# Effects of Different Fin Shapes on Apogee and Stability of Model Rockets

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# *Effects of Different Fin Shapes on Apogee and Stability of Model Rockets*

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***Abstract*— The main aim of this study is to examine the effects of geometric sizing parameters of different fin shapes on apogee and stability of model rockets using response surface method. Four different fin variants which are clipped delta, swept, trapezoidal and triangular are examined separately within the content of this research. Effects of the variation of certain geometric parameters such as: span, root chord, tip chord, sweep angle, and thickness of the fin on apogee and stability of the model rockets are examined for each the fin shapes. Apogee and stability calculations are accomplished on Open Rocket Simulator for a generic model rocket that is designed to deliver 8 kg payload to 7 km altitude. As a result of this work, using the advantageous of the response surface method the most effective parameters on apogee and stability of the model rockets are determined for each different fin variants. The results of this research provide to model rocket designers to produce much more efficient fins that are suitable for their mission.**

***Keywords — model rocket, fin, apogee, stability, response surface method***

## I. INTRODUCTION

Recently, the interest on model rocket design is increasing gradually in consequence of the model rocket competitions such as Intercollegiate Rocket Engineering Competition (IREC) and Teknofest Rocket Competition. There are so many model rocket design alternatives and each alternative are providing another advantage to competitors. To make the design process easier and to understand the physics behind the design process there are limited number of researches are performed so far. Asilyazici prepared a M.Sc Thesis on model rocket design and he explained model rocket motors, rocket structure, and flight analysis processes in detail [1]. Niskanen developed an open source model rocket simulation software: Open Rocket Simulator within the content of his M.Sc thesis [2]. Recently, model rockets are started to use as an education tool for engineering students. Campbell et. al used the model rockets for flight trajectory simulation purpose while Brewer et. al used them for propellant analysis purposes [3-4].

One of the critical components that should be carefully designed for model rockets are fin structures. Tola and Nikbay were conducted a study examining the effect of basic sizing parameters of a trapezoidal fin on flutter speed using response surface method [5]. Shape and size of the fins effect the apogee and stability of the model rocket. In order to make an efficient fin design, effects of fin shapes and sizes on apogee and stability should be examined in detail. Therefore, within the content of this study, effects of the different sizing parameters of four different fin shapes that are clipped delta, swept, trapezoidal and triangular are examined on apogee and on stability of a generic model rocket that is designed to deliver 8 kg payload to 7 km altitude. First of all, a suitable constant nose, body, and motor configuration is constructed. After that, this constant configuration is solved for each of the fin shapes having different sizes on Open Rocket Simulator. Finally, 4 different response surfaces summarizing the effects of certain sizing parameters for each different fin shape on apogee and on stability are constructed.

## II. MODEL

### *A. Configuration of the Generic Model Rocket*

The constant generic model rocket has a diameter of 17 cm and length of 320 cm. Thrust is produced via an "O" type reloadable rocket motor having a total impulse 30907 s. An aluminum ogive shaped nozzle and an aluminum cylindrical motor case is used. Total take-off weight of the rocket is 59.344 kg excluding the weight of the fins. The model rocket geometry is illustrated at Fig. 1. For each response surface analysis number the number of fins are arranged as three.

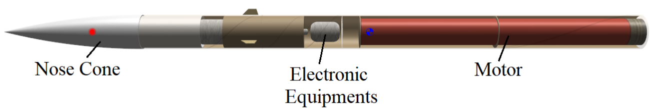


Fig. 1. Generic Model Rocket Geometry without Fins.

### *B. Speficications of the Frequenctly Used Fin Shapes*

Various alternative fin shapes can be used during the rocket design process considering the mission requirements. The most commonly used fin types are clipped delta, swept, trapezoidal and triangular. Each of them can be sized using different number of geometric sizing parameters such as: span length, root chord length, tip chord length, sweep angle, and thickness. Within the content of this research the four fin shapes illustrated in Fig. 2 are examined.

