ANALYSIS OF THE EDUCATIONAL MINI ROCKET FUSELAGE THROUGH THE OPENROCKET SOFTWARE

Ugo Magaldi [a,b] , Bernardo Mattos [a,b], Tiago Lima [a,b]

a, Polytechnic Institute, Multidisciplinary Center UFRJ - Macaé, Brazil,

b, Universidade Federal do Rio de Janeiro-UFRJ-Centro Multidisciplinar de Macaé-Instituto Politécnico – Macaé-RJ-Brazil

Abstract: The “Bellatrix” mini rocket was developed in CAD and manually copied to the OpenRocket software in order to accelerate the prototyping stage, during the construction of model rockets, using the method presented here in order to investigate whether the physical integrity of the vehicle will be preserved during flight. In addition, by simplifying structural calculations engineering students can start practicing engineering in the early years of the course through mini-rocket projects. OpenRocket was used to obtain the necessary coefficients to find the forces acting on the mini rocket during flight, treating it as a beam approximately in equilibrium, and thereby estimating the stresses in the fuselage. With this information, it is possible to compare the maximum tension obtained with the results of tensile tests or in the literature of several materials, which can be used in the manufacture of the fuselage of the rocket. Using the rigid PVC material as an example, the mini rocket would be able to withstand the stresses during flight.

Keywords: Mini rocket; OpenRocket; Tensile Test; Education; Model rocket

ANÁLISE DA FUSELAGEM DE MINIFOGUETE EDUCACIONAL ATRAVÉS DO SOFTWARE OPENROCKET

Resumo: O minifoguete “Bellatrix” foi desenvolvido em software CAD e copiado manualmente para o software OpenRocket com intuito de se acelerar a etapa de prototipagem, durante a construção de foguetemodelos, usando o método apresentado aqui a fim de investigar se a integridade física do veículo será preservada durante o voo. Além disso, através da simplificação de calculos estruturais estudantes de engenharia podem começar a prática da engenharia já nos primeiros anos do curso através de projetos de minifoguetes. O OpenRocket foi usado para obtenção dos coeficientes necessários para encontrar as forças atuantes no minifoguete durante o voo, tratando-o como uma viga aproximadamente em equilíbrio, e com isso estimar as tensões na fuselagem. Com essas informações, pode-se comparar a tensão máxima obtida com os resultados de teste de tração ou em literatura de diversos materias, os quais podem ser usados na fabricação da fuselagem do foguete. Usando o material PVC rígido como exemplo, o minifoguete conseguiria suportar os esforços durante o voo.

Palavras-chave: Minifoguete; OpenRocket; Ensaio de Tração; Educação; Foguetemodelismo

1. INTRODUCTION

Rockets have always been an object of fascination for human beings, whether in their playful use such as fireworks, their destructive power as in weapons of war, or as a tool to obtain knowledge such as vehicles for space exploration. Despite its many uses, the rocket remains a tool and we can use it for good. Regarding engineering, we can use it to study important concepts from different areas of knowledge and transform it into a learning tool within universities, one way is through model rocket competition teams, which this mini rocket "Bellatrix" is an example and was created by GESAM (Group of Engineering and Aerospace Systems of Macaé), which is the model rocket team of the Multidisciplinary Center UFRJ-Macaé, which also has the task of scientific dissemination as exemplified in the article published on the “cienciahoje” website [1]. Before using computationally heavy simulation software, an analysis of the forces acting on the mini rocket, which generate tensions in the vehicle's structure, can be done with OpenRocket, which is a free and fast software, that does not require an expensive computer, and so students of engineering courses can have a faster approach with the practice of engineering within a college course and apply the concepts learned in the first years of the course.

2. METHODOLOGY

To obtain the necessary data for force calculations, the rocket model was transferred to the OpenRocket software by manually copying the components.

Figure 1. Unfinished 3D rendering of the mini rocket in OpenRocket. (Source: Author)

Table 1. Flight data and rocket characteristics in OpenRocket.

