Imperius Project Technical Reports for the IREC

Team 48 Project Technical Report for the 2017 IREC

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Abstract

In this report it is described the subsystems of an experimental rocket for the 10k-SRAD category with a M class motor with the purpose of raising 10000 ft of altitude taking a payload of 8.8 lbs in it and landing without causing any critical damage to the rocket components. The payload has the objective of collecting data during the flight so it is possible to reconstruct the rocket trajectory. Ultimately the rocket has some innovator concepts in its design which are the modular structure and the non-pyrotechnic parachute ejection system.

Nomenclature

A = amplitude of oscillation
a = cylinder diameter
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
LMO = Laboratory of Offshore Mechanics
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}

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I. Introduction

THE designed rocket was developed by the Projeto Jupiter which is a group of undergraduate students with the support of teachers and researchers of the school that have the objective of introducing the aerospace technology knowledge and support other brazilian universities in their aerospace initiatives. The Projeto Jupiter has 50 members of which over than 40 are in technical areas which are aerodynamics, recovery systems, propulsion system and electronic systems. Each area has its manager which is responsible for the development of its own subsystem and the integration is done by many meetings of the project focused in the integration.

II. System Architecture Overview

The experimental rocket developed by the Projeto Jupiter has a traditional shape but a innovator structure which is composed by 7 main sections: Nose cone; main parachute section; ejection system section; drogue parachute section; spacing section; payload section and propulsion section, as can be seen in figure 1. The main subsystems are the propulsion system, recovery system, electronic system and the structure. The propulsion system has as its main contribution for the rocket the M class motor. The recovery system has as its main contribution the ejection mechanism and the parachutes. The electronic system has as its main contribution the electronics responsible for apogee detection and rocket location. The structure subsystem made possible to assembly all other subsystems and grant aerodynamic properties for a stable flight. Below it will be made a more detailed description of each subsystem.

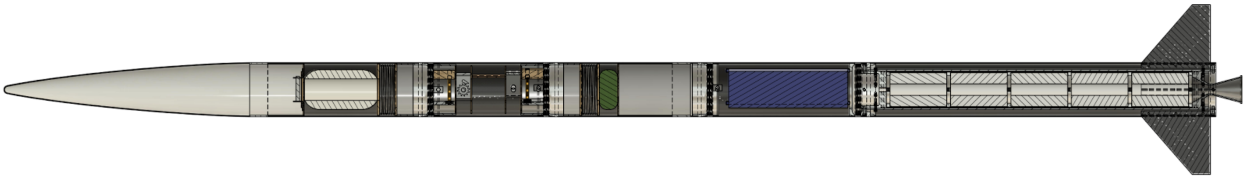


Figure 1 - Half section rocket view.

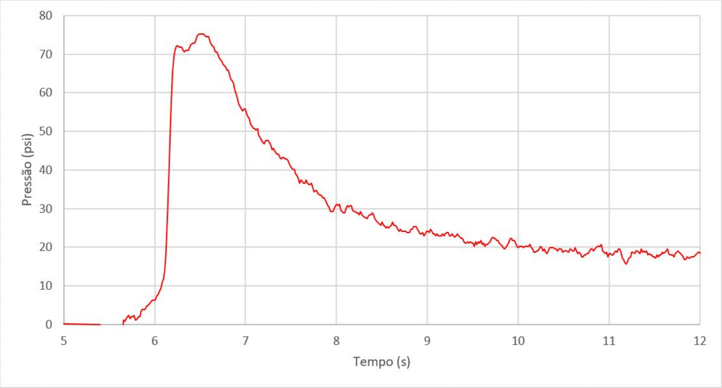
A. Propulsion Subsystems

For the First Annual Spaceport America Cup, Projeto Jupiter designed their class M class motor "Mandioca", whose details are discussed further below.

Propellant

KNSB 65-35 (65% Potassium Nitrate / 35% Sorbitol) was chosen as the motor's solid propellant, mainly due to the fact that its manufacturing process doesn't require any sophisticated equipment, along with its relative safety.

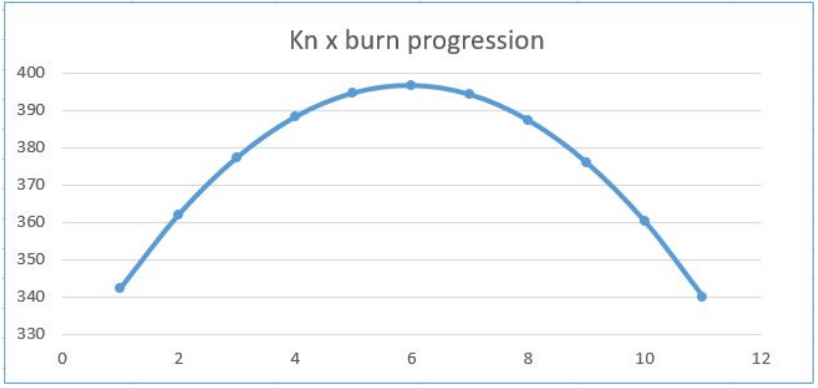
For proper propellant characterization, closed vessel tests were carried out in order to determine the KNSB's characteristic velocity, a very important indicative of combustion efficiency for a certain propellant, that has direct influence on the specific impulse. For these tests, a small amount of triturated KNSB was ignited inside a closed pressure vessel. As the system evolution was kept on track by a pressure transducer, the output of the test was a pressure-time trace. Using the highest value of pressure taken, it was possible to calculate the propellant's characteristic velocity of 816.68 m/s, representing an efficiency of 89% with respect to theoretical values.



Graph 1 - Pressure (psi) -time (s) curve from propellant c-star determination experiment.

"Mandioca" was designed to generate thrust thanks to 5 grains in BATES configuration, whose inhibition is made of Kevlar and epoxy and using paper as its thermal insulator. Its design Kn-Progression Curve is shown below

Graph 2 - Kn x Burn Progression



Data from previous static firings of smaller motors were used as a reference for burn rate estimates. Closed vessel techniques were also used for burn-rate characterization, but the pressures attained were not sufficient to produce valuable data in the desired operating pressure. Thus, parameters such as burn rate, burn time and also indirectly associated variables such as average thrust present a relatively high uncertainty.

The maximum expected operating pressure (MEOP) was predicted based on the burn geometry, burn rate and propellant characteristic velocity to the value of 50 bar. The minimum Factor of Safety of the design is that of the casing, with a value of 3.24. Previous burn rate data for that pressure is estimated at 8.84 mm/s.

Thrust coefficient analysis was carried using CFD simulations for the designed nozzle geometry and expected operation pressures. The software used for calculations was Ansys Fluent:

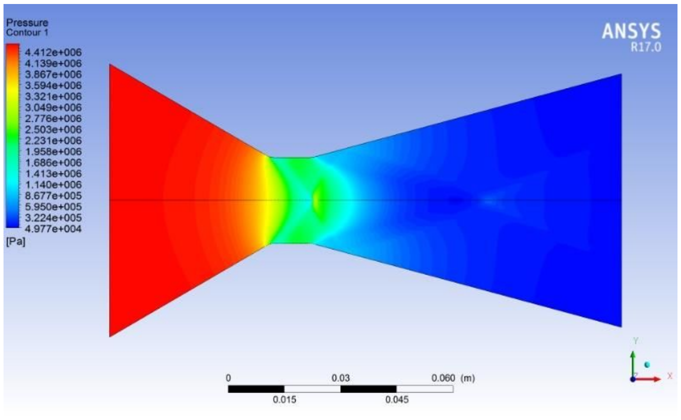


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Figure 2 - Flow in the nozzle.

The results were used to optimize nozzle design for ambient pressure conditions, resulting in an ideal expansion factor of 8.64.

Motor Structure

The motor consists of a 6101 T6 Aluminium casing, which has an external diameter of 110.7mm and a wall thickness of 4.22mm. On its both ends there are twelve holes in order to place screws designed to couple the bulkhead and the nozzle to the casing.

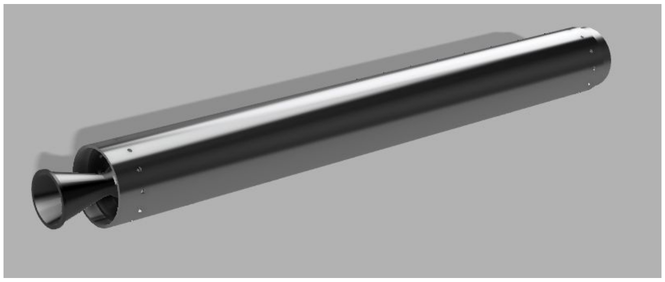


Figura 3 - Mandioca's preliminary render

The nozzle was machined from SAE1020 steel, enjoying a throat diameter of 22.8 diameter and and expansion ratio of 8.64. The bulkhead is made of 6351 T6 Aluminium, and has four M6 threads designed to sustain screws which will couple the motor to the rocket structure.

M class motor "Mandioca" design data summarizes as follows:

	Metric		Imperial	
GENERAL				
Propellant Type	*KNSB 65-35*	-	KNSB 65-35	-
Density	1.7	**g/cm³**	0.061	**lb/in³**
Propellant Mass	8.14	**kg**	3.69	**lb**
Total Impulse	9603.53	**N.s**	2158.96	**lbf.s**
Specific Impulse	120.42	**s**	120.42	**s**
Characteristic Velocity	816.68	**m/s**	2679.40	**ft/s**
Avg. Chamber P (Steady State)	45.94	**bar**	666.33	**psi**
Avg. Thrust (Steady State)	2737.92	**N**	615.51	**lbf**
Maximum Thrust	2870.95	**N**	645.41	**lbf**
Avg. Burn rate (Steady State)	8.84	**mm/s**	0.348	**in/s**
Estimated Burn time (Steady State)	3.51	**s**	3.51	**s**
GRAINS				
Number of grains	5	-	5	-
Grain Outer Diameter	94	**mm**	3.70	**in**
Grain Inner Diameter	32	**mm**	1.26	**in**
Grain Height	156	**mm**	6.14	**in**
Grain Separation	10	**mm**	0.39	**in**
Maximum Kn	397	-	397	-
Average Kn	374	-	374	-
NOZZLE				
Throat Diameter	22.8	**mm**	0.898	**in**
Divergence angle	15	**°**	15	**°**
Exit Diameter	67	**mm**	2.64	**in**
Expansion ratio	8.64	-	8.64	-
Avg. External Pressure	0.8275	**bar**	12.002	**psi**
Avg. Thrust Coeff.	1.44	-	1.44	-
Avg. Thrust Coeff. Efficiency	0.9	-	0.9	-
STRUCTURAL				
Nozzle Material	*1020 Steel*	-	1020 Steel	-
Casing / Bulkhead Material	*6061-T6 Al*	-	6061-T6 Al	-
Casing Inner Diameter	102.26	**mm**	4.026	**in**
Casing thickness	4.22	**mm**	0.166	**in**
Factor of Safety	4	-	4	-
Nozzle / Bulkhead Screw Type	*M8*	-	M8	-
Number of screws	*12*	-	12	-
THERMAL				
Casing Insulation	paper	-	paper	-
Grain Inhibitor	*Kevlar/Epoxy*	-	Kevlar/Epoxy	-

B. Aero-structures Subsystems

Base Structure

The main focus of the Aero-structures subsystem was to create a modular rocket without sacrificing its strength. Having separate modules facilitate transportation, handling and also allows all subsystems to work in their module of the rocket at the same time.

