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Investigation of Flight Performance of Notched Delta Wing Rockets on Different Types of Nose Cones

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Abstract: In this study, four solid fuel model rockets with conical, parabolic, power and haack series nose cones that can carry 4 kg payload at an average altitude of 3 km were designed in the OpenRocket program. Later, the notched delta fin model was mounted on these designed model rockets. The effects of this fin model on the changes in the speed, stability, acceleration, weight and altitude of the rockets were analyzed numerically in the OpenRocket program. As a result of the analysis, it was determined that the conical nose rocket showed the worst flight performance and the Haack series nose cone rocket model showed the best performance. When used with the notched delta fin of the Haack series model, it was determined that the rocket's altitude increased by 7.67%, and its speed increased by 1.83%, but decreased by 1.2% in mach number, 0.6% in weight, 0.3% in acceleration, and 4.5% in stability. As a result, it was seen that it would be beneficial to consider the nose cone and fin together when evaluating the flight performance of the rocket. The results obtained in the study have shown that the notched delta fin model can be used experimentally in defense industry and model rocket applications and the studies can be advanced.

Keywords: OpenRocket program, Nose cones, Notched delta fin, Rocket flight performance

Farklı Tip Burun Konilerinde Çentikli Delta Kanat Roketlerin Uçuş Performansının İncelenmesi

Öz: Bu çalışmada, konik, parabolik, power ve haack serisi burun konilerine sahip ortalama 3 km irtifaya 4 kg yükü taşıyabilen katı yakıtlı dört adet model roket OpenRocket programında tasarlandı. Daha sonra, tasarlanan bu model roketlerin üzerine çentikli delta kanat modeli monte edildi. Bu kanat modelinin roketlerin hızında, stabilitesinde, ivmesinde, ağırlığında ve irtifasındaki değişimlere etkileri OpenRocket programında sayısal olarak analiz edildi. Yapılan analizler sonucunda, en kötü uçuş performansını konik burunlu roketin en iyi performansı ise Haack serisi burun konisine sahip roket modelinin gösterdiği belirlendi. Haack serisi modelin çentikli delta kanat profiliyle birlikte kullanıldığında roketin irtifasında %7,67, hızında %1,83 artışın oluştuğu ancak mach sayısında %1.2, ağırlığında %0.6, ivmesinde %0.3, stabilitesinde ise %4.5 oranında azalmaların olduğu belirlendi. Sonuç olarak, roketin uçuş performansı değerlendirilirken burun konisi ve kanat profilinin birlikte ele alınmasının faydalı olacağı görüldü. Çalışmada elde edilen sonuçlar çentikli delta kanat modelinin deneysel olarak savunma sanayisi ve model roket uygulamalarında kullanılabileceğini ve çalışmaların ilerletilebileceğini göstermiştir.

Anahtar kelimeler: OpenRocket programı, Burun konileri, Çentikli delta kanat, Roket uçuş performansı

1. Introduction

It includes studies on issues such as aviation design problems, aerodynamics, structural components, propulsion, flight mechanics, control, manufacturing and maintenance [1-3]. Another rocket component to be considered in rocket designs is nose cones. The design of the nose cone, which first encounters the air flow, significantly changes the altitude to be reached by affecting the aerodynamic efficiency [4]. In order to increase flight performance, it is a must to design the nose cone that best suits both the physical characteristics of the rocket and the flight parameters. The nose cone design also helps maintain the rocket's static margin, which is defined as the minimum distance between the rocket's center of gravity and its center of pressure. The undesired sway of the rocket due to the wind can be controlled by nose cones designed for lifting force acting on its surface through the center of pressure [5]. In addition to aerodynamic efficiency in rockets, one of the most important conditions for flight is stability.

The location of the center of gravity and center of pressure is of great importance for a stable flight. Fins have significant effects on the center of pressure and flight stability [6].

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In recent engineering and academic studies, it is seen that flight analyzes and simulations of model rockets are made by designing them in computer environment. In this context, Niskanen developed the OpenRocket simulation program, which is a model rocket simulation software [7]. Thanks to the simulation programs developed, it has become easier to analyze and interpret the flight performances of rockets numerically. Campbell et al. used model rockets to simulate flight trajectory and examine flight performance [8]. In rocket science, it is known that the fin and nose cone design are the most important parameters that affect the flight performance of rockets. The design of these two parameters has important effects on the aerodynamic efficiency and stability of the rocket and significantly changes the altitude, speed, acceleration and stability of the rocket [9-13]. Choosing an appropriate geometry to reduce friction as much as possible is essential in nose cone design. A nose cone with an aerodynamically competent geometry that will provide the least resistance to flight makes a significant contribution to flight performance. To ensure optimum rocket flight, a wide variety of nose cones have been developed and tested to meet these and other aerodynamic requirements [14]. In rocket designs, the nose cone design is an important parameter for the stable flight of the rocket in atmospheric conditions [13]. Shah et al., in their study, designed the Ogive, VonKarman and Power nose cone models and analyzed the nose profiles in the Ansys Fluent program under certain atmospheric conditions and at different Mach numbers [15].

