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ANALYSIS OF REDUCTION OF SKIN FRICTION DRAG OF SUPERSONIC WINGLETS BY EMPLOYING WITH AND WITHOUT RIBLETS

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Abstract: Airfoil for the supersonic winglets is selected and designed to analyze the skin friction drag reduction is carried out in this paper. In this research a methodology to reduce the drag using the riblets over wing surface has been adopted. Since the aerodynamic efficiency is explained in L/D ratio, decreasing the drag component will increase the aerodynamic efficiency. 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 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 must be done by creating the models and mesh. The results will be discussed in terms of drag reduction with respect to the contours of pressure, temperature, and Mach number.

Index Terms - Supersonic winglets, Skin friction drag, Drag reduction, NACA-TSAGI 12-IL, Riblets

1.INTRODUCTION

The reduction of skin friction drags of supersonic wings by employing with and without riblets was analyzed. The skin friction drags are determined by lift and drag coefficient of the supersonic wings. The NACA series for the condition of Supersonic Airfoils is selected and design by using ANSYS tool and undergoes the analysis of velocity profiles with respected to contours of pressure, temperature, Mach number.

1.1 SUPERSONIC AIRFOILS

The basic forces acting on an airplane are lift, Thrust, weight, and drag. The airfoils create lift, and then a resisting force act on it. Power which acts perpendicularly upward to forward motion is lift and a force acting along the direction of current is to experience resistance. The main purpose of a supersonic airfoils is creating the appropriate amount of lift v supersonic flow regime. These airfoils are designed in so that it would not enable the formation of a separate bow shock. For this reason, leading the edge and trailing edge of the wing remain sharp.

Airfoils used in supersonic aircraft are usually a thin section consisting of planes that are at an angle or arcs opposite each another. When the fluid flow reaches local velocity sonic condition (Mach 1), a shock occurs at a point along the airfoils.

1.1.1 LIFT AND DRAG (supersonic conditions)

In supersonic conditions, aircraft drag is caused by:
- Skin friction due to shearing.
- Wave resistance due to thickness (or volume) or wave resistance without lift
- Drag for lift

Therefore, the drag coefficient on a supersonic airfoil is described by the following expression:

$$\mathbf{CD = CD_{friction} + CD_{thickness} + CD_{lift}}$$

Experimental data allow us to reduce this expression to:

$$\mathbf{CD = CD_{o} + KCL^{2}}$$

Where,

CD_o is the sum of $CD_{friction}$ and $CD_{thickness}$ and

K for supersonic flow is a function of the Mach number.

1.2 SWEPT BACK WINGS

The wings are swept back to reduce aerodynamic drag at an angle. This type is most used commercially airplanes and cargo planes. Figure 1.2 is a 37.5 degree swept back wing. Example: Boeing 737.

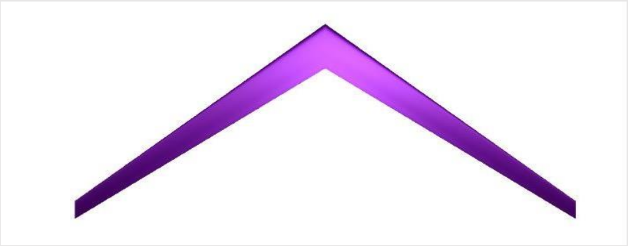


Fig 1.2 Sweptback wing profile

Table 1.2 Initial conditions of Sweptback wing

Chord length at root (C_R)	1 m
Chord length at tip (C_T)	0.4 m
Mean Aerodynamic Chord (MAC)	0.743 m
Wing area (A)	$7\ m^2$
Aspect ratio	14.286
Root to tip sweep angle (φ)	37.5°
Velocity (V)	50 m/s
Re at root	2.79e+06
Re at tip	1.11e+06

1.2.1 Reason for Sweep

There are three basic rationales for wing sweeps:

1. To better align the aircraft's center of gravity and the aerodynamic center of the wing for longitudinal balance, as seen in the Messerschmitt Me 163 Komet and Messerschmitt Me 262. Although not offset, the Douglas DC-1 wing panels outside the nacelles had a slight sweep for the same reasons.

