

Model Rocket Workshop

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Salim Benadouda, Sergi Castella, Maria Miró, Marta Raventós and Ignasi Traver
Polytechnic University of Catalonia, Barcelona
1-3 Jordi Girona, Barcelona, Catalunya, 08034

This project was done in order to determine whether the theoretical analysis of the trajectory of the launching of a model rocket and its actual experimental trajectory match. To do so, a rocket model was built and launched, its trajectory being recorded by an altimeter. The theoretical and experimental results did not correspond, allowing us to argue why this could have happened.

Keywords: Model rocket, 3D printed rocket

I. INTRODUCTION

Since the first model rocket motor was designed in 1954, rocket modelling has become very popular among young scientist. This is due to the fact that it allows an easy study of some interesting physic principles. It was also popularized between common people as a consequence of the launch of Sputnik. Being so mainstream led to the creation of the National Association of Rocketry, who wrote a Safety Code.

We chose to build a rocket so we could experiment the scientific method (we have experienced a lot of errors and failures). As the development of the rocket was not challenging enough for us, we decided to design a 3D-printed one and launch both. (See APPENDIX 1) Equipping them with an altimeter, we would be capable of knowing the altitude attained by the rockets in order to compare it to the theoretical model.

The Safety Code has a restrictive weigh, so we had to minimize it as much as possible. We planned to change the alkaline battery with a lighter lithium-ion one, but at launch day it failed so we had to use our backup standard battery. We also printed the 3D-printed rocket with the thinnest surface possible making it lighter than the cardboard one. The last procedure to fulfil the Safety Code was to test the strength of the structure.

As we needed the altimeter to get the data, we had to provide the payload with two parachutes. This parachutes made easier to find the different parts of the rocket and prevented it to get damaged.

II. ROCKET FUNDAMENTALS

For our purpose of launching the two rockets we had built, it was needed to run some simulations to know if our rockets fitted the requirements of the experiment.

We created a model of our experiment following Newton's 2nd Law of movement.

$$\vec{F} = M\vec{a}$$

Where \vec{F} stands for the sum of forces applied to the body, M represents the mass of the body and \vec{a} represents the acceleration of it. In our model, the equation is not that simple because of what we call the rocket principle.

i. The Rocket Principle

As the engine ignites it also ejects mass that will need to be taken in account in order to hold the Momentum Conservation Law. At a given time t the rocket may have velocity v and momentum $p(t) = mv$. By ejecting the propellant mass, the rocket loses mass and hence gains speed called effective exhaust velocity. The rocket principle leads us to this equation:

$$M \frac{d\vec{v}}{dt} = \frac{dM}{dt} \vec{u}$$

Where \vec{u} is the exhaust velocity. As we can see, the left term corresponds to a force, which we can rewrite as:

$$\vec{T} = \frac{dM}{dt} \vec{u}$$

Where \vec{T} represents the propellant force (thrust).

ii. The Rocket Equation

The Rocket Equation is obtained from the Momentum Conservation Law and the Rocket Principle.

$$M \frac{d\vec{v}}{dt} = \frac{dM}{dt} \vec{u} + \vec{F}$$

This equation is actually Newton’s 2nd Law. \vec{F} represents the external forces acting on the rocket. There are two basic forces operating on any object moving through the air that we will be considering. These are drag and gravity.

It is important to see that thrust must be greater than the weight of the rocket in order to overcome gravity and lift off from the earth.

iii. External forces

As told in the previous section, we will consider two external forces: drag and gravity. To calculate them, we will use these equations:

$$\vec{F}_g = Mg$$

$$\vec{F}_d = \frac{1}{2} \rho v^2 C_d A$$

Where g is the gravity on Earth, ρ is the air density, C_d is the Drag Coefficient and A the cross section area of the rocket. The direction of the gravity force is downwards and the direction of the drag force is against the velocity.

iv. Simulations

The rocket flight has three different phases: flight up to burn out, from burn out up to highest altitude (ballistic trajectory) and fuselage and nose fairing parachute gliding.

The assumptions we considered for the simulation are:

Drag coefficient	3D printed	Hand-made
Flight up	0.14	0.14
Balistic trajectory nose fairing	0.47	0.47
Balistic trajectory fuselage	0.78	0.78
Parachutes	1.2	1.2
Other parameters	3D printed	Hand-made
Total mass	200 g	258 g
Ejection impulse	13 N	13 N
Initial inclination	5°	5°

D7-3 engine has the trust like FIG 1:

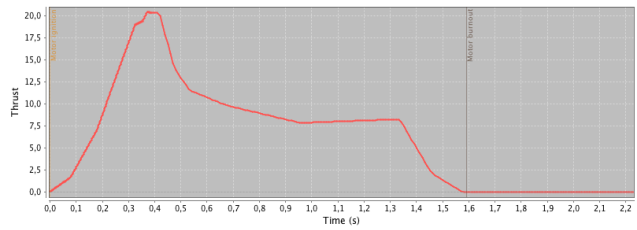


FIG 1: Thrust profile.

