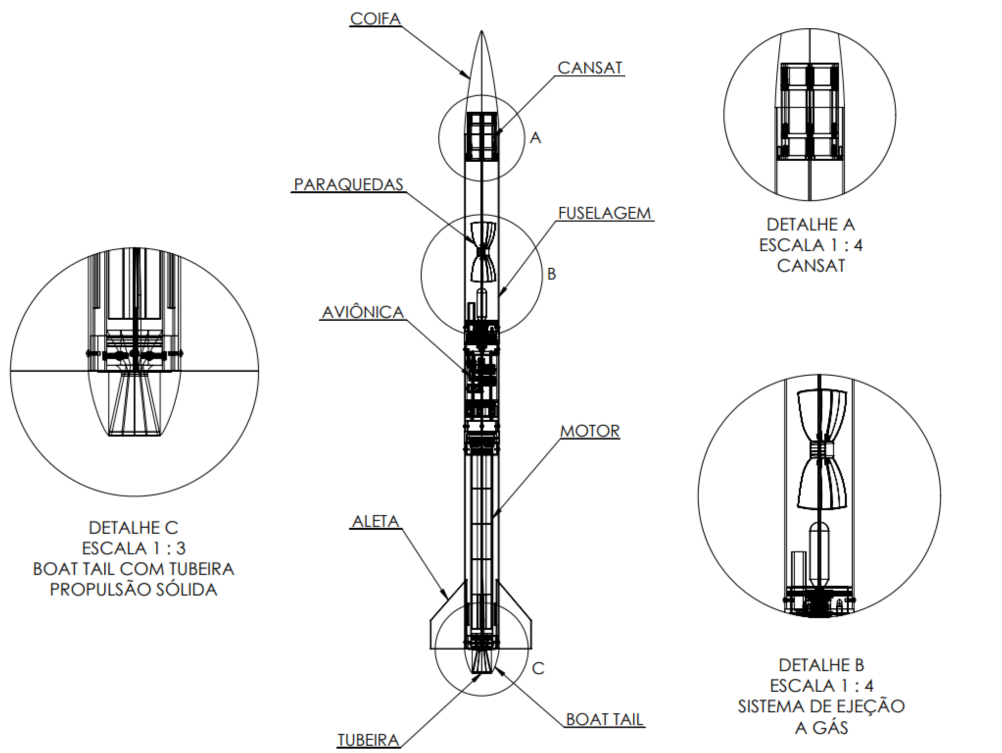


Fig. 3 *Canalle Platinado IV* in section view.

A. Propulsion Subsystems

The *Canalle Platinado IV*'s rocket engine is named J-836 and uses a solid propulsion system. The J-836 is designed in a simple and robust way with the objective of minimizing the number of parts in its construction to allow greater practicality in its assembly and manufacture. The engine in the exploded view is represented in Fig. 4 and each of its components are mentioned and described as:

- *Combustion chamber*: Component that contains the propellant and where ignition takes place.
- *Nozzle*: Component through which the gasses from the burning of the propellant are drained from the combustion chamber.
- *Bulkhead*: Acts sealing off one end of the rocket engine.
- *O-rings*: They are positioned in small gaps located in the nozzle and in the bulkhead so that the seal is guaranteed in the system.

- *Screws*: Components for attaching the nozzle and bulkhead to the combustion chamber.
- *Propellant Grain*: Acts as the fuel for the rocket to start its trajectory.
- *Inhibitors*: Wrap the propellant grains individually to inhibit burning.

Fig. 4 Exploded view of J-836 engine.

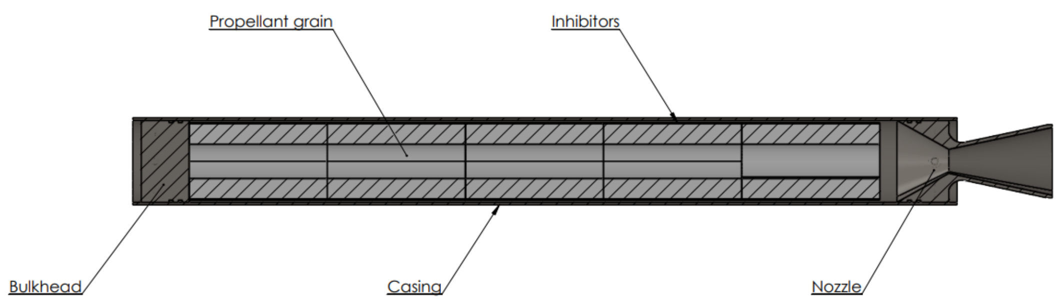


Fig. 5 J-836 engine on section view.

1) The propellant

The J-836 engine uses potassium nitrate (KNO_3) as an oxidant and dextrose ($C_6H_{12}O_6$) as a fuel as solid propellant. The cited mixture is also referred to as KNDX.

The choice of KNDX as the composition of the solid propellant was due to its ease of manufacture combined with the curing time being long enough for the molding procedures to be successful. Furthermore, the performance generated by the KNDX is satisfactory for the rocket's purpose.

Using *RPA*, with an oxidizer/Fuel ratio of 1.883, KNDX has the ideal properties as shown in Table 1.

Table 1 KNDX's ideal characteristic.

Molecular Weight (g/mol)	180.15
Melting Point (°C)	146
Density (g/cm^3)	1.879
Enthalpy of Formation (kJ/mol)	-1,274.5

To ensure the quality of the material used to compose the propellant used in the J-836 engine, burn rate tests were performed as shown in Fig. 6, thus obtaining values that approach the theoretical values.

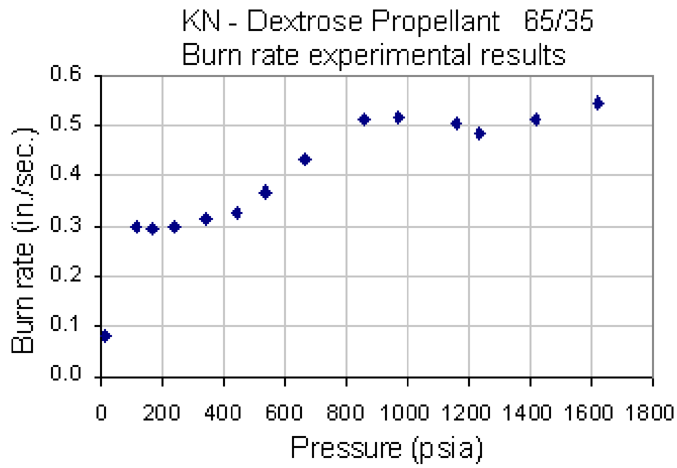


Fig. 6 KNDX burn rate experimental results.

2) Sizing and Theoretical Data

The J-836 solid propulsion engine consists of an arrangement of bulkhead, casing, nozzle, propellant grain and inhibitors as shown in Fig. 7**.**

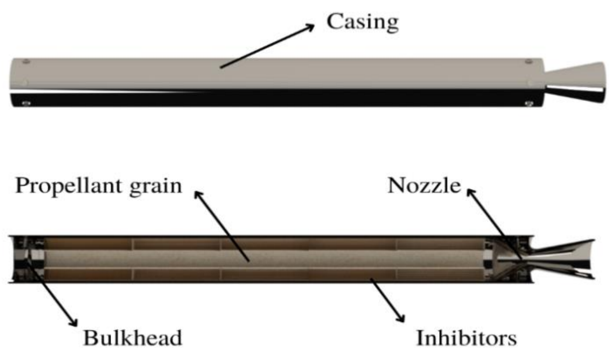


Fig. 7 Arrangement of J-836 engine components.

The combustion chamber of the J-836 engine is composed of a SAE 1020 steel cylinder whose internal diameter measures 47.8 mm. Its available length for housing the propellant segment is 410 mm, resulting in an available internal volume of $7.38\ x\ 10^{-4}$ m³, or 0.73 liters.

The nozzle present in the engine structure was machined from a SAE 1020 steel billet, obtaining a diameter in the throat region of 14 mm, a half-angle of 30° in the convergent region and an half-angle of 12° in the divergente region.

The propellant used is composed of potassium nitrate with dextrose in the proportion of 0.53 kg and 0.286 kg, respectively. In addition, the geometry used in the propellant grain follows the BATES geometry, with five axially rowed segments, each with an inhibitor made of 40kg paper. The propellant grain is illustrated according to Fig. 8 and its dimensions, as well as some other additional information, are referenced Table 2.

Fig. 8 Unit propellant grain.

Table 2 Grain design data

Length [mm]	80
Diameter[mm]	44
Core diameter [mm]	20
Number of segments	5
Total Weight [kg]	0.81
Density [g/cm³]	1.69

The engine developed in the project uses the concept of *student research and developed* (SRAD) and is classified as a class J engine, being able to deliver a total thrust of 1031.1 N·s. The thrust-time graph is shown in Fig. 9 and Table 3 lists the data obtained from this graph.

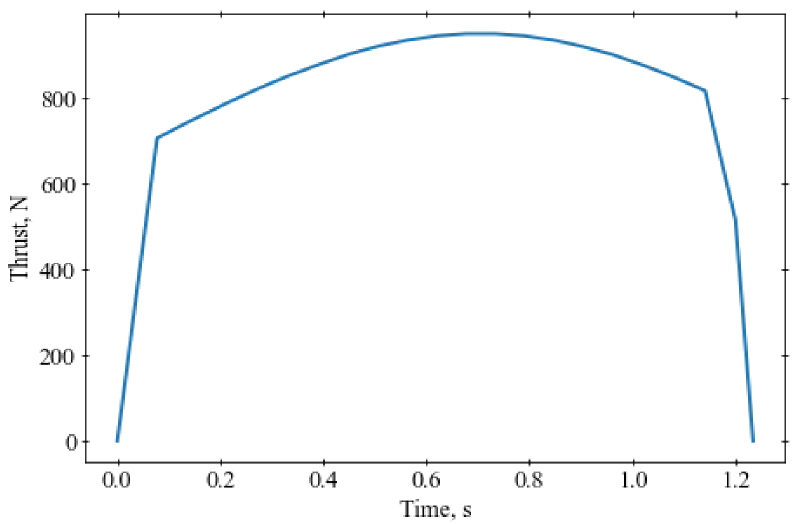


Fig. 9 Thrust-time graph developed by the J-836 rocket engine.

Table 3 Final theoretical data.

Average Thrust [N]	836.1
Maximum Thrust [N]	949
Total Thrust [N]	1,031.1
Specific Thrust [N]	128.9
Maximum Pressure [psi]	645

Later, in the Annex of the Project Test Report, the experimental data of the J-836 collected in the Fire Test, along with their comparison with the theoretical data.

3) Structure

After the theoretical dimensioning of the loads acting on the motor, the construction aspects of the project are defined. As stated earlier, the material chosen for the engine composition was SAE 1020 steel because of its ability to withstand the exposed operating conditions, making use of the thin-walled pressure vessel equation considering a cylindrical vessel, such as the case of the engine used in the project. This equation is expressed according to Eq. (1).

$$f = \frac{2\,\sigma\,t}{P\,d} \tag{1}$$

Where f is the safety margin, σ is the allowable yield stress of the material, t is the casing thickness, P is the internal gauge pressure developed by burning the impeller, and d is the average diameter.

Using the theoretical yield strength of SAE 1020 steel of 300 MPa and a combustion chamber thickness of 1.5 mm, a design safety margin of 4.6 is obtained.

To fix the nozzle and bulkhead in the combustion chamber, 12 screws are positioned with a resistance class of 12.9 in total, 6 of them at the end where the bulkhead is positioned and the other 6 screws present at the end where the nozzle is positioned.

B. Structure Subsystems

The structural design of the *Canalle Platinado IV* was developed following the purpose of obtaining an airframe with good mechanical properties and low specific mass. That is why the glass, the fiber-glass epoxy resin composite was selected, in which the epoxy resin acts as the polymeric matrix capable of evenly distributing the loads acting on the glass fibers arranged under +0/+90 orientation.

The fiber-glass epoxy resin composite guarantees important characteristics in the project, such as high mechanical resistance to traction and compression and excellent resilience in case the rocket body is required to protect the internal components most vulnerable to impacts from falls from large altitudes, in addition to the low specific mass of the material that allows a better use of the apogee reached by the rocket.

In order to improve the structural finish and reduce the drag coefficient, a layer of gel coat was applied throughout the outside of the rocket.

1) Nose Cone

The nose cone of the *Canalle Platinado IV* rocket follows the LD-Haack design, also known as the *Vón Kármán nose*. This selection was preferred because this nose is able to reduce the efforts from the drag force that causes considerable loss in the apogee of the project to be reached by the rocket. With this, the *Vón Kármán* will act by reducing the drag coefficient of the rocket in the subsonic/transonic flight region.

In making the *Vón Kármán*, was chosen to use the 3D printing manufacturing process, which allows the project the possibility of obtaining precise measurements and of easy production. The material used in the 3D printing of the nose is ABS.

In the internal region of the hood, there is a cylindrical cavity for the Payload to be positioned in the internal structure of the rocket, as it is shown in the Fig. 10.

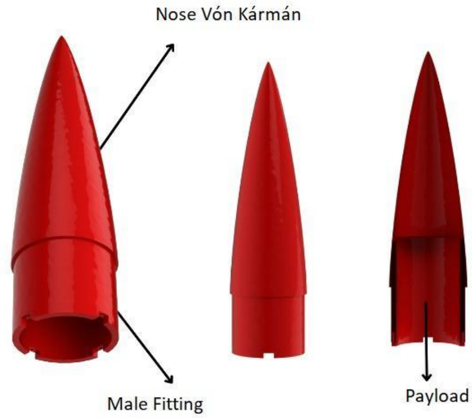


Fig. 10 *Canalle Platinado IV*'s nose cone.

2) Couplers

The couplers play a fundamental role in the structure of the *Canalle Platinado IV*. They have the function of joining the modules together in a stable way and also act to protect and secure the parachute ejection system. In addition, it is designed to meet the need to allow communication between avionics and recovery systems. The design can be seen in Fig. 11

The material used in the couplers is 6351-T6 aluminum alloy, which meets the requirements of mechanical strength and also due to its reduced specific mass compared to steel. In addition, this alloy is easy to machine, which allows it to be easily produced.

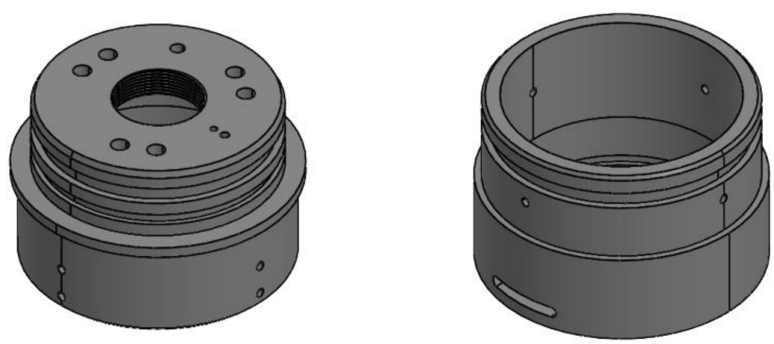


Fig. 11 Couplers separated.

