ANALYSIS OF AERODYNAMIC PERFORMANCE OFAIRCRAFT WING ATTACHED WITH VORTEX GENERATORS USING CFD

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ABSTRACT

Pressure drag is a mechanical force generated by a solid moving object in fluid. This project focuses on the reduction of pressure drag in aircraft. Pressure drag is an unavoidable force which forms as a reaction force to the motion of the aircraft and thereby decreasing its performance. So, the object must put forth a huge extra force to pass through, likewise the aircraft needs more power to overcome the pressure dragforce which leads to more fuel consumption and decreasing the aircraft's efficiency. The complete aim of the project is to add a pressure drag reducing agent called vortex generator to reduce the pressure drag and increase the performance and efficiency of the aircraft. The addition of vortex generators will reduce the pressure on the wings surface which leads to rise in velocity on the wings surface. The increase in velocity anddecrease in pressure will decrease the pressure drag force that acts on the aircraft which thereby increases theaircraft's performance. This project holds the complete process of modeling aircraft in CATIA™ V5 and analyzing the aircraft with vortex generators to clearly visualize the idea of using vortex generators to reduce pressure drag. As computational fluid dynamics analysis using ANSYS® FLUENT can easily compute resultson applications that use airflow, it is used for analyzing the aircraft's wing to show the reduction of pressure drag.

Keywords*—Pressure drag, Reduction of Pressure drag, Vortex Generators, Computational Fluid Dynamics. Abbreviations—Computational Fluid dynamics: CFD, Vortex Generators: VG's.*

INTRODUCTION

An aircraft is a machine that is able to fly by gaining support from the air. It counters the force of gravity by using either static lift or by using the dynamic lift of an airfoil or in a few cases the downward thrust from jet engines [1]. Aim of the project is to decrease the pressure drag on the aircraft by modifying the object geometry with the help of pressure drag reducing agents to increase the efficiency of the aircraft. This project on reductionof pressure drag is done on the Boeing 737-600 aircraft because all the dimensional parameters are open source data. The pressure drag is more on the aircraft wings when compared to the fuselage and other parts of the aircraft[2, 3 and 4]. The fuselage pressure drag is neglected unless it is a supersonic or an aircraft with blended wings because the induced pressure drag is very less on the fuselage and it only has parasite pressure drag [5, 6]. The pressure drag in this project on the wings is reduced using pressure drag reducing agents called as vortex generators. The shape of the vortex generators are modified to resemble like a reversed modified airfoil which isvery smaller in size for better performance and the number of vortex generators is also increased.

The literature survey for this project is from journals by Md. Fazle Rabbi, Rajesh Nandi, Mohammad Mashud et al. Induce Pressure drag Reduction of an Airplane Wing describes some of the modeling aspects for the aircrafts [7]. Mohsen Jahanmiri et al. Aircraft pressure drag reduction an overview states the various changes that have been done with respect to pressure drag reduction [8]. Staffan Hardie et al. Pressure drag force estimations on experimental aircraft states the details and basics for meshing and analysis using Computational Fluid Dynamics[9]. Shubam Agarwal, Priyank Kumar et al. Numerical investigation of flow field and effect of varying vortex generator location on wing performance states the vortex generators and correct placement of vortex generators for best results [10]. John C. Lin, Stephen K. Robinsont, Robert J. McGhee et al. Separation control on high lift airfoils using micro vortex generators states the use of micro vortex generators on airfoil and its results [11].

The scope of this project is to improve the air transportation by increasing the performance and efficiency of the aircraft. Since the aircraft is very huge, high cost and time to experiment the change with a real aircraft. So, the aircraft is modeled and a CFD analysis is carried out to get the desired result of our project. The vortex generators used in the aircraft will make the airflow to flow in a defined path and makes the air swirl, thereby making it flow along the wing surface reducing the pressure drag. The reduction in pressure drag is taken from the results of the CFD analysis.

