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# Comparative Research of Wings with Riblets and Wings without Riblets in Terms of Drag Reduction and Lift Produced During Cruising Using Wind Tunnel

**Mohammad Iqmal Mohd Ali, Muhammad Mustaqim Saad, Abdul Razak Mohd Noor**

***Abstract: Energy conservation and aerodynamic efficiency are the reason behind the research into methods to reduce turbulent skin friction drag on aircraft. Skin friction reductions as small as 10 per cent provide the potential for a 250 million dollars per year fuel savings for the commercial airline fleet. One of the ways for passive drag reduction concept is the implementation of longitudinally grooved surfaces aligned with the stream velocity. These grooves are called riblets. For further understanding of the riblets, prototypes of wings with and without riblets will be made and test using wind tunnel. Result from both types of wings will be compared and analysed to determine which type of wing is the better one.***

***Keywords: Riblets, drag reduction, lift, wind tunnel***

## I. INTRODUCTION

Research on various areas regarding aviation has been encompassing many areas, including aircraft maintenance [1], ergonomics [2-5], management [6-7], avionics [8-11], and also educational research on theoretical concepts [12-15] and technology [16-19]. Particularly for drag reduction, research methodologies relevant to flight vehicles have received considerable attention during the past 2–3 decades. Drag has been one of the major problems in utilizing aircraft efficiency. Drag itself will limit or restrain the aircraft efficiency in terms of performance wise and waste a lot of money and energy. There are several ways to reduce drag and one of them is by introducing riblets on aircraft wings and this paper will touch on the subject of drag reducing capability by using wind tunnel to analyze it. By studying the riblets ability to reduced drag and produce lift, the aircraft efficiency will be able to improve. By comparing the analysis between wings with riblets and wings without riblets, we can determine whether riblets are efficient or not. The testing will be using two prototype wings made using 3-D printer with and without riblets. Apart from that, this research is to set a platform for other students if they wish to perform this research on different types of wing. The limitation of this project would be the inefficiency of wind tunnel facility in Universiti Kuala Lumpur – Malaysian Institute of Aviation Technology (UniKL MIAT), Malaysia.

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## II. LITERATURE REVIEW

Riblets are streamwise surface striations that are aligned with the local freestream velocity. The optimum and most practical riblet have sharp valleys and sharp peaks. The purpose of the riblets is to modify the near-wall structure of the turbulent boundary layer. The spanwise surface variation down in the cross section imposes a strong spanwise viscous force that creates a wall slip Iayer. Riblets are also small surface protrusions aligned with the direction of flow, which confer an anisotropic roughness to a surface. They are one of the few techniques that have been successfully applied to the reduction of the skin friction in turbulent boundary layers, both in the laboratory and in full aerodynamic configurations. Riblets of very different geometries have been tested in wind tunnels, demonstrating drag reductions of the order of 10 per cent over flat plates. Walsh & Lindemann tested several shapes, including triangular, notched-peak, sinusoidal and U-shaped riblets, obtaining maximum drag reductions of 7–8% for riblet spacings of approximately 15 wall units .

**Fig. 1 Riblets on a wing**

The physical mechanism of the drag reduction by riblets has been investigated in detail, although some aspects remain controversial. Mean and local velocity profiles and turbulent statistics within and above the riblet grooves have been reported for experiments in wind tunnels.

Walsh & Lindemann showed that the Reynolds number dependence of the effect of riblets on the skin friction could be expressed in large part in terms of the riblet dimensions expressed in wall units,

**L+ =Lut/n**

Equation 1


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Where n is the kinematic viscosity and ut = t1/2 is the friction velocity defined in terms of the skin friction t, where we have assumed unit fluid density for simplicity [22]. A large body of data generated using 3M riblets reveal that optimum drag reduction occurs at h+ at the range of 8–15 by 3M Company.

**h+=hu*/v**

Equation 2

Where h+ refers to a nondimensional measurement of the height of the riblets, h refers to riblet height, u refers to mean velocity and v refers to kinematic viscosity. The purpose of riblets is to create a laminar boundary layer instead of turbulent. Whether a boundary layer is laminar or turbulent depends on many factors. One of the most important factors in boundary layer type is Reynolds number (Eq. 3). At Re values larger than 500,000, boundary layers usually transition to turbulent [23]. At standard commercial aircraft flight speeds, this critical number is reached almost immediately, meaning for most circumstances the boundary layer over an aircraft is turbulent.

$$\boldsymbol{Re = \frac{\rho u x}{\mu}}$$

Equation 3: Reynolds number

It can be seen on the skins of Galapagos shark and other sharks too. Galapagos shark are in small dimension, at around 1/3 millimeter.