2. Providing longitudinal stability for tethered aircraft such as the Messerschmitt Me 163 Komet.

3. Most often to increase Mach number performance by shifting to a higher speed the effects of compressibility (sudden changes in air flow density), as in the case of commercial and military aircraft.

Other reasons include:

1. To enable the position of the carrying case on the wing to achieve the required cabin capacity, as in the case of the HFB 320 Hansa Jet.

2. Supply of static aeroelastic relief which reduces bending moments during high g loads and may allow for a lighter wing structure.

1.3 SKIN FRICTION DRAG

The long and lean shapes of hypersonic vehicles cause obesity and mostly turbulent boundary layers. As a result, skin friction drag can contribute a significant amount to the overall vehicle resistance comparable to wave resistance. Reduction of skin friction drag on the supersonic airfoils therefore promises relatively large capacity reserves improvement.

The total drag can be decomposed into a skin friction drag component and a pressure drag component, where the pressure drag includes all other sources of drag, including drag caused by lift. In this conceptualization, lift-induced drag is an artificial abstraction, part of the horizontal component of the aerodynamic reaction force. Alternatively, the total drag can be decomposed into a parasitic drag component and a lift-induced drag component, where the parasitic drag is all drag components except the lift-induced drag. In this conceptualization, skin friction drag is a component of parasitic drag.

1.3.1 REDUCTION OF SKIN FRICTION DRAG

Two basic methods of reducing skin friction are delaying the transition of the boundary layer and changing the turbulence patterns in the turbulent boundary layer. The use of fins is one of the techniques to modify the turbulence structures in the turbulent boundary layer. Ribs are small grooves that run parallel to the direction of flow across the surface of the aircraft.

According to a preliminary resistance study, the maximum achievable reduction in resistance is and the target lift-to-drag ratio was estimated by considering the reductions achievable for each drag component. The vortex drag reduction factor was chosen to be 0.58. This is the theoretically optimal value achieved by using an elliptic airfoil, the least vortex drags according to Jones wing theory. Although the practical wing will have a slightly lower potential to achieve the minimum vortex drag, the reduction of the vortex drag is set as an aggressive target.

1.3.2 DRAG REDUCTION CONCEPTS

A lot of research has gone into the development of the Concorde was carried out to reduce the pressure resistance of the supersonic the plane. This was mainly based on supersonic linear theory since the condition appears to be satisfied by the linear approximation probably due to minimal resistance. The following design concepts for reduce pressure drag according to supersonic linear theory known:

(1) The first concept is to choose a slim, thin skirt shape with the subsonic leading edge lying inside the Mach cone occurs at the tip of the wing. This requires a "plan-study".

(2) The second concept is the creation of an optimal combination distribution of warp and twist over the wing. Such a one a curved wing is called a "warped wing". This requires "deformation-studies".

(3) The third concept is to design the cross-sectional area of the fuselage distribution to reduce the increase in drag due to wing and body disturbances. Such a hull with an adapted surface distribution is called a "controlled surface hull". This requires a "field rule-studies".

