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Reduction of Skin Friction Drag in Wings by Employing Riblets

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***Abstract*— Research on drag reduction methodologies relevant to flight vehicles, automotive vehicles, tall structures etc., has received considerable attention during the past 2–3 decades. In the airplane or in the wind turbine industry it shows considerable efficiency improvement. Since the aerodynamic efficiency is explained in L/D ratio, decreasing the drag component will increase the aerodynamic efficiency. In this research a methodology to reduce the drag using the riblets over wing surface has been adopted. Since the flow transition from laminar to turbulent around the half chord, the turbulent region will produce less drag when the surface is rough. By this concept this research is being carried out. The effects of riblets on the wake characteristics of a wing can delay the flow separation, operating in a compressible, high-speed environment. Lift, drag and pressure coefficients are measured and the velocity profiles are determined. It is observed that the effect of riblets changes the aerodynamic characteristics of the wing. The riblets have reduced the coefficient of skin friction drag or viscous drag and increased the coefficient of lift along with the stall angle of attack. Computational Fluid dynamic analysis has to be done by creating the models and mesh. The results will be discussed in terms of pressure coefficient, drag reduction etc.**

Keywords — Lift, Drag Reduction; Riblets; Aerodynamic Efficiency; Skin Friction Drag

I. INTRODUCTION

Generally, the role of drag in the aircraft industries is the major issue to be noted. The Drag is the resistance to airflow which consequently retards the progress of an aircraft through the air, arising from disturbing the air as it moves through it, and forms the friction due to the viscosity of the air over the surface of the wing. The air flowing along the surface of the wing creates a frictional force on the body and this force is called skin friction drag. Most parts of the airplane such as the fuselage, cowlings, landing gear, struts, and other components will have both thickness and surface area, resulting in both pressure drag and friction drag.

The turbulence structure of the wake produced by a streamlined body, such as an airfoil, is important for a variety of aerospace, aeronautical, mechanical engineering, and turbo machinery applications. Although much data are already available on the wakes produced by smooth bodies, almost no papers exist which provide information on the influences of body roughness on wake flow characteristics, especially with augmented levels of mainstream turbulence. To remedy this deficiency, the present study considers the effects of surface roughness (Ribblets) on the wake characteristics of a wing, operating in a compressible, high-speed environment, with different levels of free stream turbulence.

A boundary layer is a thin region of fluid near a wall where viscous effects are important in determining the flow field. The boundary layer is a buffer region between the wall below and the in-viscid free stream above. Boundary layer separation occurs when the portion of the boundary layer closest to the wall or leading edge reverses in flow direction. As a result, the overall boundary layer initially thickens suddenly and is then forced off the surface by the reversed flow at its bottom.

When the boundary layer separates, its displacement thickness increases sharply, this modifies the outside potential flow and pressure field. In the case of wings, the pressure field modification results in an increase in pressure drag, and if severe enough will also result in loss of lift and stall, all of which are undesirable. For internal flows, flow separation produces an increase in the flow losses, and stall-type phenomena such as compressor surge, both undesirable phenomena.

The formation of wake over the wing due to boundary layer separation causes a dramatic increase in drag which leads to increased fuel consumption and results as a lag in effectiveness of the wing. The idea to reduce drag by means of implementing riblets eliminates the wake formation. Wake formation is delayed or nullified by altering the flow separation, thus increasing the L/D ratio.

The present study is different from the other investigations mentioned because it focuses on the combined effects of riblets and increased free stream turbulence levels on wake turbulence structure in compressible, high-speed subsonic flow. One swept wing is employed with riblets of small sizes over the upper surface. The contributions and effects of riblets and inlet turbulence level to the stream wise velocity distribution, turbulence intensity, turbulence length scale, power spectral density and vortex shedding frequency across the wake at one chord length downstream of wings are described.

II. LITERATURE SURVEY

Leibeck and Smith [1] in the early seventies studied an airfoil, optimizing it for maximum lift. They assumed the distance along the airfoil as independent variable. Airfoil shape was then found using inverse method which generated high lift to drag ratio than conventional airfoils. They also assumed that the upper surface velocity distribution consisted of an arbitrary acceleration region over the leading edge stagnation point to a maximum velocity followed by a Stratford pressure recovery to the trailing edge velocity which recovers maximum pressure difference and thus high lift. But the angle of attack at which maximum lift is attained approaches the stall angle.