Considering that the recovery system will be using a ejection by gas, it was necessary to adapt the couplers. Aiming at good impermeability, pairs of o-rings and parbaks will be used.

For fixing the parts of the couplers, a 3mm nylon thread will be used. The nylon thread will fill a cavity, as can be seen in Fig. 12 which will make it impossible to uncouple them during the flight. The couplers will be fixed to the fuselage by Button Head Socket Screw, with four screwed M3 x 0.5 thread.

In addition to the recovery and avionics couplers, engine couplers were also designed. It will have the same structure as the previous coupler, but there will be no o-ring and no Parbak. A centering ring made of polypropylene will be located at the bottom of the coupler and will minimize vibration, as well as thermally protect the motor casing.

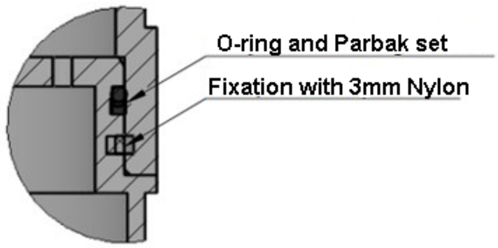


Fig. 12 Couplers fixation operating by a nylon thread.

C. Aerodynamics Subsystems

Flight and performance simulations were performed in the *OpenRocket* software. Through the rocket's first design was developed by the program, estimating masses and measurements of the components. Regarding the latest version (*Canalle Platinado III*), project updates were made to improve flight performance through mass reduction such as changes in fin shape and boat tail implementation. The rocket simulation of *Canalle Platinado IV* on *OpenRocket* simulation is shown in the Fig. 13, where it's possible to see some informations related to the flight performance, like stability, apogee achieved, maximum velocity, maximum acceleration and the positions of the center of pressure and center of gravity on the static analysis.

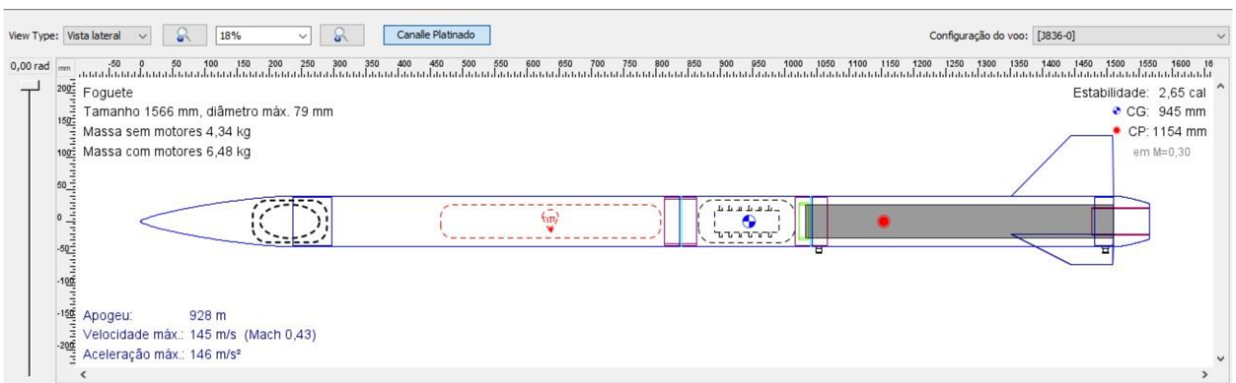


Fig. 13 *Canalle Platinado IV* on *OpenRocket* software.

1) Fins

The fins have their own design that meets the necessary stability criteria. These have sufficient area to bring the center of pressure down from the center of gravity at least 1.5 calibers, which meets the stability criterion throughout the flight. The projected geometry of the fin is shown in Fig. 14.

A flutter analysis was performed using the NACA TN 4197 V2 method – Flutter Analysis. Flutter speed found with 50% safety factor was 263.35 m/s or approximately Mach 0.77, higher speed than the maximum speed of the rocket during its flight.

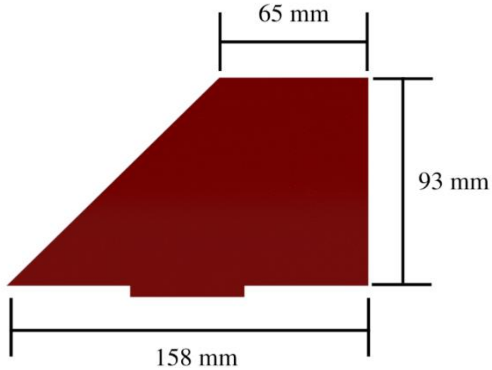


Fig. 14 Rectangular trapezoidal fin.

2) Boat Tail

The implementation of the boat tail aims to reduce the base drag produced by the difference in diameter in the wind flow at the bottom. That is why its design was made of the *Vón Kármán* geometry, which was cut in the measure and desired diameters to offer the best performance.

3) Simulations

The predicted altitude reached by the *Canalle Platinado IV* is related to the time during its flight trajectory. Using the simulation performed by the *OpenRocket*, it was possible to reach a maximum apogee of 928 meters, considering a target apogee of 1,000 m. The graph shown in the Fig. 15 expresses how altitude relates to time.

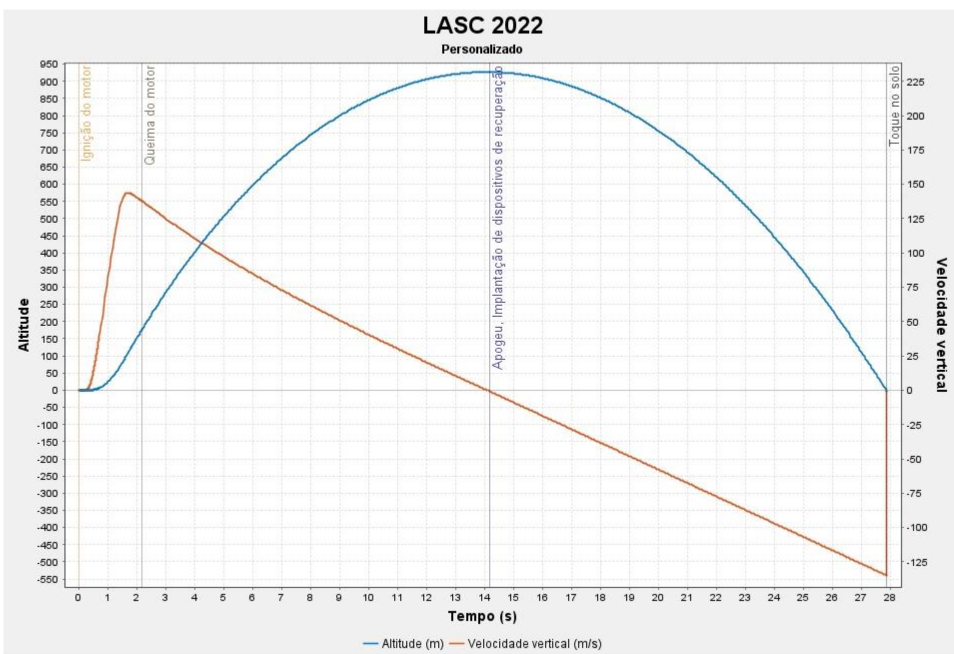


Fig. 15 Flight simulation profile on *OpenRocket*.

The data collected through the all-important simulation are listed in the Table 4.

Table 4 Flight data

Maximum speed	145 m/s
Maximum acceleration	15.3 G

The rocket stability can be seen in Fig. 16

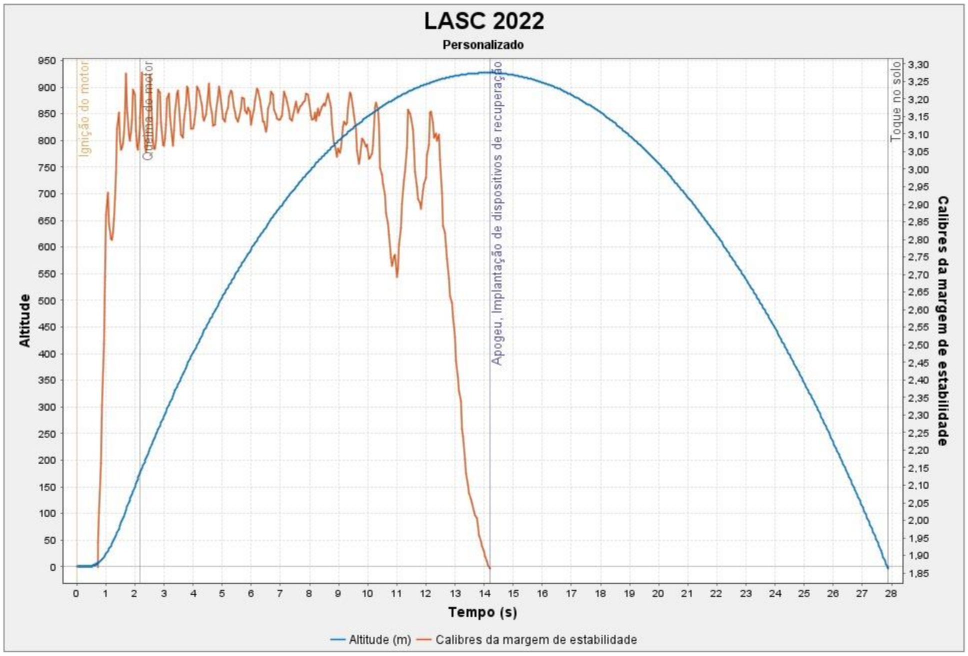


Fig. 16 Rocket Stability Margin.

All simulations regarding aerodynamics considered the estimated weight of the rocket, including the fact that the rocket's mass varies with time during the flight path. Moreover, Table 5 lists the masses of some important segments.

Table 5 Component masses

Vehicle weight	4.9 kg
Propellant weight (all)	0.8 kg
Payload weight	0.8 kg
Total liftoff weight	**6.5 kg**

In terms of aerodynamics, the centers of pressure and gravity are fundamental features in the design of the rocket. With them, the rocket can perform a stable and safer flight. Then, two simulation situations were considered to obtain these two points: static and dynamic.

The static simulation consists of determining the centers of pressure and gravity considering the rocket not being in motion. In this case, the positions of the centers of pressure and of gravity are listed in Table 6. Considering this case, the static margin achieved during the thrust is 2.5.

Table 6 Position of the centers of pressure and gravity in the static simulation.

Center of pressure	1156 mm
Center of gravity	959 mm

In the dynamic simulation, the determination of the centers of pressure and of gravity varies over time, as the thruster system is consumed during the trajectory of flight. Thus, it is not possible to estimate a fixed value for both.

However, it is possible to estimate values for each time interval through a graph produced through a simulation in the *OpenRocket* as shown in the Fig. 17.

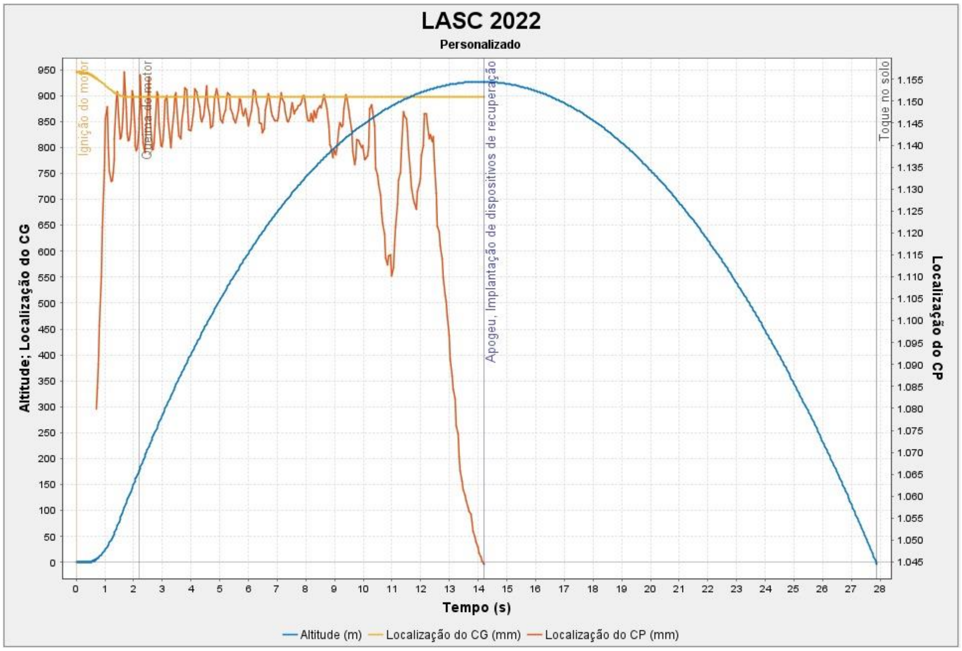


Fig. 17 Simulated center of pressure and simulated center of gravity.

D. Avionics Subsystems

The student-developed embedded system that compose avionics system is based on data acquisition and parachute drive.

The data acquisition subsystem acquires all the quantities listed in Table 7. Moreover, note that Altitude and Velocity are calculated variables rather than measured variables like the others. This is because the RRC3 Module calculates these variables from the pressure, which is also acquired by the GY-87 module, according to the Table 7.

Table 7 Avionics modules

Quantity	Module	Sensor
Atmosferic Pressure	RRC3/GY-87	MSI MS5607/BMP180
Altitude	RRC3	Calculated by Conversion
Velocity	RRC3	Calculated by Conversion
3-axis Position	GY-87	MPU-6050
3-axis Acceleration	GY-87	MPU-6050
3-axis Magnectic Field	GY-87	HMC5883L
Temperature	RRC3/GY-87	MSI MS5607/BMP180

The COTS altimeter that is used in avionics system, as mentioned before, is the RRC3 "Sport" Altimeter as the Fig. 18 shows. This device has a high reliability of operation, and for that reason it was selected by the team.

Fig. 18 COTS RRC3 Altimeter.

The device has in its core a 16-bit 16MHz Microcontroller, and it also has an 8Mbit SST Flash Memory to save all the data acquired during the flight. Furthermore, it has dimensions of 23.5 mm x 99.5 mm and the device is capable of delivering 3 A of current for 1 second during the trigger stage, which occurs twice – in the apogee stage and in the main parachute drive stage.

