Callisto Project Technical Reports for the IREC

Team 88 Project Technical Report for the 2019 IREC

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Abstract

This report describes the subsystems of an experimental rocket for the 10k-COTS category with an M class motor. The main purpose is reaching an altitude of 10,000 ft while carrying a payload of 10.68 lbs and landing without causing critical damage to the rocket components. The payload has the objective of collecting in-flight data and sending it to a land base station. The database is used to estimate the rocket trajectory and to validate the activation of the parachute deployment cycle. Ultimately, the rocket has some innovative concepts in its design: the modular structure and a cold gas parachute ejection system.

Nomenclature

C_p = pressure coefficient
Cx = force coefficient in the x direction
Cy = force coefficient in the y direction
c = chord
dt = time step
Fx = X component of the resultant pressure force acting on the vehicle
Fy = Y component of the resultant pressure force acting on the vehicle
f, g = generic functions
ISP = specific impulse
K = trailing-edge (TE) nondimensional angular deflection rate
M = merit function
A_{fins} = area of one fin
s = fin span
F_{RC} = fin root chord
F_{TC} = fin tip chord
X_{SM} = rocket static margin
σ = standard deviation for X_{SM}
ρ = air density
Vx = parachute opening speed
V_f = parachute final speed
M_T = total mass
F_D = drag force

C_D = drag coefficient
S = parachute area
V = parachute relative speed
ε_r = relative permittivity

I. Introduction

THE designed rocket was developed by *Projeto Jupiter*, a group of undergraduate students with the support of teachers and researchers from the Polytechnic School of the University of Sao Paulo. Our main objectives include the pursuit of new aerospace technology and the development of the engineering abilities of our members. We do so by participating in national and international competitions, organizing our own launches and participating in events such as industrial fairs, technologic conferences and charity.

Projeto Jupiter has 71 members of which over than 56 are in technical areas, distributed over Aerodynamics, Recovery, Propulsion and Electronic systems. We also have members working in administrative areas: Marketing and Finance. Each area has its own manager responsible for the development of the subsystem. The project integration is coordinated by the team leader, who organizes meetings focused on solving specific problems.

II. System Architecture Overview

The experimental rocket developed by Projeto Jupiter has a traditional shape but an innovative structure composed by 6 independent sections: Nose cone; main parachute section; ejection system section; drogue parachute section; propulsion section; and fins section, as can be seen in figure 1. The main subsystems are the Propulsion, Recovery, Electronic and Structure. The propulsion system is composed of a commercial Cesaroni Technology's White Thunder Pro75-6118M3100-P motor. The responsibility of the Recovery is designing the parachute and its ejection mechanism. The main contribution of the Electronic System is the functioning of the avionics responsible for apogee detection and Main deployment altitude detection, as well as the activation of the Recovery System. The Payload system is responsible for sensor data acquisition and transmission to the land base station, providing real-time rocket status data, parachute activation confirmation and further, the estimated landing point. Finally, the Structure subsystem made possible to assembly all other subsystems and grant aerodynamic properties for a stable flight. A more detailed description of each subsystem is followed.

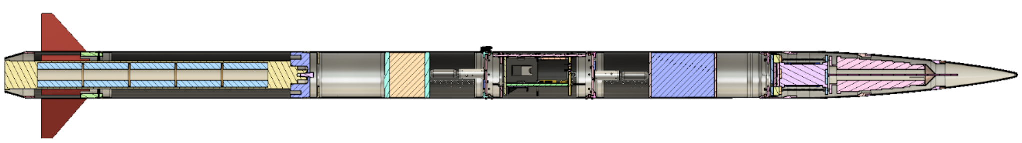

Figure 1 - Half section rocket view.

A. Propulsion Subsystems

For the Spaceport America Cup, the Propulsion Team has decided that they are going to use a commercial motor. They have been studying ways to test their hybrid motor, which was their main intention for launching the rocket at this year's competition. However, they would not have time to test it properly and safely, so the Propulsion Team continued their activities, but they chose to postpone it for SA Cup.

The motor that Projeto Jupiter will be using is the Pro75-6118M3100-P (White Thunder), manufactured by Cesaroni Technology. The test was made on 10/25/2009, and the thrust curve is shown below.

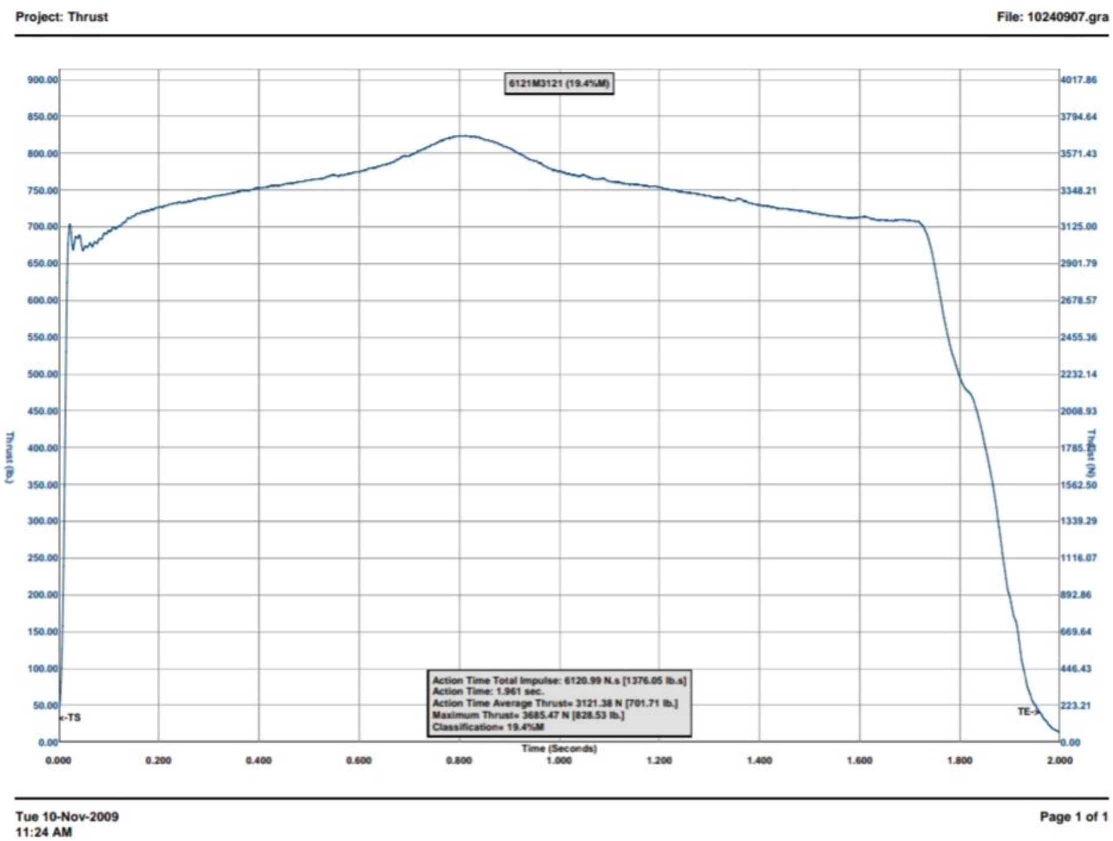

Figure 2 - Thrust Curve.

This is a reloadable motor, with 5018 g of loaded weight, 2903 g of propellant weight and 2068 g of burnout weight. The motor's classification is 19,5% M, containing five grains.

The motor dimensions are 75.00 x 757.00 mm (2.95 x 29.80 in), with total impulse of 6117.8 Ns (1375.3 lb-s). The maximum thrust is of 3709.2 N (833.9 lb), the average thrust is of 3075.0 N (691.3 lb), the ISP is 214.93 s and the burntime is of 1.99 s.

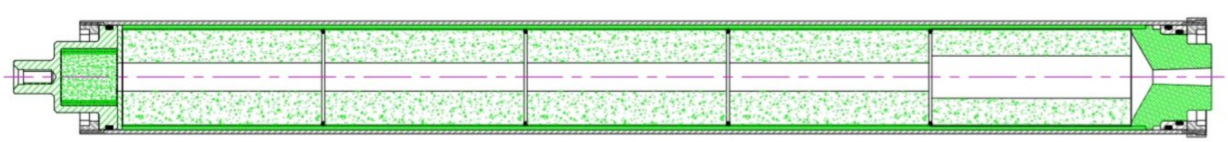

Figure 3 - Assembled Pro75-5G Dual Thrust motor.

B. Aero-structures Subsystems

Base Structure

Aerodynamic and structures design plays a key role in rockets´ performance. The main goal of the aero-structures subsystem is to provide an efficient aerodynamic and modular structure that meets the following requirements. The structure has to facilitate handling, assembly, transportation and efficient integration of all subsystems. Moreover, it requires not only suitable strength and strain performance under operation, but also the application of lightweight materials in order to optimize its performance. On the other hand, the external design provides stability and good aerodynamic performance. To assess this, manufacturing techniques, hand calculations and numerical simulations were performed.

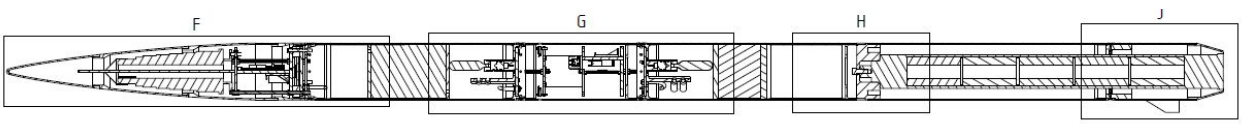

Figure 4 - Cut view of the Base Structure

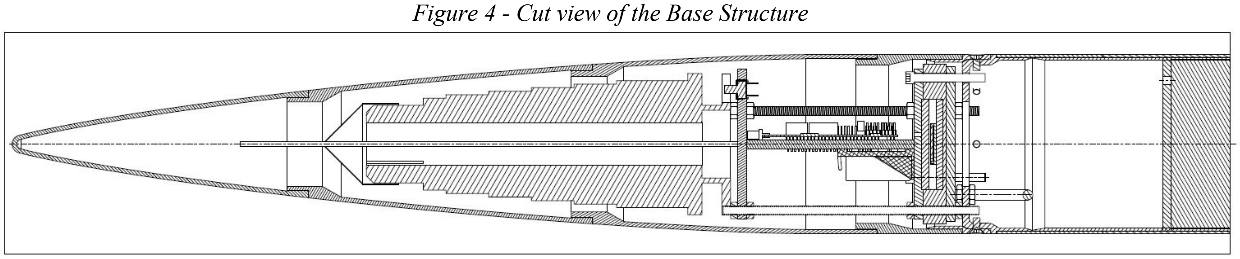

Figure 4.F - Cut view of the nose cone section.

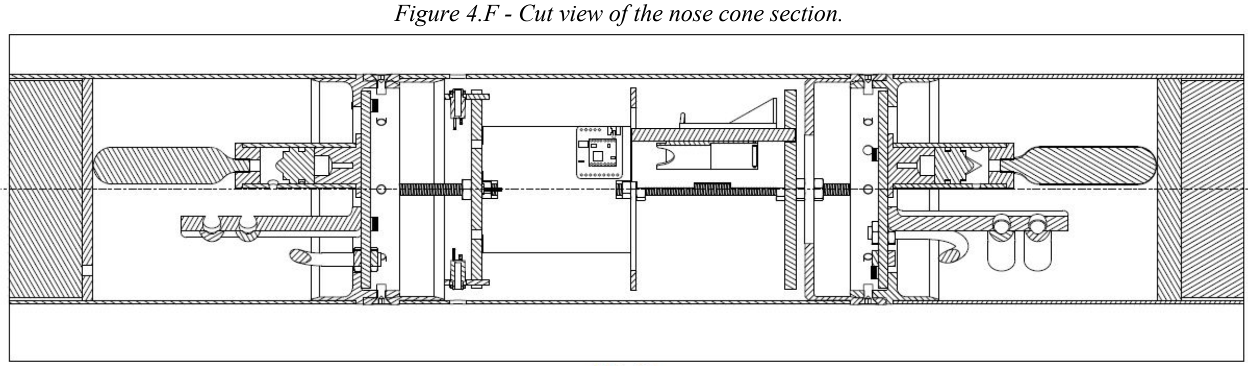

Figure 4.G - Cut view of electronic bay and parachute ejection sections. Drogue parachute ejection system (right) and main parachute ejection system (left).

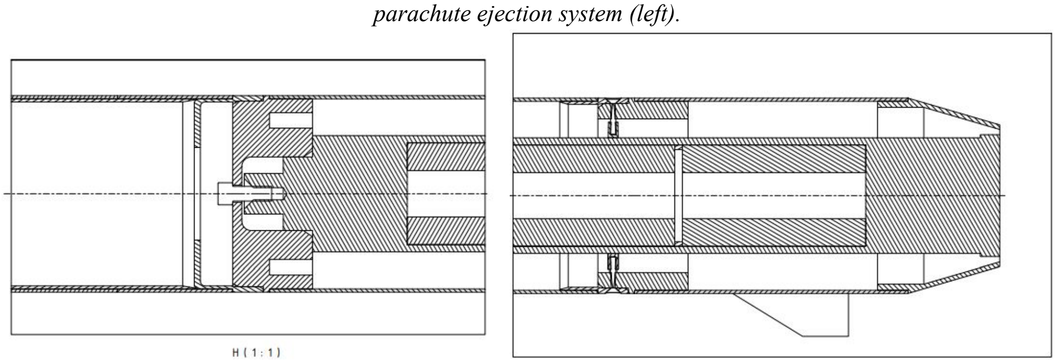

Figure 4H and 4.J - Cut view of motor mount the fin mount section.

Modules, Fins, Tail and Guide Rails

Callisto contains six modules, from top to bottom: Nose cone, main parachute, electronic system, drogue parachute, motor and fins. The payload is located inside the Nose cone. The modules connect themselves by using aluminum disks at the ends. Those disks are glued to the composite tubes on one end and, in the other end, they attach to each other by using steel screws that are subjected to shear loads along the flight.

Both the main parachute and the drogue parachute modules are separated into two parts during their parachute ejection. This is achieved by the use of shoulders which connect the two parts during liftoff. One is located below the nose cone module and the other is located above the motor module.

The three fins are attached to the fins module by a carbon fiber composite layup that provides a permanent connection of the fins to the fuselage.

The two guide rails are fixed to the aluminum disks. One is located between the motor and the fins and the second is placed between the drogue parachute module and the electronic system module.

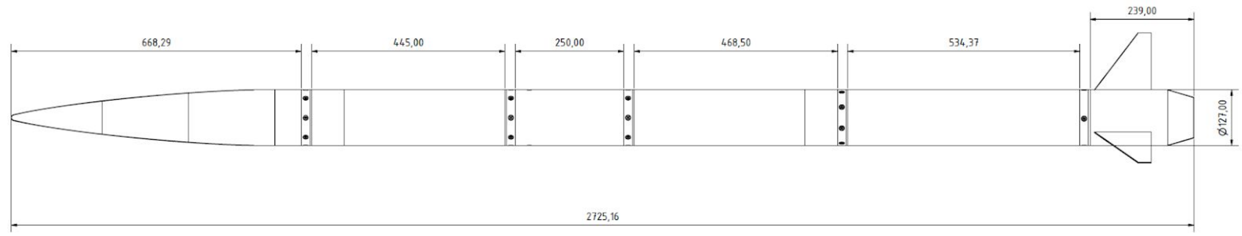

Figure 5 - Modules, disks, fins and tail illustrated.

Manufacturing

Three main manufacturing techniques were used in the making of Callisto. The first of them is additive manufacturing through 3D printing. Additionally, machining of the aluminum disks designed by the team was made by a third party company. Finally, all composite parts were manufactured either by a resin infusion process or by manual layup of carbon fiber and epoxy resin. For the fins, an acrylic plate was used as a mold. For the tubes, an aluminum tube was machined and used as an internal mold for the manual layup.

Two coupling systems are present in Callisto. The main joint is made by screws which connect two aluminum disks together. 8 steel screws (M5 thread and 12.9 class) are present in each connection. The second joint is implemented as a shoulder coupled with a tethered rope in tension. While numerical analysis showed that the bolted connection was more reliable than a shoulder, the latter was needed due to the ejection system of the parachutes, since the bolted connection could not separate during flight.

The basis of each module is a tube with an outside diameter of 127 mm (5 in) and a 2 mm (0.079 in) thick wall. The tube is made out of 5 layers of carbon-fiber twill 200gsm with epoxy resin, manufactured at our own lab by manual layup.

The rocket contains three trapezoidal fins made of 8 layers of carbon fiber, to increases its stiffness. They were manufactured by a vacuum infusion process using epoxy resin. The fins are 2 mm (0.079 in) thick. The vacuum infusion process allows the team to manufacture composites parts with 65% carbon fiber to resin volume fraction, providing almost twice the strength of traditional lay up methods.

The nose cone has a different material from the rest of the structure. It is made out of 3D printed PLA, with a surface finish out of primer and paint. Structurally, fiberglass and epoxy resin are layered up inside to allow it to endure flight stress.

