# Reduction of Induced Drag Using Wing Tip Propeller

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***Abstract****: Winglets are used to reduce the induced drag.. This paper propose an idea of using a propeller at the wing tip. The propeller is mounted in such a way that the blade tip is quite near to the wing tip. The rotation of the propeller induces two kinds of velocities namely an axial velocity and the rotational component of velocity. This rotational component does not allow the flow to curl upwards as it cancels it on the same plane of the wing and the axial component produces some thrust leading to a decrease in fuel consumption and indirectly better performance. The project aims to study the amount of reduction of the induced drag by experimental analysis in the wind tunnel. The results shows the increase in aerodynamic efficiency by using the propeller at the wing tip.*

***Keyword****- Induced Drag, Circulation, Propeller, wing tip, flow control, drag reduction, numerical simulation*

## 1. Introduction

The induced drag force is a result of downwash or wingtip vortices which shifts the lift vector backwards, thus causing an increase in the drag.

On a wing of finite span, this pressure difference causes air to flow from the lower surface to the upper surface wing along the span. This span wise flow of air combines with chord wise flowing air, causing a change in speed and direction, which twists the airflow and produces vortices along the wing trailing edge. The vortices created are unstable, and are commonly known as wingtip vortices. The resulting vortices change the speed and direction of the airflow behind the trailing edge, deflecting it downwards, leading to the lower effective angle of attack and increasing the fuel consumption to overcome the drag.

The induced drag will be maximum at low subsonic speeds and at high angles of attacks. It decreases with an increase in speed.

Throughout these years the advancement in research on induced drag, various attempts have been made to limit the vortex effect to decrease both induced drag and danger to following aircraft. Presently winglets are used to serve the purpose. A winglet is the vertical extension of the wingtip which does not allow the flow from the bottom to curl up. Various types of winglets are used in the present world. The most commonly used winglets are blended winglet, raked winglet, wing tip fence, non-planar winglet.

A blended winglet is attached to the wing with a smooth curve instead of a sharp angle in order to reduce both interference drag and the induced drag. A wingtip fence refers to the winglets used in some Airbus airplane models which include surfaces extending both above and below. Raked wingtips are a feature on some Boeing airliners, where the tip of the wing has a higher degree of sweep than the rest of the wing. Raked wingtips have been shown to reduce drag by as much as 5.5%, as opposed to improvements of 3.5% to 4.5% from conventional winglets. Non-planar wingtips are normally angled upwards in a polyhedral wing configuration, increasing the local dihedral near the wing tip, with polyhedral wing designs themselves having been popular on free flight model aircraft designs for decades.

Md. Fazle Rabbi et al studied the induced drag reduction creating three slots of same length along the span direction near the wing tip. As a result, induced drag was reduced to 25-30% relative to induced drag of wing without winglet [12]. Alekhya Bojja and Parthasarathy Garre studied the Boeing 767 wing designed with blended winglet and circular winglet. Analysis on blended winglet shows less Cd value than that with circular winglet at 12o angle of attack [2]. Mohmed Elias Inam et al conducted experiment on wing with winglet of rectangular, triangular and circular configurations to obtain induced drag on each compared to that with wing without winglet. Triangular configuration shows less drag coefficient compared to other two [13]. Swagat Prasad Das et al experimented the wing designed with single slotted raked wingtip. This experiment shows considerable reduction in drag coefficient and increase in stall angle [15]. Sangram keshari and P.K Dash conducted an experiment on cancelling out the wing tip vortices by making the suction slot at wing tip. As a result, tip vortices were cancelled out leaving behind the stream of vortices downstream of the wing. Then, one more suction slot at the bottom of the wing near trailing edge made the air leave smoothly without creating wing tip vortices. Thus the reduction in drag coefficient [14]. U. La Roche et al studied that wing designed with wing grid at the tip also reduces the drag coefficient by considerable amount [18].

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## 2. Experimental analysis

### Subsonic wind tunnel:

The experiment was conducted in sub-sonic suction type wind tunnel shown in fig.1. It consist of test section dimension 600 mm (H) × 600 mm (W) × 1200 mm (L). The overall dimension of the wind tunnel is given by 8500 mm (L) × 1200 mm (W) × 2500 mm (H) with operating velocity of 30 m/s. Honey comb structure is at the entrance of the wind tunnel to reduce the free – stream turbulence of the air and decreasing the nominal turbulence of the test section.