According to RRC3 manual, the RRC3 Module and the mDACS software both employ the NOAA "Pressure Altitude" calculation method to convert air pressure to an equivalent altitude. The conversion quoted in Table 7 is calculated using the Eq. 3 to obtain altitude.

$$h_{alt} = \left(1 - \left(\frac{\mathrm{P}}{1013.25}\right)^{0.190284}\right) \cdot 145366.45 \tag{2}$$

The velocity of the vehicle can be calculated point by point by using the Equation (3)

$$v = \frac{\Delta h_{alt}}{\Delta t} \tag{3}$$

The GY-87 and SD module are connected to the Arduino NANO on a printed circuit board designed by team, that can be seen in Fig. 19 . The SD module is responsible for recording all data acquired by the avionics system.

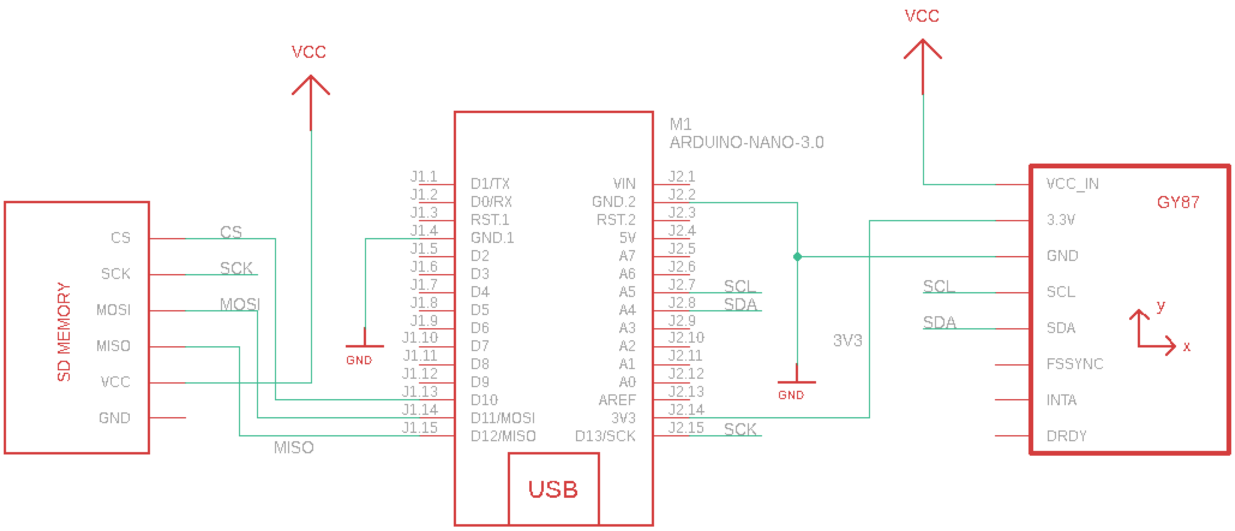


Fig. 19 *Canalle Platinado IV* PCB schematic.

E. Recovery Subsystems

The recovery of the *Canalle Platinado IV* rocket will be carried out in a single stage, consisting of 1 main parachute, 1 CO2 ejection system, a powder container for redundancy and a thermal protection blanket. The release of the parachute will take place at an altitude of 450m, the ejection system containing the gas cylinders will fire, ejecting the nose cone of the rocket and deploying the parachute that will break the rocket in two parts, allowing the vehicle to be slowed down by the parachute in a velocity of 9m/s until the gentle land.

Subsystem Components

1) Main Parachute:

The main parachute – that can be seen in Fig. 23 - was produced by the team, using the high-resistance Ripstop nylon 044 fabric, and has a flat circular geometry, in orange color, with an area of approximately 1.5 m² distributed in 8 sections. In addition, it has a spill hole, a hole in the center of the parachute, with 0.2 m in diameter to reduce oscillation during the fall. Thus, in this project there will be 8 suspension lines made of 300lb Kevlar, each 3 m long, and a central line that connects the center of the spill hole. The Parachute is disposed just above the avionics casing and will be ejected at a height of 450m. Also, the main parachute has an anchorage distributed at 3 points (1000lbs Kevlar cable).

2) CO2 system:

The ejection system is composed of 1 cylinder containing 16g of CO_2, as can be seen in Fig. 20, Fig. 21 and Fig. 22. It will be triggered by a needle piston, moved by an explosion of an exact amount of gunpowder, pressurized inside a compartment that will be triggered from a squib ignited by an electrical signal sent by avionics system. Thus, gas pressure will eject the nose cone, ejecting the parachute as well.

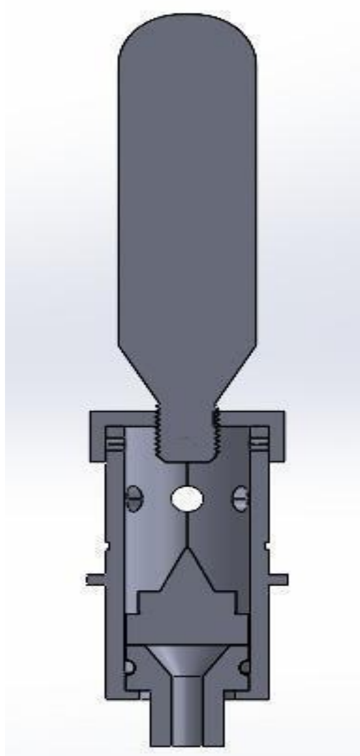


Fig. 20 CO2 Ejection Unit.

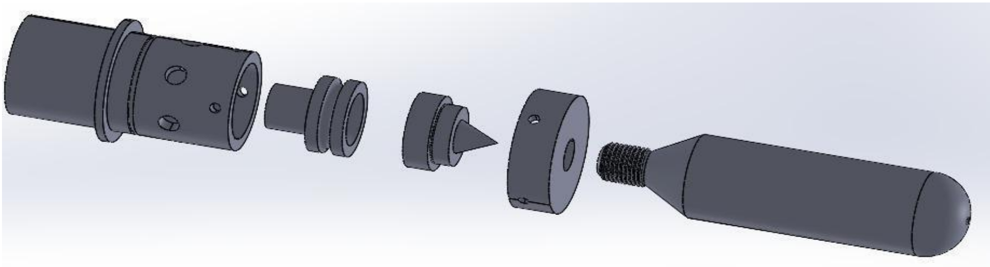


Fig. 21 CO2 ejection unit exploded view.

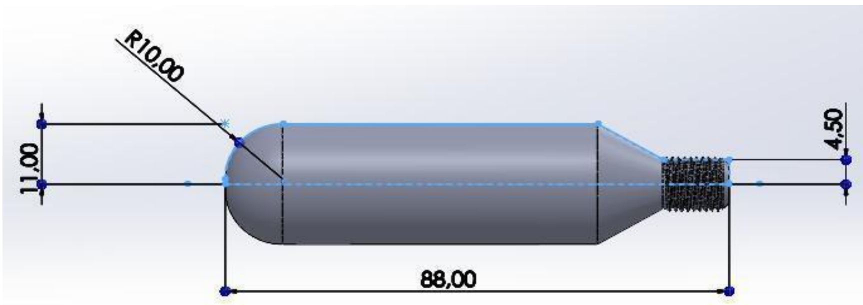


Fig. 22 CO2 Cylinder dimensions.

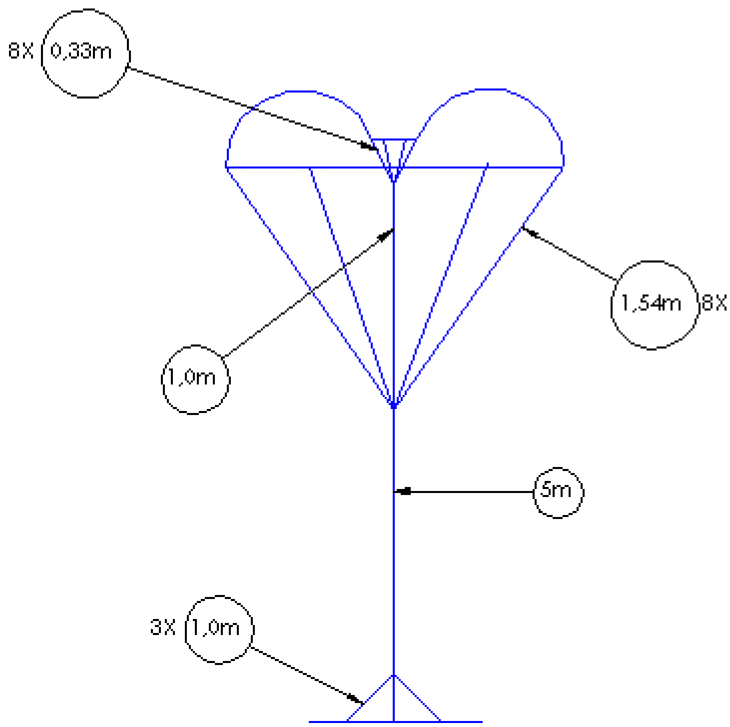


Fig. 23 Parachute dimensions.

Calculation of the Parachute Area

The main idea is to make the rocket land on the ground with constant known velocity. For this, it is necessary to make the vertical component of the Resultant Force F_R of the rocket equal to zero, as described on the equation (1).

For then, the Rocket's Weight P, given by the equation (2) must be equal to the Drag Force F_a, given by the equation (3). Thus, we have equation (4) as result, followed by the equation (5) and the equation (6)

Then there is:

$$F_R = \sum_{i}^{\infty} F_i = 0 \tag{4}$$

$$F_p = mg \tag{5}$$

$$F_a = \frac{1}{2}\rho v^2 A C_d \tag{6}$$

$$F_p - F_a = 0 \tag{7}$$

$$F_p = F_a \tag{8}$$

$$mg = \frac{1}{2}\rho v^2 A C_d \tag{9}$$

$$A = \frac{2mg}{C_d \rho v^2} \tag{10}$$

Considering the equations as follows,

$$v_{ms} = 9\ m/s$$

$$C_d = 0.75$$

$$m_t = 5\ kg$$

$$g = 9.80665\ m/s^2$$

$$\rho = 1.0862\ kg/m^3$$

$$C_s = 1.2$$

Thus,

$$A_{main} = 1.5\ m^2$$

F. Payload Subsystems

The Payload subsystem has a passive character, being therefore classified as a boilerplate non-functional. Its structure maintains a cylindrical configuration whose positioning is inside the *Canalle Platinado IV*'nose cone.

IV. Mission Concept of Operations Overview

A. Ignition

The ignition phase starts after the countdown is over and the ignition is fired. The propellant grains start to burn and with it the pressure and temperature both rapidly increase in the combustion chamber. The chamber`s thermical protection mitigates the heat transferred to the fuselage, allowing the fiberglass to maintain its mechanical properties. At this point the motor`s design is put to test, as the pressure increases, chamber, bulkhead and nozzle must have been well designed to sustain the pressure.

On another part of the rocket avionics and payload are already active, receiving and storing ground data. The pressure increases until it reaches operation pressure, and the ignition phase is over.

B. Liftoff

When the combustion chamber reaches operation pressure, combustion gases are expelled from the motor`s nozzle and the rocket is accelerated, increasing in speed and beginning its movement guided by the launch rail.

During this initial movement, little has changed to the avionics and payload subsystems, which should still be detecting conditions similar to those of the operation start, except for the acceleration and velocity increase.

When the rocket is clear of the launch rail, the liftoff phase ends.

C. Propelled Flight

On this first part of the flight, as the rocket leave the rail to a free movement, it experiences the wind interference on its trajectory. Approaching a critical point, the rocket must to have a minimum velocity compared to the wind so it guarantees a stable flight and the right direction.

In this phase, the rocket is constantly increasing its speed until the motor’s thrust runs out, which means the rocket has reached its maximum velocity and the propellants burning is over. The end of the propellants burning marks the end of the propelled flight phase

D. Main Parachute Deployment (1)

After reaching apogee of 1 km the vehicle falls until the altitude of 450 m. At this point the rocket still has a considerable velocity, as the braking efficiency is not the drogue parachute’s main purpose.

The avionics then activate the main recovery system, a much larger parachute, intended to effectively slow down the last moments of fall. The deployment of the main recovery system is the end of the fall directioning phase.

The fall velocity is decreased until reaching an appropriate speed for a safe ground hit. As soon as the rocket hits the ground that is the end of the Cushioned Fall phase and the end of the operation.

V. Conclusion

In the construction of the *Canalle Platinado IV*, several technical subsystems worked together to deliver a project capable of providing the study rocket with a launch that prioritizes technological innovations and flight safety. Therefore, the J-836 solid propulsion engine was developed in order to withstand the increase in pressure and temperature of the combustion chamber during the burning period so that it is able to withstand the mechanical and thermal loads resulting from the launch and provide the ideal propulsion parameters.

In addition, the structures and aerodynamics subsystems developed coupler and fuselage designs capable of remaining intact to the loads applied to the system, combined with the choice of the geometry of the *Canalle Platinado IV*’s’ nose cone capable of reducing the aerodynamic forces that act on the rocket. Using the COTS RRC3 altimeter, the avionics subsystem makes it possible to measure the altitude and velocity to which the rocket is submitted during the flight path. Finally, the recovery subsystem employing a gas ejection system for the main parachute, which is the only one in the configuration, allows the recovery of the rocket after the end of its trajectory, also using the 3-ring system as a considerable improvement to the project in terms of effectiveness. Therefore, the *Canalle Platinado IV* presents satisfactory technical design conditions to establish a correct and safe flight plan.

With the entire project developed, the team was able to develop project skills by establishing new options for technological improvement capable of individually and collectively enhancing each participating member. In addition, skills with regard to time and task management were highlighted as important points within the scope of projects in general and, more specifically, in the area of model rocketry and astronautics.

Appendix

1) System Weights, Measures and Performance Data

Component masses	
Vehicle weight	4.7 kg
Propellant weight (all)	0.8 kg
Payload weight	0.8 kg
Total liftoff weight	**6.3 kg**

Vehicle dimensions	
Overall vehicle length	156.9 cm
Airframe diameter	79 mm
Fin-span	93 mm

Performance Date	
Liftoff Thrust-to-Weight Ratio	13.1
Launch Rail Departure Velocity	38.5 m/s
Minimum Static Margin During Boost	2.5
Maximum speed	148.0 m/s
Maximum acceleration	15.3 G
Target Apogee	1000 meters AGL
Predicted Apogee	950 meters AGL

2) Project Test Reports

A) Recovery Test

In May 2022, bench tests were carried out to evaluate the total force obtained to release the main parachute and support of the system. This test can be seen in Fig. 24.

Satisfactory results were obtained, the system held the traction test well and the force obtained to pull the rope was sufficient for the DC Motor chosen.

Fig. 24 Rope strenght test.

