Model Rocket Workshop

Marc Far, Alberto Hernández, Joan Martínez, and Núria Pascual
Projectes de l'Enginyeria Física 2
Escola Tècnica Superior de Telecomunicació de Barcelona
Universitat Politècnica de Catalunya
(Professors: Enrique García-Berro, José I. Rojas, Santiago Torres, Joshua Tristancho)

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In this article will be explained the construction and launch of a model rocket, from the simulations to the workshop, with the materials used and the flight tests passed. Includes both simulated and experimental graphics of altitude and the comparison between them.

I. INTRODUCTION

The main goal of this project is trying to recreate as accurate as possible every aspect that is present in a real rocket building process. These aspects cover a wide range of scientific fields like classical and relativistic mechanics, programming and simulating but we have also made a real specialization of roles to ensure a good teamwork and followed a Gannt diagram to work coordinately.

Model Rocket Workshop (MRW) is a problem based learning project. That is, we set a goal, which in our case is launching a rocket and, using all possible resources, we have to achieve our objective. At the beginning we do not know the answer to all the issues that building and launching a rocket involves, but we have to be able to overcome these troubles.

The codename of the project was *Project Jericho* and the name of the rocket is Quim15.

II. THE TEAM

Four different roles are going to be assumed to manage this project: mission engineer, development engineer, test engineer and launch engineer.

- The **mission engineer** will coordinate all the tasks to be done, carry out a simulation of the flight of the rocket and is the one that will present the overall results once the project is finished.
- Everything related to the development of the rocket (including materials, placement of engine, parachute...) will be done by the **development engineer**.
- Before launching, the **test engineer** will perform safety and verification processes to ensure the rocket is safe and well built.
- Finally, the **launch engineer** will study the best conditions to launch the rocket and will ignite Quim15 the launching day.

Once roles are set, it is time to specify all the tasks and fit them in the Gannt's diagram.

III. PROCEDURE AND SCHEDULE

First thing to be done: meeting with professors and brief theoretical session. Set rocket equation to run simulation.

Integrate numerically the equation and guess some important values like maximum height, terminal velocity, time of flight..

Build a rocket according to the scale relations of a real one, using the appropriate materials. Perform reliability and safety tests.

Launch the rocket and gather information from the altimeter.

Analysis of gathered data. Make a report and present results.

Once we know the tasks and the chronological order, we fit the data in a Gannt's diagram as shown in FIG. 1.

FIG. 1. Grant diagram

IV. SIMULATION

We made a simulation of the flight of our future rocket. It was done by integrating the Newton's Force equation and assuming that the mass of the fuel is lost during the process. We also took into account the drag force of the air. The aim of the simulation was to see approximately how high would the build rocket go the day of the launch.

There are 3 phases in the flight of the rocket: the *thrust* phase, the *inertial* phase, and the *parachute* phase. In the thrust phase, the engine is thrusting the rocket so it gains all the velocity needed to reach the maximum height. When the engines run out of fuel, then the inertial phase begins: the rocket has a certain initial velocity but there is no engine, so it starts to move slower due to the gravity and the air drag force. Finally, when the rocket reaches the maximum height, the nose cone separates from the rest of the rocket and falls down tied to a parachute, that makes the fall much slower.

The equation that models the whole path is the Newton's equation:

$$\frac{d}{dt}(Mv) - (v-u)\frac{dM}{dt} = F,$$

that can be rewritten as:

$$M\frac{dv}{dt} = u\frac{dM}{dt} + F,$$

where v is the velocity of the rocket, u is the velocity of the gas respect to the rocket and F is the sum of all forces in each phase.

A. Assumed data

In order to do the simulation, we should have made some assumptions on the data involved in the calculation:

- Total mass: 300 g
- Rocket diameter: 7 cm
- Parachute diameter: 50 cm
- Drag coefficient (phase 1 and 2) D_1 and D_2: 0.14
- Drag coefficient (phase 3) D_3: 1.15
- Air density ρ_{air}: 1.2922 kg/m^3
- Expelled gases velocity: 20 m/s
- **Engine:**
  - Total mass: 45 g
  - Propellant mass: 20 g
  - Thrust: 14 N (constant)
  - Thrust duration: 1.5 s

The drag force is calculated using the following expression:

$$F_D = \frac{1}{2}\rho_{air} D A v^2,$$

where D is the drag coefficient, A is the area of the rocket section and v is the velocity.

