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# Design and Simulation of a Model Rocket Prototype

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**ABSTRACT**

In this study, a model rocket is designed for given mission parameters. Also, it is explained how a rocket prototype is produced and what parameters are used in the design phase. The design parameters may vary completely for different tasks and requirement configurations. The objective of this paper is to explain the design steps and performance analyses of a model rocket prototype. The rocket is designed from the beginning with the goal of high apogee and a higher payload. Design steps and simulations are demonstrated, and rockets are manufactured by evaluating the optimization. Nose cone, fin, and material strength calculations in rockets are performed in detail to prevent the drawbacks of instabilities. The manufacturing of the model rocket, its design, and the simulation of the rocket prototype are successfully done.

# Model Roket Prototipinin Tasarımı ve Simülasyonu

**Makale Bilgileri**

**Makale Geçmişi**

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**ÖZ**

Bu çalışmada verilen görev parametrelerine göre bir model roket tasarlanmıştır. Ayrıca bir roket prototipinin nasıl üretildiği ve tasarım aşamasında hangi parametrelerin kullanıldığı anlatılmıştır. Tasarım parametreleri farklı görevler ve gereksinim konfigürasyonları için tamamen farklılık gösterebilir. Bu makalenin amacı bir model roket prototipinin tasarım adımlarını ve performans analizlerini açıklamaktır. Roket, başlangıçtan itibaren yüksek apoje ve daha yüksek yük taşıma hedefiyle tasarlanmıştır. Tasarım adımları gösterilmiş, simülasyonlar yapılmıştır ve optimizasyon sonuçları değerlendirilerek roketler üretilmiştir. Roketlerde burun konisi, kanatçık ve malzeme mukavemeti hesaplamaları, belirsizliklerin olumsuz sonuçlarını önlemek amacıyla detaylı olarak yapılmıştır. Model roketin imalatı, tasarımı ve roket prototipinin simülasyonu başarıyla gerçekleştirilmiştir.

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## INTRODUCTION

People face countless challenges throughout their lives. These difficulties can sometimes bring people to the point of giving up. When people deal with difficulties stubbornly, life always has a good answer for them. This has always been the case throughout human history. This is how the developments in technology are progressing. In nature, all living things are born, crawl, walk, run, and reach a point. In accordance with the law of nature, everything must be in order. Never attempt to run without trying to walk. Nevertheless, do not be afraid to walk because of falling and stumbling. That's why we thought about doing such a project. The rocket prototype we're working on now can reach an altitude of 3000m. With such projects, larger rockets can be launched (Şimşek, 2023).

As we all know, our world is getting dirty every day because of harmful wastes such as fossil fuels and many other factors. One day, if we live on this planet, it can become uninhabitable. We may need to find a new world to live in. The first thing that other countries want to achieve in the space race is to be the first to discover a new World (Kulaksız & Hançer, 2022). We are involved in this space race as soon as possible, and we need to keep our eyes on the top (Ali, Dursun, Mustafa, Karabacak, & Özgören, 2023).

In these days, rockets have two different meanings (Zhu, Xiao, Zhang, & Cai, 2022). The first one is used in terms of motor type. The other one is the flying aircraft, which uses this motor. Generally, they are cylindrical-shaped. Rudely, they consist of the nose, body, fin, and motors. The rockets move by pushing the gas, which has very high velocity and pressure, from the nozzle. In other words, they work with Newton’s third law, which is the action-reaction law. The pushed gas also applies to the rocket as a reaction force, and the rocket starts to move. The velocity of the rocket increases proportionally with the velocity and mass flow of the exhaust gas. The rockets include everything for moving inside them. As you know, oxygen and fuel are needed for burning. Both of these are carried inside the rocket propellant. Therefore, air-breathing engines cannot work in space, but rockets can work in space (Byers, Wright, Boley, & Byers, 2022). Usually, there are two types of rockets that are used. These are solid propellant rockets and liquid propellant rockets. Two types of rockets have advantages and disadvantages compared to each other.

