Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 1, Number 3; October, 2014 pp. 68-72

http://www.krishisanskriti.org/jbaer.html

Design and Analysis of Fanwing Concept in Conventional Wing Aircraft

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***Abstract:** The main objective of this paper is to apply the concept of Fan wing Technology to the present day conventional airfoil and to analyze its aerodynamic performance. A CFD based numerical analysis of flow over fan wing profile and over NACA 0012 profile is carried out. The aerodynamic performance of both the profiles are predicted with the help of CFD software and compared to know the merits and demerits of fan wing profile over the conventional profile. The analysis is carried out at an inflow velocity of 50m/s in both the cases for angles of attack varying from 0 degree to 22 degree. From the computational results, it is found that the drag coefficient is comparatively less for fan wing at all angles of attack.*

1. INTRODUCTION

Conventional wing configurations have been in use since the pre-WWII era. Today, nearly all civilian transport involves aircraft with the conventional wing configurations, due to its superb versatility. The disadvantage to conventional wing configurations is that during supersonic flight, the leading edge of the wing is not always behind the shockwave created by the nose of the aircraft. This causes dynamic instability of the aircraft. It works on the principle of Magnus effect (lift produced by a rotating cylinder in a uniform flow).

1.1. Fan Wing

The Fan Wing concept was introduced by Patrick Peebles. Fan Wing is a specific kind of aircraft propelling device, which has a fan attached along its wings. Rotating fan enables airfoil to generate thrust, so that no other kind of propulsion is needed.

Fig1.1. Fan wing aircraft

The aircraft has a cross-flow fan along the leading edge of each wing. The fan, powered by a conventional engine, pulls the air in at the front accelerating it over the trailing edge of the wing. By transferring the work of the engine to the rotor, which spans the whole wing, the Fan Wing accelerates a large volume of air and achieves almost instant take-off and stable flight.

2. LITERATURE SURVEY

2.1. Theoretical Overview

When a fan wing's tangential fan rotates, it flow speed over its upper camber is increased. An increase in flow speed correlates to a reduction in pressure per Bernoulli's principle, which states:

$$1/2\rho V_2+\rho gz+p=constant \qquad (1)$$

where ρ is the fluid density, V is the relative velocity, and p is the static pressure. The term $1/2\rho V_2$ is the dynamic pressure. In the case of an airfoil, the hydraulic head term, ρgz, is zero. Therefore, Eq.(1) simplifies to

$$1/2\rho V_2+p=constant \qquad (2)$$

The static pressure differential between the upper and lower surfaces generates lift. For a symmetrical airfoil, at a positive angle of attack, airflow over the top surface moves faster than over the bottom surface. From equation (2), it follows that p is higher on the bottom surface than on the top surface. This static pressure differential between the surfaces is what generates lift. To increase the pressure differential, the air must be moved faster over the upper camber, slower over the bottom camber or some combination of the two. This is the basis for fan wing design, which increases flow speed over the upper camber. To see why it is detrimental to reduce the flow speed over the lower camber a comparison can be made to a rotating cylinder.

2.2. Lift Generation

Consider a cylinder with an angular velocity about its longitudinal axis. When the cylinder is exposed to airflow perpendicular to its axis of rotation, skin friction "pulls" the air along in the direction of rotation.

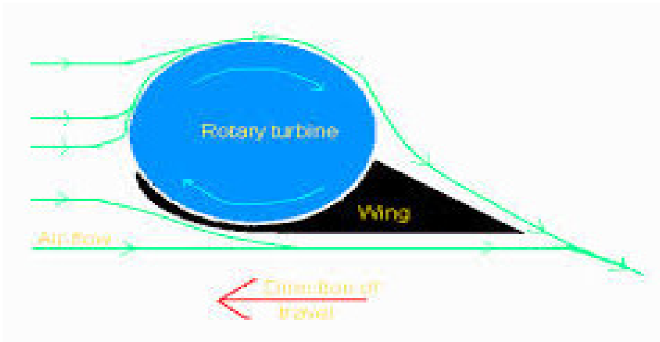

Fig.2.1. lift produced by the wing due to Bernoulli's principle

As a result, the velocity of the air over the top half of the cylinder is increased, while the velocity over the bottom half is reduced. Consequently, a pressure differential occurs, resulting in lift. This is the so called Magnus effect. However, when skin friction slows air on the bottom half of the cylinder it also increases the local drag. It would be beneficial to receive the lift inducing benefits of the upper surface without any of the detrimental effects due to the lower surface. Fanwings accomplish this by shielding the bottom half of the fan. By generating lift without additional drag from the bottom portion of the fan, fanwings may attain.