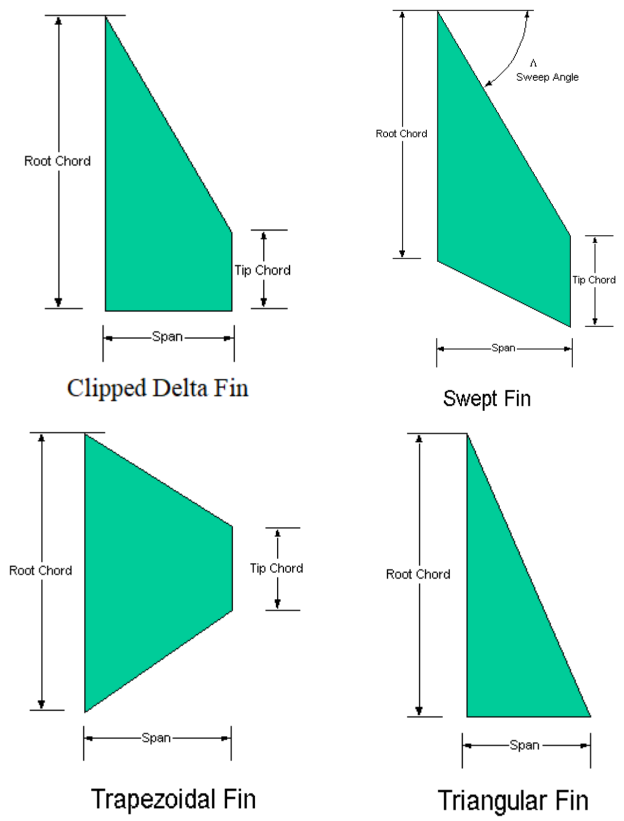


Fig. 2. Frequently Used Fin Shapes and Geometric Sizing Parameters.

Each fin shape is sized using different number of parameters. Clipped delta fin and trapezoidal fin have 4 different sizing parameters that are root chord, span, tip chord, and thickness. Swept fin has 5 different sizing parameters that are sweep angle, root chord, span, tip chord, and thickness. Triangular fin has only 3 different sizing parameters that are root chord, span, and thickness.

## III. Response Surface Analysis

Response surface method is quite efficient method for obtaining comprehensive results about the effects of design variables on a response variable. Sweep angle, root chord, span, tip chord, and thickness are defined as design variables; apogee and stability of the generic model rocket are defined as the response criteria. Considering the apogee and stability responses for each fin shape, totally 8 different response surface analysis are performed within the content of this research.

### *A. Clipped Delta Fin*

Table 1 summarizes the response surface boundaries of the four design variables for both of the clipped delta and the trapezoidal fin shapes.

Two different response surfaces are constructed for clipped delta fin shape. Each of them is created preparing full composite models consisting of 31 cases.

The first response surface focuses on examination of the effects of clipped delta fin sizing parameters on apogee of the model rocket.

TABLE I. Response Surface Boundaries for Clipped Delta and Trapezoidal Fin Shapes

| *Symbol* | *Definition* | *Lower Boundary* | *Upper Boundary* | *Unit* |
|---|---|---|---|---|
| $c_{root}$ | Root chord length | 20 | 50 | cm |
| $c_{tip}$ | Tip chord length | 10 | 20 | cm |
| $S$ | Span length | 10 | 30 | cm |
| $t$ | Thickness | 2 | 10 | mm |

Fig. 3 represents percentage effects of the sizing parameters and interactions of them on apogee.

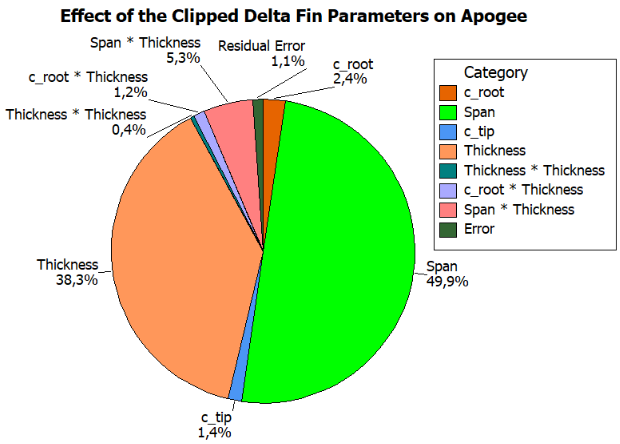


Fig. 3. Percentage Effects of the Clipped Delta Fin Parameters on Apogee.

According to the results, span and thickness are dominating the apogee of the model rocket for clipped delta fin shape. Fig. 4 summarizes the main effects of sizing parameters of the clipped delta fin on apogee.

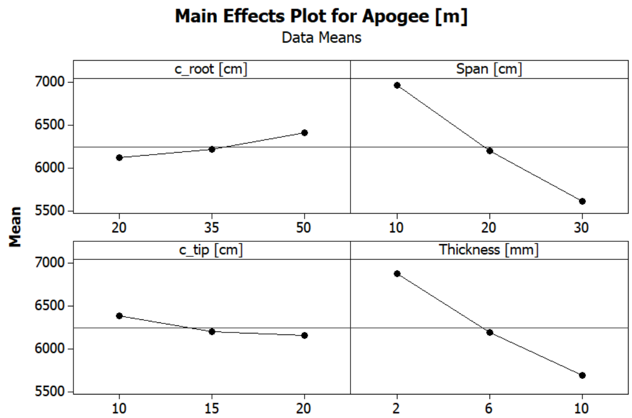


Fig. 4. Main Effects of the Clipped Delta Fin Parameters on Apogee.

