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RIBLETS FOR AIRFOIL DRAG REDUCTION IN SUBSONIC FLOW

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ABSTRACT

The use of riblet was inspired by the surface of shark skin. The skin of fast swimming sharks are covered by tiny scales named dermal denticles (skin teeth) and are shaped similar to small riblets which are allinged in the direction of fluid flow. They are micro in size and viewed closely, they for the shape of a sawtooth. Riblets are most widely made into films and are micro scaled. Placing riblets on the surface of an airfoil have shown a decent percentage of drag reduction to the airfoil. In this research study, simulation testings were done on riblets with different dimension in the height and spacing of riblets. Ultimately the application of riblets on airfoils has proven a decent result. The optimized riblet dimension further reduced drag up to approximately 46%.

Keywords: riblets, drag reduction, Taguchi method.

INTRODUCTION

There have been many attempts conducted to lessen drag acting on a wing. There were many tactics used to overcome this problem. After many researches riblet have proved quite promising. The V-grooved riblet shown in Figure-1, have showed a promising result in reducing drag and have resulted up to 8% provided the height and the spacing of the grooves are precisely dimensioned [1]. Riblets have been tested on many types of airfoil to reduce drag and have given a very positive result [2-3].

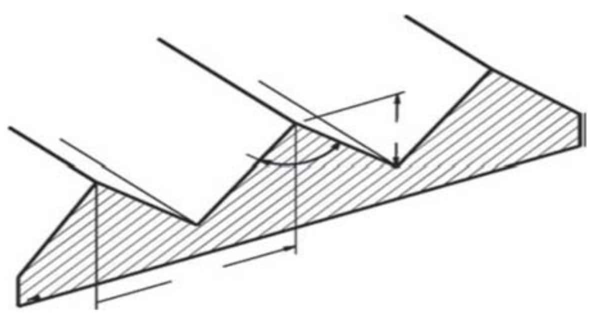

Figure-1. Sawtooth riblet showing tip and valley dimensions [4].

Later in the testing of riblets were carried on further using simulation methods [4]. The production of riblets film is very limited and difficult to produce due to its micro dimension as shown in Figure-2, hence studies on various structured and dimensioned riblets were then first tested in simulation. This gave results for each type of riblet and this method proved to be easier to determine the best result riblets design.

The mechanisms by which relate to reducing drag, however, remains poorly understood. Two possible mechanisms have been proposed. The first is that the skin friction reduction in the riblet valleys might be sufficient to overcome the skin friction increase near riblet tips. The second is the riblet tips actually reduce momentum transport by impeding the cross-flow motion.

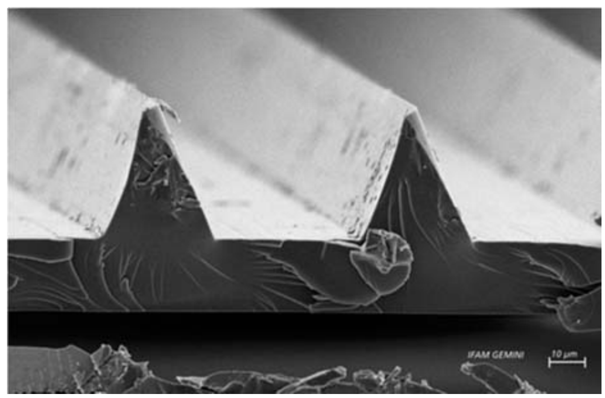

Figure-2. Structure of riblet film under a scanning electron microscope (courtesy of 3M).

The small riblets on the skin of fast swimming sharks impede the cross-stream translation of the streamwise vortices [5].The interaction between the riblets and the impede vortex translation is not yet fully understood by researchers due to the complexity of the interaction. Practically, by impeding the translation of vortices, decreases the rate of vortex injection towards the outer region of the boundary layer. The introduction of riblets intially was not considered as an obvious option for drag reduction due to the fact that it actually increases the total wetted surface area which contributes to the increase in surface friction drag [6].

In turbulent flow, drag normally increases dramatically with the increase in surface area because of the shear stresses acting on a larger surface area [7]. However, when riblets are present, the vortices are refrained from entering the lower structures by the riblet tips and enabling only the lower velocity flow to dominate the riblet valleys. This in turn only allows the high velocity vortices to interact with a minimal surface area at the riblet tips only while the low velocity flow occupies the large surface area near the bottom region. As a result, this reduces substantially the overall shear stress on the surface [8].

