Low Altitude Local Rocket Aerodynamics Analysis and Experimental Testing†

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† Presented at the 2nd Innovation Aviation & Aerospace Industry - International Conference 2021, 28-30 June 2021; Available online: https://iaai-2021.sciforum.net, https://iaai.asia/

Published: 1 July 2021

Abstract: The Thai Traditional rocket (Bangfai) or local rocket festival is well known in Northeast Thailand, which is held annually during the months of April to June for highest altitude competition in several categories by their sizes and types. The aim of this paper is to aid in designing of local rocket by investigate the aerodynamic effects after adding fins and nose cone by using CFD simulation to improve the capability of the rocket then construct the rocket and perform the experimental testing. There are 12 rocket models with different nose cone and fin designs and the original rocket model. The simulations were performed at a velocity of 128 kt (237.6 km/hr or 66 m/s). From simulation results, the rocket model with ogive nose cone has the lowest drag. Although the turbulence intensity from different fin designs are not significantly difference, the clipped triangular fin model yields the smallest intensity region behind the rocket. It is found that the model with elliptical fins and ogive nose cone has the lowest drag force of 6.37 N while the clipped triangular fins with ogive nose cone and the original design drag are 7.40 N and 8.50 N respectively. Even though, all of rocket designs in this study have stability margin higher than the recommended stability margin, the clipped triangular fins with ogive nose cone model has the highest stability margin of 6.0, which is chosen for rocket construction and experimental testing. The performance between the proposed rocket design model and the original local rocket are proven by launching experiment. The rocket containing solid fuel weighs 6 kg, which is classified as Bangfai Muen. By observing the exhaust smoke trace, launchings of the rocket showed that the original rocket reached the altitude approximately 600 m and the proposed design reached around 700 m. Therefore, the ogive nose cone is capable of reducing drag while the clipped triangular fin increases the directional stability during the launch, which permits the rocket to achieve higher altitude.

Keywords: Bangfai**,** Rocket Design; Sounding Rocket, CFD; Stability Margin

1. Introduction

The Thai Traditional rocket (Bangfai) or local rocket is well known in Northeastern of Thailand. The rocket festival is held every year during the months of April to June. The local rocket is launched by local people to celebrate and appease the spirits of the rain. It would ensure that people will be blessed with abundant of rain for their rice plantations. Local Rocket (Bangfai) comprises of major components similar to a rocket that are physically part of the rocket, which correlates to the aerodynamic theories and formula of a real rocket. Local people build the rocket with common materials and have different techniques to build their own rockets [1].

The design of local rocket is very straightforward. The body is made out of available of Polyvinyl chloride (PVC) pipe with the solid fuel compressed inside throughout the whole body. The stabilizer is a long tube made out of bamboo. The local rocket come in various sizes and types, which are classified according to their weight. The smallest ones are called Bang Fai Noi. Larger categories are designated by the counting words for 10,000 (Muen), 100,000 (Saen) and 1,000,000 (Lan). Lan in this context mean extremely large and extremely expensive. The largest are called Bangfai Lan that are 9 meters long and charged with up to 500 kg of solid fuel. It may reach altitudes reckoned in kilometers.

Each year, local rocket festival attracts the visitors and tourisms to visit their villages. Apart from tradition of appeasing the spirits of the rain, launching the rockets turns out to be an annual competition among groups of people who want to construct their own design rocket [2].

Table 1 shows the local rocket competition record [3] at Roi Et province, Phanom Phrai district, Thailand in 2017 by timing the duration of the rocket in the air starting from the lifting off point until falling down to the ground. The following record is only for Bangfai Saen category (120 kg by weight). It was found that the longest duration of the rocket was 7 minutes and 15 seconds.

Table 1. Top 10 ranking record of Bangfai competition at Phanom Phrai, Roi-Et Province 2017 [3].