B) Static Test

The static test is one of the most relevant ones, seeing as through if it is possible to subject the motor to real operating conditions, thus validating the propulsion systems thoroughly.

The test was executed in open field, adequate to all safety limits and procedures. The graphic illustrated in Fig. 25 shows a thrust curve obtained in the test in February 2019.

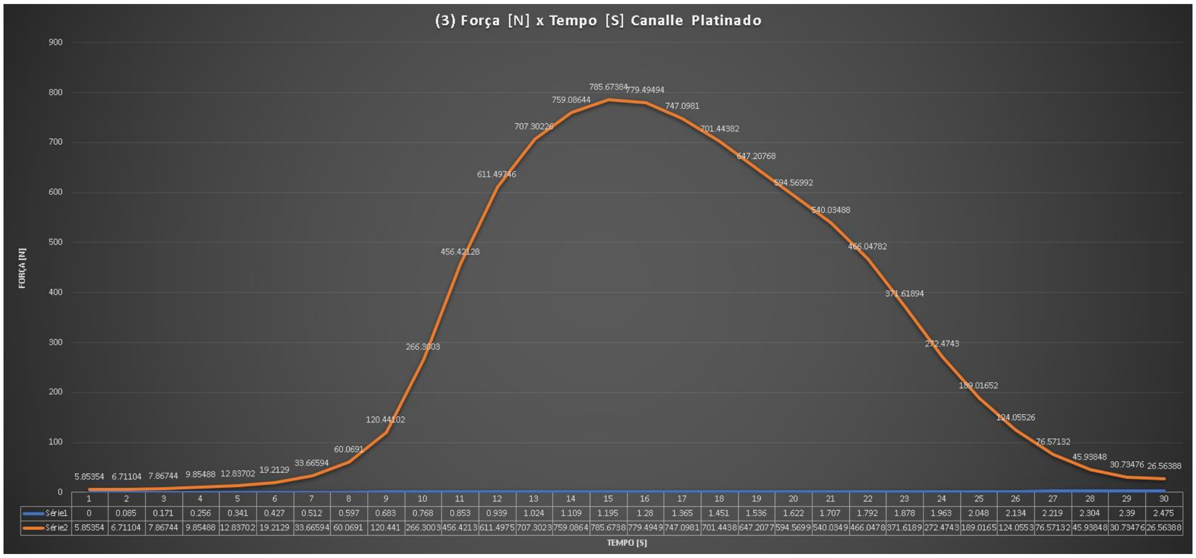


Fig. 25 Static burn test.

C) Potassium Nitrate Quality Test

To verify the quality of the potassium nitrate used, a thermogravimetric analysis (TGA) was carried out. It consists of a destructive technique in the field of thermal analysis, in which the mass variation of a sample is monitored as a function of the temperature or time in a temperature-controlled environment and atmosphere. In this way, it is possible to analyze the loss or aggregation of mass to the sample at different temperatures. In the Fig. , the wet Potassium Nitrate was analyzed. The result in red indicates that the sample was indeed still wet, since at about 250ºC, a loss of mass occurred.

In Fig. , Potassium Nitrate was analyzed after the drying process. The result in red symbolizes that the mass practically did not change as a function of the increase in temperature. Because of that, it is possible to confirm that the potassium nitrate is really dry and ready to be used in the manufacture of the propellant.

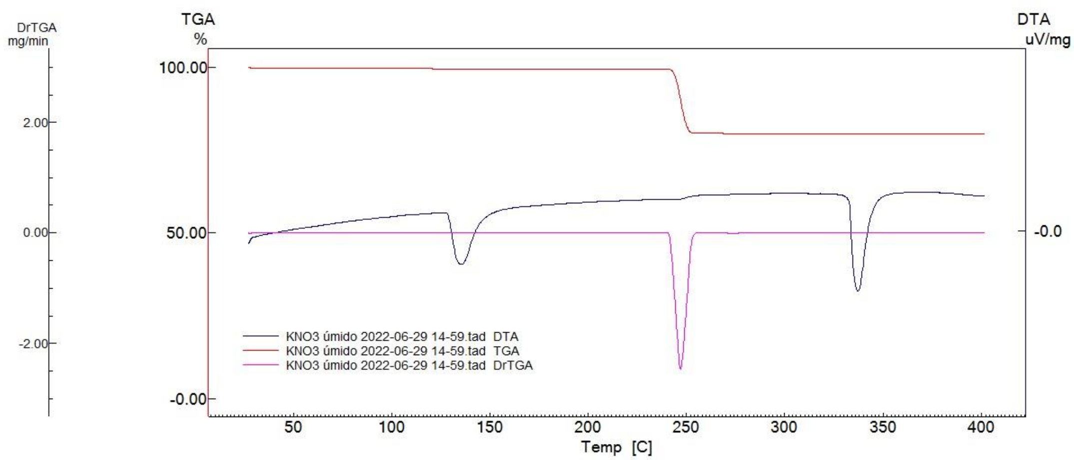


Fig. 26 Potassium Nitrate analysis.

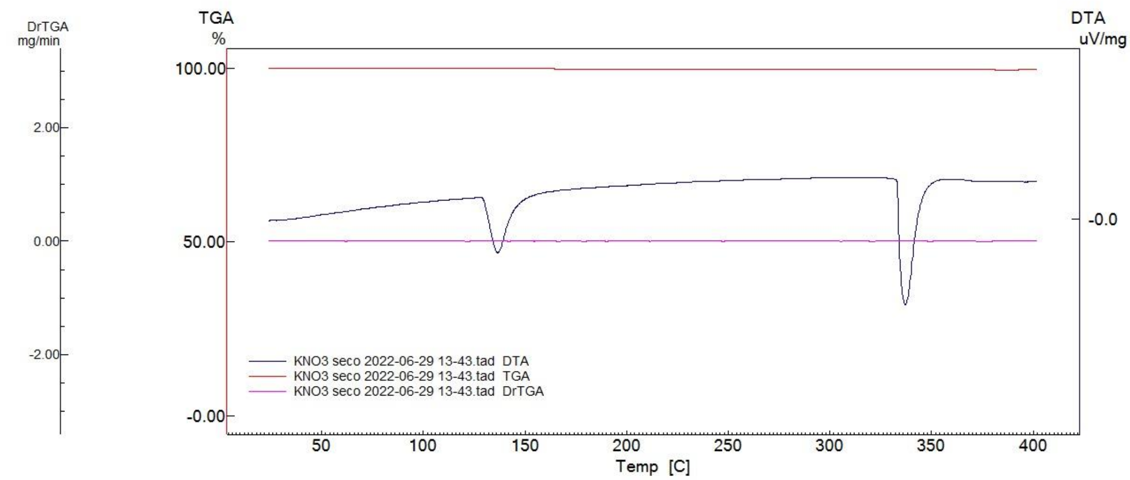


Fig. 27 Potassium Nitrate after the drying process.

D) Flight Test

The team conducted a demonstration flight of the first version of the rocket (*Canalle Platinado I*). The flight was made on 2017 on IV Festival Brasileiro de Minifoguetes, but there are not registers.

The third version (*Canalle Platinado III*) participated in the *V Festival Brasileiro de Minifoguetes* on 2018 and reached 1035 meters AGL or 3395,67 ft as in Fig. 28.

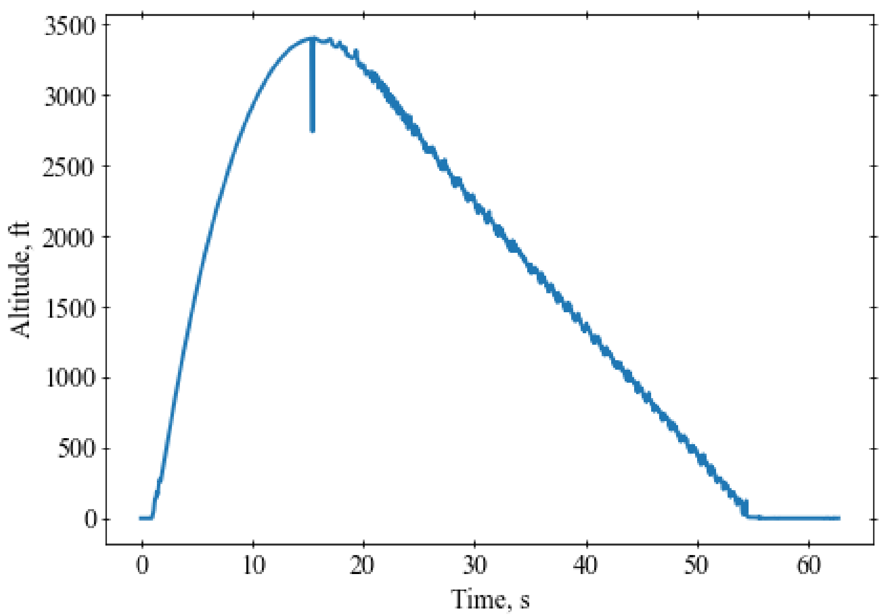


Fig. 28 Flight Record in 2018.

In this version, the rocket electronics had telemetry. With this it was had to verify the location by GPS of the rocket as shown in the Fig. 29. Therefore, allowing recovery to run quickly.

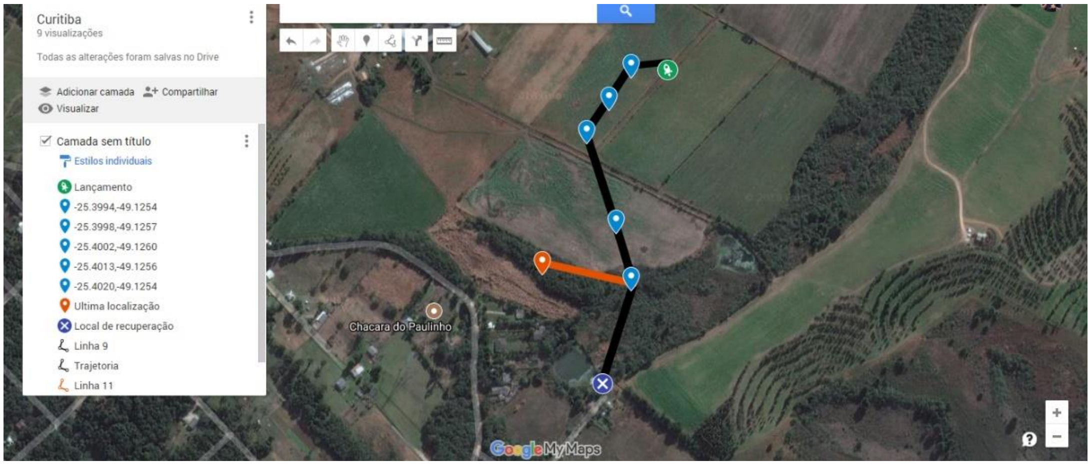


Fig. 29 Rocket Location.

3) Hazard Analysis

Team	Rocket/Project Name	Date	
GFRJ	*Canalle Platinado IV*	01/07/2022	
Hazardous material	**Possible Hazards**	**Mitigation Approach**	**Risk of injury after mitigation**
Propellant grain	Spontaneous combustion	Avoid keeping propellant grain in closed containers that may be pressurized in case of combustion	Low
		Avoid exposing it to intense heat for long periods of time	
		Avoid using polyester coats as preparing the grain. (avoiding static charges)	
Black Powder	Burn or explode	Be careful with static charges	Low
		Be careful with electronic devices and electric current near the powder	

4) Risk Assessment

Team	Rocket/Project Name	Date		
GFRJ	*Canalle Platinado IV*	01/07/2022		
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of injury after mitigation**
Explosion of solid-propellant rocket motor during launch with blast or flying	Cracks or Air Bubbles in propellant grain	Medium: student-built motor with limited testing and nondestructive	Pressure test motor case to 2 times maximum operating pressure	Low

debris causing injury	Gaps between propellant sections and/or nozzle	evaluation capability	Visually inspect motor grains for cracks and debonds during and after assembly Extra propellant grains in order to choosing the most appropriate for the operation	
	Chunk of propellant or inhibitor breaking off and plugging nozzle		Use of ductile material for motor case	
	Motor case unable to contain normal operating pressure		Inspect motor case for damage during final assembly before launch	
	Motor closures fail to hold		Only essential personnel in launch crew	
			Launch crew 200 feet from rocket at launch, behind barrier	
Rocket does not ignite when command is given, but does ignite when team approaches to troubleshoot	Ignition system malfunction	Medium; ignition system is student-built, and ignition is not always visible at first sight	Multiple testing of ignition system	Low
	Activation squib felt from rocket motor		In case of ignition failure, not approaching the rocket for a safety amount of time (5 to 10 minutes)	
	Ignition operation not properly executed		Launch operation printed and at hand	
Recovery system deploys during assembly or pre-launch and causes injury	Recovery activation malfunction	Low; both deployment systems are commercial	Avionics only activated when "remove before flight" is removed	Low
Rocket deviates from nominal flight path, comes in contact with personnel	Manufacturing is not faithful to design	High; motor and fuselage are student-built with the affordable tools and methods Wind and weather conditions hard to foresee and simulate	Simulations were made after the manufacturing with real data, presenting little the deviation from the expected results	Medium
	Rocket motor does not reach the desired efficiency		Static fire tests made point out a close to estimated efficiency	
	Vehicle does not reach minimum		Research on usual weather conditions	

	stability velocity due to windy conditions		at place of launch enable more reliable simulation results	
			Operation includes calling personnel’s attention to the launch in order to ease possible reactions to this hazard	
Low Recovery system partially deploys, rocket or payload encounter personnel	Avionics malfunction	Medium; complex operation of parachute folding, inserting and activating	Redundancy with commercial equipment rises the reliability of the system	Low
	Structure not sustaining enough tension		Tests made on similar structure guaranteed sustaining this amount of tension	
	Parachute or strings do not sustain enough tension		Commercial parachute design by professional parachute manufacturer rises the reliability of the project	
	Parachute gets stuck in the fuselage		Folding and insering procedures recommended by the manufacturer	
Recovery system fails to deploy, rocket or payload encounter personnel	Avionics malfunction	Low; redundant activation system	Redundancy with commercial equipment rises the reliability of the system	Low

