# Model Rocket Workshop

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The aim of this project was to build a rocket according to the specifications given by Castelldefels Space and Beyond Inc (CSB). In order to do so, the members of the team had to perform different rolls which, each one in a different way, contributed into the building of the rocket. It means that design, simulation, testing and launching were done in a structural and professional way. Once the rocket model had been finished, it was presented and launched. Finally, the intention was that the trajectory of the rocket would be tracked by an altimeter placed in the nose fairing of the rocket to compare it with the previous simulation.

**Keywords:** Model Rocket Workshop (MRW), 3D-Rocket

## I. INTRODUCTION

Rocketry modeling started to become a hobby in the 1950s and 1960s when there was finally no need to construct the motors and handle explosive propellants by their own self. That was possible due to the commercial production of professional motors which, in addition, carried a safety code [1]. Moreover, the Space Race, which started in 1955, surely inspired many people to develop their own model rocket not just to use in lectures of rocket-powered flight (as it was meant to be) but, instead, for fun and as an inspiration source to know and probe more about this field, e.g. how Sputnik started orbiting in 1957.

The reason why we decided to start this project was precisely for curiosity about how rockets worked and its building process. We were also attracted by the possibility of building our own rocket and, specially, designing and having it printed with a 3D printing machine. It was also interesting to see how close is the theory (simulations) with reality (launching).

To achieve our purposes, we needed to perform different roles to be the most professional and efficient we could. So we divided the tasks into design (learn a 3D-Desing program and design a rocket), development (build the rockets), test (when build, check if the rocket will be stable and safe) and calculus (model the rocket flight).

This paper is divided into different parts. The first one explains all the basics about a simple rocket flight, including the equations needed to simulate the flight of the rocket. Then there are the requirements we had to ensure with our rocket (imposed before the design and building of it). Then there is an explanation of the design of the rocket and of the simulations done. Finally, we end with a description of the launch of the rockets. We wanted to have data from the flight in order to compare it with the simulations but unfortunately we weren't able to retrieve it from the altimeter.

## II. BASICS

To start this project, it was essential to know about the equations that model the flight of a rocket.

The flight of a rocket is mainly based in the second law of Newton and in the conservation of momentum/impulse principle.

$$\vec{F} = \frac{d(\vec{p_T})}{dt} \tag{1}$$

$$\vec{F} = \frac{d(M\vec{v})}{dt} - (\vec{u} + \vec{v})\frac{dM}{dt} \tag{2}$$

Newton's second law (1) models the overall of the whole flight. The sum of all the forces acting on the rocket is represented by F, whereas p represents the total momentum of the system whose derivative is given by (2). There, u represents the propellant speed according to the rocket reference frame (e.g. the fuselage of the rocket), and v represents the velocity of the rocket with respect to an inertial system of reference (e.g. the ground). The total mass M is the sum of propellant mass and rocket mass. It is important to highlight the fact that the rocket mass itself does not depend on time whereas the propellant mass does depend. From here and assuming that u is constant it is obtained the rocket equation:

$$\vec{F} + \vec{u}\frac{d(M)}{dt} = M\frac{d\vec{v}}{dt} \tag{3}$$

Where $\vec{u}\frac{d(M)}{dt}$ represents the thrust T of the motor.

The conservation of momentum is important since the rocket moves due to the fact that propellant is expelled with a certain mass and velocity in the opposite direction. It also appears in the splitting of the rocket into the nose fairing and the fuselage where the impulse must be exactly equal in both pieces but in opposite directions.

Finally in order to get the final equation used for the simulation, the external forces acting on the system must be added. These are gravity and drag force (wind speed is not taken into account).

Drag force is given by the following expression:

$$\vec{D} = \frac{1}{2}\rho A C_D |\vec{v}|\vec{v} \quad (4)$$

Where ρ stands for the density of the medium, which in our case is air, A represents the area of contact, and $C_D$ the drag coefficient.

Finally substituting and splitting the equation into the two different coordinates (representing longitude and altitude) we obtain the following equations:

$$\frac{d\vec{v_x}}{dt} = \frac{T_x}{M} - D_x \quad (5)$$

$$\frac{d\vec{v_z}}{dt} = \frac{T_z}{M} - D_z - \vec{g} \quad (6)$$

Notice that the drag force is defined so that it is always opposite to the movement.

## III. REQUIREMENTS

The key point of this project, apart from building a model rocket, was to fulfill the requirements given by our employer. At the same time, the model had also to be design according the safety codes and be tested, so that finally, the rocket could be launched safely and trying to satisfy the company requirements.

### i. Safety code and mission requirements:

- Weight limit: 1.5 times the engine manufacturer's recommended.
- No flammable, explosive or harmful payloads.
- Transport a 20 grams altimeter to an altitude between 100 and 300 meters.
- Sinking rate of nose fairing: 2-5 m/s.
- Sinking rate of fuselage: 5-7 m/s.
- No metallic parts without the permission of CSB or heavier than 5g allowed.

