GFRJ – ATOM II Project

Team 2 Project Technical Report for the 2019 LASC

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This report presents the technical aspects of the GFRJ's project for 2019 Latin America Space Challenge that is competing in the 3km AGL apogee with solid rocket propulsion system category. ATOM II, the launch vehicle, has a M-class solid motor that uses potassium nitrate and sorbitol as its propellant. Its structure is made of fiberglass and aluminum, with its aerodynamics calculations made with a team's own software, built on Python (programming language), in addition with some others open-source software. Its primary missions are the realization of a biological experiment, present inside a 3U Cubesat, in addition to succeed in launch and recover the rocket.

I. 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 has the opportunity to 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's 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.

Our team is organized by the following organizational chart:

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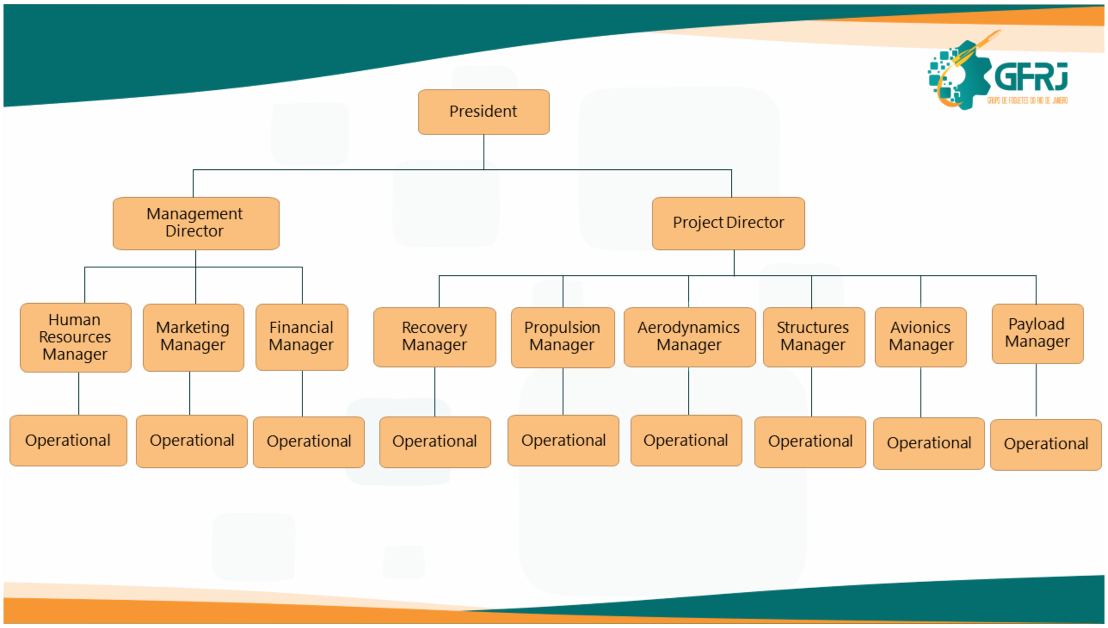
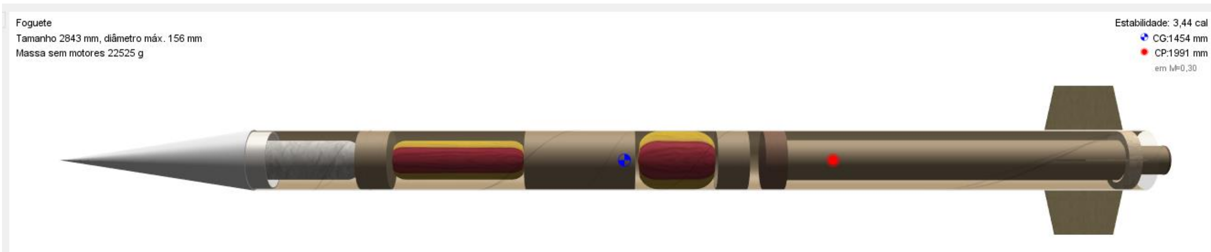


Figure 1: GFRJ's organizational chart

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 inside and outside of the group, to the meanings and make the action plan work integrated with all team.
That way, 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.

II. System Architecture Overview

ATOM II is a 2643 mm length, 156 mm diameter launch vehicle designed to reach 3km AGL, divided into four modules and equipped with a solid propelled student-built motor, a dual deployment recovery system with 2 altimeters, one COTS (StratoLogger) and one student-developed embedded system. The rocket will carry a 3D-printed 3U Cubesat, with a biological experiment. Its internal subsystems can be seen at Figures 1 and 2.



Figures 1 and 2, ATOM: illustrative and schematic cuts

A. Propulsion Subsystems

The ATOM's rocket motor received the name "MXT" and uses solid propellant. MXT was projected in a simple and robust way with the objective of minimizing the number of parts and being as practical as possible. These parts, shown in Figure 1, and its materials are as described below:

- Chamber Combustion: Location that holds the propellant and where the ignition occurs. It is made of Aluminum 6063-T5.
- Nozzle: Where the gases from the combustion chamber flows. It is made of Stainless Steel 316.
- Bulkhead: It is on the opposite side of the combustion chamber with respect to the Nozzle and aims to seal one side. It is made of Aluminum 6061 T6.
- O-Rings: Located in small gaps in the Nozzle and Bulkhead, its function is to ensure sealing. It is made of Nitrile.
- Bolts: Attach the Nozzle and Bulkhead to the combustion chamber. They are made of Carbon Steel, and have resistance class 12.9
- Propellant: It is rocket fuel, divided into 5 grains segments, each containing 150mm in length, 97mm in diameter and with a circular hole of 40mm in diameter. Its composition is called KNSB.
- Inhibitors: It serves to inhibit burning and it involves each fuel segment. It is made of 40kg paper.
- Thermal protection: It is used between inhibitors and the combustion chamber. It serves to absorb part of the thermal energy from propellant burning. The material used for thermal protection is EPDM.

Figure 2. Exploded of MXT, ATOM II's motor

1) The propellant:

MXT uses KNSB as propellant, which is composed of Potassium Nitrate (KNO3) as oxidizer and Sorbitol as combustible (C6H14O6).

The KNSB was chosen because of its ease of manufacture, its curing time is long enough for the molding procedures to be performed. The performance generated by KNSB is satisfactory for the purpose of the rocket.

Using the RPA software, the conclusion reached for the most efficient Oxidant/Combustion rate is 1,883. KNSB has the ideal features as it shows in Table 1. To ensure the quality of the propellant used, tests of burning rate (Figure 3) and pH were made, which approached the theoretical value.

Table 1. KNSB ideal features

Molecular Weight (g/mol)	182,2
Melting Point (°C)	110
Density (g/cm^3)	1,489
Enthalpy of Formation (kJ/mol)	-1353,7

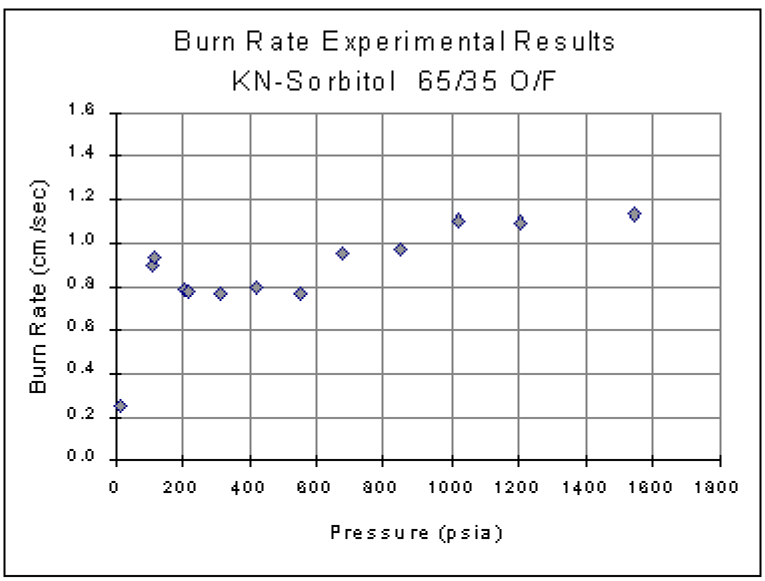


Figure 3. KNSB Burn Rate Experimental Results

2) Sizing and Theoretical Data:

- Chamber Combustion: It has 107.95mm internal diameter, the available length for segment accommodation is 770.5mm. The available internal volume for the propellant is 0,0062866134886 m³, equivalent to 6,28661348859999958 liters;
- Nozzle: It has 27mm diameter in the throat, angle 30 degrees to the convergent and 12 to the divergent;
- Propellant: The propellant theorical data can be seen in Table 2.

Table 2. Propellant Theoretical Data

Length	150mm
Diameter	97mm
Core Diameter	40mm
Number of segments	5 grains segments
Total Weight	7,621542321 kg
Density	1,6569 g/cm^3

The motor's final theoretical data is showed in Table 3, and the graphic of the theoretical thrust can be seen at Figure 4. Later, in the Project Test Report Appendix, the MXT's experimental data collected from the Fire Test can be seen, together with its comparation with the theoretical data.

Table 3. Final Theorical Data

Average Thrust	2489,089 N
Maximum Thrust	2651,423 N
Total Impulse	9392,519 N
Specific Impulse	125,675 N
Maximum Pressure	500 psi

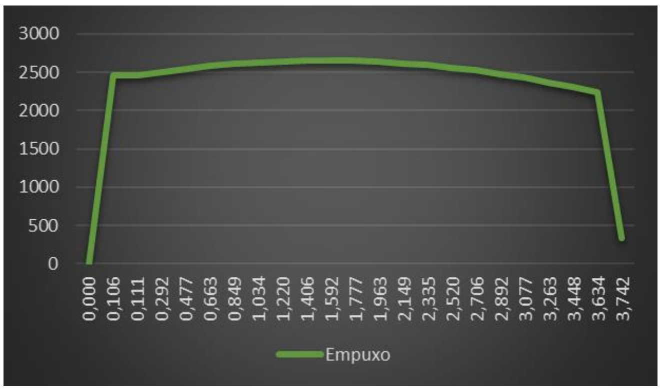


Figure 4. Graphic of Theoretical Thrust

3) Structure:

After the theoretical dimensioning, it is possible to define the aspects of the project construction. For the combustion chamber the material chosen was Aluminum 6063 T5 because it is light and sufficiently resistant to the exposed conditions, according to the calculations performed.

To define the wall Thickness of the combustion chamber, the following expression was used:

$$f = \frac{2\,\sigma\,t}{P\,r}$$

f is the safety margin; σ is the yield point of the material (which varies with temperature); t is the wall thickness; P is the internal pressure e r is the average diameter.

The yield point of Aluminum 6063 T5 is 105 Mpa.

Tests performed with 1 grain segment wrapped in inhibitor free-burning conditioning lasting approximately 30 seconds inside an unsealed tube of the same material and wall thickness of the project, found that the internal temperature at the position where the grain segment was located reached approximately 207 °C and the outside surface temperature reached 80 °C. The test allowed us to verify the heat transfer at ambient pressure to this aluminum alloy.

The wall thickness of the chamber combustion, respecting the safety margin is 3,175mm.

In addition, for fixing the nozzle and bulkhead to the combustion chamber, 28 bolts with strength class 12.9 are placed, 14 at each end of the chamber.

B. Aerodynamics Subsystems:

For stability analysis, the aerodynamic project used software as OpenRocket (Figure 4) and RockSim, that are based on Barrowman Equations, while the trajectory analysis was made on a student-developed program, named AeroPy GFRJ, written in Python and validated with others open-source programs. This program uses Newtonian dynamics and numeric methods to determine the flight path and flight characteristics, such as maximum velocity, launch rod clearance velocity, apogee and maximum acceleration.

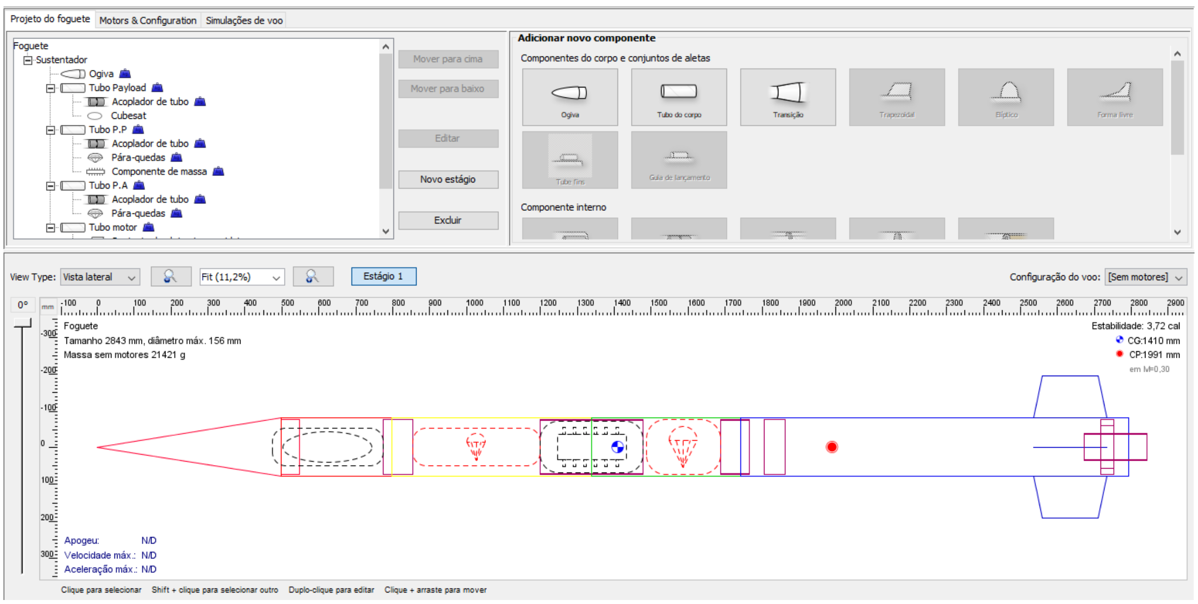


Figure 4. Software Open Rocket, where stability was analyzed

The student-developed program analyzes the project with 2 degrees of freedom (DoF), and was divided into 3 phases: thrusting, coasting and descending.

From Newton's 2nd Law, we have the following forces acting on the rocket:

$$\vec{F} = \vec{T} + \vec{D} + \vec{P} = m \times \frac{d\vec{v}}{dt} \qquad (1)$$

Where:

P is the weight of the rocket, given by $P = m \times g$, where g is the gravity acceleration, assumed -9,81 m/s².

T is the rocket thrust, that was obtained through the T x t curve of the static test of the rocket motor, and integrated into the program through a regression of order 18, in order to get a good approximation of the real curve at every instant dt.

D is the drag force.

Given that, the rocket body is nearly axis-symmetric, the assumption of the angle of attack (α), being zero leads to the assumption that lift (L), be also zero. But other forces – the drag (D), the thrust (T), and the weight (P) are variables that must be modeled with enough accuracy. Two forces, T and P, are variable only during the thrusting phase, but D is variable during all three phases.

The drag force (D) is given by:

$$D = \frac{1}{2}\rho C d A v^2 \tag{2}$$

Where:
A is the cross-sectional area (i.e. the frontal area) of the rocket body
V is the velocity of the rocket with respect to the air
ρ is the density of the air, in which we consider variable with altitude according to the equation:

$$\rho = \rho_o \times 0.9^{\frac{h}{1000}} \tag{3}$$

That is an approximation of U.S. Standard Atmosphere.

The drag coefficient (C_d) was obtained as a function of the Mach number, extracted from the Aerolab software (Figure 5) and integrated into the code in an analogous way the others used for the thrust force. With that, the C_d varies throughout the ascending trajectory.

Aerolab is a free lightweight CAD application designed specifically for carry out aerodynamic simulations that can be useful for estimating drag, lift and stability of rockets at zero angle of attack in the velocity range from 0 to 8 Mach. Based on user-defined rocket dimensions and mass properties, the tool is also able to calculate the center of gravity and inertial moments around pitch/yaw axis and roll axis.