Varma et al. examined the design features of 4 different nose cone models and their effects on rocket performance [9]. The aerodynamic response of rockets to air resistance under extreme ambient conditions and at high speeds can be largely represented by the response of the nose cone [10]. The aerodynamic behavior of the nose cone is important enough to determine the behavior of all components of the rocket [11]. Optimizing the geometric shape of the rocket nose cone is seen as the first step in the design process. In literature studies, spherically blunted conical, biconical, tangent ogive, secant ogive, elliptical, parabolic and Von Karman nose cone are generally known as the preferred nose cone types [13-18]. Among the literature studies, Ogive nose cone geometry is widely used for model rockets due to the convenience they provide in application and production [14,15]. Yeshwanth and Senthiil analyze the effect of nose cone shape on drag in subsonic flow by considering various nose cone shapes [20]. In another study, a new type of fin model called notched delta fin was designed. This airfoil was mounted on a model rocket with a conical nose cone and the flight performances of the rocket were compared with other fin models used in practice. As a result of these comparisons, the new type notched delta fin model showed the best performance [21].

In this study, the notched delta airfoil [21], which was previously presented as a new wing model, was mounted on model rockets with parabolic, conical, power and haack series nose cones, and flight analyzes of these model rockets were made. With these flight analyzes, the different nose cone profiles of the delta wing model and the speed, acceleration, altitude, center of gravity and pressure center parameters were examined in the OpenRocket program under the same flight parameters. As a result of these analyzes, the model rocket and nose cone with the best performance were determined. With the results obtained from this study, it is aimed to make a modeling on the model rocket and defense industry applications.

2. Materials and Method

2.1. The design of the model rocket

In order to analyze the changes in the speed, stability, acceleration, weight and altitude of the model rocket with 4 different nose cones according to the notched fin, the solid model of the model rocket was designed in the OpenRocket program as follows (Figure 1). In order to make flight analyzes for rocket applications, the weight is distributed throughout the rocket and it is important to know how the weight distribution is for solving the problem. The distribution of these weights on the body was determined as in Figure 1, taking into account the literature [21-25].

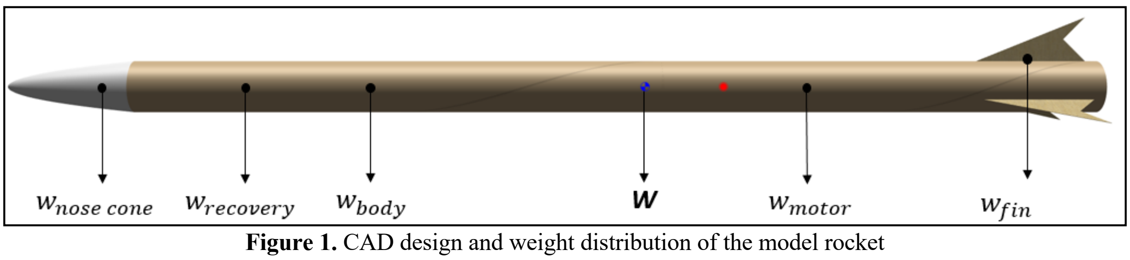


Figure 1. CAD design and weight distribution of the model rocket

The total weight of the model rocket in Figure 1 was calculated using the equation (1) below [21-25].

$$w_{Total} = w_{nose\ cone} + w_{recovery} + w_{body} + w_{motor} + w_{fin} \quad (1)$$

In this numbered equation, the weight of each component is calculated using the formula W=m.g. In this formula, m is the mass of the component and g is the gravitational acceleration. It is also important to determine the position of the center of gravity for the rocket trajectory and stability. In this study, the position of the center of gravity was determined according to the mass of the main parts of the rocket (nose, recovery system, fuselage tube, fins, engine, etc.) and the reference point as shown in Figure 2 [21-25].

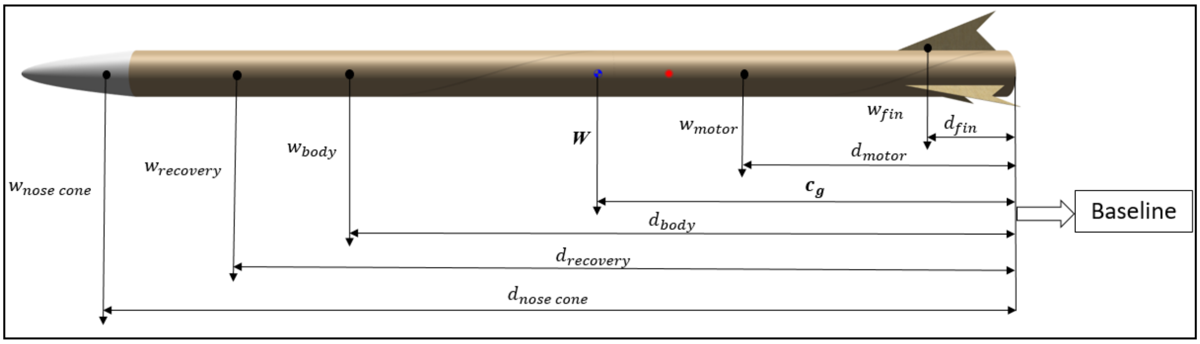


Figure 2. Center of mass of the model rocket

The distance of the center of gravity from the baseline is c_g multiplied by the total weight of the rocket, equal to the sum of the weight of each component times the distance from the baseline. In this case, the center of gravity of the rocket is calculated by equation (2) [21-25].

$$cgW = d_{nose\ cone}w_{nose\ cone} + d_{recovery}w_{recovery} + d_{body}w_{body} + d_{motor}w_{motor} + d_{fin}w_{fin} \quad (2)$$

In the literature, the center of pressure is accepted as the point where all the forces applied to any object pass but do not create a moment. This center is the point where the forces caused by the air pressure on the rocket are affected. In other words, forces due to the weight of the rocket act on the center of gravity of the rocket, and aerodynamic forces act on the center of pressure. The center of pressure of the rocket was determined as shown in Figure 3 [21-25].

