UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

Study and Evaluation of the Performance of a Multistage Solid-Propellant Vehicle, Including Atmospheric Ascent and Orbital Insertion

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Author:
Roger Vergés Eiras

Director:
Josep Oriol Lizandra Dalmases

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BACHELOR FINAL THESIS

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Chapter 1

Introduction

The analysis of the performance of the rocket along its trajectory must also take into account monetary aspects. In this way, the following Chapters will explain both the costs related to the theoretical development of the project as well as an estimation of the cost of launching the rocket itself.

Thus, it will be possible to check the budget improvements that involve optimizing the physical parameters of the vehicle.

Chapter 2

Academic fees

Next in line, there is a general description of the costs associated with the development, study, and writing of the thesis. Thus, the table elucidates the task identification and the level of effort related to such a task.

Table 2.1: Costs associated with the development of the project

Task identification	Hourly cost	Level of effort	Subtotal
Ascent profile characterization	12 €/h	10 h	120 €
Theoretical framework	12 €/h	35 h	420 €
Definition of goals	12 €/h	3 h	36 €
Choice of propellant	12 €/h	35 h	420 €
Rocket staging optimization	12 €/h	15 h	180 €
Atmosperic flight numerical solving	12 €/h	60 h	720 €
Evaluation of rocket's performance	12 €/h	60 h	720 €
Optimization proposal	12 €/h	15 h	180 €
Discussion of results	12 €/h	15 h	180 €
Follow-up of the project	12 €/h	2 h	24 €
Environmental impact	12 €/h	5 h	60 €
Budget estimation	12 €/h	10 h	120 €
Documentation	12 €/h	35 h	420 €
	Total	**300 h**	**3600 €**

On the other hand, the distribution of the costs between theoretical developments, research and evaluation and documentation is illustrated below.

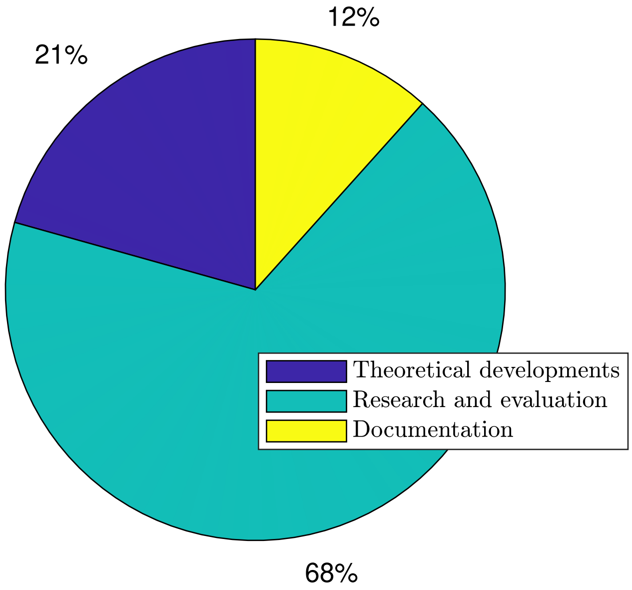

Fig. 2.1. Distribution of budget associated with departments.

Chapter 3

Estimation of costs

Apart from the academic fees, this project entailed the evaluation of the performance of a rocket, and an optimization proposal has been made. Thus, the present chapter will be devoted to determining an approximation of the total costs of launching the vehicle and the differences between both cases.

However, as total costs are not disclosed in existing missions, an estimation must be conducted. Though, propellant costs are only a fraction of the total budget [1]. For that reason, assumptions regarding items apart from propellant will also be made.

- Concerning the oxidizer, the ammonium nitrate has a cost of 50.45 €/ kg [2]
- p-Cresol, part of the fuel, presents a cost of 124.4 €/ kg [3]
- Atomized aluminum, part of the fuel, has a cost of 27.31 €/ kg [4]
- Structural costs have been assumed to be 100 €/ kg of rocket.
- Engines of each stage of the rocket will have a mean cost of 1,500,000 €.
- The payload needs to be integrated to the vehicle, with an estimated engineering cost of 1,000,000 €.
- As regards the complexity of the stages and its separation, additional 1,200,000 €/ extra stage will be assumed.
- Finally, the operation of the mission will be taken into account, with 500,000 € for the transportation and 750,000 € due to control tasks.
- When the total costs are determined, an extra 25% will be computed (due to contingencies).