1.4 LITERATURE REVIEW

The selection of the aerodynamic profile and its design is the most important step in the aircraft design process. And the airfoil is the cross-sectional geometry of the wing that is responsible for the aerodynamic forces. An aerodynamic analysis has been performed mainly to find the lift coefficient and drag coefficient of the vehicle, predict high- and low-pressure areas and breakpoints that affect vehicle dynamics. The analysis is carried out to determine the lift coefficients and drag at Mach 2 with fixed angle of attack. Application of Computational Fluid Dynamics, Pressure, Velocity, M, the temperature, and Reynolds number distributions were studied on the top and bottom surfaces airfoil. [1]. Aerodynamic parameters such as lift, drag, and the ratio of the coefficient of lift to drag, which is the CL/CD ratio, determine the efficiency of an aircraft wing. This CL/CD ratio depends on the cross-section of the wing, i.e., the airfoil. This article highlights the aerodynamic analysis of NACA 0018, NACA 2412, NACA 4412, USA 45, TSAGI-S12 and B737A airfoils used on various airfoils such as rectangular, elliptical, delta and swept tail. The results are analyzed and the best wing shape corresponding to the airfoil is reported. [2]. The challenges associated with the design of a folded rear wing for aircraft. A swept wing is a wing that turns either backward or, occasionally, forward, from the root rather than straight to the side. The aerodynamic efficiency of a wing is expressed as the ratio between lift and drag. The lift generated at a given speed and angle of attack can be one or two orders of magnitude greater than the total drag on the wing. The high lift-to-drag ratio requires significantly less thrust to propel the wings through the air with sufficient lift [3]. NACA 0012 fin wings to investigate the effects of wing sweep angle (Λ) and angle of attack (α) at the junction vortex at $Re = 8 \times 104$. Mode separation occurs at $\Lambda < 12°$ and $\alpha < 5°$. The attached mode comes up at low α for a backward-swept wing ($\Lambda > 0°$) and a pale body, the wake mode appears at high α for a forward-swept wing ($\Lambda < 0°$) [4]. Drag reduction concepts are mainly based on supersonic linear theory and include the use of a boom, a curved wing with optimum pitch and roll, and a zonal body. The friction reduction concept is the first technical approach in the world to achieve a natural laminar flow wing with a subsonic leading edge at supersonic speed [6].

2.METHODOLOGY

This study includes the NACA-TSAGI 12-IL type of airfoil which is selected and designed for the analysis of reduction of skin friction drag on supersonic winglets by employing with and without riblets. The designed airfoil undergoes the analytical procedure which includes the following progress.

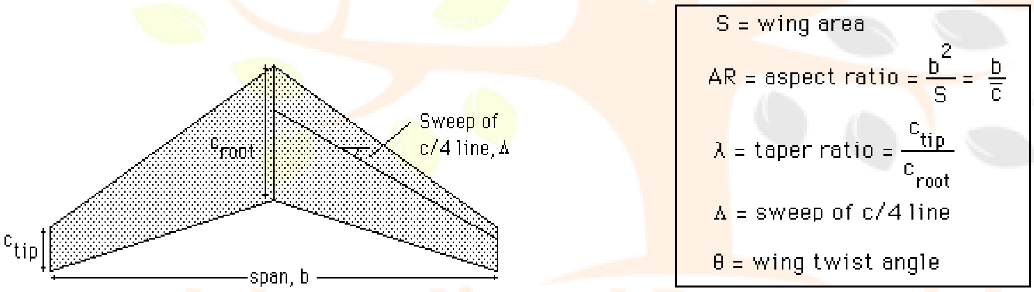
2.1 WORK PROCESS

- **Step 1 –** Literature Survey
- **Step 2 –** Parameter selection for design
- **Step 3 –** Designing 3D model
- **Step 4 –** Analytical Process
- **Step 5 –** Results
- **Step 6 –** Conclusion

2.2 DESIGN CONSIDERATIONS

The general parameters for the design of NACA – TSAG12-IL airfoil is selected in respect to wing shape, wing span, thickness, chord length, chamber, weight was considered as the design parameters in this chapter.

2.2.1 WING DESIGN PARAMETERS



S = wing area

AR = aspect ratio = $\frac{b^2}{S} = \frac{b}{c}$

λ = taper ratio = $\frac{c_{tip}}{c_{root}}$

Λ = sweep of c/4 line

θ = wing twist angle

2.2.2 SELECTION OF WINGSPAN

Choosing a skirt span is one of the most fundamental decisions when designing a skirt. Range is sometimes limited by competition rules, hangar size, or ground capabilities, but when not, we may choose to use the maximum range consistent with structural dynamic limitations (flutter). This would directly reduce the induced drag. However, as span increases, so does the structural weight of the wing, and at some point, the increase in weight offsets the resulting drag savings. However, this point is rarely reached for several reasons.

