Pró-reitoria de Pesquisa

# Model to determine the gunpowder mass for a recuperation system based on ideal gas law

Relatório final programa de pesquisa PDPD

Aluno: Victor Hassun Sarmento

RA: 21017916

E-mail aluno: v.hassun@aluno.ufabc.edu.br

Orientadora: Thais Maia Araújo (CECS)

E-mail orientadora: maia.thais@ufabc.edu.br

**Abstract:**

The challenge in recuperation system is to determine the enough amount of gunpowder needed to pressurize and eject the parachutes. The objective of this project was to develop and test a model based on ideal gas law to predict the amount of gunpowder that a rocket needs in its recuperation system. The tests were conducted simulating a rocket with recuperation system with radius and height of 0.075 m and 0.35 m, respectively. The theoretical and experimental amount established in this work showed to be in total agreement when compared to a real rocket created by UFABC Rocket Design. Two flight tests, using the determined amount of gunpowder, were successfully conducted and showed that it was enough to fulfill the rocket needs.

Keywords: recuperation system, gunpowder, parachute recovery.

**Introduction:**

Gunpowder, also known as black powder, took hundreds of years to become as sophisticated as it is known. The first written evidence about gunpowder is dated from 142 A.D., when Wei Boyang [1] wrote about a mixture of three powders that would "fly and dance violently", referring to sulfur, saltpeter and charcoal, the gunpowder composition. Around 700 A.D. gunpowder was first put on fireworks, and, only in the ninth century, inventors from China found out it could be used as a powerful weapon. By the 1100's A.D. the Chinese secret leaked and not long after that, the entire Old World started using it.

The UFABC Rocket Design, a team that builds experimental rockets, in order to participate in university competitions, uses gunpowder in its recuperation system that is responsible for returning the rocket to the ground without damages. The gunpowder is used to eject the nose cone and the parachute. Therefore, the aim of this work is to develop a trustworthy model to determine the necessary amount of gunpowder to make the recuperation system to work, avoiding errors that could end up destroying the entire rocket.

**UFABC Rocket Design:**

The team was founded in 2010 with the objective to research and build rocket engines. The team's first project was called Liberty, during two years the team produced solid engines and developed the know-how necessary to build the Boitatá I.

The next project was the Boitatá I, it was the first rocket entirely built by the team, including propulsion, avionics, recuperation and structure. In less than a year it was projected, constructed and launched in the "Centro de Estudos do Universo", in Brotas. The solid propellant used was KNSU and the structure was carbon fiber. The recovery system used a 1.3 m diameter parachute ejected by springs.

In 2014 the team participated in its first competition with two rockets, Aimoré and Eirapuâ. The former is a class *A* rocket (impulse between 1.16 and 2.5 N.s) entirely built in ABS, including the motor. The Eirapuã is a class *E* rocket (impulse between 20 and 40 N.s); its structure was carbon fiber and the engine made from PVC tube. Both propellants used KNSU as propellant and the Eirapuã won the competition, bringing a trophy to the team for the first time and in the next year the team won again with Eirapuã.

The team improved the Boitatá project, in 2016, and named it Boitatá Halitus Ignis (Fire Breath). It was a 1.000 m rocket apogee and was an inspiration for bigger projects. Afterwards a rocket named Tupã was built and launched, the biggest rocket built by the team. The aim of this project was to compete among the best teams in the world at the Spaceport America Cup, in June 2017. This goal was reached and the UFABC Rocket Design got fifth place in its category, 10.000 ft solid engine SRAD, which means and apogee around 3 km, using only solid engines researched and developed by students.

It is important to mention that the main goal of the UFABC Rocket Design team is to insert any student from any course to experience rocket science even for those who are not related to aerospace subject. The image in Figure 1 is the 2017 team moments before launching Boitatá Halitus Ignis.

Figure 1: Rocket Boitatá Halitus Ignis being hold by a member of UFABC Rocket Design team in 2017.