According to Fig. 4, increment of thickness and span length decreases the apogee of the model rocket since they are not only increasing the aerodynamic drag but also, increasing the weight of it. On the other hand, root chord and tip chord lengths are almost ineffective on the apogee of the model rocket. Fig. 5 shows the response surface representing the effects of span length and thickness on apogee of the design having clipped delta fins.

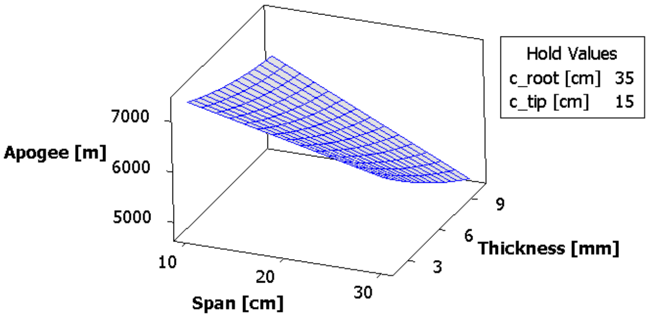


Fig. 5. Response Surface Representing the Variation of Apogee with Span and Thickness for Clipped Delta Fin.

The second surface is created to examine the effects of clipped delta fin sizing parameters on model rocket stability. Fig. 6 represents percentage effects of sizing parameters and interactions of them on stability for clipped delta fin.

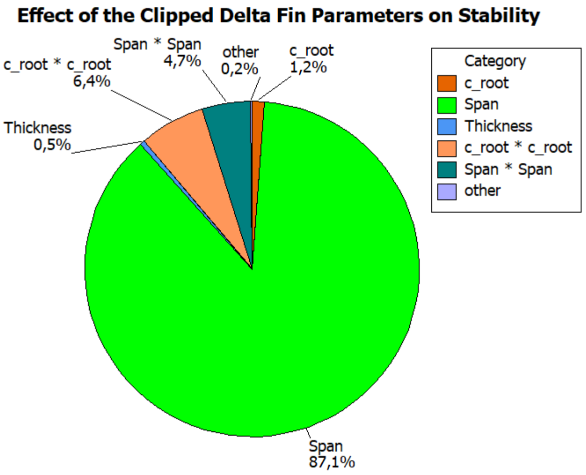


Fig. 6. Percentage Effects of the Clipped Delta Fin Parameters on Stability.

According to the results, the span dominates the stability of the design. Fig. 7 summarizes the main effects of sizing parameters on stability.

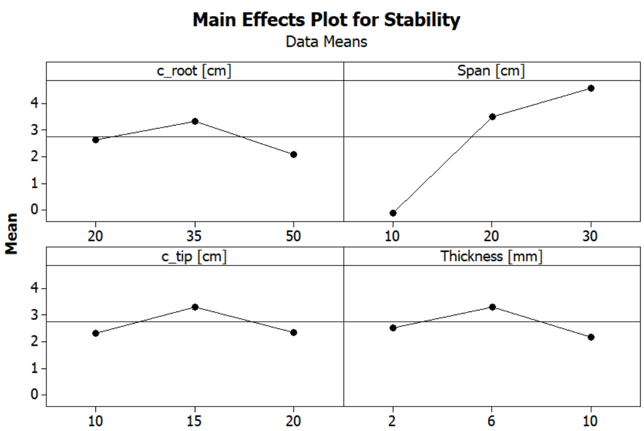


Fig. 7. Main Effects of the Clipped Delta Fin Parameters on Stability.

According to Fig. 7 increment of span length increases the stability of the model rocket. Although the root chord length does not affect the stability of the design, its square slightly affects the stability. Fig. 8 shows the response surface representing the effects of span length and root chord length on stability of the model rocket having clipped delta fins.

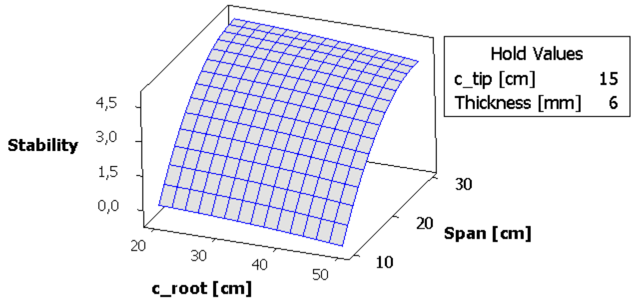


Fig. 8. Response Surface Representing the Variation of Stability with Span and Root Chord for Clipped Delta Fin.

According the results, a nonlinear relationship is observed between the span length and stability.

## *B. Swept Fin*

Table 2 summarizes the response surface boundaries of the five design variables for swept fin geometry.