5) Assembly, Preflight, Launch, and Recovery Checklists

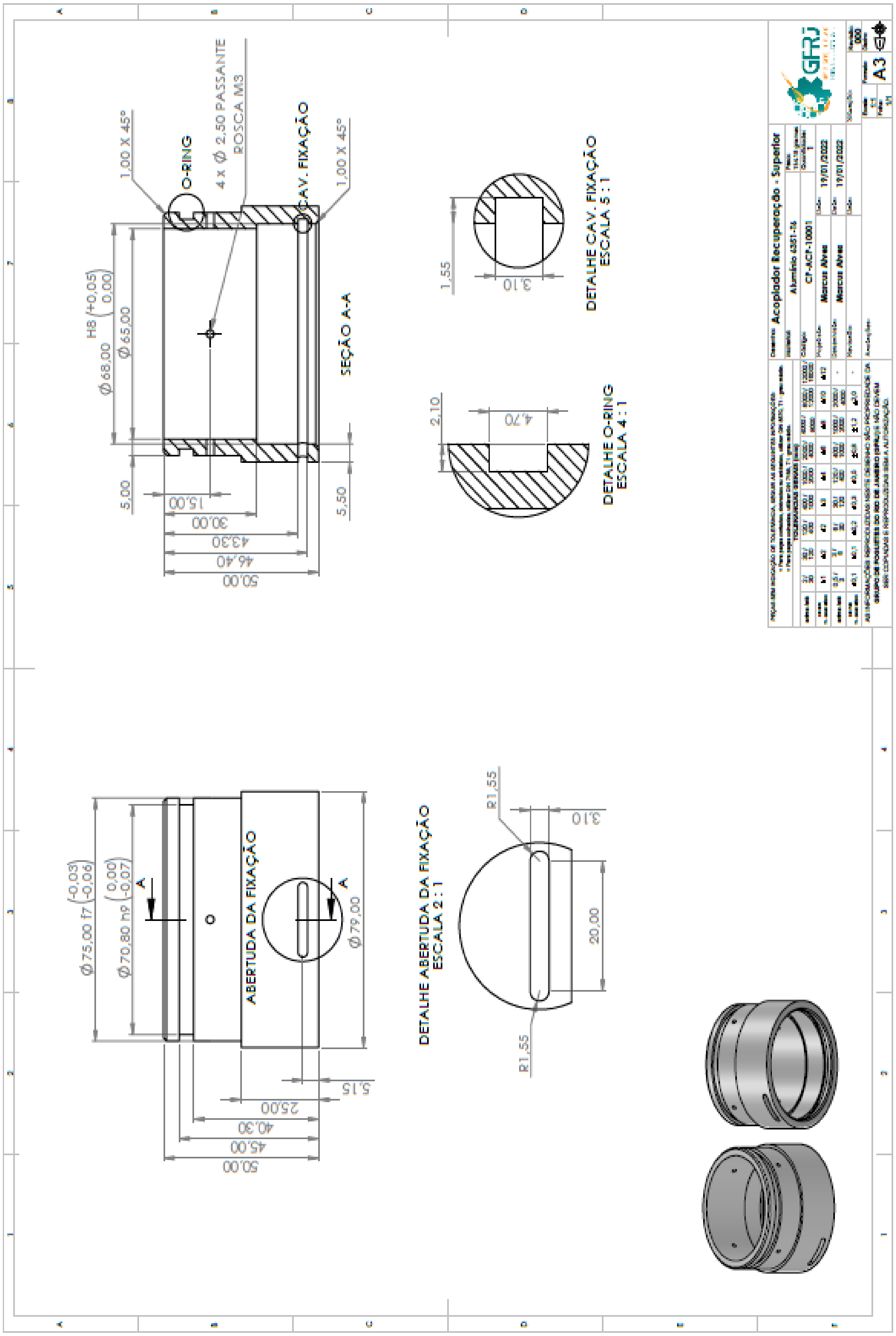
Materials Checklist		
Action number	**Action**	**Check**
1	**External structure**	-
2	Three fuselage tubes	-
3	Hole alignment	-
4	Fin integrity	-
5	Fin's attachment	-
6	Four couples	-
7	Screws	-
	Propulsion	
1	Motor tube integrity	-

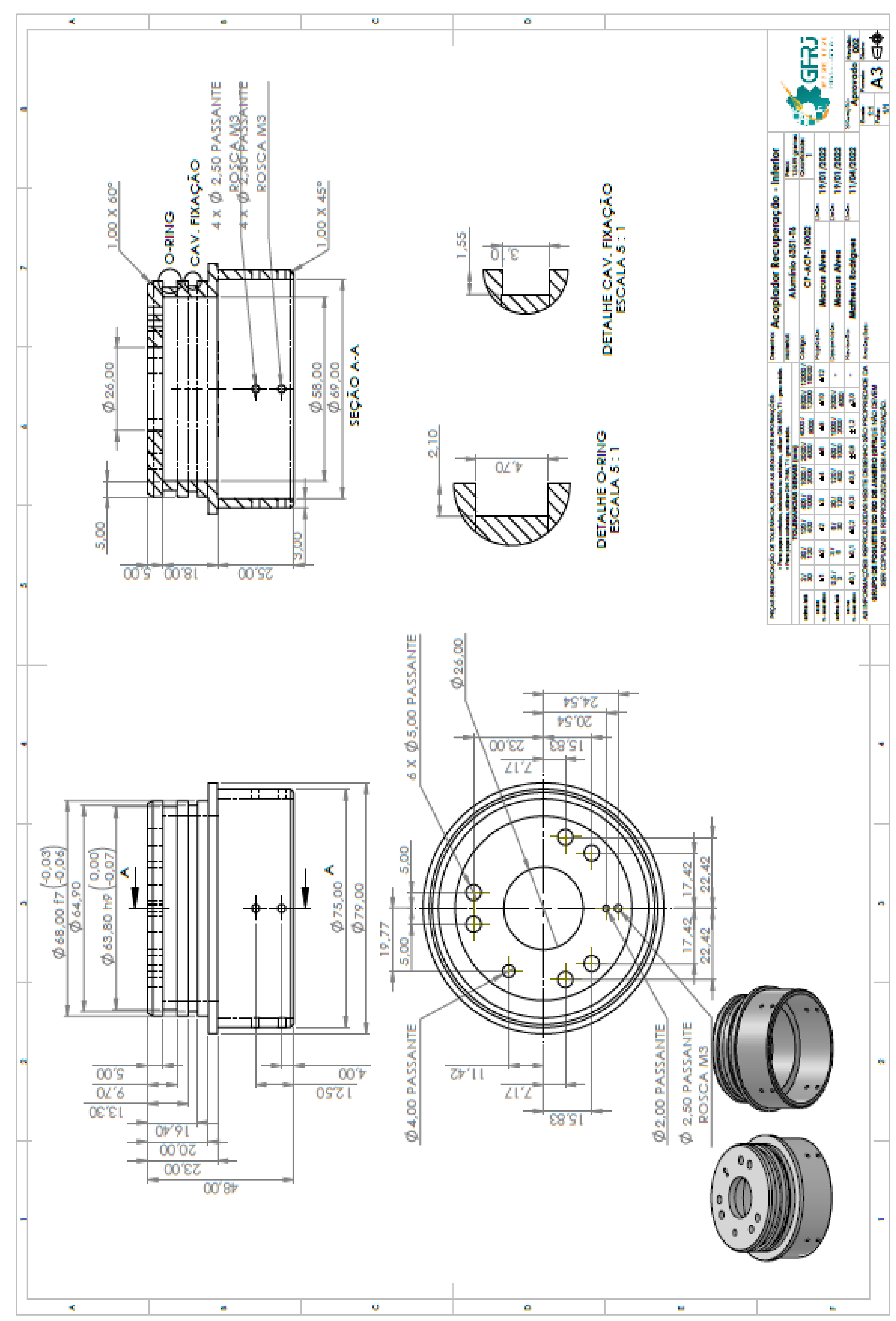
2	Propellents	-
3	Number of bolts	-
4	O-rings	-
5	Nozzle	-
	Recovery	
1	Strings	-
2	Main parachute	-
3	Gunpowder	-
	Avionics	
1	Avionic’s case	-
2	PCB	-
3	Altimeter	-
4	Batteries	
5	RBF	
	Payload	
1	Structure	-

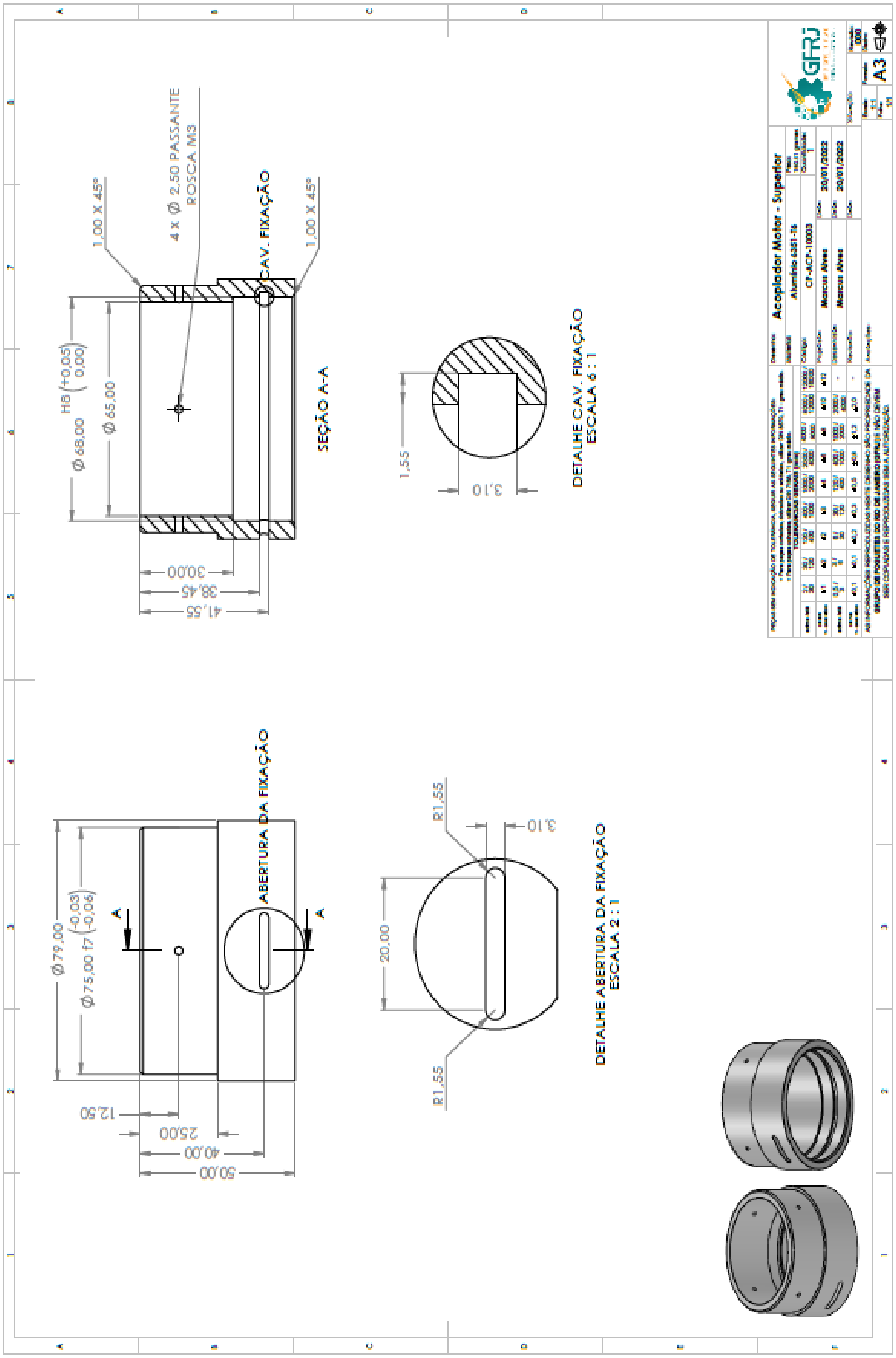
Assembly Checklist		
Action numbers	**Action**	**Check**
1	Structure Payload insertion on its module	-
2	Main parachute anchoring on payload module	-
3	Avionics coupler preparation	-
4	Avionics security key check	-
5	Main parachute powder preparation and allocation	-
7	Main parachute anchoring and allocation	-
8	Insert avionics "remove before flight" pin and turn off security key*	-
9	Anchoring drogue parachute on motor module	-
10	Connection of motor and drogue parachute module	-
11	Insert propellant in motor case	-
12	Nozzle enclosing**	-
13	Motor final check and assembly	-
14	Motor insertion***	-
15	Motor anchoring ring insertion	-
Preflight Checklist		
Action number	**Action**	**Check**
1	Check for required personal protective equipment	-
2	Check for green range status flag	-
3	Take rocket to launch pad	-

4	Rocket position on launch rail correctly	-
5	Arming avionics	-
6	Verify altimeter beep code	-
7	Check range manager's permission to install motor igniters	-
8	Motor igniter inserted and secure	-
9	Evacuate launch area	-
Launch Checklist		
Action number	**Action**	**Check**
1	Wait for MCO, RSO and LCO "go for flight" messages	-
2	Wait for LCO's final countdown	-
3	Ignition	-