R.Jones and D.H.Williams [2] in 1936 investigated the effect of surface roughness on characteristics of airfoil NACA 0012 and RAF 34 where they stated that as the surface roughness is increased the minimum drag is increased and the maximum lift is decreased. But at the backside of the airfoil the roughness is reduced by 5% of the drag produced.

KERHO AND BRAGG [3] (1997) describes the roughness induced transition process was governed by completely different mechanisms than those present in the natural transition process documented for the smooth model. Small surface roughness primarily causes premature boundary-layer transition. In general, the roughness was observed to trigger the transition process at/or very near the trailing edge of the roughness. The low turbulence intensity values of the roughness induced boundary layer are surprising. Transition due to distributed roughness is commonly described as explosive because there is no slow build-up of an instability leading to an initial break down and appearance of turbulent spots.

Corten G. P [4] (2001) explains the dynamic boundary layer reattachment takes place at smaller angle of attack than that of smoother aerofoil. The maximum dynamic lift coefficient decreased when the aerofoil surface roughness increases. The dynamic stall angle decreases with an increase in aerofoil surface roughness. The maximum dynamic pitching moment coefficient decreases with an increase in aerofoil surface roughness.

K.Freudenrich et al., [5] in the year 2004 they investigated Reynolds number and its effect on thick airfoil for wind turbine where they placed zigzag pattern at different locations and analyzed turbulence intensity effect dependence of drag on Reynolds number. They placed a zigzag pattern of height h=0.4, 0.6mm x/c=0.3 and it increased lift and reduced drag at low Reynolds number.

M.R.Solatani al., [6] states that roughness elements has little influence on surface pressure distribution. Most effects are observed at the inboard station where minimum value of coefficient of pressure is reached. For spectral analysis the roughness effect did not have any effect on the zero frequency instability. In this station there minimum value of coefficient of pressure was shifted towards the forward of the leading edge because of surface roughness.

Dr.Farag Mahel Mohammed [7] said about the influence of surface roughness on the dynamic stall of a rotary wing section in subsonic flow. For a rough surfaced airfoil dynamic boundary layer reattachment takes place at smaller angle of attack than the smooth one. The maximum coefficient of lift value decreased when the surface roughness increased. Max dynamic pitching moment coefficient decreased with increase in surface roughness.

III. EXPERIMENTAL WORK

A. Modeling of Wing with Riblets

The wing designed is swept wing as it is frequently used in most of the aircrafts. The design is done in CATIA V5R20 by using supercritical airfoils NASA SC (2) XXXX specifications. The specification of the wing designed is as follows:

Table I. Swept Wing Specification

Aerofoil used	NASA SC(2) 0610-Root NASA SC(2) 0606-Tip
Wing shape	Swept wing
Mach number	0.89M
Co-efficient of lift (C_L)	1.4
Wing area	845.39 m^2
Wing span	79.7966 m
Thickness	10.0%
Camber	1.8%
Weight	560186.6 kg
Fuel weight	283177.7 kg
Aspect ratio	7.43
Chord	17.7m
t/c	0.08
Sweep ¼ chord	33.5

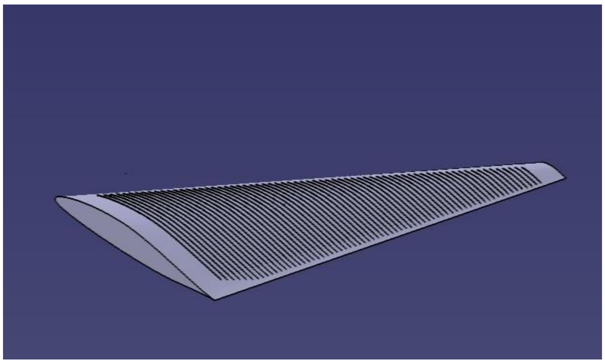

Fig 3.1. 3D View of Swept Wing with Riblets

B. Lift Coefficient for wings without Riblets

The theoretical lift values calculated from the standard formulae for wings without riblets are,