**Rockets:**

Rockets are the instrument humanity developed to take humans or object from Earth to space. The modern rocketry begun with Konstantin Tsiolkovsky's (1857-1935) statement: the speed and range of a rocket were limited only by the exhaust velocity of escaping gases, he is known as the father of modern astronautics. Another important person for the rocket science is Robert H. Goddard (1882-1945). His first experiments were with solid propellant engines and during this work he was convinced that a rocket could be better propelled if using liquid fuel. He was the pioneer in building and launching successfully a liquid propellant rocket in March 16, 1926. [5]

There are three known propellants :

Solid propellant motor: both fuel and oxidizer are in solid form. A simple one consists of casing, nozzle, grain (propellant) and igniter. The grain behaves like a solid mass, burning in a predictable way and producing exhaust gases. The nozzle is calculated to transform the exhaust gases into thrust. Once the burning begins it cannot be stopped.

Hybrid propellant motor: the fuel is solid and the oxidizer can be either solid or liquid. This motor has a oxidizer tank, a combustion chamber containing the fuel, a nozzle and valves the control the flux of the oxidizer. Therefore, the thrust is adjustable and the burning can be shut off.

Liquid propellant motor: both fuel and oxidizer are liquids. They are stored in two different tanks and using pumps they are taken to the combustion chamber, where it burns, resulting in exhaust gases that the nozzle transforms into thrust. [6]

**Recuperation system on real missions:**

A recuperation system is not only used in experimental rockets but also when manned space missions occur and have to reentry earth. Actually, the issue is way more difficult because besides having a functional ejection system the earth reentry is really dangerous and crucial to bring the astronauts back to Earth alive. The International Space Sation, for example, every few months has to bring its astronauts back to Earth and it happens due to a recovery system like the image shown in Figure 2 [7].

Figure 2: Recuperation system used on a real mission. Source [7]

**Gunpowder:**

Mostly used in the weapon market but also with its benefits in using in fireworks and even small experimental rockets, gunpowder is saltpeter, charcoal and sulfur mixed in a particular way. The most common recipes use in mass 75% of salpeter, 15% of charcoal and 10% of sulfur. This reaction is like a solid propellant, once it is ignited it won't stop because it has its own fuel and oxidizer. That is the reason small experimental rockets can use it.

The quality of the gunpowder is usually related to its burn rate, the lowest the burn rate, more energy is released in a smaller period of time. The modern blackpowder has smaller grains that it had before.

One important characteristic is that the gunpowder is a low explosive, rather than detonating, it burns quickly. Under pressure it burns even quicker and that is the reason the gases are confined inside guns.

Combustion converts less than half the mass of black powder to gas, most of it turns into particulate matter. Some of it is ejected, wasting propelling power, fouling the air, and generally being a nuisance (giving off a soldier position, generating fog that hinders vision, etc.). Some of it ends up as a thick layer of soot inside the barrel, where it also is a nuisance for subsequent shots, and a cause of jamming an automatic weapon. Moreover this residue is hygroscopic, and with the addition of moisture absorbed from the air forms a corrosive substance. The soot contains potassium oxide or sodium oxide that turns into potassium hydroxide, or sodium hydroxide, which corrodes wrought iron or steel gun barrels. Black powder arms must therefore be well cleaned after use, both inside and out, to remove the residue.

UFABC Rocket Design has difficulty in obtaining blackpowder, to solve that the team now buys fireworks and open it to take the explosive out. The gunpowder composition used for the development of this work is represented by a reaction of potassium nitrate (KNO3), also known as saltpeter, with charcoal (C) and sulfur (S), presented in Eq. 1 [1] in a stoichiometric balance. Carbon dioxide (CO2), carbon monoxide (CO) and nitrogen (N2) are the gases released as products of the combustion that pressurize the interior of the rocket and eject the nose cone and parachute. The potassium carbonate (K2CO3) and potassium sulfide (K2S) are solid products.