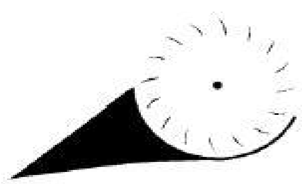

Fig 2.2 Fan wing shield the bottom surface of the fan.

2.3. Stall Inhibition

In addition to increasing lift, fan wings inhibit stall at high angles of attack. Stall is caused by flow separation at surface of an airfoil, resulting in a sudden increase in drag and loss of lift. For obvious reasons, this is undesirable in aircraft. Fan wings can inhibit stall by delaying a phenomenon known as flow reversal in the boundary layer.

3. EXPERIMENTAL TECHNIQUE

3.1. Airfoil and Fan Wing Construction

Both a fan wing and a control airfoil were constructed for testing in the USC Biegler Hall wind tunnel. The fan wing required the design and construction of an airfoil with an appropriately shaped cutout to accommodate the fan into its leading edge.

Fig 3.1 Wooden templates of the airfoil profiles

High density polyurethane foam core was obtained and, using a hot wire cutting technique, the foam core was shaped into the desired NACA0015 airfoils. Hot wire cutting was performed by guiding a heated wire around the perimeter of wooden templates adhered to the foam core. For strength, fiberglass was applied to the surfaces of the foam airfoils.

To conduct accurate wind tunnel tests on an airfoil, the setup must simulate an infinite wing. One way to accomplish this is to install endplates, which reduce induced drag by limiting wingtip vortices. After conducting research on the optimal size for endplates, it was determined that a height of 7.2 inches would be sufficient to reduce the induced drag. Steel endplates were cut to the appropriate size and installed on both airfoils.

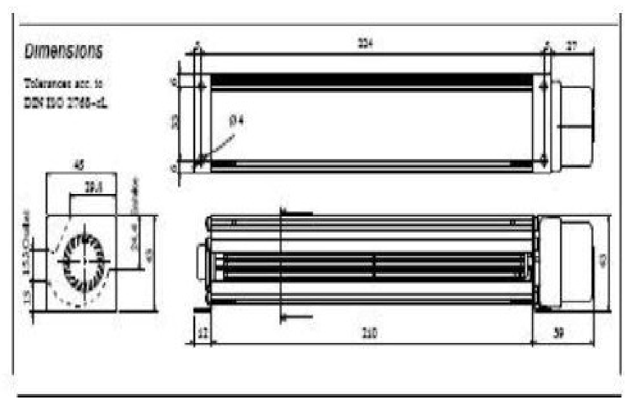

Fig3.2.Diagram of a LTG TA-40/300/24V Tangential fan.

An LTG TA-40/300/24V tangential fan was selected for several reasons:

1. With a diameter of 40mm, the LTG fan fit comfortably in the leading edge of our airfoil leaving approximately 50% exposed to accelerate air rearwards.

2. The height of the Biegler Hall wind tunnel is 18 inches. To provide enough space for the motor to mount on top of the airfoil, a 12 inch fan was selected.

3. Control of the fan's angular velocity was accomplished through adjusting the voltage. With a DC motor, the angular velocity of the fan could be adjusted with a linear potentiometer wired in a voltage divider circuit. This way the speed could be manually adjusted as needed during each trial.

4. Online purchasing of two LTG TA-40/300/24V tangential fans cost only $20.00.

The LTG TA-40/300/24V tangential fan was installed within the leading edge of the fan wing. In order to mount the fan's motor and bearing, thin wooden profiles were cut and attached to the fan wing's ends. To allow for accurate comparison, the same wooden cutouts were attached to the control airfoil, although these served no functional purpose.

