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The Effects of Fin Cant Angle and Fin Height on the Performance of a Low Altitude Rocket

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Abstract

It is known that aerodynamics play an important role in the stability of a rocket. Stability has been defined as a system's tendency to recover or revert to its initial state following a perturbation. The location of the centre of gravity and the centre of pressure fundamentally determines the stability of the rocket. One of the main issues with a small rocket is that the viscous effect becomes more prominent, which may significantly alter the pressure distribution around its body. Hence, when the scale is reduced, the study of aerodynamics effect on the rocket's centre of pressure (thus stability) becomes more crucial. In this present study, we investigate the stability of a low-altitude rocket by determining the effect of spin stabilisation on rocket stability. The locations of centre gravity and centre pressure are determined in this study using the Barrowman equations. It was found that a fin height of 4 cm produces the ideal static margin of approximately 1.5. Furthermore, largest fin cant of 10° yields highest apogee. In general, the rocket's static stability improves when the fin height is increased, while the fin cant angle affects the dynamic stability.

1. Introduction

A rocket is a versatile and potent manufacturing tool that may be used for a multitude of purposes. It is up to the nation or country to use it for that purpose. A portion of it is used to manufacture fireworks, missiles, and weapons; launch vehicles for artificial satellites; human spaceflight; and space exploration. Other organisations, such as NASA, use rockets as artificial satellites to transport probes to other planets. Saturn I, IB, and V were the first rockets built by NASA to launch men into space [1]. The rocket operates by turning fuel into hot gas to generate thrust from the engine and drive it ahead. Jet engines require air to operate, but rocket engines do not. A rocket engine can operate in space, where there is no air, because it contains all the necessary components.

Stability is the most crucial effect of a rocket [2]. Stability is defined as the tendency of a system to recover or revert to its initial state following a disruption. The nose cone and fins of a rocket are designed to reduce drag and air resistance [3], as well as provide stability and control to keep the rocket pointed in the correct direction [4]. For stability, sounding rocket fuselages typically have an aerodynamic nose cone and a tail fin. As for rocket stability, it can be understood simply by observing that the rocket does not wobble, the tail points in the direction of rotation, and the rocket loses control after launch.

The Weathervane Model can be used as a representation for rocket stability [5]. It demonstrates that air pressure being applied to the model causes it to rotate. By substituting the model with a rocket, the wind resistance will be greater at the rear and less at the nose cone [6]. Therefore, the point where the rocket turns will be the centre of gravity for the position (CG). If the rocket were positioned horizontally and balanced on a pencil, the centre of gravity (CG) would be the point at which it would balance [7]. The distribution of the rocket's components also affects the location of its centre of gravity. When heavier payloads are placed closer to the nose cone, the centre of gravity rises. As the rocket engine burns, the back end of the rocket gets lighter, and the CG position moves forward. If an indication point is used to locate the centre of gravity of a rocket after flight, the balance point will have shifted towards the nose [8].

This term will also be accompanied by the term position centre of pressure (CP). Specifically, stability exists when the centre of pressure (CP) is located behind the centre of gravity [9], as depicted in Fig. 1. The centre of pressure (CP) of a rocket is the place where the aerodynamic forces generate balanced torques [10]. The location of the centre of pressure is determined by the pressure distribution on the rocket's surface during flight. Through the rocket's fins, the pressure distribution can be adjusted to decrease the centre of pressure, which increases the rocket's stability. The farther the centre of gravity (CG) is from the centre of pressure (CP), the more stable the rocket [11]. The fins enhance the rocket's aft section's surface area and increase the forces applied to the section. Rocket fins are appendages attached to the structure of the rocket body; they play a very important role in providing stability to the space craft during the flight, which allows the rocket to maintain its flight path and orientation. The shape and design of the fins influence the stability of the rocket.

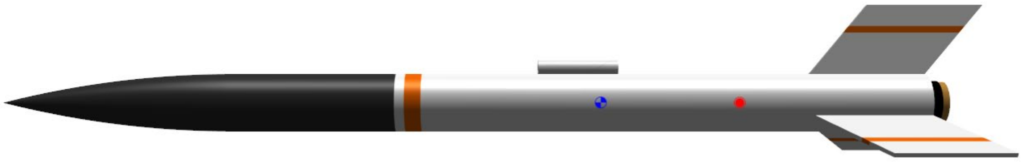


Fig. 1 *Position of centre of gravity (blue circle) and pressure (red circle)*

Overstability is not a negative quality. In addition, the rocket's stability could be jeopardised by a crosswind gust that strikes the body. During rocket flight, lightning, wind gusts, and a variety of other elements frequently cause disruptions. If there is any wind present at launch, the rocket will have a stronger tendency to weathercock. The rocket won't continue to rise in a vertical line; rather, it will angle itself progressively into the wind [12]. When designing a rocket to improve its stability, flat fins, or wrap-around fins (WAF) are the sort of fin most frequently employed. Wrap-around fins (WAFs) are analysed and contrasted with flat fins. The WAFs provide the rocket with a rolling motion. Various configurations, including span-to-chord ratio, radius of curvature, and setting angles, are explored. The Spalart-Allmaras model of turbulence is utilised [13]. The investigation revealed that drag is somewhat smaller in M=4 than in M=3. Flat fins have more lift characteristics and pitching moments, whereas WAFs have greater longitudinal axis stability.