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The purpose of this study is to investigate the effectiveness of riblets in reducing the the drag coefficient of airfoil followed by the optimization study on the riblets dimensions to obtain a further reduction of the drag coefficient. Eventhough the initial objective was to conduct both experiments and simulations, however due to the difficulties in securing the riblet film, all of the studies were done using simulations.

METHODOLOGY

Airfoil CAD model

The airfoil model was designed using Solidworks 2014 as shown in Figure-3. NACA 0012 aifoil was chosen as the model. The riblet structures were created separately and placed as a strip on the top surface of the airfoil. The chord length of the airfoil is 60 mm while the length of the riblet strip is only 10mm, placed 10 mm from the leading edge.

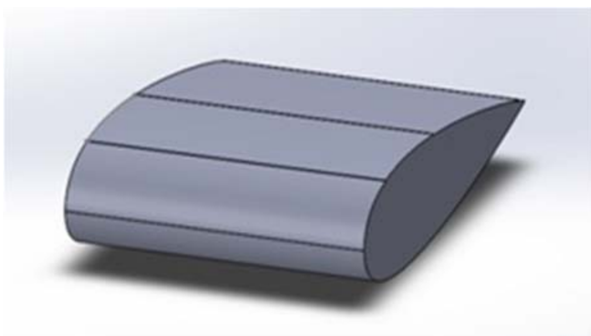

Figure-3. CAD model of airfoil with riblet structures on the top surface.

Subsonic wind tunnel

During the validation study, the airfoil was tested in the LW-9300R Subsonic Wind Tunnel shown in Figure-4, at Universiti Pertahanan Nasional Malaysia. The velocity speed used was at 100m/s. Temperature and static pressure were set at 293.20 K and 101.3 kPa. The wind tunnel is equipped with a 3-component force balance, smoke flow visualization and pressure transducers for pressure measurements.

Figure-4. LW-9300R subsonic wind tunnel at UPNM.

Simulation study

Riblets on airfoil were tested using Solidworks Flow Simulation as shown in Figure-5. Velocity was set at 100m/s. The turbulence intensity and length was at 0.10% and 5.324×10^{-5} m. The total cells for the meshing process was 14,400 inclusive of 5,040 fluid cells, 2,520 solid cells, 6,840 partial cells and zero irregular and trimmed cells.

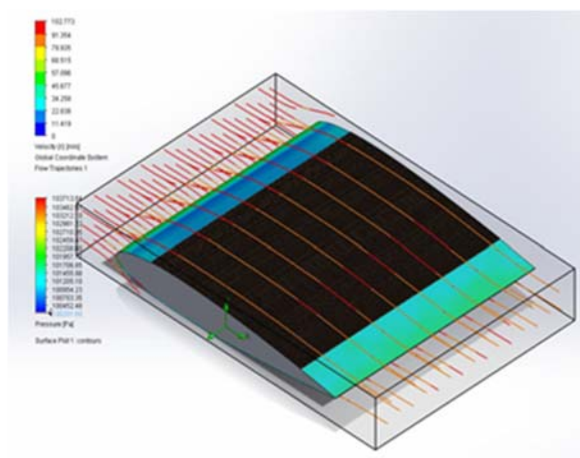

Figure-5. Riblets on airfoil in Solidworks flow simulation.

Airfoil model fabrication

The airfoil model shown in Figure-6, was fabricated using the Zortrax M-200 3D printer. Span and chord was set to 180 mm x 60 mm. Z-ULTRAT plastic material was used to print the airfoil. This material's Young's Modulus is 857 Mpa. Its tensile strength is at 25 Mpa with a maximum load of 132.4 N. The mechanical properties of this material proves to be best for subsonic wind tunnel testing.

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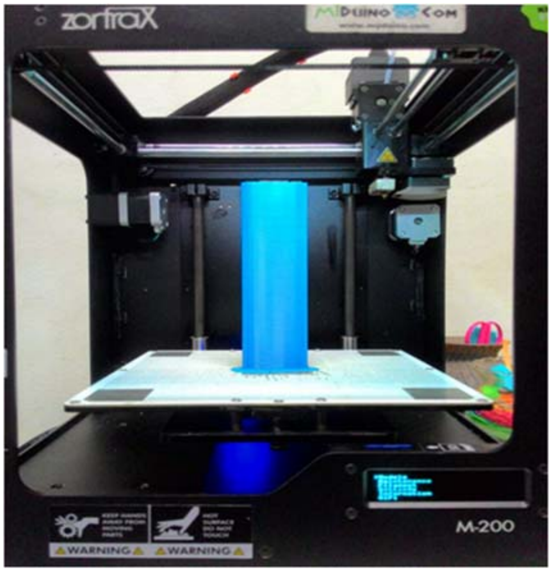

Figure-6. Construction of NACA0012 airfoil using 3D printer.