The methodology of this project is studying of the aircraft, studying of pressure drag and factors affecting pressure drag, then the modification to reduce the pressure drag. After this the aircraft is modeled in CATIA, twomodels are made; one is the existing and the other with the vortex generators for easy comparison. Then the model is meshed in HYPERMESH software and analysis in Computational Fluid Dynamics by ANSYS Fluent software. Finally the results are inferred and the existing and new design are compared.

MODELING AND ANALYSIS

A. Vortex Generators

A vortex generator is a small angled plate installed on an outer surface of an aerodynamic body. The plate causes the air to swirl and also creates a defined path to the air flow. This effect allows the air flow to remain attached to the surface even at points where the flow without a vortex would separate from the surface. This makesthe air flow properly over the wing surface and it will reduce the amount of pressure drag that will act on the airfoil.

In this project, the vortex generators are not angled but instead kept parallel to the air flow direction. This is because the absolute aim of the project is to reduce the pressure drag and not on stalling of wings. The number ofvortex generators is also increased and kept throughout the leading edge of the wing surface.

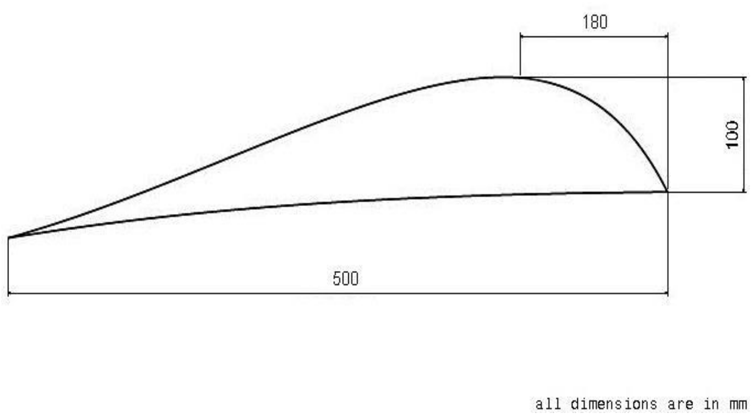


Fig. 1. New shape of vortex generator

Figure 1 shows that the shape of the vortex generator which is changed from existing triangular, rectangular, gothic, parabolic and ogive design to a shape which resembles inverted airfoil shape that is connected with spline.This is based on a concept that less area leads to less pressure drag [3] and also avoiding sharp edges. All the dimensions used in the above figure 1 are in mm. The vortex generators are placed eight percent of the chord length from the leading edge. This is because, according to literature survey, Numerical investigation of flow field and effect of varying vortex generator location on wing performance by Shubam Agarwal and Priyank Kumar [10], eight to 10 percent distance from leading edge gives good result and this placement gives best results as perleading vortex generator manufacturers.