**Figure 1:** Subsonic wind tunnel

### Wing design:

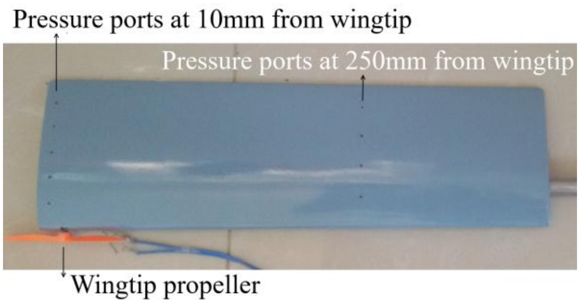


**Figure 2:** Top view of wing with pressure ports and propeller near the wingtip.

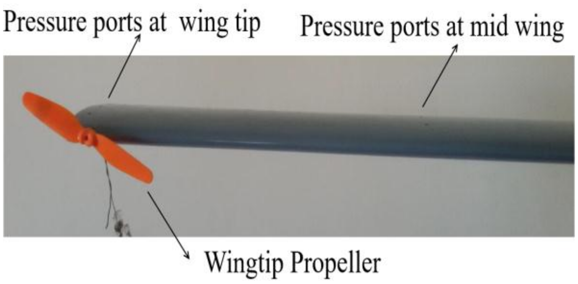


**Figure 3:** Front view of wing with pressure ports and propeller near the wingtip.

The teak wood wing model with NACA 2414 airfoil profile cross section as shown in fig. 2 & fig.3 is of 400mm in span, 120 mm in chord. Two rows of pressure ports are incorporated along the span of the wing. One set of pressure ports (10 ports) is at 250mm from the wing tip and another set (8 ports) is near the tip i.e. 10 mm from the wing tip. The motor with two bladed plastic propeller (diameter of 45mm) is inserted in the drilled portion of 3mm at the leading edge 20mm inwards from the wingtip.

### Uno Arduino and Motor:

The Arduino Uno as shown in fig.4 is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, Flash Memory 32 KB (ATmega328) of which 0.5 KB used, a USB connection, a power jack, an ICSP header, and a reset button. Also it's operating Voltage - 5V; Input Voltage (limits) 6-20V; DC Current per I/O Pin 40 mA and DC Current for 3.3V Pin 50 mA.


**Figure 4:** Uno Arduino microcontroller


**Figure 5:** DC motor

### Set up:

A pitot-static tube is placed in the test section to find the static and stagnation pressure. The aerofoil ports are connected to the multi- manometer, through which the static pressure for each ports are measured for the calculation. The rpm of the propeller is measured by using tachometer. A reflecting tape was attached on the back side of the propeller and place the tachometer behind the wing. From the finite wing theory coding it is found that, the wing with NACA 2414 aerofoil placed at the freestream velocity of 15m/s produces the circulation at the tip of the wing is 1.3m/s for the angle of attack of 4° and 1.7m/sec for the angle of attack of 6°. The RPM of the wingtip propeller to cancel the circulation at the wing tip was calculated as 570 RPM and 760 RPM for angle of attack of 4° and 6° respectively by taking no slip condition and assuming there is no frictional torque. Experiment is done for wing with/without wingtip propeller of RPM higher than the calculated vales for different angle of attack of 4° and 6° at freestream velocity of 15 m/s. Due to the speed constrain of the wind tunnel, 15 m/s flow velocity were chosen. And because of the small plastic propeller fitted into the wing, experiment was done for small angle of attacks (α ≥ 6°). Otherwise propeller will be pulled away from the wing by the freestream air flow.