Using six wrap-around fins on the rocket, previous research was conducted to explore the rolling characteristics of different wrap-around fin parameters and their aerodynamic impact on rocket stability. Comparisons have been made between simulations utilising computational methods and wind tunnel experiments with Mach numbers of 3 and 4 in place [14]. The study indicated that WAF can significantly enhance the longitudinal stability and aerodynamic characteristics of the planned rocket. Several previous studies have utilised a variety of fin designs, such as clipped delta fins, swept fins, trapezoidal fins, and triangular fins, as well as various fin parameters, such as fin span, root-to-tip, chord tip, swept angle, and thickness [15]. The length of the increment greatly adds to the nonlinear stability of the system. The eight distinct geometrical parameters for the flat fins, such as aspect ratio, taper ratio, and sweep, have been the subject of previous studies on the roll moment characteristics. The authors concluded that decreasing the taper ratio and increasing the fin aspect ratio while keeping the fins within the bow shock will lower the induced rocket rolling moment.

Stability is essentially characterised by a predictable flight path. For a rocket to be stable, the centre pressure range must be at least 1.0 body diameter below the centre of gravity [5], while a greater value is acceptable [7]. Previous research demonstrates that while doing dynamic stability analyses and flight experiments of the span and chord clipped variants of a 140-mm rocket, dynamic stability is maintained. Flight tests largely validate the beneficial effect of span clippings on the stability characteristics of the configurations revealed by the results. The National Aeronautics and Space Administration also conducted tests in the 4- by-4-foot supersonic pressure tunnel at Langley to determine the effects of variations in nose shape and fin geometry on the static stability of two sounding rocket models with length-to-diameter ratios of 18.20 and 23.20 [16]. Because of this, the fins with a greater aspect ratio had the tendency to improve directional stability and delay the induced rolling moments until higher angles of attack.

Rockets should always avoid a spinning motion because when a rolling motion occurs, the rocket will fly straighter. If a rocket only rose vertically, it would return to Earth as soon as its fuel ran out. The rotation of a rocket is caused by the deflection of its fins [17]. To achieve orbit, or a circular route of motion around the Earth, rockets must therefore lean to the side as they ascend into the atmosphere. However, by doing so, an entity, such as a satellite or a launch vehicle, is normally stabilised during launch. Spinning is not a problem of performance but of stability. By spinning the football or bullet, the object is made to behave like a gyroscope, meaning it will resist shifting its axis of rotation, which in this situation means that it will continue to point in the same direction. The performance may be enhanced by avoiding tumbling, although the improvement is not directly due to the lack of spinning. Spin stabilisation is the process of stabilising a satellite or launch vehicle through rotation along the longitudinal axis, or spin. The concept derives from ballistics, where spin is typically achieved through rifling. This method has been mostly replaced by three-axis stabilisation for satellite applications. These are referred to as roll, pitch, and yaw. The CG is the place where these three axes intersect. The spin-stabilised system has the advantage of limiting the effects of mechanical energy dissipation, such as tumbling, in contrast to the non-spinning system [18]. This air flow, rubbing and pushing against the rocket's outer surface, can cause the rocket to begin rotating about one of its three axes.

Spin stabilisation is typically employed in bullets, satellites, and other objects with a trajectory in space, but most current rockets rely on more advanced systems such as gimbaled thrust. Spin stabilisation functions by quickly rotating the rocket in flight, producing a gyroscopic effect that resists external forces that would modify its course. This rotating motion helps improve the model rocket's stability. It is essential to remember that spin stabilisation is insufficient to keep the rocket on course. Spin stabilisation is designed to complement the regular means of stabilisation, not replace them. However, finless rockets that have been meticulously developed can launch successfully. The launch vehicles Jupiter-C and Minotaur V utilised spin stabilisation [19]. Both systems' higher stages use spin-stabilisation to stabilise the system during propulsion manoeuvres.

Launching a model rocket with a spin alone is insufficient for it to launch without fins but adding a spin to a rocket can help the rocket maintain a straight trajectory. There are several basic methods for launching a spinning rocket; all of them involve modifying your model rocket's fins. Several modifications to the fin, such as spin tabs, canted fins, and cambered airfoils, can be made to ensure that the object spins [20], as shown in Fig. 2. The rocket employs canted fins and a fluted nozzle to produce the roll rotational speed to reduce dispersion due to inertial, aerodynamic, and thrust asymmetries.