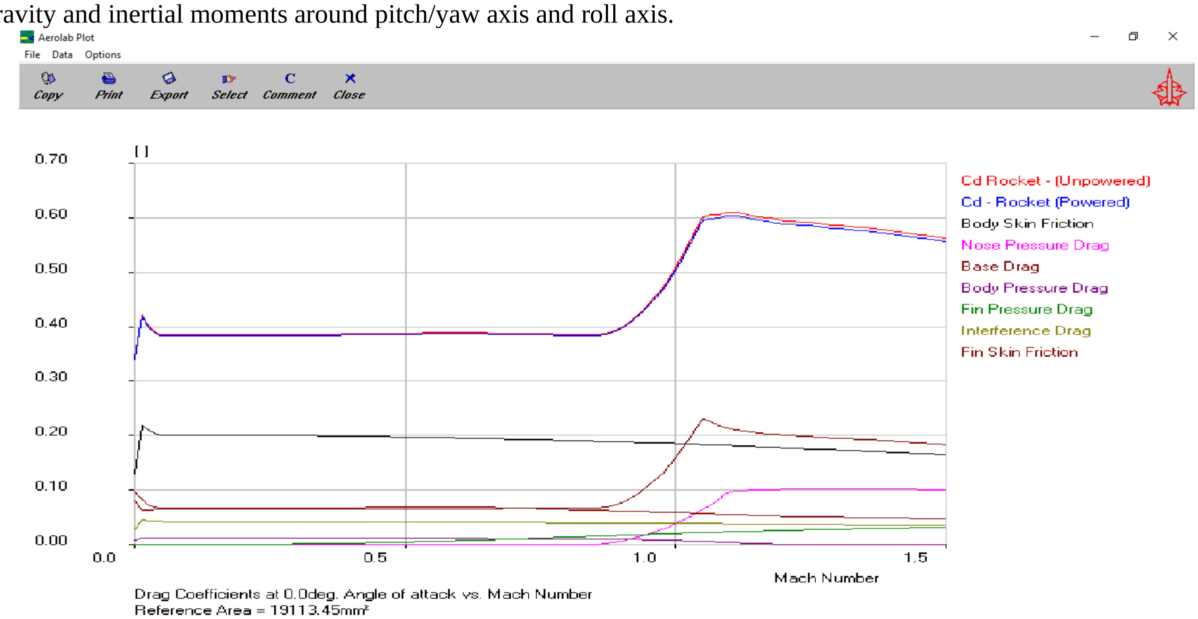


Figure 5. Aerolab, CD x Mach number Curves

During liftoff, we have:
L been the length of the launching rod, and d the distance traveled, the liftoff phase occurs while d ≤ L:

$$gx = g\cos\alpha\sin\alpha \tag{4}$$
$$gy = g\cos\alpha\cos\alpha \tag{5}$$

When d > L:

$$gx = 0 \tag{6}$$
$$gy = g \tag{7}$$

During thrusting phase, T > 0, we consider the mass variation according to the equation:

$$M_i = M_{i-1} - t \times \frac{M_P}{t_q} \tag{8}$$

Where M is the total mass of the rocket, Mp is the mass of the propellant, and tq is the engine burst time. During coast phase, T = 0, we have only drag and weight acting on the rocket.

We also consider the temperature variable according to International Standard Atmosphere (ISA) and sound speed, using regression methods to integrate into program.

To modelate the descending phase, A is the parachute area, and drag coefficient is the C_d from parachute. Wind velocity is very important in this phase. To estimate the wind velocity, we adopt the following wing profile:

$$v_w = v_o \times \left(\frac{y}{y_o}\right)^{\beta} \tag{9}$$

Where, v_o is the wind velocity at height y_o, v_w is the wind velocity at height y. And β is the Hellmann exponent that depends on the local properties.

The Figure 6 shows the altitude x wind speed, varying the Helmmann exponent:

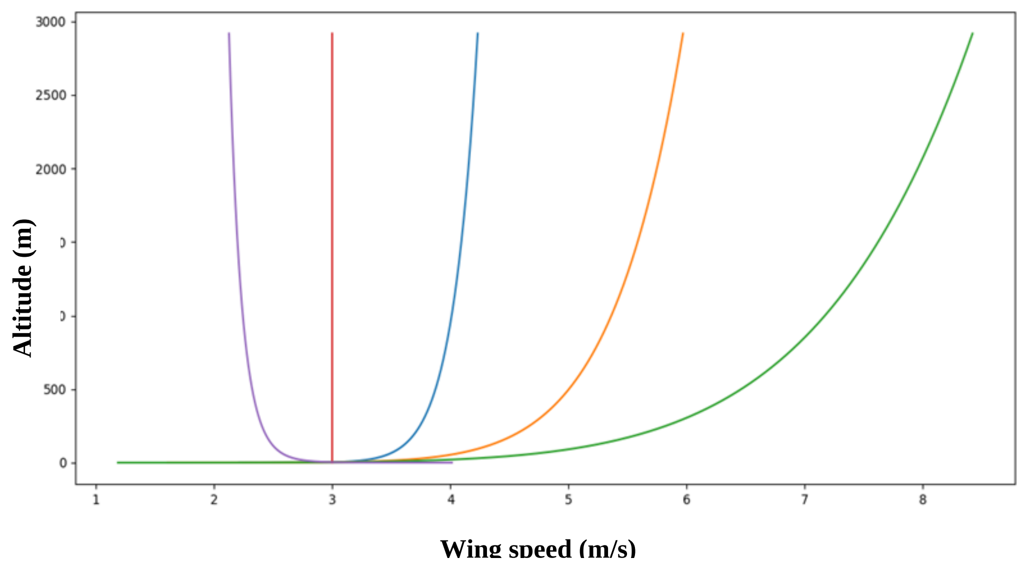


Figure 6, altitude x wind speed

Based on this approach, it was possible to predict the approximate distance from base where the rocket land, the velocity of rocket at ground, and the time since apogee until ground, considering two parachutes: the first one is activated at apogee, and the second one at 400 m of ground.

According to our code, the last simulations after some changes ATOM is expected to reach:

- Launch rod clearance velocity: 24.7 m/s
- Maximum acceleration: 9.26 G
- Maximum velocity: 261 m/s
- Predicted apogee: 2850 meters

Considering a wind speed of 4 m/s, β = 0.1, local temperature 24.85°C, 5 degrees angle with vertical.

There are some variations in predicted apogee between some commercial programs (2560m to 3200m), we notice that the main difference is due to distinctions at drag curve. Some CFD tests were executed in order to compare C_d for some Mach numbers.

The following figures show the charts for ATOM project calculated in GFRJ AeroPy code:

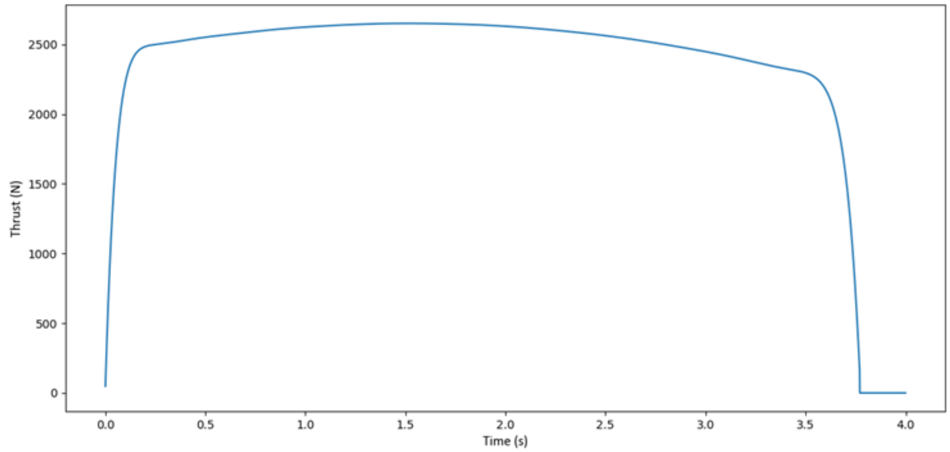


Figure 7. Thrust x time curve

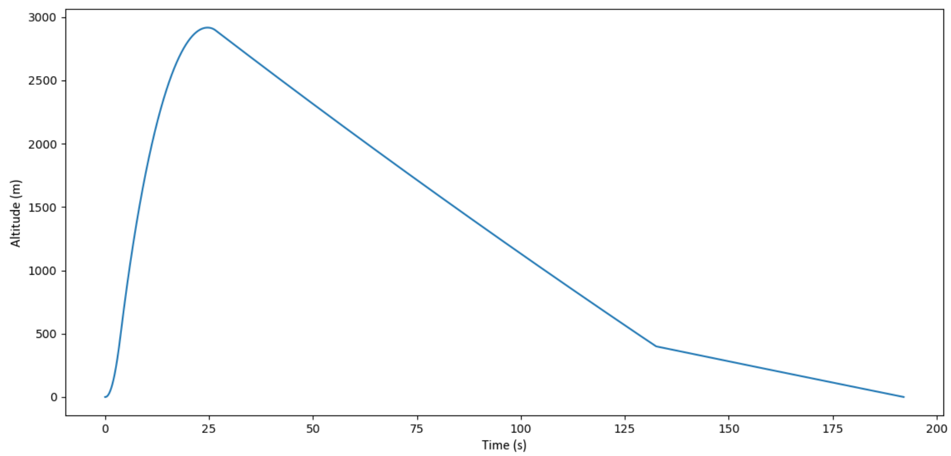


Figure 8. Altitude x time curve

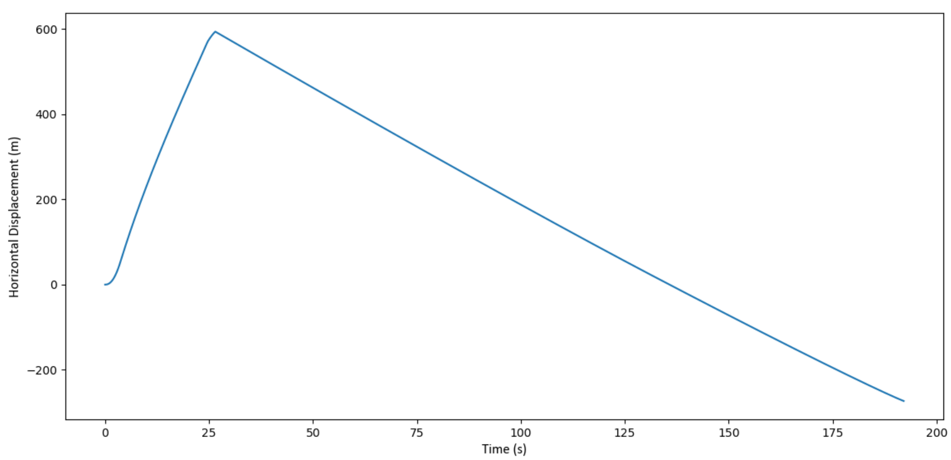
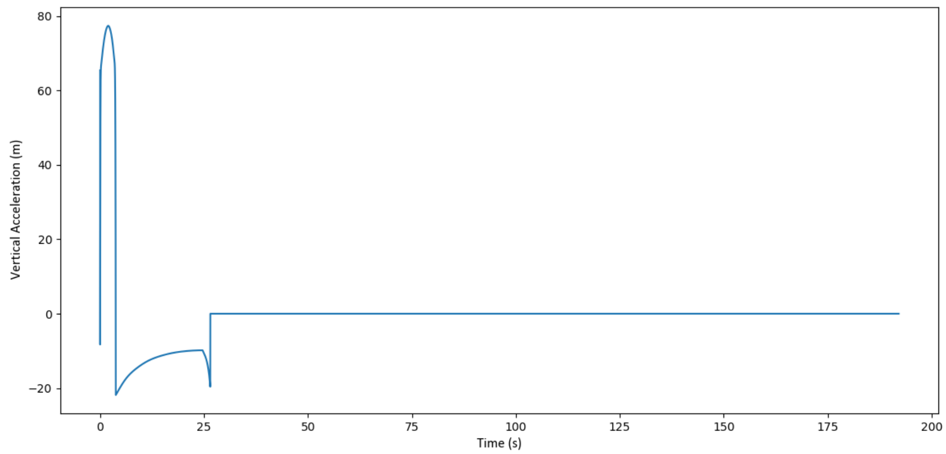
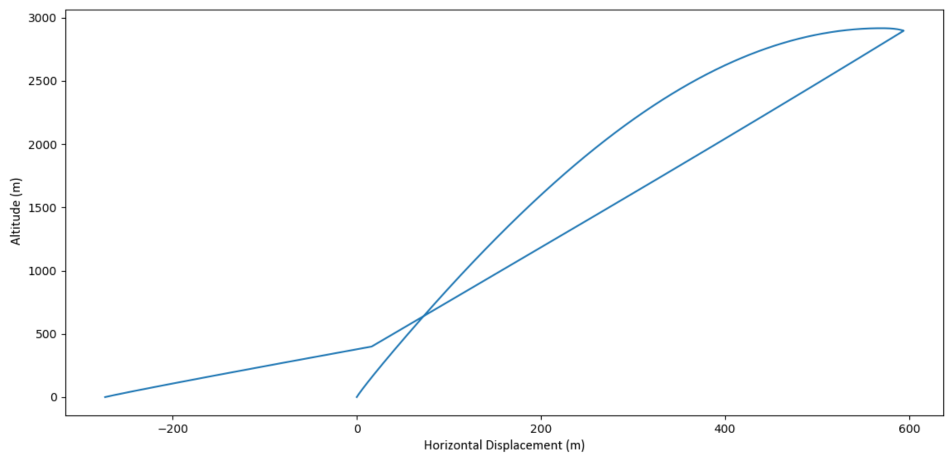


Figure 9. Horizontal displacement x time curve





Figures 10 and 11, Vertical acceleration (m/s²) x time(s) and Altitude x horizontal displacement curves

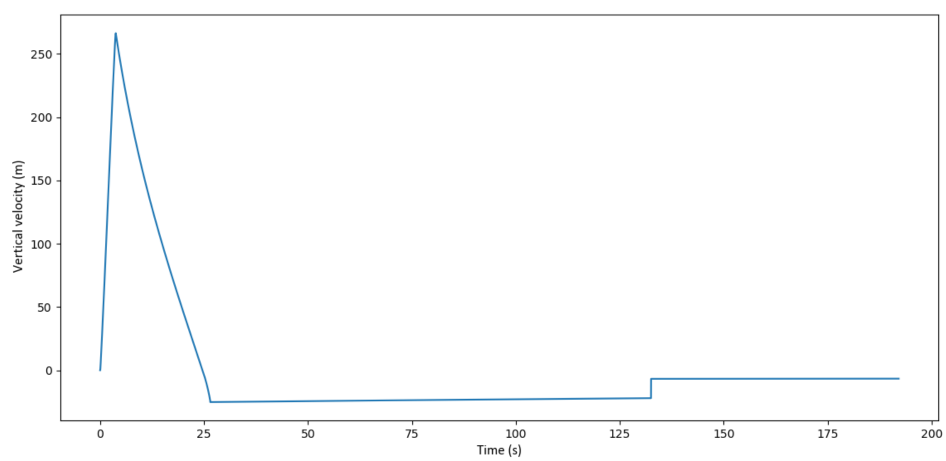


Figure 12, vertical velocity (m/s) x time(s) curve

C. Structures Subsystem:

Atom's structure has its fuselage almost entirely constructed with fiberglass. This choice was made because it has a high strength, low weight and it costs less than other materials, being more viable for our team. The structure is divided into four modules, which are:

- The lower one, for the Propulsion Subsystem;
- The second one, for drogue parachute;
- The third one, for the main parachute;
- The upper one, for the Payload Subsystem, linked to the conical nose cone.

The Avionics' casing (Figure 8) is the coupler between the two parachute modules, and its top and bottom is made of aluminum. These two sides are bounded by four threaded bars. In its center, we have all the electronics components for the avionics subsystem, that is responsible for the electrical signal that deploys both parachutes. This coupler has 'U' clamps in its top and bottom, where the parachute ropes from drogue and main parachute are tied, so that no part gets lost during the recovery stage of the rocket launch.

Figure 8. Avionics' casing, that works as coupler for both recovery modules

In the other side of both recovery modules, we have another two couplers (Figure 13) made of aluminum with clamps on its top with the same purpose of the others.

Figure 13. Aluminum couplers from other side of recovery modules

The fiberglass tubes were handmade, using 150 mm diameter PVC tubes as mold. The lamination of the nose cone was also handmade, using a wood mold, shown in Figure 6, manufactured by one of our sponsors in a router CNC machine. The nose cone's tip was machined in a metal lathe, using aluminum 6351-T6 (Figure 7).

Figure 6. Wood mold to laminate the nose cone

Figure 7. Nose cone's tip, made of aluminum 6351-T6.

The motor is bounded to fuselage in the lower module by nylon rings, that work as centering rings, which were chosen due to heat transfer characteristics. This module also has the four fins, also made of fiberglass.

Figure 7. Motor centering rings, made of nylon

D. Avionics Subsystems:

The avionics project consists in an embedded system that obeys the following data flow diagram:

External entity → Processing → Data storage and streaming

1) Operation:

The student-developed embedded system is composed by the following sensors, that works as the external entity (the first item of the data flow showed above):

- Barometer and thermometer (BMP085)
- 3-axis Accelerometer (ADXL345)
- Gyroscope (L3G4200D)
- 3-axis Magnetometer (HMC5883L)

These four sensors mentioned above are integrated into the IMU named GY-80.