B. Integration in 3 parts

Three different consecutive simulations were done in order to complete the path of the rocket along time.

Phase 1: The mass of the rocket at this stage is $M(t) = 300 - \frac{20}{1.5}t$ (t in seconds and mass in grams). We assume that the fuel is consumed constantly among time.

Phase 2: At $t = 1.5$ s, there fuel has run out and the initial velocity of the rocket at this phase is the final velocity of the rocket at the previous phase. There is no thrust force and there are no gases expelled.

Phase 3: The mass we have to consider in this stage is the mass of the nose cone and the parachute. The drag coefficient is much larger, since the parachute presents more resistance to air.

Combining all the phases, we obtain the simulation shown at FIG. 2

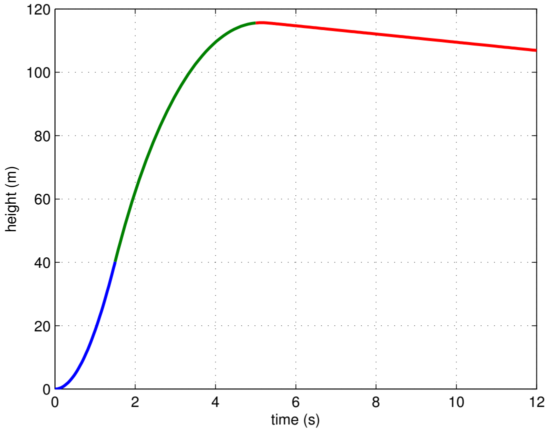

FIG. 2. Simulation results

According to the simulations, the rocket should reach a height of 115.5 m and its maximum velocity should be 50.2 m/s. In the last phase, due to the huge drag force, the terminal velocity is small, and the nose cone falls very slowly: at 1.3 m/s. The nose cone with the parachute fall to the ground at $t = 95$ s.

V. CONSTRUCTION AND MATERIALS USED

A. Dimensions

The Quim15 rocket will be essentially a cylinder 63 cm tall (45 cm of fuselage and 18 of the nose faring) and with a diameter of 8 cm. The fins will be rectangular (7 cm × 15 cm approximately). There will be three of them on the bottom of the fuselage, with an angle of $\frac{\pi}{6}$ rad between them.

The fuselage consists on a cardboard cylinder and the nose fairing is made of plastic. The rocket engine power has to be limited in order the launch to be legal without having to require additional permissions. The non-flammable cotton must be put between the engine and the payload to ensure that the altimeter is not damage in the whole process. The fins are made cutting a piece of wood from the laboratory. The altimeter and the battery are placed inside the nose fairing, and the parachute is hooked to it.

B. Mass distribution

Once in the lab, it is time to list every material that will be needed and weigh it (TABLE I), in order to identify the actual total mass and estimate where will be the mass center.

Item	**Weight (in grams)**
Rocket motor	40
Nose faring	48
Fuselage	43
Non-flammable cotton	9
Cord roll	10
Fins	60
On board computer	11
Battery	22
Engine Support	12
Parachute	11
Others	10
TOTAL	276

TABLE I. Each component and its weight on grams

We can simplify the system onto three punctual masses: the payload, placed just above the fuselage and with the combined weights of the nose and the altimeter (81 g); the engine, placed on the bottom and including the rocket motor, the engine support and others (62 g); and the fuselage, placed on the mass center including everything else (64 g). The mass center results at approximately 25 cm height.