Rank	Team	Endurance (S.)
1	Sirinapa	435
2	Taepweala	420
3	Taepanom	412
4	Taepweala	395
5	Taepanom	390
6	Taepweala	390
7	Fahmainongdang	385
8	Taepanom	380
9	Loogjowpomengsaen	380
10	Loogjowpomengsaen	375

In 2019, Airports of Thailand Public Company Limited AOT stated that there were more than 5,900 local rocket launches this year. Geo-Informatics and Space Technology Development Agency (GISTDA) had developed application “Bampen” together with GISAVIA system to monitor the rocket launch for airline alertness [4]. In 2020, the researcher team from GISTDA and AOT had attached GPS to 6 of Bangfai Muen (12 kg) and 6 of Bangfai Saen (120 kg) and then launched to monitor the direction and altitude of the rocket in their experimental program. Bangfai Muen and Bangfai Saen were able to reach an altitude of 1.0 and 5.5 km respectively [5].

By collecting the information from the local rockets that are built for competition, it is found that the head of the local rocket design is typically almost flat, which does not fully support much aerodynamics of the rocket. The head without a nose cone shape would be induced by high drag, which intuitively depleted the performance of the rocket. The tail is a long circular tube construction made from bamboo, which is intended for rocket stability [6].

The construction of Bangfai is considered to be one of the sounding rocket as it comprises of solid fuel, composite cylindrical body, nozzle and stability control feature except only non-reusable rocket fuselage. From the launching capability and altitude records, local rocket could be categorized into the lowest altitude rocket group from 3 classes of sounding rocket, which could reach below 100 km altitude [7].

The sounding rocket fuselage is normally having aerodynamic nose cone and utilizing tail fin for stability in their design. These typical research rockets can be found in the annual event, The Intercollegiate Rocket Engineering Competition (IREC), USA, which is held for student rocketry teams in designing their research rocket to achieve target altitudes up to 30,000 ft (9 km) above ground level [8].

The aim of this paper is to aid in designing of local rocket by investigate the aerodynamic effects after adding of the fins and cone by using CFD simulation to improve the capability of the rocket then construct the rocket and perform the experimental testing.

2. Local rocket design consideration

From the observation of the local rocket configuration, it is found that all of them has the same design and arrangement of the body, materials and construction technique. They have been controlled only by weight that depending on the class they enter. Bangfai is considered to be disposal sounding rocket with solid fuel at entry level. The drag reduction of the rocket body can be further improved along with balancing of the weight for better stability.

2.1. Rocket drag force

A sounding rocket is composed of 3 major parts, the nose cone, body and fins. Figure 1 shows the sounding rocket components. Each rocket components contributes to the aerodynamic drag. The total drag on the rocket can be described by:

$$D_T = D_{NC} + D_B + D_F \qquad (1)$$

Where: D_T = total drag force [N],
D_{NC} = nose cone drag [N],
D_B = body drag [N],
D_F = fin drag [N]

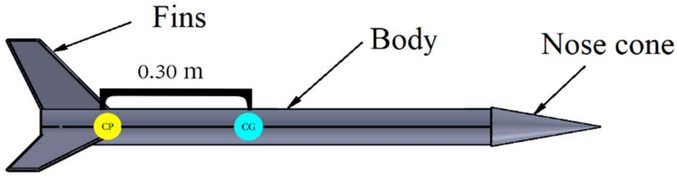


Figure 1. Sounding rocket components.

Aerodynamic drag is a force induced by relative air velocity that proportional to the dynamic pressure of the air and the area on which it acts. Drag varies with the shape of the body, surface roughness and other factors, therefore, drag coefficient is used to describe how much of the dynamic pressure force gets converted into drag. The drag force can be described by formula:

$$D = C_d \frac{1}{2} \rho v^2 A, \qquad (2)$$

Where: D = drag force [N],
C_d = drag coefficient [-],
ρ = density [kg/m^3],
v = velocity [m/s],
A = area [m^2]

Parasitic drag is the drag created from components that exposed to the airstream. Body shape of the rocket promotes parasitic drag in the form of pressure drag, which varies with non-dimensional drag coefficient, air density, velocity of the air and frontal area. In this case, reference area to be used for drag calculation is frontal projection area of the body of the rocket including of fin frontal area.