- GPS coordinates (GPS NEO-6M)

This external entity is controlled by an Arduino Pro Mini, containing a ATmega328P microcontroller, which is supplied by a 9V battery in a PCB (Printed Circuit Board), whose schematic can be seen at Figure 6. This microcontroller is the responsible for processing sensor's data (the middle item of the data flow) and send some to the MicroSD module, responsible for the data storage, and some the RFM95 module, responsible for the data streaming. Both these last modules compose the last phase of the data flow.

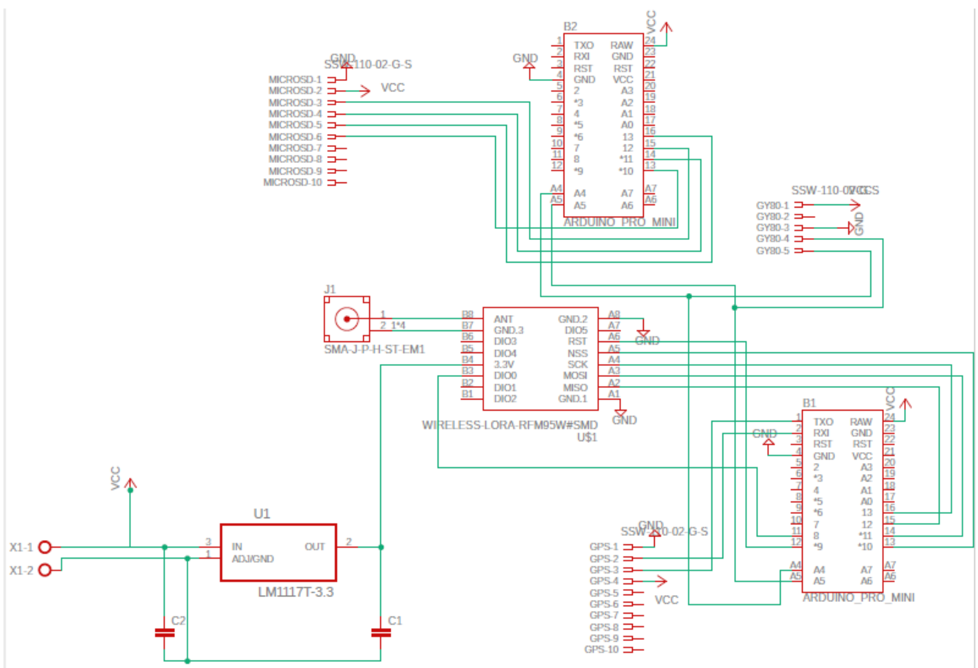


Figure 6. GFRJ's Avionics Schematic

Therefore, in flight, besides collecting and transmitting data, the system works to eject the parachutes. Thus, both altimeters, the StratoLogger, which is our COTS flight computer, and the student-developed embedded system, collect and process data to provide an electrical signal to the relay board at the apogee and at 400m AGL, to ignite the squibs and open the drogue parachute and the main parachute, respectively.

In this sense, the StratoLogger, which is independent of PCB system, is supplied by a 9V battery as well. Furthermore, the data signal of telemetry comes to the base station, which is a computer, on launch area to stay visible for the team in a graphic software called LABVIEW, providing data of each parachute activation, altitude per time, packet loss percentage (PLP) per time in rocket telemetry and received signal strength indication (RSSI) per time.

The 2 RFM95 LoRa, one inside the rocket and the other present in base station, works in 915MHz. The antennas of radio and GPS module are fixed in different parts of the rocket, out of avionics case, to have less signal attenuation induced from the aluminum couplers. Furthermore, the reception data in the base station is done by a Yagi antenna, shown in Figure, which have 14dBi of gain.

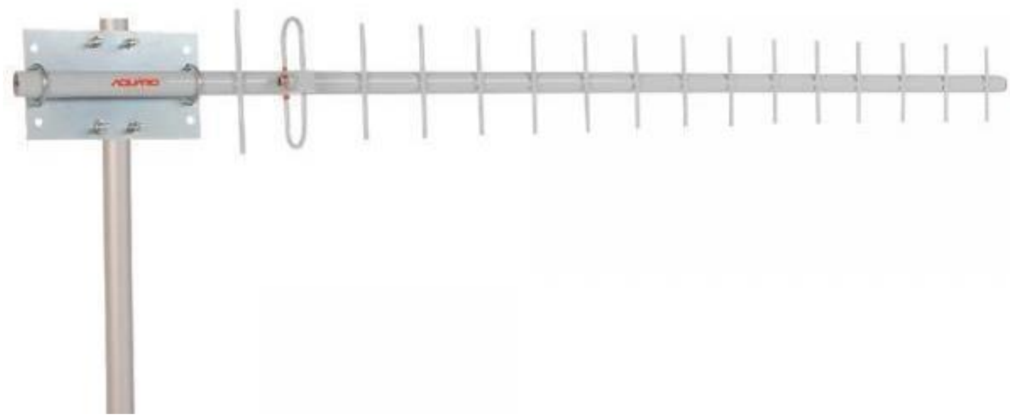


Figure. Yagi antenna

Thus, the GPS antenna is fixed in a location where is the drogue parachute, which is the smaller one, as can be seen at Figure 7. However, the LoRa antenna is fixed up there, in the same location where is main parachute, which has an orange representation. Then, both antennas are carefully involved by parachutes, so they won't be ejected.

Figure. Avionics location between the two parachute casings

2) Tests:

Avionics telemetry tests were done with the base station on the ground and with 100m distance of a twelve-floor building, which was used to pull the avionics' casing from ground to last floor, with a considerable acceleration, while we were pointing our Yagi antenna (Figure) to the casing, analyzing the signal of telemetry curve, as well as RSSI and PLP already mentioned, provided by LABVIEW on computer.

E. Recovery Subsystems

In this project will be used two parachutes, one with smaller area and other with larger area, respectively called drogue and main. The use of two parachutes is necessary because the drag force is proportional to the area of the parachute, and the use of a smaller parachute at the apogee will prevent the rocket has a very large fall radius. Thus, the drogue parachute must be ejected at rocket's apogee, while the main parachute must be ejected at approximately 400m AGL. It will ensure that the rocket returns to the ground at a safe speed. Parachute ejection will occur through the explosion of an exact quantity of powder. It is also important to note that the two parachutes will be ejected independently, due to an electrical signal from the avionics subsystem, each one within its own compartment and with its own ejection system.

1) Parachute:

- Main:

The Main was produced by the team itself, using the high tensile Ripstop nylon 045 fabric and has flat circular geometry, with an area of 12.9 m² distributed in 8 gores. In addition, it has a spill hole with 0.65 m diameter to reduce oscillation during fall. Then, in this project will be 8 suspension lines made of Kevlar 600lb, each 4.9 m length. The Main is lodge in the third module of the ATOM and will be ejected at a height of 400m AGL, and has two anchorages (1000lb Kevlar cable), one in the lower coupler and other in the avionics casing.

- Drogue:

The Drogue was produced by the team itself, using the high tensile ripstop nylon 045 fabric and has a flat circular geometry, with an area of 0.65 m². In addition, it has a spill hole just like the Main, but with 0.15 m diameter. This parachute will be ejected at the apogee, in other words when the speed is zero, so the force on the Drogue lines is lower than on the Main's, which is ejected during fall, so will be use 6 suspension lines made of Kevlar 600lb, each 1.23 m length. The drogue is lodge in module 3 and like the Main has two anchorages (1000 kb Kevlar cable), one in module 4 coupler and other in avionics casing.

- Calculation of the parachute area:

The idea is to make the rocket fall on the ground with a constant velocity, so we need to have the vertical component of the Resulting Force (Fr) of the rocket to be zero, so the Rocket Weight (P) must be equal to Drag Force (Fa). Thus, we have:

$$Fa = \frac{1}{2}\rho v^2 A C_d$$
$$P = mg$$
$$Fr = 0$$
$$P - Fa = 0$$
$$P = Fa$$
$$mg = \frac{1}{2}\rho v^2 A C_d$$

Then,

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

Considering the Main:

- v = Fall Velocity = 8,5 m/s,
- $C_d =$ Drag Coefficient= 0,75 (because of the geometry parachute),
- m = Mass = 35 kg,
- g = Gravity = 9,80665,
- $\rho =$ Air Density = 1,29 kg/m³,
- Cs = Safety Factor = 1,2.

Thus, the Main area is 12,9 m². Realizing the same procedure to the Drogue and using fall velocity like 38 m/s, we found 0,65 m².

- Line sizing:

The suspension lines length is given from the diameter of the parachute, so:

$$L = 1{,}2D$$

Considering:

- D = Parachute diameter,
- L = Line Length.

2) Ejection System:

The parachutes will be ejected independently, but both will use the same system, that consists in the explosion of an exact quantity of powder, which will be pressurized inside a compartment and will be triggered from a squib. In general, the ATOM avionics has two altimeters, which at an exact height will generate an electrical signal to activate squib and trigger powder. The powder ativation will break the nylon shear pins that hold the rocket modules. In the case of the Drogue (which will be ejected at the apogee) will be separate the lower and the second modules, and in the case of the Main (activated at 400m above the ground), will be separate the third and the upper module. In addition, to ensure the physical integrity of the parachutes, a NOMEX fabric will be used to prevent parachutes from being burned.

F. Payload Subsystems

Payload is the experiment that a space shuttle carries within it. For the LASC competition, GFRJ's Payload system will be composed of: a 3D printed Cubesat made of PETG material and consisting in three cubes of 10 cm each side; 18 sample tubes of cyanobacterias; two casings for the sample tubes in cube shape of 8 cm each side and made of polyethylene; 1 structure made of polyethylene to retain the methane gas produced by the samples; a MQ-4 sensor to analyze the methane production; 1 Arduino; 1 battery; MicrosSD, GY-80 sensor to capture height, acceleration and pressure measures. Total weight of the Payload system is estimated in 8.81849 lb.

III. 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. Telemetry (3)

At the end of the propellants burning, the rocket starts to fly only on its inertia. It continues to increase in altitude even though its velocity is decreasing due to gravity and drag.

While the vehicle flies, its avionics and payload are storing and transmitting data. The avionics are calculating its altitude, velocity and acceleration that will then be used to activate the recovery systems and validate the flight parameters. The payload on the other hand while the filming the whole flight is also receiving a much larger amount of data from its cosmic ray detector, as on higher altitudes there are more and more particles to be detected.

E. Drogue parachute deployment (1)

The speed gradually decreases, until the rocket reaches the highest spot on its trajectory. As it reaches the apogee, the free flight phase comes to end.

At the apogee and the first few moments of fall the avionics deploy the drogue parachute. The parameters received and transmitted by the avionics will indicate the beginning of the descending motion.

The fuselage and ropes from the first recovery system suffer a peak tension, as it breaks the fall, and the apogee phase ends.

The beginning of the fall is also the beginning of the Fall Directioning phase.

In this phase the vehicle starts its descending motion as the drogue parachute acts against its increase of speed without letting the wind carry the rocket too far sideways.

F. Main Parachute deployment (2)

After falling for about 2.5 km 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.

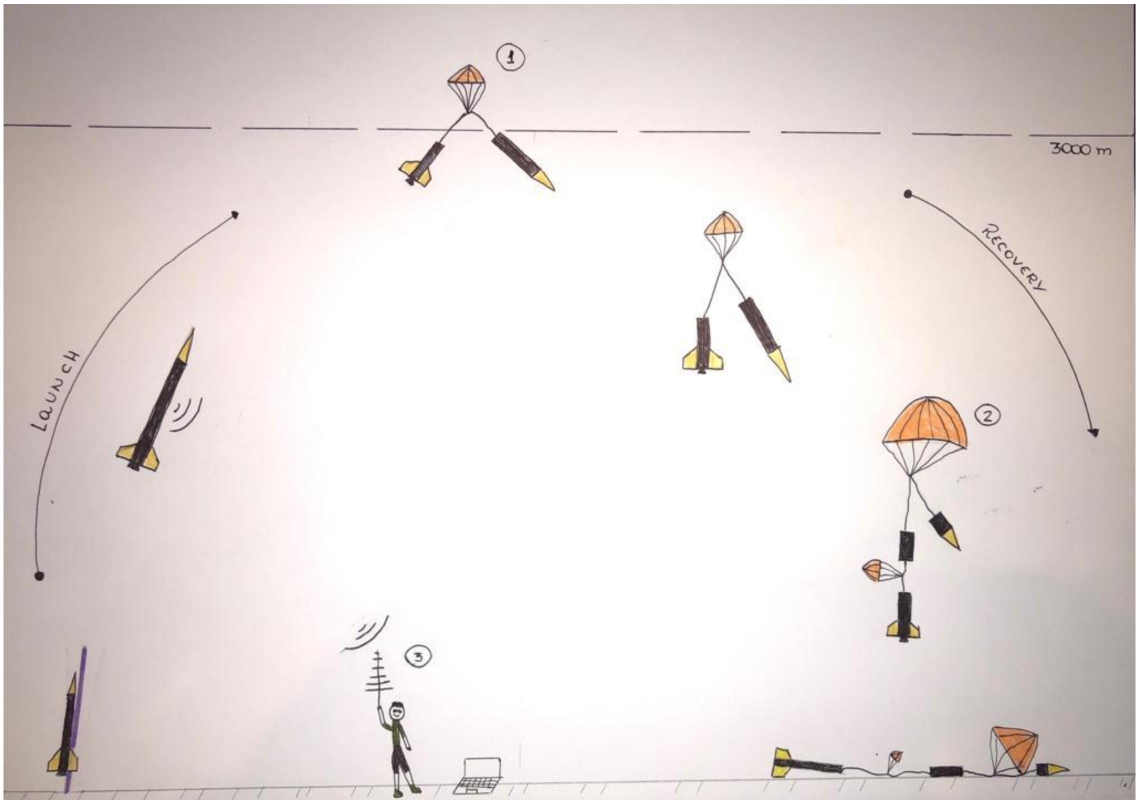


Figure. Flight scheme from launch to landing.

IV. Conclusions and Lessons Learned

This project was a huge challenge for the team since its beginning because of its difficulty and complexity. First, the team suffered a lack of funds to get the project started, causing our team to work around the problem, making us grow in economic strategy. Furthermore, the handmade manufacturing fumbled the execution of the project, taking an amount of time to get a technical experience to execute it, making some mistakes in this learning process.

The team also made a software of flight simulation by themselves, which, undeniably, brought technical troubles and a lot of learning. In addition, the team, despite having a considerable power of research, had problems to hone the avionics codes, causing delay to technical tests. Undeniably, the short project schedule and social disorders made the team run against time. By knowing all the technical problems which was overpassed to execute the project, our team decided to get hard in technical reports, being the most didactic possible to pass the technical knowledge to future members, to current members that couldn't participate at all times and to solve the waste of time and a lot of mistakes provided by the lack of technic. Therefore, several conclusions were made, all by overcoming the difficulties, teaching the team to transmit the knowledge obtained together, as was said before.

V. Weights, Measures, and Performance Data Appendix

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (mm):	2670mm	
Airframe Diameter (mm):	156mm	
Fin-span (mm):	436mm	
Vehicle weight (kg):	26kg	
Propellent weight (kg):	8kg	
Payload weight (kg):	4kg	
Liftoff weight (kg):	32kg	
Propulsion Type:	Solid Fuel	

Propulsion System: (Motor, Letter Class, Total Impulse)

Solid Motor: 4,95kg of Potassium Nitrate and 2,66kg of Sorbitol, M class, 9142,20 Ns.

Predicted Flight Data and Analysis

The following stats should be calculated using rocket trajectory software or by hand.

	Measurement	Additional Comments (Optional)
Launch Rail:	LASC Provided	
Rail Length (mm):	6000mm	
Liftoff Thrust-Weight Ratio:	8.19	
Launch Rail Departure Velocity (meters/second):	24.7 m/s	
Minimum Static Margin During Acceleration	1.6	Between rail departure and burnout.
Maximum Acceleration (G):	9.26G	
Maximum Velocity (meters/second):	261 m/s	
Target Apogee (m AGL):	3000 meters	
Predicted Apogee (m AGL):	2850 meters	

VI. Project Test Reports Appendix

A. Recovery test

Recovery tests were conducted on soil, as well as using lower scale flights of a rocket, and were enough to validate all the necessary features that this subsystem is responsible for.

