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Research paper

Feasibility study of power generation using a turbine mounted in aircraft wing

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Abstract

The main objective of this study is to increase the aerodynamic efficiency of turbine mounted novel wing. The main motive behind this work is to reduce the drag by attaining the positive velocity gradient and generate power by converting the stagnation pressure which also acts as emergency power source. By using the energy source of free stream air, Mechanical energy is converted into electrical energy. The obtained power is presented in terms of voltage generated at various angles of attack with different Reynolds number. Experimental analysis is carried out for NACA4415 airfoil at various angles with respect to free stream ranging from 0deg to 30deg from laminar to turbulent Reynolds number. The results were obtained using the research tunnel at IARE aerodynamic facility center. The aerodynamic advantage of this design in terms of voltage is 9.5 V at 35m/s which can be utilized for the aircraft on board power systems.

Keywords: *Aircraft; Angle of Attack; Flow Visualization; Feasibility; Power; Turbine; Wing.*

1. Introduction

The advancements in aeronautical field brought a tremendous changes in the aerospace engineering by considering the major innovations in the technology. Although there is a remarkable increase in numerical simulation analysis [17], at a greatly reduced cost, changing the function of wind tunnels from a scaled predictor to a data source for calibration and validation of computational codes, but the experimental data is not harmonized in many cases which clearly states the necessity of experimental research prominence [10]. The present work is based on the experimental analysis of novel wing model, a model with turbine mounted at the of the leading edge section of the wing. The concept behind this design is to reduce the load from engines and to increase the aerodynamic efficiency, lesser fuel consumption, and the voltage power during its overall flight period.

2. Turbine design

The design of the blade is modelled according to the leading edge radius of the airfoil. The blade is mounted at the sectional portion of the leading edge of the wing with rotary blades in the forward curved motion. The rotor usually induced with eight curved blades with chord of blade matching with the wing chord. A systematic experimental test has been carried out to understand the influence of velocity flow at different angles of attack over the novel wing [5] [20]. Hence obtaining the results of power generation, aerodynamic efficiency, fuel efficiency leads to further investigation [4]. The study from various researchers states that there is a reduction in the boundary layer interaction because of the flow separations over the novel wing where the rotation of the blade takes place in the anti-clockwise direction hence increase in the velocity at the upper surface of the wing[4] [5] [14]. The variation of the velocities for the different angle of attack over the slotted rotor wing are detailed in this work. In the flow visualizations techniques, the streamlines on the upper surface are comparatively more than the lower surface of the wing. Hence there is an increase in the velocity gradient on the surface of the airfoil. The design of the rotor blades and its scaled dimensions play a significant role especially in the intensification of the performance of the cross-flow rotor turbine [5] [3] [11].
The high efficiency variable speed motor and its performance, using the computational tools are detailed in [19] for analysing and validating the performance of the model. The coefficient of lift, drag and pressure forces are calculated by using conservation of mass, momentum and energy equations. This work lays a solid foundation for future efforts as detailed in [12], including wind tunnel tests on the slotted rotor wing which would directly measure the forces and power generated by rotor blades mounted. A robust design of the methodology can be implemented for future aircrafts by not only on this design knowing its performance and efficiency but also can be utilized for different design parameters [11].

3. Geometric details of the wing

A NACA 4415 airfoil model is used in current design for the turbine blade mount with the exact radius of the leading edge and for the effective variation of flow effects capture[7] [11] [8]. The turbine design enriched the boundary layer by decreasing the drag over the airfoil. The design adopted in the wing has shown in the figure. 1 representing the chord, upper and lower curve on the airfoil section. The plan view of the wing is presented in Fig. 2 which clearly states that the wing plan form is rectangular with 510 x 300 mm^2 with the leading edge radius diameter 120mm as shown in the Fig. 3.

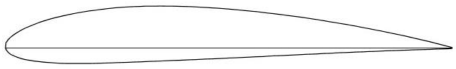

Fig. 1: NACA 4415 Airfoil Section.