Solid propellent rockets (Wei et al., 2022) are very suitable for small-diameter rockets. It is very easy to produce, transport, and store. They contain oxidizers, fuels, and lacers. The purpose of using a lacer is to keep oxidizer and fuel together. These kinds of rockets have a low cost, in contrast to their low efficiency. In addition, when the burning starts, we can’t stop the reaction, namely, they are unrestrained. Because of this, they aren’t used as the main rocket for space vehicles but are used as boosters beside the main rocket. However, they are often used at low altitudes and at short distances.

Liquid propellant rockets (Citarella, Ferraiuolo, Perrella, & Giannella, 2022) are more expensive and complex than solid fuel rockets. However, their efficiencies are greater than those of solid propellant rockets, and their burning velocity can be controlled. So in space, these types of rockets are generally used. Simply put, they contain fuel tanks, oxidizer tanks, pumps, combustors, and nozzles. Fuel tanks store fuel such as liquid hydrogen or kerosene. Oxidizer tanks store oxidizers such as liquid oxygen or nitrogen. They are pumped to the combustor and mixed there by pump. An ignition system starts the reaction. And nozzles increase the velocity of hot exhaust gas, push it out, and generate thrust.

As with every rocket, there are some missions (Meng et al., 2023) that we have designed, and we have some requirements for these missions. Firstly, the rocket we designed is designed for a specific task, and different designs can be made for other tasks and specific optimizations can be made. The mission of our rocketry consists of several basic sub-missions.

Firstly, the rocket is carefully placed on a 6 m-long 85° inclined launch platform. Then, after connecting the ignition units safely to the rocket, we move away from a safe distance to fire the rocket. After firing the rocket, the fuel in the engine burns in a short time, like 10-11 seconds, and as a result, it produces thrust. The rocket reaches a height of 3000 m. The expectation from the rocket is to remain stable until it reaches the apogee point. As a result of the design of the rocket, it reached a speed of 0.8 Mach, and our flight is made within the subsonic speed limits without transonic speeds.

According to the results of information received from electronic devices such as the flight computer, barometer, and altimeter in the rocket, the first parachute system, called the drogue parachute system, was deployed in a few seconds after reaching the rocket apogee point. The parachute system is used to slow down the speed of the rocket and provide a safe landing on the ground. Also, a payload is deployed beside the drogue parachute system. Parachute and payload release are done by a linear actuator. One of the biggest benefits of using a linear actuator is the ability to distinguish between the upper body and the nose cone with 100 N force and 75 mm extension in a second. With the help of the first parachute, the speed of the rocket will be reduced by 20–40 m/s. At the same time, the two parachutes will not be opened, and too much drift will be prevented. When the rocket approaches the ground, the main parachute system will be activated with the help of the actuator, and the body will be divided into three parts. The main parachute system should be opened at least 400 meters and at most 600 meters away from the ground. The ground speed of the rocket must be between 5 m/s and 9 m/s. That two separate systems would be healthier since the opening of the parachute from a single place would oscillate after the separation of the rocket bodies, and this would trigger the entanglement of the parachute ropes. The most suitable place for the flight was selected as Salt Lake, Konya, Turkey. Because, in terms of security, military shooting tests will also be carried out in this area. The mission and several basic sub-missions of our rocketry are given here. In sub-sections of the article, manufacturing of components, simulation of the rocket, and conclusions will be given.

## COMPONENTS

Model rockets have four main components, and they also have some sub-components in themselves. These main components form our outer geometry, and subcomponents form our inner geometry.