2.2. Rocket stability

Stability is usually judged by the stability margin (SM), where the distance between the center of gravity and center of pressure is divided by the diameter d of the rocket body:

$$SM = \frac{(CP-CG)}{D}, \qquad (3)$$

Where: SM = stability margin [-],
CP = distance of reference point to the center of pressure [m],
CG = distance of reference point to the center of gravity [m],
D = diameter of the rocket body [m]

The general rule when designing a rocket is that the ideal stability margin value should be in between 1 and 2, however the higher of the stability margin is always better in terms of stability. If the center of gravity is in front of the center of pressure as shown in Figure 1, the rocket will return to its initial flight conditions if it is disturbed. This is a restoring force to restore the rocket return to its initial condition and the rocket is said to be stable [9].

3. 3D Simulation and manufacturing

3.1. CFD Modelling

The local rocket design includes body, support stick at the tail section, which were constructed by using SolidWorks software as the original design. Dimensions of the rocket were taken from the real rocket that was launched locally. In order to increase efficiency in aerodynamics, the additional of different nose cone design shapes was added at the head of the rocket. Moreover, tail section was replaced by different shapes of fin to enhance more stability during flight. The simulations were performed with an external flow analysis at standard mean sea level conditions as shown in Table 2.

Table 2. Boundary conditions and values for 3D simulation.

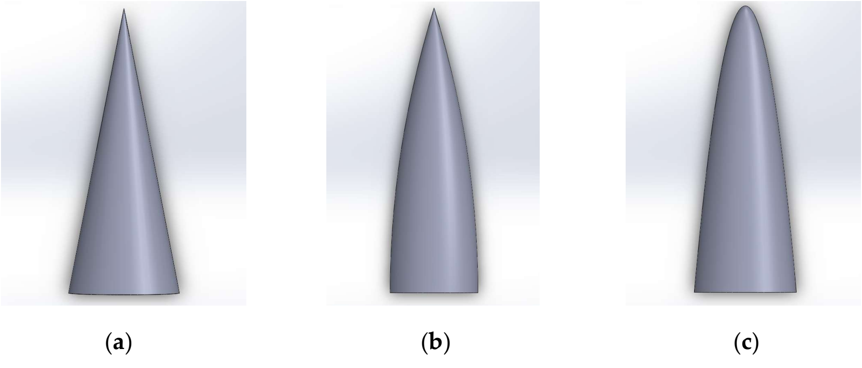
Boundary	Value	Unit
Air velocity (v)	66	m/s
Air density[1] (ρ)	1.225	kg/m^3
Air pressure[1] (p)	1.013x10^5	N/m^2
Air viscosity[1] (μ)	1.789x10^{-5}	kg/m·s
Air temperature[1] (T)	288.2	K

[1] At mean sea level.

3.1.1. Nose cone design

The nose cone is one of the most crucial parts of a rocket in terms of aerodynamic drag reduction. There have been many designs for the nose cone of rockets. However, most of them have tried to imitate the aerodynamic of bullets. The velocity and purpose that the rocket is going to be used for is often the biggest consideration that is looked at when choosing a nose cone. At supersonic speeds, a conical shaped cone is more preferable. But at subsonic speeds, a domed shape is more preferable because it causes less drag due to less surface area [10].

The nose cone can give an aerodynamic efficiency and separate the steam line that can reduce unwanted drag. The three types of nose cones chosen were the ogive, conical and parabolic as shown in Figure 2 (a), (b) and (c) respectively. The length of the nose cone is 0.22 m and the and diameter is 0.07 m. These types of nose cones were chosen due to their shape possessing and creating the best aerodynamic flow with the least amount of drag.