Length of the mini rocket	76,5 cm
Maximum diameter	7,63 cm
Total Mass with motor	1147 g
Apogee (Vertical launch)	598m
Maximum speed	132 m/s
Maximum acceleration	166 m/ s^2
Time to reach apogee	10,8 seconds
Flight time	105 seconds
Average Crosswind Speed	0,7 m/s
Standard Deviation of the Crosswind	0,07 m/s
Speed when hitting the ground	6,3 m/s
Speed off launch rod	35,2 m/s
Launch rod length	6 m

The drag coefficient is a dimensionless quantity and can be used to obtain aerodynamic forces. In this way, analysis can be done more easily on complex geometries. Equations (1) and (2), below, express the coefficients of the normal force, C_N, and the drag force, C_D, respectively.

$$C_d = \frac{2D}{\rho v_0^{\,2} A_{ref}} \tag{1}$$

$$C_N = \frac{2N}{\rho v_0^{\,2} A_{ref} d} \tag{2}$$

Where A_{ref} is the reference area, in our project it is the nosecone base area, v_0 is the maximum velocity obtained by the OpenRocket simulation, ρ is the air density, D is the drag force and N is the normal force.

The axial force can be calculated using eq.(3) , which describes how its value can be calculated in any part of the rocket [2]. Starting from the tip of the nosecone, this is our reference point, the axial force values are added; for example, if the specific point is at the base of the nosecone, add the drag force from the tip of the nosecone to its base with the other component due to acceleration, which is found by multiplying the sum of the rocket's mass from the tip to the base of the nosecone by the maximum acceleration of the vehicle. Thrust is added where the engine's thrust bulkhead is connected to the rocket.

$$F_{axial} = D_{Nosecone} + D_{Transition} + D_{Fuselage} + D_{Fins} + D_{Base} + a_{axial}\left(\sum_{Tip\ of\ the\ nosecone}^{x} m\right) - F_{Thrust} \tag{3}$$

The next step is to analyze the normal forces acting on the rocket, using eq.(4), these forces can be evaluated by treating the rocket as a beam in approximate equilibrium [2-3]. The equation takes into account the lift force of the nosecone, transition, fuselage, fins and base, in addition to the lateral acceleration of the rocket, in this case the value used was $a_{lateral} = 0.95\ \frac{m}{s^2}$, which is the acceleration due to the lateral wind used in this analysis and was obtained from OpenRocket.

$$F_{Normal} = L_{Nosecone} + L_{Transition} + L_{Fuselage} + L_{Fins} + L_{Base} - a_{lateral}\left(\sum_{Tip\ of\ the\ nosecone}^{x} m\right) \tag{4}$$

2.1 Axial and Bending Stress

The axial stress, represented by eq. (5), can be defined as the force over the tubular cross-sectional area of the rocket body.

$$\sigma_{axial} = \frac{F_{axial}}{A_{cross\ section}} \quad (5)$$

Where F_{axial} is the axial force at a given point, obtained by eq.(3) and $A_{Cross\ section}$ is the cross-sectional area of the body tube.

The maximum bending stress, which is created by the bending moment generated by the normal force in eq.(4), can be calculated by eq.(6).

$$\sigma_{Bending} = \frac{M.c}{I} \quad (6)$$

According to HIBBELER, $\sigma_{Bending}$ is the maximum normal stress in the element, which occurs at a point in the cross-sectional area farthest from the neutral axis [3].

2.2 Sum of Forces

First, the drag forces will be evaluated. Equation (1) is used to obtain the “D” drag values together with equation (7) by OpenRocket.

$$C_{d\propto} = \frac{C_d}{\propto} \quad (7)$$

Where $C_{d\propto}$ is the derivative of the drag force coefficient with respect to the angle of attack. Equations (7) and (8) below are based on Barrowman's Method, which was used extensively in OpenRocket according to NISKANEN [5-6], and is valid if the following assumptions are true :

- The angle of attack is very close to zero (< 10º)
- The flow around the body is constant and non-rotational
- The rocket is a rigid body
- The tip of the nosecone is a point
- Fins are flat plates
- The rocket is axially symmetrical.

To follow up this analysis, the mini rocket was simulated in OpenRocket following all the above assumptions. Using the OpenRocket software we obtain the drag coefficient at various points of the rocket.