B. Existing and New design with and without Vortex generators

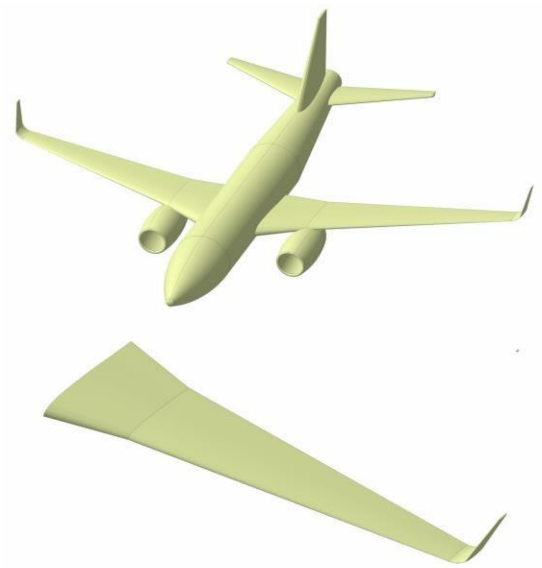


Fig. 2. Existing model of Boeing 737-600 without vortex generators

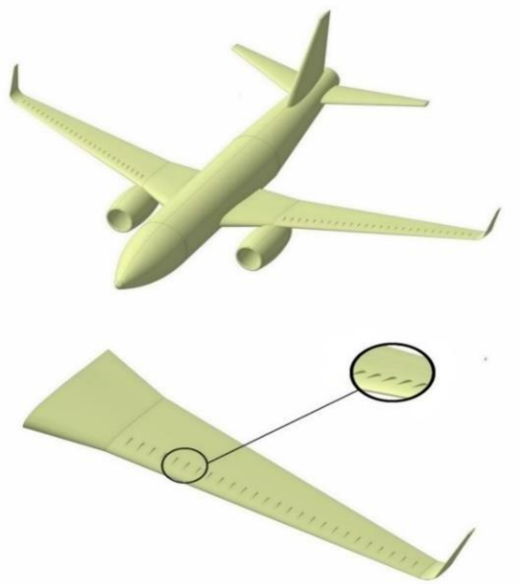


Fig. 3. New model of Boeing 737-600 with vortex generators

Figure 2 and 3 shows the model of Boeing 737-600 without vortex generators and after placing the vortex generators.

C. Analyzing using Computational Fluid Dynamics

Ansys Fluent software is the most-powerful computational fluid dynamics tool available, empowering to go further and faster as optimizing the wing's performance. Fluent includes well-validated physical modeling capabilities to deliver fast, accurate results across the widest range of CFD and multi physics applications. So, weuse Ansys Fluent as the software to do CFD analysis. The velocity of air used for analysis is $60ms^{-1}$.

RESULTS AND DISCUSSION

A. Meshing using HYPERMESH

Fig. 4. Meshing of wing without vortex generators

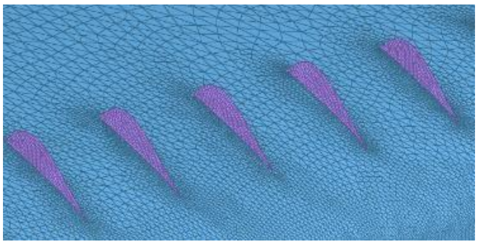


Fig. 5. Meshing of wing with vortex generators

Figure 4 and 5 shows the unstructured meshing done on the wing with vortex generators and wing withoutvortex generators.

B. Analysis of Pressure

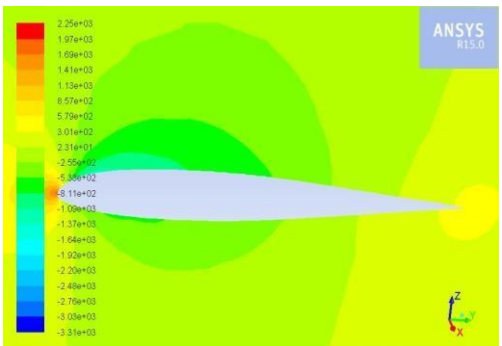


Fig. 6. Pressure without vortex generators

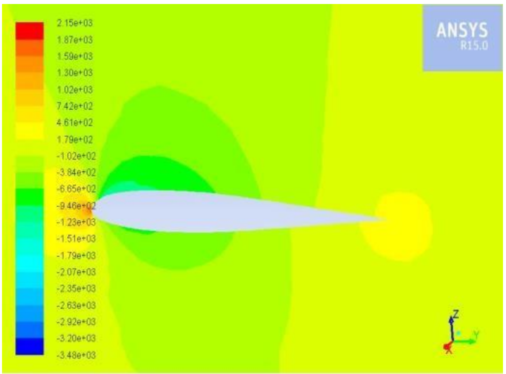


Fig. 7. Pressure with vortex generators

Figure 6 and 7 shows the pressure on the aircraft wing before and after placing the vortex generators. Pressureobtained are shown below and described in figure 8.