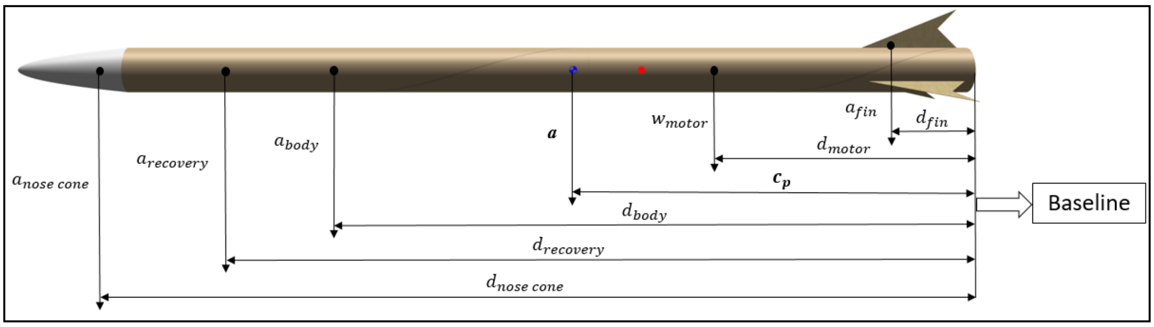


Figure 3. Center of pressure of the model rocket

The distance of the center of pressure from the reference line times the total area (A) of the c_p rocket is equal to the sum of the area of each component multiplied by the distance from the reference line. The center of pressure of the rocket is calculated by equation (3) in the literature [21-25].

$$cpA = d_{nose\ cone}a_{nose\ cone} + d_{recovery}a_{recovery} + d_{body}a_{body} + d_{motor}a_{motor} + d_{fin}a_{fin} \quad (3)$$

Rocket stability is one of the most important parameters for flight and for the rocket to go on its orbit in a stable manner. The stability of the model rocket is defined in terms of the static margin (SM), the dimensionless distance between the rocket's center of pressure and its center of gravity. In the literature, rocket stability is defined as in the equation SM, numbered [9]. In the equation, C_p is the center of pressure, C_g is the center of gravity and D is the body diameter of the rocket.

$$SM = \frac{C_p - C_g}{D} \tag{4}$$

While the model rockets were designed in the OpenRocket program, it was taken into account that these rockets could carry a load of 4 kg up to an altitude of approximately 3 km, and the other components and dimensions of these rockets were modeled with the exception of the nose cones (Figure 4).

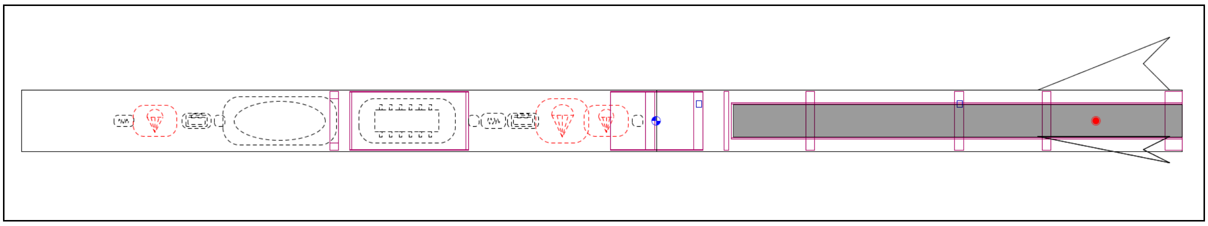
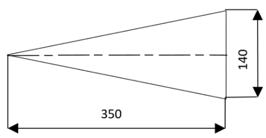
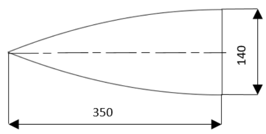
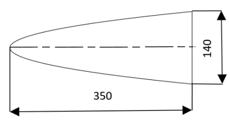
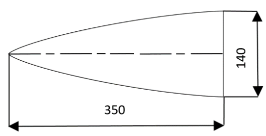


Figure 4. Design of the model rocket

In this study, conical, parabolic, power and haack models used in practice for nose cones mounted on model rockets were taken as reference. The profiles of these nose cones and the sizes on them are as in Table 1 [15,16,18,26].

The geometry and dimensions of the new type of notched fin model used on rockets with different nose cones were taken from the literature (Figure 5) [21].