Table II. Coefficient of Lift

Angle Of Attack (AOA)	Coefficient of Lift, C_L
0°	0.112366
5°	0.46716
10°	0.81066
15°	1.15416
18°	1.36026
20°	1.4976

C. Theoretical Calculation for Skin Friction Coefficient for wings without Riblets

$$c_f = \frac{x}{c}\, c_{(f,x)laminar} + c_{(f,c)turbulent} - \frac{x}{c}\, c_{(f,x)turbulent} \qquad (1)$$

$$c_{(f,x)laminar} = \frac{1.328}{\sqrt{R_{ex}}} \qquad (2)$$

$$c_{(f,c)turbulent} = \frac{0.74}{(Re)^{1/5}} \qquad (3)$$

$$\frac{x}{c} = \frac{Re_x}{Re_c} \qquad (4)$$

$$Re_c = \frac{\rho_\infty v_\infty c}{\mu_\infty} \qquad (5)$$

From gas table for altitude 10500 m,

μ_0 = 1.4355×10^{-5} kg/ms
T_0 = 220.02 K
P_0 = 2.4922×10^{4} N/m^2
V = 302.6 m/s
ρ = 0.3885 kg/m^3
T = 216.78 K

By Sutherland's law for the temperature variation of viscosity coefficient

$$\frac{\mu}{\mu_0} = \left(\frac{T}{T_0}\right)^{\frac{3}{2}} + \frac{T_0 + 110}{T + 110} \qquad (6)$$

$$\mu = \left(\frac{216.78}{220.02}\right)^{\frac{3}{2}} + \frac{220.02+110}{216.78+110}\left(1.4355\times10^{-5}\right)$$

$$\mu = 1.4178\times10^{-5}$$

$Re_x = 1\times10^7$ (from Gas Tables)

$$c_{(f,x)laminar} = \frac{1.328}{\sqrt{1\times10^7}}$$

= 0.0004

$$c_{(f,c)turbulent} = \frac{0.74}{(14.68\times10^7)^{1/5}}$$

= 0.0017

$$\frac{x}{c} = \frac{1\times10^7}{14.68\times^7}$$

= 0.0690

$$c_f = 0.0015$$

Total skin friction coefficient of wing is,

$$c_f = 2\times0.0015$$
$$= 0.0030$$

D. Analyzing of Wing with Riblets

To perform CFD analysis, following specifications are considered.

i) Velocity at Takeoff = 0.89 Mach, Cruising = 0.85 Mach.
ii) Air Properties Used: Sea Level properties for takeoff & High Altitude of 10500 m. High Altitude properties for cruising Dynamic Viscosity = 1.783x10^{-5} at SL, 1.4355x10^{-5} kg/ms at HA.
iii) Boundary Conditions are:

- Pressure far field inlet at left edges
- Free Surfaces at top and bottom edges.

The CFD analysis is done using ANSYS 15 software. Different parameters like velocity, static pressure, lift and drag coefficients, flow vector diagram to understand the flow separation are determined.

The meshing procedure has to be done before analyzing any section in any analyzing software like ANSYS, FLUENT, STAR CCM etc. The meshing process ensures more accurate results, this is because the whole test section when analyzed by splitting into several smaller elements it will be easier to analyze, accuracy increases with the number of elements. The number of elements is 2034768 and the number of nodes is 1764333.

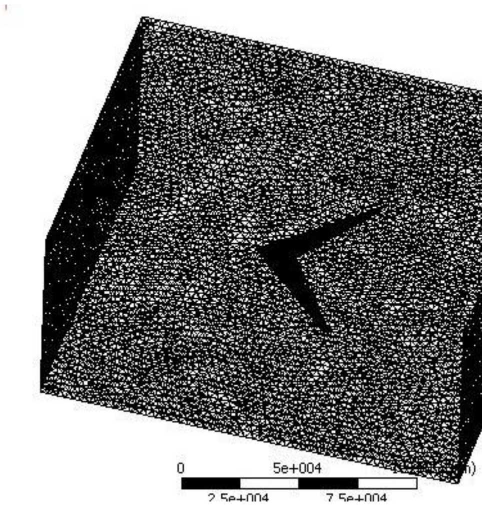

Fig 3.2. Meshed Wing

E. Static Pressure for Wing with Riblets

Static pressure is the component of pressure force which acts normal to the wing. In a wing the leading edges has higher static pressure comparing to the trailing edge. This is because the pressure force created by the free stream acts on the wing leading edge directly and varies differentially decreasing along the chord of the wing. The static pressure distribution along top of the wing surface is shown in the figure.