Leading edge pressure without VG's, P_{1L} = 1.83Kpa

Leading edge pressure with VG's, P_{2L} = 1.83Kpa Trailing edge pressure without VG's, P_{1T} = 0.44KpaTrailing edge pressure with VG's, P_{2T} = 0.32Kpa Reduction in pressure on trailing edge, $P_R = P_{1T} - P_{2T}$ P_R = 0.44Kpa – 0.32Kpa,

P_R = 0.12Kpa

Percentage of pressure reduced in trailing edge

$$= \left(\frac{\text{reduction in pressure on trailing edge}}{\text{actual pressure on trailing edge}} \right) \times 100 = \left(\frac{P_R}{P_{1T}} \right) \times 100$$

$$= \left(\frac{0.12}{0.44} \right) \times 100$$

$$= 27.27\%$$

The amount of pressure reduced in trailing edge is 27.27% after placing the vortex generators.

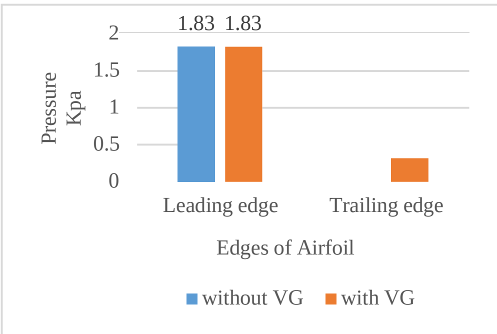


Fig. 8. Pressure on the wings

C. Analysis of Velocity

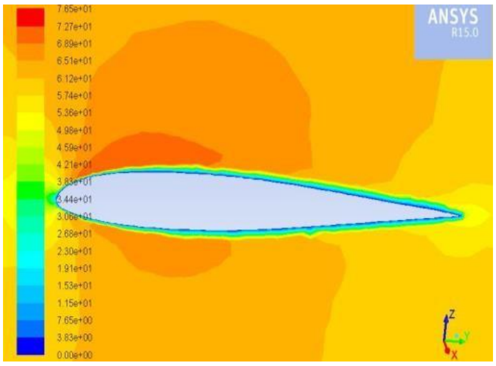


Fig. 9. Velocity without vortex generators

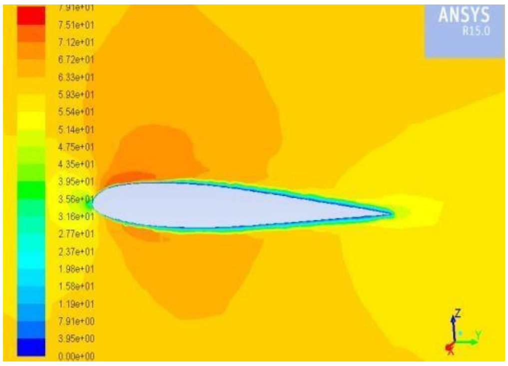


Fig. 10. Velocity with vortex generators

Figure 9 and 10 shows the velocity on the aircraft wing before and after placing the vortex generators. Velocityobtained are shown below and described in figure 11.

Leading edge velocity without VG's, V_{1L} = 28.7m/s
Leading edge velocity with VG's, V_{2L} = 28.7m/s
Trailing edge velocity without VG's, V_{1T} = 44m/s
Trailing edge velocity with VG's, V_{2T} = 50m/s
Increase in velocity on trailing edge $V_I = V_{2T} – V_{1T}$
V_I = 50m/s – 44m/s, V_I = 6m/s

Percentage of pressure reduced in trailing edge

$$= \left(\frac{\text{Increased velocity of air on trailing edge}}{\text{Actual velocity of air on trailing edge}} \right) \times 100 = \left(\frac{V_I}{V_{1T}} \right) \times 100$$

$$= \left(\frac{6}{44} \right) \times 100$$

$$= 13.63\%$$

The amount of velocity of air increased on trailing edge is 13.63% after placing the vortex generators.