Mechanical behavior and structural analysis

The main structure´s components were designed to ensure secure operation and prevent failure during liftoff, flight and landing. Hand calculations were done at first to estimate the needed thickness of tubes to prevent buckling and large deformations. Numerical simulations using Ansys Mechanical were performed to account orthotropic nature of composite materials. The following image, Figure 6, represents one of the buckling simulations using Ansys Mechanical. Two modes of buckling were founded with the most critical load of 47000 N and the difference between the two modes of failure is about 9.8%. The maximum compressive load on the rocket tubes will be smaller than the maximum thrust force, which equals to 3665N, giving a safety factor of 12.8 with respect to buckling.

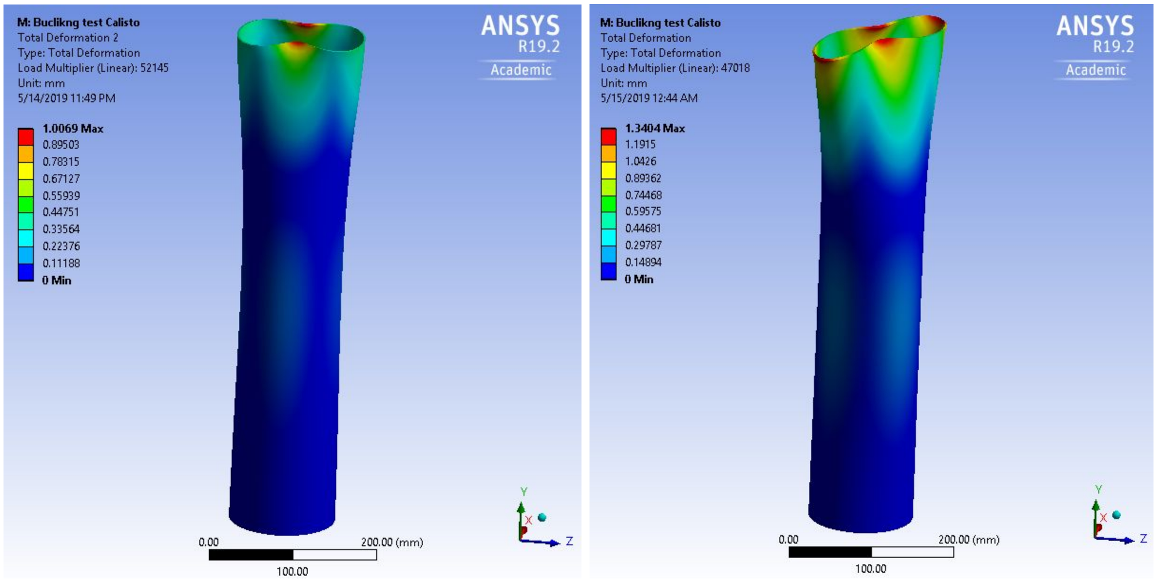

Figure 6 - Total deformation for buckling. Left: Buckling under a load of 52145 N. Right: Buckling under a load of 47000 N.

The aluminum disks were analysed using the same software, with the intent of verifying the behaviour of the threads and also the loads of force transmission. The simulations in Ansys Mechanical using a base model of the disks provided the following results shown in Figures 7 and 8. The analysis was made for the critical case of the ejection of a parachute as a load of 1000N in tension uniformly distributed over the central part. Figure 7 shows the total deformation distribution. It is interesting to note that the maximum deformation is 0.0042 mm.

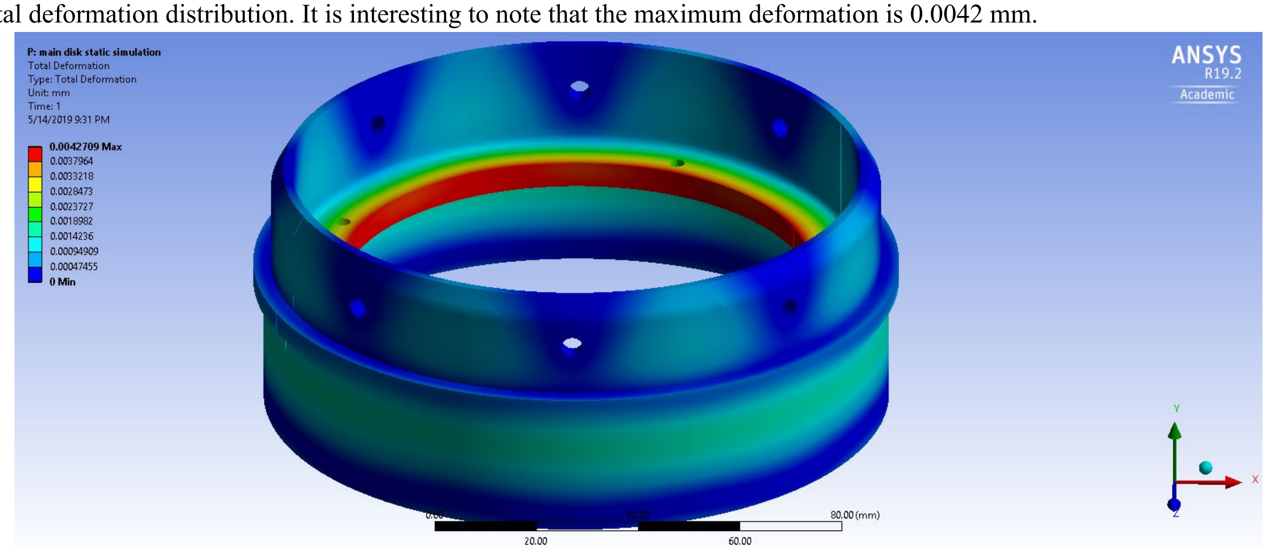

Figure 7 - Total deformation in connection disks.

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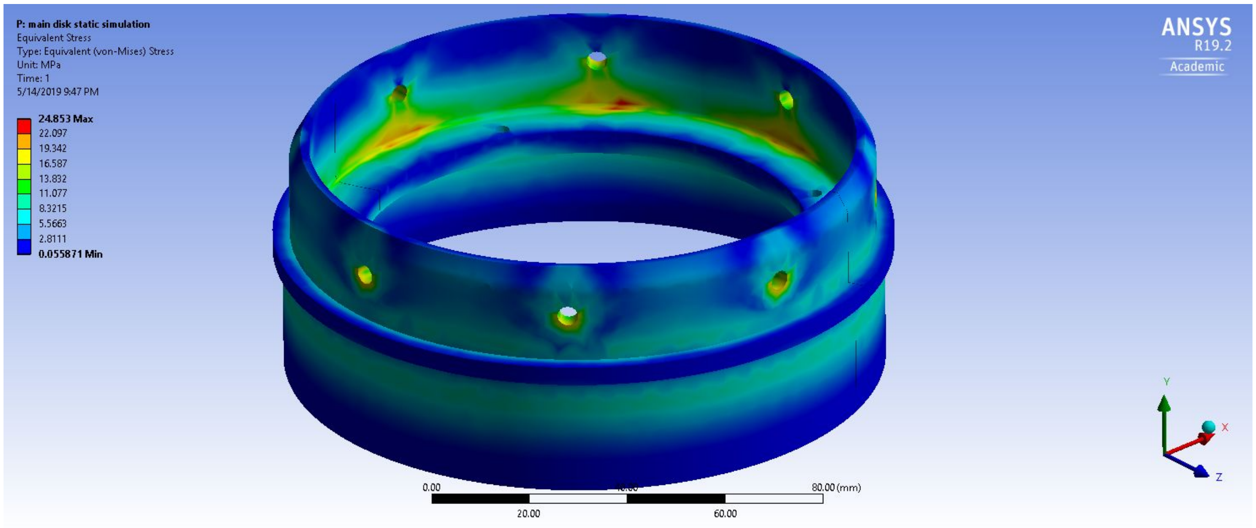

Figure 8 - von Mises Stress in connection disks.

It is possible to observe that the maximum von-Mises Stress occurs at the thread and near corner and has a value of 24.83 MPa, which provides a minimum safety factor of 8 for aluminum 6351-T6.

The shoulders were designed primarily using experimental tests and recommendation by ERSA and other rocket flight institutions. The sliding surface has length of 1 diameter (127 mm) and it is made of aluminum. It is shaped as a tube with an outside diameter of 123 mm (4.84 in) and a 2 mm (0.079 in) of thickness.

Another simulation considering the impact of a tube with ground was performed. It was used a velocity of 15 m/s in the vertical direction. Figure 9 shows the total deformation distribution. It is interesting to observe that the maximum deformation is 34.25 mm and the tube does not break for that impact conditions.

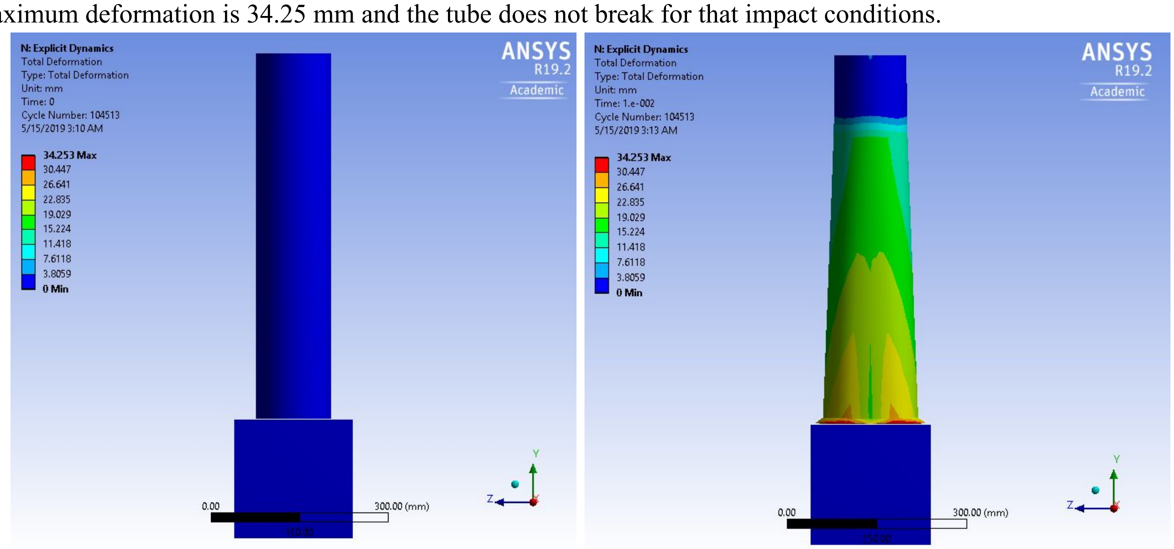

Figure 9 - Total deformation of the tube under impact at 15 m/s

Fig. 10 shows the total energy changes on time,showing that the impact time is about 3E-3 seconds. This results show that the tube will resist the impact on the ground, ensuring the integrity of internal equipments.

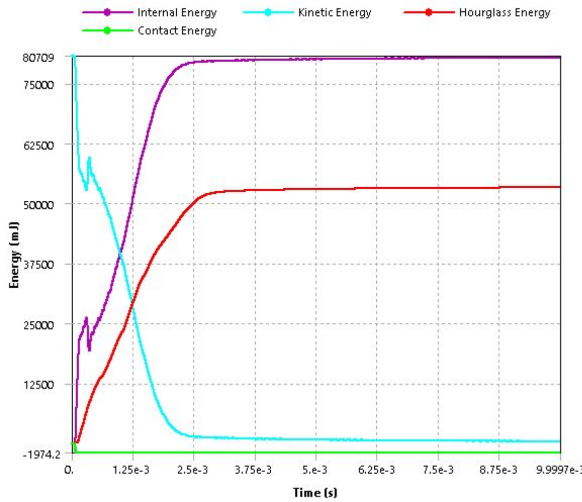

Figure 10 - Energy distribution x Time during impact

Aerodynamic CFD simulations

CFD numerical simulations offer an effective way for aerodynamic analysis. For this study a steady state RANS approach was used. It was used a tetrahedral mesh with an inflation rate of 1.2 near wall for a good boundary layer description.. The selected turbulence model was the one equation Spallart allmaras. This model represents a viable alternative to LES or DNS models which require more computational time. The simulations were made to account for Drag Force and Mach number distributions over the rocket. Pressure far field boundary conditions were applied. Flow directions and a Mach number of 0.8 were used as flight conditions.

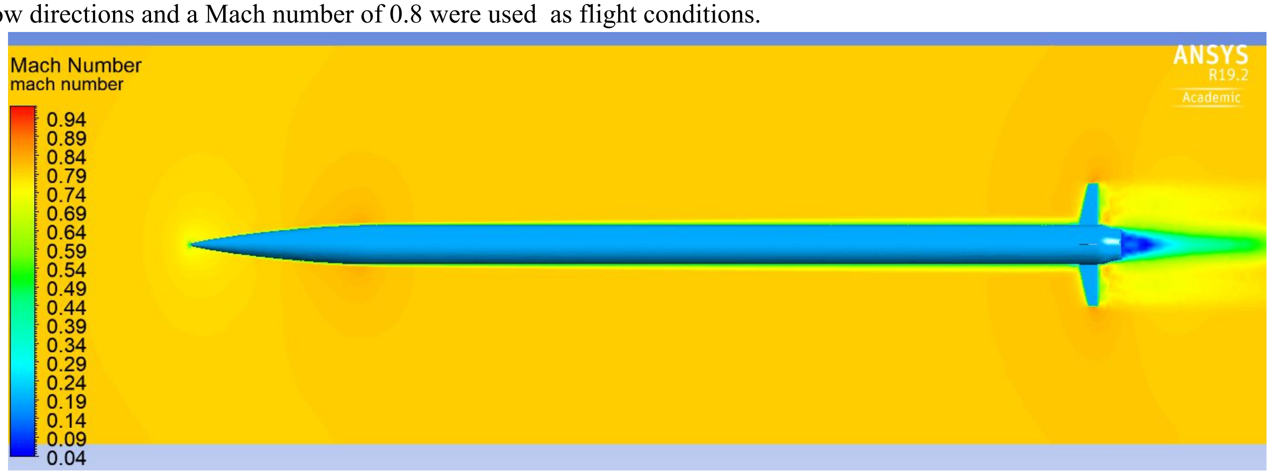

Figure 11 - Mach number contours over the rocket

Fig. 11 shows the Mach number distributions over the entire rocket. These results highlighted the aerodynamic performance over the referred flight condition. The most remarkable result to emerge from the data is the Mach number gradient over the tail.

Fig. 12 presents details of the Mach number and Pressure distributions over the nose cone. It is important to note that the Von Karman ogive guarantees a stable pressure distribution.

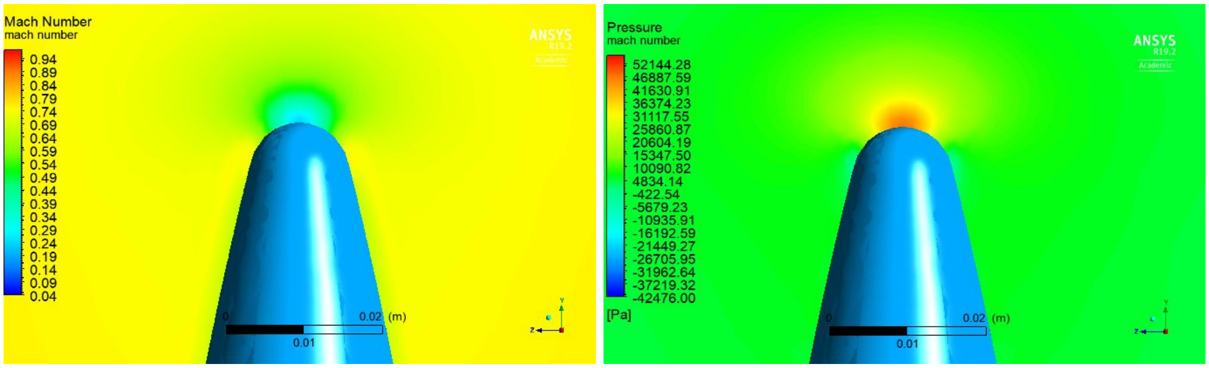

Figure 12 -Mach number and pressure distributions over the nose cone

Fig. 13 compares the Mach number distributions of 4 different fin geometries. These results offer compelling evidence of what geometry is more suitable for the rocket. The lower right image represents the selected fin that has a drag force of 75.79 N.