Soil tests were conducted to assure the actuation of the squib and verify that the quantity of powder used was indeed enough so the parachutes would eject, without damaging themselves or the fuselage. This test was divided into 4 steps: storing of the powder in its recipient; ignition of the squib; pressurization of the powder compartment and, finally, ejection of the fuselage part along with the parachutes.

Ejection tests on flight were executed with the intentions of testing our altimeter, bought in the market, as well as simulating parachute ejections on close-to-real conditions. Two flight tests were conducted, with an estimated apogee of 3000 ft. On both occasions, recovery systems functioned perfectly.

As described on item II.E, our recovery systems contain a double redundancy. Our altimeters are responsible for activating the relay, with redundancy, which will ignite the squib, ejecting the parachutes in the ideal height. It is important to emphasize that the two parachutes will eject in distinct moments.

Figure 13. Backup recovery system illustration

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 below shows a comparison between the theoretical thrust curve and the one obtained in the test.

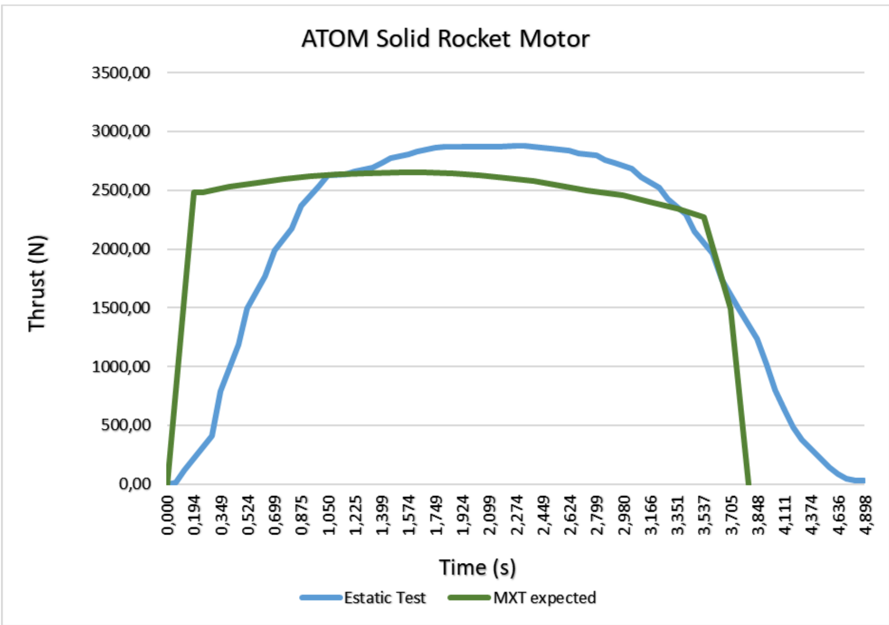


Figure 14. Static test data x Projected data

The motor was validated successfully, as the parameters measured are within designed limits. Therefore, MXT is ready for launch. A comparative table of practical and theoretical values can be seen below.

Table. Motors theoretical x experimental values after tests

Description	Theoretical Value	Practical Value	Variation
Propellant Mass	7622 g	7743 ± 1 g	+ 1,6 %
Propellant Grain Density	90%	91,2 ± 0,6 %	+ 2 %
Total Impulse	9392,52 Ns	9142,10 ± 10 Ns	- 2,77 %
Maximum Thrust	2651 N	2878 ± 10 N	+ 8,94 %
Specific Impulse (Isp)	125,7	120,4 ± 0,2	- 4,38 %

C. Hydrostatic test

The MXT casing, with the intents of testing and assuring the water tightness, even while coupled to the bulkhead, has been submitted to a pressure 100% greater than its maximum operating pressure, that is, to 1000 psi. A visual inspection was also conducted on the parts.

We, supported by the test results, hereby conclude that our sealing system successfully prevented any possible leak, and that the aluminum tube did not suffer any sort of apparent deformation.

Figure. ATOM's Hidrostatic Test

D. Flight test.

Our team conducted a full flight test demonstration on June 22th, 2018. Members traveled to Las Cruces, New Mexico to go through pre-launch procedure and witness our rocket take flight during Spaceport America Cup 2018. ATOM was vertically integrated on a 6 meters rail angled at 85 degrees from horizontal. Winds were approximately 3-4 m/s. The rocket flew straight and true. Upon main parachute and drogue deployment at the same time, we were not be able to receive active GPS signal. The launch vehicle sustained internal damage but not external and was deemed re-flyable. Given these circumstances, our team has reason to believe ATOM should fly better at LASC after some changes and enhancement.

VII. Harzard Analysis Appendix

Team	Rocket/Project Name	Date	
GFRJ	ATOM II	20/06/2019	
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	

VIII. Risk Assessment Appendix

Team	Rocket/Project Name	Date		
GFRJ	ATOM II	20/06/2019		
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 debris causing injury	Cracks or Air Bubbles in propellant grain	Medium: student-built motor with limited testing and nondestructive evaluation capability	Pressure test motor case to 2 times maximum operating pressure	Low
	Gaps between propellant sections and/or nozzle		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 stability velocity due to windy conditions		Research on usual weather 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	Avionics malfunction	Medium; complex operation of parachute folding,	Redundancy with comercial equipment rises the	Low

payload encounter personnel		inserting and activating	reliability of the system	
	Structure not sustaining enough tension		Tests made on similar structure guaranteed sustaining this ammount of tension	
	Parachute or strings do not sustain enough tension		Comercial parachute design by professional parachute manufacturer rises the reliability of the project	
	Parachute gets stuck in the fuselage		Folding and insering procedures reccomended by the manufacturer	
Recovery system fails to deploy, rocket or payload encounter personnel	Avionics malfunction	Low; redundant activation system	Redundancy with comercial equipment rises the reliability of the system	Low

IX. Assembly, Preflight and Launch Checklists Appendix

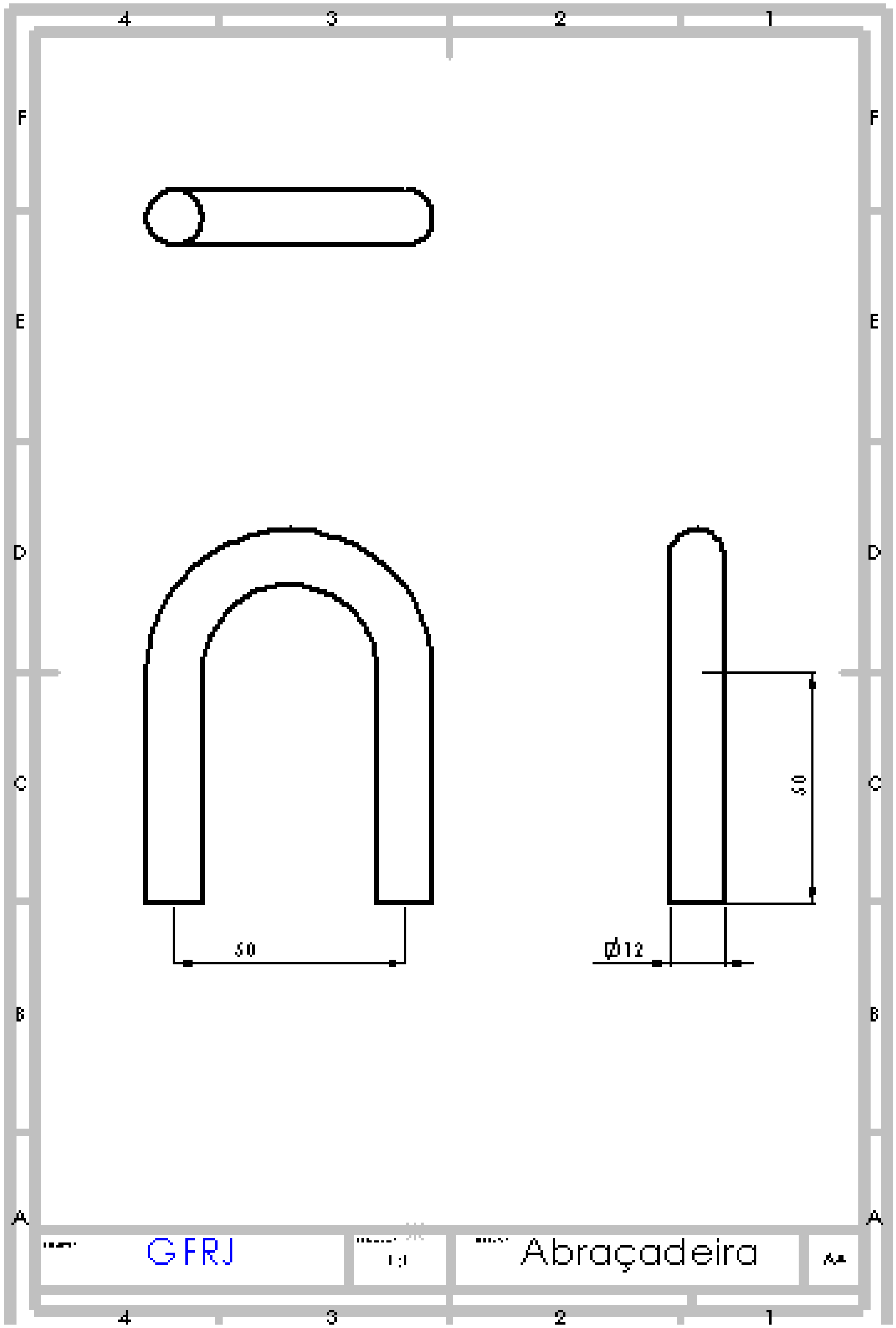
Materials Checklist		
Action number	**Action**	**Check**
1	**External structure**	-
2	Four fuselage tubes	-
3	Attach hood's tip	-
4	Hole alignment	-
5	Fin integrity	-
6	Fin's attachment	-
7	Four couples	-
8	Screws	-
9	**Propulsion**	
1	Avionic's case	-
2	Motor tube integrity	-
3	Thermal blanked	-
4	Propellents	-
5	The number of bolts	-
6	O-rings	-
7	Nozzle	-
	Recovery	

1	Strings	-
2	Main parachute	-
3	Drogue	-
4	Powder	-
	Avionics	
1	PCBs	-
2	GPS	-
3	Altimeter	-
4	Antenna	-
	Payload	
1	Structure	-
2	Experiments	-
3	Payload's eletronics	-

Assembly Checklist		
Action numbers	**Action**	**Check**
1	Check the cubesat	-
2	Insert payload's "remove before flight" pin	-
3	Cubesat insertion on its module	-
4	Main parachute anchoring on payload module	-
5	Avionics coupler preparation	-
6	Avionics security key check	-
7	Main parachute powder preparation and allocation	-
8	Drogue parachute powder preparation and allocation	-
9	Main parachute anchoring and allocation	-
10	Connection of droge parachute module with avionics coupler	-
11	Drogue parachute anchoring	-
12	Connection of drogue parachute module with avionics coupler	-
13	Insert avionics "remove before flight" pin and turn off security key*	-
14	Drogue parachute allocation	-
15	Anchoring drogue parachute on motor module	-
16	Connection of motor and drogue parachute module	-
17	Insert propellant in motor case	-
18	Nozzle enclosing**	-
19	Motor final check and assembly	-

20	Motor insertion***	-
21	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 avionicts	-
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	-