Because the fan wing is larger than most airfoils tested in Biegler Hall, an adapter was necessary to mount it to the force balance. The adapter was designed in Solid Works and 3D printed. The airfoils were then mounted to the force balance in the Biegler Hall wind tunnel.

3.2. Testing Procedure

Using Lab VIEW data collection software, lift and drag profiles were gathered for both the fan wing and the control airfoil. First, the control airfoil was placed in the Biegler Hall wind tunnel and data was gathered for airspeeds of 4, 6, 8 and 10 meters per second. At each velocity, the software was designed to vary the angle of attack from -4 to 30 degrees and collect lift and drag forces at each angle.

Testing of the fan wing required one additional variable, fan speed. Once again, data was gathered for 4, 6, 8, and 10 meters per second. The fan speed was then set to a specific angular velocity where it was actively adjusted to maintain a constant value as the angle of attack was varied. After each trial, the fan speed was set to a new rpm and the process was repeated.

3.3. Numerical Analysis of Modified Fan Wing Concept

Modification of the Fan Wing concept intended for the use at higher speeds of flight (over 20 m/s) is numerically analyzed. The principle of operation, basic aerodynamic characteristics, and the features in untypical flight situation (autorotation) are described and explained.

The aim of this work was to check if there is a possibility of using the Fan Wing concept with a more traditional kind of airfoil. In the original concept, diameter of the fan is about a half of the total width of wings. This work presents results achieved by the use of one-meter wide airfoil and a 0.195 m diameter fan. The ratio of the rotor diameter to the cord is more than two times less than in the original Fan Wing concept. The use of so much smaller fan makes it impossible to work in the same way as the original one, and to provide enough thrust. That is why there had to be found a different airfoil and fan configuration. The most important was that the new setup had to create thrust; this was the main criterion rating its work and an essential condition. It was also intended that the airfoil should work properly at the flight speed of at least 20 m/s. The original Fan Wing is designed for lower speeds, up to 20 m/s. There has been performed analysis of the airfoils properties with different kinds of nose sections. The following solutions have been taken into consideration:

1. Complete lack of nose section.
2. A rigid windshield covering the fan up to different angles.
3. Nose sections of different standard airfoils.

Different kinds of blades also have been checked. Some of its properties were also compared with an airfoil without the nose section. The studied airfoil geometry with attached fan is shown in Fig. 3.3.a

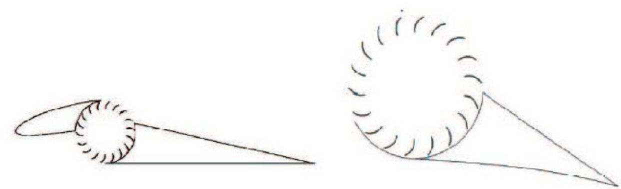

Fig 3.3.a Fan wing airfoil b. Orginal Fan wing with nose section Airfoil

All calculations were performed in Fluent, in two dimension and double precision solver version. The mesh contained 45 000 nodes, mainly concentrated near the blades of rotor. The unsteady, two dimensional, turbulent flow model of incompressible fluid was used in the simulation. The Spalart-Allmaras model was applied in turbulence modeling due to the implementation of the wall damping functions tuned for external aerodynamic flows, and because of known, good performance in boundary layer with adverse pressure gradients .Fan movement was modeled by the use of moving mesh, and the airfoil was connected with fan by the interface technique.

3.4. Aerodynamic Developments

3.4.1. Objective -Higher Cruising Speed

Recent developments of Fan Wing have concentrated on further widening the flight envelope, in particular with three aerodynamic modifications to allow flight at higher speeds. The combination of ultra-short field performance and moderate cruising speeds would greatly widen the field of potential applications of Fan Wing.