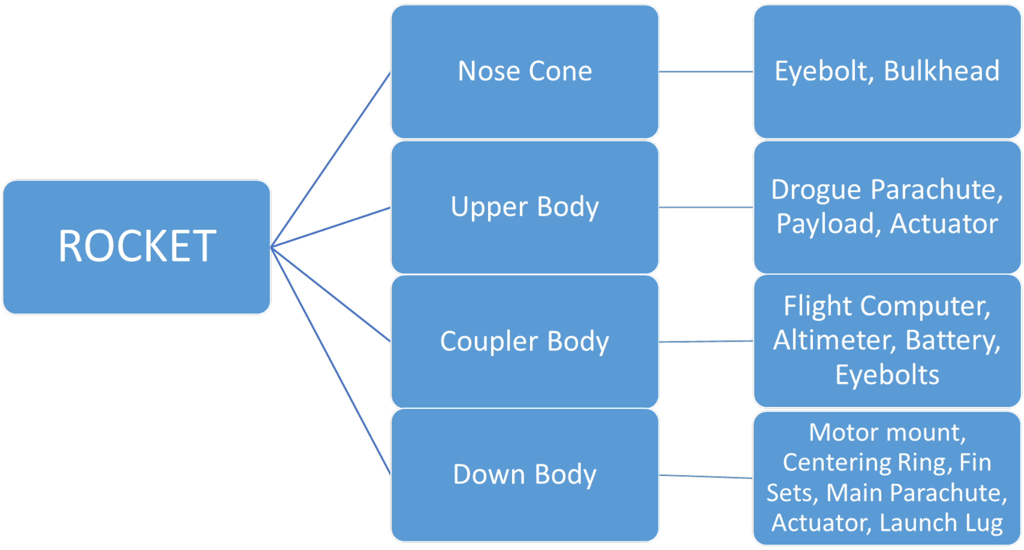

Figure 2. Rocket components

Nose cones are one of the most important components of rockets. They are located in the forward part of rockets. They are designed to decrease the drag coefficient of rockets and sometimes carry payloads. There are many types of nose cones, such as conic, spherically blunted conic, bi-conic, tangent ogive, or elliptical. All of them have advantages or disadvantages at different speeds or altitudes.

It is wanted that our rocket doesn't reach 0.8 mach. Because at this speed, the flow starts to be transonic, which is not good for stability. The turbulent flow can change all of the aerodynamic moments.

So the tangent of the given geometry have chosen. Because this shape cancels our rocket's reach for transonic flow. Also, manufacturing this shape is relatively easier than others. These equations are used (Carvalho & Claudino, 2019) for creating the nose cone shapes (Figure 3). The Solidworks program is used to generate the nose shape via the equations. After that, the part is saved in '.step' format, and nose cone shape is manufactured with a 3-D printer (Figure 4).

$$\rho = \frac{R^2 + L^2}{2 * R} \tag{1}$$

$$y = \sqrt{\rho^2 - (L - x)^2} + R - \rho \tag{2}$$

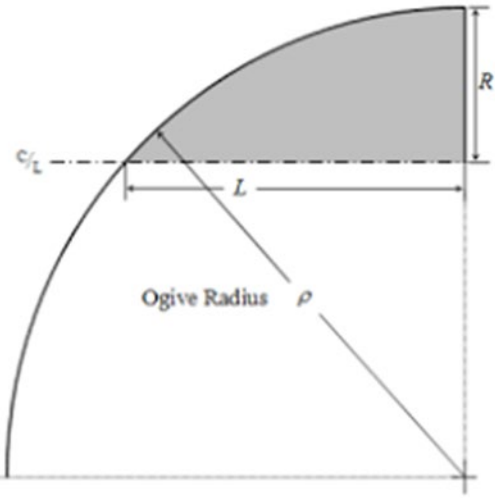

Figure 3. Tangent ogive definition(Carvalho & Claudino, 2019)