3.1 Non-optimized rocket

The first rocket characterization had a total weight of 120 000 kg, including structure, propellant, engines and payload. The breakdown costs are presented below.

Table 3.1: Costs associated with the launching process. Non-optimized case.

Item	Number	Price/item	Subtotal
Propellant			
Fuel - p-Cresol	27,056.25 kg	124.4 €/kg	3,365,797.50 €
Fuel - Atomized aluminum	27,056.25 kg	27.31 €/kg	738,906.19 €
Oxidizer - Ammonium nitrate	54,112.50 kg	50.45 €/kg	2,729,975.63 €
Structure			
First stage	1	7,800,000.00 €	7,800,000.00 €
Second stage	1	4,200,000.00 €	4,200,000.00 €
Engines	2	1,500,000.00 €	3,000,000.00 €
Payload integration	1	1,000,000.00 €	1,000,000.00 €
Separation of stages	1	1,200,000.00 €	1,200,000.00 €
Operation of the mission			
Transportation	1	500,000.00 €	500,000.00 €
Control	1	750,000.00 €	750,000.00 €
		Total	25,284,679.32 €
		Total (+25%)	**31,605,849.15 €**

The distribution of costs is depicted in Figure 3.1.

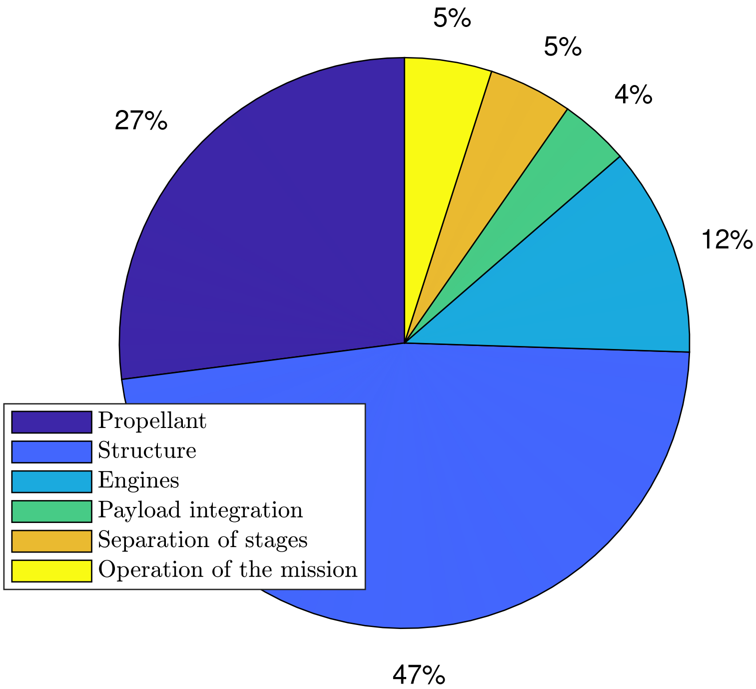

Fig. 3.1. Distribution of costs of the non-optimized rocket.

The total costs of the preliminary design resemble the budget for a single launch of *Vega C*, which accounts for approximately 37 million USD [5]. It is important to mention that the ESA's rocket presents a total weight slightly superior and more stages to the one described in this thesis and thus it is expected that the total cost would be increased.

3.2 Optimized rocket

The optimized vehicle has a total weight of 61 000 kg, including structure, propellant, engines, and payload. This rocket entails an extra stage, with the additional costs incurred. The breakdown costs are presented below.

Table 3.2: Costs associated with the launching process. Optimized case.