To accomplish this, two coupling systems were devised. The main joint is a threaded (M145x3 thread) connection with a conic alignment section, made possible by the fact that some modules end as an aluminum disk. The second joint is implemented as a shoulder coupled with a tethered rope in tension. While numerical analysis showed that the threaded connection was more reliable than a shoulder, the latter was needed due to the ejection system of the parachutes, since the threaded connection could not separate during flight.

The basis of each module is a tube with an outside diameter of 150 mm (5.9 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 a vacuum infusion process. 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. At the ends of the tube, each module is different.

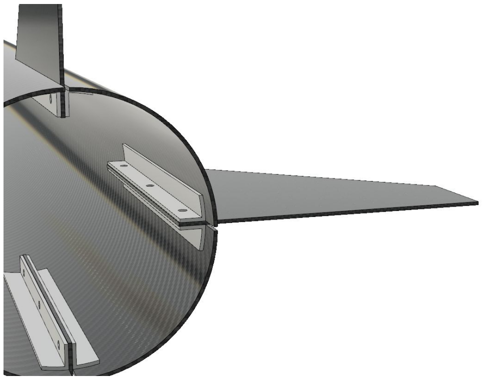
The rocket contains four trapezoidal fins made of 6 layers of hybrid carbon-kevlar fiber, in order to protect it from impact, mixed with 3 layers of pure carbon fiber, that increases its stiffness. They were also manufactured by a vacuum infusion process using epoxy resin. The fins are 2.5 mm (0.098 in) thick.

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. Structurely, fiber glass and epoxy resin are layed up inside to allow it to endure flight stress.

Modules, Fins and Guide Rails

Rocket Imperius contains seven modules: Nose cone, main parachute, electronic system, drogue parachute, spacing, payload, and motor. A brief description of the connection between each module is given.

The nose cone ends as a shoulder, allowing it to connect to the main parachute module. The main parachute module has a shoulder entrance in one end, while at the other end is a threaded aluminum disk. This disk connects the main module to the electronic system module, which also has a threaded aluminum disk. The other end of the electronic system module contains another disk which connects to the drogue parachute module. The latter also has an entrance for a shoulder, which comes from the spacing module, whose main purpose is to allow a threaded connection to the payload and a shoulder connection to the drogue module. Finally, the payload is connected to the motor module also with a threaded connection.



The four fins are attached to the motor module with staniless steel internal corners, as the image showcases.

The two guide rails are fixed to the motor modules by threads in its two end aluminum disks.

Strength Analysis and Calculations

Each tube, disk and both shoulders were studied and designed in order to make sure they would not break during liftoff, flight and landing.

Hand calculations were done at first to estimate the needed thickness of the tubes to prevent buckling. Then numerical simulations using Ansys Mechanical and Autodesk Fusion 360 were employed to account for the orthotropic nature of the composites. Further calculations were need just to check that the tube would also behave well considering compression, tension and shear loads that it is expected to endure during flight. The following image, figure 6, represents one of the buckling simulations using Autodesk Fusion 360; the critical load obtained was 717 kN, much higher than the required strength.

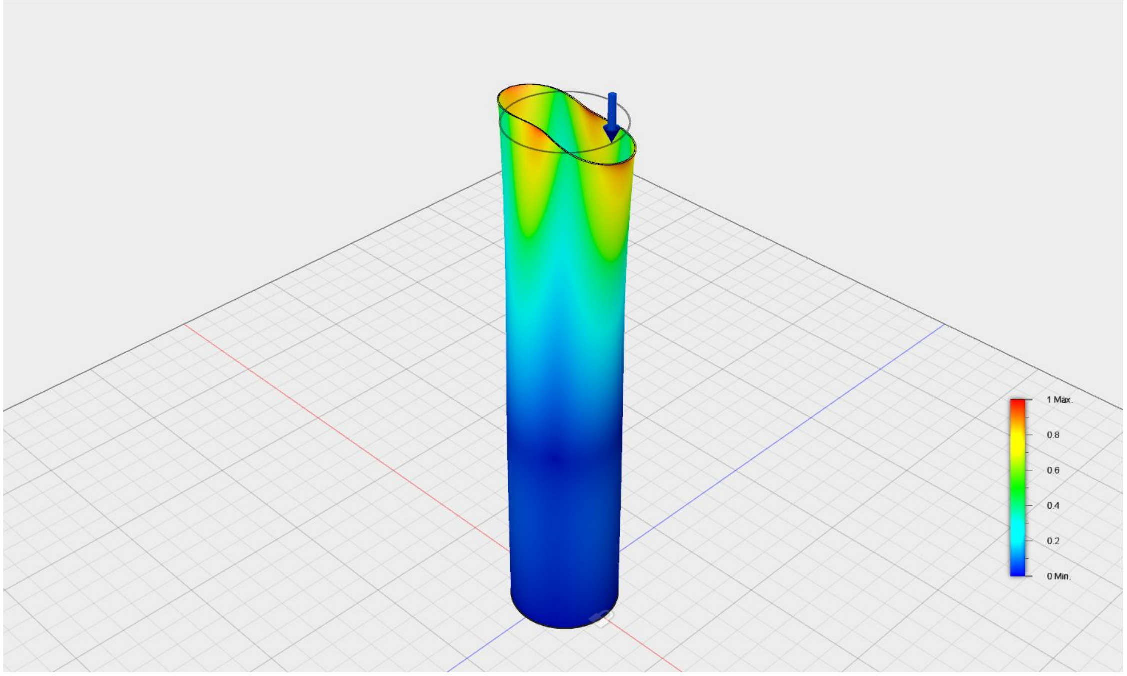
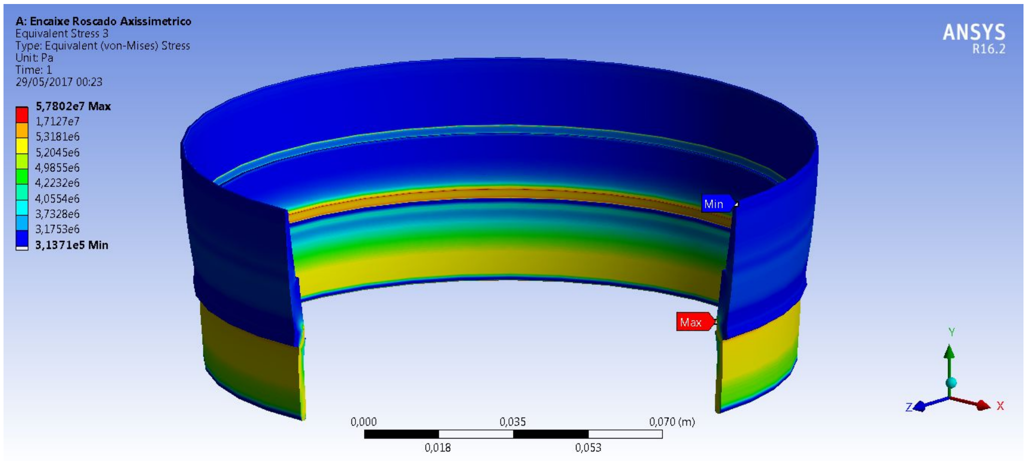


Figure 6 - Results from buckling simulation.

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 two base models of the disks provided the following results shown in figure 7 and 8.



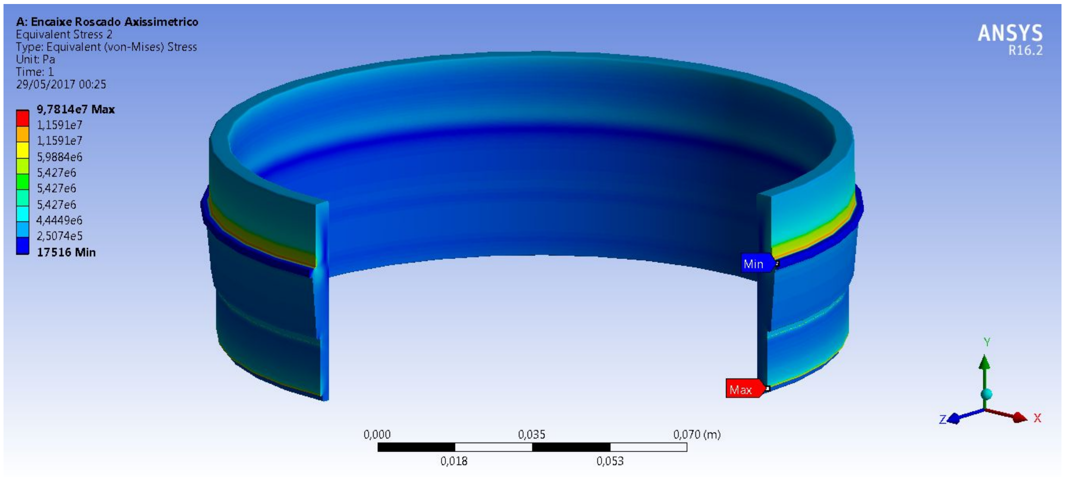


Figure 7 and 8 - von Mises Stress in connection disks.

It is possible to observe that the maximum von-Mises Stress occurs at the thread and has a value of 98 MPa, which provides a minimum safety factor of 2.75 for aluminum 6351-T6.

The shoulders were designed primarily using experimental tests and recommendation by ERSA and other rocket flight institutions.

Aerodynamic Stability

The rocket uses four 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 9, shows the center of gravity (in blue) and the center of pressures (in red), calculated by RASAero 2.0.

Figure 9 - 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 1.5, even though the rocket is expected to reach only Mach 0.95, reaching a minimum of 1.7 calibers.

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, in the form of

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

$\sigma = 0.2$. 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:

- $s =$ 16 mm (6.38 in)
- F_{RC} = 19 mm (7.48 in)
- F_{TC} = 5 mm (1.97 in)

The nose cone was optmized to reduce drag. It is designed as a Von Karman nose cone with a fineness ratio of 4.50 and a bluffness ratio of 0.15.

The rocket is to be launched with an elevation angle of 84 degrees.

Manufacturing

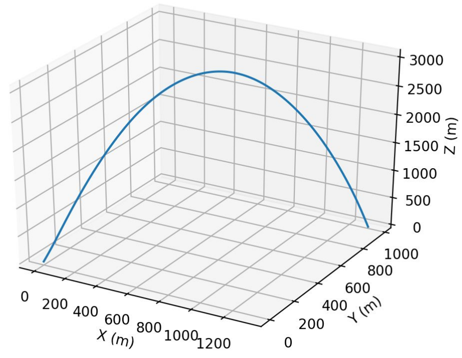
Three main manufacturing techniques were used in the making of Imperius. The first of them, is additive manufacturing, 3D printing. Aditionally, machining of the aluminum disks designed by the team was made by a third party company. Finally, all composite parts were manufactured by a resin infusion process developed by the group. For the fins, an acrylic plate was used as a mold. For the tubes, an acrylic cylinder was cut in half and used as a two sided mold.