VI. CERTIFICATION TESTS

Before the QUIM15 rocket launch, there were a set of certification tests that the rocket had to fulfill to guarantee the proper work of the rocket. These conditions were:

- Each fin had to resist a longitudinal force of

  $$F = 2M_{fin}a_{max}.$$

  Our rocket had three fins so it had to resist a force 3F. We supposed that a_{max} was the difference between maximum thrust (21 N) and the rocket weight(3 N) divided by the rocket mass ($\approx$ 300 g).The mass of each fin was F was 1.7364 N, so the total force was 5.2092 N To test it, we placed the rocket on a weighting scale and pressed the re-zero button. Then we pressed the top of the rocket till the scale showed 520 g. The fins resisted this force.
- Each fin also had to resist a transverse force

  $$F = 0.052 \cdot S_{fin}V_{max},$$

  where V_{max} is the maximum velocity of the rocket. In the simulation it was 50.2 m/s. The area of each fin was $109.9cm^2$. Hence, the transverse force based on the simulation was $F = 1.44$ N. When applying this force, the fin should have a maximum bending d/l of 0.17, where l is the length of each fin. In our case the length of each fin was 7 cm, so the maximum bending could be 1.19 cm. To measure it, we searched an object with a weight of nearly 1.44 N and placed it on the rocket (shown in Fig 3). Then we measure the bend of the fin and it was $d = 0.15$ cm.

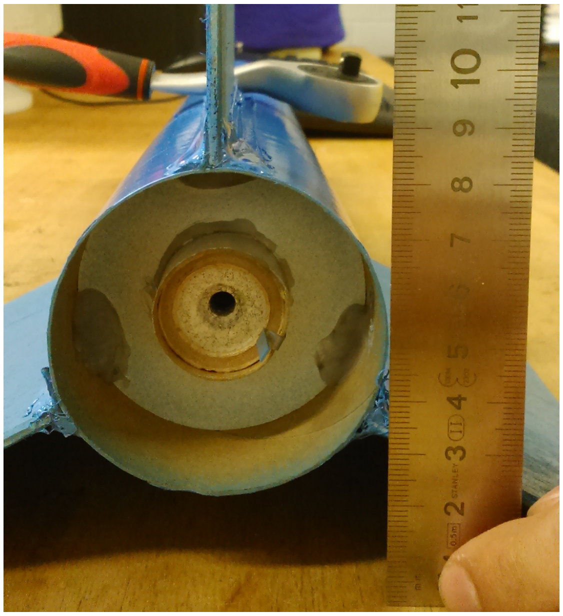

FIG. 3. Measuring the bending of the fin

- Another test was the body tube bend. It couldn't exceed the 1 per cent of the length between the center of gravity and the top of the rocket. This bend was not measurable with accuracy because the bending was almost zero.
- The fins had to be aligned. The error of the transverse alignment had to be less than 10 degrees. Our angles were 117, 121 and 122 degrees, so it passed the test.
- The engine bracket had to resist a longitudinal force of $F = 2T_{max}$, being T_{max} the maximum thrust of the engine. As we said before, $T_{max} = 21$ N, so $F = 42$ N. In order to measure it, we placed the

rocket on a scale and applied a force of 42 N (the instrument showed more or less 4.3 kg). This test is shown in FIG. 4

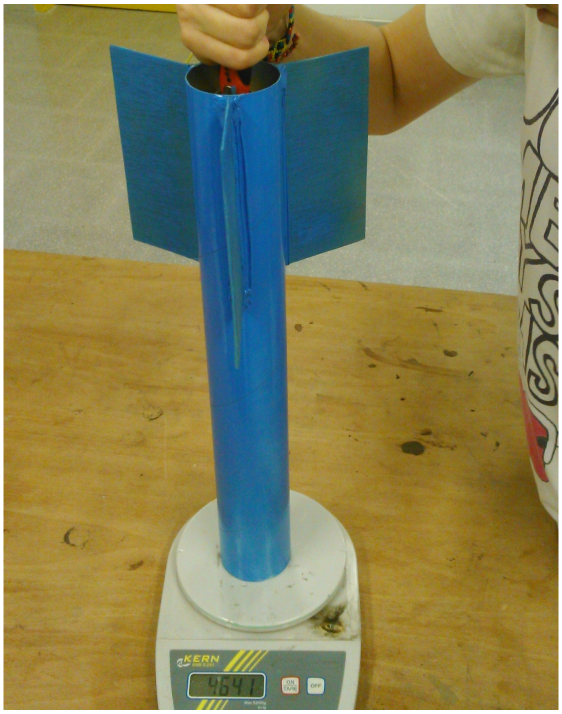

FIG. 4. Measurement of the resistance of the engine bracket

- Finally we put a string where the centre of gravity of the rocket was and we made the rocket fly in circles. The rocket flew with stability.

