

Aerodynamic analysis of seamless horizontal stabilizer

S.Nithya¹ S.Kanimozhi²

^{1, 2}Department of Mechanical Engineering, Sathyabama University, India

Abstract. This project presents an investigative view into the concept of seamless aeroelastic wing and hingeless flexible trailing edge. Wings are designed to provide maximum lift and minimal drag and weight. But with conventional wings where rivets are used and the control surfaces are separately hinged, parasite drag comes into play. This project is about analysing a smooth seamless wing with hinge-less flexible trailing edge. This type of wing reduces the drag considerably and the hinge-less trailing edge leads to a minimal control demand and reduces the noise produced when the aircraft comes for landing. Seamless aeroelastic wing will function as an integrated one piece lifting and control surface. It has been designed to enhance a desirable wing camber for control by deflecting a hinge-less flexible trailing edge part instead of a traditional hinged control surface. This kind of flexible wing can be achieved either by a curved beam and disc actuation mechanism or by piezo-electric materials, whose shape change can be achieved by electricity. The intent of this project is to analyze the effects of introducing the concept of Seamless Wing to the horizontal stabilizer. While the removal of rivets and serrations that hinge the elevators to the stabilizer reduces the overall drag by a reasonable value, the overall concept of a control surface-less stabilizer where the maneuvers are done by deflecting the trailing edge offers better maneuverability.

1. Introduction

Surfaces on aircraft are embedded with millions of rivets. The model considered, Cessna 152 consists, in total of 2 million rivets. The horizontal stabilizer alone consists of about 200 rivets. The common types of rivets used are brazen head rivets and counter-sunk rivets. Some tests were conducted regarding the drag produced due to rivet heads way back in 1950's and with some positive results. Tests have been conducted in the NACA 8-foot high-speed wind tunnel to find the effect of rivet heads and spot welds on the wing drag. The tests were made of 5-foot chord airfoil. The velocity of the air was varied from 80 to 500 miles per hour and the lift coefficient from 0 to 0.30. The increment of the drag force on the 5-foot airfoil varied from 6%, due to countersunk rivets, to 27%, due to the 3/32-inch brazier rivet head, with the rivets in a arrangement. The drag increases caused by protruding rivet heads is directly related to the height of the heads. With the front row of rivets well forward, changes in span-wise pitch having insignificant effects on drag unless the pitch was more than 2.5% of chord. Data are presented for evaluating the reduction in drag attained by eliminating rivets from the forward part of the wing surface body; for example, it is shown that over 60 to 75% of the rivet drag is caused by the rivets on the forward 30 to 35% of the airfoil in a typical case.



2. Modeling.

Modeling is done using CATIA V5R20. A basic model of riveted horizontal stabilizer is made. The dimensions are taken from Cessna 152 aircraft. The dimensions of the rivets are as specified below.

The dimensions of the rivets are:

Diameter: 5.486mm

Height: 2.134mm

The distance between the rivets are calculated accordingly Edge distance = $2 \times \text{Rivet diameter}$

Rivet pitch (Spacing) = $\text{rivet diameter} \times 4$

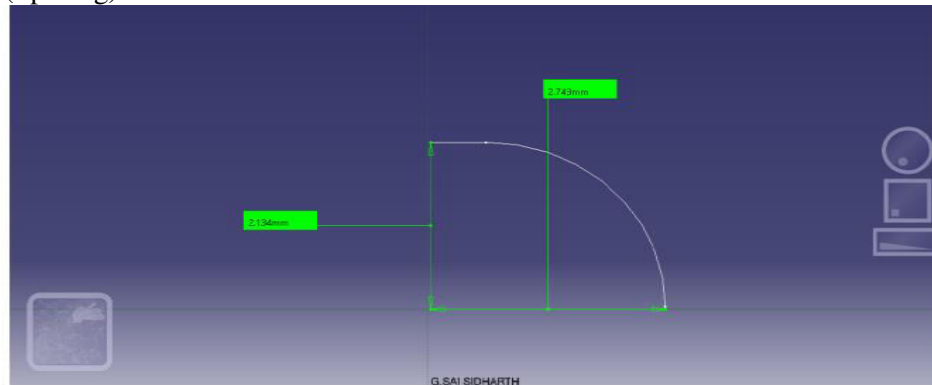


Figure 1. Rivet Dimensions.