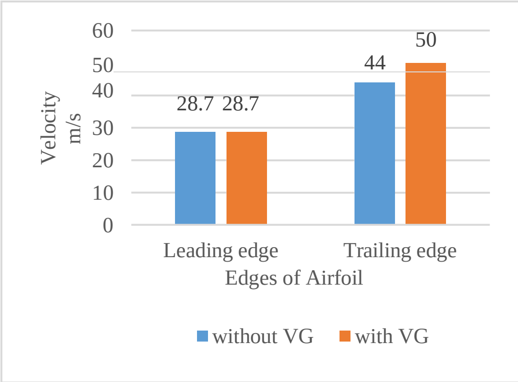


Fig. 11. Velocity of air on the wings

D. Turbulence

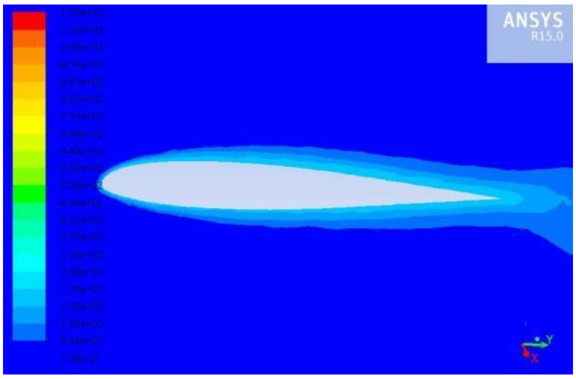


Fig. 12. Turbulence without vortex generators

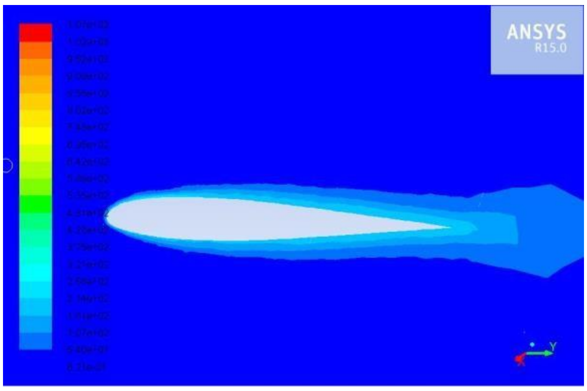


Fig. 13. Turbulence with vortex generators

Figure 12 and 13 shows the turbulence on the aircraft wing before and after placing the vortex generators. Turbulence values obtained are shown below and described in figure 14.