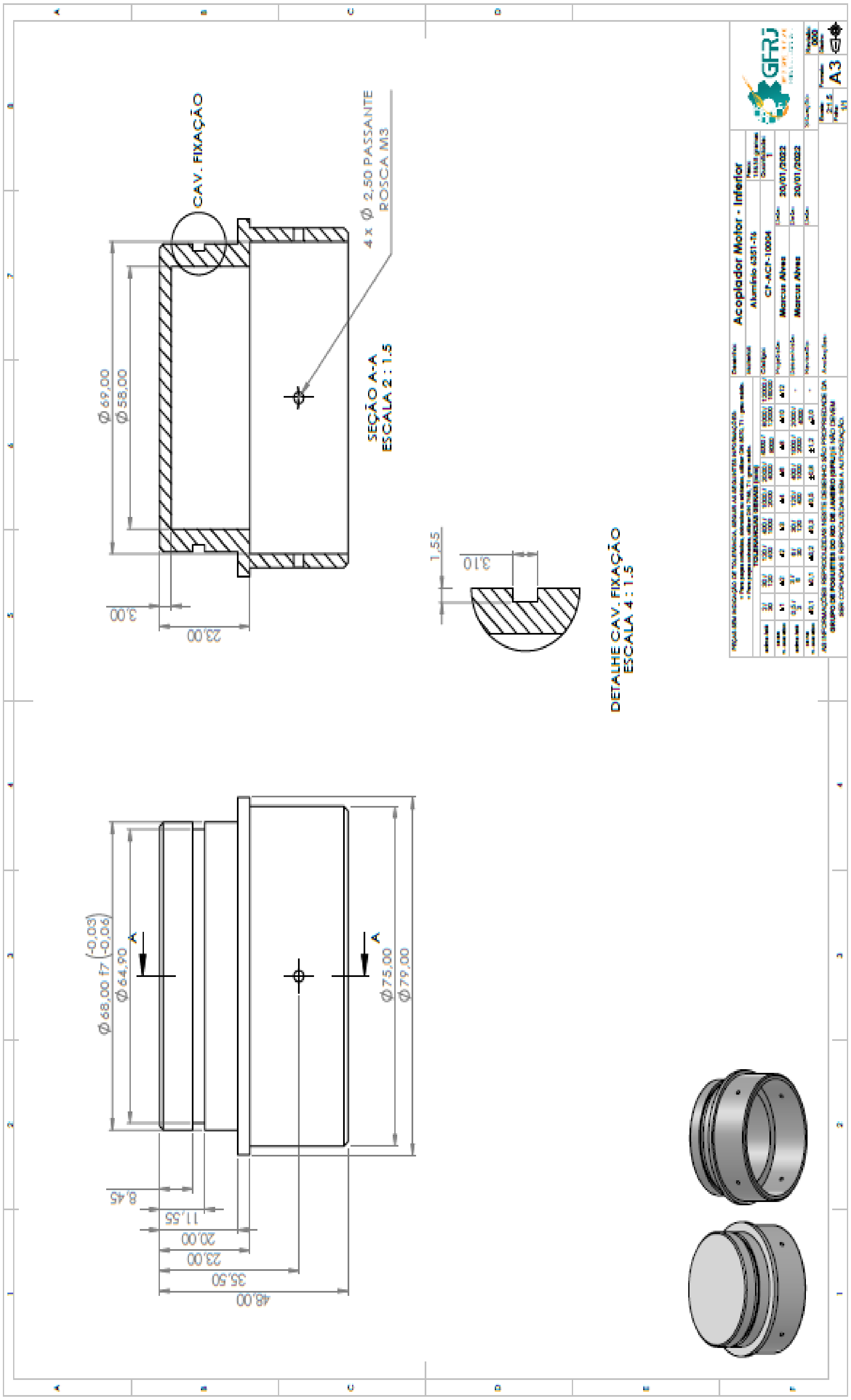
Engineering Drawings

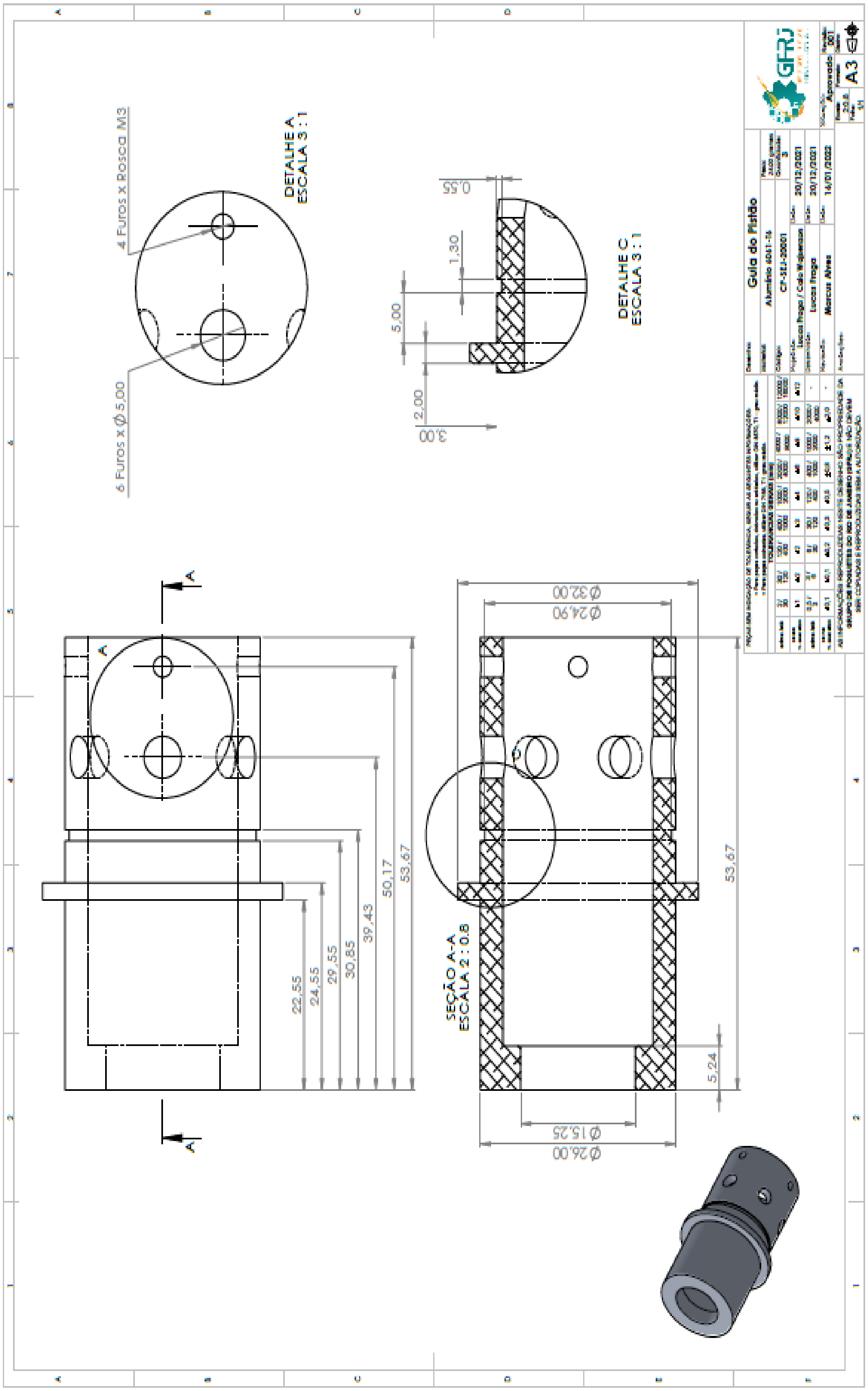


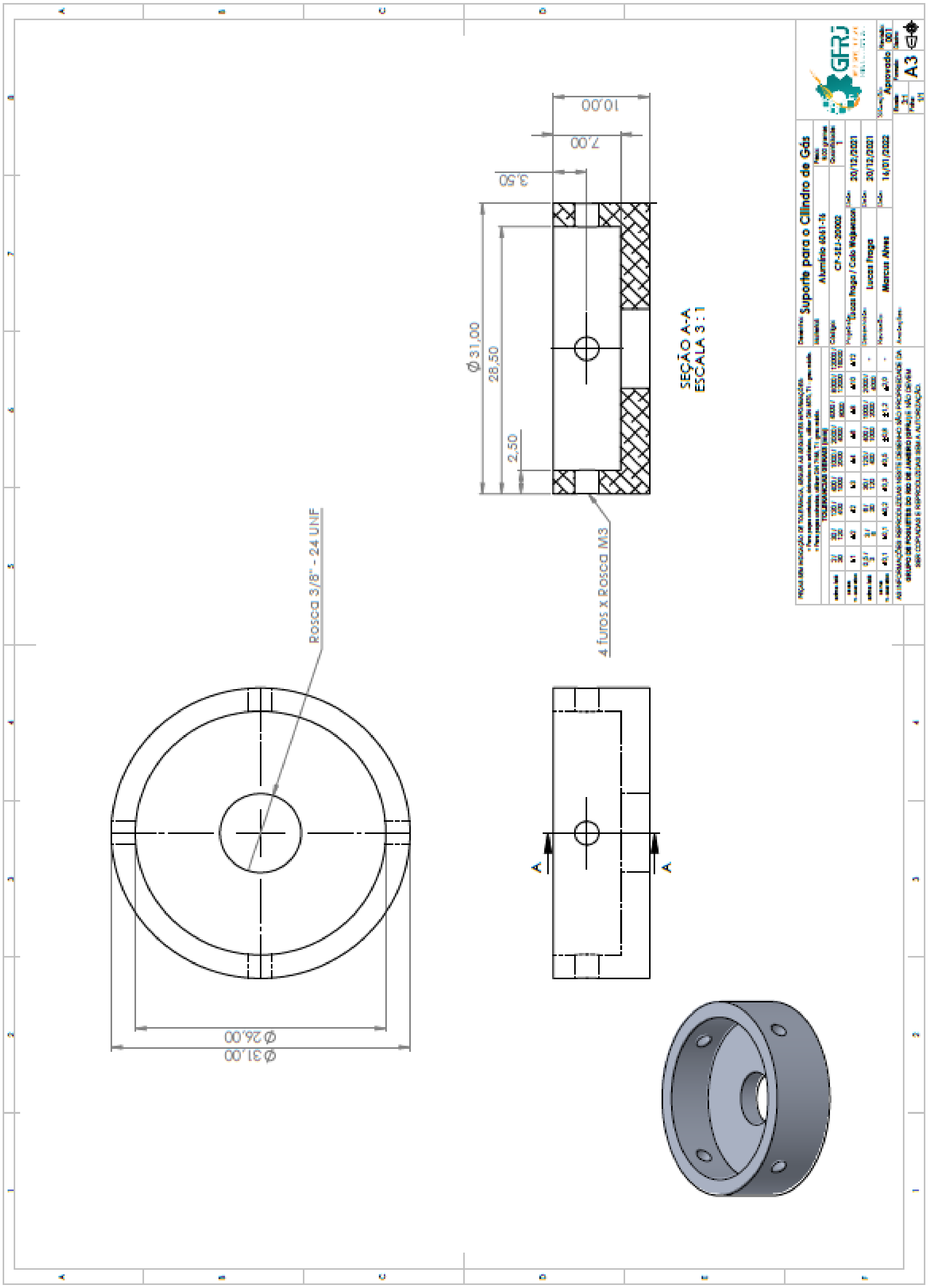

SEÇÃO A-A
DETALHE O-RING
ESCALA 5 : 1
DETALHE CAV. FIXAÇÃO
ESCALA 5 : 1
O-RING
CAV. FIXAÇÃO
6 X Ø 5,00 PASSANTE
Ø 4,00 PASSANTE
Ø 2,00 PASSANTE
Acoplador Recuperação - Inferior
A3