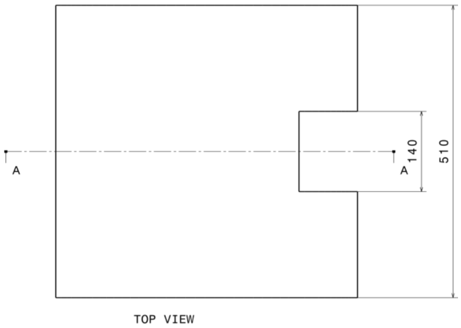

Fig. 2: Top View of the Wing.

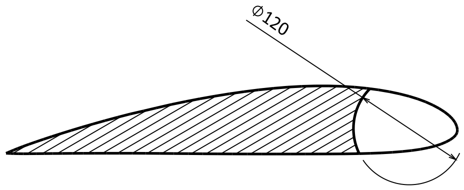

Fig. 3: Sectional View of the Airfoil with Dimensions At A-A.

3.1. Geometry of the slotted airfoil

The airfoil used for experimental setup is NACA4415. Slotted wing with turbine is shown in Fig. 4 with turbine mount plan view and Fig. 5 showing the blade side view with dimensions in mm. The experimental analysis is carried out for different angle of attack by varying the Reynolds number ranging from laminar to turbulent flow from 0 deg to 30 deg angle of attack.

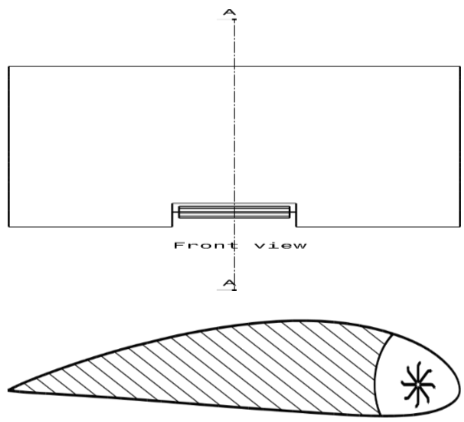

Fig. 4: Sectional View of the Airfoil with Turbine At A-A.

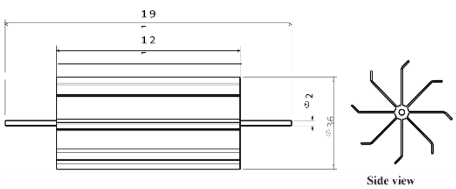

Fig. 5: Front View of the Turbine with Backward Curved Blades.

4. Methodology

The wing model fabricated as per the tunnel attachments which is supported at both ends of the extended spar of wing connected to tunnel walls. The model is mounted in the test section of size 2000 x 600 x 600 mm^3 as shown in the Fig. 6, where the maximum speed can be achieved as 50m/s. As the tunnel is open type with the minimum flow disturbances the tests were carried. The flow is considered to be viscous and incompressible. Further validation of data and accuracy of the results were investigated by using the projection manometer focused on the vertical multi manometer tubes. The required velocity is achieved in the tunnel by the axial flow fan placed at the end of the tunnel by suction of air from bell mouth entry.

Fig. 6: Low Speed Wind Tunnel Facility

4.1. Power generation

Power is generated by driving the turbine with free stream flow. This works by renovating the mechanical energy into electrical energy and the generated power is measured using the induction motor. The induction works on the principle of electromagnetic induction from the magnetic field of the stator winding [15] [12]. This clearly states that induction motor can be built without electrical connections to the rotor. As an open, drip proof (ODP motor allows a free air exchange from outside to the inner stator windings, this style of motor tends to be slightly more efficient because the windings are cooler [14]. The study suggests that lower the speed the larger the frame.