Flight Simulation and Trajectory

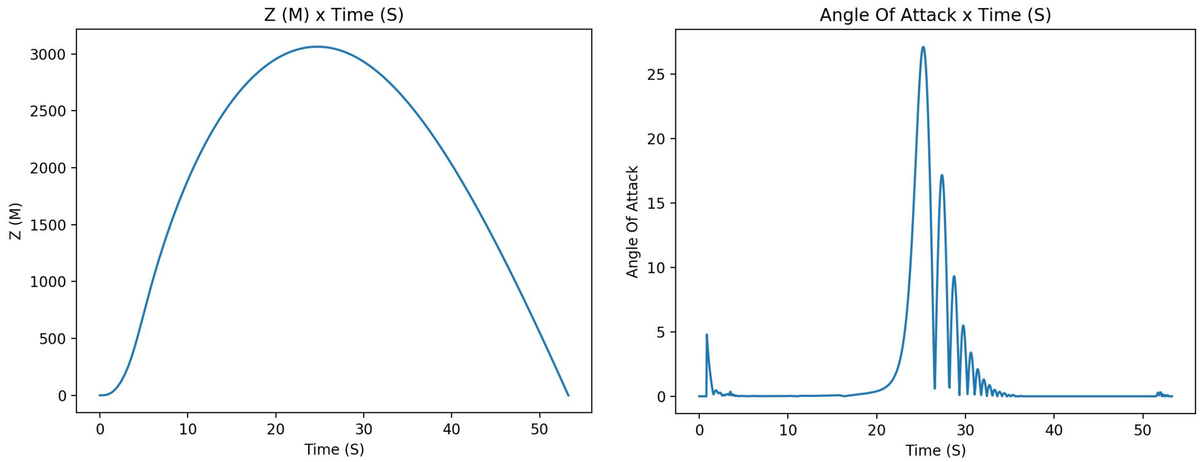
This year, Projeto Jupiter made a new version of its own flight simulation software, now featuring 6 degrees of freedom motion and wind data imported from Wyoming Weather Web. This allows for a realistic simulation of the rocket`s flight in different wind scenarios. From this, the group can obtain a good aproximation for the expected apogee and the dynamic stability of the rocket.

The predicted 3d path in the case the parachute does not open is given in graph 3.

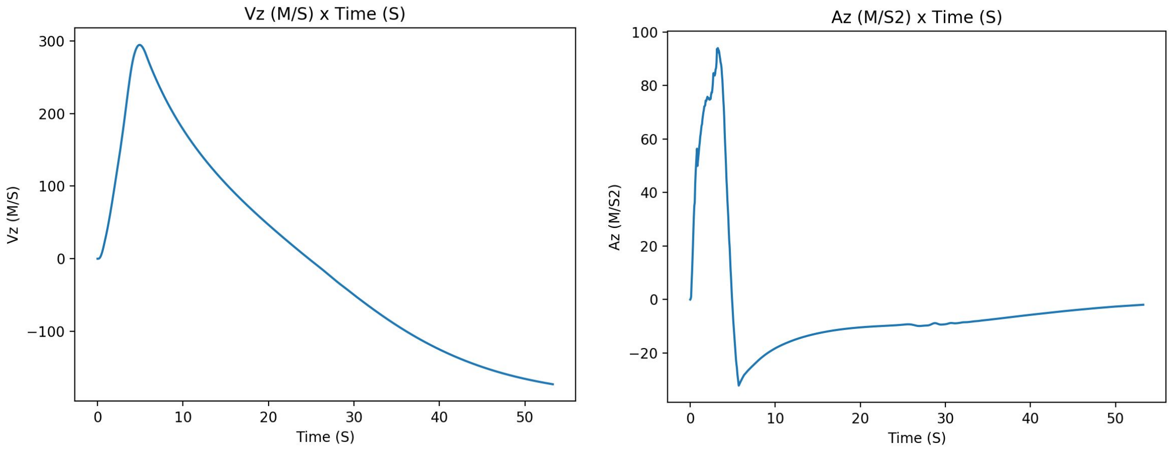
More detailed information is given in the graph 4 and 5 below:



Graph 3 - Predicted 3D trajectory with launch angle 85 degrees and without parachute opening.



Graph 4 - Left: height Z (AGL) measured in meters as a function o time. Right: absolute angle of attack, measured in degrees as a function of time.



Graph 5 - Left: velcoity Vz measured in meters per second as a function o time. Right: acceleration Az measured in meters per second squared as a function o time.

C. Recovery Subsystems

Introduction

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

Along with that, an innovator way to improve damping of the opening shock forces and instability momentum was designed, by implementing a combination of damping methods and canopy shapes.

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 Imperius, just below the rocket's nose cone, is the main module. Closer to the length center of the rocket, between the avionics and the payload module, is the drogue module. Both systems use equal, springs, fix pins, release systems and lock systems, so the parts were designed to withstand the worst scenario in both cases.

Parachutes

Main Parachute

The main parachute canopy shape is cruciform. The developing method and reasons will be presented below. To start the develop and equation methods, first attempt to the steady flow and opening conditions:

- $V_x = 27\ \frac{m}{s}$, Opening relative velocity
- $\rho = 1{,}05\ \frac{Kg}{m^3}$, air density
- $T = 40\ {}^{o}C$, work temperature
- $M_t = 23\ kg$, total mass
- $V_f = 7\ \frac{m}{s}$, final velocity
- $g = 9{,}81\ \frac{m}{s^2}$, gravity

Figure 10 - Main Parachute

By modeling analysis, and the hypothesis that the parachute is fully open, we find the following equation to determine the drag force at the vertical direction, on the parachute:

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

$$(C_D S)_p \approx 8{,}77\ m^2$$

By analyzing several parachute canopy shapes, the cruciform canopy shape was chosen for its high stability, low average angle of oscillation, and relatively lower impact characteristics and ease of manufacturing.

Using a catalog of tests realized by the parachute design company Baiuca Sports, we have that for similar models, the drag coefficient is 1.4, and there is common relationship between the central area, that is projected, and the panel side areas of $S_p = 1{,}5 S_{sp} = 0.6\ S_T$:

- $C_D \approx 1{,}4$, drag coefficient
- $S_p = 6{,}3\ m^2$, projected area
- $S_{sp} = 4.2\ m^2$, side panels area
- $S_T = 10{,}5\ m^2$, total fabric area

From these data, it is possible to estimate the inflation time using that $t_f = \frac{nD}{V^{0.9}}$:

- $t_f = 1.13$ s, is the filling time
- n = 8.7 is the fill constant
- D is the central square diagonal.
- V is the velocity at the line stretch.

Test data shows a filling time around 1.7 s.

To calculate the opening force, it was used the following method:

- $$F(t) = (C_D S)_P \frac{1}{2}\rho V^2 + M_T \frac{dv}{dt} + v\frac{dm}{dt} + W_t \sin \emptyset$$

The hypothesis to determinate the opening forces are:

1. There is no mass significant mass variation
2. $\emptyset = 90°$
3. $\frac{dv}{dt} = \frac{20}{1.7}$ is almost constant, because of the parachute canopy inflation characteristics and pocket bands add

So, the opening force is equal to:

- $$F_x = 392{,}73 \text{ Kgf}$$

The opening force coefficient at infinite mass condition is:

- $C_x \approx 1{,}15$. The result is close to NASA`s data $C_x = 1{,}2$.

The length of the suspension lines is equal to 2.5 m, to obey the equation $\frac{Ls}{D} = 1$. It is interesting to use this relationship to keep the drag coefficient equal to 1.4.
The riser length is equal to 3 m, to permit the parachute gets filed away of the rocket parts.
To increase damping characteristics additional pocket bands were added connecting each side panel to its neighbor side panel, totalizing 4 pocket bands.
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

The drogue parachute canopy shape is 30° conical. The developing method and reasons will be presented below.
To start the develop and equation methods, first attempt to the steady flow and opening conditions:

- $V_x = 25 \frac{m}{s}$, Opening relative velocity

- $\rho = 1{,}05\ \frac{Kg}{m^3}$, air density
- $T = 40\ ^{\circ}C$, work temperature
- $M_t = 23\ kg$, total mass
- $V_f = 27\ \frac{m}{s}$, final velocity
- $g = 9{,}81\ \frac{m}{s^2}$, gravity

By modeling analysis, and the hypothesis that the parachute is fully open, we find the following equation to determine the drag force at the vertical direction, on the parachute:

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

$$(C_D S)_p \approx 0.6\ m^2$$

Compared to other canopy shapes, we decide to use the 30°Conical shape for drogue parachute because it is suitable for in-flight or landing deceleration due to his high opening coefficient, nearly 1,8, giving a rapid deceleration. Also it has a good drag coefficient (0,75-0,90). It has a very common canopy shape and is therefore easy to manufacture. Using literature tables and technical specifications from Parachute Recovery Systems Design Manual [1] and a catalog of tests realized by the parachute design company Baiuca Sports with the same shape and material used, we determine the possible drag coefficient is 0.75.

- $C_D \approx 0{,}75$, drag coefficient
- $S_p = 0{,}8\ m^2$, projected area
- $N = 6$, is the number of gores

From these data, it is possible to estimate the inflation time using that $t_f = \frac{nD}{V^{0.9}}$:

- $t_f\ =\ 0{,}45$ s, is the filling time
- n = 8 is the fill constant, typical for each parachute type.
- D is the nominal diameter.
- V is the velocity at the line stretch.

To calculate the opening force, it was used the following method:

- $$F(t) = (C_D S)_P \frac{1}{2}\rho V^2 + M_T \frac{dv}{dt} + v\frac{dm}{dt} + W_t \sin\emptyset$$

The hypothesis to determinate the opening forces are:

1. There is no mass significant mass variation
2. $\emptyset = 90°$
3. $\frac{dv}{dt} = \frac{-2}{.45}$ is negative, so it doesn't apply, since the parachute is not rigid.

So, the opening force is equal to:

- $$F_x\ =\ 43{,}07\ \text{Kgf}$$

The opening force coefficient at infinite mass condition is:

- $C_x \approx 1{,}88$. The result is close to NASA`s data $C_x = 1{,}8$.

The length of the suspension lines is equal to 1.2 m, to obey the equation $\frac{Ls}{D} = 1$.2. It is interesting to use this relationship to keep the drag coefficient equal to 0.75.

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

To increase damping characteristics additional pocket bands were added connecting each side panel to its neighbor side panel, totalizing 4 pocket bands.

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.
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- Riser: nylon cord 1000.
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The English sewing method, using nylon thread, was used to make the links as robust as possible.