Item	Number	Price/item	Subtotal
Propellant			
Fuel - p-Cresol	13,412.5 kg	124.4 €/kg	1,668,515.00 €
Fuel - Atomized aluminum	13,412.5 kg	27.31 €/kg	366,295.38 €
Oxidizer - Ammonium nitrate	26,825.0 kg	50.45 €/kg	1,353,321.25 €
Structure			
First stage	1	3,965,000.00 €	3,965,000.00 €
Second stage	1	1,220,000.00 €	1,220,000.00 €
Third stage	1	610,000.00 €	610,000.00 €
Engines	3	1,500,000.00 €	4,500,000.00 €
Payload integration	1	1,000,000.00 €	1,000,000.00 €
Separation of stages	2	1,200,000.00 €	2,400,000.00 €
Operation of the mission			
Transportation	1	500,000.00 €	500,000.00 €
Control	1	750,000.00 €	750,000.00 €
		Total	18,333,131.63 €
		Total (+25%)	**22,916,414.54 €**

Analyzing the total costs of both cases, it is verified that the optimized case provides less costs than the first proposal. Nonetheless, even though the propellant is reduced by 49%, the total costs are meliorated by:

$$\Delta B = 100 \cdot \frac{31,605,849.15 - 22,916,414.54}{31,605,849.15} = \boxed{\mathbf{27.49\%}}$$

Where ΔB accounts for the budget cost improvement.

This situation is produced because there are costs which are fixed (the operation of the mission, payload integration and so on) and others that depend on the complexity of the vehicle and the number of stages.

The distribution of costs is depicted in Figure 3.2.

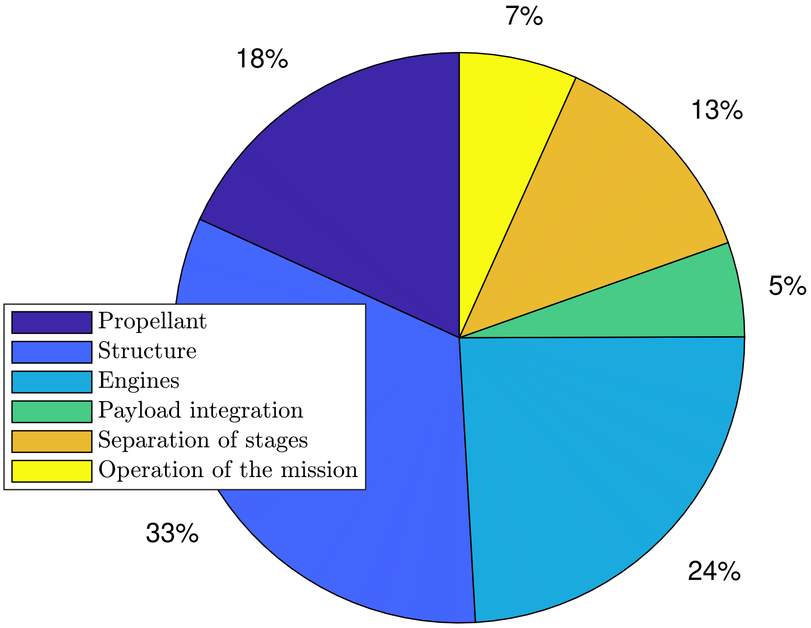

Fig. 3.2. Distribution of costs of the optimized rocket.

References

[1] NASA Spaceflight. (2020). *Cost of launch unrelated to cost of building rocket*. https://forum.nasaspaceflight.com/index.php?topic=49967.0 (accessed: 05-06-2021)

[2] Carl Roth. (2021). *Ammonium nitrate, 1 kg*. https://www.carlroth.com/com/en/a-to-z/ammonium-nitrate/p/x988.2 (accessed: 06-06-2021)

[3] Sigma-Aldrich. (2020). *p-Cresol*. https://www.sigmaaldrich.com/ES/en/product/sigald/c85751?context=product (accessed: 06-06-2021)

[4] Inoxia. (2021). *Aluminium Powder (Atomized)*. https://www.inoxia.co.uk/products/chemicals/elements/aluminium-powder-atomized (accessed: 06-06-2021)

[5] European Space Agency. (2018). *Vega-C*. http://www.esa.int/Enabling_Support/Space_Transportation/Launch_vehicles/Vega-C (accessed: 06-06-2021)