TABLE II. RESPONSE SURFACE BOUNDARIES FOR SWEPT FIN SHAPE

| *Symbol* | *Definition* | *Lower Boundary* | *Upper Boundary* | *Unit* |
|---|---|---|---|---|
| $c_{root}$ | Root chord length | 20 | 50 | cm |
| $c_{tip}$ | Tip chord length | 10 | 20 | cm |
| $S$ | Span length | 10 | 30 | cm |
| $\lambda$ | Sweep angle | 15 | 75 | deg |
| $t$ | Thickness | 2 | 10 | mm |

Two different response surfaces are constructed for swept fin shape. Each of them is created preparing full composite models consisting of 52 cases.

The first response surface is constructed to examine the effects of swept fin sizing parameters on apogee. Fig. 9 represents percentage effects of sizing parameters and interactions of them on apogee for swept fin.

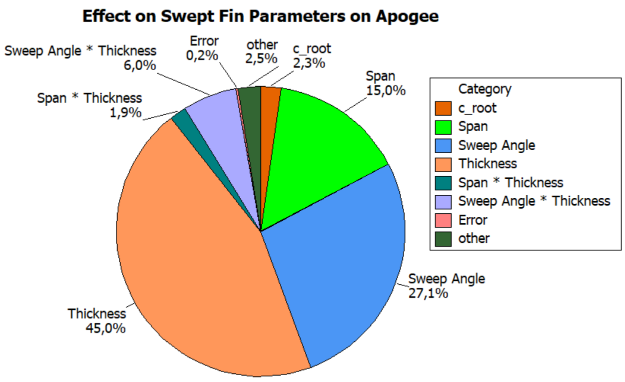


Fig. 9. Percentage Effects of the Swept Fin Parameters on Apogee.

According to the results, thickness, sweep angle and span length are dominating the apogee of the model rocket for swept fin shape. Fig. 10 summarizes the main effects of sizing parameters of the swept fin on apogee.

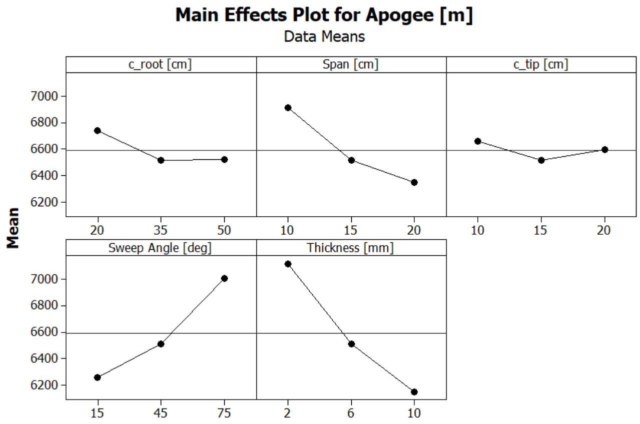


Fig. 10. Main Effects of the Swept Fin Parameters on Apogee.

According to Fig. 10 increment of thickness and span length decreases the apogee of the model rocket due to the same reason with clipped delta fins. Additionally, increment of the sweep angle has a positive contribution on apogee. By the way, root chord and tip chord lengths are almost ineffective. Fig. 11 shows the response surface representing the effects of span length and sweep angle on apogee of the design having swept fins.

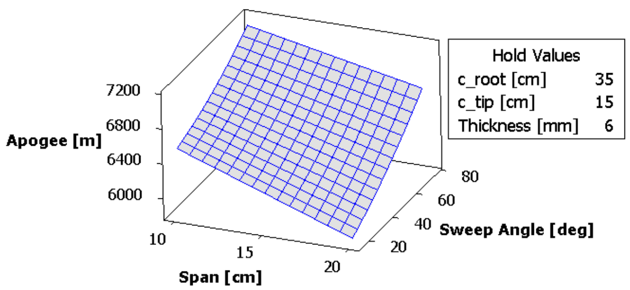


Fig. 11. Response Surface Representing the Variation of Apogee with Span and Sweep Angle for Swept Fin.

Fig. 12 shows the response surface representing the effects of span length and thickness on apogee of the model rocket having swept fins.

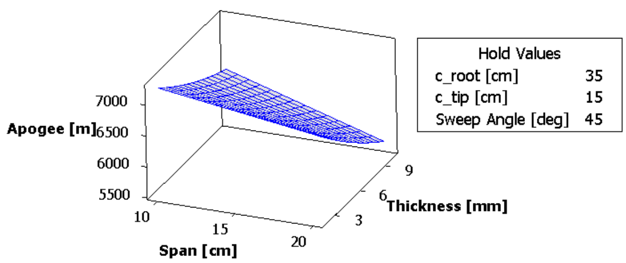


Fig. 12. Response Surface Representing the Variation of Apogee with Span and Thickness for Swept Fin.

As it can be observed from the Fig. 11, and Fig. 12 there is a nonlinear relationship between the sweep angle and apogee.

The second surface is constructed to examine the effects of five different sizing parameters of swept fin on stability of the model rocket. Fig. 13 illustrates percentage effects of sizing parameters and interactions of them on stability for swept fin.