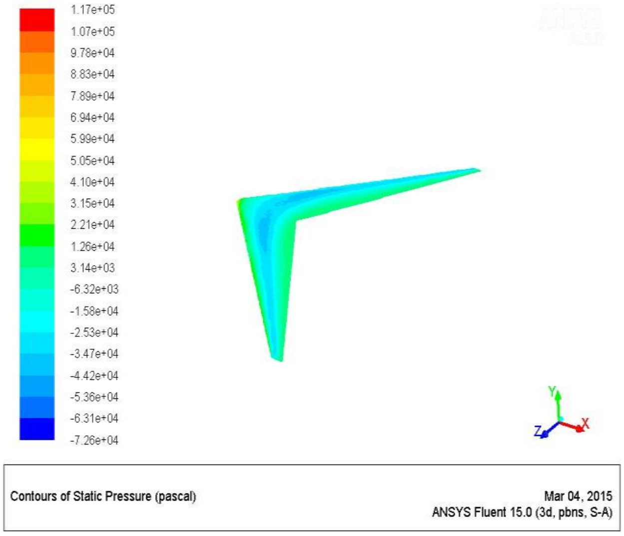

Fig. 3.3. Distribution of Static Pressure over the Upper Surface of the Wing Employed with Riblets

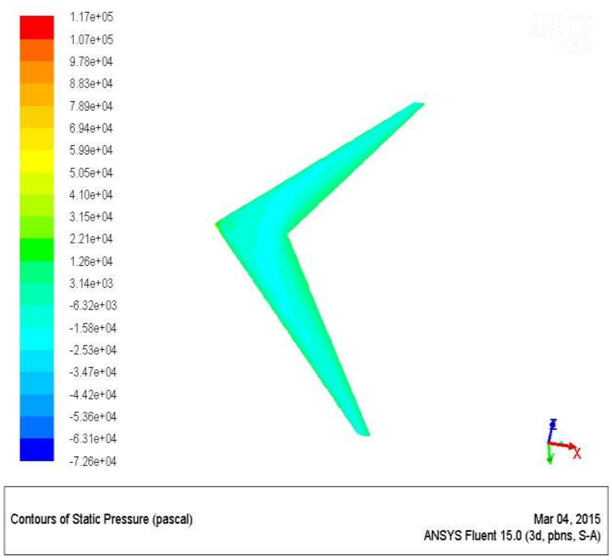

Fig. 3.4. Distribution of Static Pressure over the Lower Surface of the Wing Employed with Riblets

Here a low pressure area is found on the surface of the swept wing employed with riblets which implies better lift characteristics.

F. Coefficient of Lift for Wing with Riblets

The coefficient of lift is the amount of lift generated by the wing at a particular free stream velocity. The free stream velocity of air is taken as 0.89 Mach and swept wing with an aspect ratio of 7.43 generates a C_L value of 1.787. The coefficient of lift varies with the variation in free stream velocity and angle of attack. In this case the wing has a natural sweep angle of 33.50°.

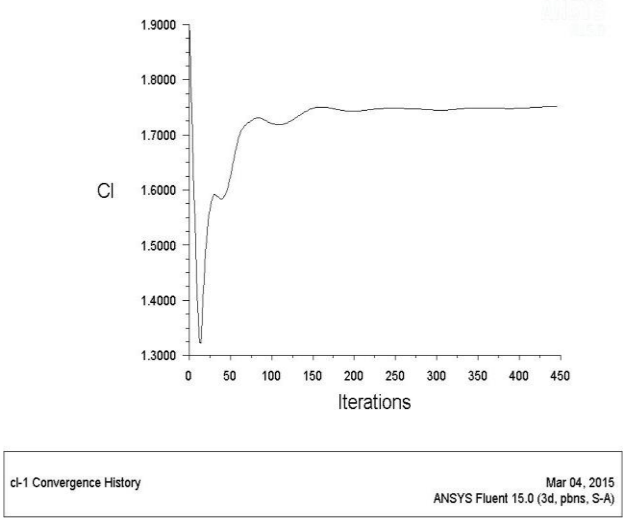

Fig.3.5. Graph of coefficient of lift with riblets

G. Skin Friction Drag of Wing with Riblets

The flow over the swept wing was analyzed using ANSYS software at a particular free steam velocity. Skin friction drag occurs differently depending on the type of flow over the lifting body.