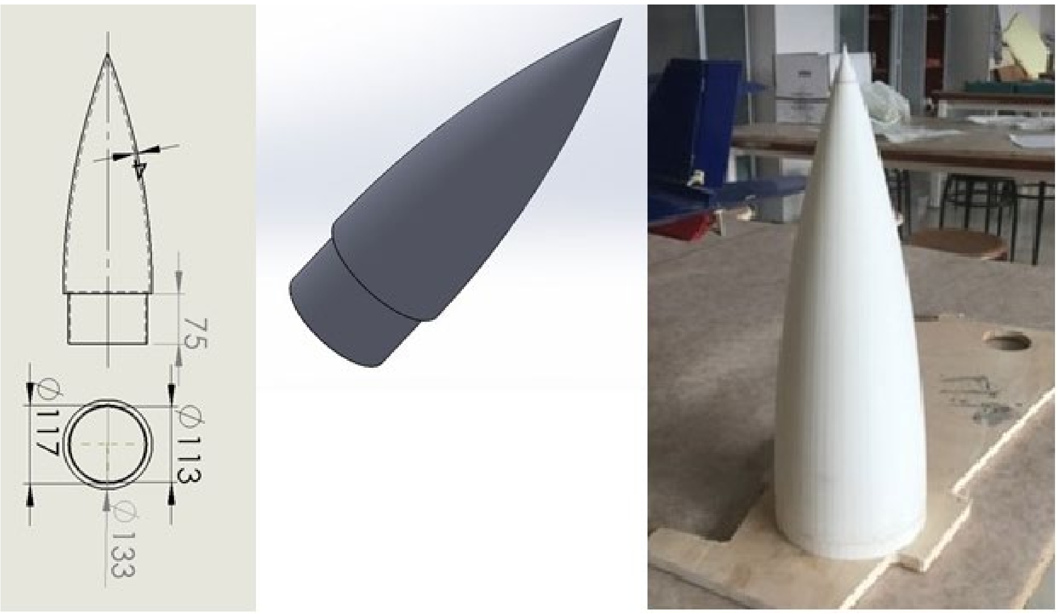

Figure 4. Nose cone

Eyebolt is used to fix the drogue parachute and nose cone with paracord. One of the eyebolts is fixed to the nose cone and the other one to the coupler body. The rocket is designed like this because the payload is placed between the nose cone and the coupler body. A bulkhead is used as a connector and support element. One of them is fixed to the nose cone, and the other is fixed to the coupler body. Plexy is used, and it was manufactured with a CNC milling machine. The upper body is manufactured with glass fiber reinforced plastic composite, and the hand lay-up method was chosen. The reason for choosing fiber glass is that it is cheap and has high strength (Uyaner Mesut, 2019). Firstly, the fiberglass is laid out on the desk. The fiberglass is wetted with epoxy. A PVC tube was used as a mold. Polywax is applied to the tube, and the wet fiberglass is wrapped around the PVC tube. Lastly, for curing, one day is awaited.

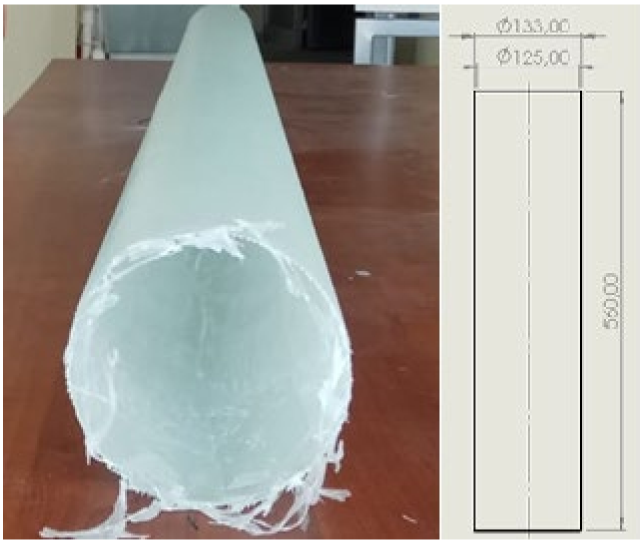

Figure 5. Fiberglass body

There are a lot of ways to design a recovery system, such as a carbon dioxide tube, a spring system, or servo motors. But more extensive research is done and linear actuators are found. They hadn't been used before the model rockets. But we thought it was the safest way to recover. There is no moving part, and this system is very stable and trustworthy. This actuator works at 12 or 24 volts. The linear actuator was chosen, which works at 12 volts. The actuator we chose has 100 N force, and it splays the stroke out in 1 second. Its stroke length is 75 mm. These values are suitable for our rockets.