Leading edge Turbulence without VG's = 108%

Leading edge Turbulence with VG's = 108%

Trailing edge Turbulence without VG's = 243%

Trailing edge Turbulence with VG's = 241%

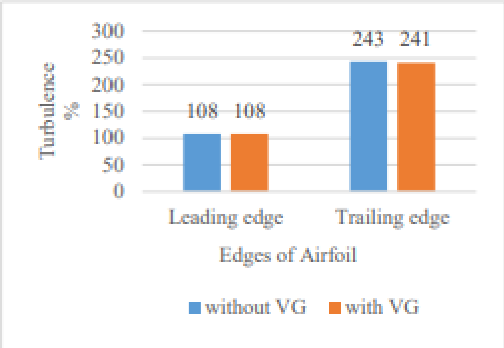


Fig. 14. Turbulence on wings

E. Vorticity

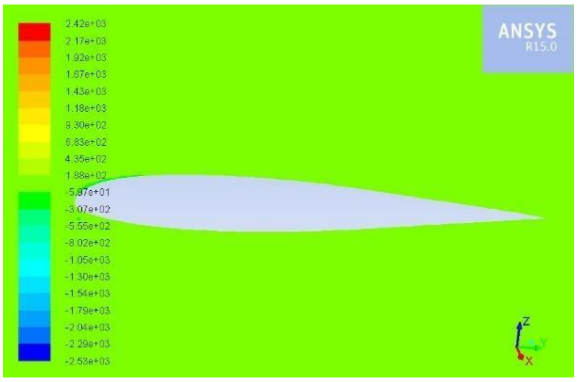


Fig. 15. Vorticity without vortex generators

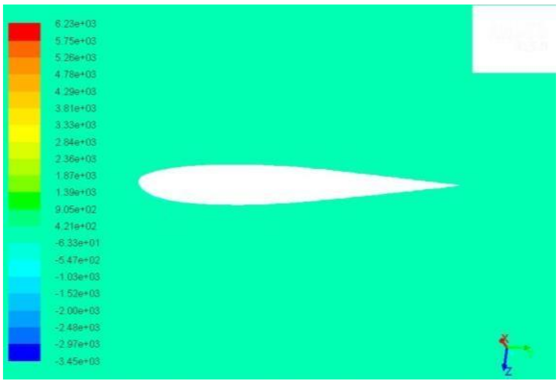


Fig. 16. Vorticity with vortex generators

Figure 15 and 16 shows the vorticity on the aircraft wing before and after placing the vortex generators. Vorticityvalues obtained are shown below and described in figure 17.

Leading edge Vorticity without VG's = 64s^{-1}

Leading edge Vorticity with VG's = 64s^{-1}

Trailing edge Vorticity without VG's = 311.5s^{-1}

Trailing edge Vorticity with VG's = 178.85s^{-1}

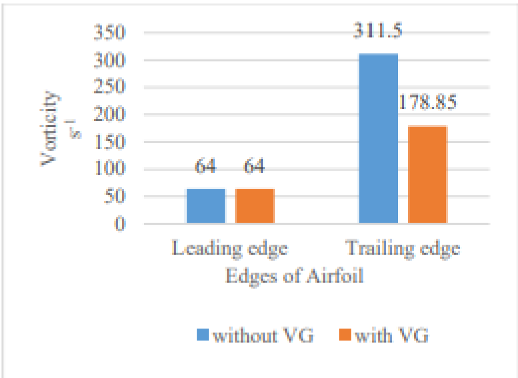
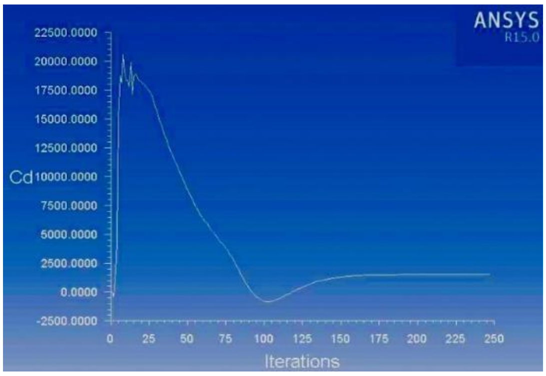


Fig. 17. Vorticity on wings

F. Convergence of Pressure drag, Lift and Equations



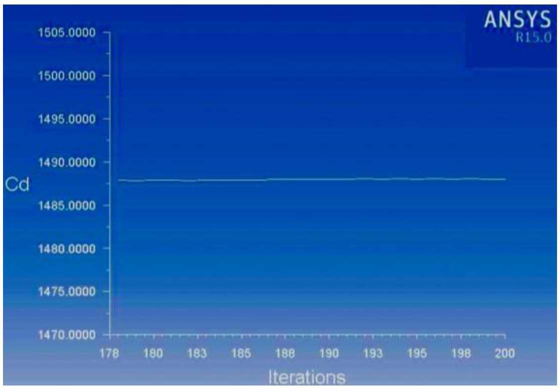


Fig. 18 and 19. Convergence of coefficient of pressure drag without and with VG's respectively