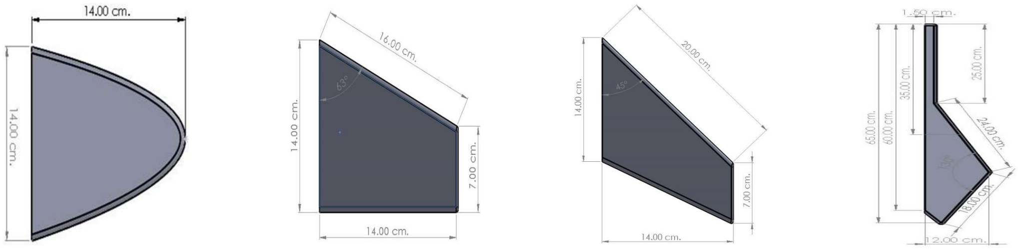


(**a**) (**b**) (**c**)

Figure 2. Nose cone shape (**a**) Ogive; (**b**) Conical; (**c**) Parabolic.

3.1.2. Tail fin design

The purpose of adding fins on a rocket is to provide stability during flight to allow the rocket to maintain its orientation and intended flight path. Equipping the tail fins on a rocket serves to locate the center of pressure aft of the center of gravity. To provide stability during flight, the 4 types of fins were chosen, which included the elliptical, delta, delta-swept, clipped triangular as shown in Figure 3 (a), (b), (c) and (d) respectively.



(**a**) (**b**) (**c**) (**d**)

Figure 3. Fin shape (**a**) Elliptical; (**b**) Delta; (**c**) Delta-swept; (**d**) Clipped triangular.

3.2. Rocket manufacturing for launching

3.2.1. Original design

The local rocket consists of 4 main components, which are rocket body, support stick, stability tail (Bamboo fin) and solid fuel as shown in Figure 4. The main body is made from polyvinylchloride (PVC) pipe, which is the motor section part. The support stick is secured by stainless steel wire from the nose to the end of the main body and the stability tail is tied on top of the support stick near the end of the main body. Solid fuel will be compressed inside of the main body by hydraulic press, which is the mixture between potassium nitrate and coal.

Figure 4. Original design rocket with bamboo tail stick.

3.2.2. Proposed design

The main components are the same as original design but without stability tail. The ogive nose cone and clipped triangular fins were added to improve aerodynamic effect and stability. The nose cone was made from Polylactic Acid plastic (PLA) by 3D printing machine as shown in Figure 5 (a). Clipped triangular fins were made up of carving solid wood then attached at the tail of rocket as shown in Figure 5 (b). The rocket is prepared at launch site as shown in Figure 5 (c).

(**a**) (**b**) (**c**)

Figure 5. Additional features on original local rocket: (**a**) Ogive nose cone; (**b**) Clipped triangular fins; (**c**) Proposed design with ogive nose cone and clipped triangular fins at the launch pad.

4. Results and Discussion

4.1. Result from simulations

4.1.1. Drag force

The simulations of the total 12 combination of nose cone and tail fins including an original design were performed. The drag force results were grouped by fin types. The value of drag force from lowest to highest group were elliptical, delta-swept, delta and clipped triangular respectively. The reason being is clipped triangular fin type has highest frontal area of the fins among other designs. The average drag was 6.55, 6.83, 7.37 and 7.61 N correspondingly. However, the original design yielded the highest drag, which was determined to be 8.5 N. The lowest drag was from elliptical fin and ogive nose cone, which was 6.37 N among all rocket designs. It is found that the ogive nose cone is the best aerodynamic shape since it produces the lowest drag value within each tail fin group. Figure 6 shows the value of the drag results.