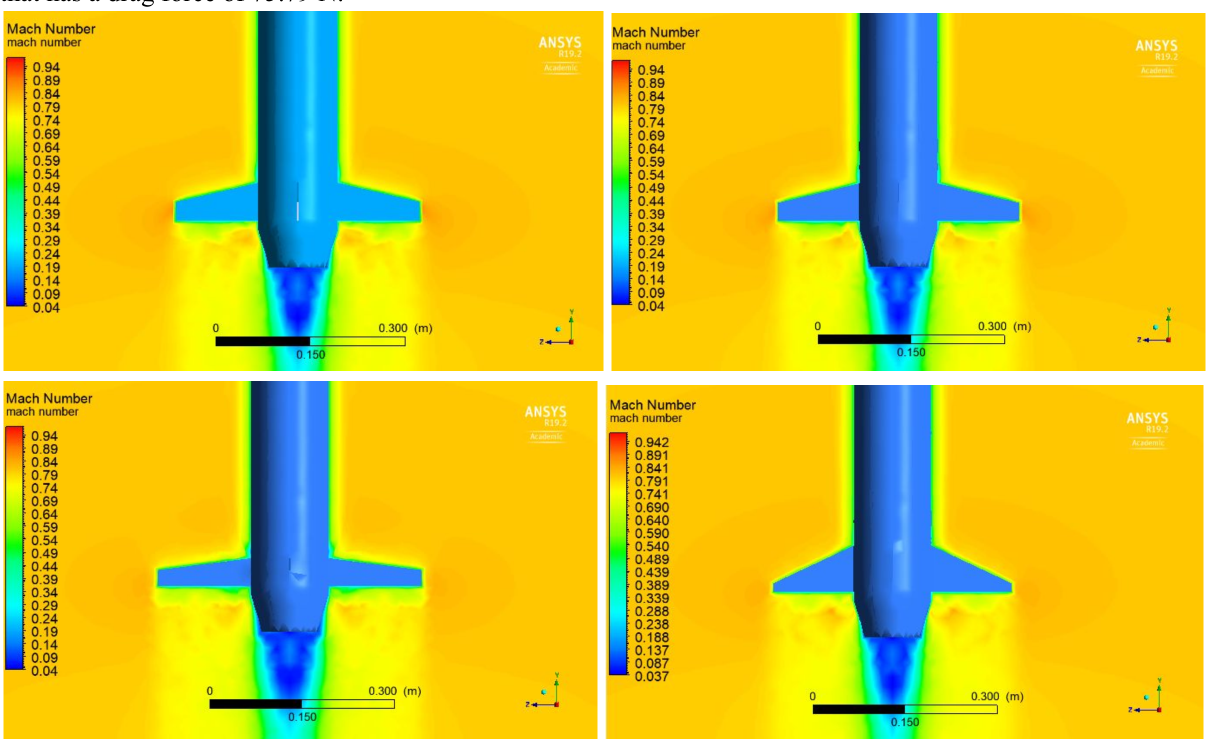

Figure 13 - Mach number distribution over 4 different fin geometries

Aerodynamic Stability

The rocket uses three trapezoidal fins for a passive stability technique. The simplified Barrowman equations were used to determine the dimensions of the fins and the final static margin of the vehicle is 2.0 calibers. The image below, Figure 14, shows the center of gravity (in blue) and the center of pressures (in red), calculated by RASAero 2.0.

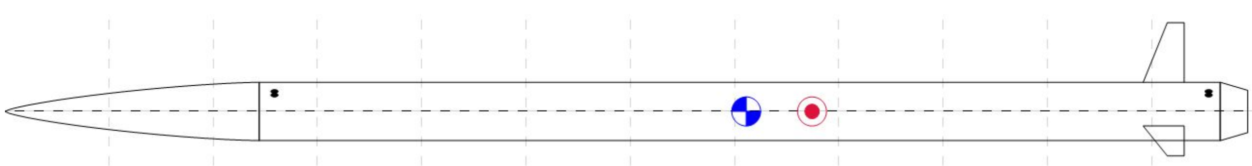

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Figure 14 - Center of Mass (Blue) and Center of Pressure (Red) calculated with RASAero.

Using RASAero, the static margin was verified and also analyzed for Mach numbers different from zero, all the way up to Mach 1.6, even though the rocket is expected to reach only Mach 0.8, reaching a minimum of 2.07 calibers.

The static margin was also verified through the flight simulation, to be presented in the next section.

The optimization method to determine the dimensions of the fins should minimize the area of the fins and find a value for X_{sm} close to 2.0. Therefore, a merit function was created using a Gaussian:

$$M = \frac{exp -[\frac{(X_{sm}-2.0)}{2\sigma}]^2}{A_{fins}}$$

σ =0.2. Iterating over values of F_{RC} , F_{TC} and s , the optimal values were found using the maximum of function M. The area of each fin was calculated using the simple equation for a trapezium. The final dimensions of the fins is as follows:

- $s =$ 130 mm (5.12 in)
- F_{RC} = 90 mm (3.54 in)
- F_{TC} = 37 mm (1.46 in)

The nose cone was optimized to reduce drag. It is designed as a Von Karman nose cone with a fineness ratio of 4.4 and a bluffness ratio of 0.1.

The rocket is to be launched with an elevation angle of 85 degrees.

Flight Simulation and Trajectory

Projeto Jupiter has developed its own flight simulation software, which features 6 degrees of freedom motion and wind data imported from Wyoming Weather Web. This allows for a realistic simulation of the rocket's flight in different wind scenarios. From this, the group can obtain a good approximation for the expected apogee and the dynamic stability of the rocket. The code was developed in Python.

The predicted 3D path is given in Figure 15, which contains also the projection of the trajectory (in red) in the three planes.

More detailed information is given in Figures 16, 17 and 18 below. They show the evolution in time of four important parameters during the flight: velocity magnitude, acceleration magnitude, mach number and angle of attack.

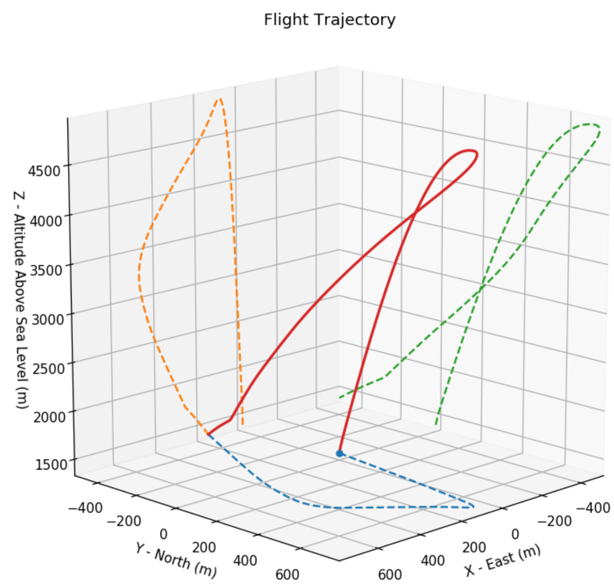

Figure 15 - Predicted 3D trajectory with launch angle of 85 degrees, heading north, and with drogue and main parachutes ejection

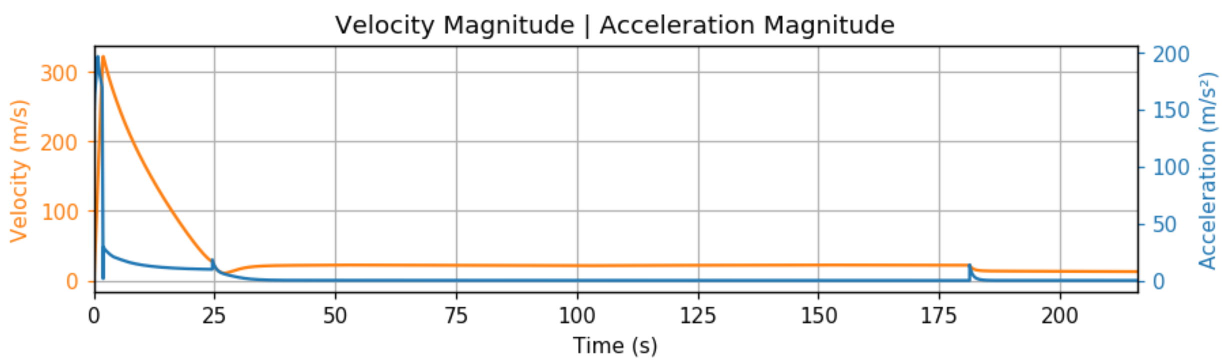

Figure 16 - Orange: magnitude of velocity as a function of time. Blue: magnitude of acceleration as a function of time.

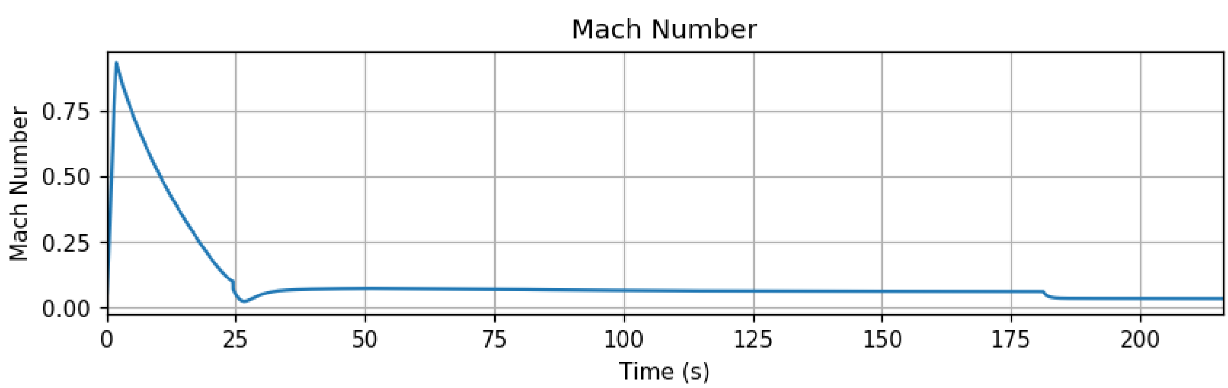

Figure 17 - Mach Number as a function of Time.

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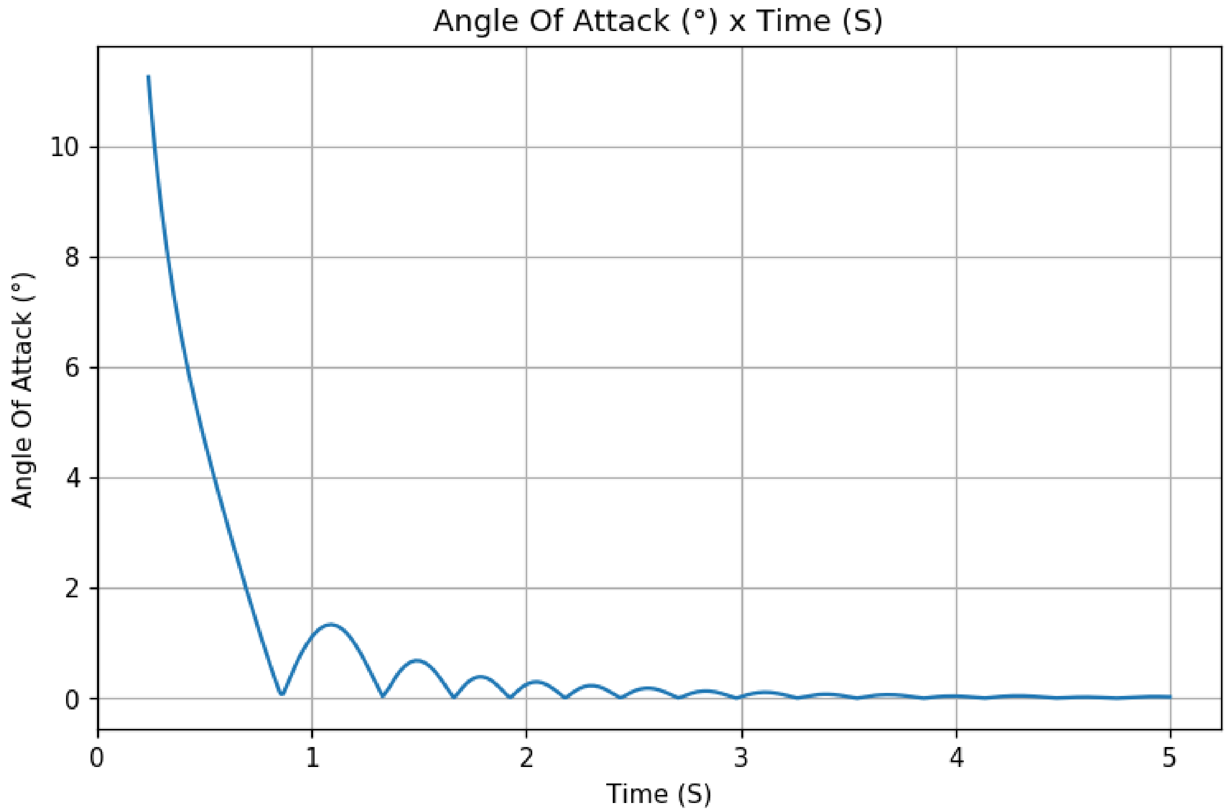

Figure 18 - Angle of Attack as a function of Time.

C. Recovery Subsystems

Introduction

The main task of the Recovery subsystem was to design a cold gas functional ejection system, capable of launching the parachutes over 1.5 meters away from the body.

The structure of the Recovery system is mainly based on two modules: the main module and the drogue module. At the top of the rocket Callisto, just below the rocket's nose cone, is the main module. Closer to the length center of the rocket, between the avionics and the motor module, is the drogue module. Both systems are symmetrical and use the same CO_2 cartridge, cartridge opening mechanism, lock system and U bolt. This arrangement is designed to ensure both systems would be able to withstand the worst scenarios.

Parachutes:

Main Parachute

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Figure 19 - Main parachute.

The main parachute canopy shape is of a semi-ellipsoid, a flattened hemisphere with a ratio minor/major axis of 0.707. By analyzing several parachute canopy shapes, the semi-ellipsoidal shape was chosen mainly for its ease of manufacturing while also retaining medium C_D,average angle of oscillation and impact characteristics.

The developing method and reasons presented below are based on Knacke- Parachute Recovery Systems Design Manual.

To start the develop and equation methods, first attempt to the steady flow and opening conditions:

- $Vx = 22.75\ \frac{m}{s}$, opening relative velocity
- $\rho\ =\ 1.11\ \frac{kg}{m^3}$, air density
- $M_t =\ 22.00\ kg$, total mass
- $V_f = 11.96\ \frac{m}{s}$, final velocity
- $g =\ 9.81\ \frac{m}{s^2}$, gravity

The final velocity value above can be inputted to the formula for the drag force in order to determine the parachute $C_D S$:

$$F_D\ =\ \frac{1}{2}\rho(C_D S)_p V^2\ \Leftrightarrow\ (C_D S)_p\ =\frac{2mg}{\rho V^2}\ \Leftrightarrow\ (C_D S)_p\ = 2.72\ m^2$$

Using a C_D of 0.9, a área of $S = 3,02\ m^2$ is determined.

Using the spreadsheet developed by Richard Nakka and available on the website “Richard Nakka's Experimental Rocketry Web Site”, we calculated the profile of each panel of a 12 gore semi-ellipsoidal parachute that would reach the area determined above. This profile can be found at the Engineering Drawings Appendix

The opening force can be determined by the formula from Knackle, where $C_x = 1.6$ for ringsail parachutes and $X_1 = 0.7$:

$$F_x = (C_D * S * \rho * V^2 * 0.5 * C_x * X_1)\ \Leftrightarrow\ F_x = 1089,35\ N$$

The length of the suspension lines is equal to 3 m. The riser length is equal to 3 m, to permit the parachute gets filed away of the rocket parts.

The materials used in each parachute part are:

- Canopy fabric: high tension polyamide 6.6
  - A typical parachute material resistant to impacts, ideal to work up to 250 Celsius degrees, with high porosity to decrease the opening forces and improve damping qualities
- Suspension lines: nylon cord 550.
  - Chose because of good shock absorption and friction resistance.
- Riser: nylon cord 1000.
  - Chose because of good shock absorption and friction resistance.

The English sewing method, using nylon thread, was used to make the links as robust as possible.

Drogue Parachute

Figure 20 - Drogue Parachute

The drogue parachute canopy is a ringsail model and has been chosen for its high stability.

The developing method and reasons presented below are based on Knacke- Parachute Recovery Systems Design Manual e EWING, Edgar G., Ringsail Parachute Design, 1972.

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To start the develop and equation methods, first attempt to the steady flow and opening conditions:

- $V_x = 24,23 \frac{m}{s}$, Opening relative velocity
- $\rho = 1.11 \frac{kg}{m^3}$, air density
- $M_t = 22.00\ kg$, total mass
- $V_f = 22.75 \frac{m}{s}$, final velocity
- $g = 9.81 \frac{m}{s^2}$, gravity

The final velocity value above can be inputted to the formula for the drag force in order to determine the parachute $C_D S$:

$$F_D = \frac{1}{2}\rho(C_D S)_p V^2 \Leftrightarrow (C_D S)_p = \frac{2mg}{\rho V^2} \Leftrightarrow (C_D S)_p = 0.75\ m^2$$

Using a C_D of 0.75, a área of $1m^2$ is determined.

From Knackle page 6-37 the nominal diameter (Do) and gore height Hr are:

$$Do = 1,1248\sqrt{S} \Leftrightarrow Do = 1,12\ m,\ Hr = 0.519Do \Leftrightarrow Hr = 0.58\ m$$

The opening force can be determined by the formula from Knackle, where $C_x = 1.2$ for ringsail parachutes and $X_1 = 0.9$:

$$F_x = (C_D * S * \rho * V^2 * 0.5 * C_x * X_1) \Leftrightarrow F_x = 263.92\ N$$

The length of the suspension lines is equal to 1.5 m. The riser length is equal to 3 m, to permit the parachute gets filed away of the rocket parts.