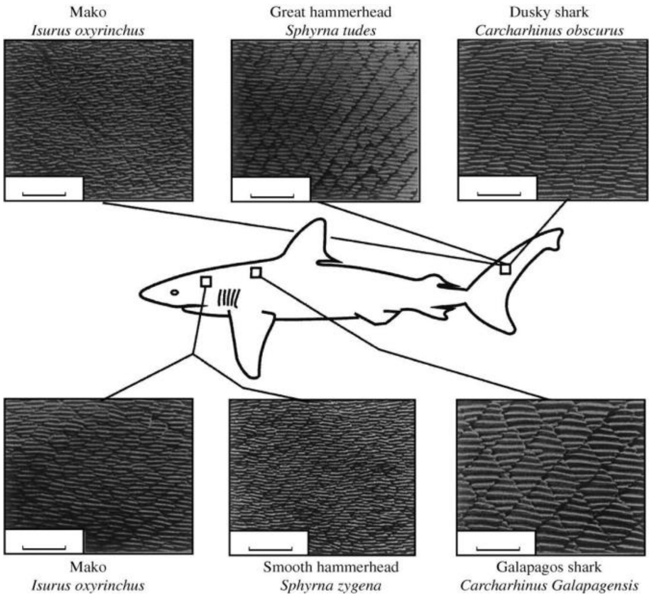


**Fig. 2 Riblets on sharks**

### Lift and drag ratio

It is known that aircraft have four forces acting on it in order to fly. These forces are lift, drag, weight and thrust.

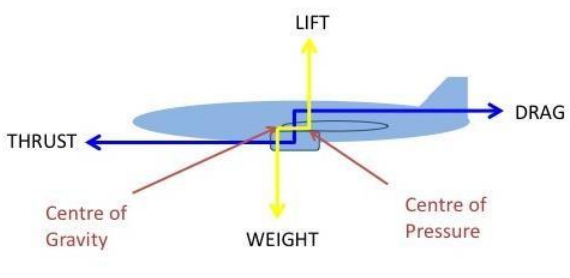


**Fig. 3 Forces on aircraft**

Drag is the price paid to obtain lift. The lift to drag ratio (L/D) is the amount of lift generated by a wing or airfoil compared to its drag. The lift/drag ratio is used to express the relation between lift and drag and is determined by dividing the lift coefficient by the drag coefficient, CL/CD. A ratio of L/D indicates airfoil efficiency. Aircraft with higher L/D ratios are more efficient than those with lower L/D ratios.

$$\mathbf{L = \frac{1}{2}\rho v^2 A C_L}$$

Equation 4: Lift formula

Where L refer to lift, $\rho$ refer to density of air, v refers to velocity of aircraft, A refer to wing area and $C_L$refer to coefficient of lift.

$$\mathbf{D = \frac{1}{2}\rho v^2 A C_D}$$

Equation 5: Drag formula

Where D refer to drag, $\rho$ refer to density of air, v refers to velocity of aircraft, A refer to wing area and $C_D$refer to coefficient of drag. The shape of an airfoil and other lift producing devices (i.e., flaps) affect the production of lift which will vary with changes in the AOA (Angle of Attack). The maximum lift/drag ratio occurs at one specific CL (Lift Coefficient) and AOA (Angle of Attack). If the aircraft is operated in steady flight at Lift/Drag maximum ratio, the total drag is at a minimum. Any AOA lower or higher than that producing the maximum Lift/Drag ratio reduces the Lift/Drag ratio and consequently increases the total drag for a given aircraft's lift. Lift/drag ratio also determines the glide ratio and gliding range. Since the glide ratio is based only on the relationship of the aerodynamics forces acting on the aircraft, aircraft weight will not affect it. The only effect weight has is to vary the time that the aircraft will glide for. The heavier the aircraft is, the higher the airspeed must be to obtain the same glide ratio. If two aircraft have the same L/D ratio but different weights and start a glide from the same altitude, the heavier aircraft gliding at a higher airspeed will arrive at the same touchdown point in a shorter time. Both aircraft will cover the same distance but the lighter one will take a longer time to do so.

Another essential that applies to understanding how airplanes fly are the laws of motion described by Sir Isaac Newton. Newton explained the three laws of motion. Newton's first and third laws of motion are especially helpful in explaining the phenomenon of flight. The first law states that an object at rest remains at rest while an object in motion remains in motion, unless acted upon by an external force. Newton's second law states that force is equal to the change in momentum per change in time. For constant mass, force equals mass times acceleration or F=m·a. Newton's third law states that for every action, there is an equal and opposite reaction. For aircraft, the principal of action and reaction is very important. It helps to explain the generation of lift from an airfoil. In this problem, the air is deflected downward by the action of the airfoil, and in reaction the wing is pushed upward. Similarly, for a spinning ball, the air is deflected to one side, and the ball reacts by moving in the opposite direction.

However, there are also different views on the matter of generation of lift. As such lift is generated through Bernoulli's principle. In case of airfoils, an important application of this phenomenon is made in giving lift to the wing of an airplane, an airfoil. The airfoil is designed to increase the velocity of the airflow above its surface, thereby decreasing pressure above the airfoil. Simultaneously, the impact of the air on the lower surface of the airfoil increases the pressure below. This combination of pressure decreases above and increase below produces lift.