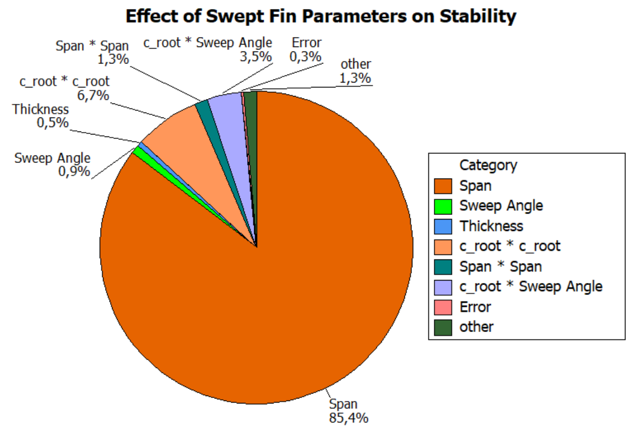


Fig. 13. Percentage Effects of the Swept Fin Parameters on Stability.

According to the results, the span length dominates the stability of the model rocket. Fig. 14 summarizes the main effects of sizing parameters of the swept fin on stability.

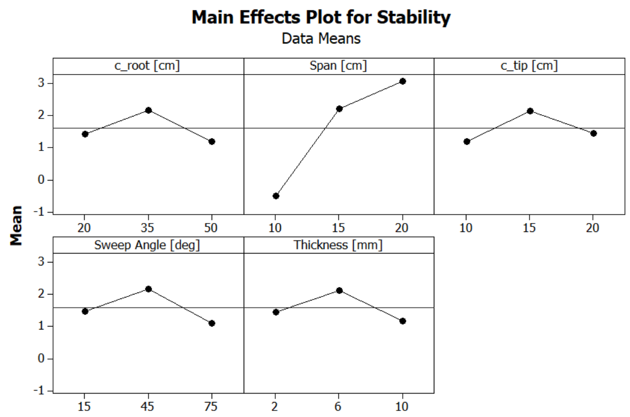


Fig. 14. Main Effects of the Swept Fin Parameters on Stability.

According to Fig. 14, increment of span length increases the stability of the model rocket similar to the clipped delta fin shape. Although the root chord length does not affect the stability of the model rocket, both of its square and its multiplication with sweep angle slightly affects it. Fig. 15 shows response surface representing the effects of span length and root chord length on stability.

According the results, a nonlinear relationship is also observed between the span length and stability for swept fin.

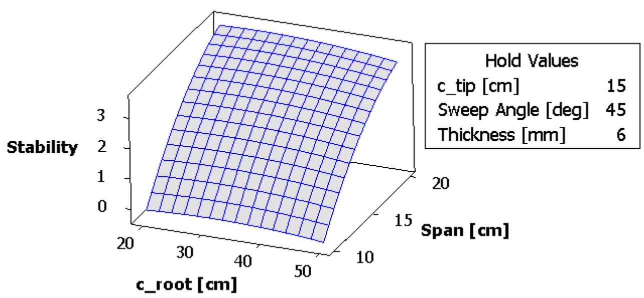


Fig. 15. Response Surface Representing the Variation of Stability with Span and Root Chord for Swept Fin.

## C. *Trtapezoidal Fin*

Both of the response surface boundaries and four design variables of the trapezoidal fin shape is exactly same with the clipped delta fin shape that are summarized in Table 1. Two different response surfaces are also constructed for this fin shape. Each of them is created preparing full composite models consisting of 31 cases.

The first response surface is created to examine the effects of sizing parameters of trapezoidal fins on apogee of the model rocket. Fig. 16 represents percentage effects of sizing parameters and interactions of them on apogee.

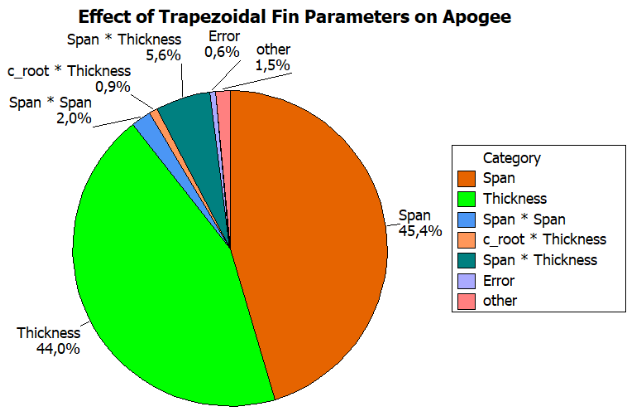


Fig. 16. Percentage Effects of the Trapezoidal Fin Parameters on Apogee.

According to the results, span length and thickness have almost equal amount of effect on apogee of the model rocket and they are dominating it for trapezoidal fin shape. Fig. 17 summarizes the main effects of sizing parameters of the trapezoidal fin on apogee.