The materials used in each parachute part are:

- Canopy fabric: high tension polyamide 6.6
  - A typical parachute material resistant to impacts, ideal to work up to 250 Celsius degrees, with high porosity to decrease the opening forces and improve damping qualities
- Suspension lines: nylon cord 550.
  - Chose because of good shock absorption and friction resistance.
- Riser: nylon cord 1000.
  - Chose because of good shock absorption and friction resistance.

The English sewing method, using nylon thread, was used to make the links as robust as possible.

Ejection system

The ejection system was designed in a mirrored way. Therefore, the principle of operation in both systems is the same. The mainly difference between the drogue and main modules is the length of each one, that is different because of the size of each parachute.

Besides the parachutes, the ejection system has 4 vital parts: locking mechanism, U bolt anchor, CO2 cartridge and the cartridge opening mechanism.

- **Locking mechanism**

The recovery modules are closed on both ends by two plates each. The plate is secured in place by 4 standard M4 bolts. On the side that is opposite of the avionics module there is a shoulder which can slide inside the module's tube. In order to ensure the structural integrity of the rocket, this sliding range of motion must be locked down. To tackle this issue, a paracord is tied to both ends at the U bolts that anchor the parachute and is tensioned through the turning of the nuts that secure the bolt in place. The paracord has its insulation stripped off near the U bolt closest to the electronics module, where two pyrotechnic cutters are placed in parallel in order to ensure redundancy. The cutters burn the uninsulated paracord through the ignition of a very small black powder charge, smaller than 0.05g.

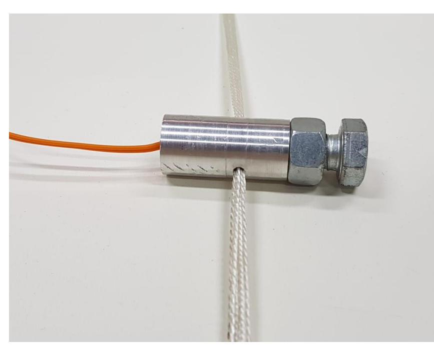

Figure 21 - Locking mechanism

- **U-Bolt**

Both main and drogue parachutes are attached to the modules by a pairs of U-Bolts secured with two nuts at the opposing side. These are steel bolts which have been tested and found to resist the opening forces imposed by the parachutes.

- **CO2 cartridge**

The ejection main energy source is a commercial 25g sealed CO2 cartridge. Through the breaking of its seal, the cold gas pressures the module, generating the force that pushes the shoulder out of the tube, alongside the parachute.

Figure 22 - Ejection System

- **Cartridge opening mechanism**

The CO2 cartridges seal is broken by a sharp conical punch, which is propelled by a small black powder charge, smaller than 0.1g, The punch is a cylindrical stainless steel with a conical tipp dedicated to break the cartridge's seal and trigger the recovery system once it for all..

The punch has a slit to involve a sealing ring that provides friction to the movement of the punch inside the tube, which is fundamental to avoid the punch to get stuck in CO2 cartridge exit, and block the gas expansion which would cause the failure of the recovery system. The tube has 2 holes of 6mm of diameter to release the pressure properly and let the system to work well.

Figure 23 - The components of the Ejection System

D. Electronic System

The electronic system is redundant, powered by six 9V battery with two completely independent dual-deploy system, both connected to the payload system via a 433 MHz wireless link.

1. *Primary system*

The first electronic system detects the altitude using a RRC3 “Sport” Altimeter [1], from MissileWorks. It is powered by a single independent 9V battery.

Each of the RRC3 outputs is connected directly to the e-matches which are attached to a 9V battery (one battery for Drogue parachute activation and another battery for the Main parachute) responsible for the Recovery System activation.

When the RRC3 activates drogue or main deployment, it produces an electrical current from the 9V battery that will activate the e-matches and consequently activating the Recovery System.

Figure 24 - RRC3 “Sport” Altimeter

The Primary System is also connected to the Secondary System through a digital port for serial communication. The Primary System will be able to send its data to its redundant counterpart.

2. Secondary system

Hardware

The second ejection system, in terms of hardware, is composed by a pressure sensor (BMP-280[2]) and a microcontroller board Nucleo-F446RE from STMicroelectronics, interfaced using a custom base PCB.

The microcontroller will act as a filter, which will be activated at the Drogue and Main ejection, producing a signal to the Signal Conditioning System, which is another custom base PCB.

The Signal Conditioning System will produce an electric current from the 9V battery, associated to the e-matches, that will activate them and consequently the Recovery System.

Parallel to the filter system, the microcontroller will use a 433 MHz wireless link [3] for the internal rocket communication with the Payload System, transmitting the output data from the BMP-280 and the serial data from the RRC3 Altimeter.

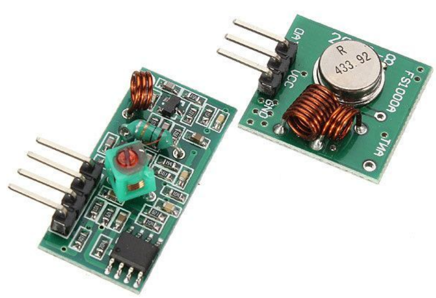

Figure 25 - 433 MHz wireless link

The activation of the Secondary System will be made by a key-lock system, positioned at the rocket fuselage. When the key is turned, the system will be activated, followed by a distinguishable noise produced by a buzzer.

Software

The implemented software running on the microcontroller has the main goal of detecting the apogee and the Main parachute deployment altitude. Since the sensor takes about 6.4 ms to supply a new pressure value after being asked to do it, there is enough time for the filter to perform its calculations. During the time remaining after the filter update and the next pressure data read, the system will attempt to read the incoming data from the RRC3 Sport Altimeter through a serial port and to send it alongside the BMP280 data to the Telemetry System via the 433 MHz Link. The described behavior is depicted in figure 25:

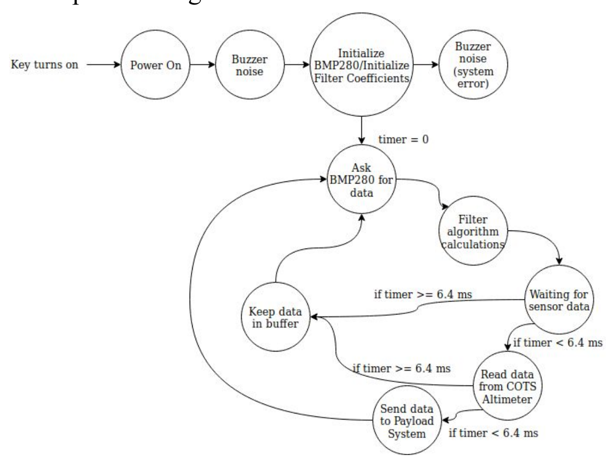

Figure 26 - Software operating diagram

System Activation

The RRC3 is powered on and followed by a beep signal. Subsequently, the electronic system is activated by a key-lock activation system (pacri key, as shown in the figure 26). The system activation is followed by a beep signal. A potential malfunctioning of the system will be indicated by a sequence of beeps signals after the required time for the system's internal checkout. With a fully-functioning altimeter and ejection system, the next step is to activate the Payload system.

Figure 27 - Pacri key

Functional Description

The purpose of this system is, given the data from the pressure sensor, to trigger the parachute deployment events at the correct time. The system can assume four states: "Initial", "Detect Drogue", "Detect Main" and "Final". At each cycle an update routine is called, which receives the pressure as input and updates the state accordingly.

- **State Descriptions**

Initial

State in which the system is set at initialization. In this state, the data buffers are guaranteed to be initialized with an initial value and are not updated. The transitions from this state to the "Detect Drogue" state, when an enable event is triggered, that is, 5 seconds after the activation of the system's enable switch.

Detect Drogue

State in which the system is processing the data to detect the apogee event, which will cause it to transition to the "Detect Main" state. This transition triggers the activation of the drogue parachute deployment signal.

Detect Main

State in which the system is processing the data to detect the main parachute deployment event, which will cause it to transition to the "Final" state. This transition triggers the activation of the main parachute deployment signal.

Final

State in which the systems stays after both parachutes were deployed. In this state the system is in a idle state and no calculations are performed.

- **Filtering and Detection**

Given the complexity of the actual dynamics of the system and the difficulty of getting precise altitude data from the pressure data (given dynamic effects), an adaptive approach was taken for the data filtering and pressure data was used directly for both filtering and detection.

Filtering

The filtering stage is an Adaptive Line Enhancer based on an NLMS adaptive filter. It consists in an NLMS adaptive filter, using the pressure signal as the pressure signal as reference signal (d(i)) and a using as input this same signal, but delayed. In this way, the algorithm estimates a discrete system model (in this case a Finite Impulse Response filter), which is used to estimate the current pressure value from past ones, and thus, under some conditions, filtering out the non-deterministic components of the signal.

Apogee Detection

The detection algorithm relies on the fact that near the apogee, the speeds are small and thus the trajectory near this point can be approximated fairly well as a parabola. The detection is done by having a normalized vector with the points of a parabola arc, and getting the best approximation of the current pressure vector as a multiple of this vector plus a constant. This constant, given the small speed condition near apogee, can be approximated as a function of altitude times the acceleration of gravity. Thus, by checking if this constant is greater to some threshold and by checking if the error of the approximation is less to some other threshold, an specific point of the trajectory can be detected. These two parameters are determined from the trajectory data from statistical simulations which take into account both the noise in the sensors and the variability of the trajectory and are optimized to get a probability of detection failure less than 10^{-6} and to meet the specified mean and uncertainty values for the parachute deployment times. Below are examples of the mean results of and the parabolic arc curve used in a simulation run with 1 million realizations and sampling frequency fs = 100Hz:

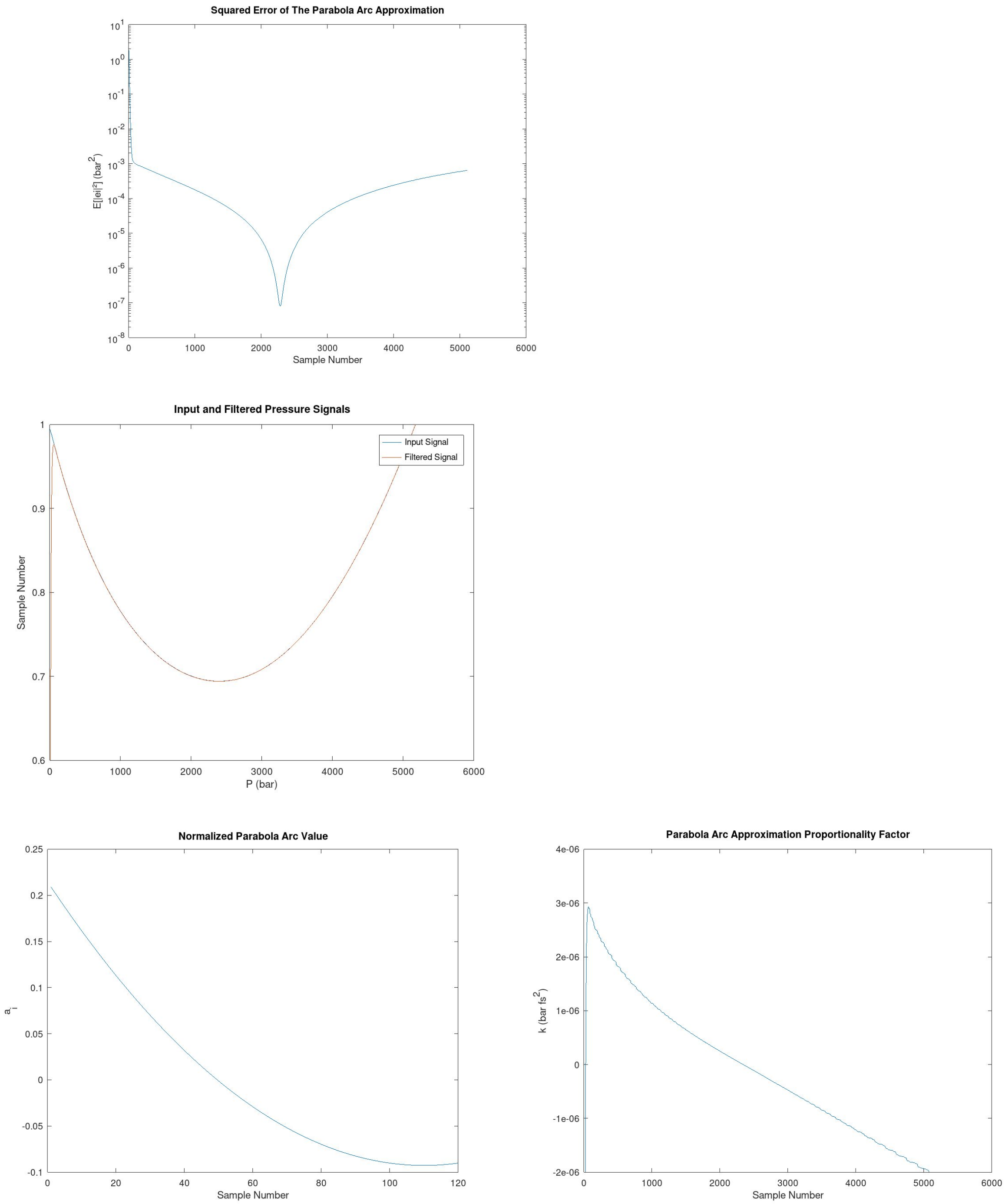

Figure 28 - Apogee detection graphics

Main parachute altitude detection

Given the low-noise nature of the filtered signal, and the fact that detection of this event only occurs after the deployment of the main parachute, a simple method can be employed for detection. Given an pressure (or, equivalently, an altitude) specified in the design, it is sufficient to check whether the measured pressure signal has crossed this value, indicating that the desired point has been reached.

E. Payload System

The Payload System will be composed of a Data Communication System and a Data Acquisition System, both running on a single B-L072Z-LRWAN1 LoRa®/Sigfox™ Discovery Kit by STMicroelectronics (Arm® Cortex®-M0+ core) and the CMWX1ZZABZ-091 LoRa®/Sigfox™ module by Murata. It also receives data from the Electronic System.

The structure of the Payload System is composed of a steel plates to certify rigidity and integrity to the system. An SD Card Module is placed inside of an enclosure made of a cylinder steel external structure and an internal coating of polyurethane foam, directly in contact with the SD Card. That structural artifice was made to prevent the rupture of the SD Card in flight, caused by strong oscillations, in case of a unexpected increase of the impact velocity.

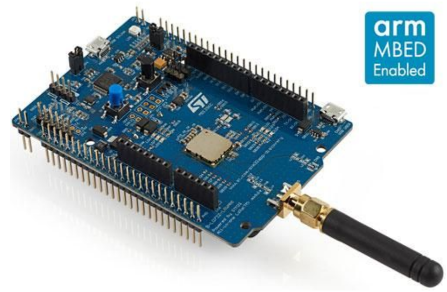

Figure 29 - B-L07Z-LRWAN1

Figure 30 - Payload Structure

1. Data Acquisition System

a. Hardware

The sensor data will be received from a GPS GY-NEO6MV2 [4] Module present in a custom made PCB, attached to a X-NUCLEO-IKS01A2 expansion board by STMicroelectronics, which is connected to the LoRa® Discovery Kit. It will provide the following sensors [5] :

- LSM6DSL MEMS 3D accelerometer (up to 16 g measurements) and 3D gyroscope (up to 2000 dps), up to 6664 Hz output data rate;
- LSM303AGR MEMS 3D accelerometer (up to 16 g measurements) and magnetometer ($\pm$ 50 gauss), up to, respectively, 5376 Hz and 150 Hz output data rates;
- LPS22HB MEMS pressure sensor, up to 1260 hPa measurements absolute digital barometer, up to 75 Hz output data rate ;
- HTS221 capacitive digital relative humidity and temperature sensor, both sensors up to 12.5 Hz output data rate.

The 433 MHz wireless internal communication module will provide data from the redundant Electronic system.

When the system is activated, is followed by a distinguishable noise produced by a buzzer.

b. Software

The designed software is based on custom libraries developed by STMicroelectronics based on Mbed-OS [6]. It will attach all the data supplied by the sensors in data arrays, containing approximately 932 bits. The software will attempt to optimize the data income so that the slower sensors will not limit the data output rate for the Data Transmission System. The following image illustrates the behavior of the designed software.