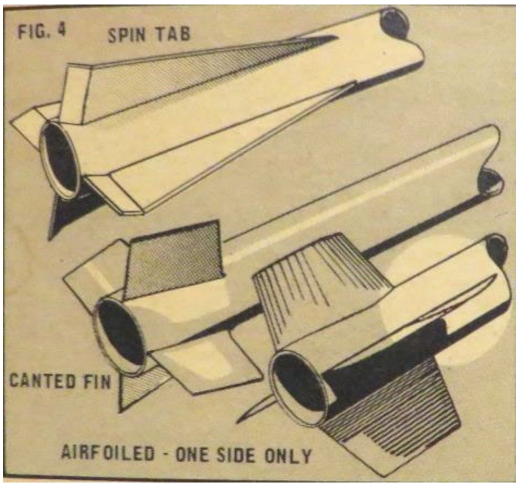


Fig. 2 *Various fin shapes to induce moment*

Some of the previous studies stated that to decrease the influence of thrust misalignment on the battle trajectories of sounding rockets and other types of spacecraft, spin stabilising techniques are routinely utilised. Monte Carlo simulation techniques provide statistical data that are used to analyse the relationship between spin motion and flight dispersion [21]. The results indicate that by canting the fins on the first stage, the rocket starts spinning immediately after launch, the fight is stabilised, and the dispersion can be significantly reduced. Adding this spin motion to a rocket can make the rocket fly straight and stable, but it reduces the rocket's capacity to reach higher altitudes.

According to a prior study, this project utilised six Aerotech Airspike rocket kits. Five of the rockets featured fin tabs positioned at different angles to generate varying degrees of spin [22]. The flight data was captured on the RDAS device, downloaded to a computer, and graphed for study. The greater the velocity of a rocket's spin, the lower its height. In addition, they noted in the conclusion that the fin tabs caused greater roll with higher fin tab angles. Most amateur rocketeers used the OpenRocket software to forecast the stability of the planned rocket, which is based on the Barrowman equations. However, this software has other capabilities that can be used to determine the state of the rocket. Therefore, the purpose of this study is to analyse rocket spin stabilisation in static and dynamic motion using the design parameters of fin tail height and fin cant. This research is anticipated to expand the capabilities of this open-source rocket analysis software, thereby increasing rocket analysis.

2. Methodology

In this study of the designed rocket's stability, a mathematical method was adopted to meet the study's objectives. In this method, Barrowman equations were solved using OpenRocket software, which can greatly simplify the equation solving calculations. OpenRocket software is one of the most popular user interfaces for folks who enjoy designing and simulating rockets. This open-source software is packed with tools for designing model rockets prior to flight. The software has been validated against test flights and the comparison data were reported in [23], [24]. The data were also compared with simulation results from Rocksim software, which is one of the *de facto* standards software for model rocket performance estimation. The comparison of experimental data is conducted in different conditions, such as a small rocket model, a hybrid rocket, a rolling rocket, and a wind tunnel. It was reported that the OpenRocket software can accurately predict the moment from launch where the roll rate peaks, despite a discrepancy in its magnitude. Furthermore, OpenRockets predicts an apogee with a 7% error relative to the experimental data, which is much lower than the error produced by the RockSim software at 19%.

In the present analysis, the variables of concern are the rocket's stability, apogee, and roll characteristics. A 3D rocket model is first developed to serve as the representational model for this analysis. Calculating the distance between the nose's leading edge and the longitudinal centre of pressure yields the distance between the two points. The centre of gravity must coincide with the longitudinal pressure centre. As a rule of thumb, the CP distance should be at least one rocket behind the CG.

This Barrowman equations was developed by Barrowman [25], and it is quite simple to use and check the rocket's stability. The application of the physics of flow to the typical design of model rockets has led to the development of an immediate approach for predicting the location of the centre of pressure using just information about the aerodynamic geometry. The Barrowman approach has been the only way to calculate the rocket's margin of stability as a fundamental. Those modellers who have used it more regularly and proven to be reliable are also generally good choices. Five identical model rockets with varied fin heights were constructed to test the simpler approaches, and only one way, the complete Barrowman equations, was a reliable prediction of stability [26]. There are also some researchers conducting studies to extend the Barrowman equations concept [27]. By using this software to construct a 2D model rocket, the location of the centre of gravity and the centre of pressure can be identified rather quickly. The specifications of the model and terms used to define the entire Barrowman equations are provided in Fig. 3.

The figure number and caption should be typed below the illustration in 10pt and centered. Artwork has no text along the side of it in the main body of the text. However, if two images fit next to each other, these may be placed next to each other to save space. For example, see Fig. 1. The figures and the number should be placed in the table. Then, the table border needs to be adjusted to no border.

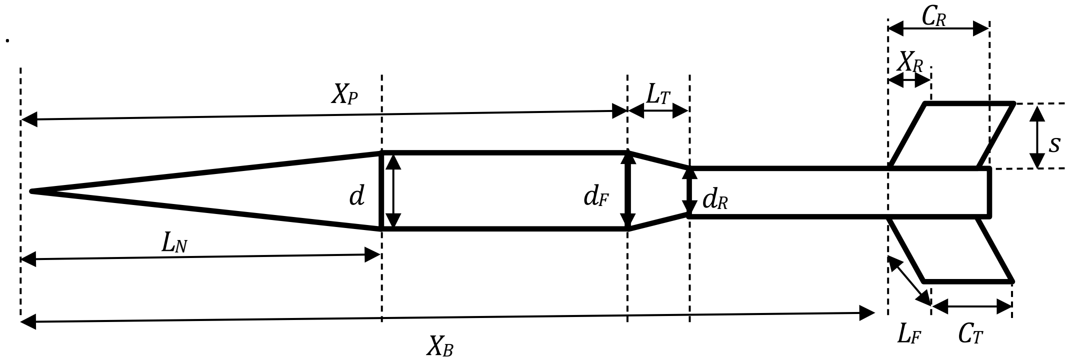


Fig. 3 *Geometrical definitions of a typical rocket*

The terms represented in Fig. 3 are defined as follows: L_N = length of nose, L_T = length of transition, L_F = length of the fin mid chord line, X_R = distance between fin root leading edge and fin tip leading edge parallel to body, X_B = distance from nose tip to fin root chord leading edge, X_P = distance from tip of nose to front of transition, C_R = fin root chord, C_T = fin tip chord, d = diameter at base of nose, d_F = diameter at front of transition, d_R = diameter at rear of transition, R = radius of body at aft end, S = fin semispan, and N = number of fins.