The coupler body holds the electronic parts of the rocket. It locates between the upper body and the lower body. This component holds the upper body and lower body together. This part is generally manufactured with PVC or cardboard. These materials are suitable for signal transduction. Flight computers are the brain of the rocket. These computers decide when the recovery system will be activated. Also, these computers sent some data to us during the flight. There are some kinds of flight computers on the internet.

The down body includes fins, motor mount, centering ring, and main parachute. Fins are the most important part of a rocket for stability. A rocket that is not stable cannot fly on a linear path. For the manufacturing of fins, male and female molds are made. Fiberglass is chosen for fins. Because it is light, durable, and cheap. During burning, the temperatures of the combustor can reach 600°C–700°C, and this can damage the centering ring and rocket body. To avoid this situation, it was decided to use a motor mount. The best and cheapest material for a motor mount is cardboard. Those are good insulators, and those are very strong materials. Centering rings are used for centering the motor mount to the down body. Also, those fix the motor mount with a down body and use it as a support element. Plexy was used for the centering ring, and it is produced with a CNC milling machine. For safety, landing, and reusability, a main parachute is needed. It is activated with a linear actuator when the altitude is 450–500 meters. The determining factors for choosing a parachute are the mass of the rocket and safety landing velocity.

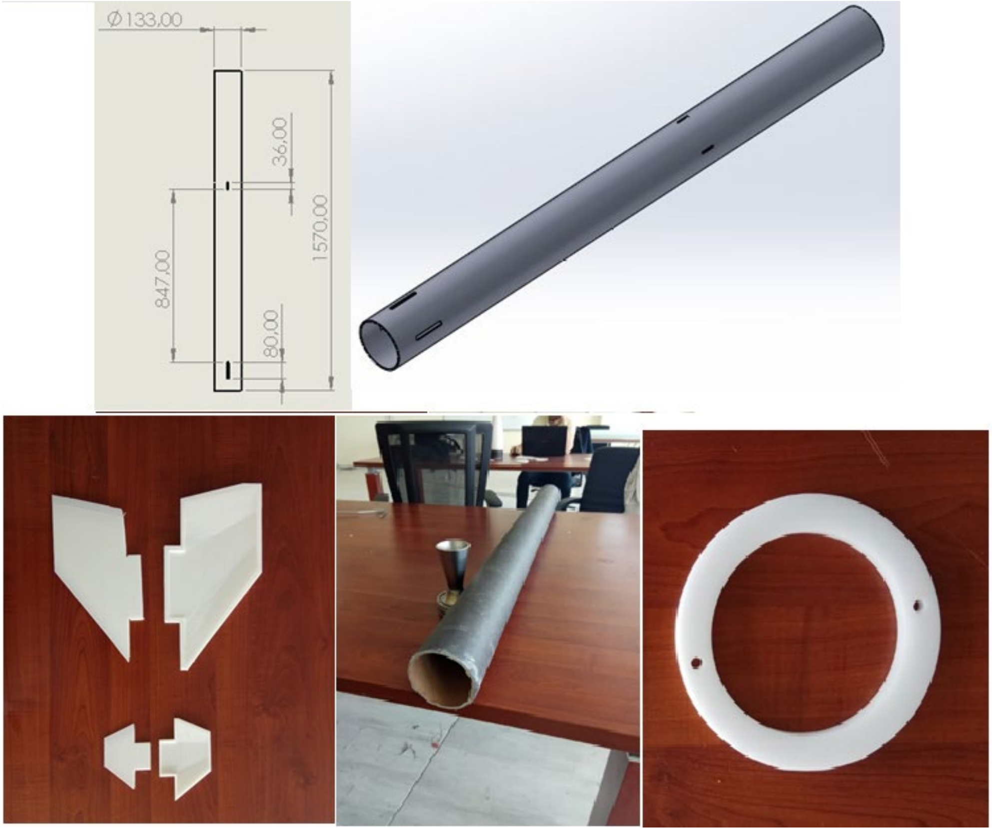

Figure 6. Upper body, fin molds, motor mount, centering ring

The desired nose cone shape (0.8 Mach) is the Von Karman series. But Tangent Ogive is used in our design. In theory, Von Karman seems to be more advantageous, but in practice, Tangent Ogive has a more useful design. Because when the Von Karman type is used, according to our analysis, our flight reaches transonic speeds. This is something not wanted.

The male and female molds were formed using the Solidworks program according to the fins to be produced. Generated molds were produced with a 3D printer. The gelcoat was applied between the molds so that the epoxy did not adhere. The female mold is applied with three layers of fiberglass and epoxy. Male mold is added to the female mold, and weight is applied over 24 hours. In this way, half of the wing is made, and the other half is produced. Two half-pieces of epoxy composites are produced, and the wing was produced in three dimensions (3D).

## SIMULATION

After finishing the design and optimizations, the flight is simulated with the Open Rocket program. Based on the results of the simulation, the necessary data can be obtained before the flight to change the design parameters and proceed with the improvement. From this simulation, many important pieces of information can be getted, such as altitude, maximum speed, stability margin, and flight time. First of all, start by filling in the input areas for the simulation. Salt Lake, Konya, Turkey is the launch site, and the coordinates of this area will be entered in the blanks. Then fill in some information about wind and launch rods, which have already been mentioned. After this part, we have to choose what the x and y coordinates are. It depends on our requirements. The Figure 7 indicates the result of the simulation. As we can see from the simulation result, it will complete the burning of the fuel inside the engine for 10-11 seconds. After a few seconds of reaching the maximum altitude, the drogue parachute system will have been deployed. Then the main parachute will have deployed, and the rocket will slow down and perform its safe landing.