### ii. Certification requirements:

- Longitudinal force that fins must resist: $F=2M_{fin}a_{max}$.
- Transversal force that fins must resist: $F=0.052S_{fin}v^2_{max}$.
- Maximum fin bending applying transversal force: d/l=17%
- Maximum fuselage bending: l/L=1%.
- The engine bracket shall resist a force $F=2T_{max}$.
- Center of gravity must be indicated.
- Rocket must be stable.
- Fins transversal alignment within 10º tolerance and longitudinal misalignment less than 5º.
- Altimeter shall be tested to check readiness and a hole of 2-4 mm of diameters must be done in the nose fairing.
- Parachute shall have a hole in the middle of 3-4 cm of diameter to ensure stability.

These requirements had to be tested before launching. In order to do that, the applied force was done by different weights which multiplied by the force of gravity exert the desired force. The tests of stability were more complicated and required ropes and swinging the rocket.

## IV. DESIGN

In this project, the aim was to construct two rockets. One was mostly given by the employer: it mainly consisted in a cylindrical tube and a nose fairing. We only had to design the fins and ensemble it altogether also with a device that would keep the motor fixed and stable (the different parts of this device where also given by the employer).

The design of the other rocket was the one that was interesting as we designed it in a 3D model in order to, later, have it printed in a 3D printing machine.

As we had no previous knowledge of digital 3D design we learned how to use Autodesk Inventor. The design of the rocket is the one in the picture below.

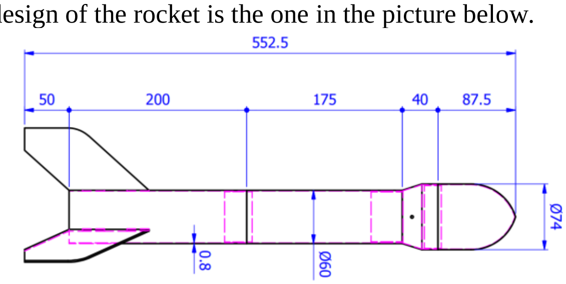


*FIG. 1. Design of the rocket made with Autodesk Inventor.*

The design was a little inspired in the Falcon 9 rocket (of Space X) and it consisted of 7 parts. The fuselage body was divided in two to be able to be printed. The nose fairing also was divided in two parts to be able to hold the altimeter during the flight and later retrieve it safely. The other three parts were the fins.

The drawings of each part can be found on appendix I, were the different parts and the overall model can be seen in detail.

The device that would keep the motor in place during the combustion for this rocket was made manually. In consisted in a cylindrical tube a little larger than the motor that was fixed to the cylindrical tube of the fuselage body with two rings of cardboard (with the large diameter the same as the fuselage body and the smaller one the same as the cylindrical tube that kept the motor in place). It was inspired in the one given by the employer for the other rocket.

It would be also important to note that two parachutes would be placed inside of the fuselage body, one fixed with cords to the fuselage body and the other to the nose fairing, to be able to retrieve the different parts safely. Each parachute would be fixed to each part with 6 cords and the parachutes will deploy during the flight when, 2 seconds after the combustion of the motor a solid piece will be thrusted from the motor that will push the parachutes and the nose fairing out of the fuselage body.

The end result of the two rockets used in this project is the ones in the figure below.

*FIG. 2. Left: Rocket designed in 3D. Right: Rocket constructed by hand.*

## V. SIMULATION

The software used to simulate the rocket flight is MATLAB. To program the flight in an easy and understandable form, as well as accurate, we divided the flight into 3 stages:

### i. 1st stage

Period in which the rocket stays in contact with the launch platform. Therefore, this part is simulated in a 2D-system of reference created by the longitudinal and perpendicular axis of the launch pad. It is simpler since there is no movement in the perpendicular axis due to the normal force exerted by the launch pad, so that there is force only in the longitudinal axis.

### ii. 2nd stage

Period when the rocket is propelled by the motor and it is not anymore in contact with the launch platform. Once it has abandoned the launch platform it is easier to turn back into the regular system of reference, x and z coordinates.

### iii. 3rd stage

Starting from the impulse given by the motor (that separates the nose fairing from the fuselage body and deploys the parachutes) to the safe landing. This stage is taken into account separately for the nose fairing and the fuselage body.

To do the calculus of the thrust of the motor and its mass and delay time, which is provided by the company [2]. Other parameters used for the simulation are summed up in the following tables:

| **Drag coefficient** | **Value** |
|---|---|
| Whole rocket | 0.14 |
| Fuselage. | 0.78 |
| Nose fairing. | 0.47 |
| Unfolded parachutes. | 1.1 |

| **Part of the rocket** | **Mass(g)** |
|---|---|
| Hand-made nose fairing | 50 |
| Hand-made fuselage | 166 |
| 3D nose fairing. | 43 |
| 3D fuselage | 193 |

| **Other parameters** | **Value** |
|---|---|
| Motor total mass | 27 gr |
| Motor final mass | 11 gr |
| Delay time | 5. s |
| Impulse | 13N during 0.01s |
| Initial inclination | 5º |
| Air density | 1.225 kg/m$^3$ |
| Gravity | 9.81 m/s$^2$ |

It is assumed that the motor mass decays linearly with time. Moreover, air density and gravity are supposed to be constant although they depend on the altitude.