Nose Cone term: $(C_N)_N = 2$,

$$X_N = 0.666L_N \tag{1}$$

$$X_N = 0.466L_N \tag{2}$$

$$X_N = 0.5L_N \tag{3}$$

Eq. (1) is for cone, while Eq. (2) and Eq. (3) are for Ogive and special shape cone, respectively.

Fin term:

$$\left(C_N\right)_F = \left[1+\frac{R}{S+R}\right]\left[\frac{4N\left(\frac{S}{d}\right)^2}{1+\left(1+\left(\frac{2L_F}{C_R+C_T}\right)^2\right)}\right] \tag{4}$$

The Eq. (4) is suitable for 3, 4, or 6 number of fins design only.

$$X_F = X_B + \frac{X_R}{3}\frac{\left(C_R+2C_T\right)}{\left(C_R+C_T\right)} + \frac{1}{6}\left[\left(C_R+C_T\right)-\left(\frac{C_R C_T}{C_R+C_T}\right)\right] \tag{5}$$

To stabilise the rocket, the design of the fins also influences the airflow over the rocket's body portion. Since all the fins have the same shape and size, the tail's centre of pressure is no longer dependent on the number of fins, as shown by Eq. (5).

Sum up coefficients:

$$\left(C_N\right)_R = \left(C_N\right)_N + \left(C_N\right)_F + \left(C_N\right)_T \tag{6}$$

Finding Center of Pressure (CP) distance from nose cone tip:

$$\overline{X} = \frac{\left(\left(C_N\right)_N X_N + \left(C_N\right)_T X_T + \left(C_N\right)_F X_F\right)}{\left(C_N\right)_R} \tag{7}$$

By inputting the model rocket's specifications into the OpenRocket software, the equations were solved to estimate the location of the center of pressure, as depicted in Fig. 4. For the purpose of this study, other parameters such as wind disturbance speed and the height and cant of the rocket fin were varied. This study utilises a clipped delta fin. Fig. 5 and Fig. 6 show parameter indicators for the rocket fin and fin cant angle on rocket body, respectively. While Table 1 and Table 2 show specifications of the model representative rocket and parameters used in rocket stability analysis.

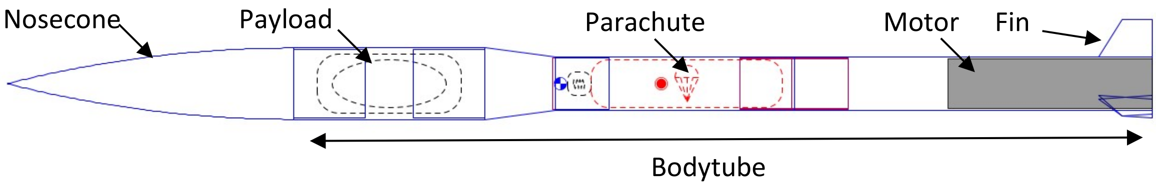


Fig. 4 *Model representation of the present study*

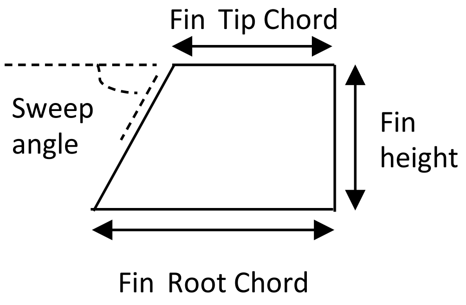


Fig. 5 *Parameter indicator for rocket fin*

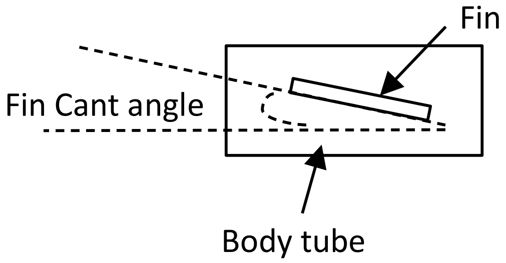


Fig. 6 *Fin cant angle definition on a rocket body*

Table 1 *Specification of model representative rocket*

Component	Parameter	Dimension
Nosecone	Length	30.5 cm
	Based Diameter	7.62 cm
	Wall thickness	0.127 cm
Bodytube	Overall Length	122 cm
	Max diameter	7.62 cm
	Mass with motor	3576 g
	Mass without motor	2824 g
Fin	Number Fins	3
	Root Chord	5.74 cm
	Tip Chord	3.2 cm
	Height	4 cm
	Sweep length	2.54 cm
	Sweep angle	32.4 °
	Thickness	0.3 cm