### Wind tunnels and Computational Fluid Dynamics (CFD) as a method of testing

To design a wing, a lot of factors need to be considered or considered as it would have considerable effect on the drag and lift produced. In general, any airfoil shape would create high lift, but which would turn out to create more drag. To ensure the efficiency of wings, they should be tested either using wind tunnel or software simulation. A wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects. A wind tunnel consists of a tubular passage with the object under test mounted in the middle. Air is made to move past the object by a powerful fan system or other means. The test object, often called a wind tunnel model, is instrumented with suitable sensors to measure aerodynamic forces, pressure distribution, or other aerodynamic-related characteristics. The development of wind tunnels accompanied the development of the airplane. Large wind tunnels were built during World War II. Wind tunnel testing was considered of strategic importance during the Cold War development of supersonic aircraft and missiles.

### Wing and airfoil geometry

The primary lifting surface of an aircraft is its wing. The wing has a finite length called its wing span. If the wing is sliced with a plane parallel to the x-z plane of the aircraft, the intersection of the wing surfaces with that plane is called an airfoil. This airfoil shape can be different if the slice is taken at different locations on the wing. However, for any given slice, we have a given airfoil. We can now think of the airfoil as an infinitely long wing that has the same cross-sectional shape. Such a wing (airfoil) is called a two-dimensional (2-D) wing. Therefore, when we refer to an airfoil, you can think of an infinite wing with the same cross-sectional shape. Since calculating lift and drag coefficients with a reference area of infinity, would not make sense, we base airfoil lift and drag coefficients for airfoils on the planform area, assuming the span is unity [25]. The front of the wing (at the bottom) is called the leading edge; the back of the wing (at the top) is called the trailing edge. The distance from the leading to trailing edges is called the chord. The ends of the wing are called the wing tips, and the distance from one wing tip to the other is called the span. For a rectangular wing, the chord length at every location along the span is the same. For most modern aircraft, the chord length varies along the span, and the leading and trailing edges may be swept [26]. The aspect ratio (AR) of a wing is defined to be the square of the span (s) divided by the wing area (A). Aspect ratio is a measure of how long and slender a wing is from tip to tip. For a rectangular wing, this reduces to the ratio of the span to the chord length (c):

$$\textbf{Aspect Ratio} = \frac{\mathbf{s}}{\mathbf{c}}$$

Equation 6: Aspect ratio formula

A low aspect ratio can be considered as when the ratio obtained between 0.6 to 3. Some example of low aspect ratio aircraft are fighter jet and trainer aircraft. On the other side, a high aspect ratio wing means it has a bigger wing span compared to its standard mean chord. For example, if an aircraft aspect ratio = 9, its wing span is 9 times bigger than its mean aerodynamic chord. A high aspect ratio wing also will experience less induced drag compared to low aspect ratio wing since it has less end edges (tips). When aircraft wing experience less induced drag, it also will consume less fuel in order to maintain its speed [27]. Airfoil drag characteristics is the drag on an airfoil (2-D wing) is primarily due to viscous effects at low speed and compressibility effects (wave drag) at high speed. In addition, at high angles of attack, the flow can separate from the upper surface and cause additional drag. Hence as indicated in our dimensional analysis, the drag coefficient depends on three quantities; Reynolds number, Mach number, and the angle-of-attack.

## III. METHODOLOGY

A prototype of constant airfoil wing shape with and without riblets will be made. The designing of the wings with and without riblets will be made by using CATIA software. Wind tunnel will be used in calculating the difference of lift and drag produce between the two wings that have been designed with and without riblets.

### Study of wing shape and riblets

The type of wings and riblets that will be used will be study upon first and the size will remain constant for both wings, with and without riblets. Research on the wing shapes will be made mainly through the internet and the UniKL MIAT hangar resources as they are readily accessible and reliable.

### Wing and airfoil shape

It is said that the preferred airfoil shape is from the existing commercial aircraft as Boeing 737 being the main choice. However, the airfoil profile from the two main contenders in aviation industry which is Airbus and Boeing are highly confidential. Therefore, it is not possible to gain access towards the design. The NACA chosen for the airfoil for this project is NACA sc(2)-0714. The main reason for this is because it is used by the previous student's thesis. Although he does not use it in his final testing using CFD, he recommends me to use this NACA as he can help me with the designing.

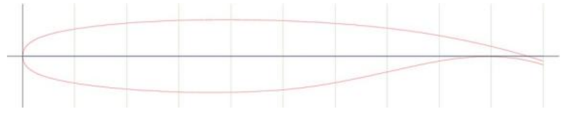

**Fig. 4 NACA sc(2)-0714**

The wing geometry below is 0.25 meter in span and 0.1 meter in chord length.


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**Table. 1 Airfoil configurations**

| Airfoil name | Span | Chord |
|---|---|---|
| NACA sc(2)-0714 | 250mm | 100mm |

### Designing of wings

There will be two design made by using CATIA software. Both of the design will be made constant and the only difference is one with riblets and another one is not. Both designs using CATIA will then be made using 3D printer as a prototype.

### Designing and manufacturing process

As stated earlier, the design will be made by using CATIA and with the helped of the previous student and his thesis. These are the several pictures of the design from CATIA.