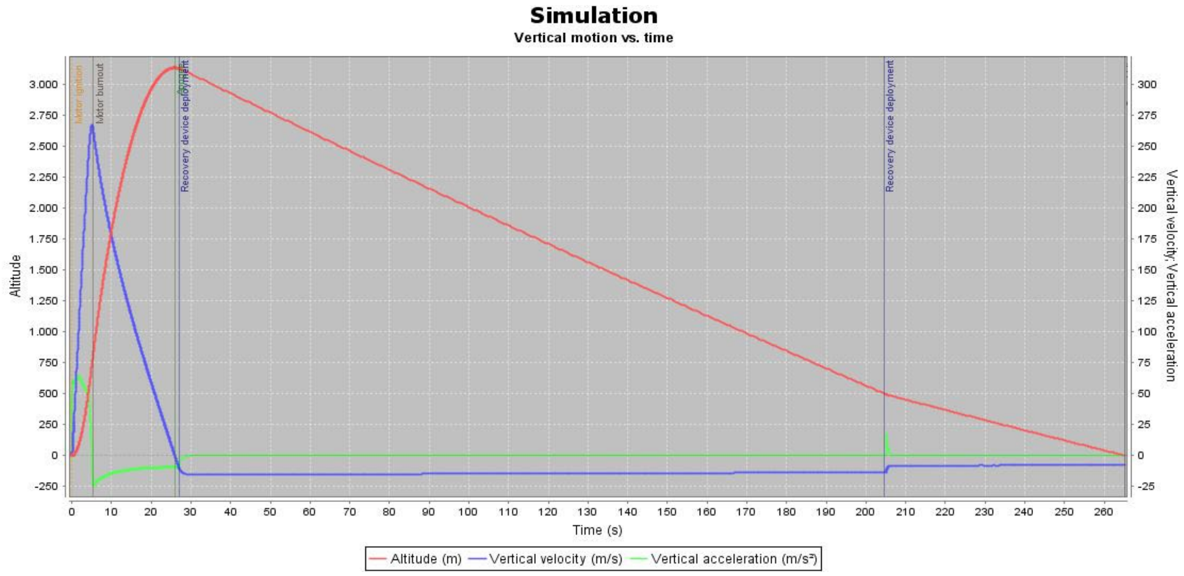

Figure 7. Simulation result

## CONCLUSION

In this study, the design, optimization, and production of a model rocket are done. The nose cone, upper body, lower body, and coupler body of the rocket are manufactured according to the desired mission requirements and objectives. In the design and optimization stages, it is aimed at applying the best aerodynamic performance to be used in rocketry. A tangent-ogive type nose cone design is selected and manufactured. Also, rocket components like eyebolts, bulkheads, drogue parachutes, payloads, actuators, flight computers, batteries, motor mounts, centering rings, and fin sets are successfully selected or manufactured using 3D printing and composite production techniques. As a result, this study can be a reference for designing and optimizing a model rocket prototype.

## REFERENCES

Ali, M., Dursun, A., Mustafa, K., Karabacak, M., & Özgören, M. (2023). Havadan Havaya Katı Yakıtlı Füze Tasarımı Air-to-Air Solid Propellant Missile Design. *Aerospace Research Letters (ASREL)*, *2*, 27–47.

Byers, M., Wright, E., Boley, A., & Byers, C. (2022). Unnecessary risks created by uncontrolled rocket reentries. *Nature Astronomy*, *6*(9), 1093–1097. https://doi.org/10.1038/s41550-022-01718-8

Carvalho, L., & Claudino, G. (2019). CFD analysis of drag force for different nose cone design. *Presented at the IX Forum de Pesquisa e Inovacao Do Centro de Lancamento Da Barreira Do Inferno*, (October).