3.4.2 OHS Tail Configuration:

One of the current flight-test vehicles has been modified to accept a novel OHS twin-tail arrangement which moves the tails from the intense fan-stream and wing downwash flow directly behind the wing, to positions where they can exploit the up wash flow from the wingtip vortices.

The OHS tail arrangement was first developed and flown on radio-controlled models over 20 years ago by Professor John Kentfield at Calgary University, The author has derived design rules for the optimum use of OHS and estimates of the performance advantages of OHS Flight testing of Fan Wing with the OHS twin-tail has shown both increased flight stability and reduced drag, leading to higher flight speeds.

In addition, when the elevators of the OHS tails are used differentially, they can provide roll control as well as pitch control. This allows the wing to be built as a simple lifting surface without ailerons.

3.4.3 High-Speed Wing Section Design

The fixed wing section of Fan Wing has recently been modified following a series of 2-D and 3-D wind tunnel tests of many alternative fan and wing combinations. Examples are shown below of the wing section with its trailing edge lengthened to reduce profile drag at lower lift coefficients whilst retaining the excellent C_{Lmax} values.

4. COMPUTATIONAL METHODOLOGY

4.1 Governing Equations

The unsteady, two dimensional turbulent flow model of incompressible fluid was used in the simulation. The spalart-allamars was applied in the turbulence modeling due to the implementation of the wall damping functions tuned for external aerodynamic flows, and because of known, good performance in the boundary layer with adverse pressure gradient. Fan movement was modeled by the use of the moving mesh, and the airfoil was connected with the fan by interference technique.

4.2. General form of Navier-Stokes Equation

To simplify the Navier-Stokes equations, we can rewrite them as the general form.
When $U\ T\ j\ \Phi = 1$, we can respectively get continuity equation, momentum equation and energy equation.

4.3. Finite Volume Method

The Navier-Stokes equations are analytical equations. Human can understand and solve them, but if we want to solve them by computer, we have to transfer them into discretized form. This process is discretization. The typical discretization methods are finite difference, finite element and finite volume

4.4. Geometric Modeling

Computer Aided Three-dimensional Interactive Application is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company default Systems. Written in the C++ programming language, CATIA is the cornerstone of the default Systems product lifecycle management software suite. The Boeing Company used CATIA V3 to develop its 777 airliner and used CATIA V5 for the 787 series aircraft.

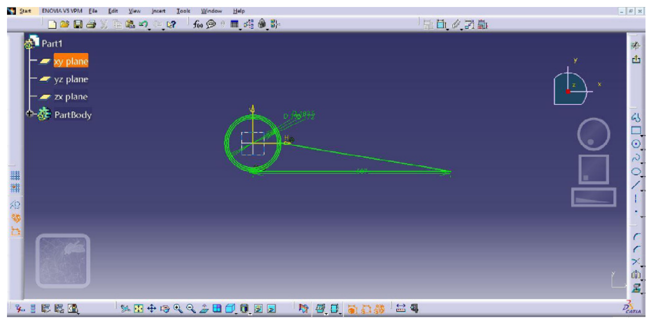

Fig 4.1. 2D-view of Fan wing Concept

To specify the airfoil geometry, we'll import a file containing a list of vertices along the surface is imported in GAMBIT. These vertices are joined to create two edges, corresponding to the upper and lower surfaces of the airfoil. These edges are spitted into 4 distinct edges to control the mesh size at the surface.

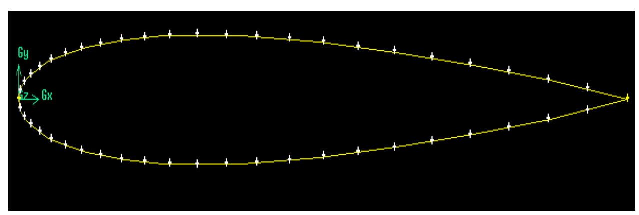

Fig 4.2. Gambit (NACA-0012 airfoil)

Table 4.1 Co-ordinates used to construct Flow domain

Label	x-coordinate	y-coordinate
A	C	12.5c
B	21c	12.5c
C	21c	0
D	21c	-12.5c
E	C	-12.5c
F	-11.5c	0
G	C	0