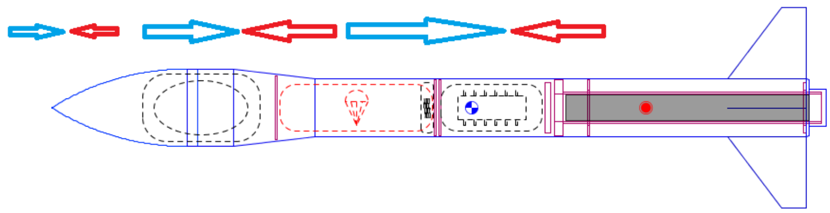
It is possible to evaluate the normal forces using eqs. (2) and (8), similarly to what was done previously with drag forces.

$$C_{N\propto} = \frac{C_N}{\propto} \tag{8}$$

Where $C_{N\propto}$ is the derivative of the normal force coefficient in relation to the angle of attack $\propto$, calculated in OpenRocket.

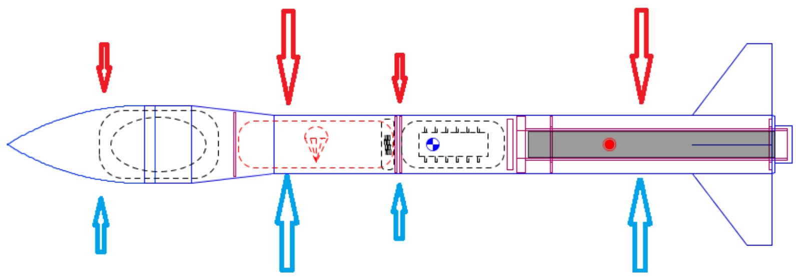
There are three forces acting axially on the rocket during flight. These forces are thrust, inertial forces, and drag. Our thrust force is the maximum value produced by the engine, evaluated by the OpenRocket software at 193 N. The inertial load from acceleration during flight will be evaluated as the maximum acceleration of 16.82 G, where 1G is the local gravity acceleration, also evaluated by OpenRocket software. For the calculation of the axial force, the rocket is divided into several “parts” as illustrated in Figure 2 below, and each “part” has a drag and inertial force that are combined through eq. (3), where each “part ” has its mass discriminated for calculating the inertial force and a drag force obtained through eq.(1). The calculation starts from the tip of the nosecone and goes to the base. The force values of each previous “part” are added to the next one.

Figure 2. Sketch of drag forces in blue and inertial in red, which when combined generate the axial force acting on the rocket. (Source: Author)



The normal force calculation is similar to the axial force calculation illustrated earlier.

Figure 3. Sketch of normal forces in blue and inertial in red that when combined generate the normal force acting on the rocket. (Source: Author)

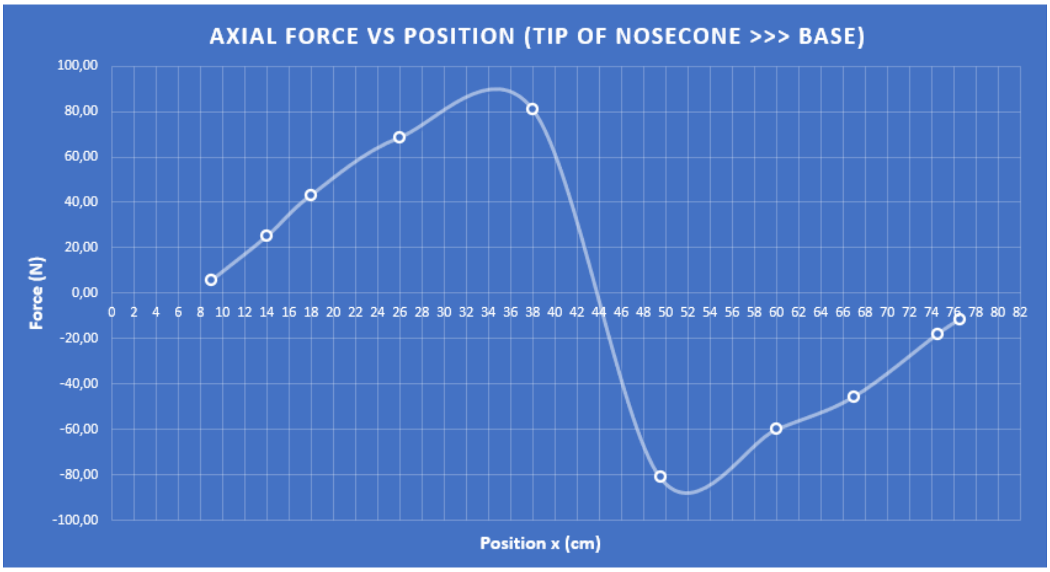


Integrating the shear force graph using the trapezoid method, it is possible to find the bending moments in various parts of the rocket. The values are in Figure 5.