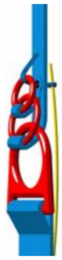
Ejection system

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 6 vital parts: The source of energy to deploy the parachute, the lock system, the ratchets, the fixed pin, the deployment bag and the DC motors.

- **Deployment bags**
  The deployment bags are designed to protect the parachutes from any friction that it would suffer during the ejection.

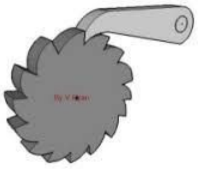
- **The Source of Energy**
  The ejection system uses a carbon steel spring with 135 mm of diameter and 600 mm lengththat in operating condition is fully compressed on the inside of the module, with a 44 mm length, with a maximum force of 32 Kgf. The spring is designed to overcome the friction forces, the drag forces and eject the parachute over 2 meters in vertical height outside the rocket body.
  To calculate the dimensions of the spring, it was calculated how much energy would be needed to launch the main parachute at a distance of 1.5 m. Besides that, the book Shigley's Mechanical Engineering Design [BUSYNAS; NISBETT 2016] was consulted to do the sizing of the springs.

- **The 3 Ring Release System**
  The 3 rings release system is used to compress the spring and keep the modules compressed against it other, and it is responsible to resist against normal traction forces.



This system is very important for the ejection system, because each ring promotes a reduction of half the needed force required to hold the springs in place, resulting in a total reduction of 16, which facilitates the ejection of the parachutes

- **The Ratchets systems**
  The ratchets are the mechanism that we use to pull the 3 ring release system to maximum. The ratchets are fixed on a structural disk, so they are fixed as well, in a way that facilitates to pull the system**.**



- **The DC Motors**
  The system uses 2 DC motors with a capacity of 1,5 kgf.cm to release the 3 ring system.

- **The Fixed Pin**
  the fixing pin is a standard M12 10.9 not heat treated that is dimensioned to resist the main parachute opening shock conditions. The drogue riser fixing pin security factor is 7.1 and the main security factor is 1.55.
  The sizing of the pin was based on the maximum normal stress exerted on the pin, in relation to it’s yield stress.

- **Functional description**
  Both systems will follow the steps below:
  - **Electrical Sign**: the DC motors receive the electrical signal and pull up the semi rigid cable that locks the 3 rings release system. This system uses the motor rotation for winding a thread that connects the semi rigid cable to an axis.
  - **Release of the 3 rings system**: after the semi rigid cable release of the 3 rings system, there is no significative compression forces between the modules. In the case of the main parachute, there is no compression forces to maintain the connection between the nose cone and the main module, and in the drogue case, no more forces to maintain the drogue module and the modules underneath.
  - **Spring release**: without compression forces acting on the spring, it ejects the parachute out.

D. Electronic System

The electronic system is redundant, with two completely independent systems (from batteries to motors).

1. Primary system

The first electronic system detects the altitude using a StratoLoggerCF, from PerfectFlite. Its outputs are connected to a signal conditioning system that sends the signals to a motor driver boards with the L298 driver, in order to interface the system with the DC motors.

When the StratoLogger activates drogue or main deployment, it produces an electrical current that are conditioned by the system to send a signal to the motor driver that will activate the drogue or main DC motor, respectively, and ejects the parachutes.

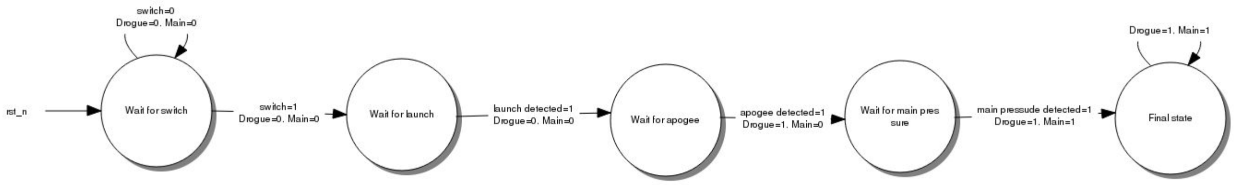
2. Secondary system

- **Hardware**

The second ejection system, in terms of hardware, is composed by a pressure sensor (BMP-180[1]) and a microcontroller board (Arduino Nano), interfaced using a custom base PCB. Also there are two motor driver boards with the L298 driver, in order to interface the microcontroller board with the DC motors.

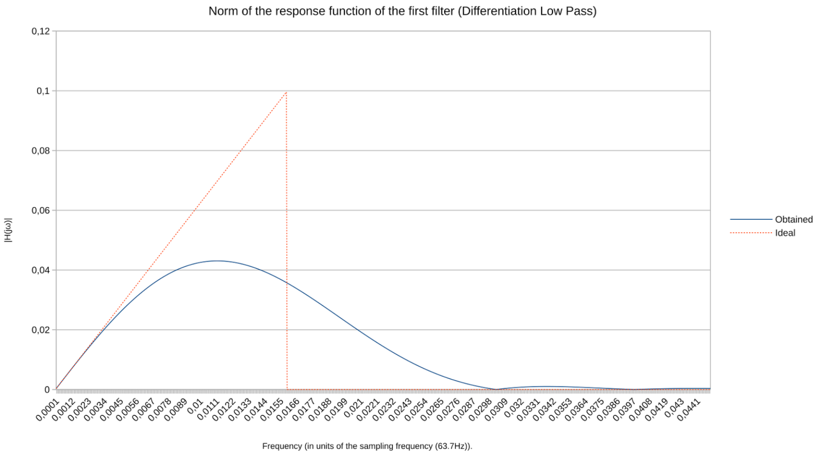
- **Functional Description**

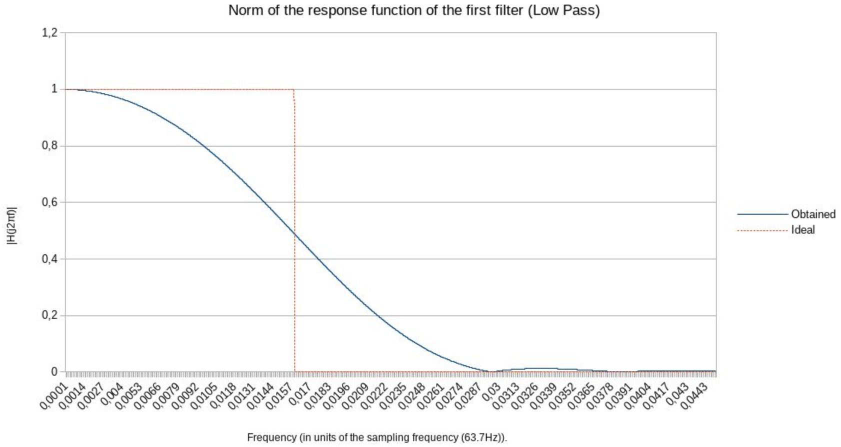
The control software is made up of five states: *wait for switch* state, a *wait for launch* state, *wait for apogee* state, *wait for main parachute deployment altitude* and the *final state*,which are organized like the following diagram shows:



- **Filtering Methods**

In all three detection states (launch, apogee and main) use finite linear response filters to process the data coming from the sensor, those being a differentiation low pass filter for the first two and a common low pass filter for the last one, all of them with a cutoff frequency of $f_s/63$, where f_s is the sampling frequency, which is equal to approximately 63.7Hz and using a window of 97 samples. The plots of the response function of each filter can be seen below:





- **Detection Methods**
    - **Launch**

To detect launch, the system simply checks if the current derivative of the pressure with relation to time is smaller than a given value (approx. -45 Pa/s), which corresponds to a speed of about 3.92 m/s, considering the altitude of the launch site. After that, it waits for 1s, so the dynamic pressure can stabilize.

- **Apogee**

In order to detect the apogee, the system checks, first, for the event of the pressure derivative in relation to time goes from positive to negative, indicating a pressure minimum, thus a height maximum. Also it checks if the pressure derivative a few seconds (about 350ms) before the peak is lower than a threshold (approx. -21Pa/s), so to check that the minimum is "deep" enough.

- **Main Parachute Deployment Point**

For the point of deployment of the main parachute, the system simply checks whether the pressure is higher than a threshold that is, due to the characteristics of the main parachute, approximately 820 mbars.

III. Mission Concept of Operations Overview

The mission of our rocket launch consist in 3 phases: Launching; free flight and recovery. In the launch process the rocket is mounted in the rail, the electronic systems are activated, it is placed an ignitor inside the motor and after everyone is clear of the launching area the igniter is activated and then the motor starts. In the process of activating the igniter the sign “Ignition” is said so everyone is noticed that the ignition should start. After motor ignition the rocket should start to move and at this moment the sign of “Liftoff” is said. After the free flight of the rocket it will be released the drogue parachute and in that moment a sign of “Drogue” should be said. The next event should be the main parachute release and in this event the sign of “Main” should be said. At least when the rocket touch the ground the sign of “Land” should be said.

IV. Conclusions and Lessons Learned

Aerodynamic system managing view

The difficulties found in the aerodynamic system was to develop a vacuum infusion manufacturing method for composites, which was used to make the rocket fins and the main carbon fiber structure. The threaded connections also required a significant time to be simulated numerically in order to assure the required strength. The CFD simulations were carried out to verify the drag coefficient and the design stability. Therefore, the group had made great advances in composite manufacturing technology and CFD analysis this year.

Staff wise, this subsystem was formed by 9 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

One of our biggest difficult was integrate the motor and structure allowing the construction with commercial materials and promoting the principal objectives of thrust from the motor. Another difficult which the group faced up was keep all the members actualized with the new problems that appeared in middle of the project promoting the appropriated updates on the tasks developed. Another relevant problem was finding a determined material to machine the motor "Mandioca", we did not find a supplier which issued the a certificate from this initial material proposed on the project.

The problem of integration was solved with solid communication and interaction between all the members from the group allowing that in each new decisions and important tasks, all the members could contribute to the problems resolutions. The way that we found to solve the problem with material not found was change the project, so we had to redesign the dimensions motor, therefore the group had to developing the capacity to adapt the project in function from the problems emerged.

Electronic system managing view

The difficulties found in the electronic system was to find a method of filtering the signal that did not take a lot of time, resulting in a small delay in the apogee. Through researches a good method was found, and with the tests this proved appropriate. Weekly meetings were very important to the group, asks were delegated so that everyone would collaborate on the final project. Using all possible ways to complete the project, documenting all pieces, so that everyone involved gained experience with it.

The integration with other project areas to keep all members updated about everything that was happening were also very important.

Recovery systems managing view

- Recovery difficulties : in research group, principally in the parachute research, there are many difficulties to find good and reliably literature. In ejection systems tests subgroup the main difficult was to keep everyone updated and with tasks the role project.
  Solutions : to ensure the analytical methods used were correctly, test at IPT-USP in a wind tunnel gave us data from our last project, It made possible to confirm analytical methods that proved the analytical method used at this years project. And to keep the role group updated, the email and Whatsapp group were created to delegate tasks and discuss then, besides that, 2 weekly meeting, in the beginning of the week to introduce new tasks and discuss methods of problem resolution, and one in the end of the week to present results.
- Integration difficulties : in order to keep every member updated from structural work and to always exchange informations with other areas about technical details from the project.
  Solutions : 2 weekly meetings, the first one to discuss project problems with the role group, and a second one to avoid misunderstands and discuss about group managing problems and show results.