2.1 Modelling of the Horizontal stabilizer

Horizontal stabilizer of cessna 152 is used for modelling, as it was available at the Sathyabama University Aero-Hangar and was available to be measured. A total of 24 models are meshed and analyzed to establish a set of results.

Root chord : 4feet

Tip chord : 2feet 7inches

Span length : 4feet 7inches

Elevator at root : 1foot 8inches

Elevator at tip : 1foot 2inches

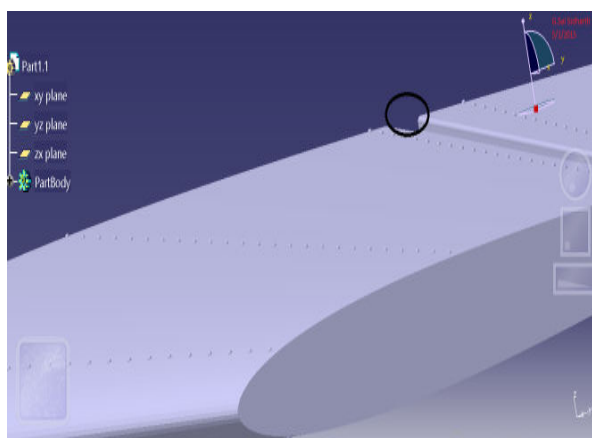


Figure 2. Regular surfaces with rivets.

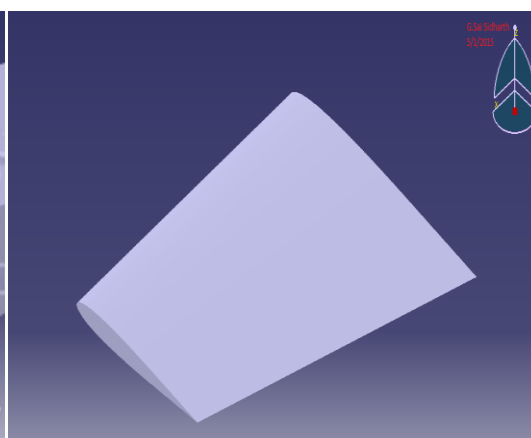


Figure 3. Devoid of rivets and serrations.

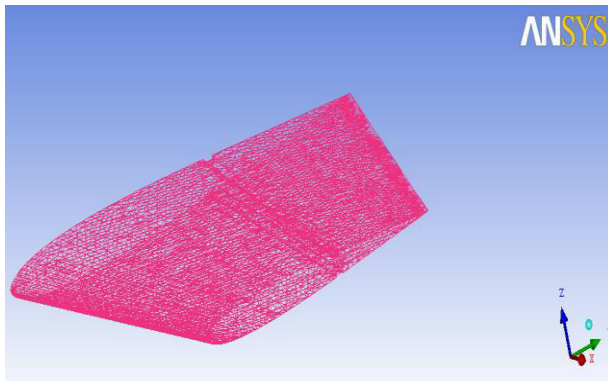


Figure 4. Meshed model of Regular surface.

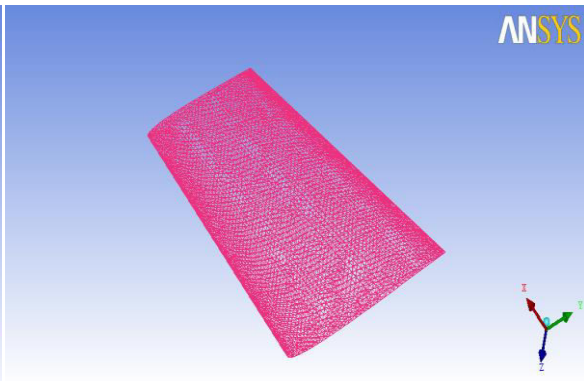


Figure 5. Seamless surface.