For our simulations we used OpenRocket software. We recreated our rockets in the program and set the drag coefficient and the motor we were using (D7-3). We used this program not just to simulate the flight altitude, but also to calculate maximum velocities and accelerations in order to test the rockets in the laboratory and see if they were able to resist in such circumstances.

The first simulation corresponds to hand-made rocket, and the second simulations corresponds to the 3D printed rocket.

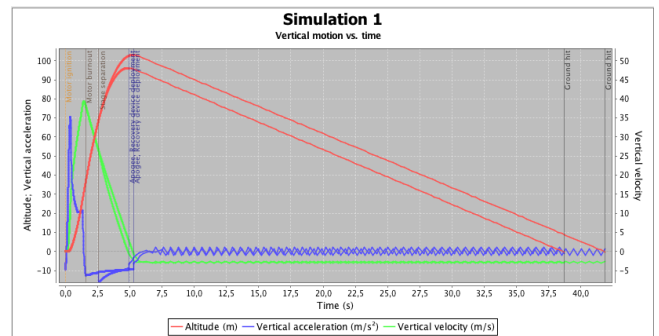


FIG 2: Hand-made rocket simulation.

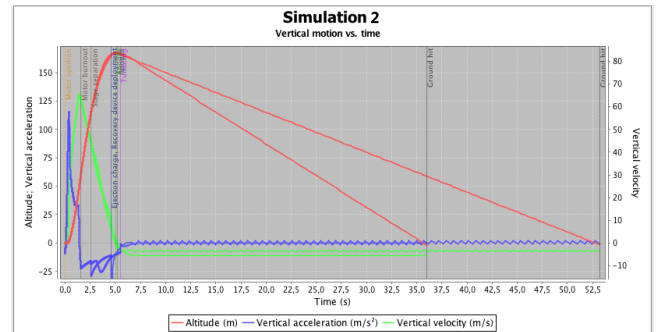


FIG 3: 3D printed rocket simulation.

The thrust we used for our simulations is the thrust of the motor we are using (D7-3). The motor we are using has an ejection charge that is expelled at burn out and hits the nose fairing separating the two parts of the rocket and allowing the nose fairing to go higher thanks to the loss of mass.

As we can see, there are some differences between the simulations. We have two different apogees, the first one it’s about 110 meters, and the second it’s about 157 meters. So, the 3D printed rocket reaches a higher apogee.

III. CERTIFICATION REQUIREMENTS

Once both rockets had been built, we had them undergo some certification requirements to make sure the launching was safe and, basically, that the rocket could handle all the forces and stresses it would be under the effects of. These certifications included:

- The fins have to resist a longitudinal force of $F = 2 \cdot M_{FIN} \cdot a_{MAX}$
- The fins have to resist a transversal force of $F = 0.052 \cdot S_{FIN} \cdot v_{MAX}^2$
- Applying a transversal force, the maximum fin bending has to be of 17%
- The maximum fuselage body bending has to be of 1%
- The engine bracket has to resist a force of $F = 2 \cdot T_{FIN}$
- The centre of gravity has to be indicated
- The fins transversal alignment has to be within $\pm 10\%$ tolerance, and the longitudinal misalignment has to be less than $\pm 5^\circ$
- At least two fins or part of them must lean on the launch pad. The distance between the rocket nozzle base and the launch pad must be at least 5 cm when the rocket is standing vertically on its fins. There must be a gap of 3-5 mm between the engine bracket base and the metal hook. A device should be disposed so it allows rigid guidance of the rocket by the launch guiding rod during take-off
- The rocket has to be designed in such a way that a stable flight is guaranteed
- The recovery system has to be able to withstand the loads during its operation and meet the sinking rate requirements for both the rocket nose fairing and the fuselage. In case recovery parachutes are used, they should have a 3-4 cm diameter hole on the top part to ensure stability when at gliding phase
- The altimeter has to be tested to check readiness and correct operation. A 2-4 mm hole in the nose fairing wall should be allocated in the vicinity of the altimeter sensor. Altimeter operation knowledge has to be demonstrated by team's members. Battery and altimeter will only be sealed inside the nose fairing the immediately prior to launch

We carried each and every single one of the tests and had perfect results. Therefore, we made sure the launching could be done correctly.

IV. MEASUREMENTS

Measurements were performed with the air-pressure based altimeter *MINIALT/WD*, which records height at a sample rate of 20 samples/second. Then data was captured

using a DT2x transfer kit along the specific software¹ for the altimeter and analysed using Matlab®. Data treatment included a *smoothing spline fitting*² of the altimeter measurements to reduce noise and improve visual clarity.