Table 1 *Parameter used for rocket stability analysis*

Windspeed (m/s)			0		10		20		30	
Cases	Cant (°)	Height (cm)	Apogee (m)	Calibre	Apogee (m)	Calibre	Apogee (m)	Calibre	Apogee (m)	Calibre
A1	0	4	1095	1.41	918	1.41	677	1.41	520	1.41
A2	0	4.5	1086	2.14	866	2.14	587	2.14	403	2.14
A3	0	5	1077	2.74	832	2.74	580	2.74	328	2.74
A4	0	5.5	1068	3.23	814	3.23	566	3.23	344	3.23
A5	0	6	1059	3.64	810	3.64	504	3.64	295	3.64
A6	0	6.5	1050	3.99	762	3.99	469	3.99	246	3.99
B1	5	4	1095	1.41	1050	1.41	915	1.41	809	1.41
B2	5	4.5	1086	2.14	1018	2.14	857	2.14	669	2.14
B3	5	5	1077	2.74	978	2.74	808	2.74	543	2.74
B4	5	5.5	1068	3.23	935	3.23	669	3.23	469	3.23
B5	5	6	1059	3.64	884	3.64	624	3.64	431	3.64
B6	5	6.5	1050	3.99	869	3.99	619	3.99	379	3.99
C1	10	4	1095	1.41	1078	1.41	1047	1.41	959	1.41
C2	10	4.5	1089	2.14	1059	2.14	1005	2.14	917	2.14
C3	10	5	1077	2.74	1039	2.74	950	2.74	807	2.74
C4	10	5.5	1068	3.23	1022	3.23	907	3.23	765	3.23
C5	10	6	1059	3.65	1000	3.65	839	3.65	839	3.65
C6	10	6.5	1050	3.99	987	3.99	756	3.99	599	3.99

The differences between the fin cant and fin height are illustrated in Fig. 7 and Fig. 8. The increment is five degrees for fin cant and half a centimetre for fin height. The selection of parameter values was guided by typical values commonly employed in the construction of rockets of comparable size. In addition, deviations from the designated parameter limitations, whether smaller or bigger, can result in the rocket exhibiting either instability or excessive stability. Both of these situations are considered unfavourable in the context of rocket flight.