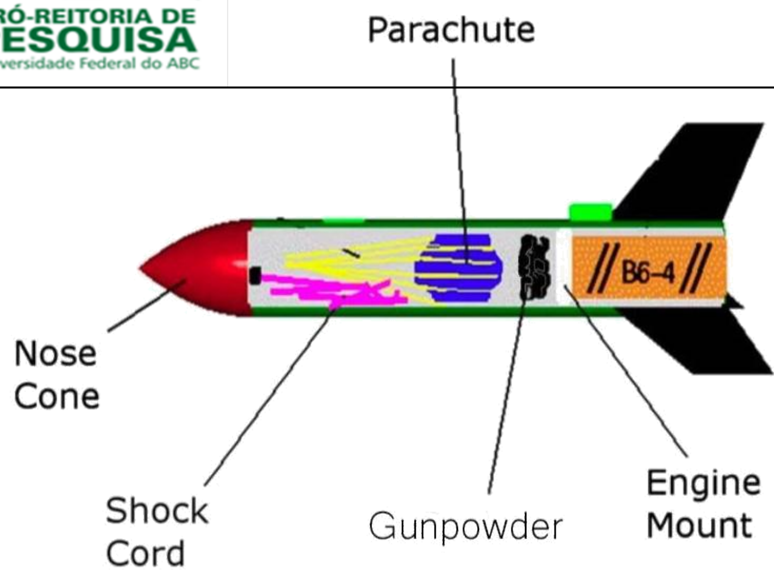
$$4\ KNO3 + 7\ C + S \rightarrow 3\ CO2 + 3\ CO + 2\ N2 + K2CO3 + K2S \qquad (1)$$

**Recuperation System At Experimental Rockets:**

The rockets built for competitions are comprised of four main systems: propulsion system, avionics system, structural system and recuperation system. The propulsion system is responsible for designing the engine and producing the propellant, the avionics system gathers all the data from the flight, the ones which were used to develop graph 1, and also is the trigger to the recovery system. The structural system builds the entire structure of the rocket. The recuperation system aims to return the rocket to the ground without damages. The system consists of a parachute that needs to be ejected in the right time, which is an avionics task. The avionics system creates a current that lights and e-match, enough to start the combustion of the black powder and eject the nose cone and parachute. A schematic drawing of a rocket is presented in Figure 3, indicating where the parachute and gunpowder are storage.

Figure 3:

Recuperation




system representation [2].

**Methodology:**

The Boitata Halitus Ignis, created by UFABC Rocket Design, was chosen to be the reference for this work. Radius and height of Boitata’s recuperation system are 0.075 m and 0.35 m, respectively.

Tests for determining the force to eject the nose cone were conducted and the arrangement can be seen in Figure 3.

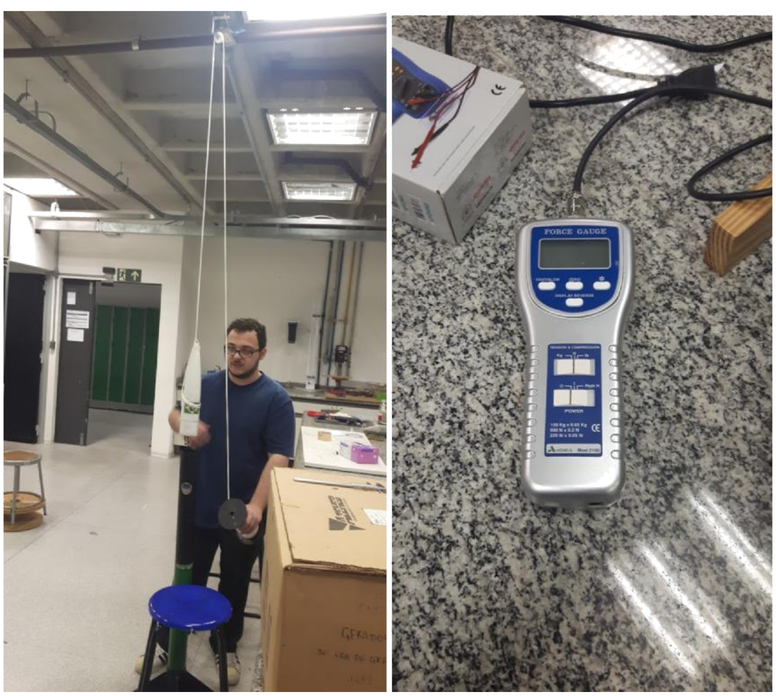



Figure 3: a) Testing the Boitata’s force to eject the nose cone using a roller fixed on the ceiling, and b) dynamometer used on test.