SYSTEM WEIGHTS, MEASURES, AND PERFORMANCE DATA APPENDIX

2017 Spaceport America Cup
Entry Form & Progress Update

Color Key	SRAD = Student Researched and Designed	v17.1

🟥 Must be completed accurately at all time. These fields mostly pertain to team identifying information and the highest-level technical information.

🟦 Should always be completed "to the team's best knowledge" , but is expected to vary with increasing accuracy / fidelity throughout the project.

🟨 May not be known until later in the project but should be completed ASAP, and must be completed accurately in the final progress report.

Submit Date:	5/29/2017	Team ID:	48
			* You will receive your Team ID when you submit your project entry form.

Team Information

Rocket/Project Name:	Imperius	
Student Organization Name	Projeto Jupiter	
College or University Name:	Polytechnic School of the University of São Paulo	
Preferred Informal Name:	Projeto Jupiter	
Organization Type:	Club/Group	
Project Start Date	8/1/2016	*Projects are not limited on how many years they take*
Category:	10k – SRAD – Solid Motors	

Member	Name	Email	Phone
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Faculty Advisor	Bruno Souza Carmo	bruno.carmo@usp.br	+55(11)3091-9882
Alternate Faculty	Edilson Hiroshi Tamai	edhtamai@usp.br	+55(11)99617-0224

For Mailing Awards:

Payable To: Breno de Almeida Avancini

Address Line 1: 56 Antonio Bento St. apt 52 São Caetano do Sul, São Paulo, Brazil, 09520-050

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Length (inches):	133,9	
Max Diameter (inches):	5,9	
Vehicle weight (pounds):	39,68	* Payload not included in vehicle weight
Liftoff weight (pounds):	66,43	
Number of stages:	1	* Not including Kinetic Energy Dart
Strap-on Booster Cluster:	No	
Propulsion Type:	Solid	
Propulsion Manufacturer:	Student-built	
Kinetic Energy Dart:	No	

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

1st Stage: SRAD Solid, 17.95 pounds (design, 17.61 pounds actual measured in 1st static firing) of Potassium Nitrate - Sorbitol (KNSB) 65-35 propellant, M Class, 10125 Ns (design, 9604 Ns actual measured in 1st static firing).

Total Impulse of all Motors: 9604 (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):	18	
Liftoff Thrust-Weight Ratio:	7.65	
Launch Rail Departure Velocity (feet/second):	85.12	
Minimum Static Margin During Boost:	2.1	*Between rail departure and burnout
Maximum Acceleration (G):	12.02	
Maximum Velocity (feet/second):	989.74	
Target Apogee (feet AGL):	10000	
Predicted Apogee Altitude (feet AGL):	10027	

Payload Information

Payload Description:

Flight data acquisition system, with embedded sensors: gyroscope 3-axis accelerometer (MPU6050), pressure sensor (BMP180), temperature sensor (DS18B20) and SD card. Furthermore, a COTS Stratolegger will be used as an alternative data acquisition system.

Recovery Information

Payload Recovery Method:	Parachute	
1st Stage Recovery:		Additional Comments
Type:	Parachute	30 degree conical canopy . (CdS)p = 0.56 m²
Primary Initiation Sensor:	Barameter	
Secondary Initiation Sensor:	Barameter	
Deployment energy Source:	Springs	
2nd Stage Recovery: (If Applicable)		Additional Comments
Type:	Parachute	Cruciform canopy shape. (CdS)p = 8.4 m²
Primary Initiation Sensor:	Barameter	

Secondary Initiation Sensor:	Barameter	
Deployment energy Source:	Springs	
3nd Stage Recovery: (If Applicable)		Additional Comments
Type:	N/A	
Primary Initiation Sensor:		
Secondary Initiation Sensor:		
Deployment energy Source:		
Strap-On Booster Recovery: (If Applicable)		Additional Comments
Type:	N/A	
Primary Initiation Sensor:		
Secondary Initiation Sensor:		
Deployment energy Source:		
Kinetic Energy Dart: (If Applicable)		Additional Comments
Type:	N/A	
Primary Initiation Sensor:		
Secondary Initiation Sensor:		
Deployment energy Source:		

Planned Tests

* Please keep brief

Date	Type	Description	Status	Comments

1/10/17	Ground	Parachute wind tunnel testing	Successful	Cd determinations
1/15/16	Ground	Ejection system	Successful	Spring loaded system
4/16/17	Ground	Parachute car testing	Minor Issues	opening force method determination
4/20/16	Ground	Ejection system dropped from a tower	Successful	full deployment
3/17/17	Ground	Propellant c*determination	Successful	Closed vessel technique
3/25/17	Ground	Propellant burn rate determination	TBD	Cancelled (Previous data will be considered for design)
4/6/17	Ground	Motor casing hydrostatic test	Successful	Pressure = 75 bar (1.5 MOP)
4/14/17	Ground	Motor 1st Static Firing	Successful	Instrumented Thrust
5/6/17	Ground	Motor 2nd Static Firing	TBD	Cancelled
5/12/17	Ground	Barometric Initiation sensor	Successful	Vacuum chamber
5/1/17	Ground	Fins Impact Test	Successful	Fins dropped from 10 m to simulate impact velocity with added weigth
4/25/17	Ground	Aerodynamics Wind Tunnel Test	TBD	Cancelled

PROJECT TEST REPORTS APPENDIX

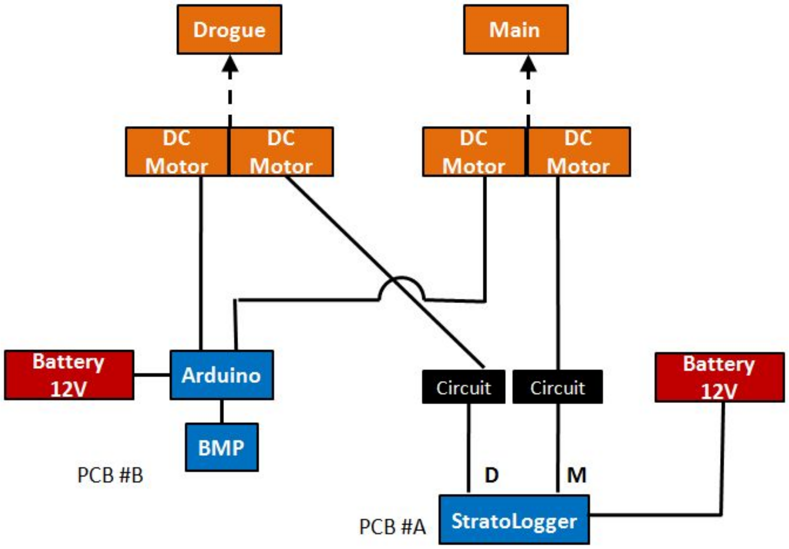
- **Recovery tests**

Cruciform opening force tests realized with Baiuca Sports company resulted at an opening force between 350 kgf and 420 kgf . Which is close to the opening force calculated by the group 392,73 kgf.

The conical parachute tests were made with a similar model at IPT-USP, resulting a 0.85 Cd, however, the material porosity of the prototype was less resistant and less porosity. The material of the final project is more resistant, and porosity. Baiuca Sports manufacturer of the parachute, estimated the Cd of 0.75 with the new fabric.

To ensure the reliability and functionality of the ejection system, several tests were made this year. With the final prototype all the test so far were successful, with a sample of 14 tests. Video of the tests are on our Facebook Page, on the link : https://www.facebook.com/ProjetoJupiter/videos/1901264146754568/

- **Dual redundancy of recovery system electronics**



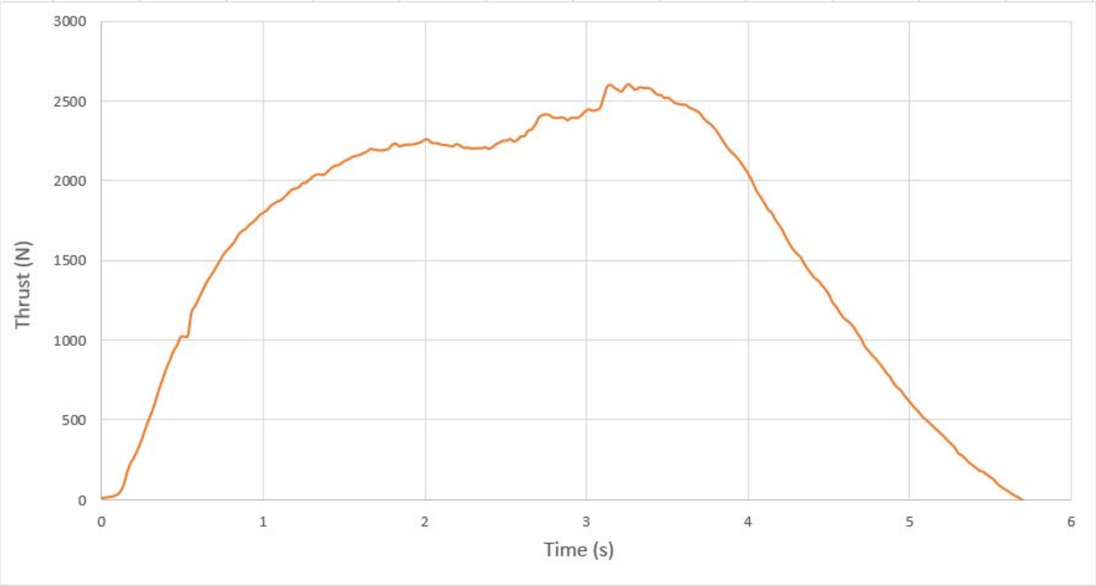
The primary system contains a Stratologger COTS (Commercial off-the-shelf) sensor. It is connected to a conditioning system with a LM555 and a 1n4733, that sends the signal to the dc motors connected to the H bridge L298. This system was prototyped and tested.
The secondary system contains a PCB with a BMP180 pressure sensor and an Arduino microcontroller. This system was prototyped and the tests were realized with a vacuum chamber.

- **SRAD Propulsion System Testing**

M class motor “Mandioca” was loaded and submitted to a full scale static test on May 7, 2017. For safety concerns, the test took place at a remote location, and a 40kg steel plate was put on top of a hole dug in the ground and held in place by four 1 ton-force resistant threaded rods. The motor was fixed in a vertical inverted configuration, exerting force against a 5kN maximum force load cell located at the bottom of the test platform.

Test site arrangement and test platform in place after static firing.