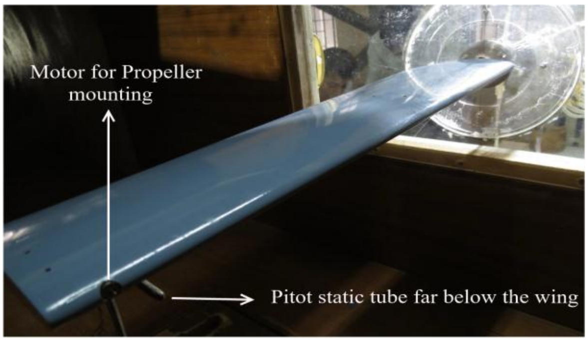


**Figure 6:** wing fitted inside the test section without propeller

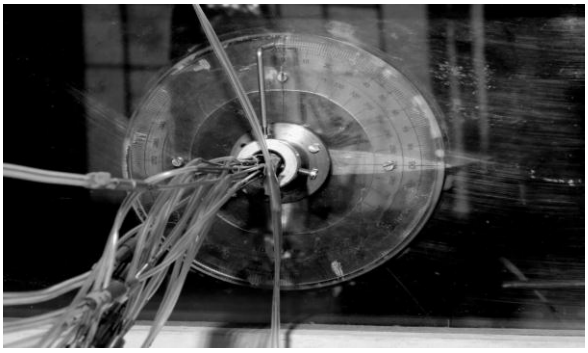

**Figure 7:** left side of the test section with pressure port tubes from wing

## 3. Results and Discussions

The NACA 2414 reference wing model of 400mm in span, 120 mm in chord with/without the wingtip propeller is taken for experimental analysis for the velocity of 15m/s and for different angle of attack (α) 4˚ and 6˚. Fig.8 shows the decrement of coefficient of drag near the tip of wing (10mm from wingtip) with wingtip propeller for different angle of attack for freestream velocity of 15 m/s. the slipstream of propeller cancelled the curl around the wingtip hence drag is decreased. Fig.9 shows the increment in lift to drag ratio (Aerodynamic efficiency) near the tip of wing with wingtip propeller for velocity of 15 m/s.