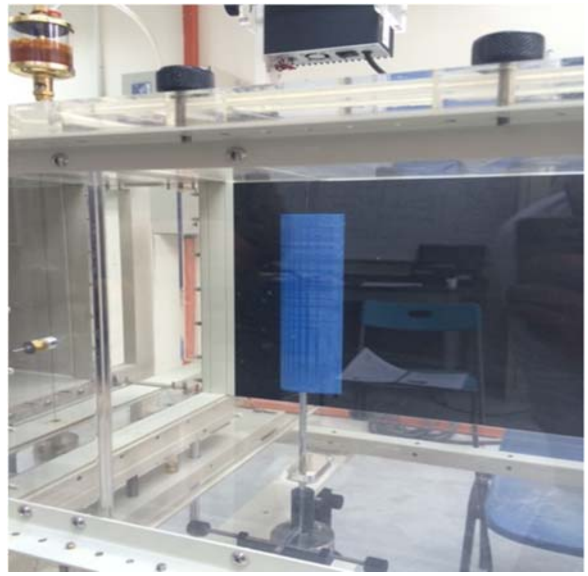

Figure-7. Airfoil connected to 3-component force balance being tested in wind tunnel.

RESULTS AND DISCUSSIONS

Validation of simulation study

This process is very vital when conducting a research. Validation process was carried out in order to compare results that were obtained experimentally and through simulation. The airfoil model was mounted inside the test section and connected to the 3-component force balance located near the floor section of the test section as shown in Figure-7. From this comparison it was determined that the results obtained during the simulation testing can be approved or not. Table-1 and Table-2 shows the results obtained from both the experimental and simulation testing.

Table-1. Results of simulation.

Test	Drag Coefficient ($\times 10^{-3}$)
1	3.61

Table-2. Results of experiments.

Test	Drag Coefficient ($\times 10^{-3}$)
1	3.93
2	3.81
3	3.88

A total of 6.6% error margin was obtained from the results shons in the tables above. This proves that the simulation results obtained are valid. Hence, this also validates all the other simulation results carried out in this study.

However there were a few reasons that might have caused the error. Firstly will be the angle of attack of the airfoil in the wind tunnel. There was no accurate method in positioning the airfoil in a 0° angle of attack so a rough estimation was done when placing the airfoil in the force balance area. In addition to that, during the calibration of the force balance, there was a very small error margin. After a few trials during the calibration process, the error still existed. This could also have had an effect on the drag force results. Furthermore, the surface finishing of the airfoil after the fabrication was not completely smooth. Due to this the surface had to be sand-papered. However even after using sand paper the surface was not completely smooth. Because of this, the results accuracy might have reduced slightly.

Effectiveness of riblets

Figure-8 shows the velocity contour on both the baseline (no riblets) and with riblets. A slight difference in the velocity contour on the top surface can be observed. At zero angle of attack, the size of the separation region near the trailing-edge has been slightly reduced with the presence of riblets.

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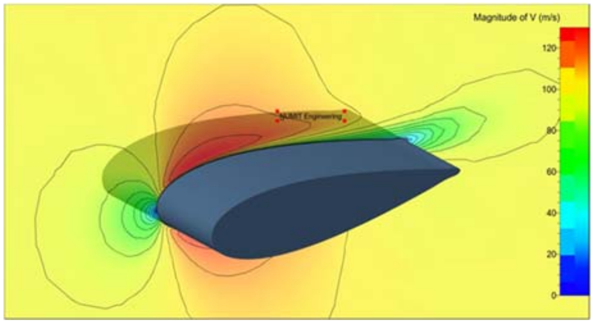

Figure-8. Simulation result of velocity contour on airfoil without riblets.

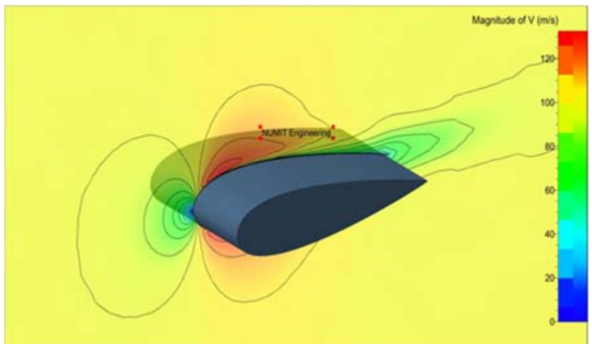

Figure-9. Simulation result of velocity contour on airfoil with riblets.