3. Analysis and Results

3.1 Method Of Analysis

3.1.1 Effect of span-wise location of rivets

To find the effect of span-wise location of rivets, four rows of rivets have been considered, one each at 0.275 feet, 1.2 feet, 2.4 feet and 3.9 feet from the root chord leading edge.

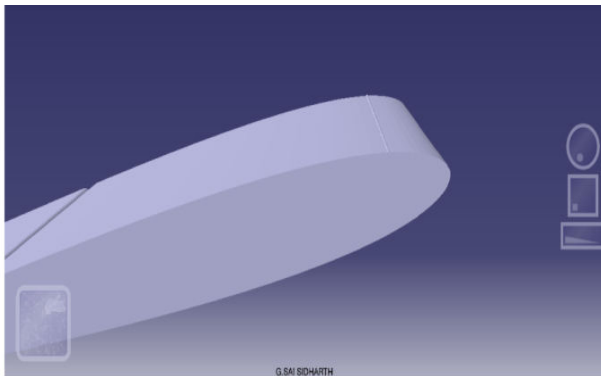


Figure 6. Rivets at 0.275 feet from chord.

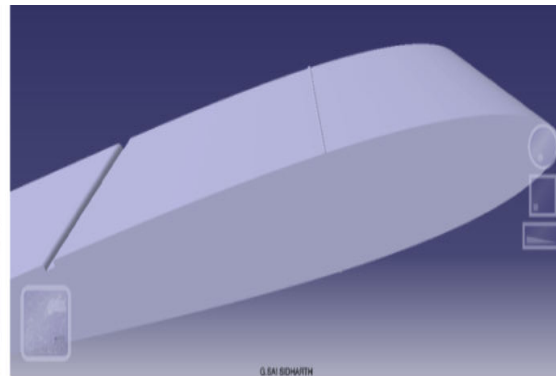


Figure 7. Rivets at 1.2 feet from chord.

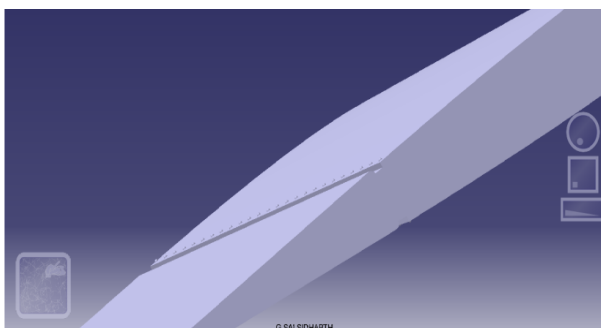


Figure 8. Rivets at 2.4 feet from chord.

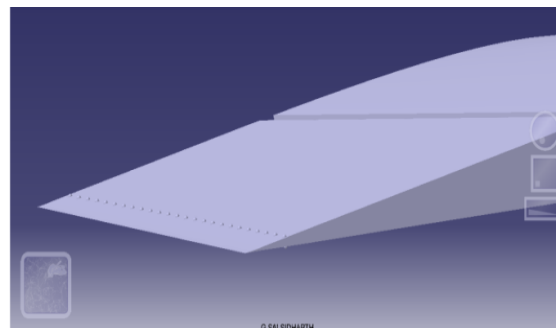


Figure 9. Rivets at 3.9 feet from chord.

The above three models had rivets at 0.275 feet, 1.2 feet and 2.4 feet respectively, the former two setup is located within 30% of the leading edge of the 4 foot chord airfoil, where the flow separation initially takes place. The fourth model is setup to have rivets at its trailing edge.

3.1.2 C_L vs α

To find the overall increase of Lift coefficient due to the use of seamless aerofoil over regular airfoil, 12 models are considered. -3° , 3° , 6° , 9° , 12° , 15° for each, regular and seamless surface. A graph depicting the angles of attack and C_L values of both the types are plotted.

3.1.3 δ_e (angle of deflection of elevator) vs C_L

CATIA models of both, regular surface and seamless surface with elevator deflection depicted at angles of 0° , 5° , 10° , 15° are made, meshed and analyzed. The resulting graph is used to arrive at the elevator efficiency, which is the parameter used to differentiate the stabilizers considered.