Table 1. Geometry of nose cones given in the literature [15,16,18,26]

Nose Cone Types	Dimensions of Nose Cones Used in the Study
Conical	
Parabolic	
Power Series	
Haack Series (Von Karman)	

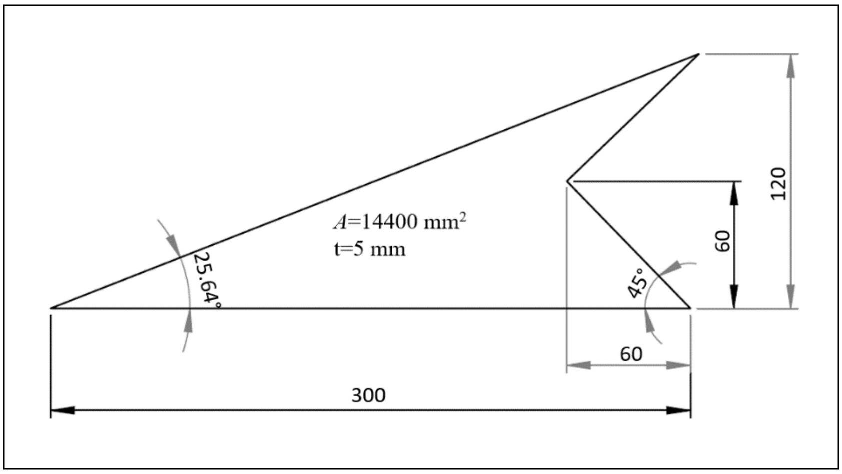


Figure 5. New type notched delta fin [21]

Table 2. Dimensions (mm) and weights (gr) of nose cone models

Nose Cone Model	Conical	Parabolic	Power	Haack
Nose Cone Length (L)	560	560	560	560
Diameter (D)	140	140	140	140
Weight (G)	4653	6251	6571	6251

All components, weights, materials and dimensions of the model rocket used in the study were calculated by considering equations (1, 2 and 3) and baseline (Figures 2 and 3). In Figure 6, the assembled state of all the components of the rocket and the calculated values in Table 1 are given.

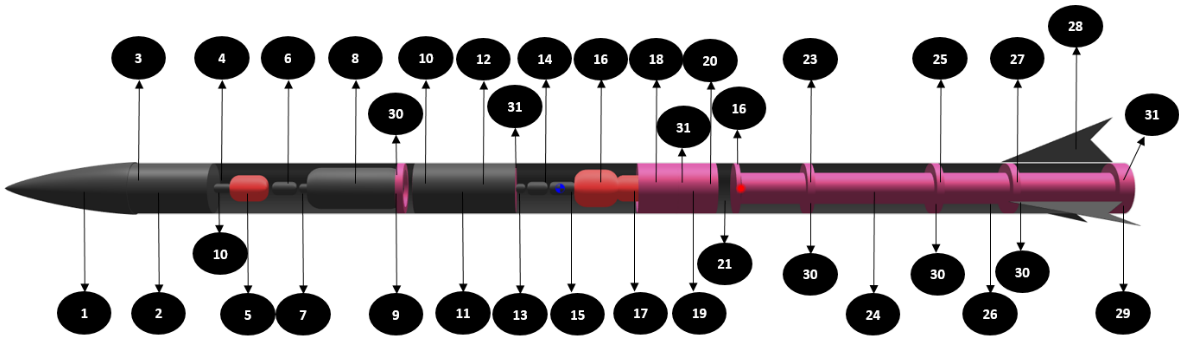


Figure 6. Components of the notched delta fin model rocket

Table 3. Dimensions, weights and materials of all components of the model rocket

Component	Piece	Number	Size (mm)	Material	Weight (gr)
Components of the nose cone					
Nose cone and body	1	1,2	560	Carbon fiber	Table 2
Map	1	3	25	Hammered steel	104
Shock cord	1	4	35	Paracord	2.7
$W_{nose\ cone}$					423.7
Components of the recovery system					
Payload parachute	1	5	100	Ripstop Nylon	131
Launch mechanism	1	7	65	ABS Filament	200
$W_{recovery}$					331
Body components					
Map	1	6	25	Hammered steel	104
Payload	1	8	260	-	4000
Centering ring	1	9	20	Blockboard	21.2
Electronic circuit box	1	10	270	Fiberglass	383
Flight computer	1	11	220	-	1450
Upper body	1	12	Length (1700) diameter (140)	Carbon fiber	3333
Map	1	13	25	Hammered steel	104
Shock cord	1	14	35	Paracord	2.7
Launch mechanism	1	15	65	ABS Flement	200
Big parachute	1	16	150	Ripstop Nylon	874
Small parachute	1	17	100	Ripstop Nylon	132
Body connecting element	1	18	210	Aluminum	700
Bulkhead	1	19	20	Blockboard	90.3
Bulkhead	1	20	20	Blockboard	90.3
Underbody	1	21	Length (1100) diameter (140)	Carbon fiber	2758
Bulkhead	1	22	20	Blockboard	90.3
W_{body}					14332.8
Components of the engine					
Motor centering ring	1	23	51	Blockboard	55.6
Motor stock	1	24	940	Carbon fiber	1262
Motor and fin centering ring	1	25	51	Blockboard	55.6
Motor	1	26	51	-	7878
W_{motor}					9251.2
Components of the fin					
Motor and fin centering ring	1	27	51	Blockboard	55.6
Fin	3	28	30	Carbon fiber	340
Motor centering ring	1	29	40	Blockboard	55.6
W_{fin}					1131.2
M5 screw	27	30	6	Steel	1.21
M8 screw	4	31	10	Steel	5.03
W_{screw}					52.79

2.2. Investigation of rocket flight analysis

The effects on the weight, speed, acceleration, stability, center of gravity and pressure and mach number of the rockets were analyzed in the open-source program, open rocket, for 4 different nose cones designed with the same length and height, at constant engine power, with constant parameters such as wind speed.