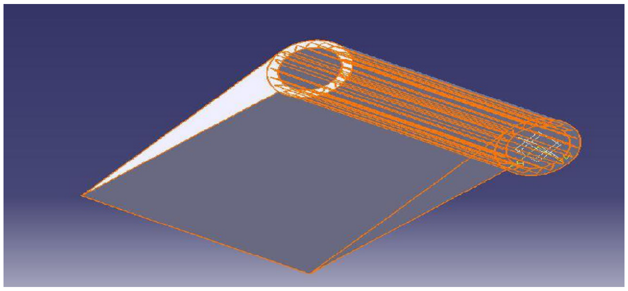

Fig 4.3 3D-view of fan wing concept

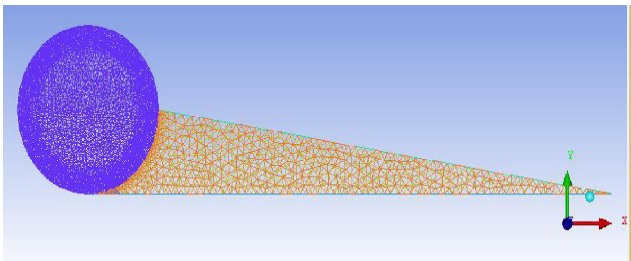

Fig 4.4 Structured mesh of fan wing concept in ICEM

Table 4.2 No of iteration used with respect to rpm

Rotational velocity (rpm)	Courant fredy lewis number(cfl)	No. of iterations
5	0.1	50
10	0.1	50
50	0.3	100
100	0.3	100
250	0.5	100
500	0.5	100
750	1	250
1000	1	250
1250	2	250
1500	2	250
1750	3	250
2000	3	250
2000	5	500

4.5. The CFL Condition

In order to make a reasonably formally precise statement of the condition, it is necessary to define the following quantities

1. Spatial coordinate: it is one of the coordinates of the physical space in which the problem is posed.
2. Spatial dimension of the problem: it is the number of spatial dimensions i.e. the number of spatial coordinates of the physical space where the problem is posed.
3. Time: it is the coordinate, acting as a parameter, which describes the evolution of the system, distinct from the spatial coordinates.

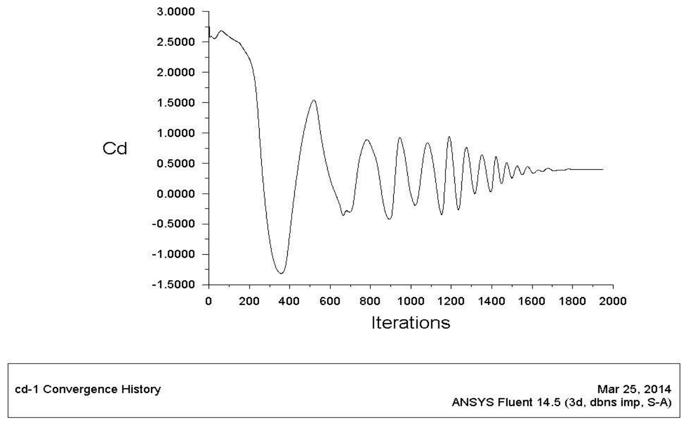

Fig. 4.5. Coefficient of Drag at 22 degree angle of attack

5. CONCLUSION

This works presents a modification of fan wing concept which shows that a fan attached as a propulsion system along the wing is an interesting solution. It might be possible that there are more such setups of fan and wing that give advantages results. The one presented in this work fullfills one essential condition which is the requirement to generate thrust and lift.

However, it has two significant disadvantages, which are: 1.low efficiency and impossibility of safely emergency landing with the use of autorotation. Both of them result from the necessity to put some extra energy forcing the fan to rotate in the direction opposite to the natural one.

6. ACKNOWLEDGEMENT

We express our sincere thanks to DR.M.SHANMUGA RAJA & MR.P.SURESH for his constant encouragement and support throughout our research, especially for the useful suggestions given during the research period.

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