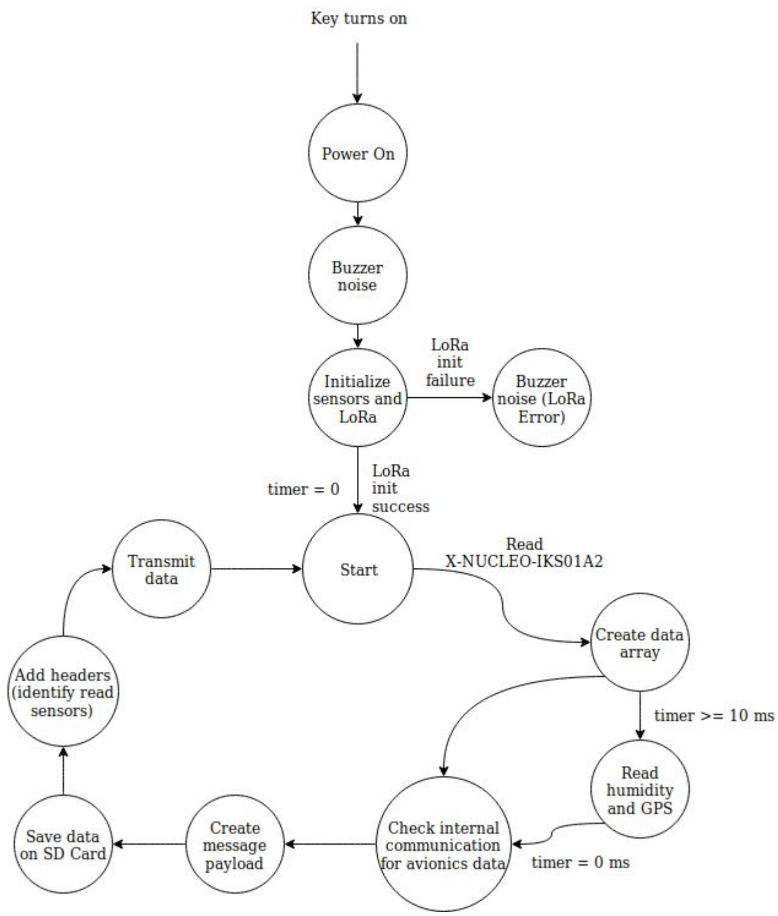

Figure 31 - Electronics Scheme

The calibration of some of the sensors (accelerometer and magnetometer) provided by STMicroelectronics is viable through software implementation, following the instructions [7] from their producer.

c. Payload System Activation

The Payload activation is identical to the RRC3 and electronic systems. For a potential malfunctioning warning, the Telemetry system must be checked. If it operates successfully, the ground team will succeed to receive its data and will be able to check which sensor is malfunctioning. Using the telemetry data, there can also be a confirmation of the correct activation of the RRC3 and ejection systems. The launch will be authorized only if the altimeter and ejection systems are operating under normal conditions.

2. Data Communication System

a. Transmission

The transmission module will be the LoRa CMWX1ZZABZ-091 by Murata, with the following characteristics:

- Operational distance:
- Output Power: +20 dBm;
- Operation frequency: 915 MHz;
- Transmission rate: up to 300 kbit/s

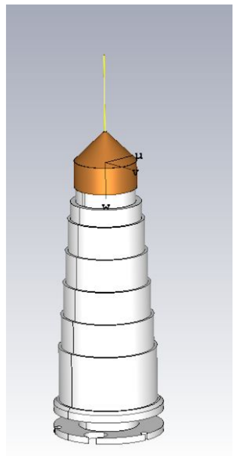

Figure 32 - Monopole Antenna

The transmission device is a custom made monopole antenna, developed for 915 Mhz frequency. As characteristics, it has linear polarization and an impedance of 50 Ω.

The structure of the antenna is composed a copper plate ground plane bent into a truncated cone and a cylinder, both soldered to each other. The monopole is made of the inner conductor of a RGC-58 Celular Coaxial Cable [8] . There is also a nylon structure under the conductive elements, acting as a dielectric.

Electromagnetic simulations through the software *CST Studio* show that this nylon structure is not only a structural support for the conductive elements, but also important for the irradiation characteristics of the whole transmission device. The following graphs show the reflection coefficient magnitude (expressed as the Scattering Parameter S2,2 normalized, in decibels).

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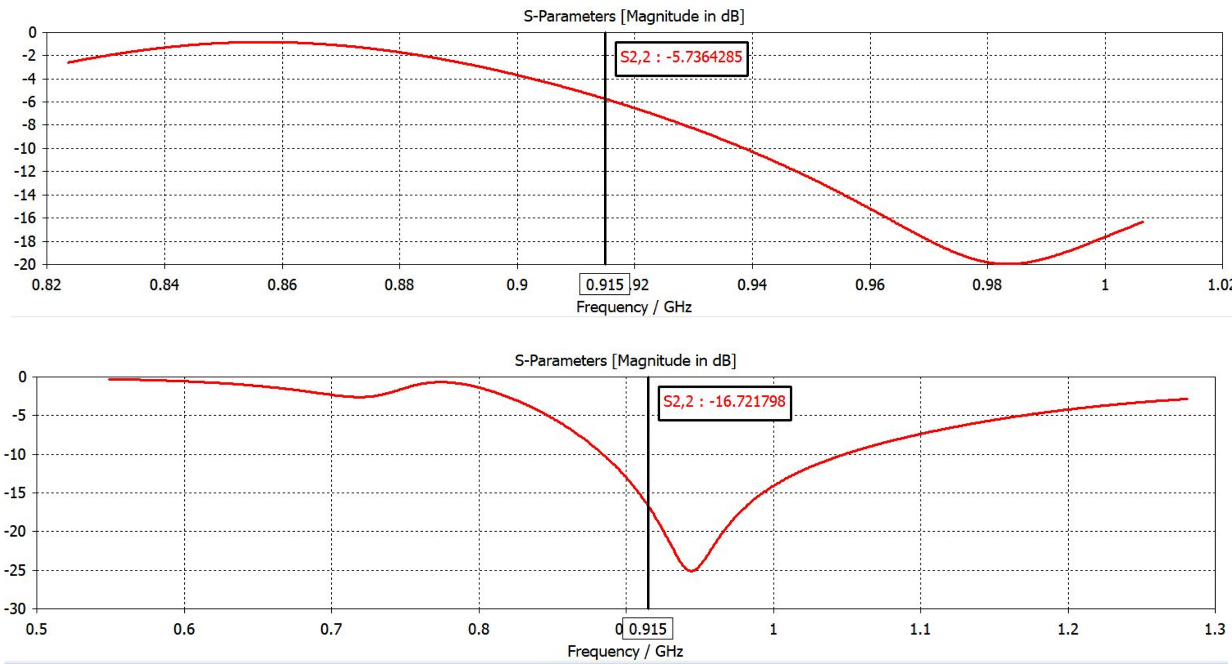
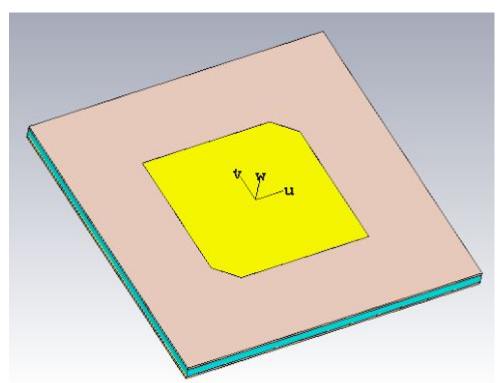


Figure 33 - S-Parameters

It is possible to see that in the second image that the reflection coefficient is much smaller for the 915 MHz central frequency of the Transmission System. This effect happens because the electrical relative permittivity of the nylon ε_r is greater than the air's electrical permittivity, thus increasing the electrical width of the antenna and moving the resonance frequency to the left, closer to 915 MHz, as desired.

b. Reception

The reception module will be the LoRa CMWX1ZZABZ-091 by Murata, with the characteristics described above. In addition to the LoRa CMWX1ZZABZ-091 by Murata, is used an B-L072Z-LRWAN1 LoRa®/Sigfox™ Discovery Kit by STMicroelectronics (Arm® Cortex®-M0+ core) to interface the data transference by serial communication to a team computer, that will receives all data and work with them.



The reception device is a microstrip planar antenna, designed to match the transmission antenna frequency. As characteristics, it has circular polarization and an impedance of 50 Ω. The antenna structure is composed by two PCB's, a polypropylene substrate and a 50 Ω RG-58 coaxial cable. One of the PCB' s at the bottom of the antenna, acting as a ground plane and the other on the top with the radiating element (microstrip), between the two PCB' s is the polypropylene substrate, acting as the antenna dielectric.

c. Data usage and applications

During the data acquisition/transfer, in a team member's computer, the data will be conditioned and will serve for many different uses. If the GPS data is received through the telemetry with no errors, the rocket coordinates can be obtained. With these coordinates the recovery team work can be improved, restricting the search area or even providing a fairly accurate collision point.

With the barometer, gyroscope, magnetometer, accelerometer and GPS, through a sensor fusion algorithm, many informations about the flight can be obtained, such as trajectory of the rocket, its attitude, acceleration and angular velocity, describing its mechanical behavior. The team can compare these data with data received by a previous trajectory simulation and improve the rocket trajectory simulation method for the next launches.

Data about each system (Electronic and Payload) will be received, so it's possible to determine more accurately which of the rocket systems may have failed, helping the team to develop a better project constantly.

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III. Mission Concept of Operations Overview

The mission of our rocket launch consist in 3 phases: launching, free flight and recovery. In the launching process the rocket is mounted in the rail, the electronic systems are activated and tested, the ignitor is placed inside the motor and, with a secure launching area, the igniter is activated and then the launch starts. There will be an "Ignition" sign to alert everyone about the ignition process. As the rocket starts to move, the sign "Liftoff" is said. After the phase of free flight, the drogue parachute will be released and the sign "Drogue" should be said, indicating the start of the recovery phase. The next event should be the main parachute release followed by the sign "Main". Finally, when the rocket touches the ground, there will be the last sign "Land" to confirm landing. The recovery team will only actuate after the confirmation of a safe landing point. The telemetry system will provide the GPS data indicating the ground rocket location.

IV. Conclusions and Lessons Learned

Aerodynamic system managing view

The difficulties found in the aerodynamic system were: the development of a vacuum infusion manufacturing method for composites, which was used to make the rocket fins; manufacturing of the composite tubes, which required significant amount of testing to assure a reliable production; the bolted connections also required a significant time to be simulated numerically in order to assure the required strength; and the CFD simulations were carried out to verify the drag coefficient and aerodynamic stability. Therefore, the group has made great advances in composite manufacturing technology and CFD analysis this year.

Staff wise, this subsystem was formed by 13 members and each one of them had a significant contribution to the final project. For the next cycle, elections will be held for a new manager, which will follow the goals of innovating and developing new technologies for the university.

Propulsion system managing view

During the motor project, it was planned to build and test a hybrid motor, but unfortunately some unexpected events made it hard to conquer the objectives safely. The project is being developed and will still be tested, but the time left for the competition would not be enough to get it done. Therefore, it was decided to postpone it and, for this year, the rocket launched is going to use a commercial motor. It was found a motor that would fit our specifications.

Electronics and Payload systems managing view

The Electronics System has found the design of the filtering method for the redundant apogee detection, the most troublesome activity. The filtering method chosen needed extensive calibration to determine good base thresholds, which needed to be tested several times.

The Payload System encountered several difficulties. First of all, the manufacturing of the designed antennas was difficult. The tools and materials available made it arduous to achieve the correct dimensions for each aspect of the antenna, so it took many prototypes to obtain a reasonable result. Secondly, all the sensors, communication systems and microcontroller architectures were changed, so the software developed in the last years had to be redesigned and tested. Thirdly, the team was not able to develop a more useful interface for data reception in terms of data visualization and sensor fusion. With these tools, it would be faster to analyze real-time incoming data, to visualize the rocket's attitude and trajectory, and to determine the impact point, which would accelerate the later rocket retrieval. However, it was not defined as a main goal for the team since the beginning of the this project's development, consequently, due to cronogram issues, there was not enough time to develop this solution.

Another difficulty found in both systems was that the knowledge of the many parts of the Filtering and the Telemetry, was condensed in a very small group of people, leaving most of the members with a shallow understanding of the software and the theory behind many concepts.

As a matter of mitigation for these problems, the team shall reuse the designed antenna if the rocket is fully recovered or develop a new design that should be easier to fabricate, reproduce and would not suffer as much influence from the other rocket parts as the current antenna does. Furthermore, the filtering method needs to be improved, which takes deep research, testing and also demands the teaching of the filter operation to other members. Moreover, the team plans to start the development and research of a good data reception solution early for the next rocket development cycle.

In terms of knowledge dissemination, the next Electronics and Payload manager shall implement better communication and project control tool, suck as Slack and Trello for the subsystem. Another solution proposed is to teach lessons for the newer members as well as the gathering of better bibliography to be indicated to the personnel.

Lastly, it is notable that many of the problems encountered in the Payload and Electronics Systems may not be encountered in the future rocket projects because if they as nominal during the rocket launch, they could be reused for further applications.

Recovery systems managing view

- Recovery difficulties :
  - Parachute research: finding good and reliable literature.
  - Ejection systems testing: keeping members updated and working throughout the project.
- Solutions :
  - Parachute research: to ensure the analytical methods used were correct, parachutes were tested in action after manufactured. This test consisted in attaching the piece to a car and driving it at the flight speeds expected after apogee while measuring the exerted force with a load cell. Through this it was possible to assure the analytical method used at this years project were correct.
  - Ejection systems testing: through a WhatsApp group, tasks were weekly updated and results posted. Also, a document with the weekly meeting discussion was created. This document allowed for members to initiate discussions beforehand, and therefore have more efficient meetings.

SYSTEM WEIGHTS, MEASURES, AND PERFORMANCE DATA APPENDIX

Spaceport America Cup

Intercollegiate Rocket Engineering Competition

Entry Form & Progress Update

Color Key | COTS = Commercial Off The Shelf | v15.1

IMPORTANT CHANGE EFFECTIVE IMMEDIATELY FOR SA CUP 2019 EVENT

All inputs are mandatory for all submissions of this document. We understand some data may change over time. This is completely acceptable.

Feel free to add additional comments where needed, and be sure to fill out the last page. Treat the last page as a "cover letter" for your project.

Date Submitted: 5/17/2019

Team ID: 88 — * You will receive your Team ID after you submit your 1st project entry form.

Country: Brasil

State or Province: n/a — State or Province is for US and Canada

Team Information

Rocket/Project Name:	Callisto
Student Organization Name:	Projeto Jupiter
College or University Name:	Escola Politécnica da Universidade de São Paulo / Polytechnic School of University of Sao Paulo
Preferred Informal Name:	n/a
Organization Type:	Engineering Class
Project Start Date:	10/1/2017 — *Projects are not limited on how many years they take*
Category:	10k – COTS – All Propulsion Types

Member	Name	Email	Phone
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Address Line 3:	São Paulo
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Address Line 5:	Brasil

Demographic Data

This is all members working with your project including those not attending the event. This will help ESRA and Spaceport America promote the event and get more sponsorships and grants to help the teams and improve the event.

Number of team members

High School	0		Male	59
Undergrad	71		Female	12
Masters	0		Veterans	0
PhD	0		NAR or Tripoli	0

Just a reminder the you are not required to have a NAR, Tripoli member on your team. If your country has an equivalent organization to NAR or Tripoli, you can send them in the NAR or Tripoli box. CAR from Canada is an example.

STEM Outreach Events

- FEIMEC 2018: The second Brazilian international machinery and equipment exhibition. It is organized by ABIMAQ, the Brazilian Machinery Builders Association, representing nearly 7800 companies.
- FEIPLAR and FEIPUR 2018: The third Brazilian international plastic composites and polyurethane exhibition.
- POLI BEN 2018: Charity event for showing needy children more of the engineering course and motivating them to follow this career. It is organized by several student organizations of the Polytechnic School of University of Sao Paulo and the NGO "Agente".
- Cobruf Rockets 2017: The first rocket competition hosted in Brazil. In this event, we won the first place.
- MiniRocket Launch in 2017: Our team launched an mini-rocket to simulate our previous rocket impulse.

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	107.29	
Airframe Diameter (inches):	5	
Fin-span (inches):	5.12	
Vehicle weight (pounds):	28.692	
Propellent weight (pounds):	6.40	
Payload weight (pounds):	9	
Liftoff weight (pounds):	44.093	
Number of stages:	1	
Strap-on Booster Cluster:	No	
Propulsion Type:	Solid	
Propulsion Manufacturer:	Commercial	*Our hybrid project had some setbacks and we had to postpone it, therefore our solution in order to enable launching our rocket was to use a commercial one.*
Kinetic Energy Dart:	No	

Propulsion Systems: (Stage: Manufacturer, Motor, Letter Class, Total Impulse)

1st Stage: Cesaroni Technology, Pro75-6118M3100-P (White Thunder), M Class, 6117.8 Ns

Total Impulse of all Motors: 6117.8 (Ns)

Predicted Flight Data and Analysis

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

Pro Tip: Reference the Barrowman Equations, know what they are, and know how to use them.

	Measurement	Additional Comments (Optional)
Launch Rail:	ESRA Provide Rail	
Rail Length (feet):	17	
Liftoff Thrust-Weight Ratio:	17	
Launch Rail Departure Velocity (feet/second):	111.696	
Minimum Static Margin During Boost:	2.055	*Between rail departure and burnout
Maximum Acceleration (G):	18.748	
Maximum Velocity (feet/second):	991.362	
Target Apogee (feet AGL):	10K	
Predicted Apogee (feet AGL):	10,7K	

Payload Information

Payload Description:

The Payload will be a flight data acquisition system with ground-station telemetry. The embedded systems for data acquisition are based on the X-NUCLEO-IKS01A2 expansion board by STMicroelectronic with accelerometer, gyroscope, magnetometer, barometer, temperature probe and humidity sensor. A GPS GY-NEO6MV2 GPS module and a 433 MHz RF link connected to the avionics system to receive its data will both work alongside the expansion board. Telemetry system is be based on a COTS LoRa radio module (CMWX1ZZABZ-091by Murata) operating at 915MHz, provided by B-L072Z-LRWAN1 LoRa®/Sigfox™ Discovery Kit by STMicroelectronics, via an antenna designed by our team to meet the tight space constraints set on the design requirements. Both the Telemetry and the data acquisition will be connected to the microcontroller STM32L072CZ, which is also available at the B-L072Z-LRWAN1 Kit. A SD card will save all data inside the rocket, aiming to provide a secondary analysis of the rocket data, after its recovery.