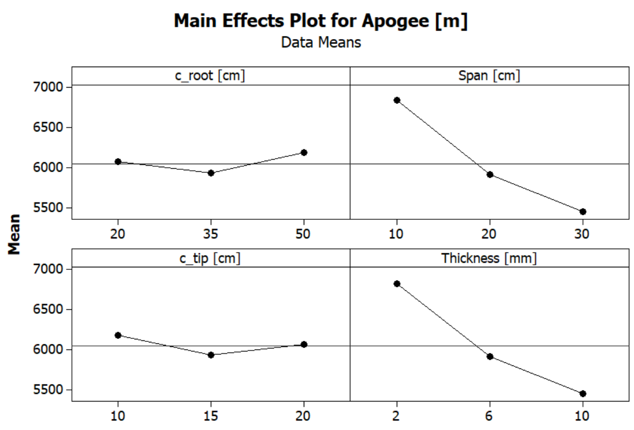


Fig. 17. Main Effects of the Trapezoidal Fin Parameters on Apogee.

According to Fig. 17, increment of thickness and span length decreases the apogee of the design due to the same reason with the clipped delta and the swept fins. Similar to the previously examined fin types, root chord and tip chord lengths are almost ineffective on the apogee of the model rocket. Fig. 18 shows the response surface representing the effects of span length and thickness on apogee of the design having trapezoidal fins.

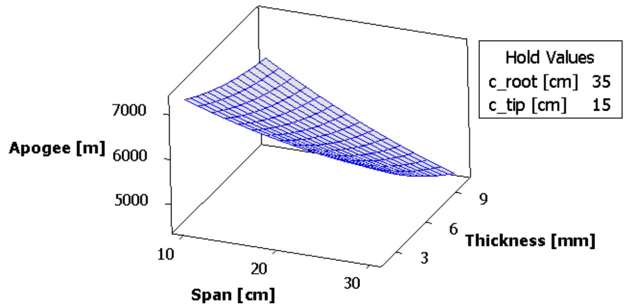


Fig. 18. Response Surface Representing the Variation of Apogee with Span and Thickness for Trapezoidal Fin.

The second surface is constructed to examine the effects of trapezoidal fin sizing parameters on stability. Fig. 19 represents percentage effects of sizing parameters and interactions of them on stability.

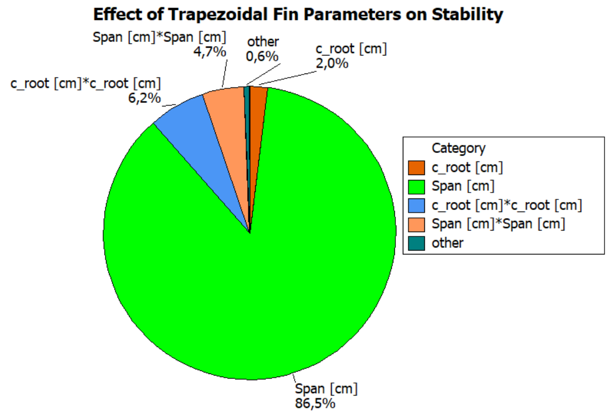


Fig. 19. Percentage Effects of the Trapezoidal Fin Parameters on Stability.

Similar to the results obtained for the previously examined fin shapes, the span dominates the stability of the model rocket also for the trapezoidal fin shape. Fig. 20 summarizes the main effects of sizing parameters of the trapezoidal fin on stability.

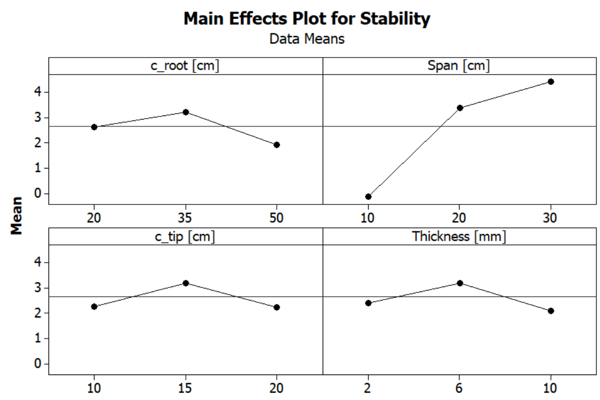


Fig. 20. Main Effects of the Trapezoidal Fin Parameters on Stability.

Main effect results are almost same with the results obtained for the clipped delta fin. Fig. 21 shows the response surface representing the effects of span length and root chord length on stability of the design having trapezoidal fins.