Citarella, R., Ferraiuolo, M., Perrella, M., & Giannella, V. (2022). Thermostructural Numerical Analysis of the Thrust Chamber of a Liquid Propellant Rocket Engine. *Materials*, *15*(15). https://doi.org/10.3390/ma15155427

F. Şimşek, S. B. B. (2023). *High Altitude Model Rocket Design: Flow Analysis and Optimization to Reach 3000 Meters Aim*. *6*(2), 1589–1610.

Kulaksız, N., & Hançer, M. (2022). Hava Aracı İçin Simulink-Flightgear Ortamlarında Uçuş Testlerinin Gerçeklenmesi Ve Aerodinamik Etkilerin Stabilite/Gövde Eksenlerinde Karşılaştırılması. *Aerospace Research Letters (ASREL)*, 69–83. https://doi.org/10.56753/asrel.2022.2.1

Meng, X., Tian, H., Yu, R., Lu, Y., Gu, X., Tan, G., & Cai, G. (2023). Three-dimensional numerical simulation of hybrid rocket motor based on dynamic mesh technology. *Aerospace Science and Technology*, *141*, 108573. https://doi.org/10.1016/j.ast.2023.108573

Uyaner Mesut, A. Y. (2019). Nano Elyaf Takviyeli Nanokompozit Üretimi ve Karakterizasyonu. *Necmettin Erbakan Üniversitesi Fen ve Mühendislik Bilimleri Dergisi*, *1*(1), 10–19.

Wei, Z. ting, Li, N., Nie, J. xin, Liang, J. hao, Guo, X. yong, Yan, S., … Jiao, Q. jie. (2022). The properties of Sn–Zn–Al–La fusible alloy for mitigation devices of solid propellant rocket motors. *Defence Technology*, *18*(9), 1688–1696. https://doi.org/10.1016/j.dt.2022.02.008

Zhu, H., Xiao, M., Zhang, J., & Cai, G. (2022). Uncertainty design and optimization of a hybrid rocket motor with mixed random-interval uncertainties. *Aerospace Science and Technology*, *128*, 107791. https://doi.org/10.1016/j.ast.2022.107791