X. Engineering Drawings Appendix



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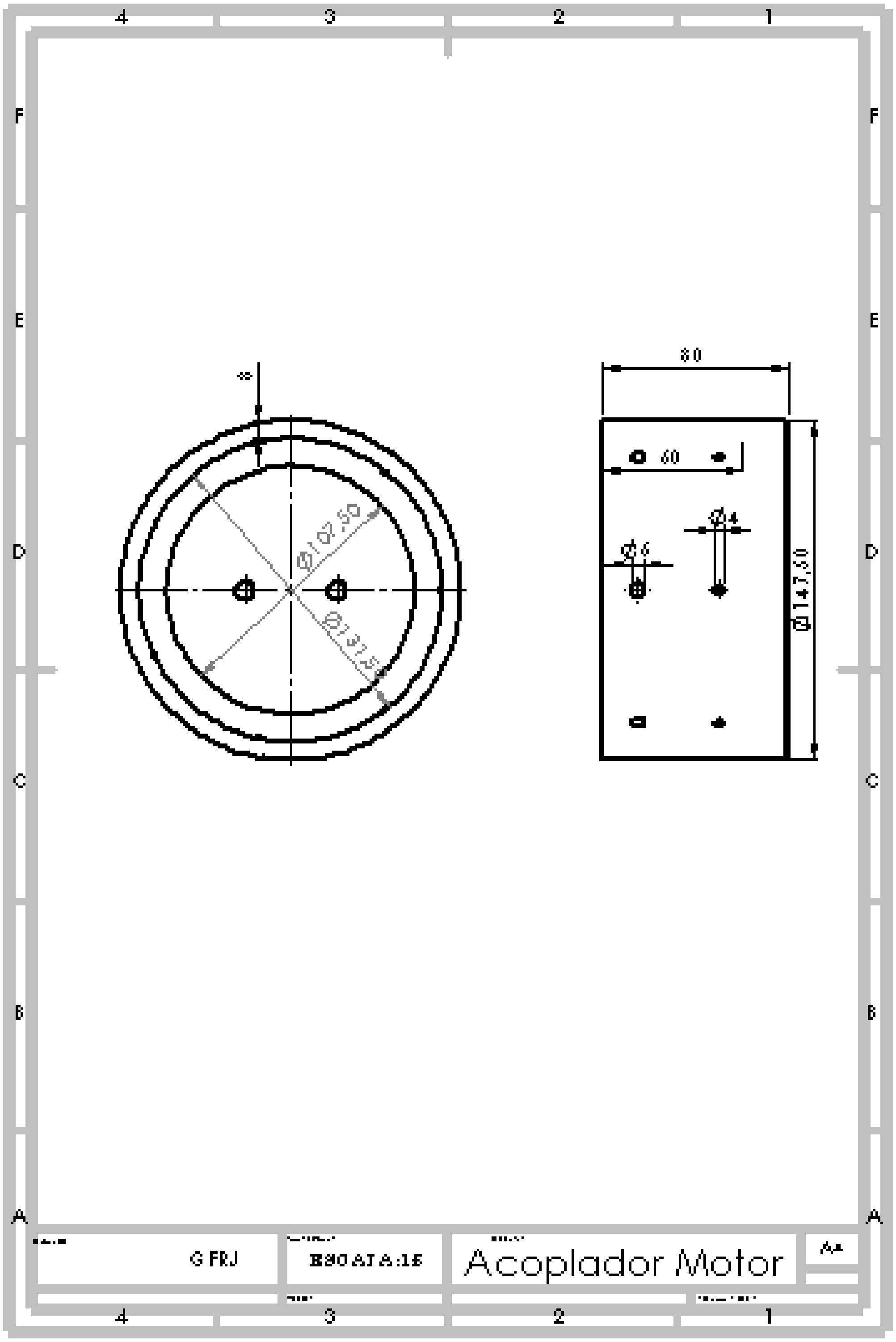
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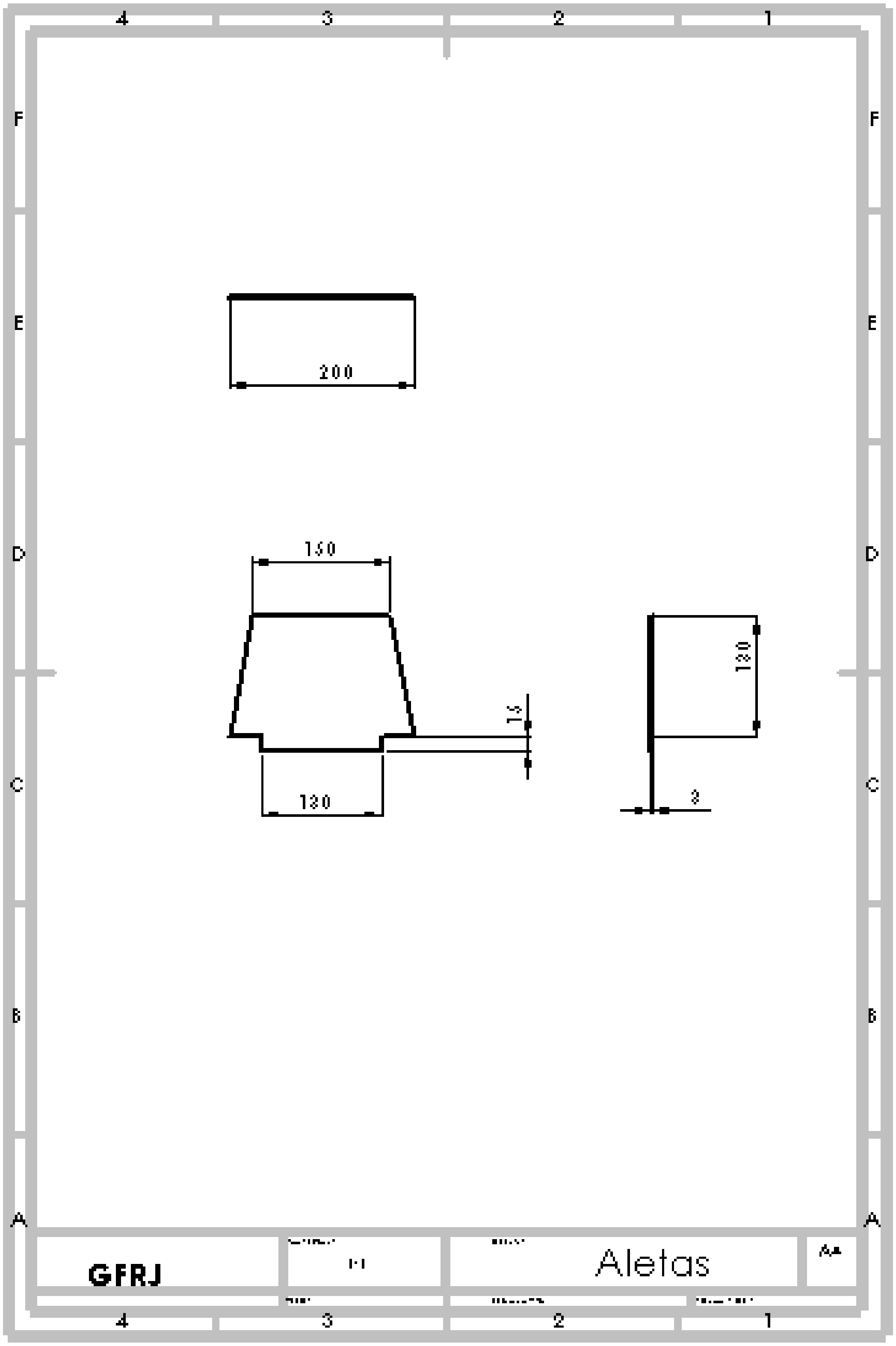
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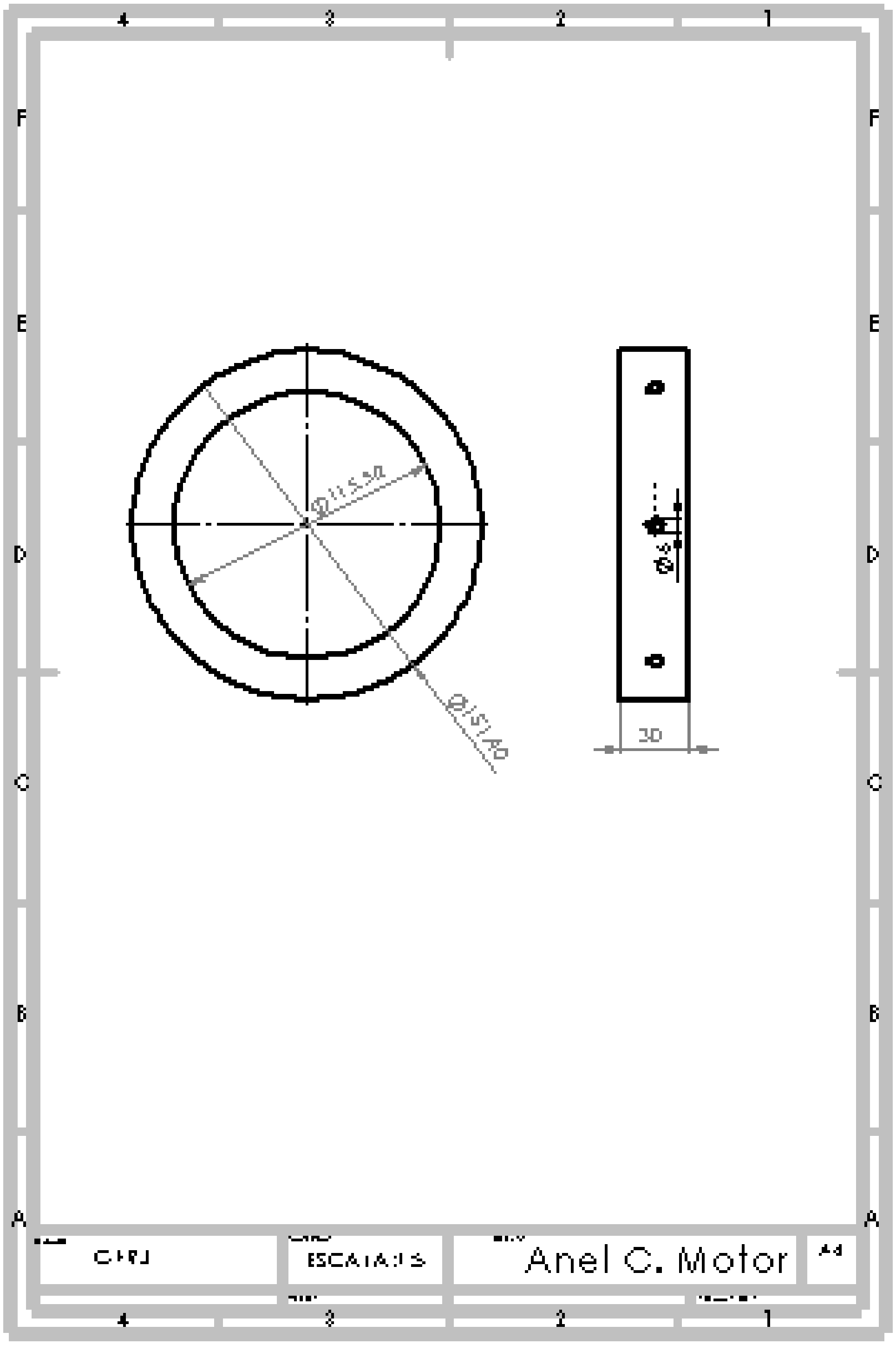
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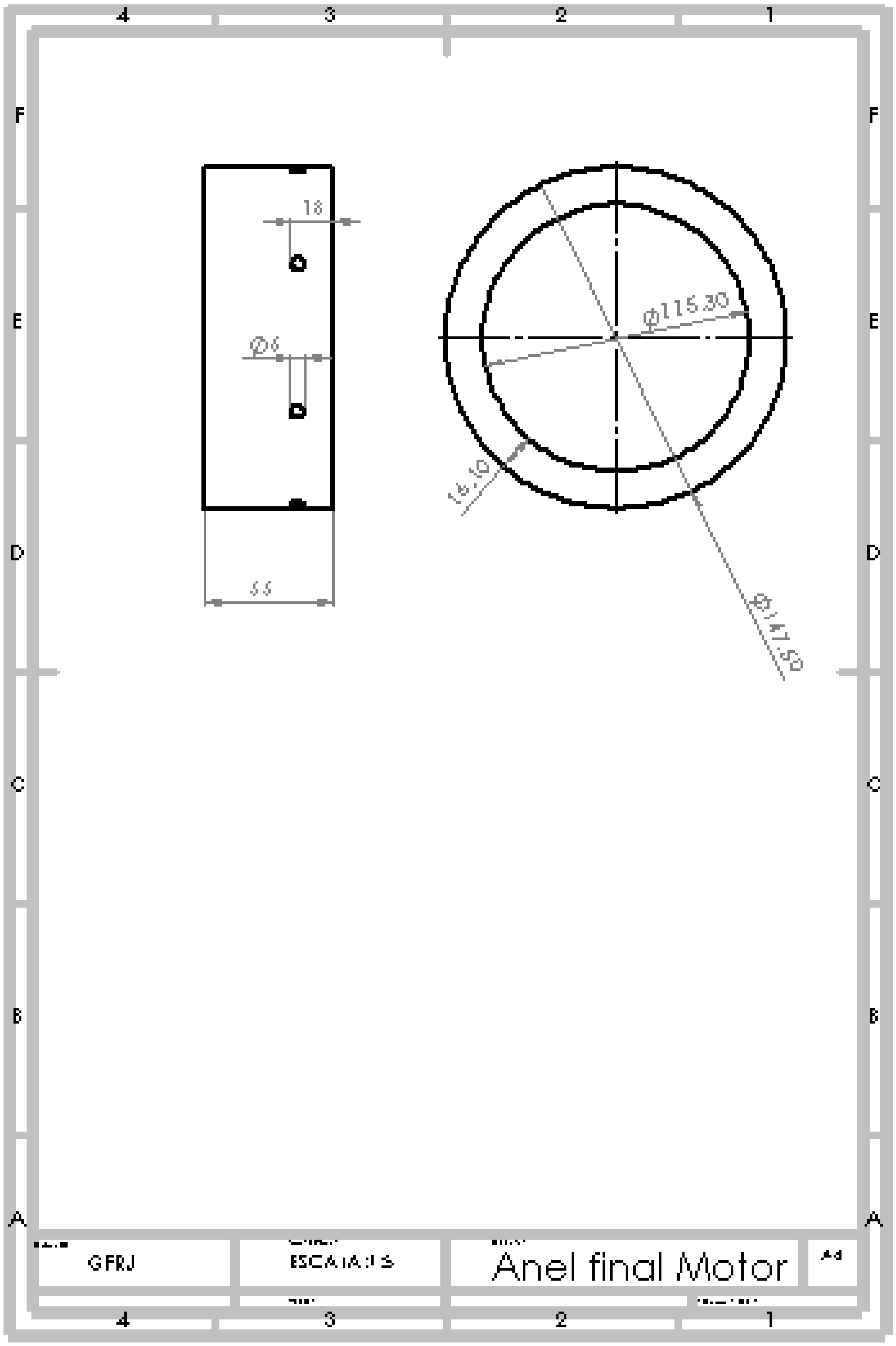
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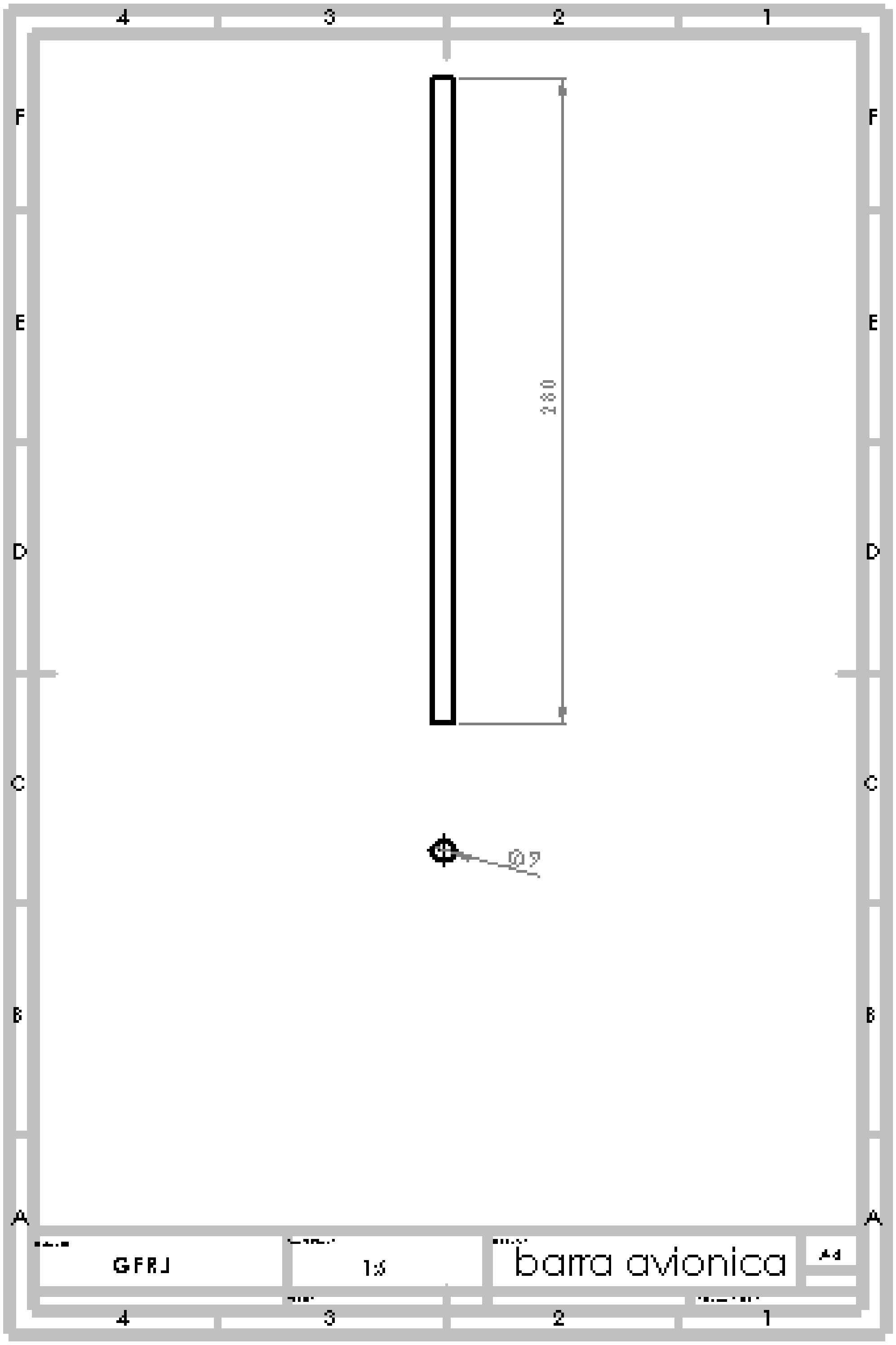
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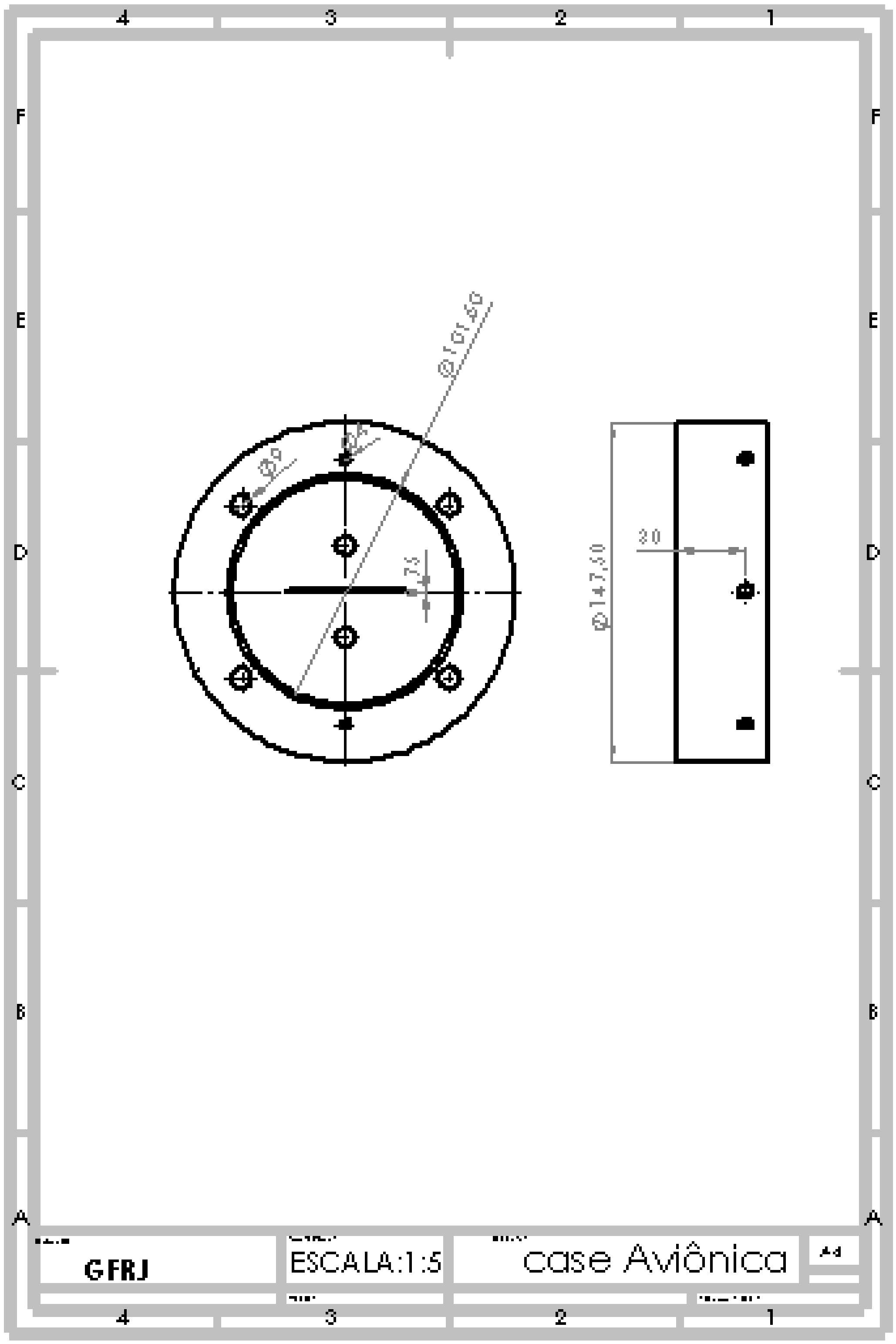