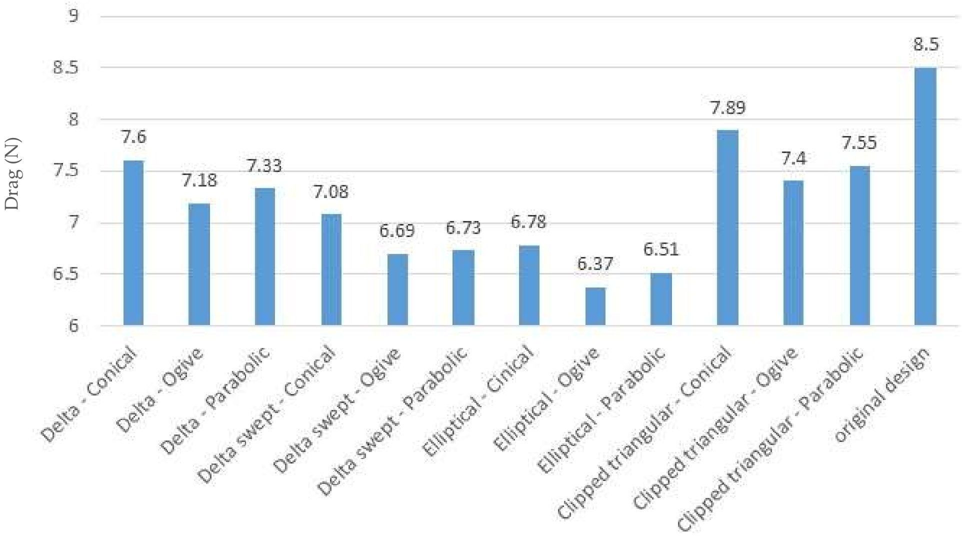


Figure 6. Graph relationships between Drag (N) and Rocket design.

4.1.2. Stability margin

In order to calculate stability margin, the center of pressure and center of gravity location on the rocket were taken from the simulation. Center of pressure and center of gravity values were measured from the nose of the rocket, which were calculated from the simulated mass of the solid fuel density together with rocket weight of 6 kg. Table 3 shows the CP and CG locations as well as the calculated stability margin by using the diameter of the rocket of 0.07 m. The stability margin once grouped by fin type, the average stability margin from lowest to highest values were 5.06, 5.09, 5.28 and 5.70 from clipped triangular, elliptical, delta-swept and delta fin respectively. The corresponding order from grouping of the fin and drag force was somewhat correlated except only clipped triangular fin type. The clipped triangular fin shape design makes the total rocket length longer than other rocket by its distinctive design. The extra length of clipped triangular yields the highest stability margin of 6.00 among the rocket design. Nevertheless, the original rocket design yields the highest stability margin of 14.57 of all rocket types since the very long stability tail moves center of pressure further away from the nose.

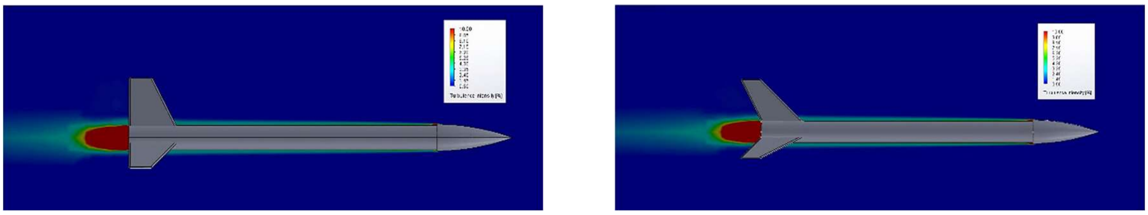
Table 3. Stability margin.