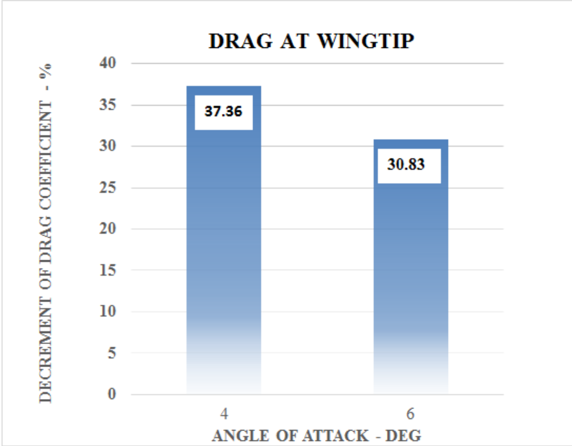


**Figure 8: P**lot of decrement of coefficient of drag near the tip of wing with wingtip propeller

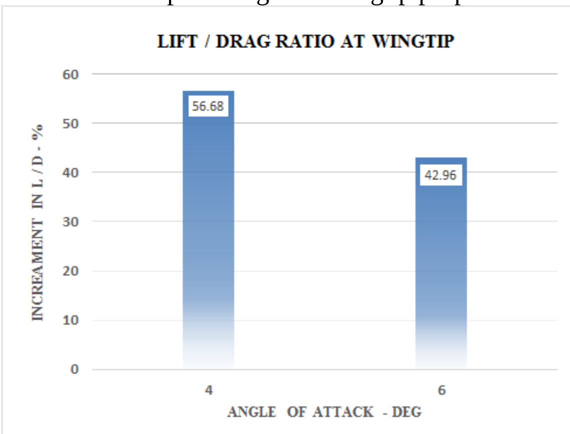


**Figure 9:** Plot of increment in lift to drag ratio near the tip of wing with wingtip propeller

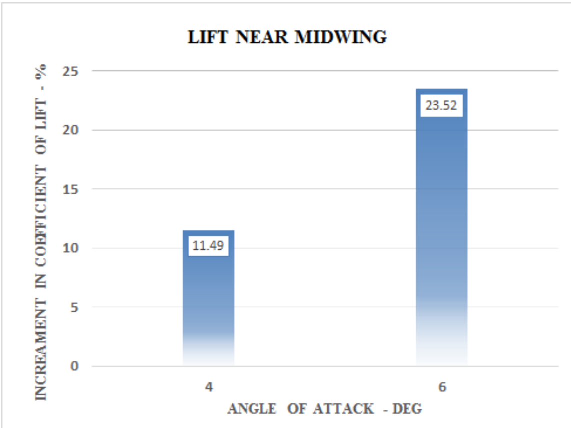


**Figure 10:** Plot of increment of coefficient of lift near midsection of wing with wingtip propeller

Fig.10 shows the increment in coefficient of lift at 250mm from the wingtip (near midsection of wing) of wing with wingtip propeller. Propeller slipstream blocked the inward flow on the upper surface of the wing as it cancelled the curl flow around the wingtip. So it is observed that the increment in lift to drag ratio near midsection of wing with wingtip propeller compared to the reference wing as shown in Fig.11.

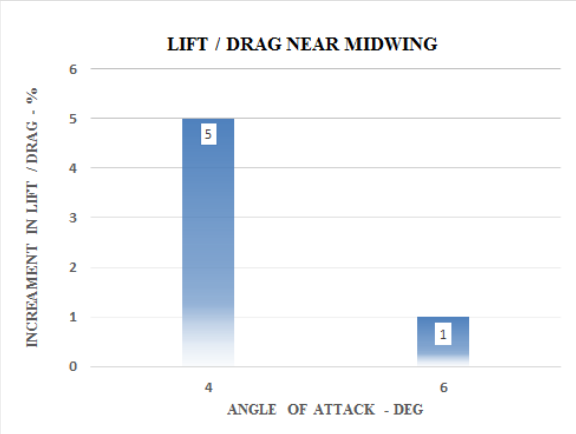


**Figure 11:** Plot of increment in lift to drag ratio near midsection of wing with wingtip propeller

*At 4 degree angle of attack:*
Near the tip of the wing with wingtip propeller, $C_D$ value reduced by 38 %, $C_L$ value decreased by 2 %, and L/D ratio increased by 57 % compared to the wing without wingtip propeller. At 250mm from the tip of the wing with wingtip propeller, $C_L$ value increased by 12 %, $C_D$ value slightly increased by 7 %, and L/D increased by 5 % compared to the wing without wingtip propeller.

*At 6 degree angle of attack:*
Near the tip of the wing with wingtip propeller, $C_D$ value reduced by 31 %, $C_L$ value decreased by 1.12 %, and L/D ratio increased by 43 % compared to the wing without wingtip propeller. At 250mm from the tip of the wing with wingtip propeller, $C_L$ value increased by 24 %, $C_D$ value slightly increased by 22 %, and L/D increased by 1 % compared to the wing without wingtip propeller.

## 4. Conclusion

The wing with propeller mounted at the wingtip of chord 120mm and span of 400mm is subjected to experimental analysis in subsonic wind tunnel for velocity of 15m/s and for small angle of attack less than 6˚. The reduction in induced drag has been the aim of the project. For the same, an investigation has been done on the aerodynamic effects of the wing tip mounted propeller. The major conclusion for the experimental analysis is summarized in the following paragraphs. It has been observed:

In a wing without propeller, the flow curls up at the tip, creating a downwash and decreasing the lift and increasing the drag. But Wing with the propeller, the angular component of propeller slipstream flow does not allow the flow to curl upward, thereby reducing drag to a great extent and increasing the L/D ratio of the wing.

At small angles of attack ($\alpha \geq 6°$), a significant reduction in drag of the order of 30-37 % at the wingtip. Although there had been a decrement in the lift, but the L/D ratio was seen to increase 43-57% at the tip and 1 - 5% at 250mm from the wingtip.