The rocket was fixed on the floor and using a dynamometer (HOMIS MOD 2100),showed in Figure 3b, the nose cone, Figure 3a, was pulled out of the rocket fifteen times in order to find out the value of force that guarantee that the coif is always being ejected

The model developed was based on the ideal gases theory [3], represented by Eq. 2, being P the pressure, V is volume, n is the number of moles, R is the constant of ideal gases, and T is temperature. The difference of the inside to the outside pressure was obtained dividing the force by the area of the rocket. The temperature was obtained by using CEAgui-Nasa software [4].

$$PV = nRT \qquad (2)$$

The gunpowder mass is then obtained using the data of moles number from Eq. 1.

After calculating the theoretical amount of gunpowder the next step was to test it. The first test happened on the ground: a PVC tube simulates the rocket and it is placed 30 m far from the base. At this distance the gunpowder is ignited using a battery. Different amounts were tested from the least amount to the biggest and when the ejection happened successfully it was repeated another 3 times.

Once the amount was tested and retested on the ground, the first flight test happened at the "Centro de Estudos do Universo" in Brotas. At this point, all the systems are also being tested, because it is impossible to reach a successful flight without the fully function of all four systems. A good result on this flight means the rocket is ready to compete.

**Results:**

A force of 84.8 N was obtained from the tests and for the Boitata the pressure resulted in 19,2 kPa. The temperature combustion simulation obtained was 1608.58 K that applied to Eq. 2 resulted in 0.0022 moles. A mass of 1.16 g was found to be the amount of gunpowder sufficient to eject the parachute.

At the ground test the amount of 1.3 g of gunpowder was enough to eject, several times, the nose cone and the parachute.

Boitatá flew twice this year and a summary of the two tests is presented in Table 1, and the tests are described and commented as followed.

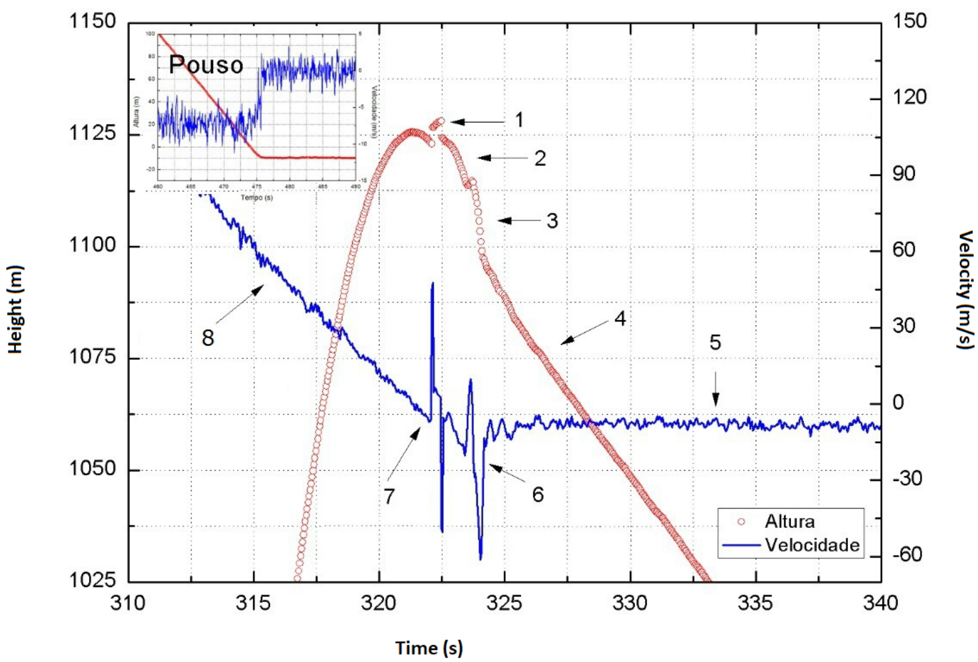
Table 1: Summary of the two tests.