Recovery Information

The recovery system will split into two systems, main and drogue, which will have their respective parachute independently deployed through a cold gas approach, where a small black powder charge will open one 25g CO2 cartridge and similar system will cut the tractioned line used to prevent the module from opening prematurely during the flight . The signal to deploy will come from two redundant systems: the COTS RRC3 "Sport"® Altimeter by MissileWorks and a system based on pressure measurements from a BMP280 barometer with a NLMS based adaptive line enhancer filtering developed by our team. The drogue parachute is expected to deploy at apogee at a speed of 24.227 m/s (79.484 ft/s), resulting in an opening force of 293.36N (65.94 lbf) . The main parachute is expected to deploy at 400m (1312.34 ft, altitude) at a speed of 22.75m/s (74.639 ft/s), estimated drogue terminal velocity, resulting in an opening force of 1089,35 N (246.553 lbf) and a terminal velocity of 11.96 m/s (39.241 ft/s).

Planned Tests

* Please keep brief

Date	Type	Description	Status	Comments
2/9/19	Ground	Parachute Ejection and Drag Tests	Successful	Measurements of opening forces, drag and opening time for both Drogue and Main parachutes.
2/17/19	In-Flight	Mini-Rocket Launch (Caldene)	Minor Issue	Mini-rocket designed to reproduce the speed on apogee, the maximum velocity and the maximun aceleration of our rocket. The main propouse of this operation is to test the eletronic (more specifically: the determination of apogee and recovery system) and recovery (more specifically: the deployment system of the parachute and the droogue parachute). We successfully launched the mini-rocket with Callisto's eletronic and recovery systems. The trajeory of the rocket was different from our calculations and the parachute did not open. At this moment we couldn't find the rocket because it felt in a rainforest area, with dificult access. Despite of those problems, we could aquire valid informations for our eletronics, recovery and aerodynamics systems that will certanly result in improvments in Callisto
5/4/19	Ground	Airframe Material Characterization	TBD	Tensile Test of CFRP specimens

Any other pertinent information:

Entry Letter

Projeto Jupiter is a student organization from the Polytechnic School of the University of Sao Paulo (Brazil), the most recognized Engineering University in Latin America. We are a team dedicated to design, build and research experimental rockets, which is an achievement since our College does not have its own space engeneering program.

Furthermore, we are the second Brazilian team to compete at Space Port America Cup. Since 2015, we are trying to reach better performances and use more creative and innovative solutions in our rockets at SACUP.

Despite that, we did not participate at the 2018 Space Port America Cup. That is due to a combination of three primary factors. First of all, the team decided to change our propulsion system from a solid based propellent to a hybrid based propellent, whose manufacture wouldn't be finished on schedule because of too much time spent learning how to make a hybrid motor. We ended

up making the choice to launch a commercial motor, but everyone agreed it would be much better to launch one of our own making. Secondly, we were in the middle of a big change in our crew, since most of the experienced and knowledgeable members of the project were leaving our team. Thirdly, at the beginning of the project cycle we did not expect a devaluation of the Brazilian currency, which made the trip to Space Port America more expensive than usual.
In spite of those problems, we feel much more confident in our participation in SACUP 2019, because we managed to solve them: we had more time to manufacture our motor, and tests to assure it is efficient and secure are planned; our members are much more familiar with technical, logistical and administrative needs to launch a rocket; and it's agreed that from the moment of an eventual approval of our team in SACUP 2019, we are going to plan and manage our resources for the competition. Also, we had more time to develop our other subsystems, such as our Payload, Recovery System and Avionics.
In conclusion, we feel prepared to launch a new, innovative (at least in our parameters) and competitive rocket at SACUP 2019. Many project progresses were made in the rocket, tests of those improvements are already scheduled, and we are a better organized team as well.

PROJECT TEST REPORTS APPENDIX

- **Caldene Project**

The Caldene Project was developed in December, 2018 as a small project that would allow the team to test its subsystems and acquire experience regarding launching and security protocols.

A mini-rocket with solid propellant propulsion was projected to carry similar structures from Electronic and Recovery subsystems used in the previous launches and, therefore, test them. Since the mini-rocket has no telemetry system, an additional flight recorder was added to ensure data collection in a malfunctioning parachute ejection scenario.

During the assembly process, both Aerodynamics and Recovery subsystems faced difficulties. This experience provoked the necessary corrections that leaded to a safer assembly process. In addition, the Electronic subsystem tested the prototype for the telemetry antenna.

In overall, the project was a great training activity to new members. The experience during the launching process helped the team to improve its launching protocol.

- **Payload message**

The previously mentioned Telemetry System will transmit data in the form of a header followed by a message payload. The following tables indicate the designed protocol for data transmission:

Header	
Bit number:	Header information:
Bit 0	-
Bit 1	-
Bit 2	LSM6DSL updated
Bit 3	LSM303AGR updated
Bit 4	LPS22HB updated
Bit 5	HTS221 updated

Bit 6	GPS updated
Bit 7	BMP280 and parachutes' status updated
Bit 8	COTS Altimeter data updated

Message Payload					
Byte offset	Format	Size	Name	Unit	Description
1	int	4 bytes	Time	ms	Time between successive transmissions
5	int32_t	4 bytes (each dimension)	ag[3]	m/s²	LSM6DSL (accelerometer)
17	int32_t	4 bytes (each dimension)	w[3]	rad/s	LSM6DSL (gyroscope)
29	int32_t	4 bytes (each dimension)	a[3]	m/s²	LSM303AGR (accelerometer)
41	int32_t	4 bytes (each dimension)	m[3]	mGauss	LSM303AGR (magnetometer)
45	float	4 bytes	p	mbar	LPS22HB (pressure)
49	float	4 bytes	temperatureLPS22HB	. ºC	LPS22HB (temperature)
53	float	4 bytes	humidity	%	HTS221 (humidity)
57	float	4 bytes	temperatureHTS221	. ºC	HTS221 (temperature)
61	unsigned_long	4 bytes	Time of week (ms)	ms	GPS data
65	long	4 bytes	Time of week fractional part (ns)	ns	GPS data
69	unsigned char	1 byte	GPS Fix		GPS data
70	long	4 bytes	ECEFX	cm	GPS data
74	long	4 bytes	ECEFY	cm	GPS data
78	long	4 bytes	ECEFZ	cm	GPS data
82	unsigned long	4 bytes	3D position accuracy	cm	GPS data
86	long	4 bytes	ECEFVX	cm/s	GPS data
90	long	4 bytes	ECEFVY	cm/s	GPS data
94	long	4 bytes	ECEFVZ	cm/s	GPS data
98	unsigned long	4 bytes	Speed accuracy	cm/s	GPS data
102	unsigned char	1 byte	Number of satellites		GPS data
103	float	4 bytes	Pressure	bar	
107	float	4 bytes	Temperature	. ºC	
111	int16_t	2 bytes	Timestamp	s	Timestamp from COTS Altimeter
113	int16_t	2 bytes	AGL Height	m	Above ground level height
115	int8_t	1 byte	Battery Voltage	V	Battery voltage reading from COTS Altimeter

	bool	1 bit	Drogue Status		Parachute status provided by Avionics
	bool	1 bit	Main Status		Parachute status provided by Avionics
	bool	1 bit	Main Status		Parachute status provided by COTS Altimeter
	bool	1 bit	Drogue Status		Parachute status provided by COTS Altimeter

RISK ASSESSMENT APPENDIX

Team	**Rocket/Project Name**	**Date**		
Escola Politécnica da USP	Callisto/ Projeto Jupiter	5/17/2019		
Hazard	**Possible Causes**	**Risk of Mishap and Rationale**	**Mitigation Approach**	**Risk of Injury after Mitigation**
Accidental ignition of motor before assembly, causing potential injury to nearby personnel	Propellant is exposed to any favorable condition such as heat, flames or sparks so that it may cause an unprogrammed ignition	Low; the commercial propellant is composed of mainly slow burning grais, without ignition enhancer.	Stock the grains separately and inside a thermal bag.	Low
	Propellant igniter exposed to static electricity or other heat source	Medium; Igniter pyrogen is more sensitive to initiation.	Only install igniter when rocket is assembled in launch pads. Use proper protective gear while doing this procedure. Always shunt igniter leads.	
Explosion of solid-propellant COTS rocket motor during launch with blast or flying debris causing injury	Debonding of propellant from inhibitor	Low; COTS rocket motor is certified by Cesaroni Technology and has been in the market for several years.	Visually inspect motor grain for cracks, debonds, and gaps during and after assembly	Low
	Gaps between propellant sections and/or nozzle		Use ductile (non-fragmenting) material for motor case	
	Chunk of propellant breaking off and plugging nozzle		Inspect motor case for damage during final assembly before launch	
	Motor case unable to contain normal operating pressure		Only essential personnel in launch crew	
	Motor end closures fail to hold		Launch crew 200 feet from rocket at launch, behind barrier	
Rocket does not ignite when command is given (“hang fire”), but does ignite when team approaches to troubleshoot	Ignition signal is still "on" when approaching launch pads	Low; ignition signal requires two action command	Remove ignition jumper before approaching launch pads	Low
	Propellant burns unsteadily and takes some time to ignite completely	Low; The propellant is designed by Cesaroni Technology and has a single fast burning grain to ensure easier ignition.	Wait for appropriate time before approaching launch pads. Watch for any sign of incomplete burn of propellant (smoke, flames).	
Rocket deviates from nominal flight path, comes in contact with personnel at high speed	Failure on connection with launch platform	Medium; besides de the COTS motor, the rocket is student-built with limited testing, but launch crew 200 feet from rocket at launch, behind barrier (vehicle).The project of the aerodynamic shape	The rocket will be suspended in front of judges horizontally from a section of guide rail as a test	Low
	Unstable flight		Design of the structure and the fins based on aerodynamic models and simulations	

	Excessive wind speed	doesn't predict the behavior of the rocket to winds with speed higher than 15m/s	Static margin between 1.9 and 2.1 calibers;	
Rocket falls from launch rail during prelaunch preparations, causing injury	Rail buttons misplaced or not strong enough attached to the rocket	Low;	The rocket will be suspended in front of judges horizontally from a section of guide rail as a test	Low
Break of the main structure	Over thrust from the motor or violent attitude changes causes structure overstress	Low; The project of the structure doesn't attend to possible motor malfunction	Use of safety coefficient higher than 1.5 for every components of the rocket structure	Low
Rail issues	Rail guider problems	Low; Low stiffness of the rail guider and low friction between guider and rail	Highly stiff setting of the guider and use of low friction material	Low
Recovery system completely fail or partially fail to deploy , rocket or payload comes in contact with personnel	3 ring semi rigid cable and connections rupture during flight	Medium risk. Vibrations could make the semi rigid cable get stuck on a living corner or gear	The mechanical position gives a clean way between the semi rigid cable and the motor. It keeps the cable under tension to avoid freedom of movement.	Low
	Failure on logic circuit to detect ejection situations	Medium risk	Data filtering methods to avoid wrong detections and use of a parallel second commercial system	Low
	DC motors break due to acceleration	Low risk	Motors fixed on a base to keep it fixed during the flight	Low
	Drogue/Main parachute fail to inflate	Low risk.	Use of deployment bags and package methods	Low
	Bridles winding in spring	Medium risk .The Bridles cables may wind around the spring during flight	There will be a sacrifice fabric around the Bridles cable and canopy	Low
	Suspension lines winding in the parachute body	Medium risk. Depending on parachute folding the suspension lines may wind in parachute body after deployment	Right folding and correct packaging in the ejection module	Low
	Wires or welding disconnection	High risk. Vibrations could disconnect wires or weld during the flight	Instead of welding connections, the use of mechanical connections	Low
Recovery system partially deploys, rocket or payload comes in contact with personnel	Barometer does not detect apogee or main launch point in the right moment	Medium risk	Data filtering methods to avoid wrong detections and use of a parallel second commercial system	Low
	Drogue/Main parachute fail to inflate	Low risk.	Use of deployment bags and package methods	Low
	Suspension lines winding in the parachute body	Medium risk. Depending on parachute folding the suspension lines may wind in parachute body after deployment	Right folding and correct packaging in the ejection module	Low
Recovery system	Spring thrown during	Medium risk.	Maintain the spring	Low

deploys during assembly or prelaunch, causing injury	system's assembly		compressed by an auxiliar cable during assembly. During prelaunch the spring will be secured by a Ratchtet Tie-Down mechanism	
	Sudden activation of the ejection system	Medium risk.	Data filtering methods to avoid wrong detections and use of a parallel second commercial system	Between Low and Medium
	Ratchet system fail	Low risk	Use of auxiliar cable during assembly. Use commercial ratchet systems with a safety coefficient over 4	Low
	Premature release of the 3 ring system due to slippage of semi rigid cable	Low risk. Accident pull of the semi rigid cable during assembly	Use of long rigid cables during assembly and adjustment after finishing assembly	Low
	Rings or tapes of the 3 ring release system rupture	Low risk	Use of rings with a safety coefficient over 3, tapes with safety coefficient over 5 and reinforcements at the seams	Low
Main parachute deploys at or near apogee, rocket or payload drifts to highway(s)	Premature release of the 3 ring system due to slippage of semi rigid cable	Low risk .The connection between the semi rigid cable and the 3 ring release system is maintained by the spring force, wich is enough to secure the semi rigid cable in place by friction forces.	Lengthen the size of the semi rigid cable	Low
	Rupture of rings or tapes of the 3 ring release system	Low risk	Use of rings with a safety coefficient over 3, tapes with safety coefficient over 5 and reinforcements at the seams	Low
	Barometer failures to detect apogee	Medium risk	Data filtering methods to avoid wrong detections and use of a parallel second commercial system	Between Low and Medium
Recovery System deploys before apogee	Premature release of 3 ring release system due to semi rigid cable slipping	Low risk. The connection between the semi rigid cable and the 3 ring release system is maintained by the spring force, wich is enough to secure the semi rigid cable in place.	Lengthen the size of the semi rigid cable	Low
	Premature release of the 3 ring system due to slippage of semi rigid cable	Medium risk. Slippage of the semi rigid cable during acceleration time.	Lengthen the size of the semi rigid cable, use of friction forces and weight distribution	Low

			around the attachment point.	
	Barometer performs incorrect measurement	Medium risk	Data filtering methods to avoid wrong detections and use of a parallel second commercial system	Between Low and Medium

ASSEMBLY, PREFLIGHT, AND LAUNCH CHECKLISTS APPENDIX

Assembly Checklist:

1. Go to Electronic Systems Assembly Checklist
2. Go to Recovery Systems Assembly Checklist
3. Screw electronic system modules into parachute modules (both drogue and main)
4. Go to Propulsion Systems Assembly Checklist
5. Go to Payload checklist
6. Insert the payload above the main parachute module and fix it with 3 screws
7. Attach the nose cone module to the main parachute module
8. Screw the motor module in the drogue parachute module

Propulsion Systems Assembly Checklist:

1. Insert the motor sustaining screw through the disk between the motor module and the drogue main.
2. Slide the motor inside de motor module.
3. Align the motor with the screw.
4. Screw the screw at the bulkhead of the motor.
5. Insert the fin fixer disk through the space between the nozzle and the motor module.
6. Align the fins with the holes and the fin fixer disk.
7. Screw the four screws at the fin fixer disk, they are used to align the motor casing as well.

Propulsion Systems Pre-flight Checklist:

1. Wait for authorization from the safety officer.
2. Check ignition box jumper is in disarmed position and all personnel are using adequate protective gear.
3. Un-shunt igniter leads.
4. Connect igniter leads to ignition terminals.
5. Insert igniter into the rocket motor, up to the bulkhead.
6. Connect jumper in ignition box

Propulsion Systems Disarming Checklist:

1. Wait for authorization from the safety officer
2. Disarm ignition box jumper and check all personnel are using adequate protective gear.
3. Approach launch pad and remove igniter/ igniter leads from rocket motor.

Recovery System Assembly Checklist:

1. CO2 cartridge opening mechanism:
    1. Shunt e-match wires and insert e-match into place.
    2. Add ~0.05g of black powder and seal with sticker.
    3. Insert punch into tube.
    4. Screw gunpowder compartment into tube.
    5. Screw cartridge support into tube.
    6. Screw cartridge into support.
    7. Screw cartridge opening mechanism to the assembly disk.
2. 2x lock cutter:
    1. Shunt E match wires and insert e-match into place.

    2. Add ~0.03g of black powder.
    3. Insert lock paracord cable through cutter holes.
    4. Insert fixing bolt through angle bracket and screw to cutter.
    5. Screw L piece to assembly disk.
3. Module:
    1. Screw U bolt to assembly disc.
    2. Attach lock paracord cable to U bolt.
    3. Attach parachute riser to U bolt.
    4. Screw assembly disc to module.
    5. Insert parachute.
    6. Insert shoulder.
    7. Screw opposing U bolt.
    8. Attach opposing end of lock paracord cable to U bolt.
    9. Attach opposing parachute riser to U bolt.
    10. Close shoulder hole.
    11. Unshunt e-match wires and connect to Avionics.