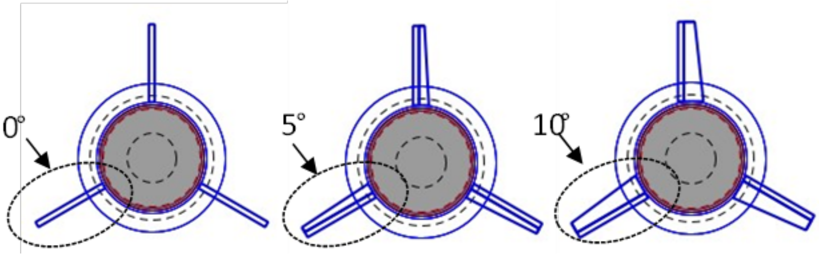


Fig. 7 *Comparison fin cant angle*

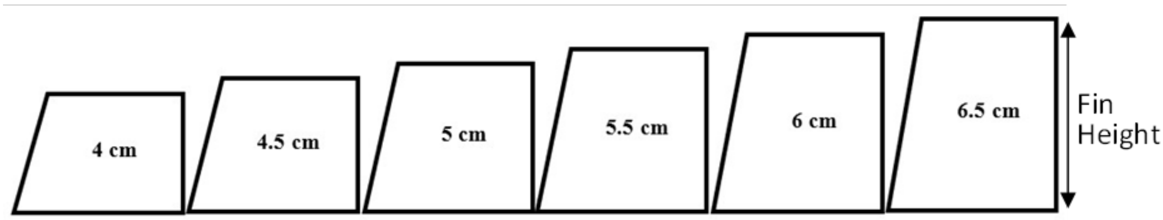


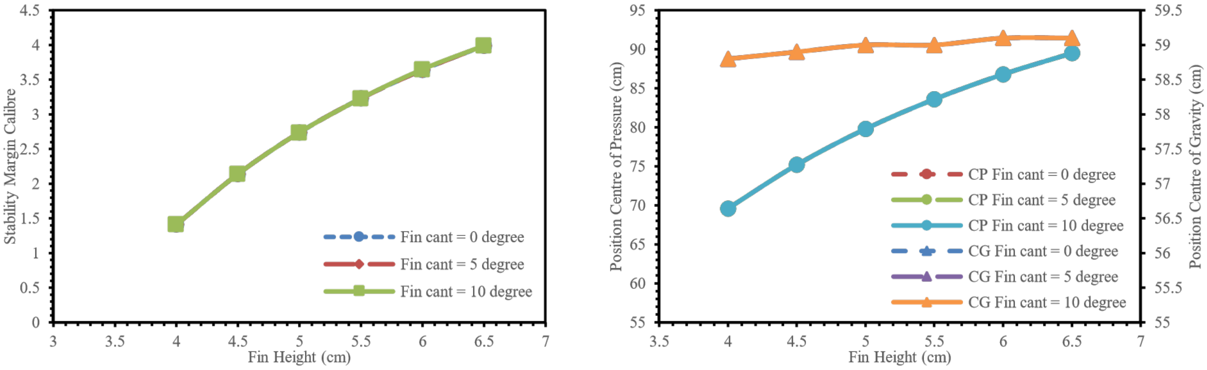
Fig. 8 *Fin height comparison*

3. Results

3.1 Stability Margin and Position of CP and CG

The study's primary purpose is to analyse the stability of rockets with different fin-tail configurations, including fin height and fin cant. The fin height was adjusted between 4 cm and 6.5 cm by increments of 0.5 cm, while the fin cant angle was altered between 0 and 10 degrees by increments of 5 degrees. Fig. 9 depicts the difference in rocket stability based on fin height and cant. The stability of the rocket is defined as the distance between the centre of pressure and the centre of gravity, which can also be referred to as the dimensionless stability margin calibre. The pressure centre was computed using the Barrowman equations and OpenRocket software.

According to Fig. 9 and the resulting data, the increment of fin cant has little to no effect on the rocket's margin stability. This is because the fin cant angle has very little effect on the rocket's mass and pressure distribution. The rocket's static stability can only be determined by the fin height increment. The reason for the stability of a rocket is the distribution of mass and pressure, which is affected by the rocket's height. At a higher range of fin height, the weight increased significantly, which produced a larger impact on the surface pressure near the rear of the rocket body. The position of the centre of pressure increases proportionally with the position of the centre of gravity, which increases at a slow rate as the height of the fin increases.



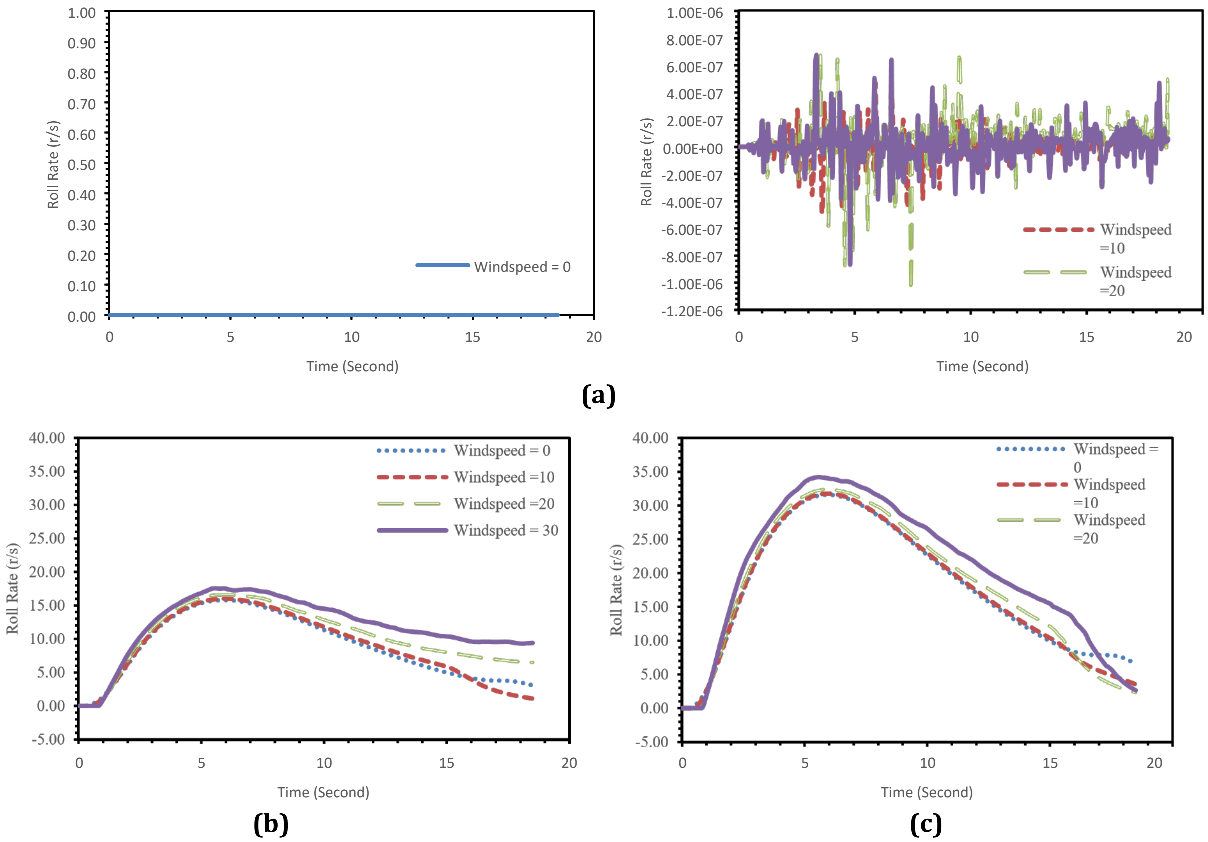
(a) **(b)**

Fig. 9 *Fin cant angle and fin height increment on (a) Stability Margin Calibre; and (b) Position of CG and CP*

3.2 Roll Characteristic

Spin stabilisation for a rocket relates to the launched rocket's rolling feature. Although fins have no effect on the rocket's static stability, the fin cant parameter is employed to ensure the rocket's rotation. The results were based on the varying effects of fin cant on the rocket under 0 m/s, 10 m/s, 20 m/s, and 30 m/s wind disturbance speeds. OpenRocket software produced various solution, including roll rate, roll moment, and pitch rate. Using a result comparison based on a fin tail height of 4 centimetres and a stability margin calibre of 1.41 because the stability margin calibre range is between 1 and 2 calibres and most rocketeers prefer stable conditions.