3. Results and Discussion

Flight analyzes of each of the model rockets, whose designs are given in Figure 5, were performed in the OpenRocket program. The results obtained from these analyzes are given below in terms of both bar diagrams and time-dependent changes in weight, velocity, acceleration, center of gravity and pressure, stability, Mach number and altitude of each model rocket (Figure 7-13). The nose cone design directly affects the rocket weight and flight performance of the rocket. The lowest weight in the nose cone designs was achieved in the conical nose model rocket design. Rocket weight directly affects all results from rocket flight data. In the literature, it is stated that the changes in the design of the nose cones cause significant changes in the altitude, speed, acceleration, stability and weight of the rockets [3,9-13,27]. As a matter of fact, in this study, it was observed that the flight performances of each rocket model with the same components but different nose cones changed (Figure 7-13). While the flight performance of the conical-nosed model rocket with the lowest rocket weight is expected to give better results than other models, it was seen that the Haack series nose cone rocket gave the best performance as a result of all flight analyzes (Figures 9 and 10). This result was found to be in agreement with the literature [9,15,28]. The conical-nosed model rocket also showed the lowest performance compared to other models other than the Haack series (Figures 9 and 10).

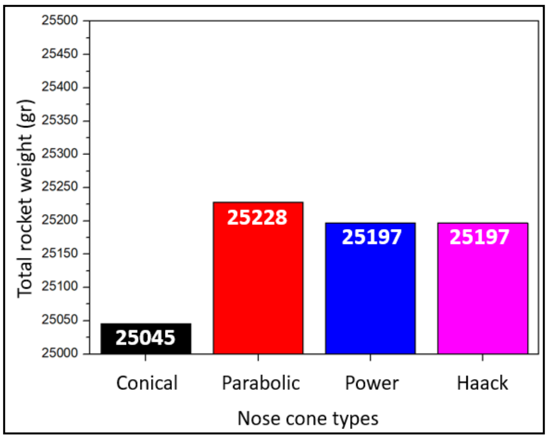


Figure 7. Total weights of model rockets

In previous studies in the literature, it was stated that the Mach number should be greater than 0.8 for a rocket that will fly at subsonic speeds, in the range of 0.8-1.2 in transonic flights, in the range of 1.2-5 in supersonic speeds and 5-10 in hypersonic speeds [29- 31]. In this study, it was seen that the Mach number reached in the model rockets whose flight performance was examined was greater than 0.80 and the rocket was suitable for flight at transonic speeds (Figure 8).

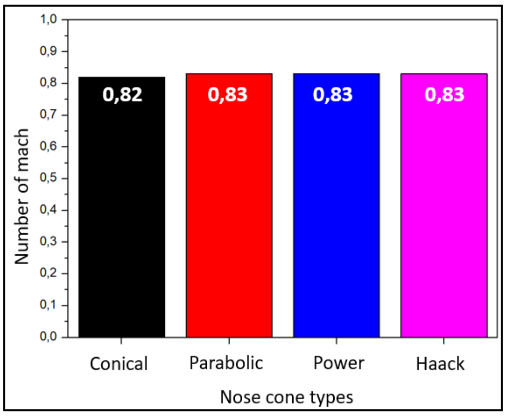
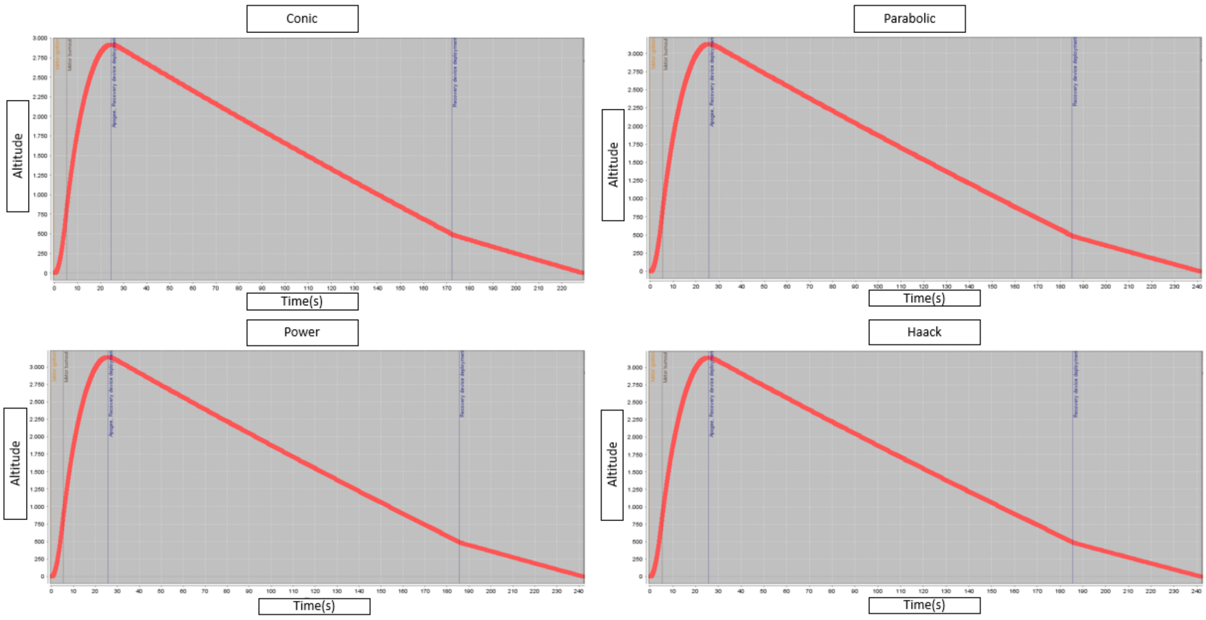
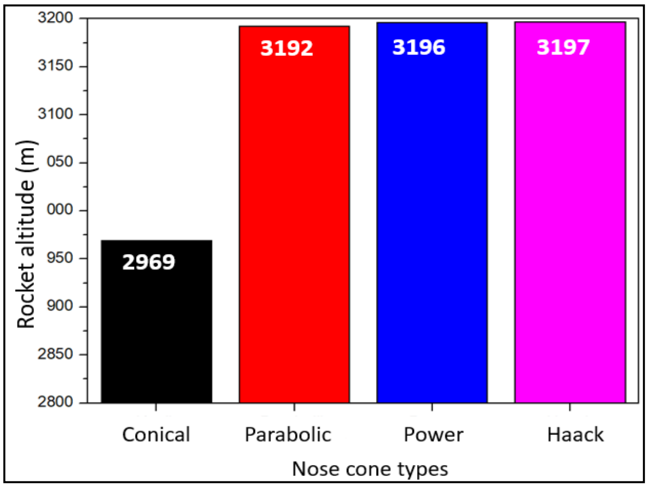