From the simulation results in Table-3, show that airfoil with riblets has a much lower Drag Coefficient (C_D) compared to airfoil without riblets. This then proves that riblets indeed has the ability to reduce drag acting on airfoil surface by reducing the surface area.

Table-3. Comparison of C_D from simulation.

Configuration	Drag Coefficient ($\times 10^{-3}$)
Without riblets	3.61
With riblets	3.26

Optimization study

Taguchi Method was the option chosen to carry out the optimization method on the riblets. Optimization method was used to determine the best riblets with the best dimension in order to minimize the drag coefficient value. The 25 Orthogonal Array Matrix was used where 25 simulations with three control factors of 5 levels were carried out. The list of control factors and levels is shown in Table-4.

Table-4. Control factors and levels selected.

Control Factors/Levels	1	2	3	4	5
Height (mm)	0.044	0.071	0.098	0.125	0.152
Spacing (mm)	0.044	0.071	0.098	0.125	0.152
Angle (°)	45	48.75	52.5	56.25	60

Table-5 lists all 25 combinations that were produced for simulation testing with the CD results obtained. 25 different models were designed for this purpose.

Table-5. 25 Orthogonal array matrix table with simulation results.

Experiment No.	H (mm)	S (mm)	A (°)	C_D 1	C_D 2
1	0.044	0.044	45.00	4.049	3.760
2	0.044	0.071	48.75	4.454	3.962
3	0.044	0.098	52.50	3.488	3.827
4	0.044	0.125	56.25	3.625	3.625
5	0.044	0.152	60.00	3.609	3.311
6	0.071	0.044	48.75	4.276	5.010
7	0.071	0.071	52.50	4.189	4.756
8	0.071	0.098	56.25	4.299	4.039
9	0.071	0.125	60.00	3.889	3.742
10	0.071	0.152	45.00	3.775	4.345
11	0.098	0.044	52.50	4.654	5.375
12	0.098	0.071	56.25	4.357	5.053
13	0.098	0.098	60.00	4.162	4.175
14	0.098	0.125	45.00	4.100	3.862
15	0.098	0.152	48.75	4.055	5.195
16	0.125	0.044	56.25	5.201	5.491
17	0.125	0.071	60.00	4.581	4.745
18	0.125	0.098	45.00	4.670	4.188
19	0.125	0.125	48.75	4.582	4.717
20	0.125	0.152	52.50	4.398	4.742
21	0.152	0.044	60.00	4.607	4.063
22	0.152	0.071	45.00	5.163	4.734
23	0.152	0.098	48.75	4.986	5.579
24	0.152	0.125	52.50	4.873	4.397
25	0.152	0.152	56.25	4.861	4.705

Based on the results from the 25 combinations, the Taguchi spreadsheet then predicted the optimal riblet dimension shown in Table-6, with the range of predicted results shown in Table-7. It shows that the spacing factor is dominant with 82% of influence while the angle of the riblet plays almost negligible role in affecting the drag coefficient.

Table-6. Optimal riblet dimensions.

Control Factors	1	2	3	4	5	Optimum Level	% Factor Effects	Dominant or negligible
Height	0.044	0.071	0.098	0.125	0.152	0.044	18	DOMINANT
Spacing	0.044	0.071	0.098	0.125	0.152	0.044	82	DOMINANT
Angle	45	48.75	52.5	56.25	60	-	-	negilible

Table-7. Predicted optimized results by Taguchi spreadsheet.

See the 'RESULTS' here →	1.40E-06	to	2.28E-06		Drag Coefficient (Cd) / Range / Center Value	1.78E-06

The optimized riblets dimensions were then used for the final simulation run and the value of C_D obtained was 1.94×10^{-3}, which is a significant reduction of 46% from the baseline case (without riblets) and the value falls in between the predicted range of C_D as shown in Table-7.

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CONCLUSIONS

The validation of simulation study proved that Solidworks Flow Simulation indeed produces valid simulation results. Besides that, riblets have proven its capability in reducing drag acting on an airfoil. Riblets reduces the surface area on the airfoil due to the tiny area of the riblet tips which act as the drag reducing agent. The optimum riblet dimensions were obtained using Taguchi Method. The optimized riblet dimensions were able to further reduce drag acting on the airfoil of up to 46%.

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