Fig.3.6. Distribution of skin friction drag over wing surface with riblets

H. Coefficient of Skin Friction Drag of Wing with Riblets

The coefficient of drag value for the wing with riblets obtained through analysis is 0.089.

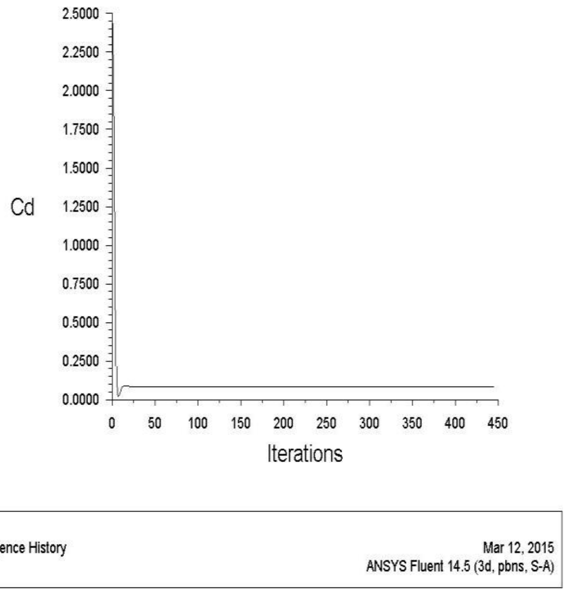

Fig.3.7. Graph of drag coefficient with riblets

I. Lift and Drag Calculation

Without Riblets

$$L = \frac{1}{2}\rho \times v^2 \times s \times C_L \qquad (7)$$

$$= 0.19425 \times 302.62 \times 845.39 \times 1.4$$

$$= 21051547.04\text{ N}$$

$$D = \frac{1}{2}\rho \times v^2 \times s \times C_d \qquad (8)$$

$$= 0.19425 \times 302.6^2 \times 845.39 \times 0.14269$$

$$= 2145349.95\ N$$

$$\frac{L}{D} = 13.79$$

With Riblets

$$L = \frac{1}{2}\rho \times v^2 \times s \times C_L \qquad (9)$$

$$= 0.19425 \times 302.6^2 \times 845.39 \times 1.787$$

$$= 26867617.6\ N$$

$$D = \frac{1}{2}\rho \times v^2 \times s \times C_d \qquad (10)$$

$$= 0.19425 \times 302.6^2 \times 845.39 \times 0.089$$

$$= 1338118.6\ N$$

$$\frac{L}{D} = 20.07$$

The comparison of the aerodynamic parameters between wing with and without riblets are shown in table III.

Table III. Comparison of Aerodynamic Parameters

S.NO	PARAMETER	WING WITHOUT RIBLETS	WING WITH RIBLETS
1	Coefficient of Lift	1.4	1.787
2	Coefficient of Drag	0.14269	0.089
3	Lift	21051547.04N	26867617.6N
4	Drag	2145349.95N	1338118.616N
5	Skin friction Drag	0.0030	0.00222
6	Lift to Drag ratio	13.79	20.07
7	Lift to Weight ratio	3.83	5.43

IV. RESULT AND CONCLUSION

From the studies, it can be concluded that the skin friction drag is reduced when the wing is employed with riblets and the lift has increased to a small extent. The skin friction drag is reduced as the flow separation is delayed and the pressure gradient is avoided. The changes in aerodynamic characteristics has attained by changing the riblets size and spacing. And the comparisons of theoretical and analytical values have shown only small percentage of error.

More design alterations can be done by changing the riblets size and spacing through which effective and desirable aerodynamic characteristics can be attained. Other factors such as weight of riblets and the icing factors can be considered..

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