1. The optimum is quite flat and the range needs to be stretched a lot to reach the actual optimum.

2. Wing flexing concerns as it affects stability and flapping installation as span increases.

3. The cost of the wing itself increases as the structural weight increases. This must be included so we don't spend 10% more on the wing to save 0.001% on fuel.

4. The volume of the wing in which the fuel can be stored is reduced.

5. It is more difficult to locate the main landing gear on the wing root.

6. The Reynolds number of the wing sections is reduced, which increases the parasitic drag and reduces the maximum lift capacity [3]

2.2.3 DESIGN PARAMETERS FOR WING MODEL

Wing shape, Wing span, Wing area, Thickness, Camber, Chord length and Weight were selected as the parameters for the designing of the winglet.

Table 2.2.3 design parameters for wing

Airfoil used	**NACA- TSAGI12-IL (ROOT)** **NACA- TsAGI SR-3 (TIP)**
Wing Shape	Swept Back
Wing Span	10.085 m
Wing Area	20.6 m^2
Thickness	12%
Camber	2%
Chord Length	1 m
Weight	3681 kg

2.2.4 DESIGN PARAMETERS FOR AIRFOIL MODEL

Table 2.2.4 design parameters for airfoil selection

Airfoil	**Max thickness**	**Max camber**
Root - NACA TSAGI12-IL	11.9% at 30% chord	2% at 30% chord
Tip - NACA TsAGI SR-3	12.1% at 23.1% chord	3.1% at 24.1% chord