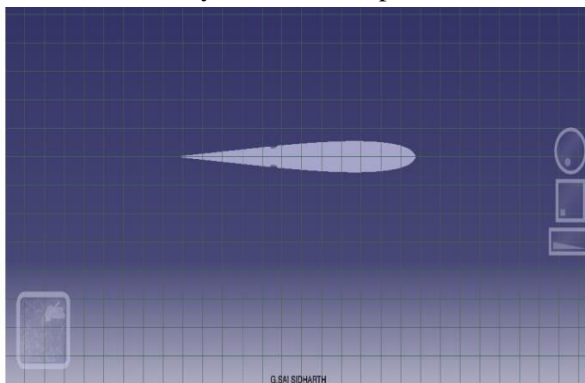


Figure 10. Zero degree deflection.

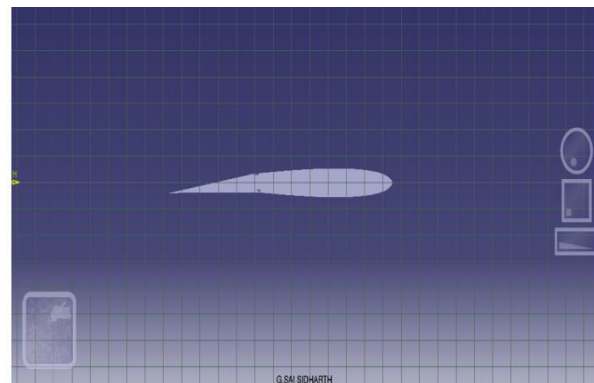


Figure 11. Five degree deflection.

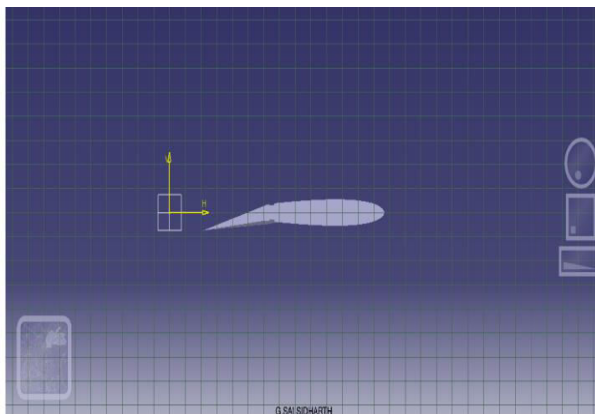


Figure 12. Ten degree deflection.

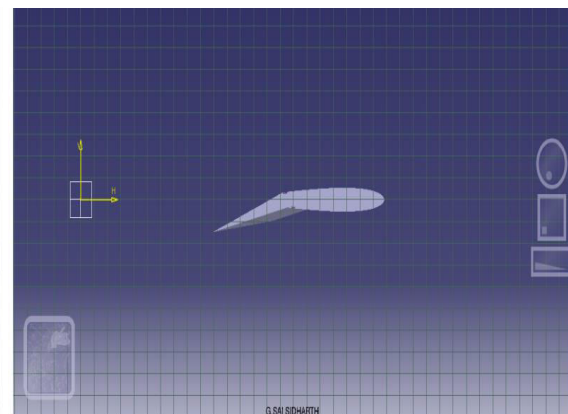


Figure 13. Fifteen degree deflection.

3.2 Analysis

Meshing is done in ICEM-CFD and the analysis is done in CFX, both are a part of the ANSYS workbench. The analyses are all carried out in the same boundary conditions.

The inlet and outlet of the domain is maintained at subsonic as the aircraft considered is a subsonic aircraft and supersonic analysis does not offer any further solutions to the horizontal stabilizer problem at hand.

The density of the atmosphere considered is 1.27 kg/m^3 , which indicates the altitude to be sea level and the temperature is at 25°C .

- Subsonic inlet and outlet

- Density: 1.27 kg/m^3
- Relative Velocity: 200 m/s
- Wall: No slip wall
- Air at 25°C
- Altitude: Sea level

This test was generic in nature and carried out to check the drag caused due to the span-wise location of rivets on a lifting surface.