Fig. 10 demonstrates that when the fin cant is angled at 0 degrees, the magnitude of the roll rate is significantly smaller than in the angled cases, indicating that the rocket does not spin in the air. When there is no wind disturbance, the roll rate of the fin cant at 0° remains constant since there is no resistance acting on the rocket, leading to a stable flight condition. Compared to a change in fin cant at an angle of 5°, the wind speed increases the roll rate by adding more spinning motion to the rocket, indicating that the rocket continues to roll on its axis even in the absence of external influences such as the presence of wind. The increment on fin cant angle of 10° varies the roll rate more than fin cant angle of 5°, which reaches a range of 30 to 35 r/s, or around 286 to 334 revolutions per minute, depending on the presence or absence of wind disturbance. This finding indicates that the fin can indeed boost the rocket's spin.



(a)

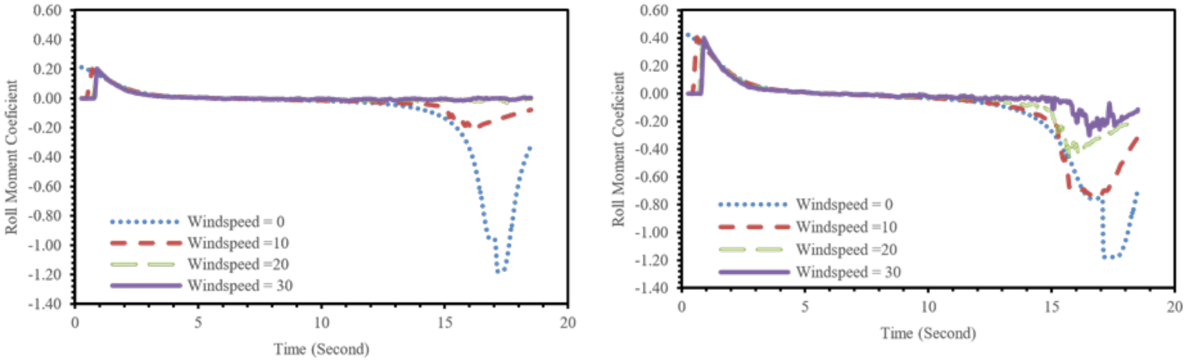
(b)

(c)

Fig. 10 *Roll rate against time in various wind disturbance speed and fin cant angle – (a) Fin cant 0°; (b) Fin cant 5°; and (c) Fin cant 10°*

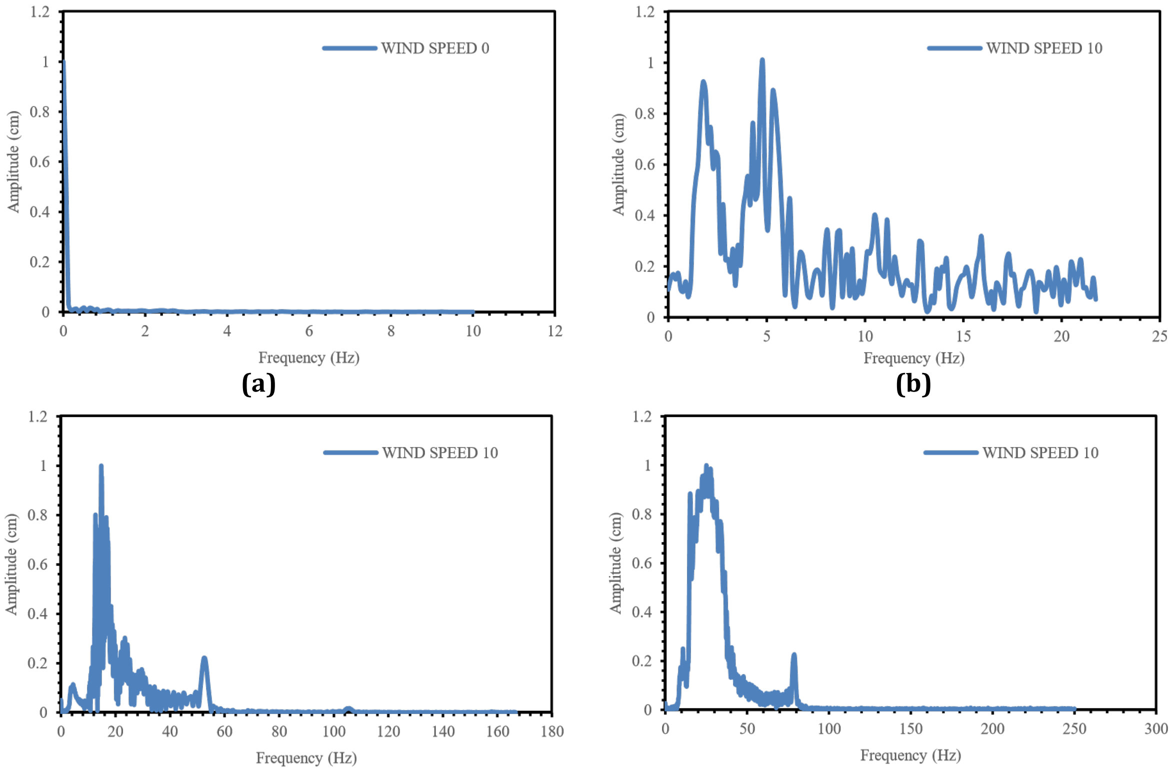
In addition, Fig. 11 shows the roll moment, which indicates that the fin cant has contributed to the rocket's spin motion in two types of rotation, which are positive and negative roll moments. Without a fin cant angle configuration, the rocket's roll moment is in a static state with a constant coefficient value of zero. In both rotations, the 5° fin cant angle initiates the shift to a rolling motion for the rocket. The rocket begins to roll at a positive value until around 6 seconds, then it begins to roll at a negative value. The roll moment decreases over time because of an increase in wind disturbances. This is due to the interaction between the rocket's rotational motion and the wind disturbance, with the rocket attempting to resist the opposing forces. Additionally, it is noteworthy to see a substantial decrease in the roll moment throughout the time interval from 13 seconds to 14 seconds of flight. This phenomenon can be explained by the rocket nearing its apogee, which typically occurs roughly 18 seconds after launch. Consequently, the rocket's orientation shifts, causing it to rotate in a downward direction. Throughout this rotational period, there is an observable increase in the negative roll moment, as depicted in Fig. 11.