2.3 3D MODEL OF AIRFOIL

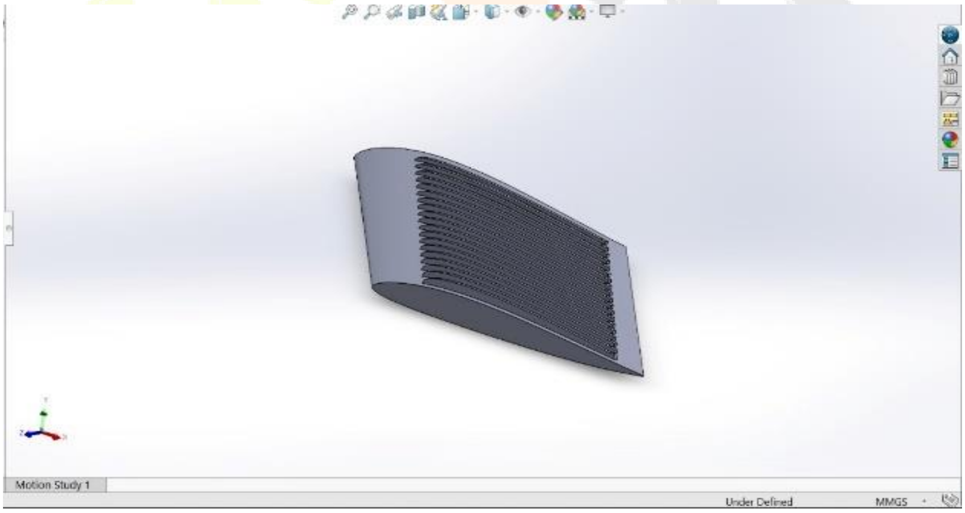


Fig – 2.3 3D model of airfoil

2.3.1 STEPS INVOLVED IN DESIGN

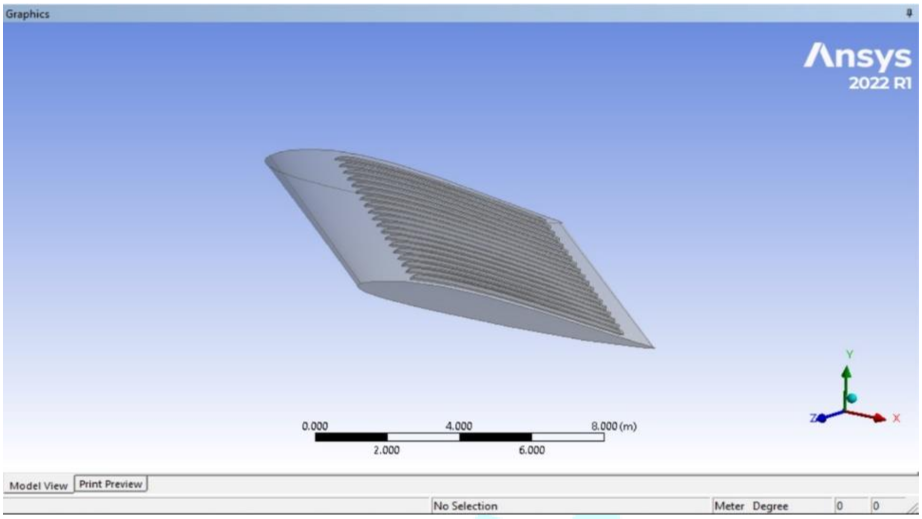
Step 1: Download airfoil data from tools.
Step 2: Create the airfoil coordinates in an Excel spreadsheet using the above format.
Step 3 : Import the data into the design software and use glue to connect each point together in a tight loop sketch.
Model chord length: 1 meter

3. MODEL ANALYSIS

The analysis of the airfoil was performed using the ANSYS analysis tool and the steps involved in this process were explained. Meshing and model analysis was performed and static pressure, Mach number and temperature contours were analyzed using with and without riblets in the wings. And the analytical results for the supersonic wings which is employed with and without riblets were determined.