3. RESULTS AND DISCUSSION

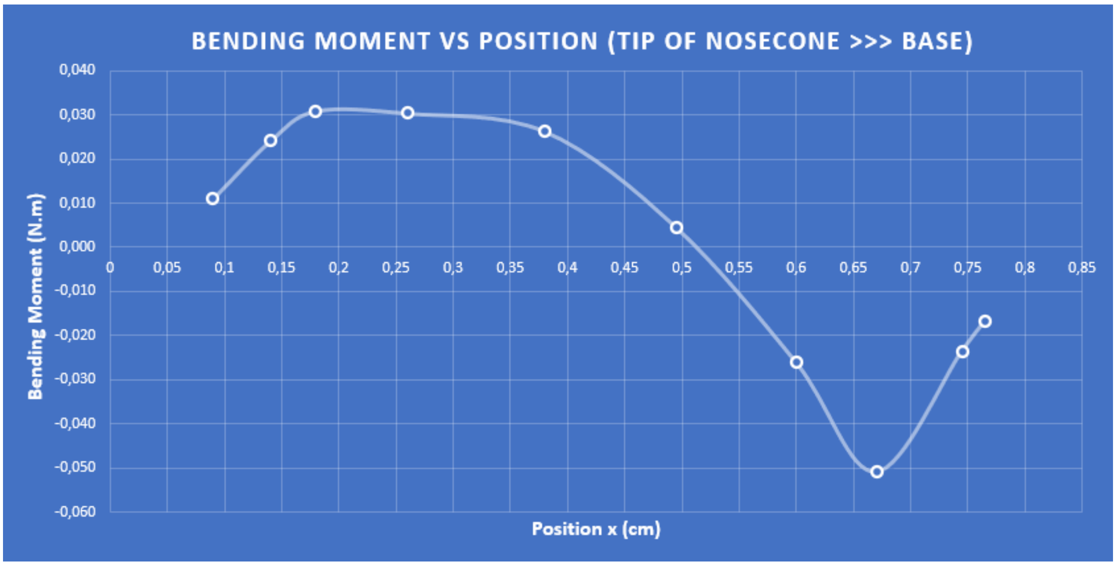
As you can see, the axial force due to drag increases as we move along the body of the rocket, then the thrust created by the engine shifts the axial force in the opposite direction, and finally the drag due to the fins brings the axial load back close to zero.

Figure 4. Axial force along the rocket body. (Source: Author)



The graph in Figure 5 shows the bending moment, starting and ending at approximately zero, as a simply supported beam in equilibrium. The bending moment is caused by external loads that tend to bend the body around a longitudinal axis [4]. Calculation of bending moment is important in structural engineering to determine the ability of a structure to withstand applied loads. The maximum bending moment occurs at a point between the thrust bulkhead and the fins. The values are very low due to the rocket's low flight speed, being only 131 m/s at its maximum.