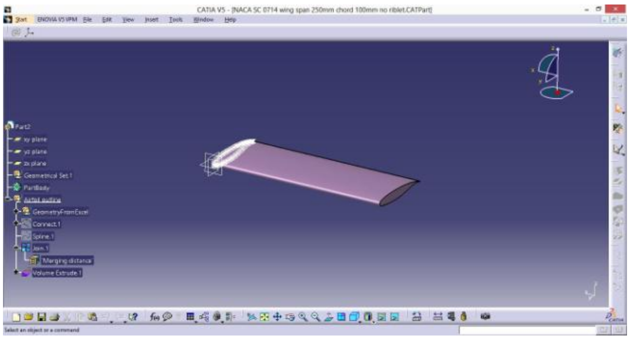

**Fig. 5 Airfoil without riblets**

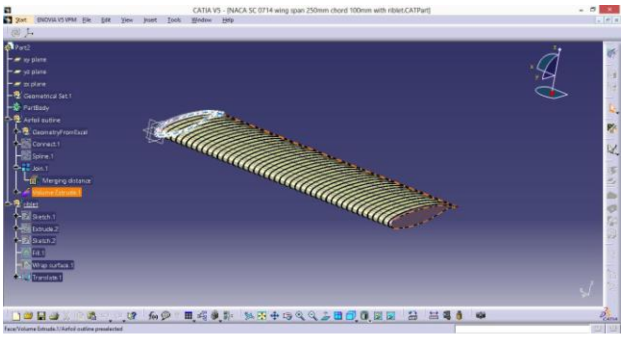

**Fig. 6 Airfoil with riblets**

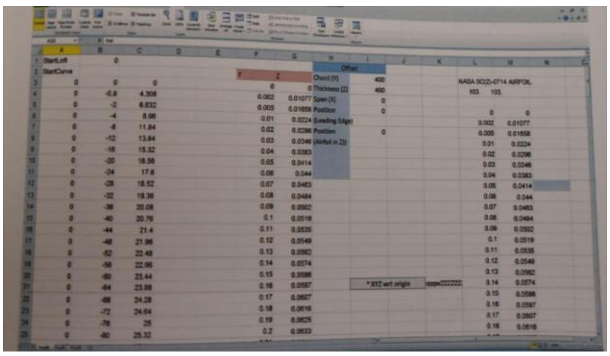

**Fig. 7 Airfoil coordinates**

### Material selection

The prototype will be made by using 3D printer, thus the material will be chosen by the compatibility with the 3D printer. Hence, the material chosen for this project is polylactic acid also known as PLA. PLA is one of two common plastics used on 3D printing and is commonly available as a 3D printable filament.

**Fig. 8 PLA filament**

The reason behind choosing PLA as the materials for this prototype is because one of the major advantages of PLA is its biodegradable nature and the sustainable process by which it is made, making it the environmentally friendly choice. Other than that, PLA is also ideal for 3D prints where aesthetics is important. Due to its lower printing temperature, it is easier to print with and therefore better suited for parts with fine details. Although, their strength, ductility, machinability and thermal stability are not as good as other material, but it is good enough to be use on this prototype.

### 3D Printing process

As stated earlier, the prototype will be made by using 3D printer, in which the CATIA file will be converted into stereolithography (stl.). file so that it can be open by using 3D printer software. It then will be printed out using 3D printer. Here are some of the photos taken during the process.

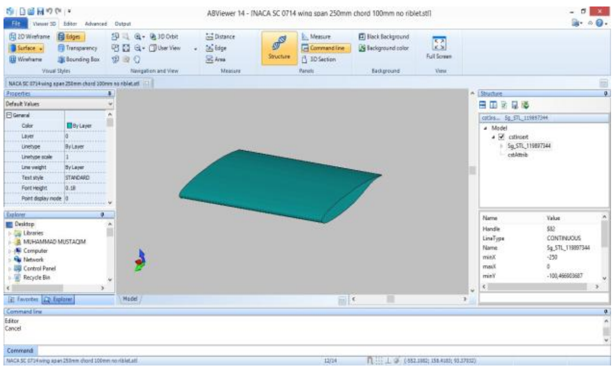

**Fig. 9 Airfoil with no riblet in AB viewer software**

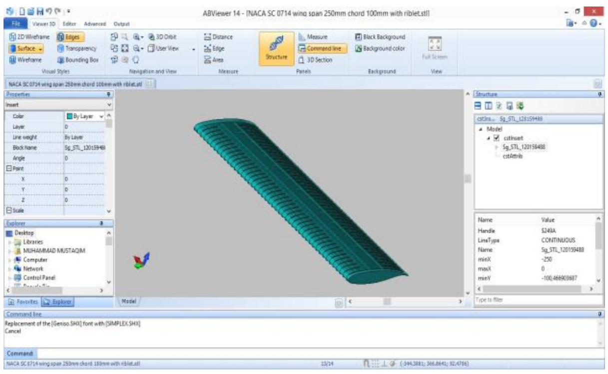

**Fig. 10 Airfoil with riblet in AB viewer software**

Those figures above are the stl. file that have been converted from CATIA file. AB viewer is one the software used to view stl. file. After that, the printing process will begin. 3D printing method is chosen because it provides better accuracy in geometry rather than other method. Although it is quite expensive, it is the best way to get the accurate results from this testing.