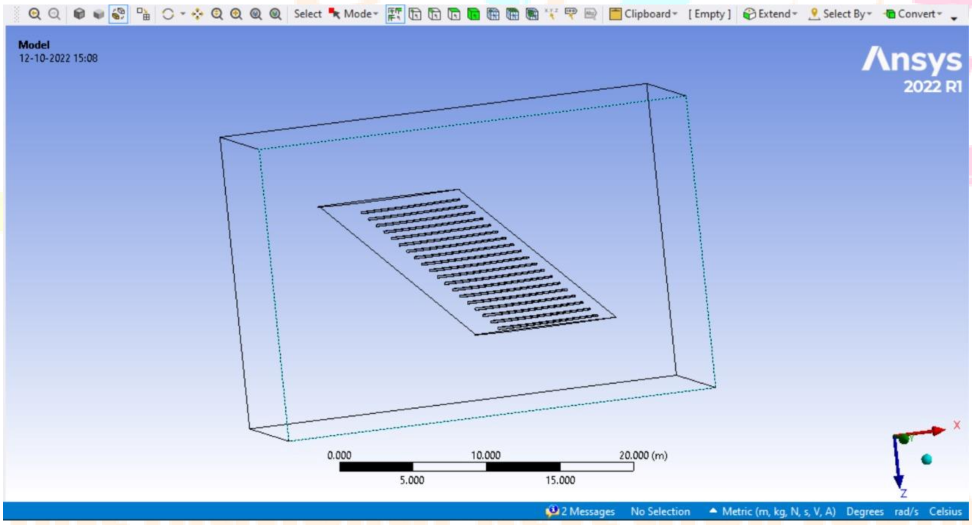
3.1 STEPS INVOLVED IN ANALYSING MODEL

Step 1: Insert the model

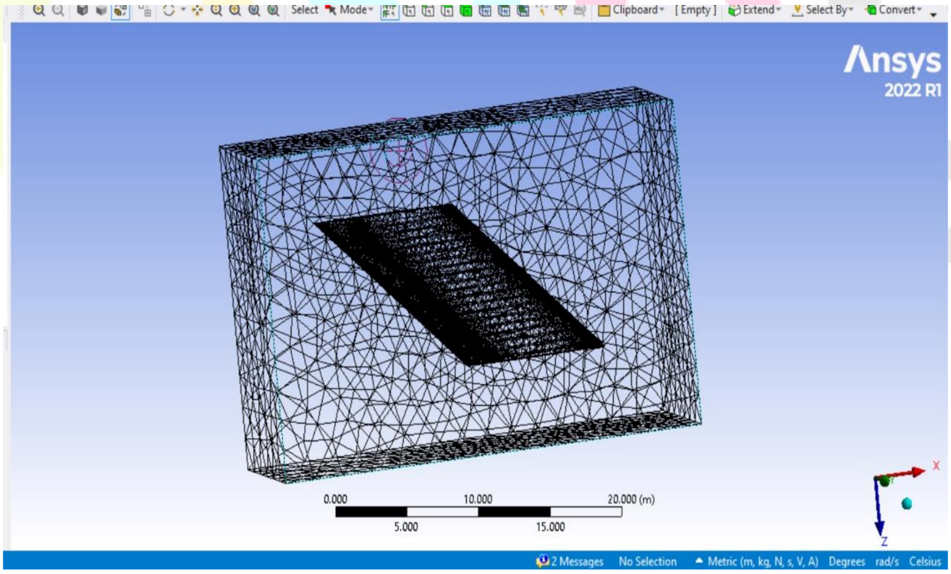


Step 2: Apply the Enclosure to create the control volume around the 3D model.

Step 3: apply the Boolean to subtract the parts



Step 4: Generate mesh.



3.2 ANALYTICAL RESULTS

3.2.1 Analytical results of winglet without riblets

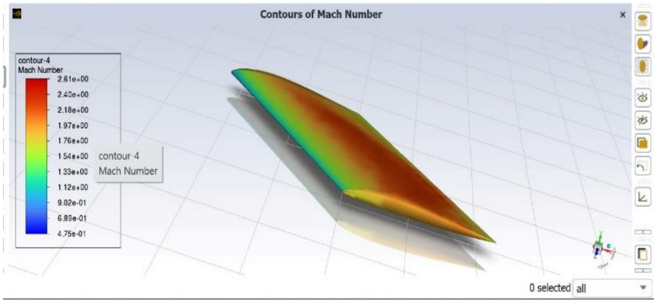


fig – 3.1 contours of mach number

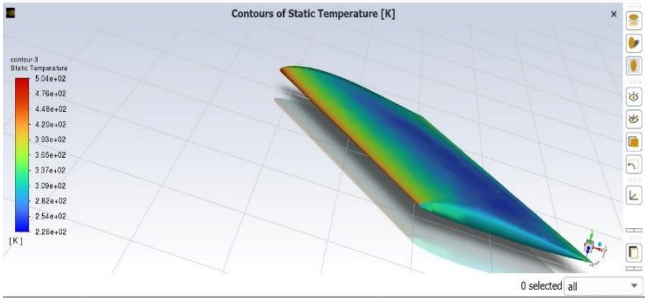


fig – 3.2 contours of Static Temperature

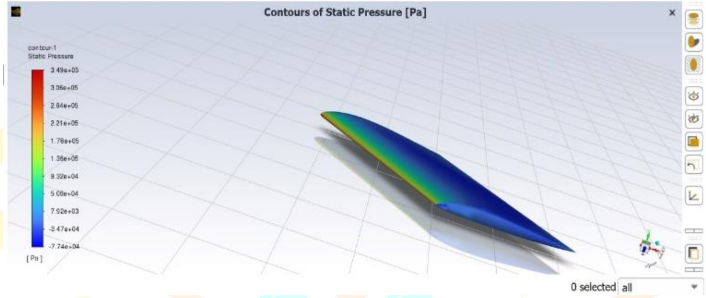
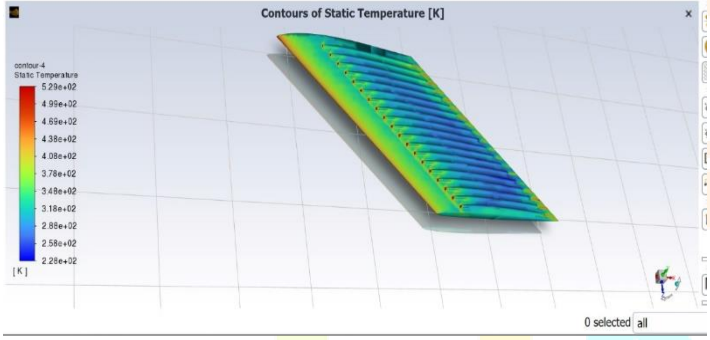