The static firing of the motor yielded the following results:



Thrust curve for “Mandioca” motor

Variable	Value	Unit
Propellant mass	7985	g
Total impulse	9252	N.s
Specific impulse	118	s
Total burn time	5.67	s
Average thrust	1600	N
Maximum thrust	2606	N

It is possible to notice an acceptable deviation of 2% between the expected and actual Isp, which validates the theoretical study of the motor. The greater deviation for the total impulse can be explained by the mass difference.

This results were incorporated into the trajectory simulations in order to increase the accuracy of the predictions.

- **SRAD Pressure Vessel Testing**

A hydrostatic test was carried out in order to guarantee that the casing was fit to stand pressures up to 1.5 times its mean operating pressure of 50 bar, which was calculated theoretically. Therefore, the casing was successfully submitted to a pressure of 75 bar.

Hydrostatic test setup, with the casing placed inside a protective screen

Maximum tested pressure of 75 bar

The motor resisted to the tested pressure and no leakage or permanent deformation of any parts were detected. This test was conducted at the LMO (Laboratory of Offshore Mechanics) inside the Escola Politécnica da Universidade de São Paulo in May 25, 2017. A Certified Flutrol Haskel pump was used.

HAZARD ANALYSIS APPENDIX

In accordance with IREC design, test & evaluation guide recommendations, the propellants used in this project are classified as non-toxic, in the sense that they don't require any breathing apparatus, special storage and/or transport infrastructure, extensive personal protective equipment, etc. There are, though, risks associated with the flammable nature of the propellant which need to be taken into consideration. Some potential hazards applicable to handling, transportation and storage procedures of propellants and their corresponding mitigation approach are related as follows:

Hazard	Possible Causes	Mitigation Approach
Propellant-related accidental fire resulting in burns to nearby personnel.	Accidental ignition of propellant batch during mixing	All involved personnel required to use adequate protective gear, including long-sleeved cotton lab coats, face shields, protective glasses and heat resistant gloves. Quantities of propellant in each batch or grain storage kept to a minimum. Only trained and essential personnel authorized to handle propellant samples. Grains stored separately in a thermally insulated container prior to motor assembly.
	Accidental ignition of grains after casting process	
	Accidental ignition of propellant residues in workspace or clothing	All personnel involved in propellant handling required to maintain a high level of cleanliness and orderliness regarding both propellant handling areas and their own personal and protective clothing. Personnel not allowed to smoke or use any open-flames devices or leave propellant handling areas using possibly contaminated clothing.
Ignition of solid rocket motor prior to assembly to structure or during transportation causing burn or impact injuries to nearby personnel	Exposure of solid propellant grains to conditions favorable to initiation inside solid rocket motor, including heat, flames or sparks.	Transport rocket motor inside a thermally insulated and anti - static bag. Prepare rocket motor immediately before transportation. Always leave at least one end of the motor open to prevent any pressure build-up. Never transport motor with ignited installed.

RISK ASSESSMENT APPENDIX

Team	**Rocket/Project Name**	**Date**		
Escola Politécnica da USP	Imperius I/ Projeto Jupiter	5/29/2017		
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 so that que may ignite, such as heat, flames or sparks	Low; propellant composed of KNSB without ignition enhancer and has presence residual water	Stock the grains separatedly and inside a thermal bag. Further, prepare the propellant with a low ignability characteristic	Low
	Propellant igniter exposed to static electricity or other hear source	Medium; Ingiter 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 rocket motor during launch with blast or flying debris causing injury	Cracks in propellant grain	Medium; student-built motor with limited testing and nondestructive evaluation capability	Pressure test motor case (with end closures) to 1.5 maximum expected operating pressure	Low
	Debonding of propellant from inhibitor		Visually inspect motor grain for cracks, debonds, and gaps during and after assembly	
	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	Medium; The propellant is student-manufactured, but with proper quality control doesn't exhibit intermittent burn behaviour.	Wait for appropriate time before approaching launch pads. Watch for any sign of uncomplete 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; student-built rocket with limited testing, but launch crew 200 feet from rocket at launch, behind barrier (vehicle).The project of	The rocket will be suspended in front of judges horizontally from a section of guiderail as a test	Low
	Unstable flight		Design of the structure	

		the aerodynamic shape doesn’t predict the behavior of the rocket to winds with speed higher than 15m/s	and the fins based on aerodynamic models and simulations	
	Excessive wind speed		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 guiderail 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 or high 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 stucked on a living corner or gear	The mechanical position gives a clean way between the semi rigid cable and the motor and keeps the cable under tension to avoid freedom of moviment.	Low
	Failure on logic circuit to detect ejection situations	Medium risk	Data filtering methods to avoid wrong detections and use of a parallel second comercial 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 disconection	High risk. Vibrations could disconect wires or weld during the flight	Instead of welding conections, the use of mechanical conections	Low
Recovery system partially deploys, rocket or payload comes in contact with personnel	Barometer does not detect apogee or main launch point in the righ moment	Medium risk	Data filtering methods to avoid wrong detections and use of a parallel second comercial 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 deploys during assembly or prelaunch, causing injury	Spring thrown during system's assembly	Medium risk.	Maintain the spring compressed by an auxiliar cable during assembly. During prelaunch the spring will be secured by a Ratchtet Tie-Down mechanism	Low
	Sudden activation of the ejection system	Medium risk.	Data filtering methods to avoid wrong detections and use of a parallel second comercial system	Between Low and Medium
	Ratchet system fail	Low risk	Use of auxiliar cable during assembly. Use comercial ratchet systems with a secutity factor 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 securtiry factor over 3, tapes with security factor 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 conection 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
	Rings or tapes of the 3 ring release system rupture	Low risk	Use of rings with a securtiry factor over 3, tapes with security factor 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 comercial 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 conection 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	Medium risk. Sllipage of the semi rigid cable during acceleration time.	Lengthen the size of the semi rigid cable, use of friction forces and	Low

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

ASSEMBLY, PREFLIGHT, AND LAUNCH CHECKLISTS APPENDIX

Assembly Checklist:

1. Insert payload into the payload module.
2. Screw spacing module into the payload module.
3. Go to Recovery System Assembly Checklist.
4. Screw electronic system modules into parachute modules.
5. Go to Propulsion Systems Assembly Checklist
6. Screw payload module into motor module.
7.

Propulsion Systems Assembly Checklist:

1. Install nozzle into pre-assembled rocket motor, by securing 12 M6 screws in position.
2. Install motor centalizer disk to the rear of the motor, fastening 4 M6 screws.
3. Slide motor into position, aligning 4 holes in the bulkhead with the holes in the motor disk. Secure the set in place using 4 M6 screws.
4. Install rail buttons to both structural disks.
5. Screw the motor module in place.

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 Dis-arming 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. Spring compression: using an auxiliary cable for maintain it compressed during assembly
2. Fasten Bridles connectors and 3 rings ribbons in modules.
3. Pack the parachute into rocket space along with deployment bag.
4. Pull the ratchet until the rockets shoulder is completely inside the rocket.
5. Remove auxiliary cable.
6. Close the rocket.

Recovery System Dis-arming Checklist:

1. Open the ratchet system and remove a tape from the 3-ring system in a controlled manner so as to relax the spring.
2. Open the connection between modules letting the spring relaxed.

Payload Checklist:

1. Connect sensor and microcontroller board to base board shelve, into their respective connectors.
2. Make sure activation switch is off (disarmed).
3. Measure battery voltage (nominal 9 V).
4. Connect battery to the base board.
5. Attach the sides of Payload box, and screw them together, except the front.
6. Push the shelves in its places.
7. Screw the front of Payload box.
8. Insert payload into payload module.

Electronics Systems Assembly checklist:
Recovery System:
Primary System:

1. Connect each of the outputs of the StrattologerCF boards to each of the signal conditioning boards.
2. Connect Each motor driver board to its respective motor.
3. Connect each of the signal conditioning boards its respective motor's driver boards logical input.
4. Make sure activation switch if off (disarmed).
5. Measure battery voltage (nominal 12V).
6. Connect battery to StrattoLoggerCF, to the signal conditioning boards and to the motor drivers.
7. Screw StratologgerCF board, signal conditioning boards and motor drivers on their respective places in the rocket.

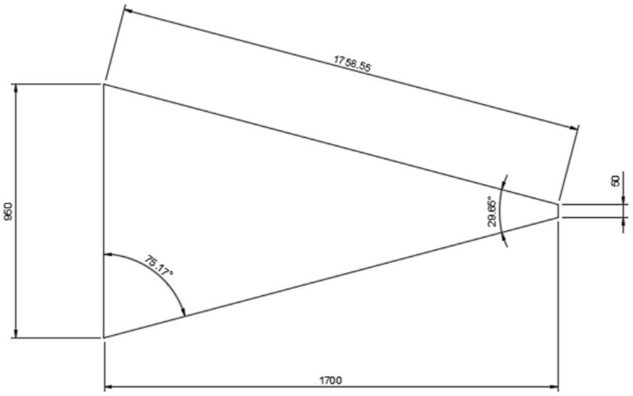
Secondary System:

1. Connect sensors and microcontroller board to base board, into their respective connectors.
2. Connect motor drivers to the base boards.
3. Connect Motors to motor drivers.
4. Make sure activation switch is off (disarmed).
5. Measure battery voltage (nominal 12V).
6. Connect battery to the base board and to the motor driver boards..
7. Screw the base board and motor drivers on their respective places in the rocket.

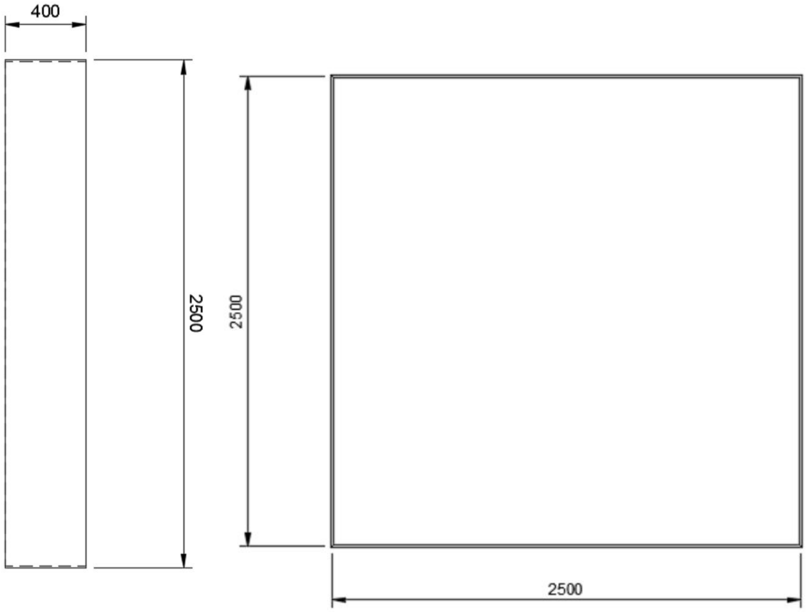
ENGINEERING DRAWINGS APPENDIX

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.