## 5. Acknowledgements

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## 6. References

[1] Bojja A., and Garre P., “Analysis on reducing the induced drag using winglet at the wingtip”, IJERT, 2013, Vol. 2, Issue-12.
[2] Bowers A. H., Murillo O. J. , Jensen R., Eslinger B., and Gelzer C., “On Wings of the Minimum Induced Drag: Span load Implications For Aircraft And Birds,” NASA/TP—2016–219072.
[3] Chigier, N. A. & Corsiglia, V. R., “Tip Vortices-Velocity Distributions,” Preprint 522, Presented At The 27th Annual National V/STOL Forum of The American Helicopter Society, Washington, D.C., May 1971.
[4] Das S. P., Samal S. K., Dalai R., Padhi M. R., “Reduction of Induced Drag by Single Slotted Raked Wingtip,” IJIRRSET, March 2015, Vol. 4, Issue 3.
[5] Dehaan, M. A., ‘‘Induced Drag of Wings with Highly Swept and Tapered Wing Tips,’’ AIAA Jr., Aug. 1990, Vol. 90, Pp. 3062.
[6] E.V. Laitone, “Positive Tail Loads For Minimum Induced Drag of Subsonic Aircraft,” Jr. Aircraft, Vol. 15, No.12, Dec. 1978, Pp. 837-842.
[7] Hess J. L., “The Problem of Three-Dimensional Lifting Potential Flow and Its Solution by Means of Surface Singularity Distributions,” Computer Methods in Applied Mech. and Engg., Vol. 4, 1974, Pp. 283-319.
[8] Hossain A., Rahman A., Iqbal A. K. M. P., Ariffin M., and Mizan M., “Drag Analysis of an Aircraft Wing Model with and Without Bird Feather Like Winglet,” World Aca. of Sci., Engg. & Tech., 2011, Vol.57.
[9] Inam M. I., Mashud M., Nahian A.A., And Selim S.M.S., “Induced Drag Reduction For Modern Aircraft Without Increasing The Span of The Wing By Using Winglet,” Int. Jr. of Mech. & Mechatronics Engg., June 2010, Vol.10, No.03, Pp.49–53.

[10] M. D. Maughmer M. D., S. S. Tmothy S. S., And S. M. Willits S. M., "The Design And Testing of a Winglet Airfoil For Low-Speed Aircraft," AIAA Jr., 2001, Pp. 2001-2478.
[11] Mamada H., Andof S., "Minimum Induced Drag of A Hemi-Circular Ground Effect Wing," Jr. Aircraft, Vol. 10, No. 11, Pp. 660-663.
[12] Marchman iip J. F., and Uzelt J. N., "Effect of Several Wing Tip Modifications on A Trailing Vortex," Jr. Aircraft. Vol. 9, No. 9, Pp. 684-686.
[13] Rabbi M.F., Nandi R., Mashud M., "Induce Drag Reduction of an Airplane Wing," American Jr. of Engg. Res., Vol. 4, Issue-6, 2015, Pp-219-223.
[14] Samal S. K., & Dash P. K., "Reduction of Wingtip Vortex from Suction at Wingtip," Mech. Engg. Res., 2013, Vol. 3, No. 1.
[15] Scheiman J., and Shivers J. P., "Exploratory Investigation of the Tip Vortex of a Semi span Four Several Wing-Tip Modifications," TN D-6101, Feb. 1971, NASA.
[16] Smith M. J., Komerath N., Ames R., Wong O., and Pearson J., "Performance Analysis of A Wing with Multiple Winglets," AIAA Jr., 2001, Pp. 2001-2407.
[17] Smith S.C., Kroot I. M., "Induced Drag Computations on Wings with Accurately Modelled Wakes," Jr. Aircraft, Vol. 34, No. 2, Pp. 253- 255.
[18] Srikanth G., Bogadi S., "Experimental Investigation on the Effect of Multi-Winglets", Int. Jr. of Mech. & Ind. Engg., Vol.1, Issue-1, 2011.
[19] Whitcomb R. T., "Methods for Reducing Aerodynamic Drag," NASA Conf. Pub. 2211, Pro. of Dryden Symposium, California, Sep. 1981.
[20] Winkelmann A., "Flow Visualization Studies of the Tip Vortex System of a Semi-Infinite Wing," 20th Fluid Dynamics, Plasma Dynamics and Lasers Conference, 1989.
[21] Yeung R. K., and Leet B. H. K., "Particle Image Velocimetry Study of Wing-Tip Vortices," Jr. Aircraft, Vol. 36, No. 2, Pp. 482-484.