fig – 3.3 contours of static pressure

3.2.2 Analytical results of winglet with riblets



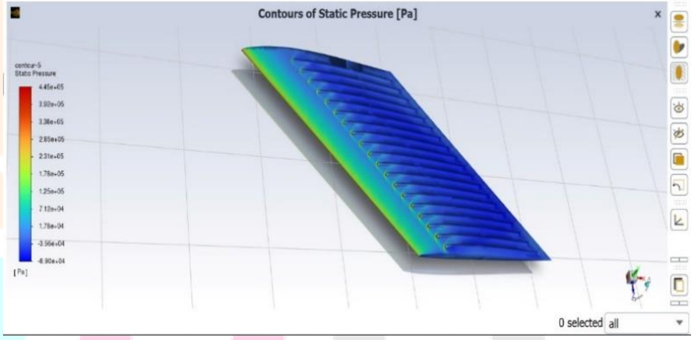


fig – 3.4 contours of static temperature **fig – 3.5 contours of static pressure**

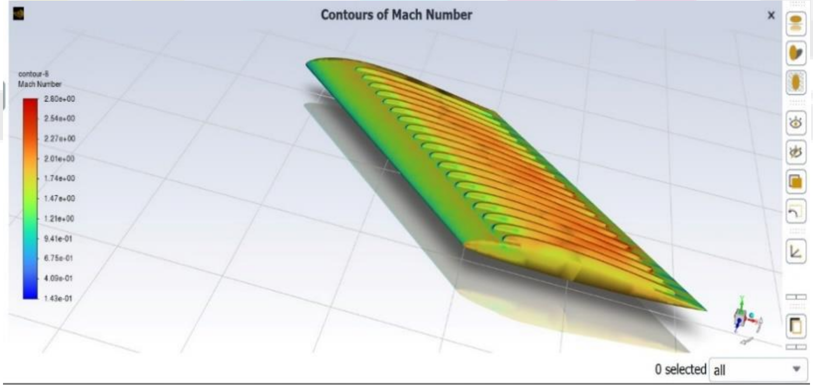


fig – 3.6 contours of mach number

4. RESULT AND DISCUSSION

4.1 RESULTS

Table 4.1 results

3D MODEL	LIFT	DRAG
Airfoil without riblets	157575 Newton	1.38516 e6 Newton
Airfoil with riblets	274335 Newton	1.24075 e6 Newton

According to the analytical results and the obtained data, the lift and drag is calculated for the chosen airfoil which is employed with and without riblets. The Lift of the model by employing without riblets is **157575 N** and the drag of the model by employing without riblets is **1.38516 e6 N** and the Lift of the model by employing with riblets is **274335 N** and the drag of the model by employing with riblets is **1.24075 e6 N**.

Therefore, the lift produced by the model using riblets is 274335 N, and the drag produced by the model using riblets is 1.24075 e6 N. As lift increases, drag decreases, so the results conclude that the skin friction drag reduction is determined using riblets on supersonic wings.