**Fig. 11 3D printing process for airfoil with no riblet**

**Fig. 12 3D printing process for airfoil with riblets**

The finished prototype model of wings with riblets and wings without riblets are shown below;

**Fig. 13 Wings without riblets**

**Fig. 14 Wings with riblets**

**Wind tunnel testing**

Wind tunnel will be used to measure the lift and drag generated on both wings. UniKL MIAT wind tunnel will be used to perform this test. The important part of this research is getting the required data for both models to be analyzed and conclusion will be made based on the data. The models will be put in the wind tunnel and a test will be carried. The data that can be collected from the wind tunnel is like value of the drag, lift and pitching moment of the wing. Before testing, both wings will be mounted on a holder inside the wind tunnel. One holder being attached below the wing by screw and one platform was created to ease the process of assembly between the holder and the platform. The holders are being attached by screws.

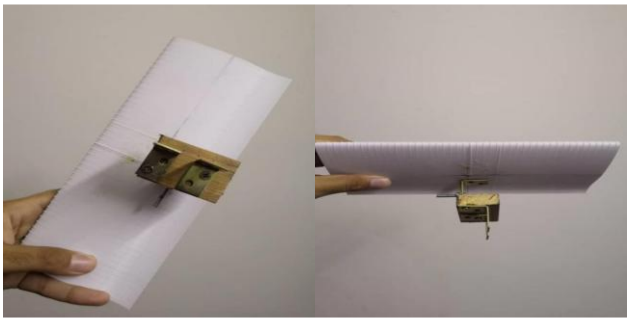

**Fig. 15 Holder of the wings**

For this testing, the fan speed (RPM) will be the constant at 510 RPM as it can be controlled manually from the control panel. Both wings will be tested at 4 different angles of attack (AOA). This is to show the variation result of lift and drag from both wings. The angle of attack for this project will be tested from $0^0$, $5^0$, $10^0$, and $15^0$. The temperature will be kept constant at 29.7 C. The computer will show the fan speed (RPM), velocity, temperature, drag force, lift force and pitching moment.


**Fig. 16 Wind tunnel control panel**


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**Fig. 17 MIAT wind tunnel**

Figures below shows the wing being tested at 510 RPM. The angle will be adjusted along the way. The way of how the holder is holding the wing is also being shown below.

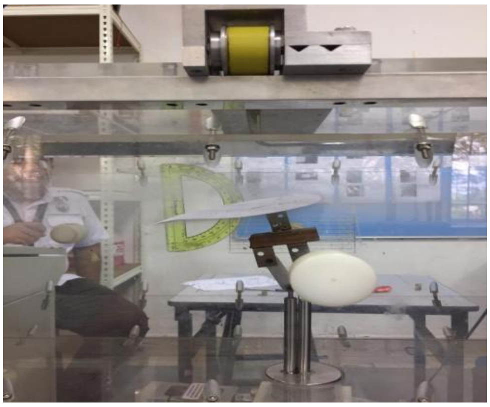

**Fig. 18 Airfoil being tested in wind tunnel**

The angles are being adjusted by looking through the protractor.

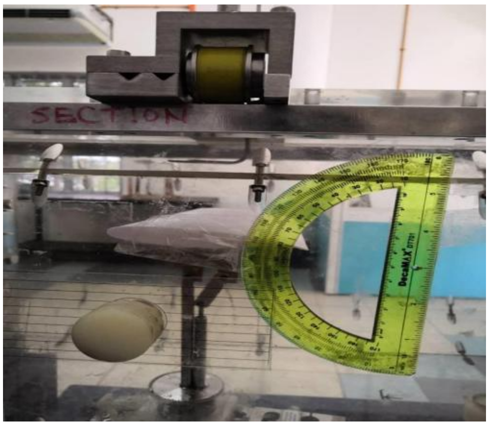


**Fig. 19 Airfoil at $0^0$**

**Analyzing data process**

Result obtained from the wind tunnel will be recorded and the data will be analyzed. The data are taken from prototypes, the wings with riblets and the one without riblets. All of them are taken at different angles of attack that vary from 0°, 5°, 10° and 15°. The fan speed and the temperature will remain constant at 510 RPM and 29.7 C respectively. The lift and drag data will be taken directly from the wind tunnel. Table will be inserted to show the detail of the data collected. This table consist of the variation of angle of attack, the fan speed (RPM), the air speed (m/s), the lift (N) recorded and the drag (N) recorded. This table will be made for both prototypes.

**Table. 2 Example of data collected**

| Angle of attack (Ø) | Fan speed (RPM) | Air speed (m/s) | Lift (N) | Drag (N) | Lift/Drag ratio |
|---|---|---|---|---|---|
| 0 | | | | | |
| 5 | | | | | |
| 10 | | | | | |
| 15 | | | | | |

A graph will be made to study the behavior of the lift and drag for both prototypes after tabulating the data. The graphs that will be made are lift vs. angle of attack, drag vs. angle of attack and lift/drag ratio vs. angle of attack. Some explanations will be made based on the graph for every results and data.

## IV. ANALYSIS

**Wings without riblets**

For this research, the wing without riblets was tested using wind tunnel. It was tested at four different angles of attack at 0°, 5°, 10° and 15°.The fan speed (RPM) and the temperature are kept constant at 510 RPM and 29.7 C respectively. The result of the test is shown in the table and graphs below.