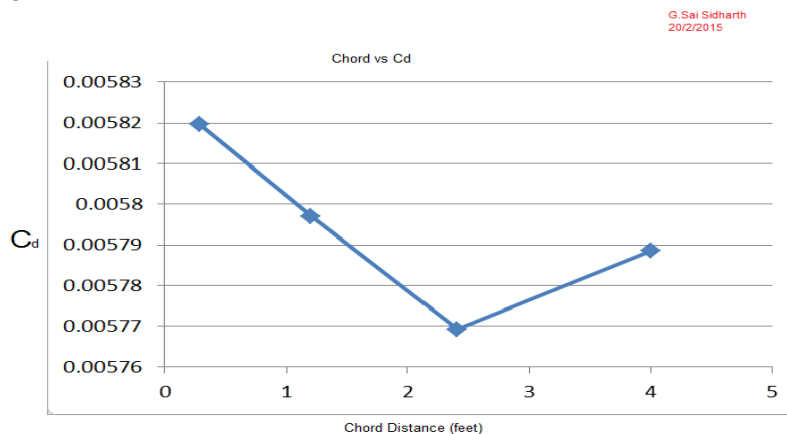


Figure 14. Chord vs C_d .

There is a high drag coefficient at the leading edge, which seems to reduce at 1.2 feet and 2.4 feet of chord and then there is a surge in the drag at the trailing edge.

Elevator Effectiveness

Elevator effectiveness is a parameter largely used to design horizontal stabilizers to suit an aircraft design.

The primary design of elevator in an aircraft is for the pitch rate. The non-dimensional derivative which represents the longitudinal control power derivative is the rate of change of pitching moment coefficient of aircraft with respect to elevator deflection ($C_{m\delta_e}$).

3.3 Contribution of elevator to tail lift

" $dC_l/d\delta_e$ " } Contribution of elevator to tail lift.

It is determined from the slopes of the graph C_l vs δ_e of both, regular surface and seamless surfaces.

Slopes of C_l vs δ_e = " $dC_l/d\delta_e$ "

The slopes from both the graphs are taken separately to figure out the contribution of elevator to tail lift.

" $dC_l/d\delta_e$ " (For regular surface)=0.01351

" $dC_l/d\delta_e$ " (For seamless surface)=0.01395

3.4 Longitudinal Control Power

Longitudinal control power is defined as the coefficient of pitching moment produced by the horizontal stabilizer for a given deflection of the elevator.

$$C_{m\delta e} = (-V_H \eta) dC_l / d\delta e$$

Where V_H is defined as the horizontal stabilizer volume ratio. It changes with a change in pitching moment. η is the pressure ratio and the value is a constant for given aircrafts, for Cessna 152, the value is 0.85.

$$V_H = 0.50$$

$$C_{m\delta e} = -0.00574175$$

3.5 Seamless Surface

$$C_{m\delta e} = (-V_H \eta) dC_l / d\delta e$$

$$V_H = 0.50$$

$$C_{m\delta e} = -0.00592875$$

Table 1. C_L vs δ_e for seamless surface.

Angle	Stress N/m ²
0'	0.00029557
5'	0.0667603
10'	0.136463
15'	0.209329

4. Conclusion

Seamless surface offers 3.25% more efficiency in control power and elevator tail lift. This can be observed due to the entire horizontal stabilizer acting as a one piece lifting surface. There is an increase in the span area of the stabilizer due to the absence of the gap where the elevator is attached to the horizontal stabilizer. The reduction in drag varies from 3% to 8% depending upon the angle of attack of the horizontal stabilizer and the location of rivets. The rivets placed at the leading and trailing edges cause the most of the drag whereas the rivets positioned at the center of the airfoil produce minimal or even negligible drag. Introduction of seamless surface to elevators may initially prove to be a bit costly on the economic aspects. But with usage, the economic returns start turning profitable to the airlines. A better control power, longitudinally can lead to shorter runways with advanced research. Due to the removal of the serration, there is no flow separation and no build up in pressure at the gap. This leads to a smoother flow over the surface.

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