4.2 ANALYTICAL RESULTS OF MODEL WITH RIBLETS

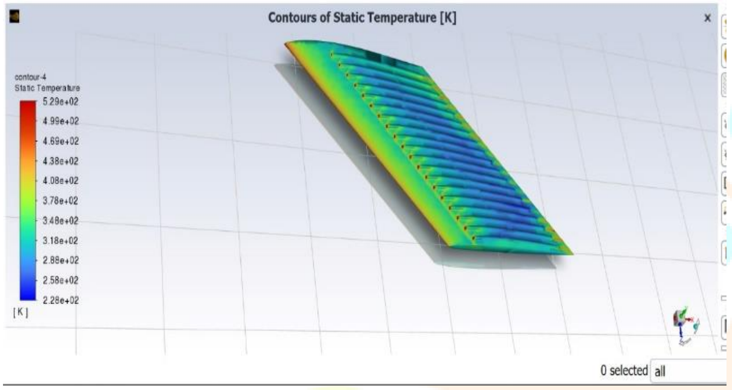


fig – 4.2.1 contours of static temperature

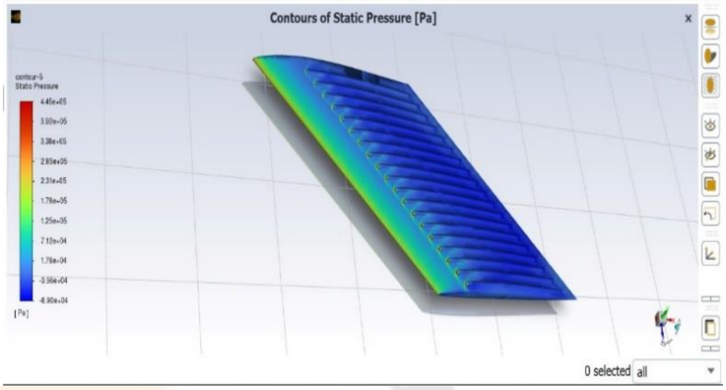


fig – 4.2.2 contours of static pressure

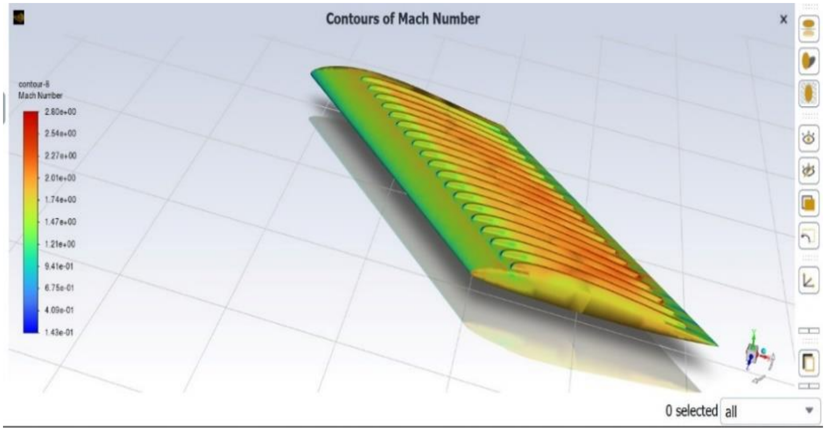


fig – 4.2.3 contours of mach number

5. CONCLUSION

The 3-D model of the winglet was created and analysed by using CFD tool Ansys to determine the meshing and contours of Mach Number, Static Temperature and Static Pressure by employing with and without riblets on the Supersonic winglet. The design parameters were selected for the winglet selection and airfoil selection for the design process. The overall purpose of this paper is to analyse the reduction of the skin friction drag of supersonic winglet by employing with and without riblets. From the above-mentioned results, the lift produced by the model by employing with riblets has more effective than the model employing by without riblets. Therefore, the lift produced by the model by employing riblets is **274335 N** and the drag produced by the model by employing riblets is **1.24075 e^6 N.** As lift increases, the drag decreases therefore it is concluded by the results that the reduction of the skin friction drag is determined by employing with riblets on supersonic winglets.

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