**Table. 3 Result for airfoil without riblets**

| Angle of attack (Ø) | Fan speed (RPM) | Air speed (m/s) | Lift (N) | Drag (N) | Lift/Drag ratio |
|---|---|---|---|---|---|
| 0 | 510 | 15.3 | 1.70 | 10.14 | 0.17 |
| 5 | 510 | 15.3 | 3.26 | 13.18 | 0.25 |
| 10 | 510 | 15.3 | 4.96 | 29.01 | 0.17 |
| 15 | 510 | 15.3 | 7.50 | 30.90 | 0.24 |


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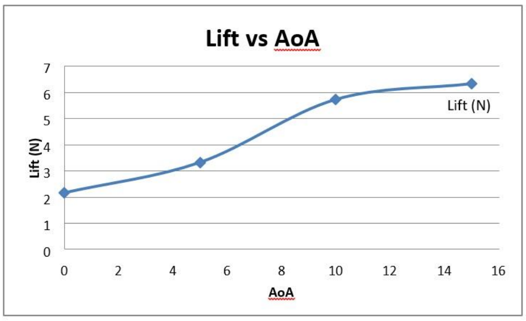


**Fig. 20 Lift vs AoA graph**

According to the table above, the lift produced for the wings without riblets starts at 1.70 N at 0°. Then, it keeps increasing and reached 3.26 N at 5°. The trend of lift keeps increasing as the angle of attack increases as it reached 4.96 N at 10°. At 15°, the lift force continued to peak up at 7.50 N.

The trend of the lift force for wings without riblets shows a consistency as it keeps on increasing at a steady level. What can be concluded from the graph is that the lift force continues to increase and there is no sign the lift force would be dropped.

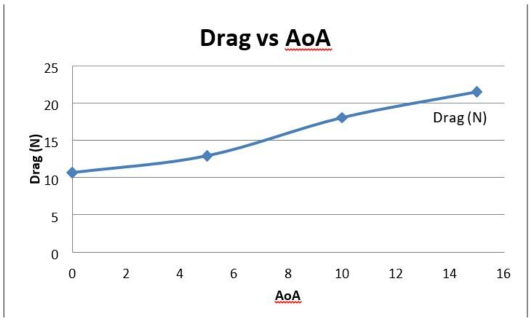


**Fig. 21 Drag vs AoA graph**

From this drag vs AoA graph, the pattern of the drag on wings without riblets can be seen. The drag force starts at 10.14 N at 0°. Then, it increases slightly towards the 5° mark and it reached 13.18 N at 5°. However, towards the 10° mark, the drag increases rapidly and reached up to 29.01 N at 10°. Later, the graph become less rapid as the amounts of drag force only increase slightly higher towards the 15° mark. The drag recorded at 15° is only 30.90 N which is a small different compared to the increment of drag force from 5° to 10° of angle of attack where the biggest change in drag force produces can be seen.

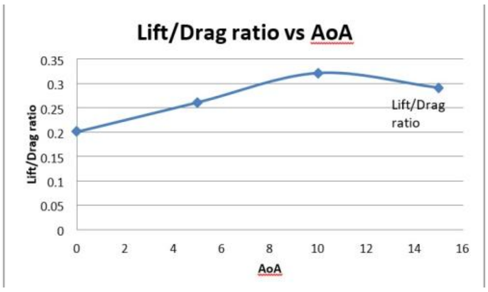


**Fig. 22 Lift/Drag ratio vs AoA graph**

The above graph shows the pattern of the lift/drag ratios for wings without riblets. The ratio starts low at 0.17 at 0° which later increases towards the 5° mark. The lift/drag ratios peak at 5° with the amount of 0.25. However, the ratios the dropped towards the 10' mark and reached 0.17 at 10°. The ratios at 0° and 10° are the same. Then, the ratios increase back towards the 15° mark and reached 0.24 at 15°. The conclusion from the graph is the most optimum lift/drag ratios are recorded at 5°. The highest ratios are considered as the most optimum because the higher the ratios, the wings are more efficient.

### Wings with riblets

For this research, the wing or airfoil with riblets was tested using wind tunnel. It was tested at four different angles of attack at 0°, 5°, 10° and 15°. The fan speed (RPM) and the temperature are kept constant at 510 RPM and 29.7 C respectively. The result of the test is shown in the table and graphs below.

**Table. 4 Result for airfoil with riblets**

| Angle of attack (Ø) | Fan speed (RPM) | Air speed (m/s) | Lift (N) | Drag (N) | Lift/Drag ratio |
|---|---|---|---|---|---|
| **0** | 510 | 15.3 | 2.15 | 10.58 | 0.20 |
| **5** | 510 | 15.3 | 3.31 | 12.85 | 0.26 |
| **10** | 510 | 15.3 | 5.71 | 17.99 | 0.32 |
| **15** | 510 | 15.3 | 6.31 | 21.46 | 0.29 |

The table shows all of the data obtained from the experiment. This data is taken directly from UniKL MIAT's wind tunnel.