Pitch is one of the motions that might occur during a rocket's performance. During launch, the movement of the rocket is a sinusoidal signal wave. Therefore, the signal wave is converted using MATLAB software into frequency and amplitude to make it more intelligible. Without a fin cant angle and wind disturbance, the rolling motion of the rocket fluctuated at a single dominant frequency. According to the results shown in Fig. 12 , under the influence of wind disturbance, the rocket's amplitude decreases gradually as its frequency increases. It also shows that the dominant frequency is becoming smaller under different fin cant angles. This also shows that the rocket is making slight up and down movements under a very small movement when launched in the sky to keep it straight. This is also indicating that the rocket's pitching is stabilising its position more regularly. Therefore, increasing the fin cant angle can raise the rocket frequency while preserving the rocket's ability to fly straight and stable.



(a) **(b)**

Fig. 11 *Roll moment Coefficient against time in various wind disturbance speed and fin cant angle – (a) Fin cant 5°; and (b) Fin cant 10°*



(a) **(b)**

(a) **(b)**

Fig. 12 *Frequency against amplitude for pitch rate at wind speed of 10 m/s – (a) Fin cant 0°; (b) Fin cant 0°; (c) Fin cant 5°; and (d) Fin cant 10°*

Lastly, based on Fig. 13, a comparison between each increment of the fin cant and the apogee indicates that employing a higher fin cant under windy conditions results in the rocket reaching a greater apogee. The apogee decreases when the wind disturbance speed increases. Although, the configuration of the fin cant has different results, the fin cant under zero angle degree has a significant drop for its apogee compared with other fin cant angles. There are only small changes at the apogee of fin cant angles of 5° and 10° under high wind disturbance. The result also shows that fin cant is more stable as it is spinning with a higher fin cant under high wind disturbance. Indeed, wind speed affects the rocket's apogee, and increasing the angle of the fin cant increases the rocket's altitude. It also indicates that rockets are more stable and can achieve a higher apogee.

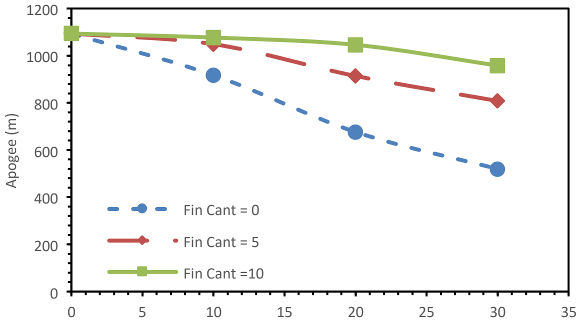


Fig. 13 *Apogee against wind disturbance speed in various fin cant*

4. Conclusions

This research was conducted to investigate the effect of a fin's height and cant angle on its overall stability. The mathematical methodologies have been utilised, and the results have indicated that increasing the rocket's fin height enhances its stability. Variations in the angle at which the rocket's fins cant add a miniscule amount to the overall stability of the rocket and nearly have no influence at all. The analysis revealed that the fin cant have a significant potential since it can provide the rocket with a roll moment. The spinning motion also functions as a barrier that can limit the rocket's apogee; yet, in the presence of stronger wind disturbances, the spinning motion can raise the rocket's apogee and make it more stable.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Data collection:*** *Zuraidah Salleh, Mohamad Amirul Muhammad;* ***data analysis and interpretation of results:*** *Ahmad Hussein Abdul Hamid;* ***draft manuscript preparation and proofreading:*** *Alif Abni Adnan, Szymon Gwozdz, Ahmad Hussein Abdul Hamid. All authors reviewed the results and approved the final version of the manuscript.*

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