Rocket Design (Fin type – Nose cone)	**CP Location (m)**	**CG Location (m)**	**CP-CG (m)**	**SM**
Delta - Conical	1.06	0.68	0.38	5.42
Delta - Ogive	1.08	0.67	0.41	5.85
Delta - Parabolic	1.08	0.67	0.41	5.85
Delta swept - Conical	0.98	0.68	0.30	4.28
Delta swept - Ogive	1.07	0.67	0.40	5.71
Delta swept - Parabolic	1.09	0.68	0.41	5.85
Elliptical - Conical	1.06	0.67	0.39	5.57
Elliptical - Ogive	1.00	0.67	0.33	4.71
Elliptical - Parabolic	1.02	0.67	0.35	5.00
Clipped triangular - Conical	1.13	0.76	0.37	5.20
Clipped triangular - Ogive	1.18	0.76	0.42	6.00
Clipped triangular - Parabolic	1.04	0.76	0.28	4.00
Original design	1.55	0.53	1.02	14.57

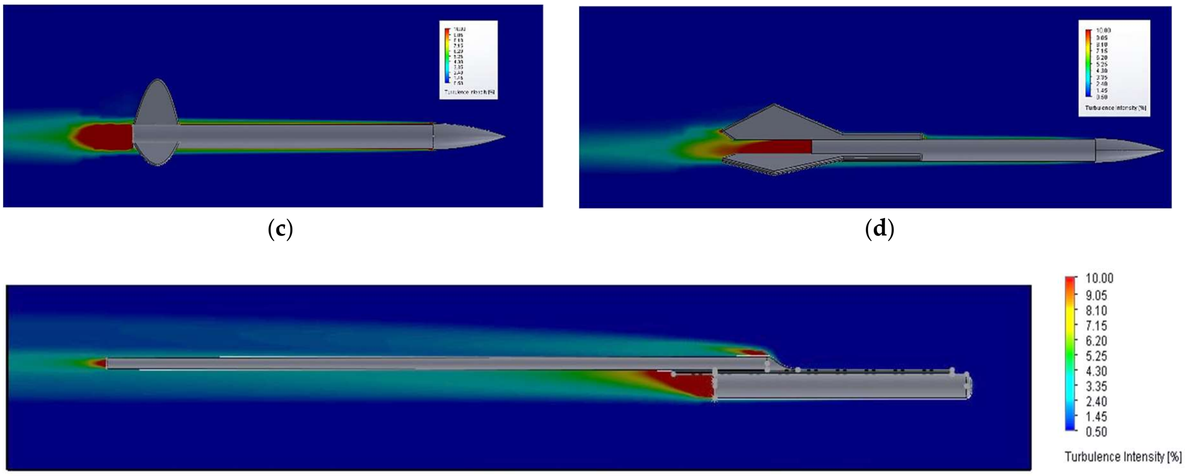
4.1.3. Turbulence intensity and length

Turbulence intensity usually describes the intensity of wind velocity fluctuation in a percentage as it indicates turbulence level. The more turbulence intensity the less performance the rocket will have. If there is a vast amount of turbulence intensity at a certain surface area of the rocket, it means in that area is where the greatest energy loss will occur. Turbulence creates drag, which implies high drag area with amount of turbulence intensity.

When analyzing the turbulence intensity at the tail of the rocket designs, it shows that all of the rocket design has quite similar turbulence intensity at the end near the fins except the original local rocket design, which has different turbulence area. All turbulence intensity of the rocket is within 10%, which is determined to be high turbulence level. Plot of turbulence intensity of ogive nose cone with different fins are shown in Figure 7 (a), (b), (c) and (d).



(**a**) (**b**)



(**c**) (**d**)

(**e**)

Figure 7. Turbulence intensity plot: (**a**) Delta fin-Ogive nose cone; (**b**) Delta-swept fin-Ogive nose cone; (**c**) Elliptical fin-Ogive nose cone; (**d**) Clipped triangular fin-Ogive nose cone; (e) Original rocket design.

Turbulence Length is a physical quantity describing the size of the large energy-containing eddies in a turbulent flow. The turbulent length scale is often used to estimate the turbulent, which can be determined the amount of the drag force.