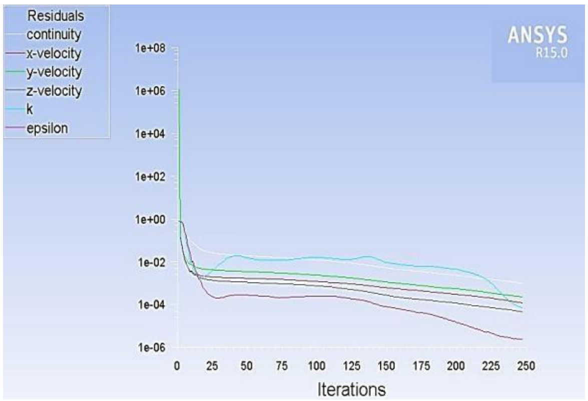


Fig. 20. General Convergence of equations

Convergence is a criteria where at a particular iteration, all the values will remain the same henceforth. The convergence criteria at which it should converge is fed in ANSYS Fluent. So, after convergence, the analysis is over denoting that upcoming values have no change. Figure 18 and 19 shows the convergence of the coefficient of pressure drag. Figure 20 shows the general convergence of the equations. All the equations like continuity equation, momentum equation (x, y and z velocity), turbulent kinetic energy equation (k) and the turbulent dissipation equation (epsilon) are converged.

G. Force

Table 1

Forces acting on wings in X, Y and Z direction without vortex generators

ZONE	PRESSURE DRAG FORCE (N)		
	F_{X1}	F_{Y1}	F_{Z1}
WING BOTTOM	27.21	718.76	-8552.99
WING TOP	413.80	175.82	18958.70
WING TAIL	-219.96	22.07	52.77
WING HEAD	-655.67	13.13	-0.26
NET FORCE	-434.61	929.81	10458.22

Table 2

Forces acting on wings in X, Y and Z direction with vortex generators

ZONE	PRESSURE DRAG FORCE (N)		
	F_{X2}	F_{Y2}	F_{Z2}
WING BOTTOM	224.13	642.95	13075.49
WING TOP	532.10	233.54	23046.90
WING TAIL	-112.59	14.73	44.65
WING HEAD	-955.05	12.95	-0.11
TURBULATORS	88.87	3.59	0.15
TURB-SHADOW	10.61	3.60	0.15
NET FORCE	-389.66	911.38	10016.26

Table 1 and 2 shows the total forces acting in x, y and z direction that is inferred from ANSYS Fluent. The datain the table is for without and with vortex generators respectively. The forces shown in the above table are for thewing's bottom, top, tail and head surfaces. The negative direction in the forces indicates the direction of the force.It can be inferred from the table that,

The total force on wing without vortex generators

$F_{wvg} = F_{x1} + F_{y1} + F_{z1}$

$F_{wvg} = -0.43 + 0.92 + 10.45$

$F_{wvg} = 10.94$ KN

The total force on wing with vortex generators

$F_{vg} = F_{x2} + F_{y2} + F_{z2}$

$F_{vg} = -0.38 + 0.91 + 10$

$F_{vg} = 10.53$ KN

Pressure drag force reduction in the wing

$F_R = F_{wvg} - F_{vg}$

$F_R = 10.94 – 10.53$

$F_R = 0.41$ KN

Percentage of overall pressure drag reduced in the wing is

$$= \left(\frac{\text{Overall Pressure drag reduction}}{\text{Pressure drag force on wing without VG's}} \right) \times 100 = \left(\frac{F_R}{F_{wvg}} \right) \times 100$$

$$= \left(\frac{0.41}{10.94} \right) \times 100$$

$$= 3.74\%$$

Pressure drag reduction considering total aircraft neglecting fuselage, is the average of pressure drag reduction percentage in each wing. Pressure drag reduction on wing on both sides are equal since both the wings are symmetrical.