Figure 8. Effect of nose cone on Mach number

In the flight analyzes made depending on time, it was seen that the nose cone had a significant effect on the maximum altitude that the model rocket could reach (Figure 9). In the case of using the notched delta fin model on the Haack nose cone rocket, it was observed that an increase of 128 meters occurred in the altitude of the rocket compared to the cone nose rocket (Figure 9 a and b). The results were also visualized in bar diagrams so that the numerical values of the maximum altitudes reached by the model rockets could be seen much more clearly (Figure 10b).



a) Changes in altitude over time



b) Maximum altitudes

Figure 9. Changes in altitude of rockets

The changes in the stability of model rockets depending on time are shown in Figure 10. The center of gravity and pressure of the model rockets were calculated using the equations (2) and (3) given in the literature, and these values are given in Figures 11a and b. Again, the effects of the centers of gravity and pressure on the stability values of the rockets were calculated using the equation (4) given in the literature [9]. Bar diagrams are presented in Figures 11 a, b, and c to show the changes in all these values more clearly.

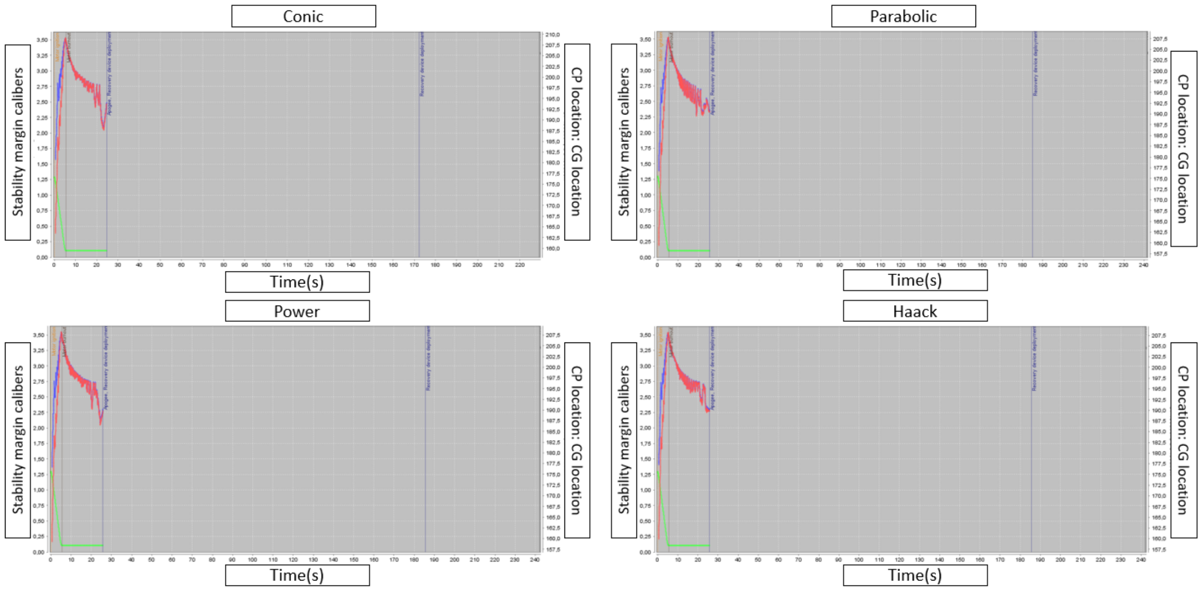
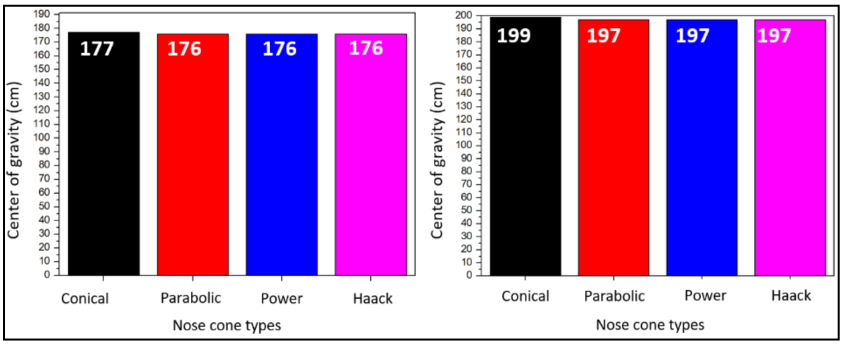
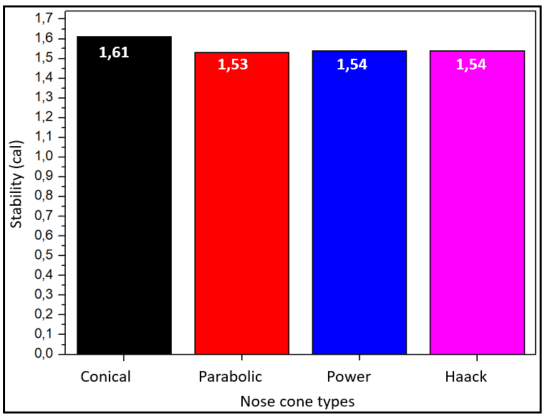