As we can see, all the specifications were fulfilled, so the rocket was able to be launched.

VII. LAUNCH

The sky is clear. The wind is at 5 m/s. It is time to launch. A minute later, Quim15 is on fire, and starts to rise (FIG. 5).

The flight elapses with no mishaps. The payload is released, the parachute opens and the rocket lands and it is recovered.

VIII. DATA ANALYSIS AND COMPARISON

Once we have gathered data from the altimeter it is time to compare it to the predictions we made from the simulation.

Raw data obtained from the altimeter draws the following graphic shown in FIG. 6

FIG. 5. Three, two, one, fire.

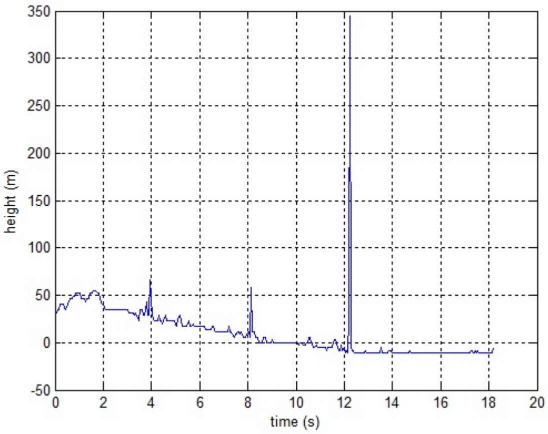

FIG. 6. Direct raw data from the altimeter

The first thing we see is that the data obtained starts at $h = 40m$ approximately. This is due to the fact that the altimeter needs a big and sudden change of pressure that happens just at the very first moments of the thrust. When this change of pressure happens the altimeter starts to capture data. The time that takes this change of pressure to be created and starting the altime-

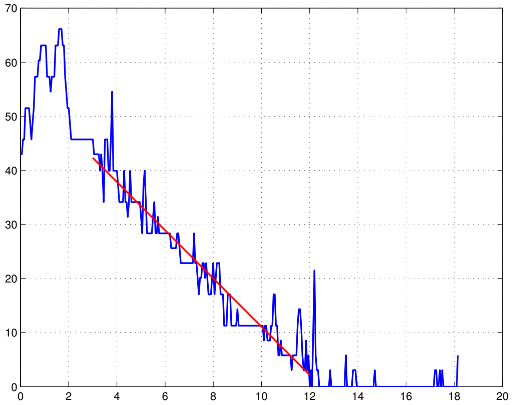

FIG. 7. Raw data from the altimeter in meters with corrected offset and linear regression

ter explains this delay.

It is very to easy to realise that the peak which is around $t = 12s$ is a mistake committed by the altimeter. The graph follows a (approximately) regular profile describing a rocket ascending and then falling down. Another inconsistency is that the rocket shows to be launched from under the ground level and this is not true. To correct these mistakes we are going to replace the values of the high peak with values according to a continuous profile and adding an offset (+11m) to counteract the error committed by the altimeter.

Applying these simple corrections (and omitting two more irregular peaks) we get a graphic like shown in FIG. 7

Obviously, the peaks showing an irregular profile are also mistakes committed by the altimeter. This is because it is a device that detects changes of pressure. However, the misleading data could be caused by the hole made in the upper part of the rocket, wind or just other meteorological issues.

Treating with the corrected data, we get that the maximum height is $h = 64.8m$ at $t = 1.65 + d$ where d is the delay caused by the altimeter.

After that peak, there is a very fast fall corresponding to the whole QUIM15 falling, just before the final explosion and parachute ejection. When the parachute is ejected, the falling speed falls to approximately $v_{terminal} = 4.45m/s$, which is within the limits specified by the simulation. This number was obtained making a linear regression of the data corresponding to the falling nose cone (seconds 3 to 12).

Overall, the real launch and experimental data fits with the previsions made in the simulation. What else is misleading? The maximum height is $64.8m$, nearly $50m$ less than calculated. This decrease of the height can be explained by two factors: wind an direction. On the one hand, the launch day it was a little bit windy, increasing drag forces which is translated into less height reached. On the other hand, as shown in the video, the QUIM15 takes off not a perfect vertically way.