4.2. Flow visualization

As air is transparent, it is difficult to observe the dynamic behaviour of air. As an alternative or substitute, multiple methods of both quantitative and qualitative flow visualization methods can been implemented for testing in a wind tunnel.
Tufts and smoke flow visualization techniques are used in the current work. Tufts are small length string like structure made of fabric or any other lightweight [6] [16]. Popular materials for tufts are made of monofilament nylon, and polyester or cotton No. 60 sewing threads [1] [18]. Surface tufts only give data about the surface flows in the lowest part of the boundary layer [4]. Encapsulating the surface patterns to visualize the free stream flow over the model takes some skills and knowledge.
The airfoil coordinates are selected for maximum lift area. The selected airfoil is mounted with turbine blade according to the dimensions specified in Fig. 1-4. Flow visualization techniques are set for the wing with tufts. The results at different angles of attack at diverse velocity conditions are given in Fig. 13. Smoke flow visualization test is carried out for airfoil with different angle of attack at different velocities is carried out for the wing. The obtained results are shown in the fig. 7 to fig 12. The main objective of the work is to find the voltage for the turbine motor with slotted wing, the experiment is carried for various angle of attack at different velocity conditions as given in the following figures from Fig. 9-13.

5. Results and discussions

Experimental results are obtained in two ways one is with flow visualization and other is to determine the feasibility of voltage generated by the turbine at various speeds and angle of attack. In case of flow visualization smoke and tuft grid methods both are taken for resultant flow distribution and disturbances on the wing. For the measurement of voltage a dynamo was used and voltage was measured using a voltmeter for different speeds (16 m/s, 20m/s, 24m/s, 28m/s, 32m/s, 35m/s) as presented in table 1.

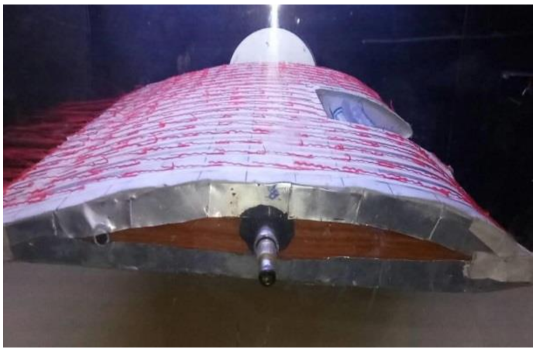

Fig. 7: Side View of the Tufted Airfoil in Wind Tunnel at 0degree AoA.

Fig. 8: Side View of the Tufted Airfoil in Wind Tunnel at 15 Degree AoA.

Fig. 9: Side View of the Tufted Airfoil in Wind Tunnel at 25 Degree AoA.

Fig. 10: Side View of the Stream Lines over Wing at 0 Degree AoA.

Fig. 11: Side View of the Stream Lines over Wing at 15 Degree AoA.

Fig. 12: Side View of the Stream Lines over Wing at 25 Degree AoA.

The streamline flow pattern over the airfoil at 0 degrees AoA in Fig. 7, it's also known as a laminar flow because of each layer of the flow stream having the same velocity which doesn't even get affected by the airfoil at the 0 degrees of AOA. The flow is being separated at the leading edge of the airfoil at 15 degrees AoA in Fig. 8. As the flow is no longer able to overcome the surface friction which causes the flow to separate from the body. Side view of the flow visualization, at 25 degrees of AoA as in Fig. 9, where the flow is getting separated at the tip of the leading edge, which is always occurred due to adverse pressure gradient at the surface which led to the separation of the boundary layer.

The flow visualization was done on a wing to identify the flow behaviour at various sections of the wing. Initially, the smoke test (2 m/s) was done on the wing at 0° AoA shown in fig. 10, where investigation has stated the flow to be streamlined at the surface. But with change in AoA, the flow started separating at the surface of the wing. As further increase in AoA is shown in fig.11 and fig 12, the flow is separated from the leading edge due to the adverse pressure gradient and also found the vortex formation at the corner of the slotted area and leading edge of the wing. Secondly, the tuft test was done on the wing to identify the flow behaviour by using threads which floated freely under the flow.