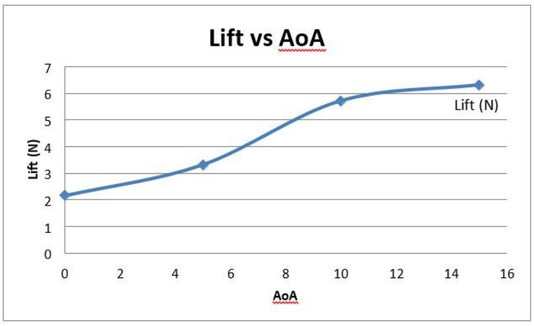


**Fig. 23 Lift vs AoA graph**

From the lift vs AoA graph above, we can see that the trend of the lift data keeps increasing. From 0° the lift force slightly increases from 2.15 N to 3.31 N at 5°. Then the trend keeps increasing rapidly towards 10°. The lift force increases from 3.31 N to 5.71 N at 10°.


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However, the trend of lift slows down a bit as we can only see a slight increase of lift force from 10° to 15°. It increases from 5.71 N to only 6.31 N. The conclusion from this graph is the most optimum lift achieve is at 10°. The reason behind this will be shown in the last graph as it involves drag force in determining which is the most optimum angle of attack.

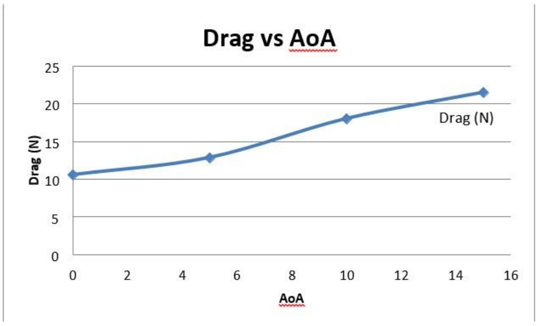


**Fig. 24 Drag vs AoA graph**

From the drag vs AoA graph, the characteristics of the drag can be seen increasing and the way of the drag force increase is almost like a straight line which means the differences of the drag on every angle of attack are not that big. The drag force at 0° is 10.58 N and it increases slightly towards 5° and when it reached 5°, the drag force is at 12.85 N. Then, it keeps increasing to 17.99 N at 10°. At 15°, the drag slightly increases to 21.46 N. The trend of the drag graph is quite like the lift graph, but the drag graph increases more steadily than the lift graph.

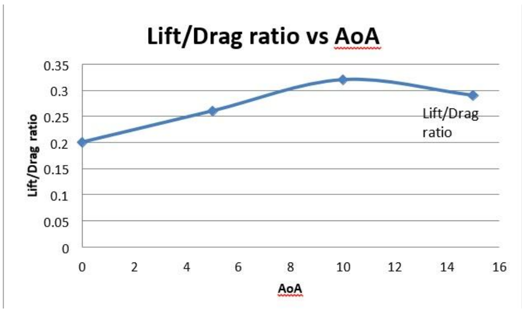


**Fig. 25 Lift/Drag ratio graph**

From Figure 25, the trend of lift/drag ratio for wings with riblets can be seen starting at 0.20 at 0°. The lift/drag ratio keeps increasing and it reaches 0.26 at 5°. The highest lift/drag ratio for this prototype is obtained at 10° where it reached 0.32. After that, the trend began to decrease as it reached 0.29 when the wing angle of attack are change to 15°. The conclusion that can be made from this graph is that the most optimum lift/drag ratios are reached 10° where it recorded the highest amount of lift/drag ratio. The most optimum lift/drag ratios are chosen based on the highest one. This is because, highest lift/drag ratios mean it has the most efficiency.

## Discussion

To find the most efficient wings in terms of lift and drag, comparison between the two wings had been done by testing it in the wind tunnel. Lift and drag must be optimum to reach to a conclusion on which wing are the best one.

Based on the test, the values of lift and drag, as well as the lift and drag ratios are obtained. The values of all the data are shown in the tables below and the analysis are made based on the graphs produced below.

**Table. 5 Lift and drag comparison between wings with riblets and wings without riblets**

| Angle of Attack (Ø) | Wings without riblets | | Wings with riblets | |
|---|---|---|---|---|
| | Lift (N) | Drag (N) | Lift (N) | Drag (N) |
| **0** | 1.70 | 10.14 | 2.15 | 10.58 |
| **5** | 3.26 | 13.18 | 3.31 | 12.85 |
| **10** | 4.96 | 29.01 | 5.71 | 17.99 |
| **15** | 7.50 | 30.90 | 6.31 | 21.46 |