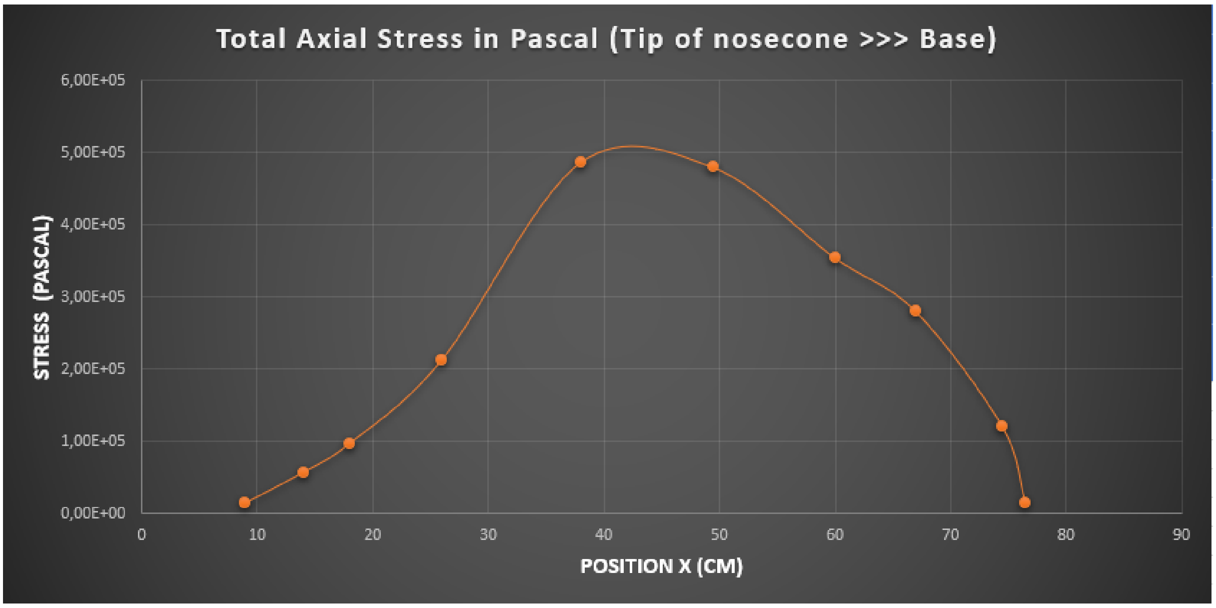
Figure 5. Bending moment along the rocket body. (Source: Author)



Through Equations (5) and (6) it is possible to calculate the axial and bending stresses, respectively. To find the total axial stress, combine the axial and bending stresses, adding the absolute values of each [2].

By the graph of Fig. 6, based on the Honors Research Projects from Akron University, it can be seen that the Total Axial Stress in the mini rocket body is below 0.517 Mpa, so this estimated value can be used in the calculation of the material failure criterion in a rocket project.

Figure 6. Graph of Total Axial Stress along the mini rocket. (Source: Author)



4. CONCLUSION

In this work it was possible to estimate the stresses supported by the mini rocket fuselage and as a result choose an appropriate low cost material that can withstand the stresses during the flight. Thus, the prototyping of mini rockets, in relation to the material that composes its structure, can be accelerated.

As shown in the text, this method of structural analyses uses concepts of the first years of engineering study and so the freshman students of college can get involved in a fun project early on, encouraging them to follow an engineering career.

In addition, it is important that more volunteers can help in the development of the OpenRocket free software, so that better structural simulations can be done and hobbyists can acquire deeper preliminary information about their amateur rockets, before using computationally heavy software such as CFDs (computational fluid dynamics).

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6. REFERENCES

[1] A NOVA CORRIDA ESPACIAL: UMA PERSPECTIVA TECNOLÓGICA, Disponível em:<https://cienciahoje.org.br/artigo/a-nova-corrida-espacial-uma-perspectiva-tecnologica/>. Acesso em: 20/12/22.

[2] LOSTOSKI, MICHAEL R. MR; SZUCS, JEFF; AND SCHWENNING, MATT, STRUCTURAL DESIGN AND FABRICATION OF A ROCKET, 2016. Honors Research Projects. 387. Disponível em: <http://ideaexchange.uakron.edu/honors_research_projects/387> . Acesso em: 03/06/22.

[3] DEHOFF, KYLE W. AND HRUSCH, NICHOLAS J., "DESIGN OF THE STRUCTURAL AND PROPULSION SYSTEMS FOR THE 2015 UNIVERSITY OF AKRON ROCKET TEAM" (2015). Honors Research Projects. 52. http://ideaexchange.uakron.edu/honors_research_projects/52 . Acesso em: 28/08/23.

[4] R.C. HIBBELER, MECHANICS OF MATERIALS, 10ª ed., Pearson Education, London, 2017.

[5] JAMES S. BARROWMAN, THE PRACTICAL CALCULATION OF THE AERODYNAMIC CHARACTERISTIC OF SLENDER FINNED VEHICLES, Dissertação (Mestrado) — The Catholic University of America, 1967.

[6] SAMPO NISKANEN, OPENROCKET TECHNICAL DOCUMENTATION, 2013 Disponível em: <https://github.com/openrocket/openrocket/releases/download/OpenRocket_technical_documentation-v13.05/OpenRocket_technical_documentation-v13.05.pdf> . Acesso em: 01/11/22.