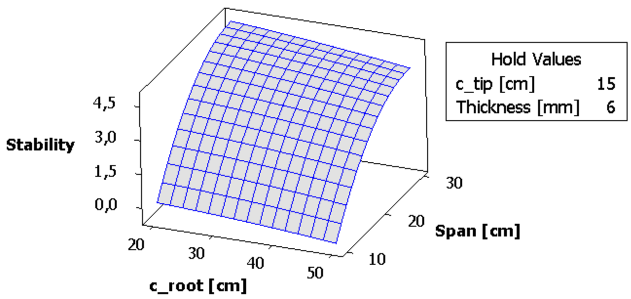


Fig. 21. Response Surface Representing the Variation of Stability with Span and Root Chord for Trapezoidal Fin.

## D. Triangular Fin

Table 3 summarizes response surface boundaries of three design variables that are used to size triangular fin shape.

TABLE III. RESPONSE SURFACE BOUNDARIES FOR TRIANGULAR FIN SHAPE

| *Symbol* | *Definition* | *Lower Boundary* | *Upper Boundary* | *Unit* |
|---|---|---|---|---|
| $c_{root}$ | Root chord length | 20 | 50 | cm |
| $S$ | Span length | 10 | 30 | cm |
| $t$ | Thickness | 2 | 10 | mm |

Two different response surfaces are also constructed for this fin shape. Each of them is created preparing full composite models consisting of 20 cases.

Similar to the previous topics first response surface is constructed to examine the effects of triangular fin sizing parameters on apogee of the model rocket. Fig. 22 represents percentage effects of sizing parameters and interactions of them on apogee.

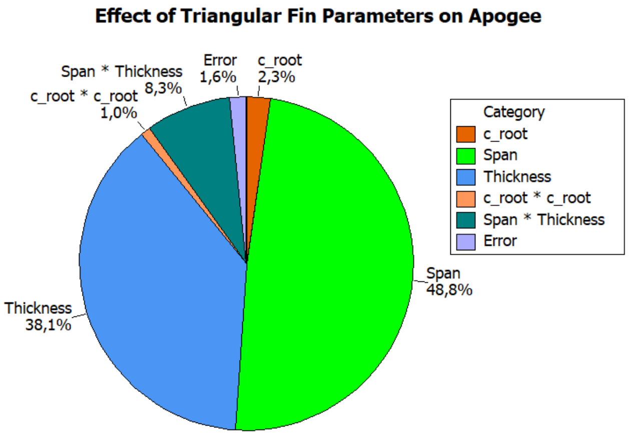


Fig. 22. Percentage Effects of the Triangular Fin Parameters on Apogee.

Similar to the previous fin shape results, span and thickness are dominating the apogee of the model rocket for triangular fin shape. On the other hand, multiplication of those parameters has considerable effect on the apogee of the design. Fig. 23 summarizes the main effects of sizing parameters of the triangular fin on apogee.

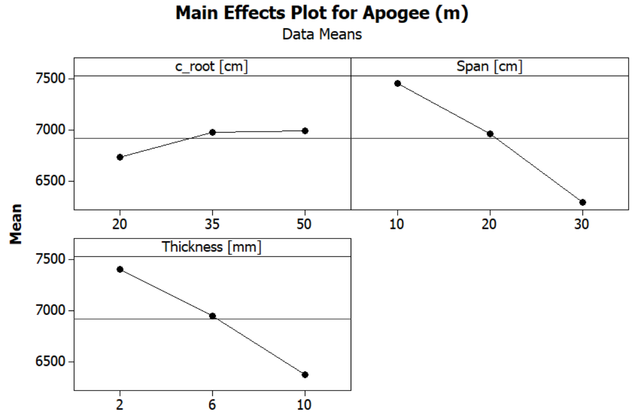


Fig. 23. Main Effects of the Triangular Fin Parameters on Apogee.

According to Fig. 23 increment of thickness and span length decreases apogee of the model rocket due to the same reason with the previous examined fins types. Root chord is almost ineffective on apogee. Fig. 24 shows response surface representing the effects of span length and thickness on apogee of the model rocket having triangular fins.

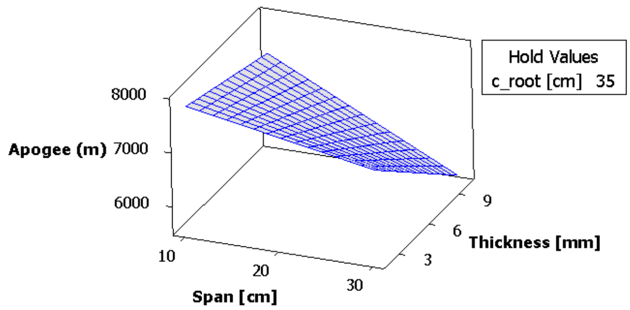


Fig. 24. Response Surface Representing the Variation of Apogee with Span and Thickness for Triangular Fin.

The second surface is constructed to examine the effects of three sizing parameters of triangular fin on stability. Fig. 25 illustrates percentage effects of sizing parameters and interactions of them on stability.