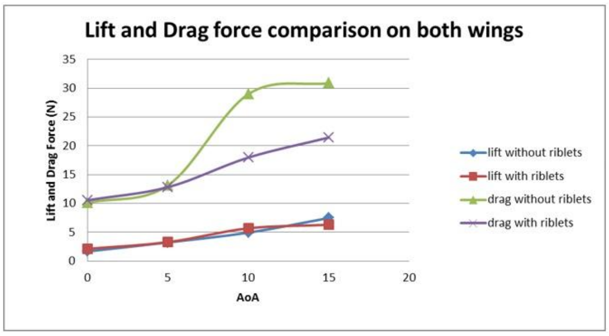


**Fig. 26 Lift and drag force comparison on both wings**

Based on the graph, the pattern of lift and drag for both wings can be seen. The lift force for both wings increases from the angle of attack 0° up to the 15° mark. However, the biggest difference in the lift force obtained happen at 10° and 15° mark. At 10°, the wings with riblets produce higher lift than the wings without riblets at the difference of 0.75 N while the wings without riblets produce higher lift force at 15° with the difference of 1.19 N. Although there are differences of lift produced at 0° and 5° but the differences are small compared to the lift produced at 10° and 15°. For the drag, both wings also show an increasing pattern for the drag force produced. From 0° to 5°, the drag produced by wing with riblets is slightly higher compared to wing without riblets. On the other hand, starting from 5° onwards, wing without riblets produce a rapid increase in the drag force compared to wing with riblets. At 10° and 15°, the drag forces are 29.01 and 30.90 respectively. At this point, the differences of drag produced on wing without riblets and wing with riblets are significantly big.


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At 10°, the differences of drag produced are 11.02 N and at 15°, the differences are 9.44 N. The conclusion that can be made from this graph is that there is a significant difference in both types of wings. The riblets does not seem to play a big role in the lift force production as the comparison between both wings made does not show any big or significant difference in the data obtained. However, the riblets played a big role in reducing the drag force as the differences between wing without riblets and wing with riblets in terms of drag produced are significantly big. Thus, it proves that the riblets do help in reducing the drag force while maintaining the lift force produced close to the wing without riblets. In other words, the wing with riblets is better than wing without riblets in terms of drag reduction.

Next is to analyze which type of wings are better in terms of efficiency. To prove which is better, the lift and drag ratios on both wings at different angle of attack must be compare with. Table and graph below show the comparison between both types of wings.

**Table. 6 Lift/Drag ratio comparison between wings with riblets and wings without riblets**

| Angle of attack (Ø) | Lift/Drag ratio | |
|---|---|---|
| | Wings without riblets | Wings with riblets |
| **0** | 0.17 | 0.20 |
| **5** | 0.25 | 0.26 |
| **10** | 0.17 | 0.32 |
| **15** | 0.24 | 0.29 |

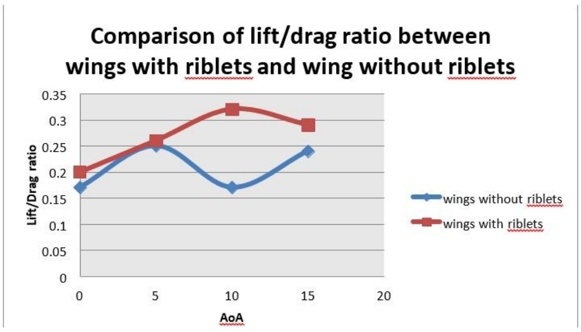


**Fig. 27 Comparison of Lift/Drag ratio graph**

It is said that higher lift and drag ratios equal to better efficiency. From this and based on the graph we can conclude that the wing with riblets are better in terms of efficiency. The ratios of wing with riblets are higher on all angle of attack. Although the differences of the ratios from 0° to 5° are not that big as the wing without riblets ratio are coming in close. It is the comparison between the angle of attack of 10° and 15° that made the difference. This proves that in terms of lift and drag ratio, the wing with riblets are better. Another analysis that can be made from the graph is at which angle of attack that the wing with riblets gives the most optimum lift and drag ratio. From the graph, it can be concluded that the highest and most optimum ratio is obtained at 10° as the value of the ratio is 0.32. This proves that the most optimum angle of attack that maximizes the efficiency of wing with riblets is at 10'. Two conclusions that can be made are the wing with riblets is better than wing without riblets in terms of lift and drag ratio and the most optimum angle of attack for wing with riblets is 10°.

## V. CONCLUSION

### Summary

This research has achieved all the objectives mentioned in research objective as both lift and drag force has been measured and the result between the two wings also has been compared with each other. Based on the result that has been analyzed and discussed, the better wing prototypes could be decided. The test was done in UniKL MIAT's wind tunnel and it involves two types of wing prototypes. Both using NACA sc(2)-0714 for reference and the only difference is one of it is a normal airfoil, while the other one have riblets on it. Both are tested in the same environment with the same configuration. From the result, it is evident that the wing with riblets is better than the wing without riblets. It is shown in the discussion that it is not only better in terms of drag reduction but also in the overall efficiency of the wing itself. High efficiency means it is suitable for long range and it consumes less fuel rather than the less efficiency wing. This is important because drag reduction as small as 10 per cent provide the potential for a 250 million dollars per year fuel savings for the commercial airline fleet. Lastly, the drag forces are proven to be reduced by using riblets. Hence, it is recommended to have riblets on wings to increase its efficiency.

### Future work recommendation

In future work, there are a lot of ways to improve this research. Hence, this is a few suggestions that can be followed:

- Use a better wind tunnel to test the prototypes
- Use different type of wings with different NACA
- Vary the fan speed RPM
- Use more variation of Angle of Attack
- Vary the distance between the riblets

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