Percentage of Overall pressure drag reduction

$$= \left(\frac{3.74 + 3.74}{2} \right) = \left(\frac{7.48}{2} \right) = 3.74\%$$

Overall pressure drag reduction in the total aircraft is 3.74%.

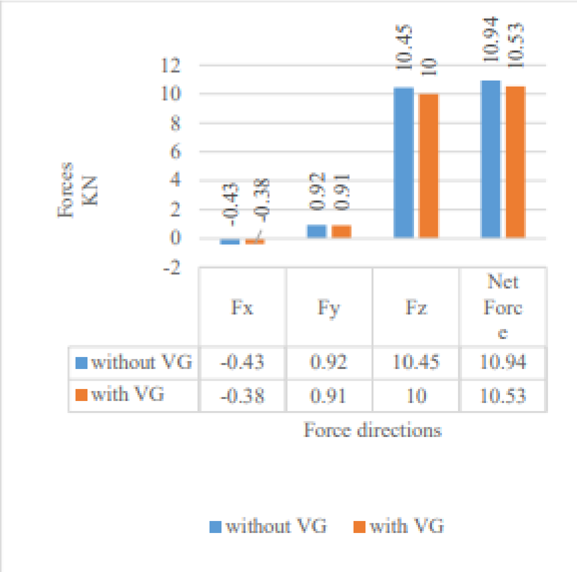


Fig. 21. Forces with and without VG's

CONCLUSION

Table 3

Conclusion from the results

WITHOUT VORTEX GENERATOR	WITH VORTEX GENERATOR
1. Pressure in trailing edge is 0.44 Kpa.	1. Pressure in trailing edge is 0.32 Kpa.
2. Velocity in trailing edge is 44 m/s.	2. Velocity in trailing edge is 50 m/s.
3. Turbulence in trailing edge is 243%.	3. Turbulence in trailing edge is 241%.
4. Vorticity in trailing edge is 311.5s^{-1}.	4. Vorticity in trailing edge is 178.8s^{-1}.
5. Total pressure drag force on wing 10.94 KN.	5. Total pressure drag force on wing 10.53 KN.

Table 3 shows the conclusion of the project showing the analysis results for the existing design and the new design. From the results we can infer that

- Percentage of pressure reduced after placing vortex generators is 27.27%. The Pressure should be reduced because more pressure leads to more Pressure drag [12, 13 and 14]
- Percentage of velocity increased after placing vortex generators is 13.63%. The Velocity should be increased because pressure and velocity are inversely proportional. If pressure decreases, the velocity will increase [15,16] and vice versa. In other way, high velocity means less pressure drag.
- Turbulence decreased from 243% to 241%. The Turbulence should be decreased because increase in turbulence intensity leads to increase in Pressure drag [17].
- Vorticity decreased from 311.5 s^{-1} to 178.85 s^{-1}. Vorticity should be decreased because increase in vorticity leads to more induced drag.
- Percentage of overall pressure drag force reduced is 3.74%. The aim of the project is achieved.

From the CFD analysis results, it is clearly observed that the pressure drag force on the aircraft is reduced. It has been found that placing these vortex generators can decrease pressure drag and increase the performance andefficiency of the aircraft. There are many works that can be done on aircraft wings in future like as to change shape of vortex generators like extending its edges and placing them at a different region like trailing edge or evenon the middle of chord that may increase the performance of the aircraft. The reduction in aircraft pressure drag has many futuristic aspects as this particular field of research have got no end. Many aspects of an aircraft can bechanged to reduce the pressure drag without altering the basics of flight.

NOMENCLATURE

P_L = Pressure at leading edge
P_T = Pressure at trailing edge
P_R = Reduction in pressure at trailing edge
V_L = Velocity of air at leading edge
V_T = Velocity of air at trailing edge
V_I = Increase in velocity of air at trailing edge
F_{wvg} = Force without vortex generators
F_{vg} = Force with vortex generators
F_R = Reduction in pressure drag force

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