| Test | Gunpowder mass | Did the parachute open? | Did it cause damage? |
|---|---|---|---|
| 1 | 1.3 g | Yes | Yes |
| 2 (competition) | 1.3g | Yes | Unknown |

TEST ONE

The first flight was a test one, obligatory to participate the “Festival de Minifoguetes” that happened in May. Our team took the rocket to the “Centro de Estudos do Universo” in Brotas in order to do so. The mass used was 1.3 g of gunpowder, which was enough to eject the parachute, but due to a bad parachute folding the gases were trapped in the bottom part of the recovery system and broke the structure as we can see in the pictures 4 a and 4 b. It is important to mention that damaging the rocket structure is a minor mistake and would not affect much in the results of a competition, and it was a fully successfully flight despite of the tube break. A structural damage like this also does not affect the descent of the rocket as it can be observed in Graph 1 following steps 1 to 7. On step 1 and 7 is the moment the ejection charge explodes. The curve is not continued on this point because the height is measured through pressure and a great amount of gases are formed at the burning. The step 2 indicates the full opening of the parachute and after this point an accelerated descent starts. The rocket reaches equilibrium at step 4, a descent with no acceleration and remains at this same velocity during step five until it reaches the ground. The step 6 shows the parachute stride and 8 is a decelerated ascent. The big oscillation that can be seen on events 6 and 7 are actually fake data that are generated due to change in pressure the gunpowder burn generates and mechanical shock at the parachute opening.

Figures 4 a) Boitata’s tube damaged by the pressure inside the recuperation system. b) Another angle of the damages caused at the same flight.




Graph 1:Recovery events

TEST TWO

The second flight was the one in the competition. The team decided to use 1.3 g of gunpowder again, but at this time some improvements were made in the parachute folding to avoid high pressure areas like happened before. Unfortunately the geography of the launch area was not appropriate for these rockets' apogees and the rocket was lost after flight, meaning no access to the flight data or the rocket conditions. Visually the recovery system worked properly, the parachute was ejected on the apogee as expected.

**Conclusions:**

The model developed to determine the amount of gunpowder to eject the parachute based on ideal gas law showed to be in total agreement when compared to a real rocket created by UFABC Rocket Design. Two flight tests, using the determined amount of gunpowder in this work, were successfully conducted and showed that it was enough to fulfill the rocket needs.

The theoretical calculus resulted in a value of 1.16 g of gunpowder, and the mass obtained from the laboratorial ground tests showed that 1.30 g of gunpowder agreed better in order to make sure the system works and avoid damages. This variance can be explained by the fact that aerodynamic pressure was not involved in the calculations and other loss are expected to happen, for example, the system not being perfectly sealed.

**REFERENCES**

**[1]** KELLY, Jack. **Gunpowder:** Alchemy, Bombards, and Pyrotechnics: The History of the Explosive That Changed the World. New York: Basic Books, 2004.

**[2]** JAYARAM, Sanjay et al. **Project-based introduction to aerospace engineering course**: A model rocket. Saint Loius: Elsevier, 2009.

[3] HALLIDAY, David; RESNICK, Robert; WALKER, Jearl. F**undamentals of physics.** New Jersey: John Wiley and Sons, 8th edition, 2008.

[4] SNYDER, Christopher A. **Glenn Research Center**. Available in <https://www.grc.nasa.gov/www/CEAWeb/> Accessed 25/09/2017

[5] BENSON, Tom. **Brief History of Rockets**. Available in <https://www.grc.nasa.gov/www/k-12/TRC/Rockets/history_of_rockets.html> Acessed 25/09/2017

[6] SUTTON, George P. BIBLARZ, Oscar. **Rocket Propulsion Elements**. New Jersey: John Wiley and Sons, ninth edition, 2017.

[7] GARCIA, Mark. **International Space Station**. Available in <https://www.nasa.gov/mission_pages/station/main/index.html> Acessed 25/09/2017