Unfortunately, a presumed engine malfunction made the first rocket explode almost instantly after launch breaking its body. Consequently, we could only analyse data from the 3D printed rocket, which is shown in FIG 4.(See APPENDIX 2)

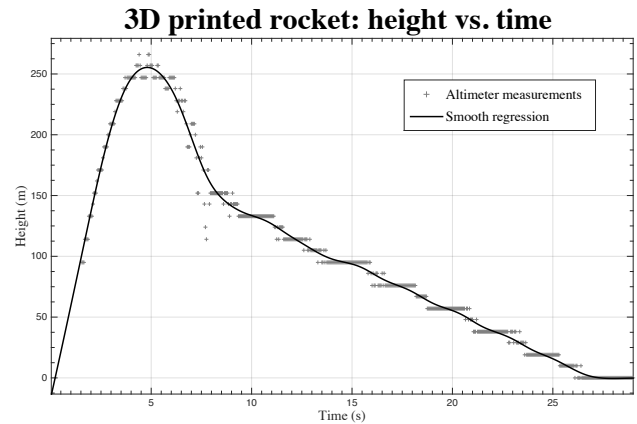


FIG 4: height versus time plot of the 3D rocket model. In grey crosses altimeter measurements are shown and the black line represents a smooth regression.

The plot clearly shows the different stages of the rocket flight: first, the ignition phase followed by a parabolic movement when the thrust is over and the top is ejected, and finally, after the parachute deployment, a constant-speed fall down to the ground. Maximum height, $\sim 260\text{m}$, was reached approximately 5s after take-off and the parachute deployed approximately 3s later; from there, it took about 19s for the rocket to hit the ground after descending 140m, giving us an average speed of:

$$v_{av} = \frac{140\text{m}}{19\text{s}} \approx 7.4\text{m/s}$$

All time intervals are coherent with the video recorded. Comparing these results with the numerical simulation exposed in the previous section, we can see how the flight exceeded our forecast in terms of maximum height reached. Moreover, the simulation assumed that the parachute would be deployed when the top of the rocket was ejected but in fact it took about 3 seconds in which this part fell freely; and this explains the different shape of the plot in FIG 4 with respect to FIG 2 and FIG 3.

¹ Downloaded from the website

² Detailed information on the method available on mathworks.com/help/curvefit/

The simulation's maximum height error could be explained by many factors such as not ideal drag calibration due to aerodynamic properties that we did not take into account. In addition, greater engine's thrust than advertised could have altered the rocket trajectory. Although we must say that we were not able to find the thrust tolerance in the datasheet, previous experiences of other people around the world using these engines seem to indicate that this hypothesis is plausible. Finally, although the launch day was not meteorologically complicated, conditions such as wind could also have played a part in this inconsistency.

If we consider a new simulation with other motor parameters we obtain other trajectory, that trajectory matches with the obtained one.

Further study with different rockets launched and more simulations made should be done in order to statistically clarify the origin of this inaccuracy.

V. CONCLUSIONS

After completing both the theoretical analysis of the trajectory of the rocket and the actual launching and comparing both results, we were able to draw some conclusions. These can be separated into two groups: conclusions about the data gathered in the project and the results obtained and thoughts on how the process followed in order to do so positively affected us.

The first set of conclusions has to do with the comparison between the theoretical and experimental results. As it has already been expressed, the data obtained in each part of the project does not match. The different reasons why this happened have already been discussed and one main conclusion can be drawn from this: theory and reality do not always match. Nevertheless, both studies allowed us to gain some important knowledge and so did the fact that they do not correspond, because it made us think about the reasons why this happened. On top of all of this, we also learned that we cannot completely control the behaviour of model rocket motors, since one of them did not work correctly, preventing us from collecting all the data we wanted to.

Apart from the analysis of numerical results, this project also helped us develop several qualities that are most certainly going to be helpful in the future. First of all, we practiced working in a group; we saw how the important decisions had to be agreed on by all the members of the group but also how we needed to trust each other to do a good job in the parts in which we worked separately. Secondly, we appreciated greatly the chance to do some manual work, something we do not often get the chance to do. We also found the freedom and autonomy granted to us by the teachers really motivating. For all of these reasons, we can confidently say that not only did we learn a lot during the project but also we had plenty of fun!

VI. ACKNOWLEDGEMENTS

We would like to express our gratitude for Enrique García-Berro, Santiago Torres and Jose Ignacio Rojas for making everything convenient and understanding all the setbacks that we have suffered.

This link is the presentation of both rockets:
<http://bit.do/modelrocketvideo>