In the case of the flow simulation of turbulence length, the original local rocket design yielded the highest value of 0.0095 m. It implies that this rocket design has the highest energy loss. The second highest turbulence length is in the group of clipped triangular rocket, which is in between 0.0075 to 0.0076 m as shown in Figure 8. The rest of the rocket design are having quite similar turbulence length. The results are allied with drag results that the group of clipped triangular rocket has highest amount of drag.

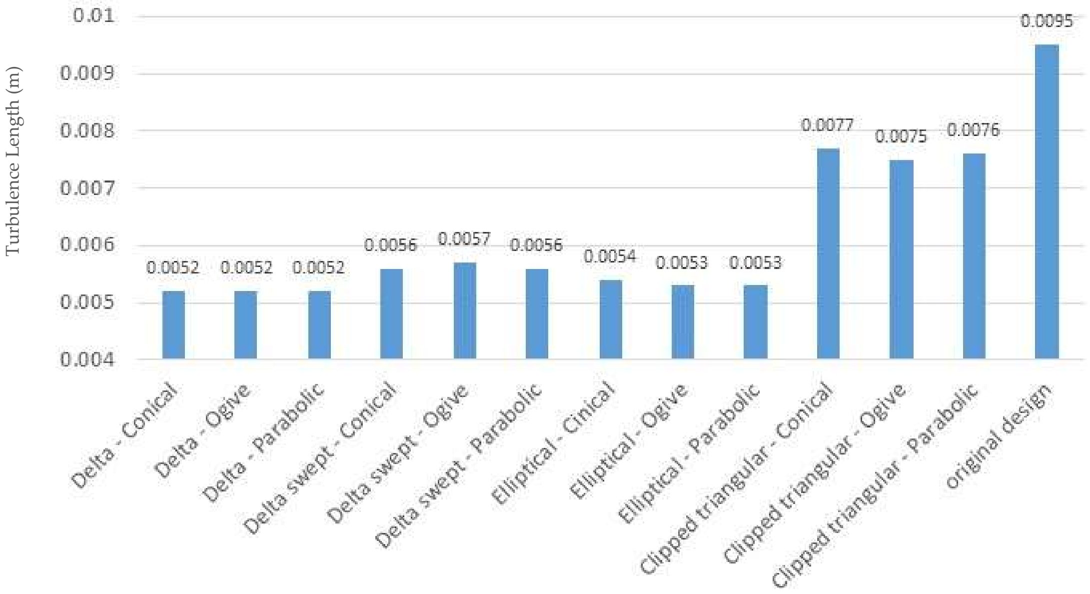


Figure 8. Graph relationships between Turbulence length (m) and Rocket design.

4.2. *Result from experimental testing*

The original rocket design was launched as the benchmark. The proposed design rocket was then manufactured and launched to compare the performance of the rocket alteration. The proposed design was based on both aspects, drag and stability. Eventhough the clipped triangular fins together with ogive nose cone was not producing the lowest drag but it generated the lowest drag among clipped triangular fin rocket. The high value in drag of 7.4 N will trade off with high stability magin of 6.00. This type of the design was then taken into the consideration to manufacture the rocket for the experimental testing.

From the launching observation, the weather condition was calm with sunny skies, which was the best conditions for rocket launching. The rocket was at its initial position that the nose cone was pointed upwards and then launched as shown in the Figure 9 (a). After 6 seconds of launching, the original rocket was slightly unstable and the rocket flight path was unstraight. It can be seen in the Figure 9(b). It is clear that the rocket had experienced minor weathercock but with the support of the long stabilizer fin it still could maintain its course. After 9 seconds, the rocket flew up so far that it could barely be seen by the naked eyes. The altitude of the rocket will be determined by using optical tracking between the elevation angle and the distance from the observation point together with flight duration.