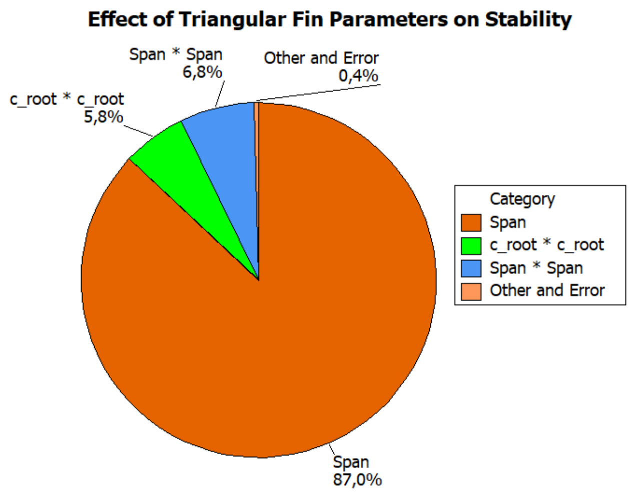


Fig. 25. Percentage Effects of the Triangular Fin Parameters on Stability.

Similar to previous fin shape results, span length dominates the stability of the model rocket for triangular fin shape. Fig. 26 summarizes the main effects of sizing parameters of the triangular fin on stability.

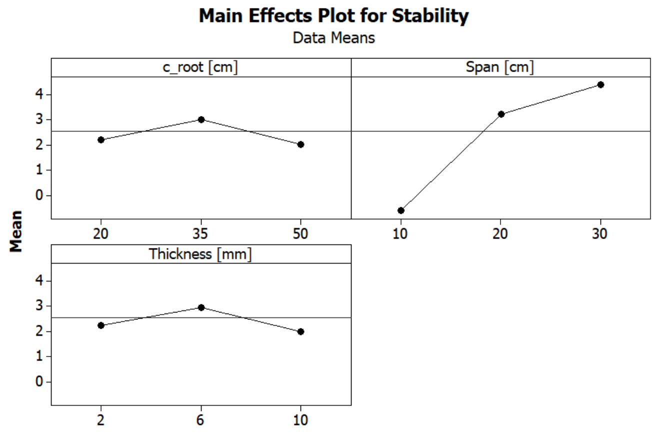


Fig. 26. Main Effects of the Triangular Fin Parameters on Stability.

According to Fig. 26, increment of span length makes a positive contribution on the stability of the model rocket. Although the root chord length does not affect the stability, its square and square of the span length slightly affect it. Fig. 27 illustrates a response surface representing the effects of span length and root chord length on stability.

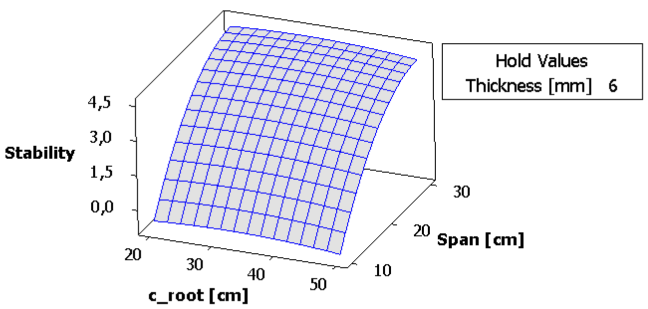


Fig. 27. Response Surface Representing the Variation of Stability with Span and Root Chord for Triangular Fin.

## IV. Conclusion

Within the content of this research effects of geometric sizing parameters such as root chord length, tip chord length, span length, sweep angle, and thickness belonging to four different kind of fin shapes that are clipped delta, swept, trapezoidal, and triangular on apogee and stability of a generic model rocket designed to deliver 8 kg payload to 7 km altitude is examined benefiting from the response surface method. Apogee and stability calculations are performed using Open Rocket Simulator. 8 different response surfaces are constructed.

According to the results, span length and thickness are dominating the apogee of the system for all different kinds of fins. Increment of those parameters are decreasing the apogee of the model rocket since they are not only increasing the aerodynamic drag but also, increasing the weight of the design. It is also obtained that, sweep angle is the secondary dominant parameter effecting the apogee of the model rocket having swept fins. Increment of the sweep angle leads to the increment of apogee. This research also showed that there is a nonlinear relationship between sweep angle and apogee. On the other hand, other parameters such as root chord length and tip chord length does not directly affect the apogee of the model rocket for all different types of fin configurations.

Stability analysis obtained that; the stability of the model rocket is dominated by span length of the fins. Increment of this length provides a great contribution of the system's stability nonlinearly. Additionally, squares of root chord length and span length has minor effects on model rocket stability.

Finally, the study also proves benefits of the response surface method for designers. Applying this method, they could have detailed information about the behavior of design variables on response variables and so it is possible to gain time during the preliminary design processes.

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