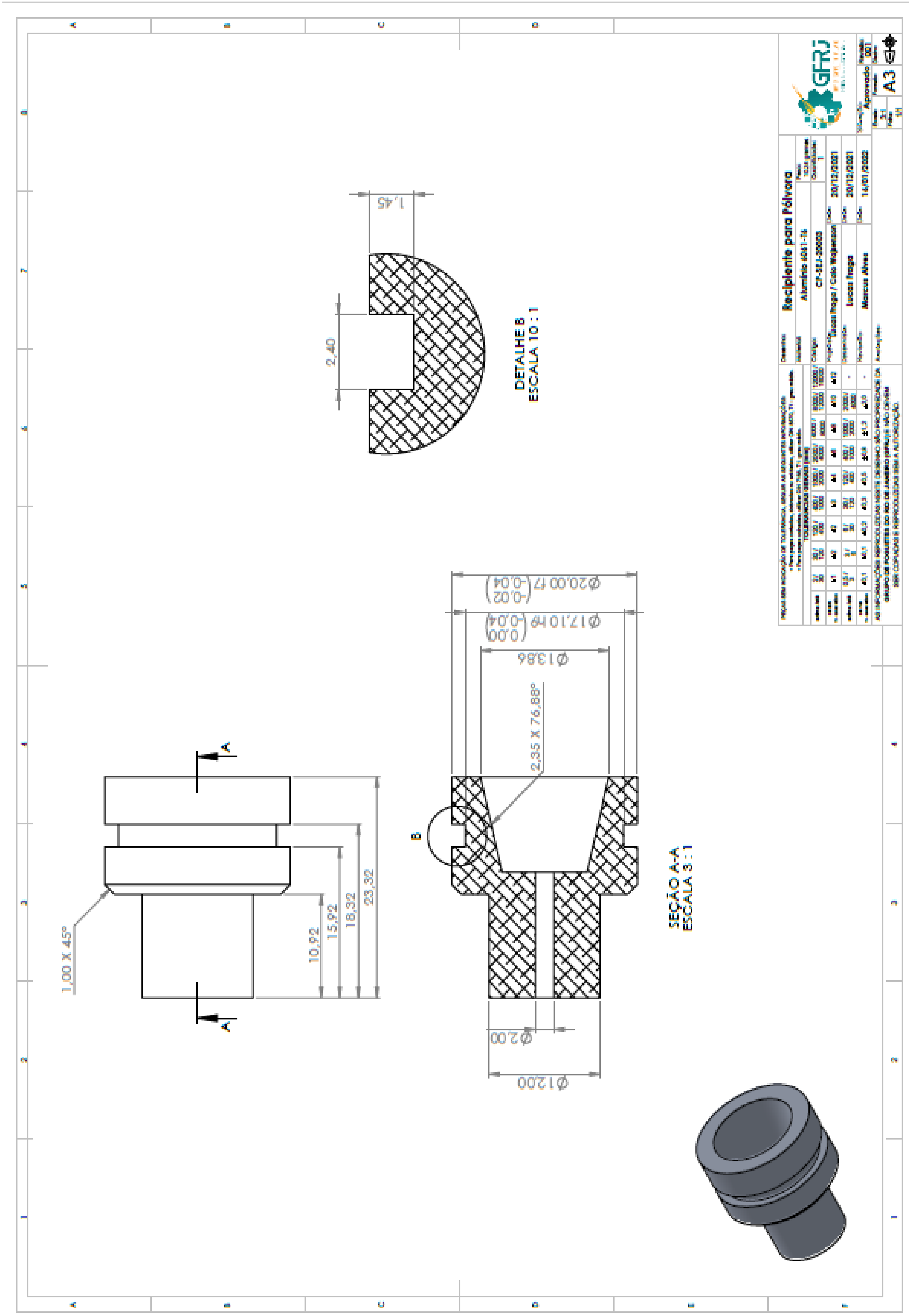


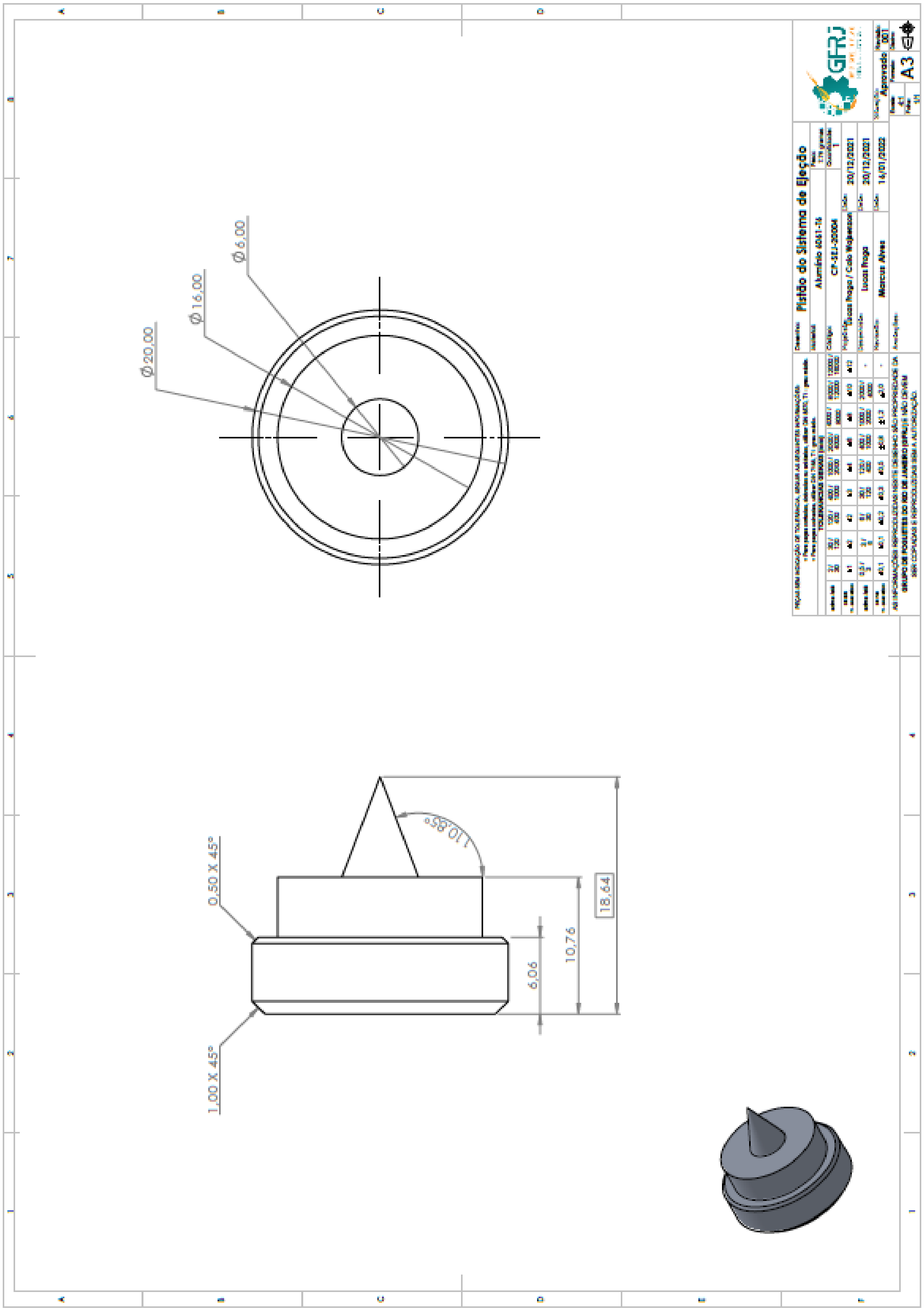
1,00 X 45°
4 x Ø 2,50 PASSANTE
ROSCA M3
CAV. FIXAÇÃO
1,00 X 45°
Ø 68,00 H8 (+0,05 / 0,00)
Ø 65,00
30,00
38,45
41,55
SEÇÃO A-A
1,55
3,10
DETALHE CAV. FIXAÇÃO
ESCALA 6 : 1
Ø 79,00
Ø 75,00 f7 (-0,03 / -0,06)
A
A
ABERTURA DA FIXAÇÃO
12,50
25,00
40,00
50,00
R1,55
3,10
20,00
R1,55
DETALHE ABERTURA DA FIXAÇÃO
ESCALA 2 : 1
Acoplador Motor - Superior
Alumínio 6351-T6
CP-ACP-10003
Marcos Alves
20/01/2022
Marcos Alves
20/01/2022
GFRJ
A3


CAV. FIXAÇÃO
4 x Ø 2,50 PASSANTE
ROSCA M3
Ø69,00
Ø58,00
3,00
23,00
SEÇÃO A-A
ESCALA 2 : 1.5
1,55
3,10
DETALHE CAV. FIXAÇÃO
ESCALA 4 : 1.5
Ø68,00 f7 (-0,03 -0,06)
Ø64,90
A
A
Ø75,00
Ø79,00
8,45
11,55
20,00
23,00
35,50
48,00
Acoplador Motor - Inferior
Alumínio 6351-T6
CP-ACP-10004
Marcus Alves
Marcus Alves
20/01/2022
20/01/2022
A3

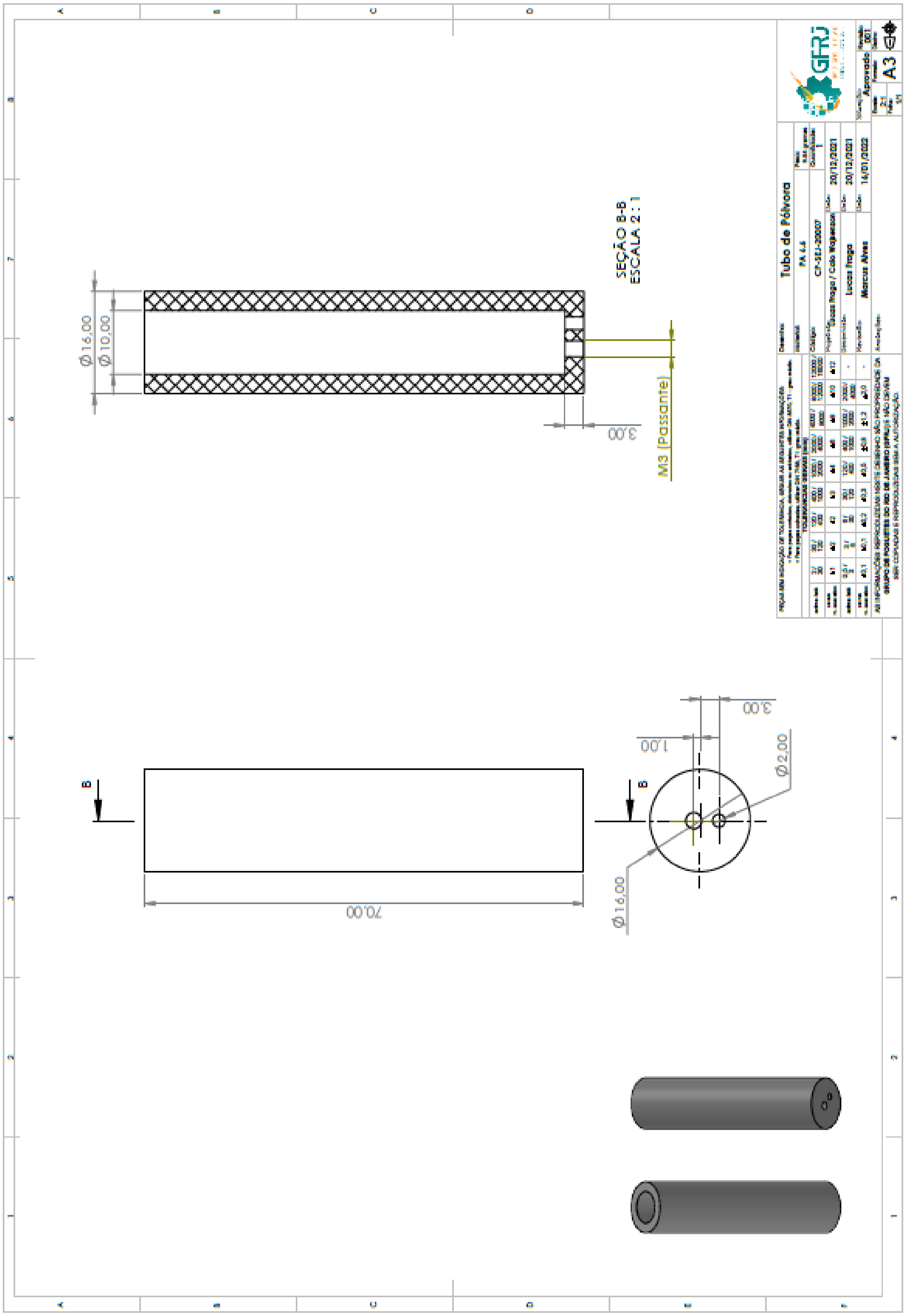

DETALHE A
ESCALA 3 : 1
4 Furos x Rosca M3
6 Furos x Ø 5,00
DETALHE C
ESCALA 3 : 1
0,55
1,30
5,00
2,00
3,00
Ø32,00
Ø24,90
Ø15,25
Ø26,00
22,55
24,55
29,55
30,85
39,43
50,17
53,67
5,24
SEÇÃO A-A
ESCALA 2 : 0.8
Guia do Pistão
A3

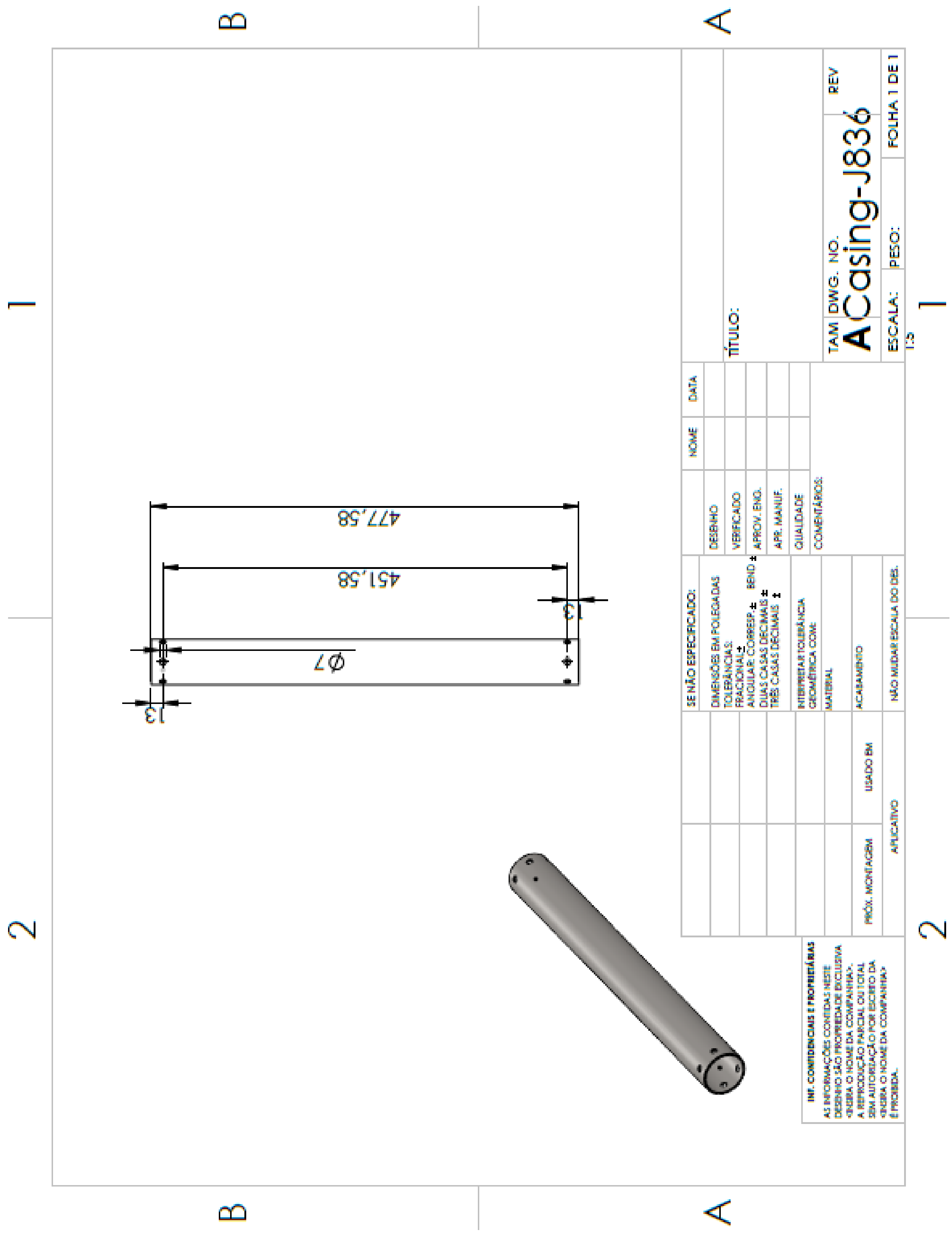

Suporte para o Cilindro de Gás
Alumínio 6061-T6
Lucas Fraga / Caio Weijenberg
Lucas Fraga
Marcus Alves
20/12/2021
14/01/2022
Aprovado
A3
SEÇÃO A-A
ESCALA 3 : 1
Rosca 3/8" - 24 UNF
4 furos x Rosca M3
Ø31,00
28,50
2,50
3,50
7,00
10,00
Ø26,00
A


Recipiente para Pólvora
Alumínio 6061-T6
Lucas Fraga
Marcus Alves
20/12/2021
14/01/2022
A3
DETALHE B
ESCALA 10 : 1
SEÇÃO A-A
ESCALA 3 : 1
1,45
2,40
2,35 X 76,88°
1,00 X 45°
10,92
15,92
18,32
23,32
Ø13,86
Ø2,00
Ø12,00