From the proposed rocket launching, the weathercock also occurred due to the wind but the rocket quickly stabilized itself with clipped triangular fins. After 6 seconds, the rocket was more stable as shown in Figure 10 (b). The ogive nose cone and the clipped triangular fins supported the rocket to have a more linear and stable flight path. The proposed design rocket exhaust flow looked more stable than the original local rocket. After 9 seconds, it can be seen that the clipped triangular rocket had a much more stable flight course than the original local rocket as shown in Figure 10 (c).


(**a**) (**b**) (**c**)

Figure 9. Launching of original rocket design: (**a**) At 3 seconds; (**b**) At 6 seconds; (**c**) At 9 seconds.


(**a**) (**b**) (**c**)

Figure 10. Launching of proposed rocket design: (**a**) At 3 seconds; (**b**) At 6 seconds; (**c**) At 9 seconds.

5. Conclusions

The simulations of the different combination of rocket fins and nose cone totally of 12 rocket designs including original design were performed. All of the rocket designs that have an ogive nose cone has the least amount of drag within the same fin types, which make the ogive nose cone the best aerodynamic shape. From turbulence intensity results, the plots show no significant differences between them. The clipped triangular fin rocket gives the highest stability margin among other types of fin design.

When assembling the fins and nose together, the best design in terms of the lowest drag force is the elliptical fin and ogive nose cone, which has drag value of 6.37 N. Combining with the stability margin, the clipped triangular fin contributes highest stability margin among other types of fin design, which is 6.00. Although the original design stability margin is 14.57 but with the highest drag amount of 8.50 N.

From the experimental testing, it was found that both local rocket design and the clipped triangular fins with an ogive nose cone design were categorized in the Bangfai Meun type by weight. The maximum altitude of the local rocket design was determined to be nearly 600 m, while the maximum altitude of the improve design was estimated at around 700 m. From the observation of the exhaust smoke, the improve design has more straight streamline trace than the local rocket design. Therefore, it can be concluded that equipping fins and nose cone to the local rocket are capable of improvement of the aerodynamic and stability of the rocket thus reaching of higher altitude.

Funding: This research received no external funding.

Acknowledgments: The author would like to thank you to the RSU rocket team, which are Natthi Sirayotthanawong, Thana Pergchoei and Kritnarin Poopuang for specimen preparation, experimental set up and technical support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Srisupan, P.; Apichatvullop Y.; Manorom K. Bun Bangfai (Rocket Festival): The Risk Culture in Modern Era. *J. Liberal Arts, UBU* **2012**, 8(1), 36-73.
2. Kinnareewong, S; Namphong, W; Boonpok, D. An Ethnography of Communication: A Case Study of BoonbangfaiFestival at Tambon Sangming, Amphoe Loeangnoktha, Yasothon Province *J. of Liberal Arts, PSU*, **2011**, 3(1), 122-141.
3. Bangfai Fectival. www.thailocalfestival.com (Accessed on 20 June 2020).
4. Bangfai Launching Statistics (2019). www.airportthai.co.th (Accessed on 10 June 2020).
5. Applications "Bampun" Ready for Bangfai Control. www.gistda.or.th (Accessed on 20 June 2020).
6. Boon Bangfai. www.m-culture.go.th (Accessed on 25 July 2020).
7. Okninski, A. Multidisciplinary optimisation of single-stage sounding rockets using solid propulsion. *Aero Sci & Tech*, **2017**, 71, 412–419.
8. Intercollegiate Rocket Engineering Competition (IREC) Rules. www.soundingrocket.org (Accessed on 15 Aug 2020).
9. Taylor, T.S. *Introduction to Rocket Science and Engineering,* 2nd ed.; CRC: FL, **2017**; pp. 94-102.
10. Alekhya, N; Manthena, S. Drag prediction on the conical and ogival shaped noses of aerodynamic bodies. *IOP Conf. Series: Mat Sci & Eng* **2018**, 455.