The tufts placed on the wing as shown in Fig. 7 to Fig. 9 placed in the wind tunnel at 0 degree AOA is tested at various speeds ranging from 16-35m/s. Result was found that the threads at the trailing edge appeared to be straight under the flow which simply indicates that the flow streamlines. Increase in AoA, has lead the threads at the surface got twisted due to the reverse flow which has occurred at the time of separation of the flow at the surface. In the meanwhile, the threads were merged and got curled and formed like a rope which indicates the strength of the flow behind the wing trailing edge induced drag is increased with an angle of attack and at different free stream velocity [15] [2].

Table 1: Voltage Generated by Turbine by Variation of Angle of Attack with Different Speeds

Velocity	Angle of Attack (AoA)								
m/s	-15	-20	-25	-30	0	15	20	25	30
16	NR	R	R	R	NR	NR	R	R	R
	0	3.8	4.5	3.3	0	0	3.9	4.6	3.4
20	NR	R	R	R	NR	NR	R	R	R
	0	4.8	4.9	4.7	0	0	4.9	5	4.8
24	NR	R	R	R	NR	NR	R	R	R
	0	4.3	4.9	4.8	0	0	4.3	5.1	4.8
28	NR	R	R	R	NR	NR	R	R	R
	0	5.1	5	4.9	0	0	5.2	5.3	4.8
32	NR	R	R	R	NR	NR	R	R	R
	0	7.6	7.5	5.1	0	0	7.5	7.6	5.2
35	NR	R	R	R	NR	NR	R	R	R
	0	9.4	8.4	5.4	0	0	9.5	8.5	5.5

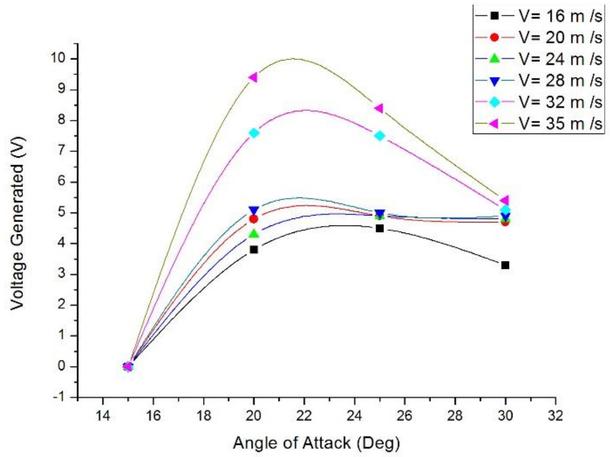

Fig. 13: Angle of Attack Increment with Velocity.

Moreover, at the higher AOA, the threads at the trailing edges got rolled up due to the vortex formation at the corner of the edges [6]. Similarly, the same phenomena occurred at the surface near to the slotted area of the wing while tested at a higher AOA. This resulting phenomenon has indicated that the turbine mount at the trailing edge is not a feasible input.

The turbine mounted on the wing was successfully tested for various Reynolds numbers resulting in power generation which is presented in the Fig.9 states that the power generated from turbine measured in volts has raised to 10 volts at a speed of 35 m/s with angle of attack between 20 deg – 25 deg. In the present result the power is proportional to the angle of attack within the aerodynamic limits of the geometry of airfoil and the optimized results have been achieved for the angle of attack of 20 deg.

Further increment in angle of attack resulted in the loss of power at the turbine compared to the previous limit and can be indicative of drag increment due to adverse pressure gradient the turbine loses its energy.

6. Conclusion

In comparison to various tests of flow visualization at various angle of angle of attack and velocity it is determined that the flow deviates from the trailing edge resulting in strong trailing edge vortices elucidated the position of the turbine. The turbine blades in this design is 45 deg angled blades provides the power for the aircraft which can be utilized in emergency systems if adopted on the aircraft wing. The power values are investigated on the scaled model if the same concept is adopted in real aircraft wing this will change the current requirements of power in flight conditions. Optimal values in this current design is in between 20 deg to 25 deg angle of attack. Feasibility of this idea did not work for low angle of attack which is less than 15 deg. As one turbine generates the power of 9.5 volts this can be increased to the requirements of a hydraulic system to compensate the need of axial systems for power generation.

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