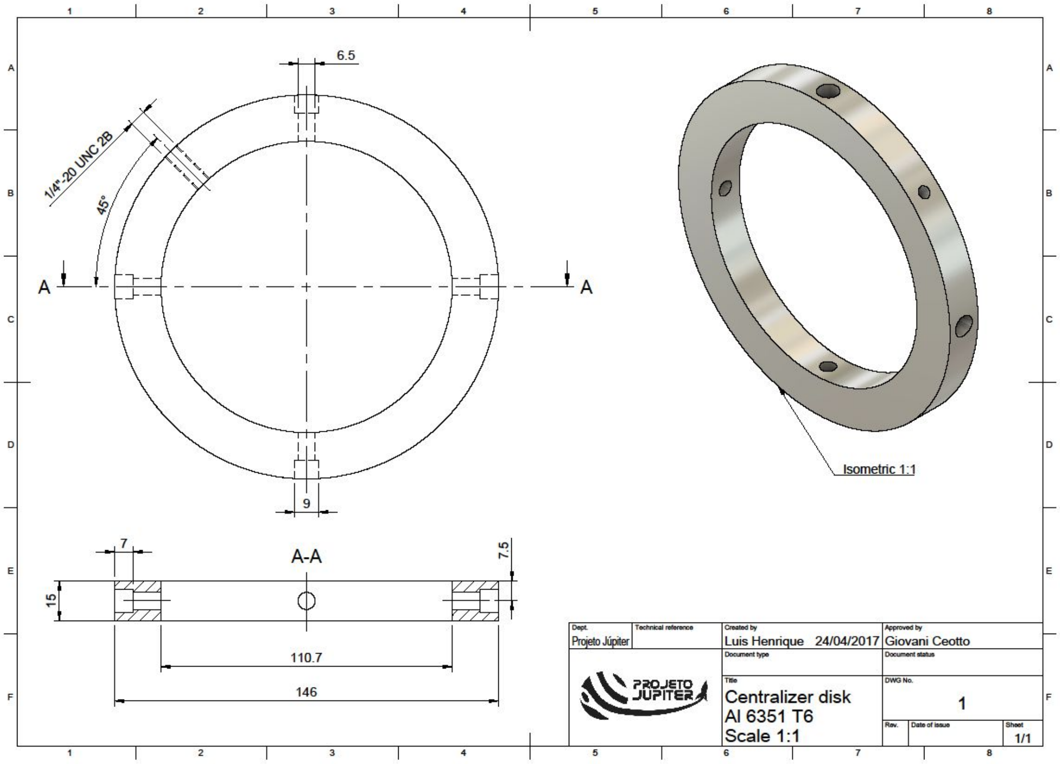
- Drogue gore technical draw



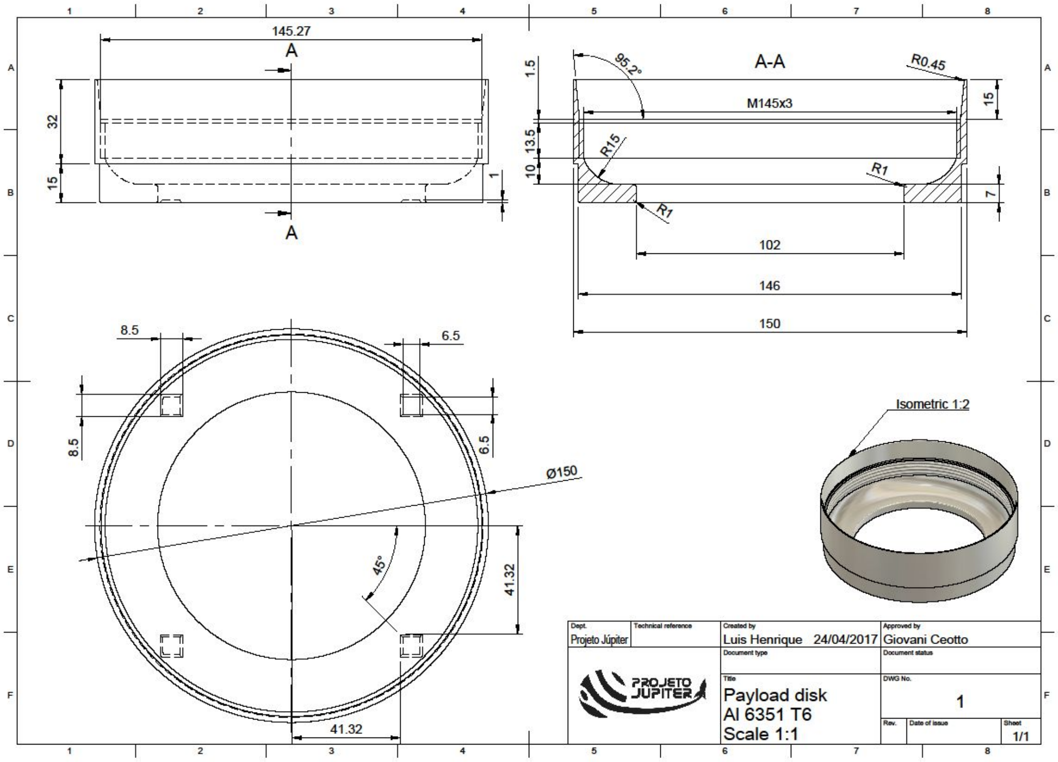
- Main parachute central square and side panel views



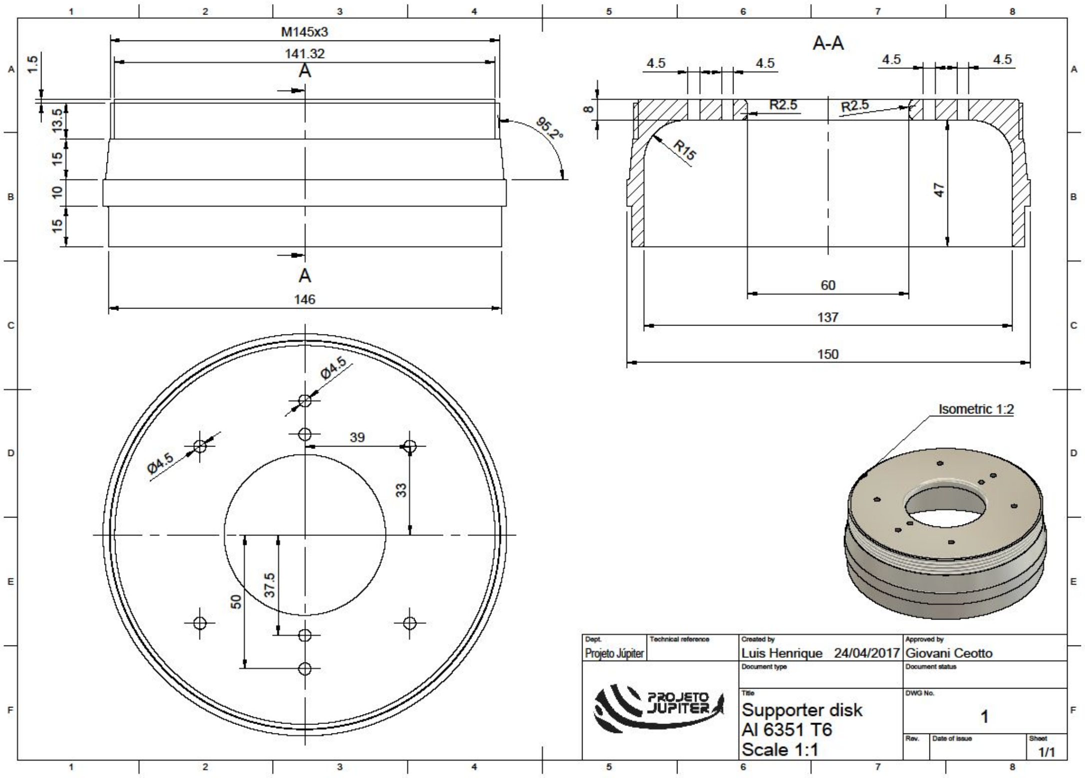
- Centralizer disk:



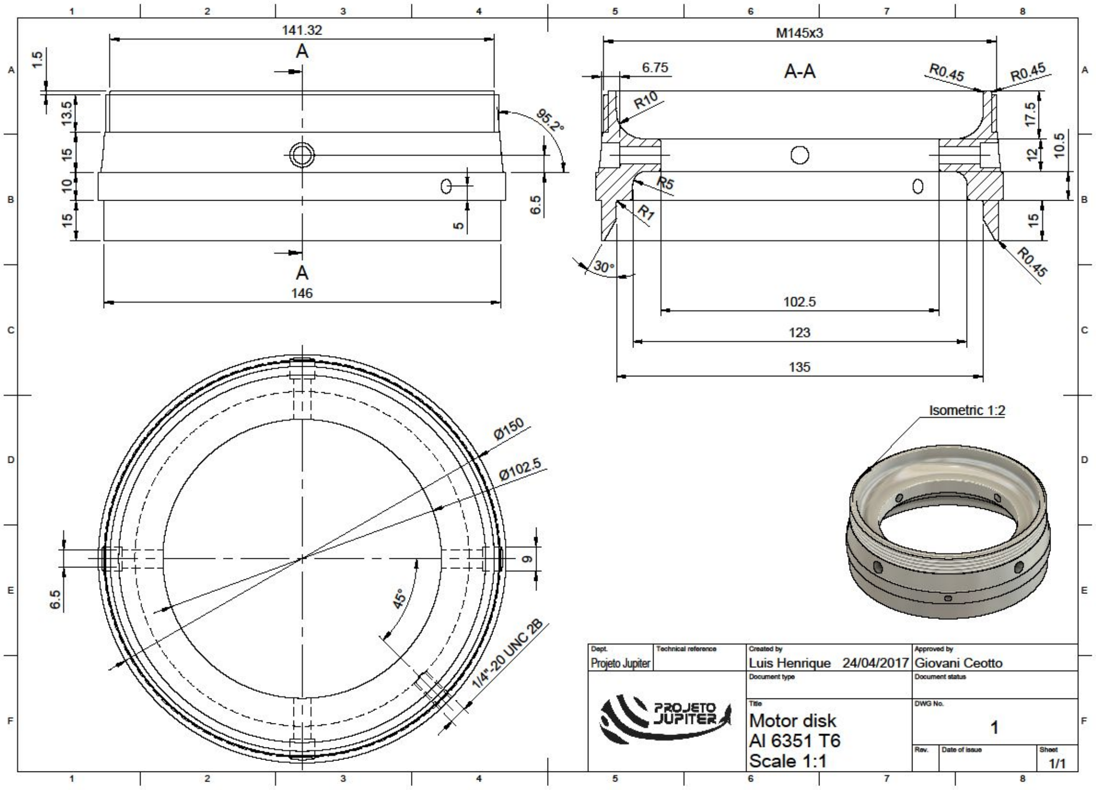
- Payload disk:



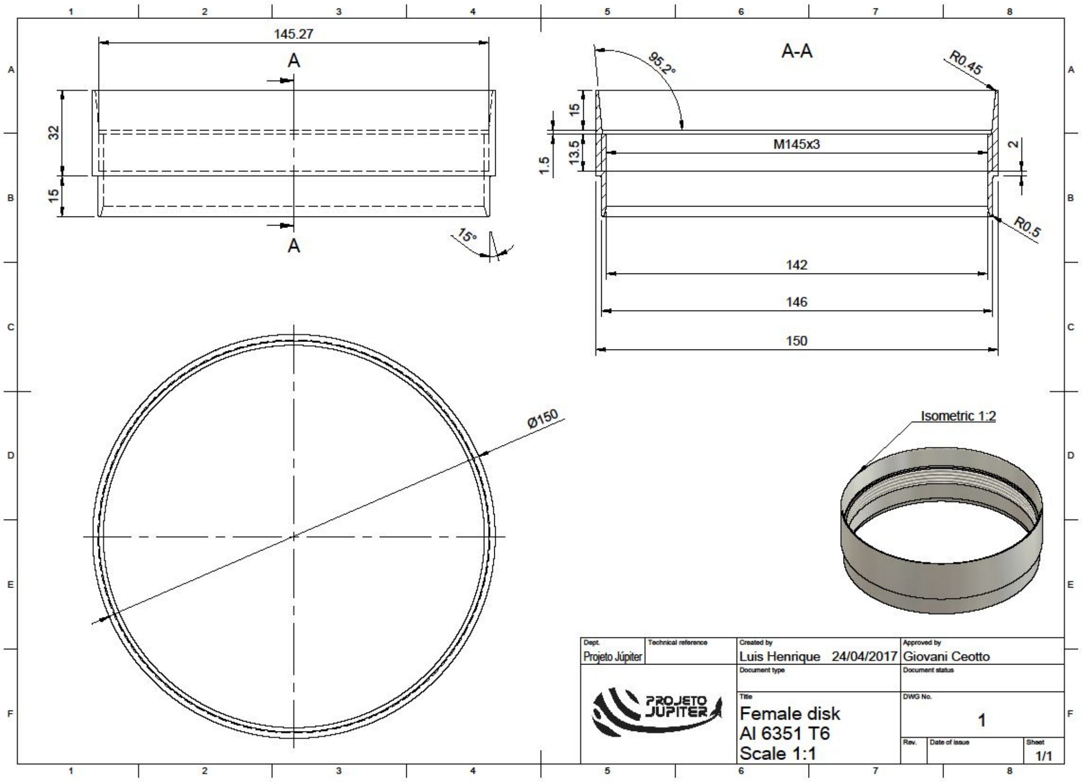
- Supporter disk:



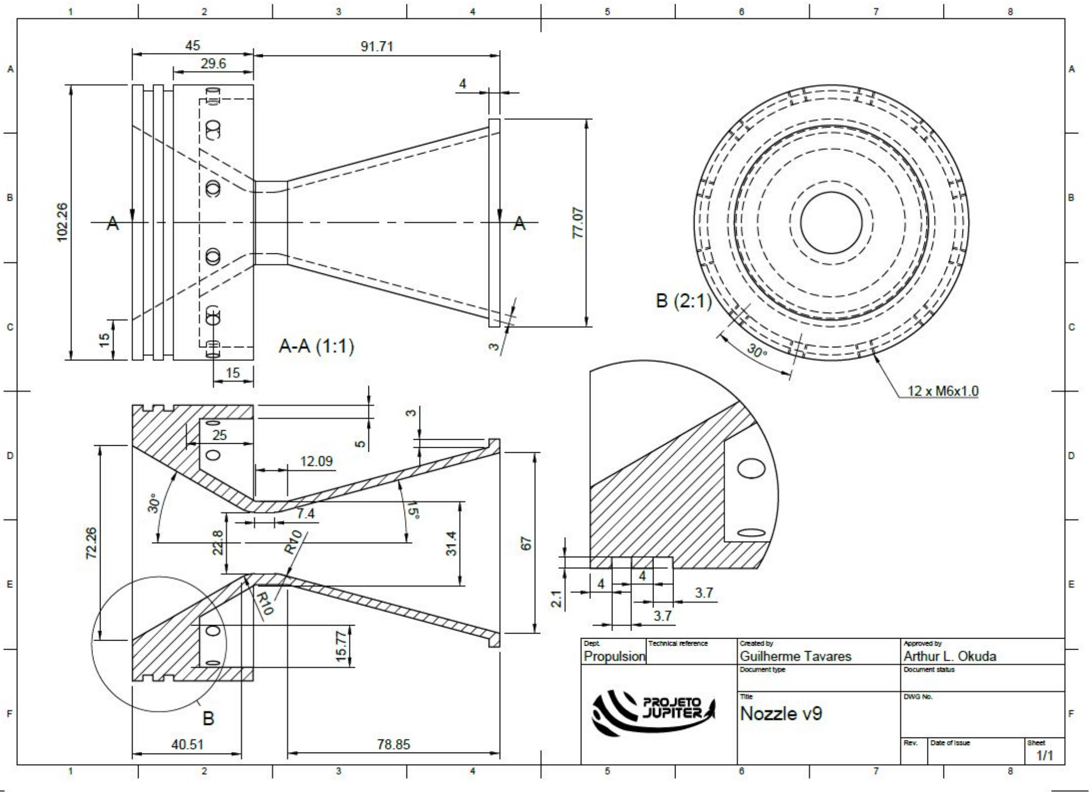
- Motor disk:



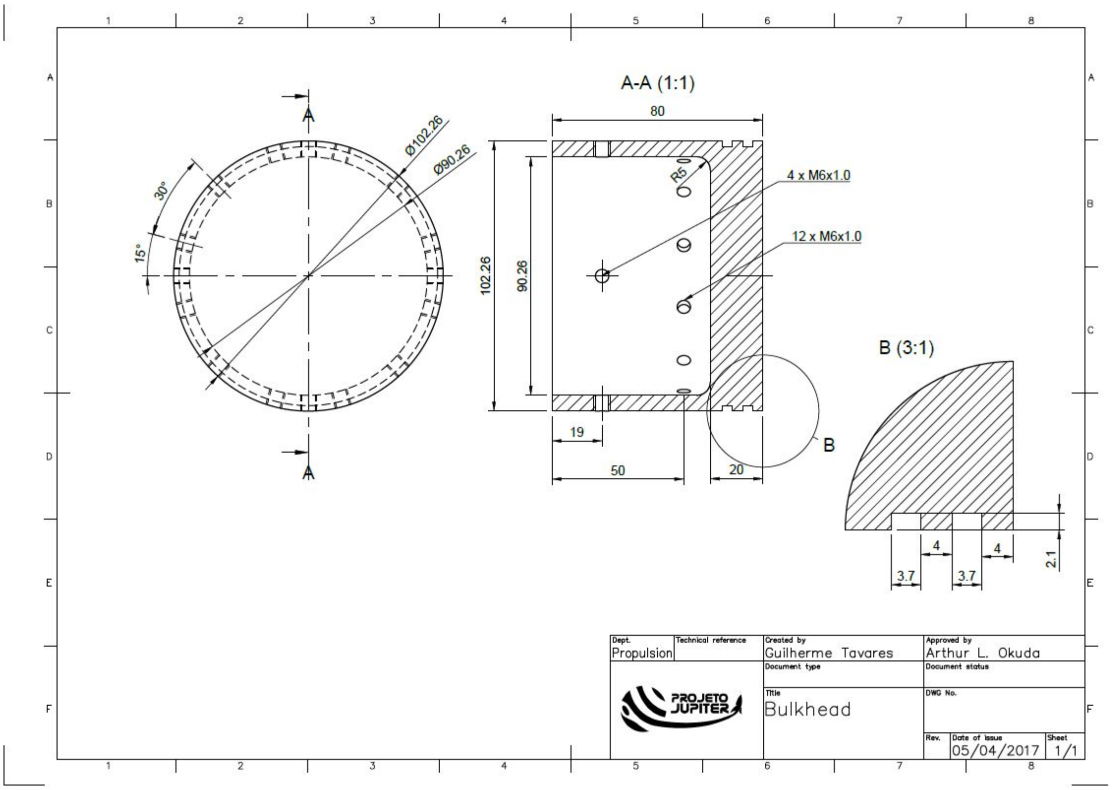
- Female disk:



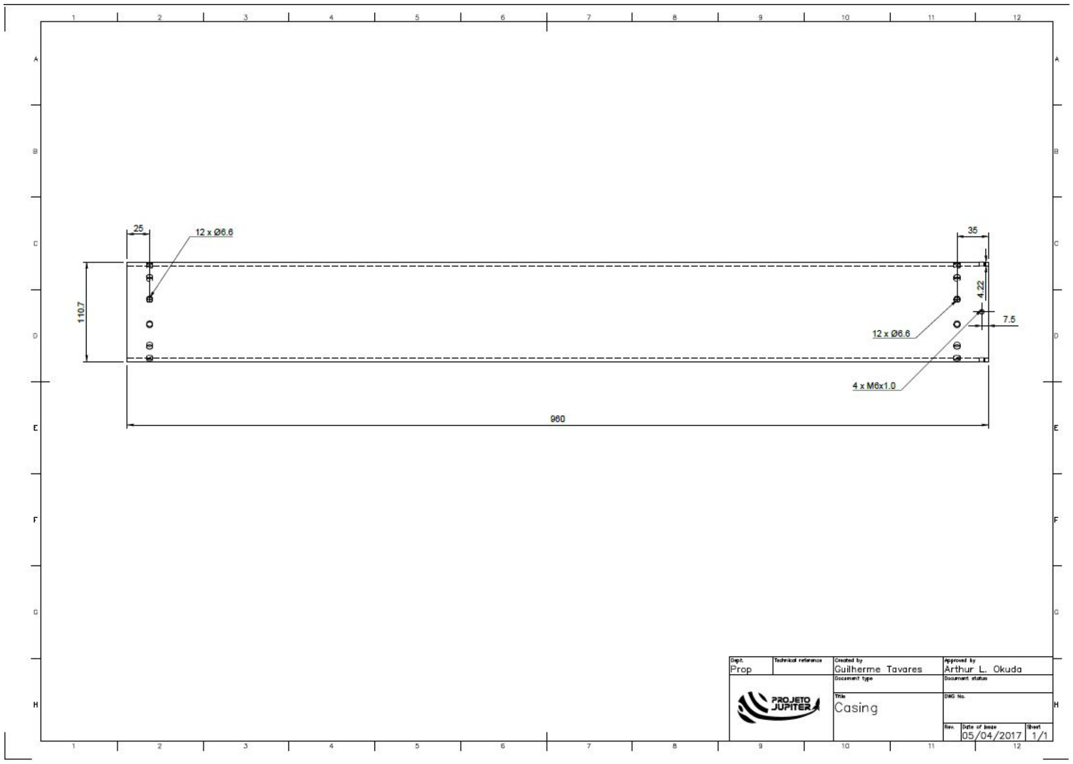
- Nozzle



- Bulkhead



- Motor Casing



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