Recovery System Disarming Checklist:
1. Disconnect E match wires from Avionics.
2. Shunt E match wires.

Payload Checklist:
1. Mount the Payload structure.
2. Screw microcontroller board to the Payload main structure.
3. Connect sensor boards to the microcontroller.
4. Connect the antenna coaxial cable to the microcontroller.
5. Fit the dielectric and the antenna on the top of the Payload main structure.
6. Insert SD Card Module into the Payload structure enclosure, and connect it to the microcontroller.
7. Insert polyurethane foam disks into the enclosure.
8. Make sure activation is off (disarmed).
9. Measure battery voltage (nominal 9 V).
10. Attach the battery to the main structure and connect to the system.
11. Check electrical continuity and integrity of the connections.
12. Lock the Payload structure with nuts.
13. Attach the Payload to the assembly disk.
14. Insert Payload into the nose cone.

Electronics Systems Assembly checklist:
Ejection System:
1. Mount Electronics structure.
2. Mount Primary System.
3. Mount Secondary System.
4. Attach the Electronics module to the assembly disk.
5. Insert the module into the Electronics tube.

Primary System:
1. Screw RRC3 to the Electronics main structure.
2. Connect each of the outputs of the RRC3 board to the signal conditioning board.
3. Connect the signal conditioning board to the Recovery System’s connectors.
4. Check connections electrical continuity and integrity.
5. Measure battery voltage (nominal 9V)
6. Make sure activation switch if off (disarmed).
7. Attach the battery to the structure.

8. Connect battery to RRC3 and to the signal conditioning board.

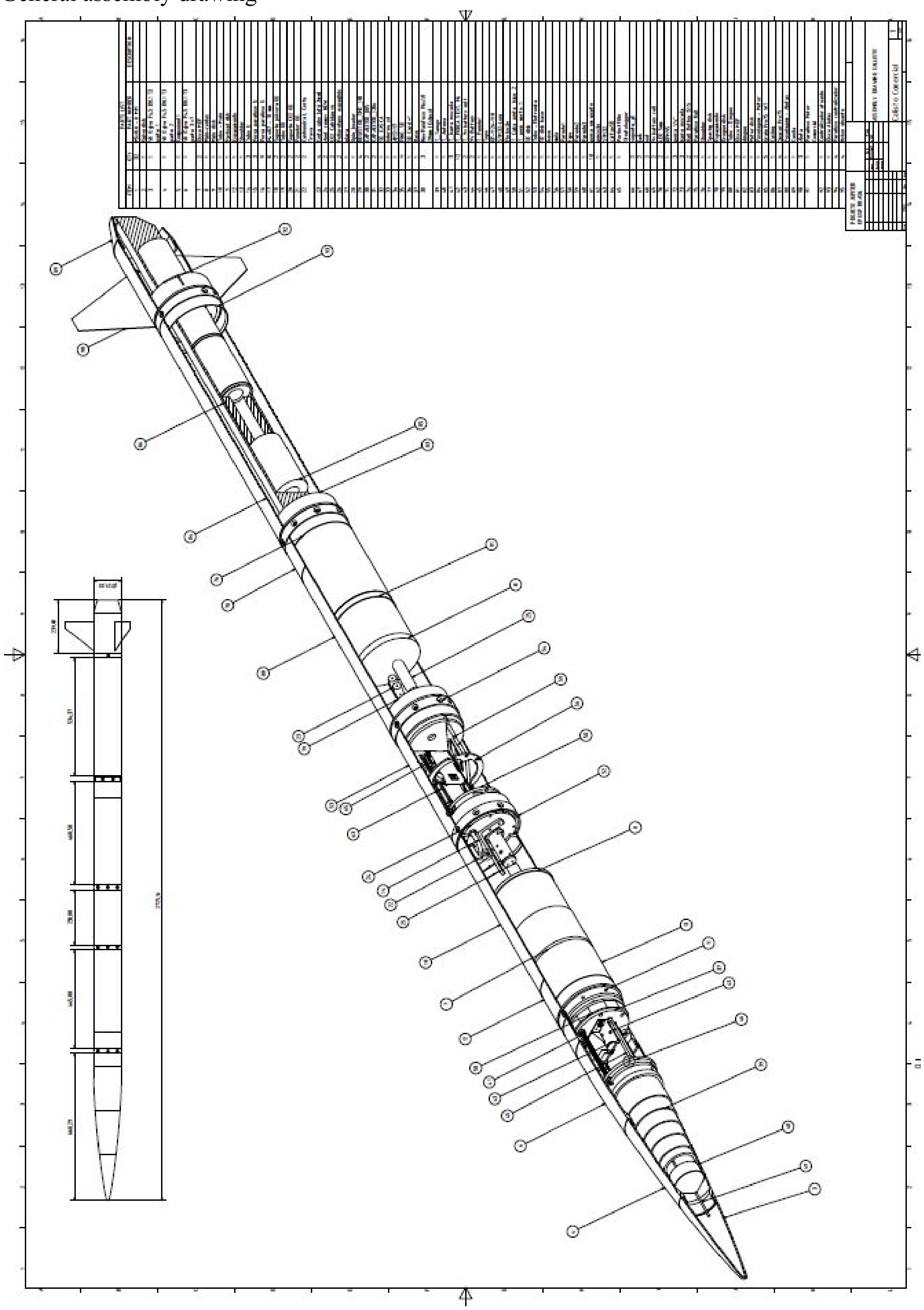
Secondary System:

1. Screw the microcontroller and sensor board to the Electronics main structure.
2. Connect the microcontroller to the signal conditioning board.
3. Connect the signal conditioning board to the Recovery System's connectors.
4. Connect the activation key to the system.
5. Make sure the activation key is off (disarmed)
6. Check connections electrical continuity and integrity.
7. Measure batteries' voltages (nominal each 9V).
8. Attach the batteries to the Electronics structure.
9. Connect the batteries to the system.

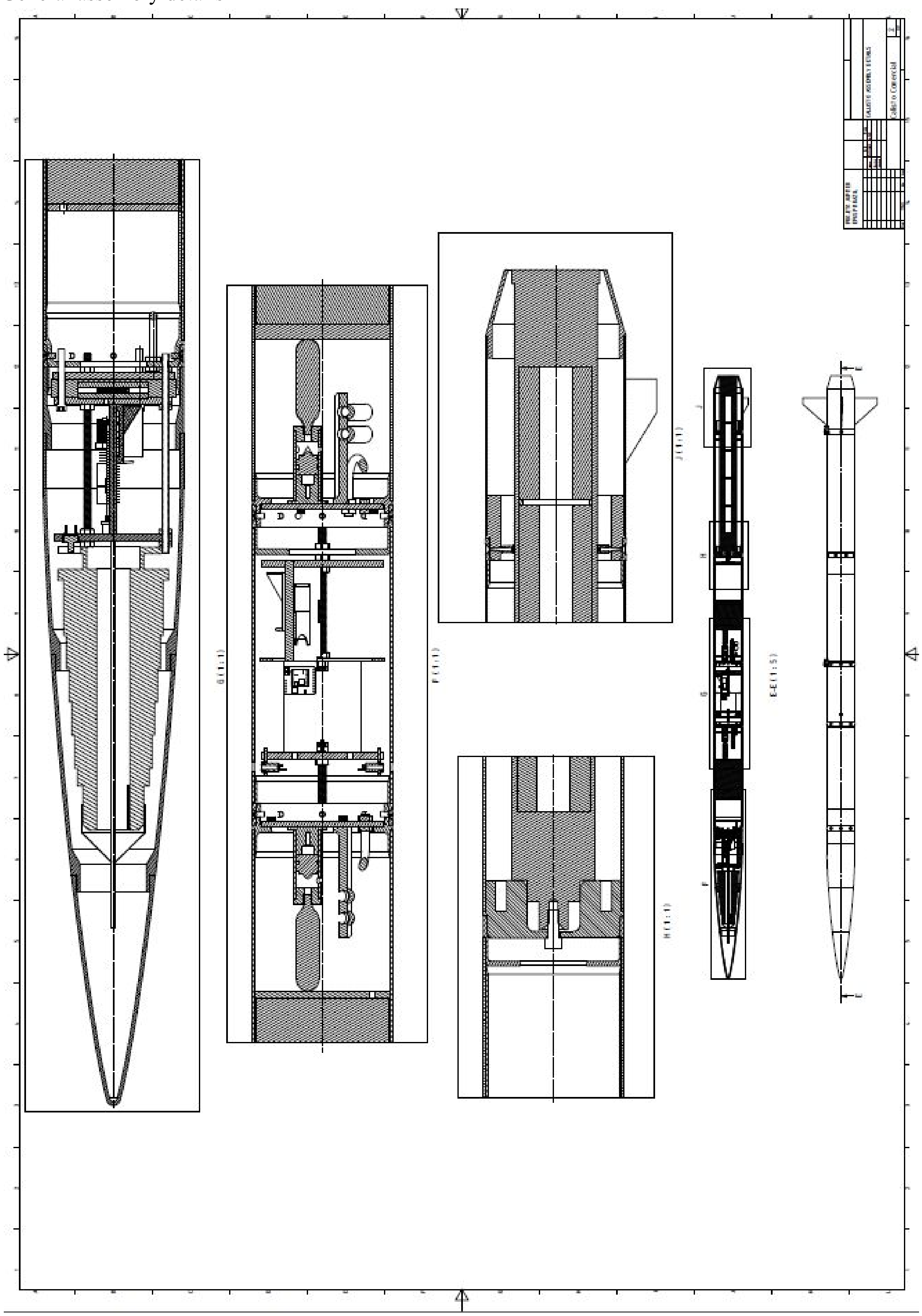
ENGINEERING DRAWINGS APPENDIX

The sixth Project Technical Report appendix shall contain Engineering Drawings. This appendix shall include any revision controlled technical drawings necessary to define significant subsystems or components – especially SRAD subsystems or components.

- General assembly drawing



- General assembly details



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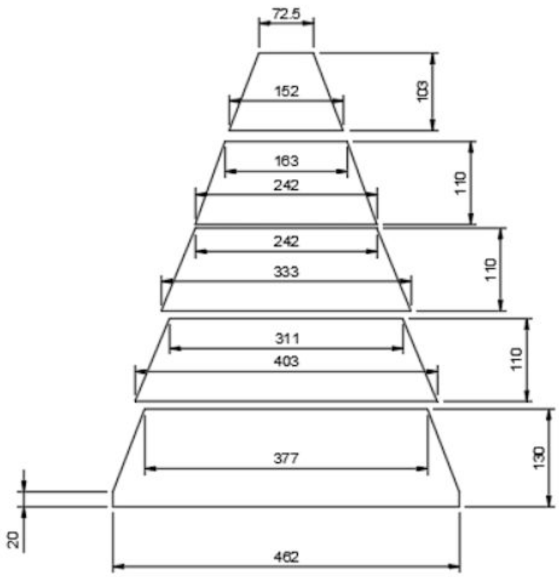
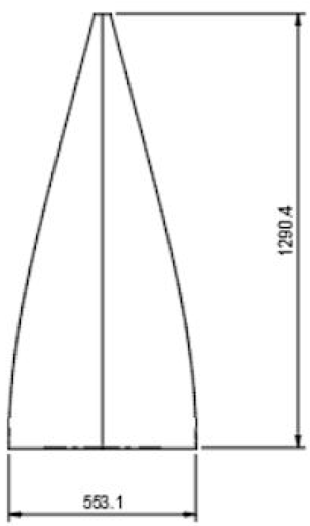
- Drogue parachute gore panels drawing:



- Main parachute gore panel drawing:



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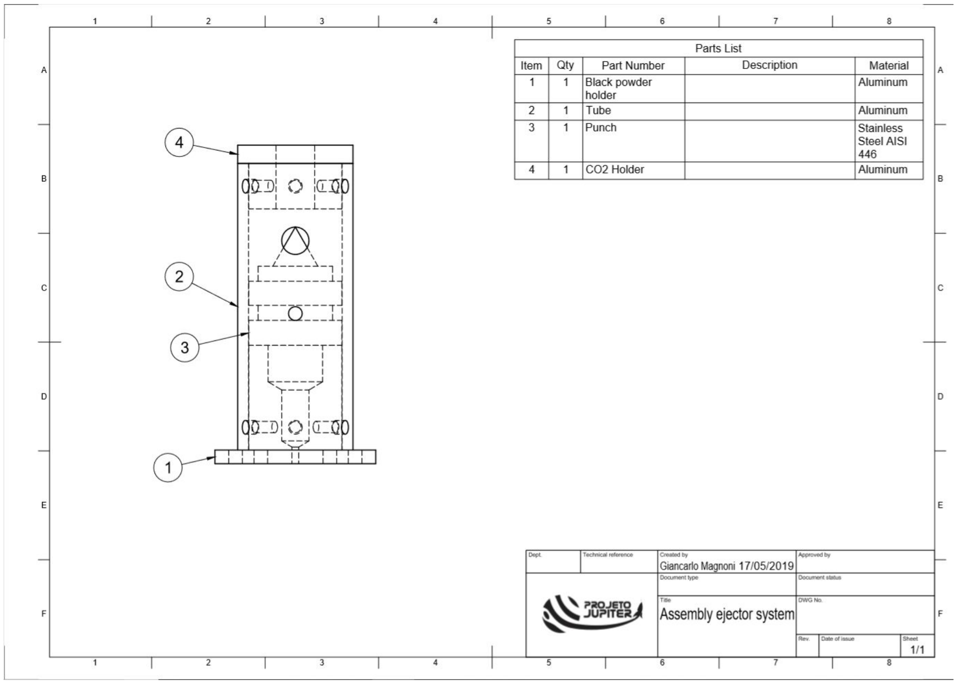
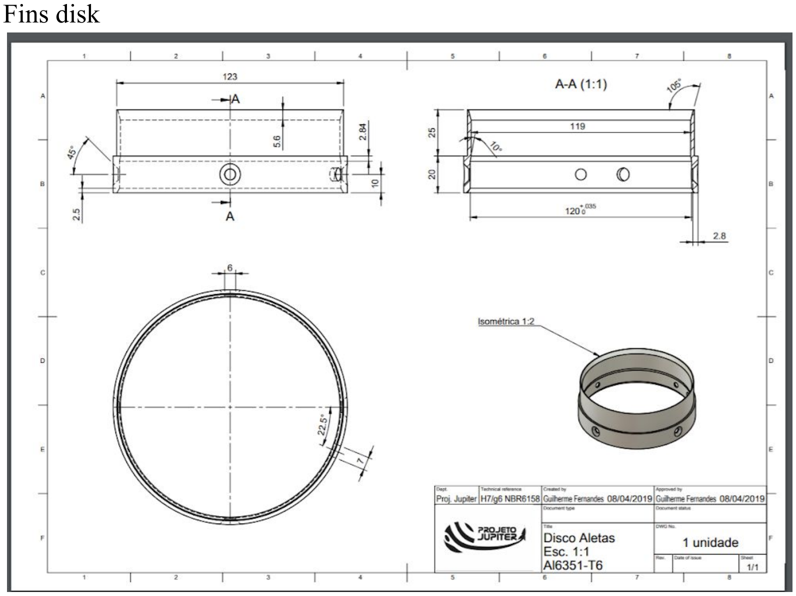
- Ejector system drawing:



- Fins disk



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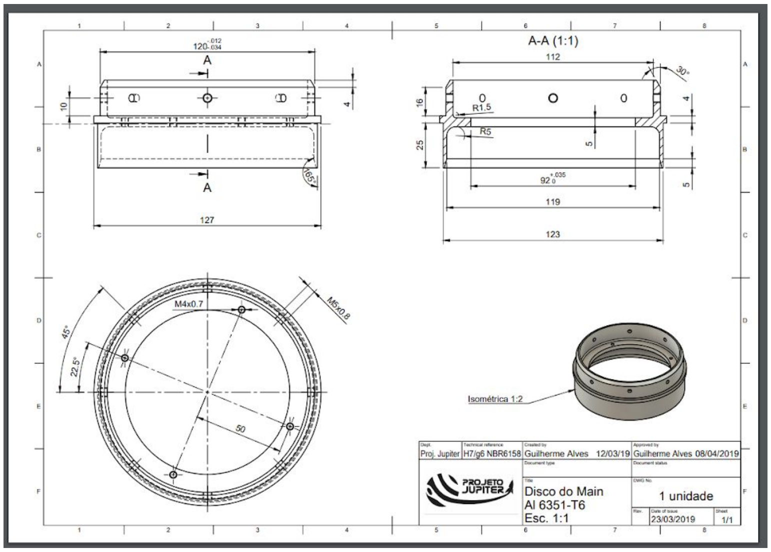
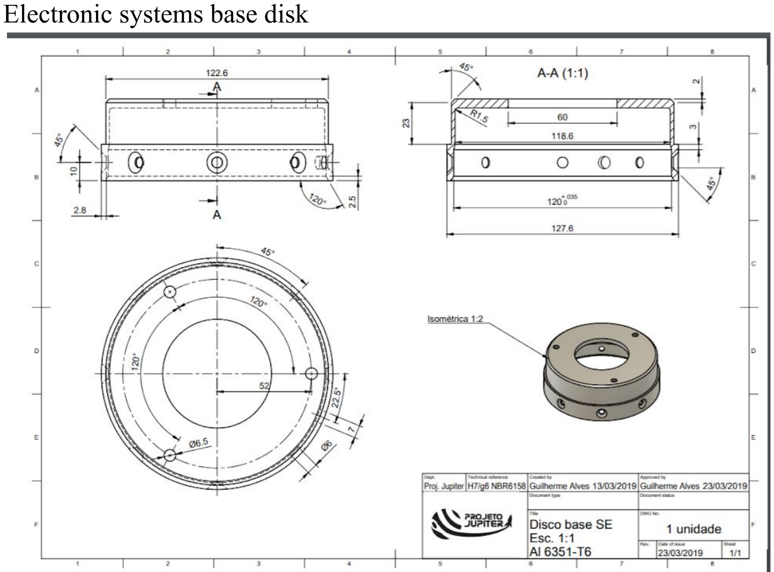
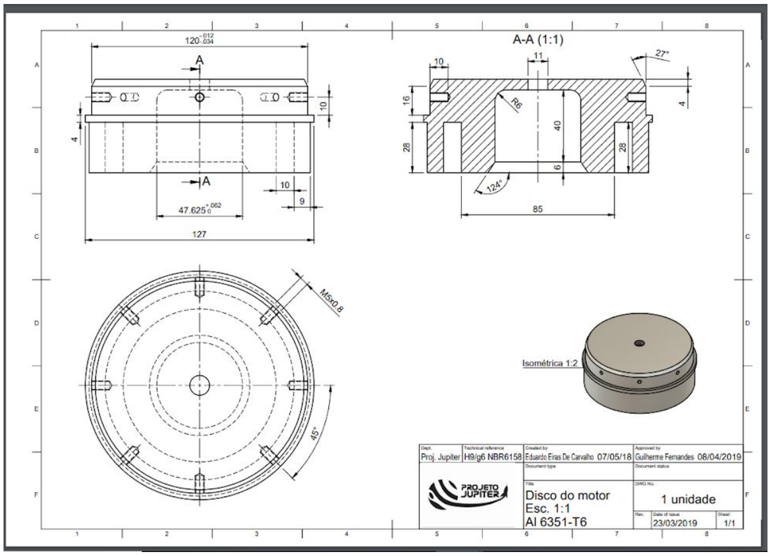
- Main parachute disk



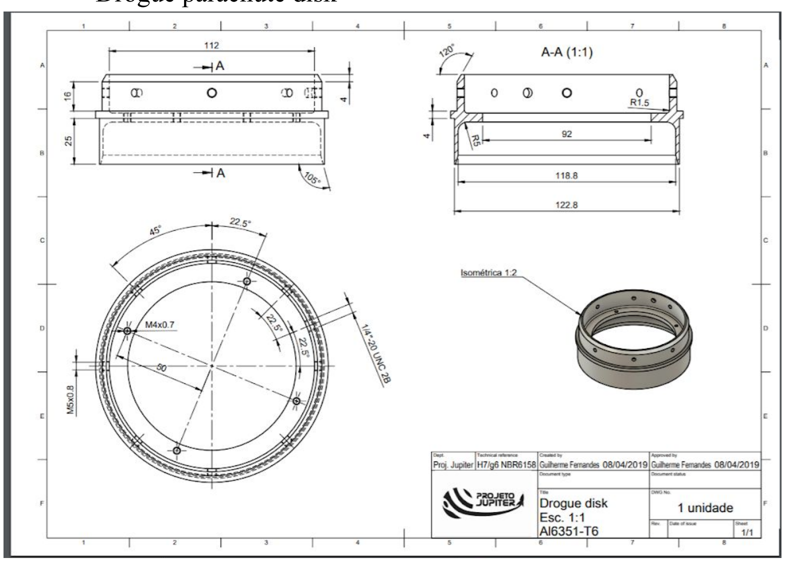
- Electronic systems base disk



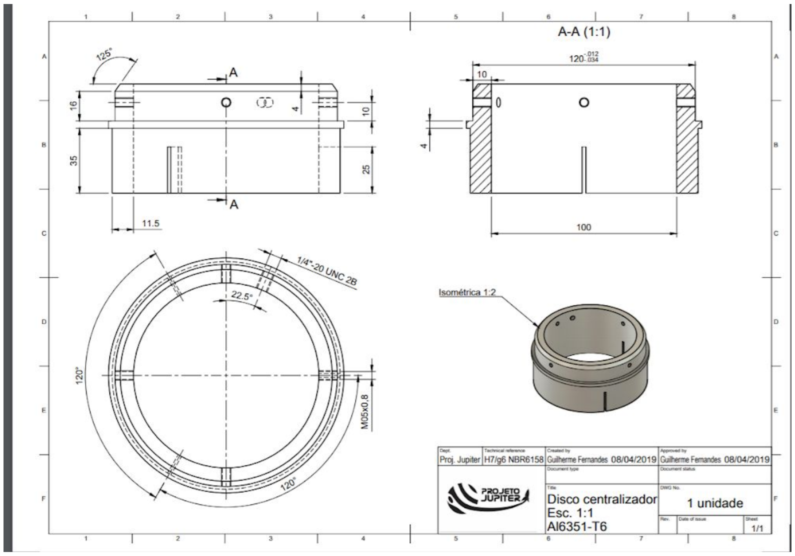
- Motor disk



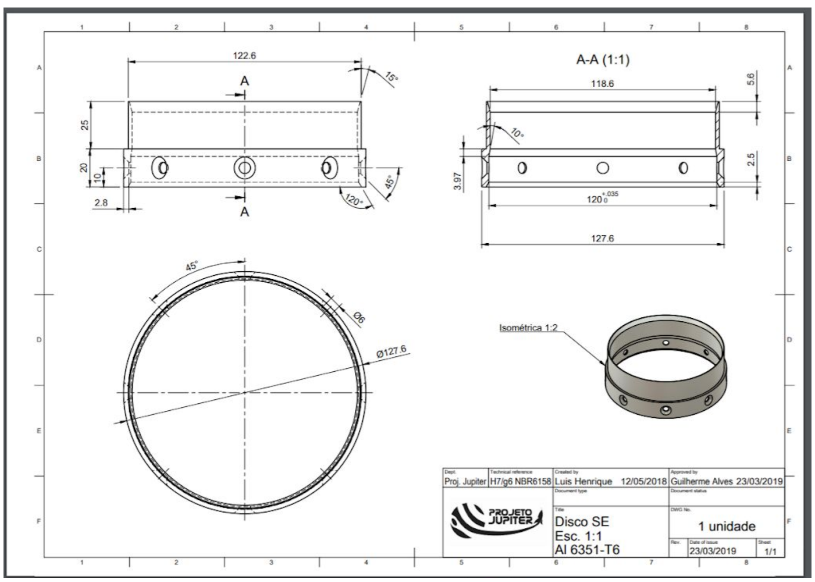
- Drogue parachute disk



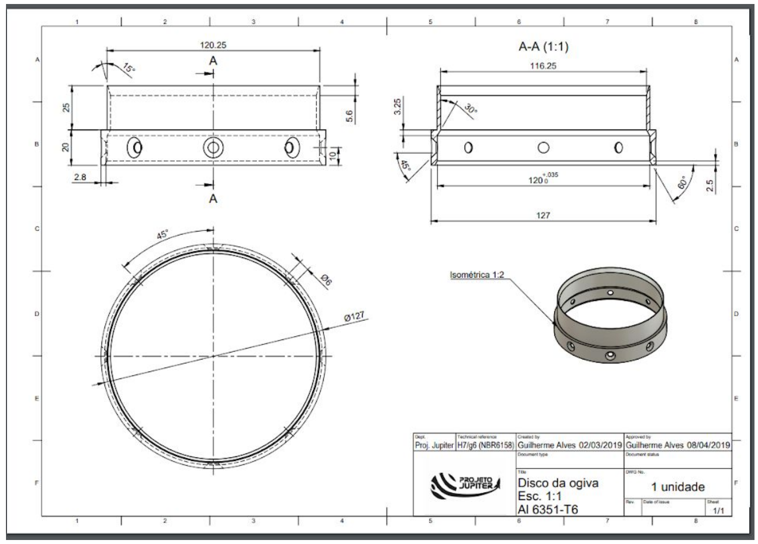
- Aligner disk



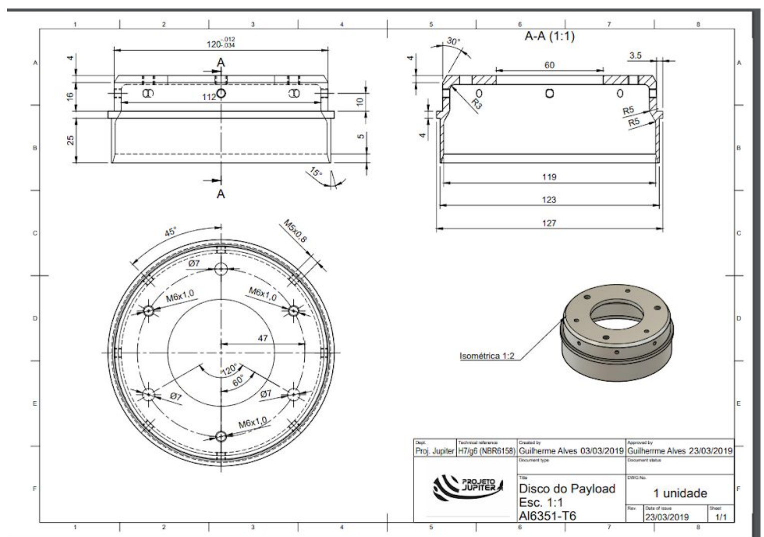
- Electronic systems disk



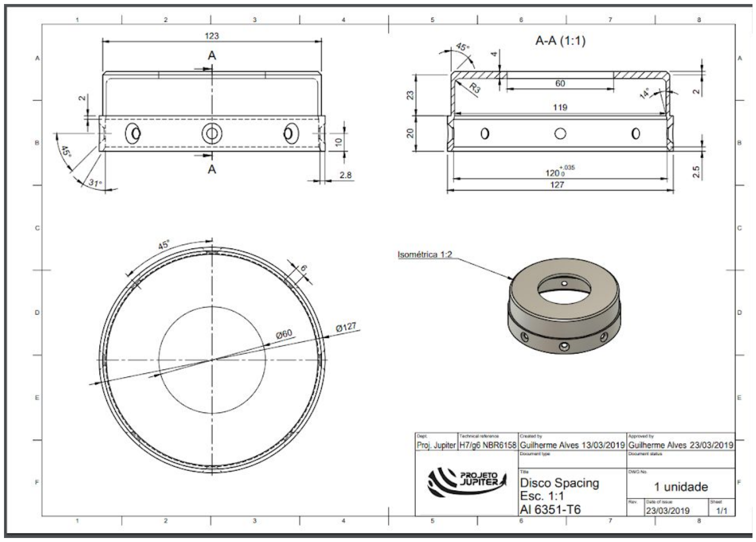
- Nose cone disk



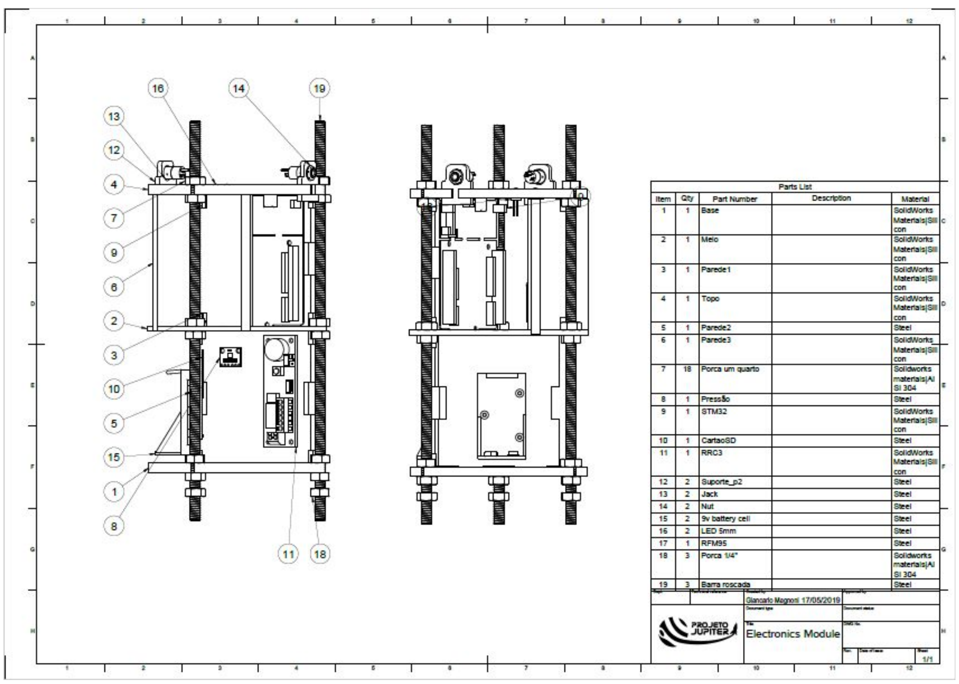
● Payload disk



● Spacing disk

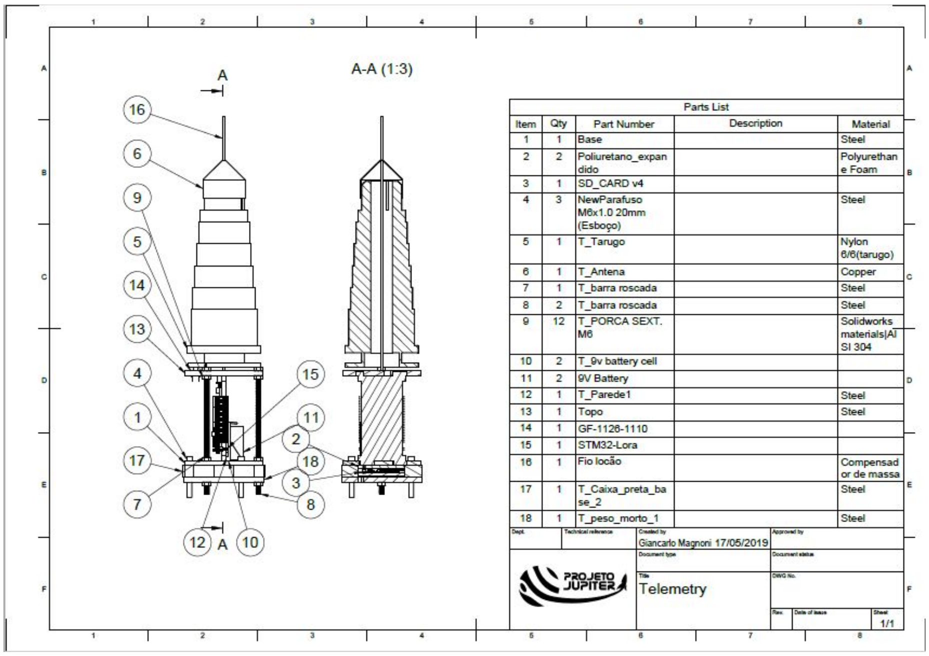


● Electronics Module:



Item	Qty	Part Number	Description	Material
1	1	Base		SolidWorks Materials|Silicon
2	1	Meio		SolidWorks Materials|Silicon
3	1	Parede1		SolidWorks Materials|Silicon
4	1	Topo		SolidWorks Materials|Silicon
5	1	Parede2		Steel
6	1	Parede3		SolidWorks Materials|Silicon
7	18	Porca um quarto		Solidworks materials|AISI 304
8	1	Pressão		Steel
9	1	STM32		SolidWorks Materials|Silicon
10	1	CartaoSD		Steel
11	1	RRC3		SolidWorks Materials|Silicon
12	2	Suporte_p2		Steel
13	2	Jack		Steel
14	2	Nut		Steel
15	2	9v battery cell		Steel
16	2	LED 5mm		Steel
17	1	RFM95		Steel
18	3	Porca 1/4"		Solidworks materials|AISI 304
19	3	Barra roscada		Steel

- Payload:



Acknowledgments

We are really grateful to Amigos da Poli's endowment for the support in this challenge. The board of directors from Polytechnic School, Department of Mechanical Engineering and Institute of Astronomy, Geophysics and Atmospheric Sciences also receives our gratitude for the sponsorship in the trip to the competition. The whole team also would like to thank the sponsorship of ESSS and Ansys, which provided the team with the simulation tools necessary to evaluate and optimize the design.

The Electronics teams would like to thank STMicroeletronics, for the Microcontrollers, development boards, sensors and telemetry solutions that were important to help the area to create their module.

The Aerodynamics & Structures area thanks our sponsors Huntsman, Araldite, Alltec, Texiglass, MAP - Materiais de Alta Performance and Suryha for helping us with all the material necessary for composites manufacturing. The team is also thankful to Wishbox for providing the 3D printed model for the nose cone.

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