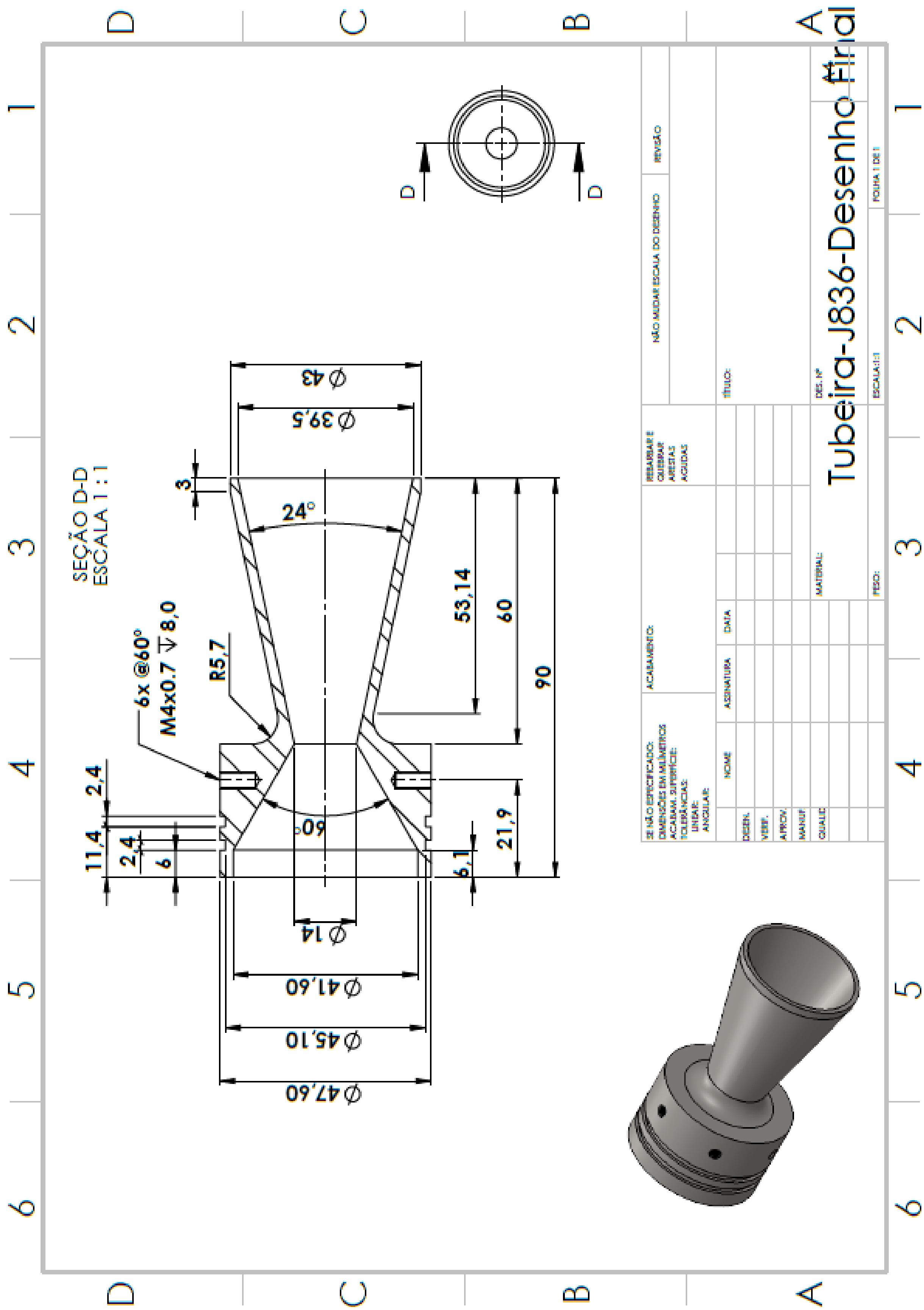


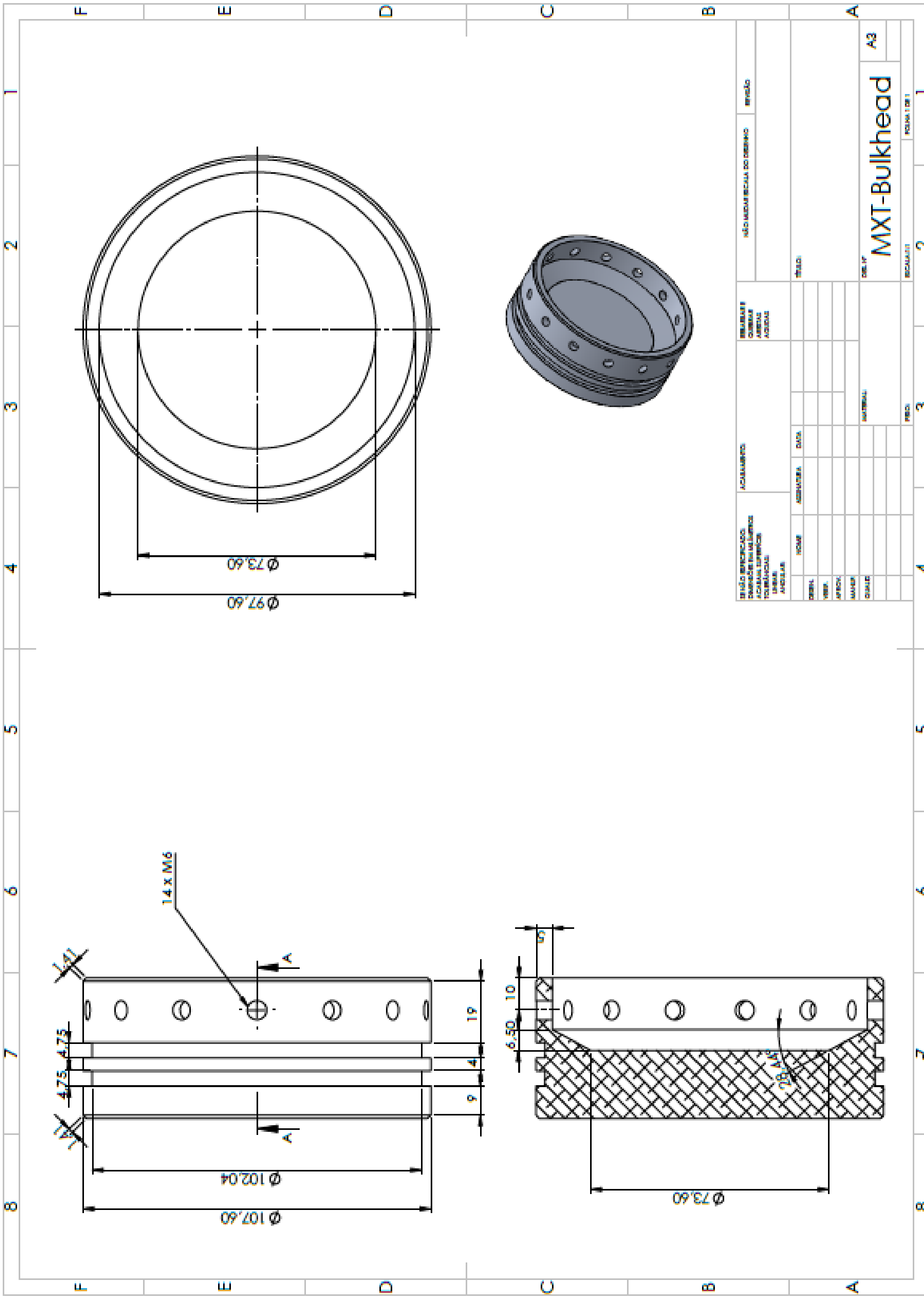
Ø20,00
Ø16,00
Ø6,00
110,85°
0,50 X 45°
1,00 X 45°
18,64
10,76
6,06
Pistão do Sistema de Ejeção
Alumínio 6061-T6
CP-SEJ-20004
Lucas Braga
Marcus Alves
20/12/2021
14/01/2022
Aprovado
A3

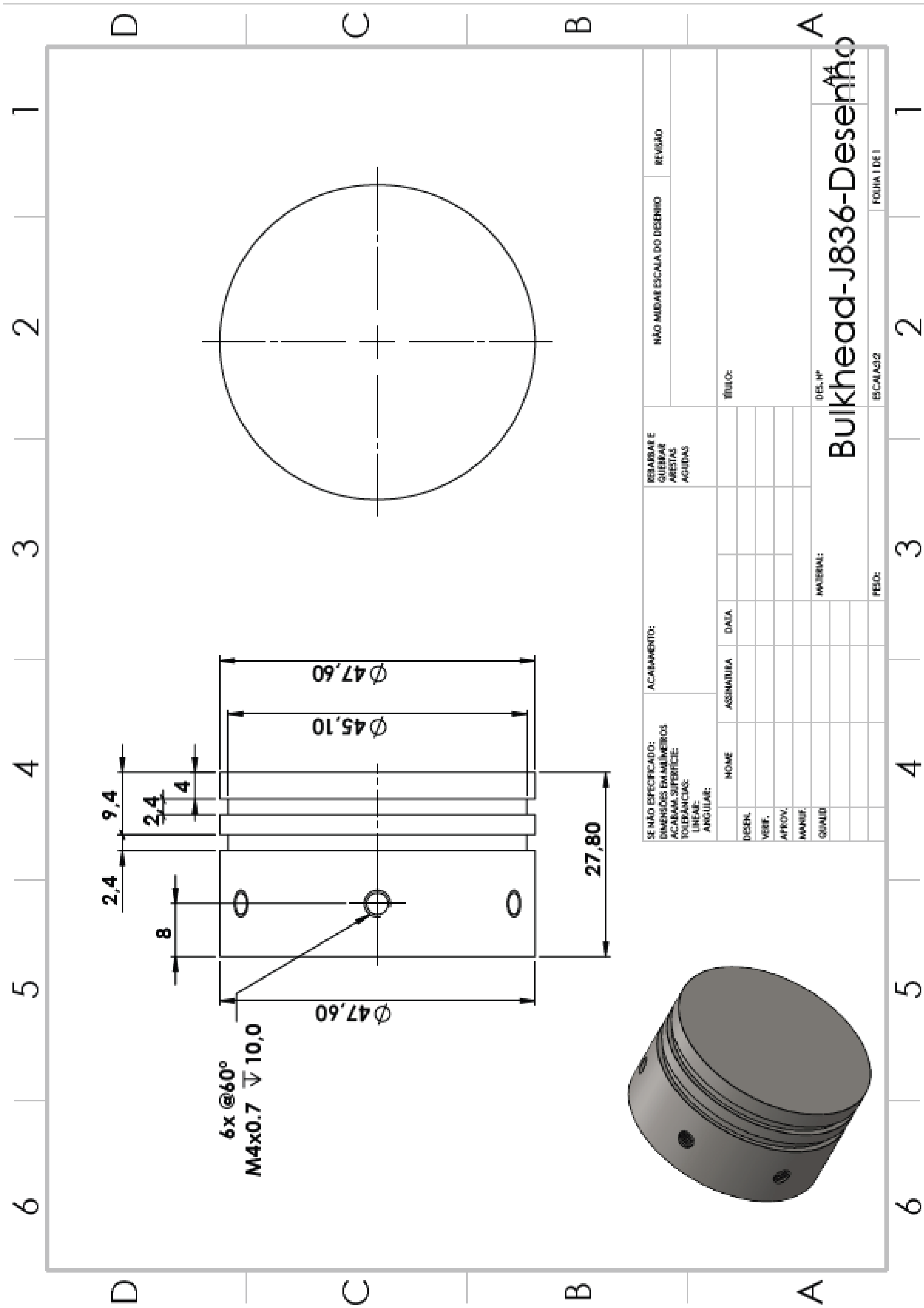

SEÇÃO B-B
ESCALA 2 : 1
Ø16,00
Ø10,00
3,00
M3 (Passante)
B
70,00
1,00
3,00
Ø2,00
Ø16,00
Tubo de Pólvora
A3



13
⌀7
451,58
477,58
13
SE NÃO ESPECIFICADO:
DIMENSÕES EM POLEGADAS
TOLERÂNCIAS:
FRACIONAL ±
ANGULAR: CORRESP. ± BEND ±
DUAS CASAS DECIMAIS ±
TRÊS CASAS DECIMAIS ±
INTERPRETAR TOLERÂNCIA GEOMÉTRICA COM:
MATERIAL
ACABAMENTO
NÃO MUDAR ESCALA DO DES.
NOME
DATA
DESENHO
VERIFICADO
APROV. ENG.
APR. MANUF.
QUALIDADE
COMENTÁRIOS:
TÍTULO:
TAM
DWG. NO.
REV
A
Casing-J836
ESCALA: 1:5
PESO:
FOLHA 1 DE 1
PRÓX. MONTAGEM
USADO EM
APLICATIVO
INF. CONFIDENCIAIS E PROPRIETÁRIAS
AS INFORMAÇÕES CONTIDAS NESTE DESENHO SÃO PROPRIEDADE EXCLUSIVA <INSIRA O NOME DA COMPANHIA>. A REPRODUÇÃO PARCIAL OU TOTAL SEM AUTORIZAÇÃO POR ESCRITO DA <INSIRA O NOME DA COMPANHIA> É PROIBIDA.
2
1
B
A


SEÇÃO D-D
ESCALA 1 : 1
6x @60°
M4x0.7 ↧ 8,0
R5,7
24°
60°
3
53,14
60
90
21,9
6,1
2,4
11,4
2,4
6
Ø 43
Ø 39,5
Ø 14
Ø41,60
Ø45,10
Ø47,60
D
D
SE NÃO ESPECIFICADO:
DIMENSÕES EM MILÍMETROS
ACABAM. SUPERFÍCIE:
TOLERÂNCIAS:
LINEAR:
ANGULAR:
REBARBAR E QUEBRAR ARESTAS AGUDAS
ACABAMENTO:
NÃO MUDAR ESCALA DO DESENHO
REVISÃO
NOME
ASSINATURA
DATA
DESEN.
VERIF.
APROV.
MANUF.
QUALID.
TÍTULO:
MATERIAL:
DES. Nº
Tubeira-J836-Desenho Final
A4
PESO:
ESCALA:1:1
FOLHA 1 DE 1


MXT-Bulkhead
A3
Ø73,60
Ø97,60
14 x M6
Ø102,04
Ø107,60
Ø73,60
SEÇÃO A-A
19
4
9
10
6,50
4,75
4,75


Bulkhead-J836-Desenho
A4
Ø47,60
Ø45,10
Ø47,60
27,80
9,4
2,4
2,4
4
8
6x @60°
M4x0.7 ⊽ 10,0
SE NÃO ESPECIFICADO:
DIMENSÕES EM MILÍMETROS
ACABAM. SUPERFÍCIE:
TOLERÂNCIAS:
LINEAR:
ANGULAR:
REBARBAR E QUEBRAR ARESTAS AGUDAS
ACABAMENTO:
NÃO MUDAR ESCALA DO DESENHO
REVISÃO
NOME
ASSINATURA
DATA
DESEN.
VERIF.
APROV.
MANUF.
QUALID.
TÍTULO:
MATERIAL:
DES. Nº
PESO:
FOLHA 1 DE 1

References

[1] Callister, William D., Jr.; Rethwisch, David G., *Ciência e Engenharia de Materiais: Uma Introdução*, 9thed., LTC, Rio de Janeiro, 2018, pp. 154, 665.
[2] Hibbeler, R. C., *Resistência dos materiais*, 7th ed., Pearson, São Paulo, 2012, pp. 1, 567.
[3] Mishra, D. P., *Fundamentals of Rocket Propulsion*, 1st ed., CRC Press, United States, 2020, pp. 1, 462.
[4] Sutton, George P.; Biblarz, Oscar, *Rocket Propulsion Elements*, 8th ed., Wiley, Unitec States, 2010, pp. 1, 764.
[5] Çengel, Yunus A.; Cimbala, John M., *Mecânica dos fluidos: Fundamentos e aplicações*, 3rd ed., McGraw Hill, Porto Alegre, 2015, pp. 1, 933.
[6] Çengel, Yunus A., Ghajar, Afshin J., *Transferência de Calor e Massa: Uma abordagem prática*, 4th ed., McGraw Hill, Porto Alegre, 1984, pp. 1, 409.
[7] RPA: *Rocket Propulsion Analysis* v.2.3.2 Standard Edition - Trial Version, Neunkirchen-Seelscheid, Germany.