Figure 10. Change in the stability of rockets over time



a) Centers of gravity of rockets b) Pressure centers of rockets



c) Effects of gravity and pressure centers on the stability of rockets

Figure 11. Effects of changes in nose cones on weight, pressure and stability of rockets

In order for the stability of the rocket to be stable, there must be a distance of at least the diameter of the hull between the center of pressure and the center of gravity. If the center of pressure and the center of gravity are too close to each other, the rocket may be dynamically underdamped [32]. Likewise, if the distance between the center of pressure and the center of gravity is too far, the rocket becomes overstable, which may cause the rocket to fall. In order for the rocket to make a stable flight, the center of pressure (C_p) must be behind the center of gravity (C_g) [2,33-35]. Considering this literature information, it is seen that all model rockets designed here can perform a stable flight. In the case of using the notched delta fin model by changing the nose cones, the changes in the velocity of the rockets over time are presented below, both graphically and as a bar diagram (Figure 12).

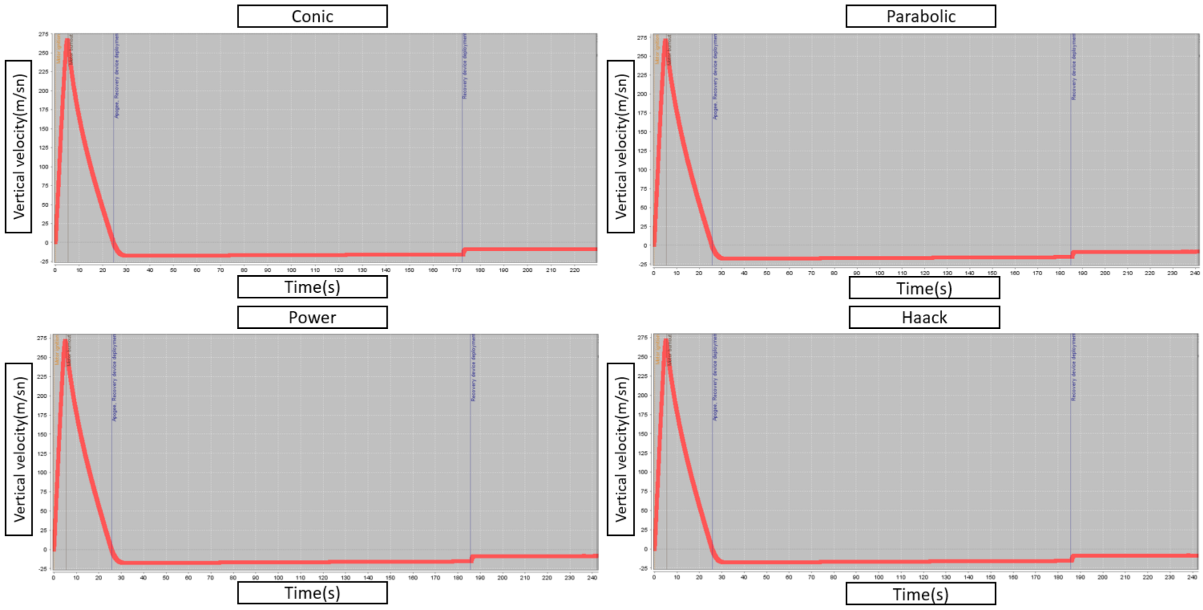
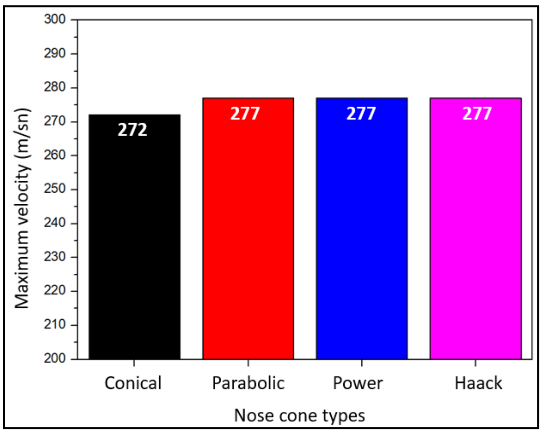