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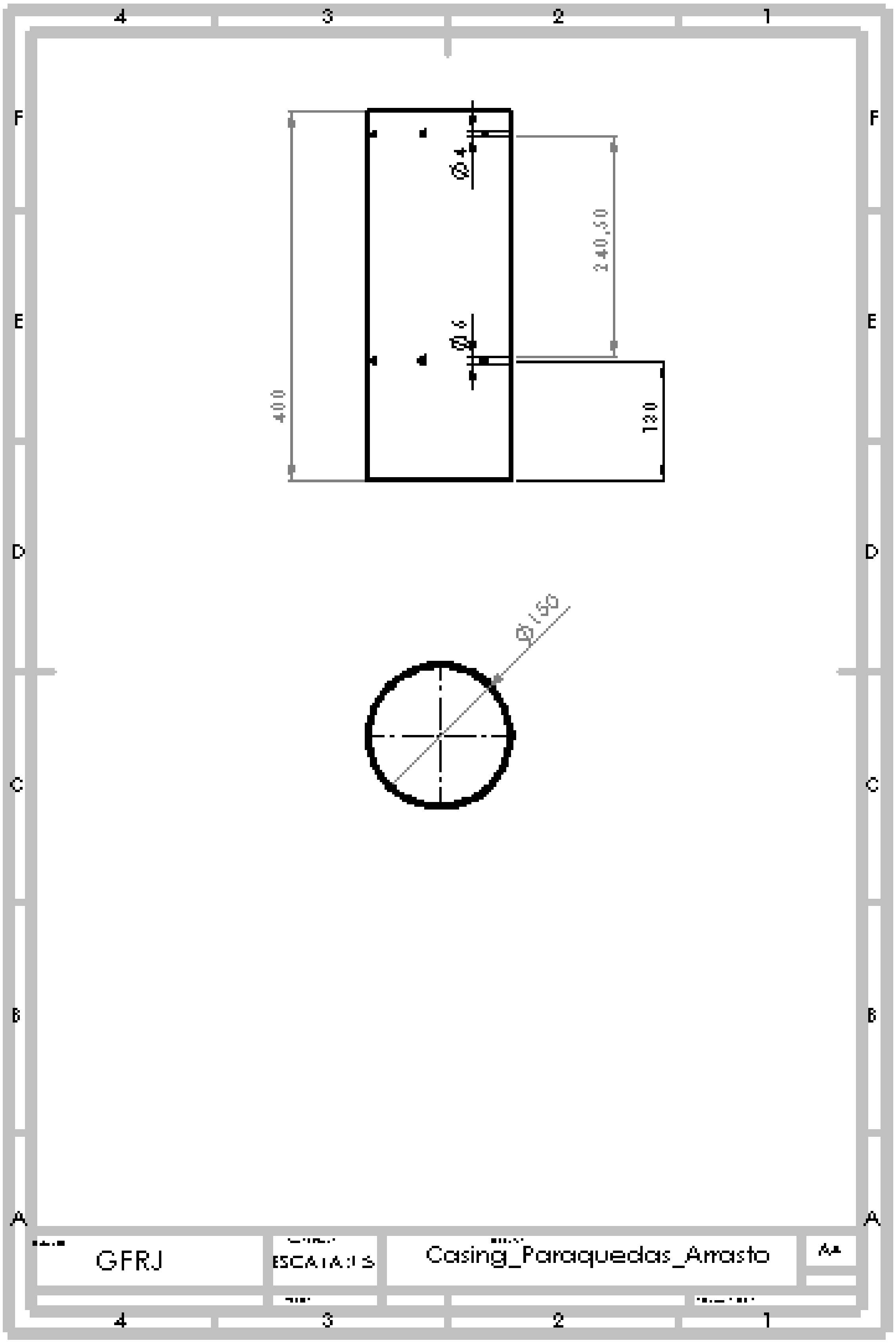
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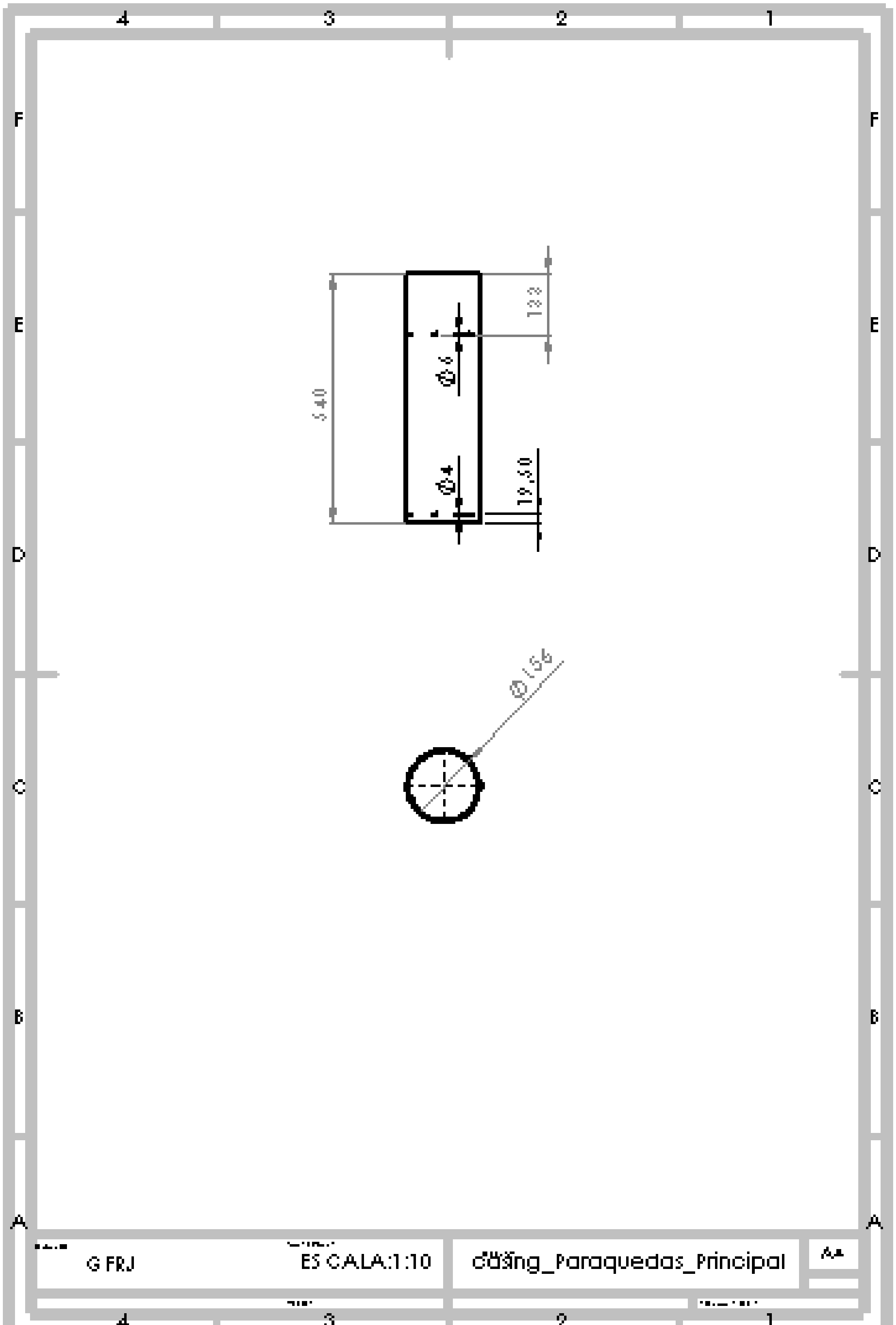
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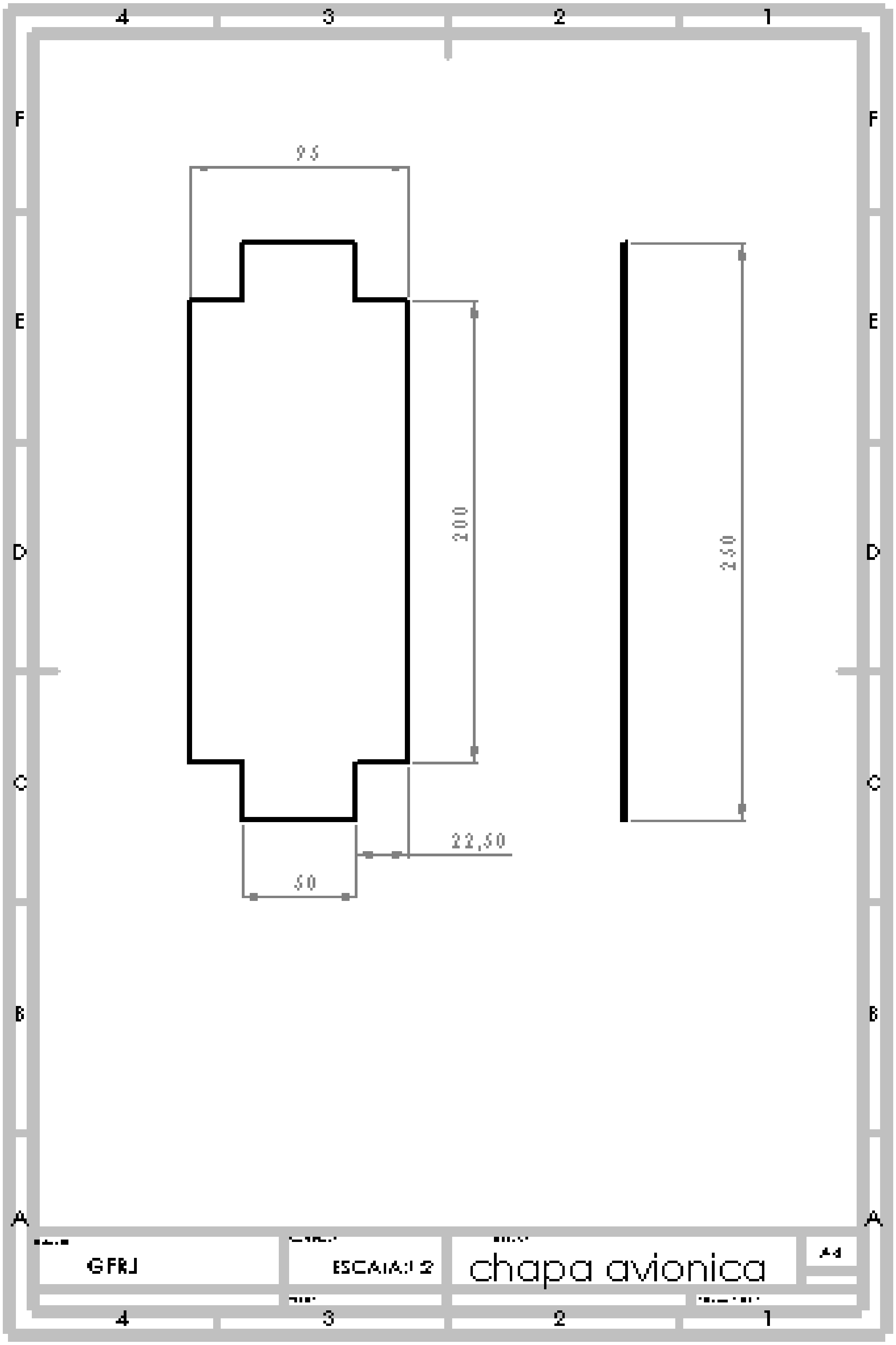
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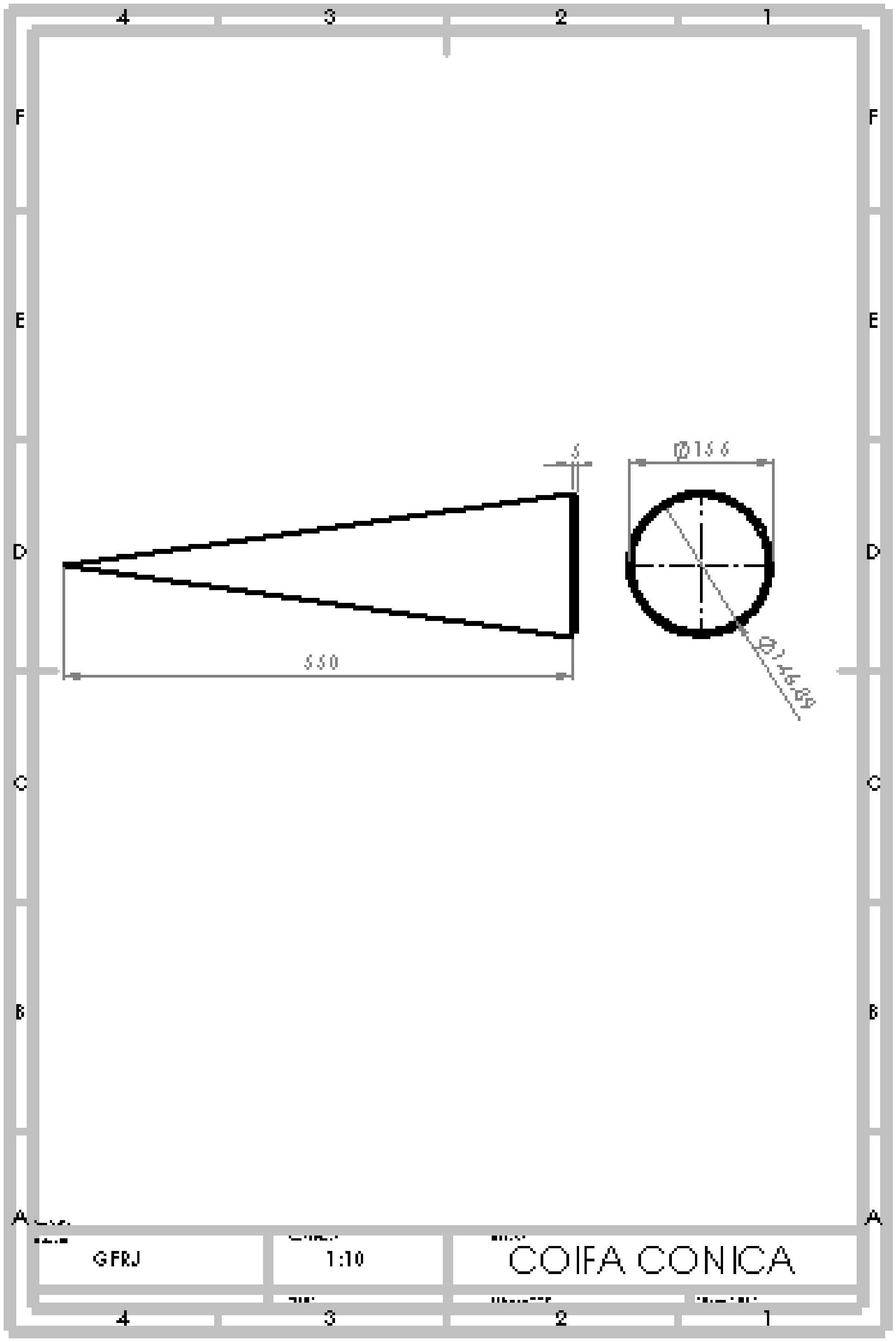
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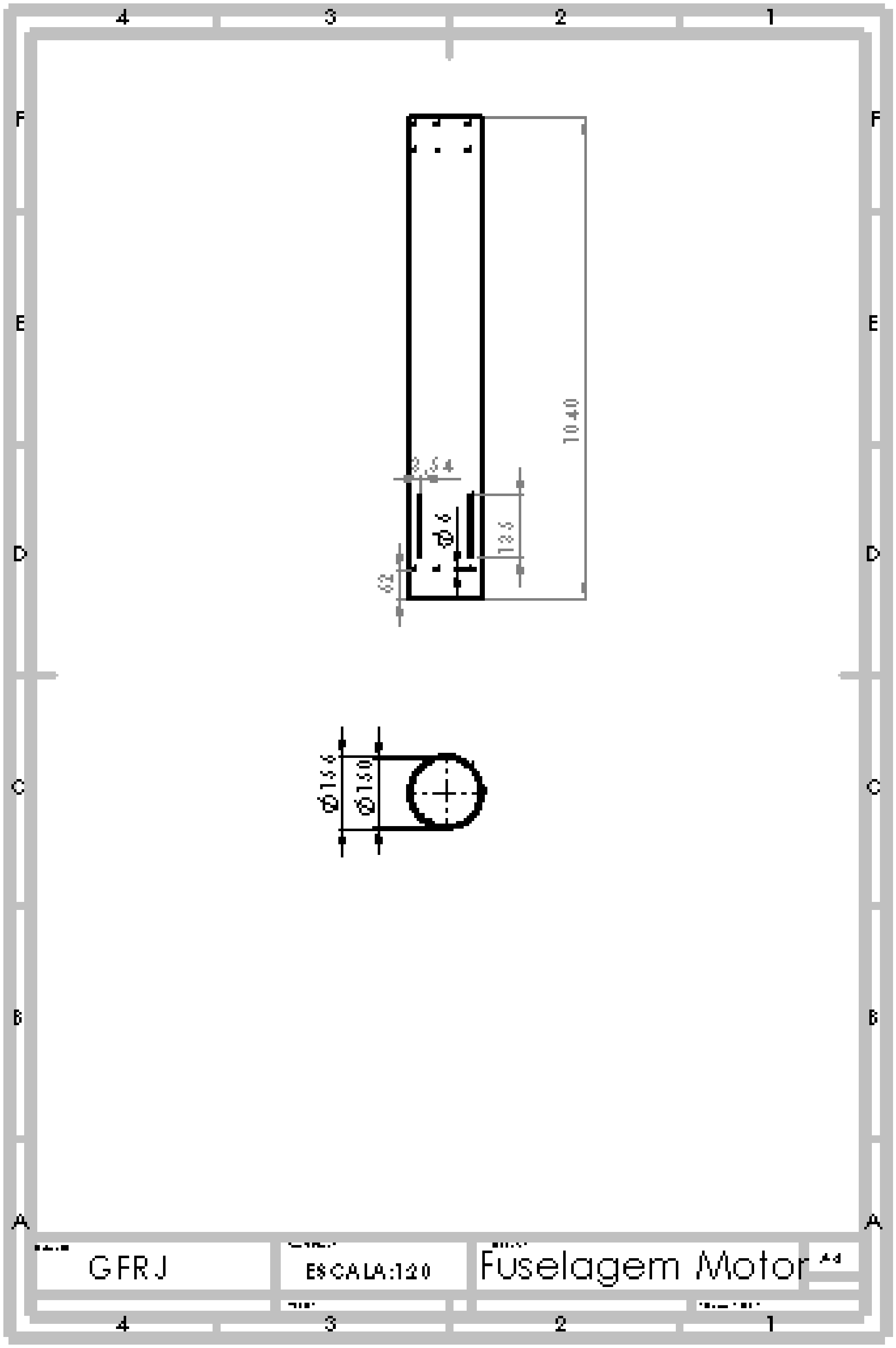
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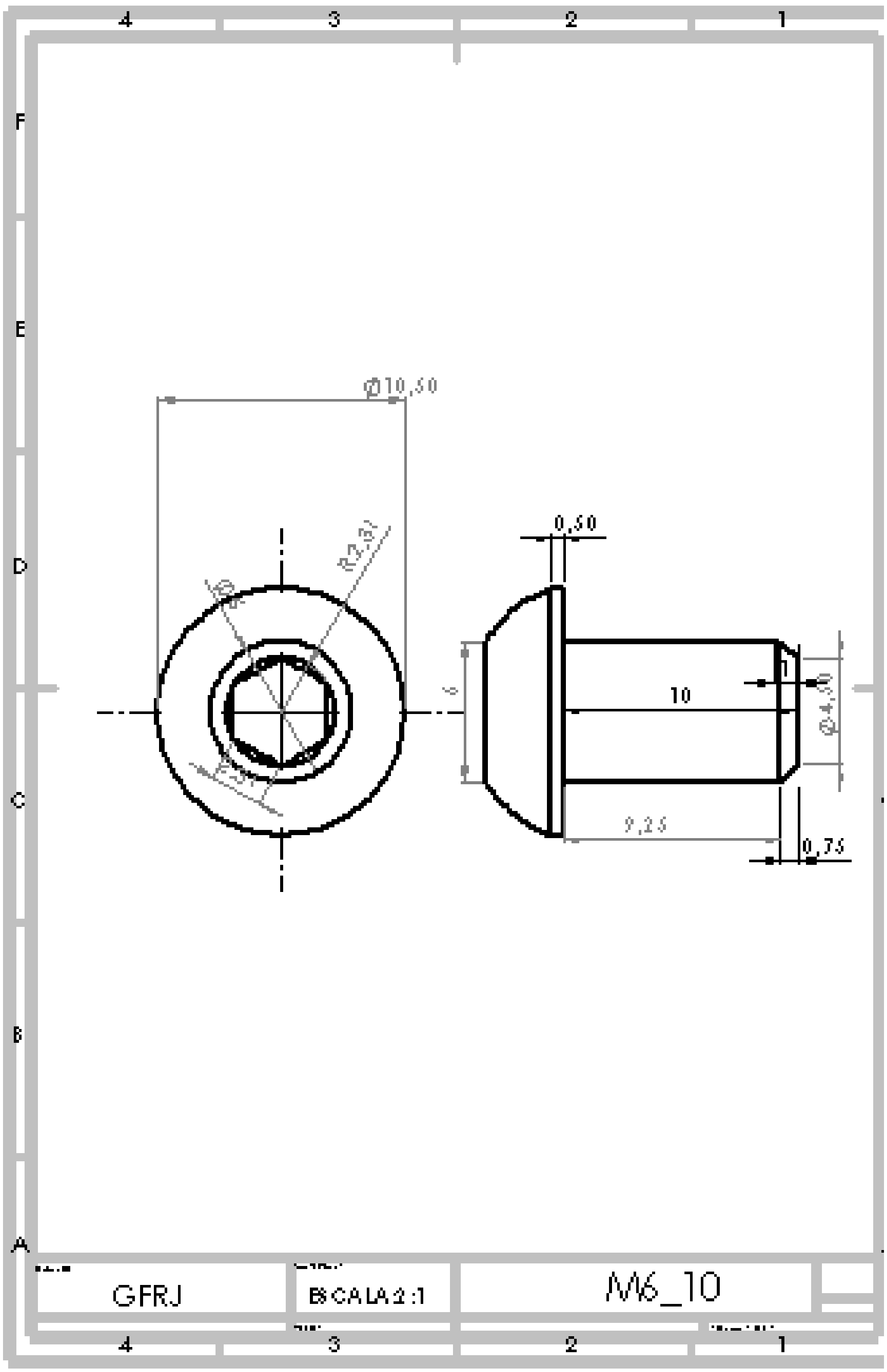