Finally with these data the flight of the rocket can be simulated from the equation obtained before (in Basics). For further information about the metering of the rockets or the code see Appendix I and II respectively.

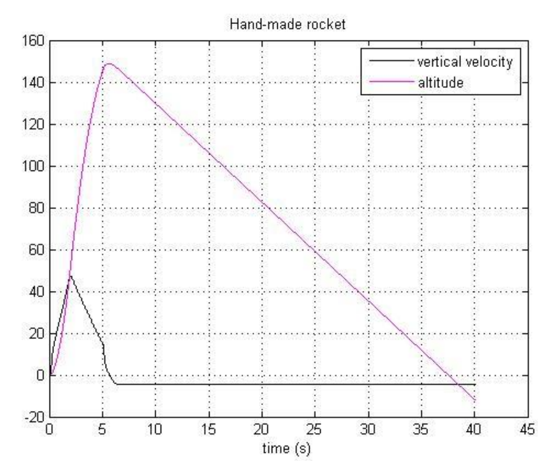


*FIG. 3: Hand-made rocket trajectory in meters (purple) and sinking rate in meter per second (black).*

The figure shows clearly two important results. First of all, the maximum altitude: it reaches 148 meters, surpassing the 100 meters. Secondly the speed at which the rocket lands: it is less than 5m/s, fulfilling the certification requirements.

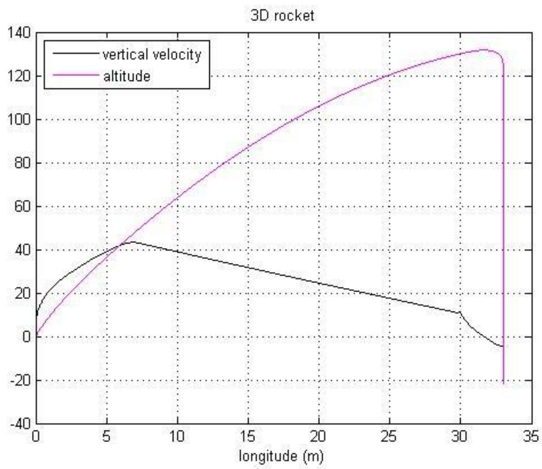


*FIG. 4: 3D rocket trajectory in meters (purple) and sinking rate in meters per second (black).*

As seen in FIG. 3. the same two important results can be seen. Although the maximum altitude is less than the hand-made rocket (133 meters) it surpasses the 100 meters and lands safely.

## VI. LAUNCHING

### i. 1st launching

The model rocket randomly failed to launch as the device that kept the motor in place got launched even when the fuselage body did not. It seems it wasn't fixed well but it is quite incredible as there had been applied several silicone layers (and it did not happen with the other rocket which had this part constructed similarly).

### ii. 2nd launching (3D designed rocket)

The launch was a success. The rocket fled straightly and got to quite altitude quite fast. When the combustion of the motor ended there was a problem with the deployment of the parachutes as the parachutes got mixed one another. This made the landing faster than desired but even if the parachutes got mixed together they still did their function as the flight down was not that fast and the rocket and the altimeter could be retrieved without much damage. The only thing that broke was one fin but it broke strangely as it didn't seem to appear as if was teared from the body as all the silicone that was used to glue it to the body had disappeared.

[1] Safety Code from NAR:http://www.nar.org/safety-information/model-rocket-safety-code/

[2] Motor data: http://www.neu.raketenmodellbau-klima.de/Download_Dateien/Motorflyer_DINA4.pdf

### iii. Measurements:

Unfortunately, the data of the flight could not be retrieved. We had some problems while trying to use the program needed to retrieve the data from the altimeter. We asked for help to the company that made the program and they responded us very kindly explaining us how it worked but even with their help we could not detect the altimeter from the computer. We suppose that there may had been a problem with the altimeter but, even before or after the flight, when connected to the power, it made the sounds that indicated that it worked correctly. And, as we could not detect it in the computer, we could not know if it recorded anything.

## VII. CONCLUSIONS

After these problems we cannot clear out a quantitative conclusion. Nevertheless, it can be said that at least the first and second stage of the 3D rocket seemed to be qualitatively in agreement with the simulations.

Even so, we have faced the problems as well as we could, and the acquired experience after the whole building process has been very positive. The fact of building a model rocket by your own hands is really inspiring and entertaining, especially when you are used to just study theory without putting it into practice.

## 1. ACKNOWLEDGEMENTS

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We are also indebted to Professor Pere Bruna who has been comprehensible and let us more time to finish our project.

## 2. APPENDIX

### I. Rocket drawings

Here goes most of the work done by our design engineer.

### II. Simulation codes