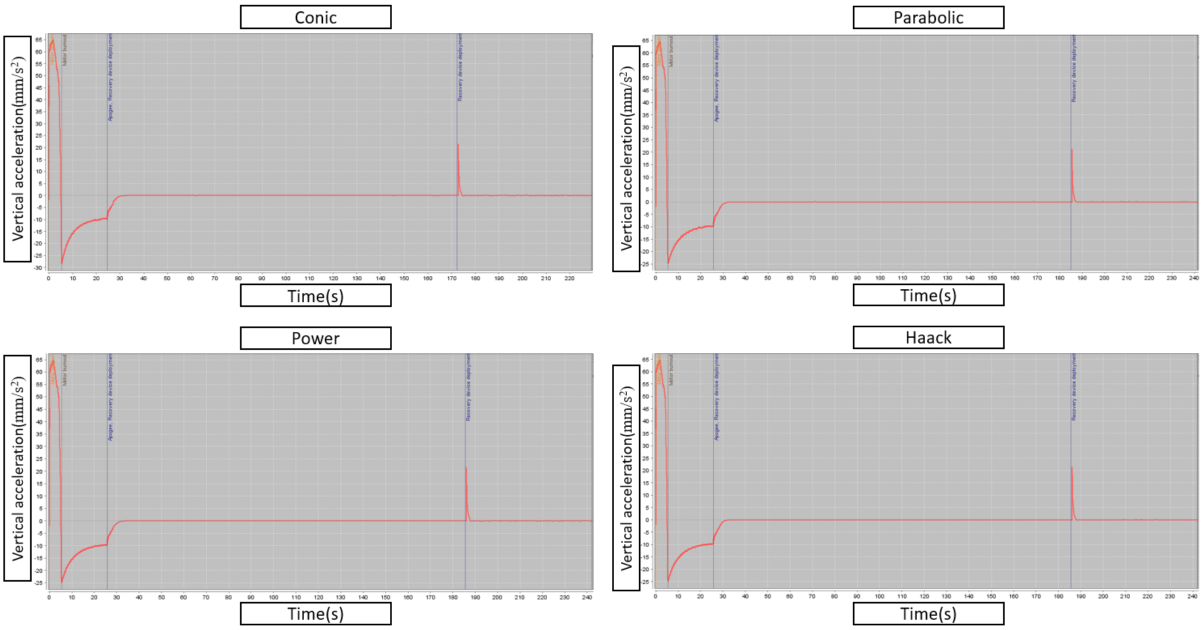
Figure 12. Changes in velocity with time

The maximum values of the maximum velocities reached by the rockets depending on the time given above are shown in the bar diagram below (Figure 13). In this graph, it was seen that the minimum velocity value was reached in the conical-nosed model rocket. The highest velocity values were reached in Parabolic, Power and Haack nose cones, respectively. The same velocity value was obtained for these three nose cones.

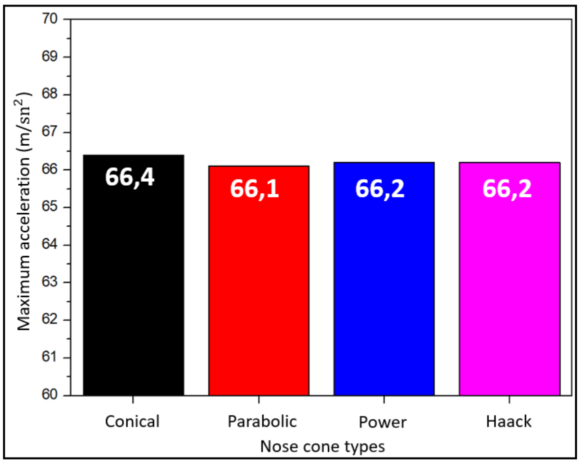


b) Maximum speeds
Figure 13. Changes in rockets speeds

The changes in the accelerations of the model rockets according to the changes in the geometry of the nose cones are given below, both in time and as a bar diagram (Figure 14a and b). According to nose cones, the highest acceleration was 66.4 mm/s^2 in the conical nose rocket, the lowest acceleration was 66.1 mm/s^2 in the Parabolic nose rocket, and 66.2 mm/s^2 in the Power and Haack series.



a) Changes in acceleration with time



b) Changes in acceleration

Figure 14. Changes in acceleration of rockets

4. Conclusion

In the article, notched delta fin mounted proof is shown in model rockets with Conical, Parabolic, Power and Haack series nose cones, and the changes in velocity, stability, acceleration, weight and altitude of these rockets are numerically analyzed in the OpenRocket open source program. According to the analysis results, while the Haack nose rocket showed the best flight performance, the Conical nose rocket showed the worst performance. Especially in the case of using the notched delta fin model in the Haack nose rocket, it was observed that the rocket's altitude increased by 7.67% and its speed increased by 1.83%. Although the rocket weight is lower in the conical nose rocket model compared to other models, it is thought that it does not provide the expected flight performance and this is due to the flat and sharp edges on the nose cone. In addition, curvature was found to be an important parameter in nose cone designs. Because in this study, it was seen that the flight performances of Parabolic and Power nose model rockets gave better results than Conical nose rockets. It is thought that the studies can be expanded experimentally, and flow analysis of the model rocket produced with the nose cone model and delta wing model, which gives the best results in future studies.

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