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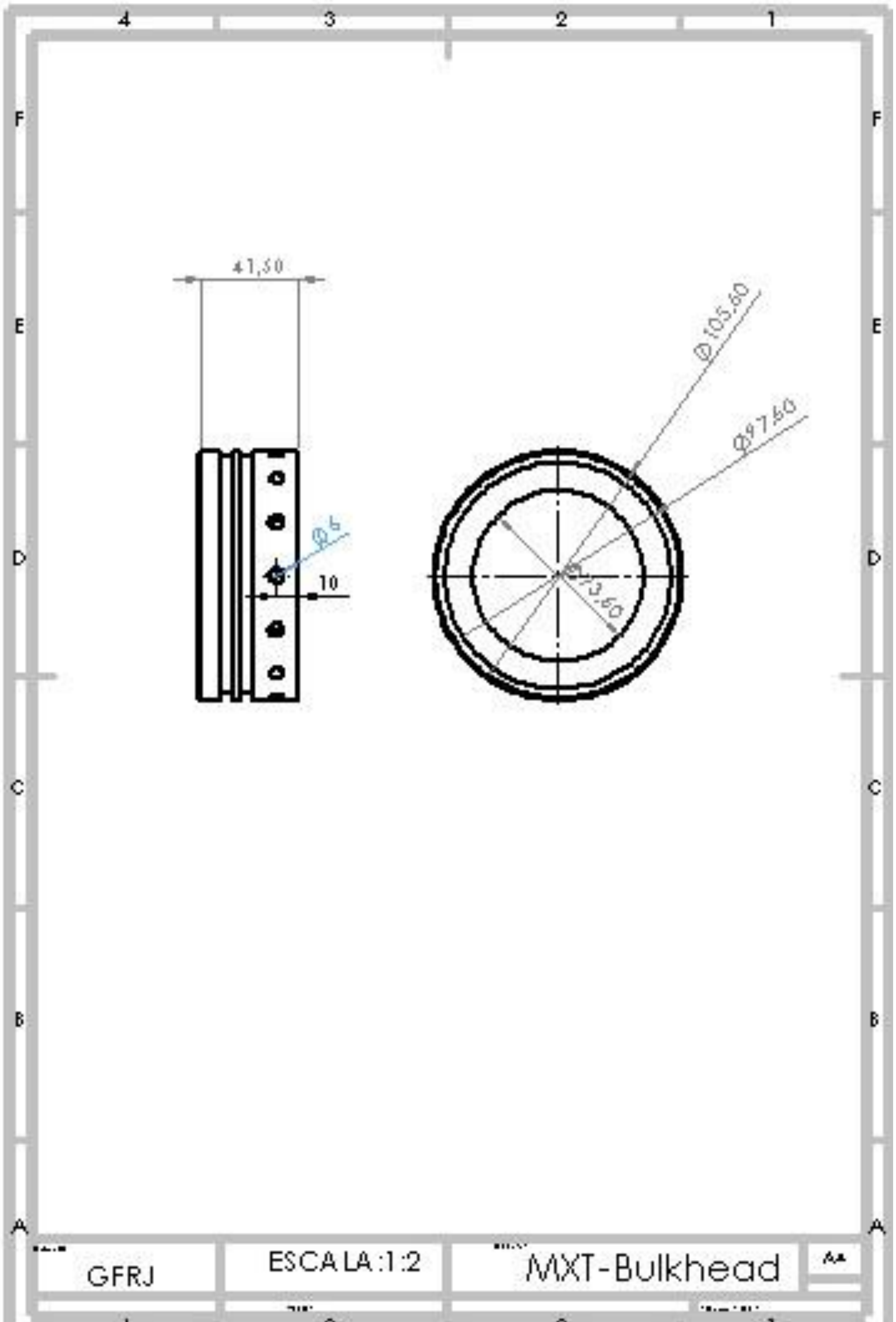
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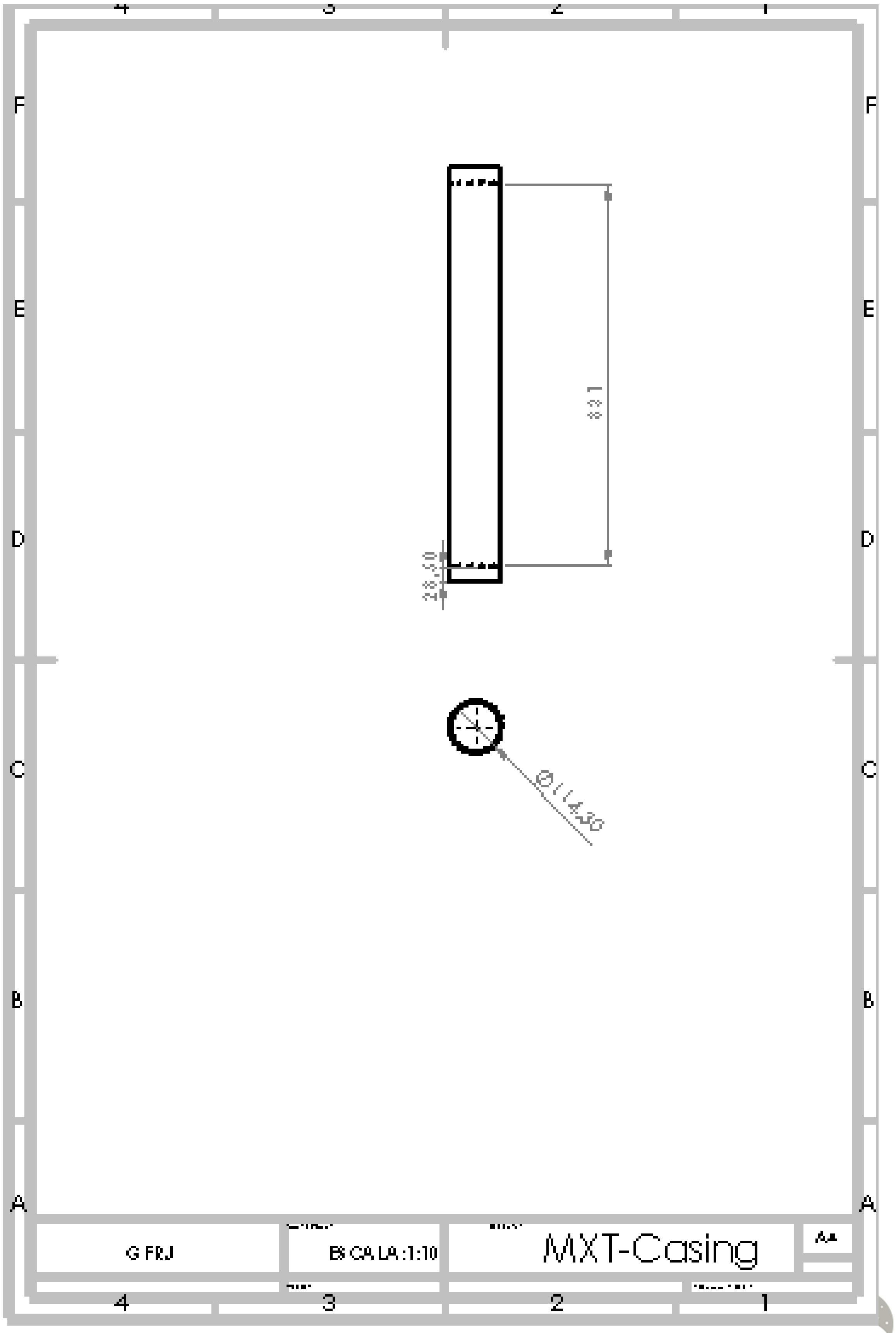
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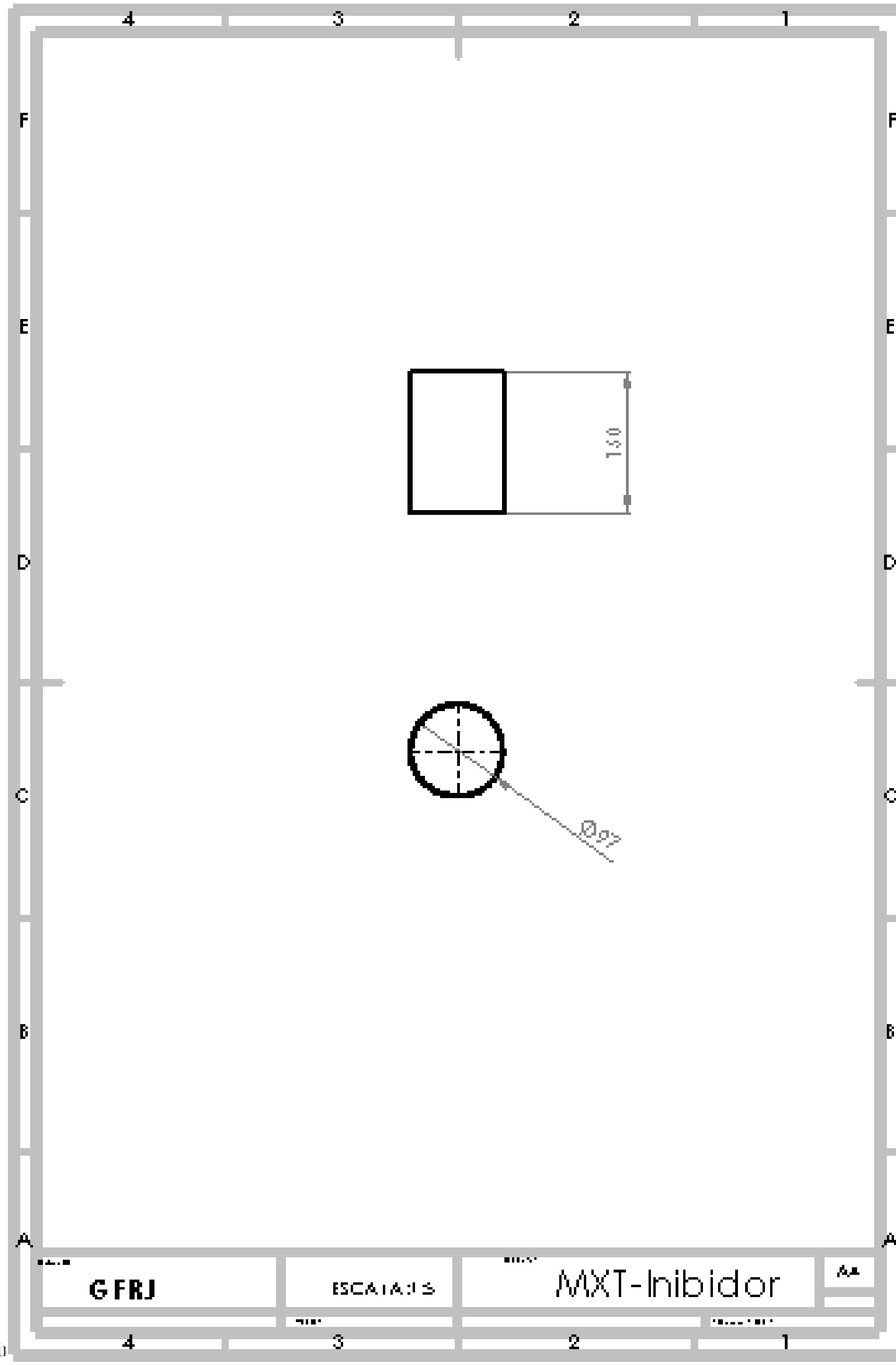
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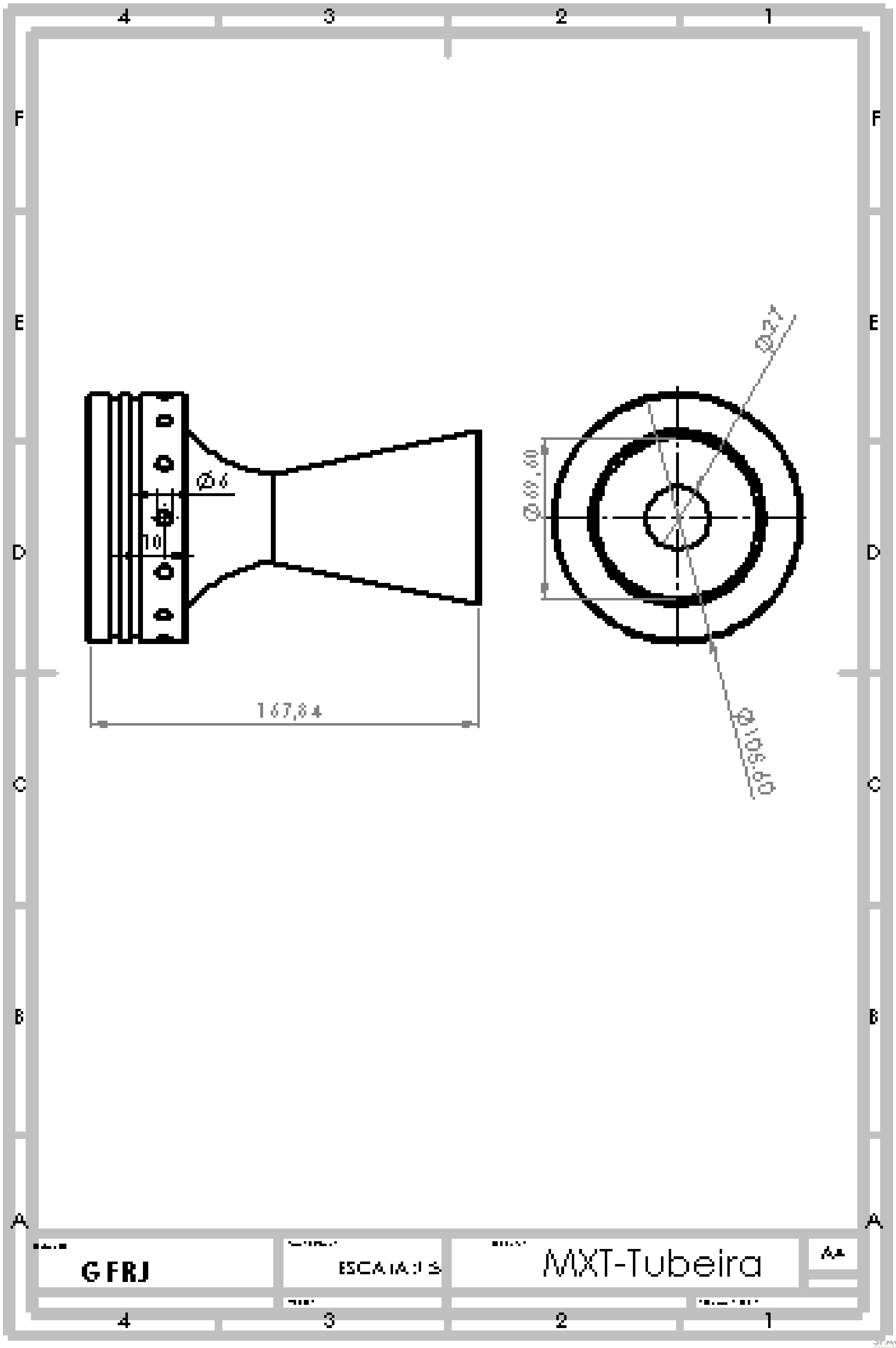

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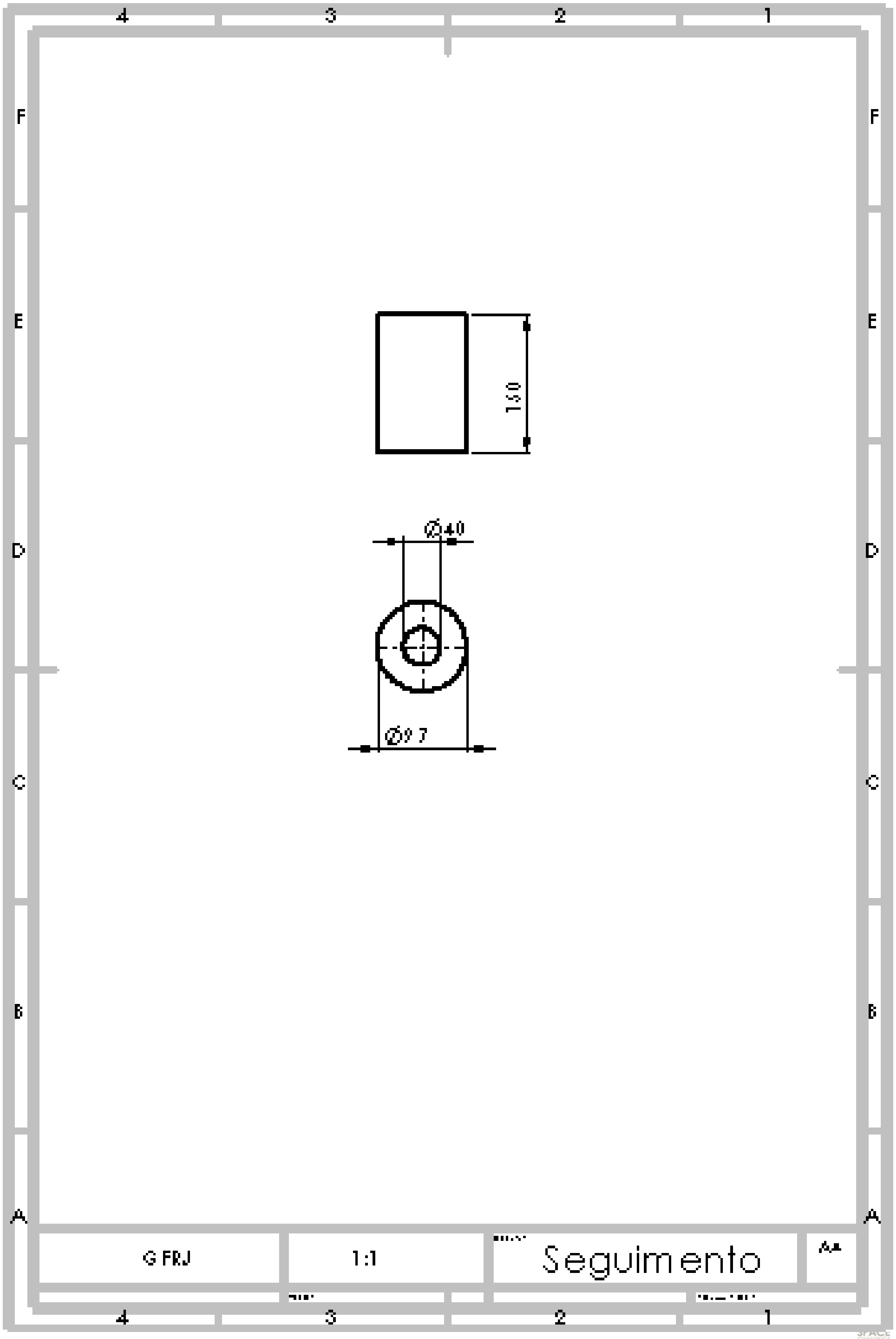
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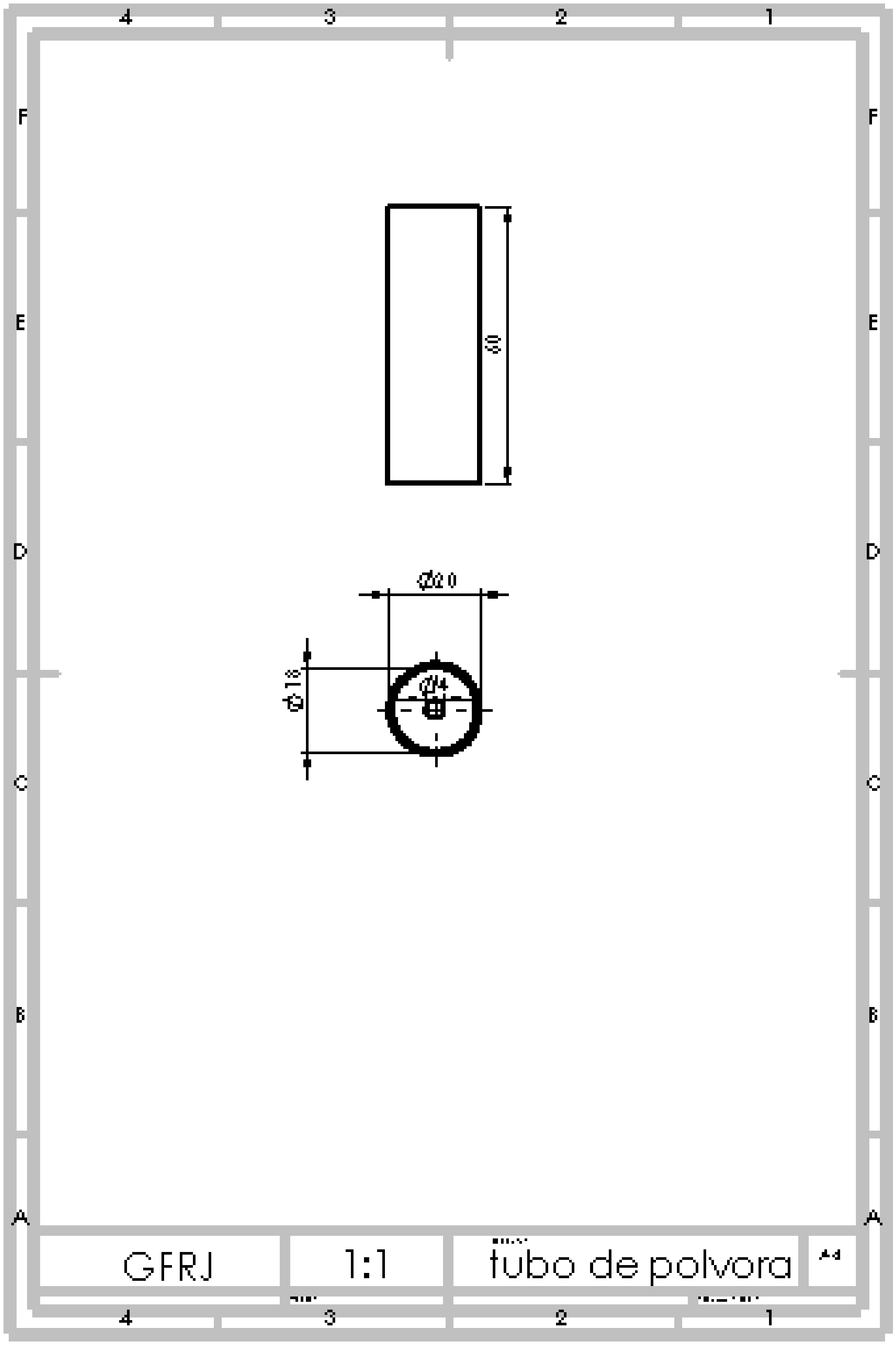
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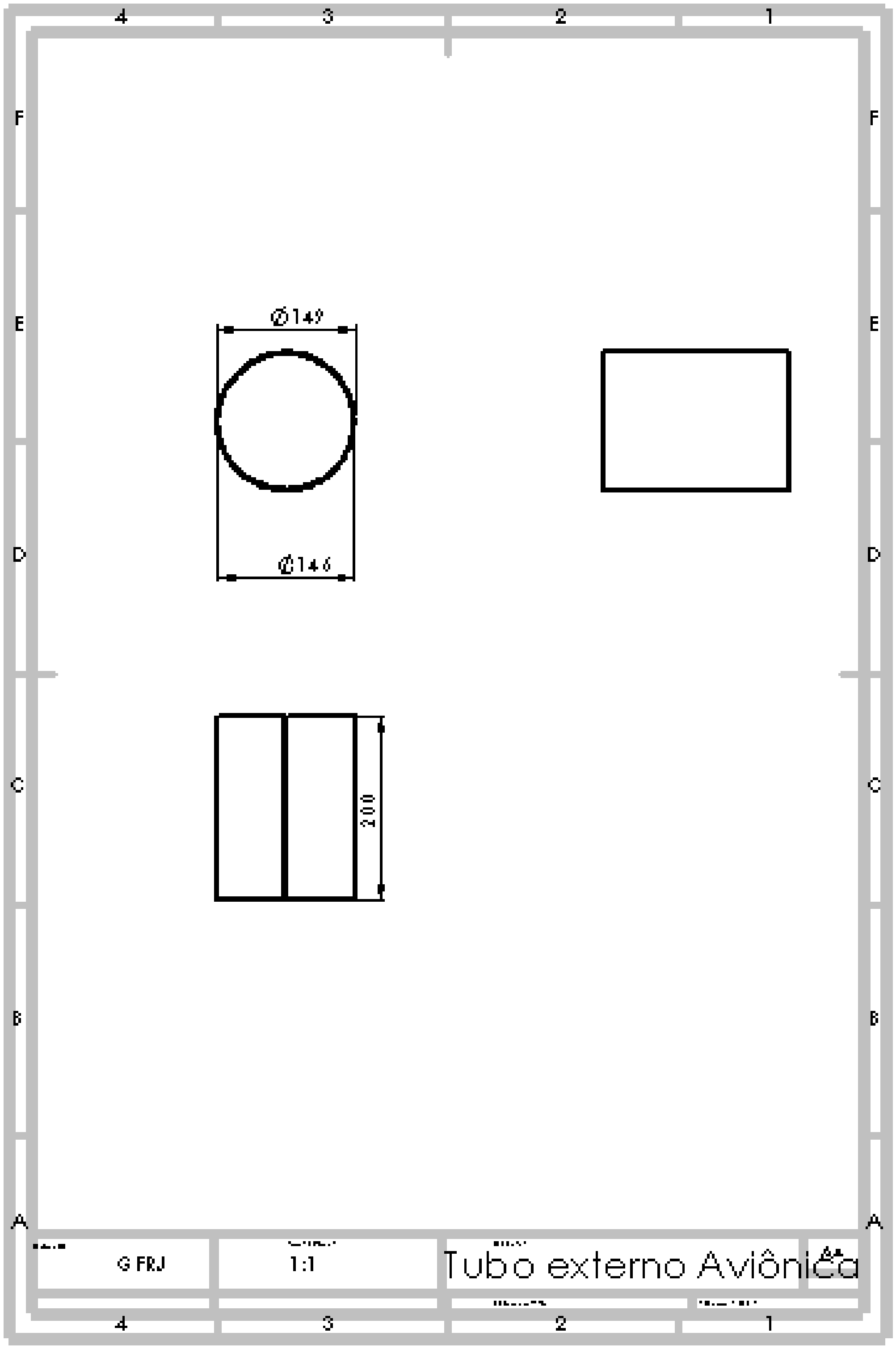

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