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Design and Analysis of Airfoil Using Simulation Techniques

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Abstract

An airfoil is the shape of a wing or blade or sail as seen in cross-section. An airfoil-shaped body moved through a fluid produces an aerodynamic force. The airfoil designing is a critical task due to various dependent variables in design process. This article deals with simulation of new airfoil section design and comparing it with a standard baseline airfoil. The calculations of lift force are done for six cases for varying altitude, constant rotor and air stream velocity. The conclusions are drawn from the simulated results obtained after analysis which will be useful in design of airfoil.

Keywords: New asymmetrical airfoil, airfoil simulation, baseline airfoil, lift force

1. Introduction

An airfoil is the shape of a wing or blade or sail as seen in cross-section. An airfoil-shaped body moved through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. The design and optimization of an airfoil is very important as it affects the lift produced by the wing of an aircraft or a helicopter. Various designs of airfoils can be tested either using wind tunnel or by simulation software through which important parameters for lift and drag forces can be determined.

For heavy lift helicopters the most important aerodynamic component of force is the lift. It needs to have sufficient amount of lift in order to lift heavy loads over a fixed distance. At times it is necessary for the helicopter to hover i.e. the condition of helicopter flight in which there is no forward movement and the helicopter remains stationery above the ground while the rotor rotates. It is one of the most challenging conditions as the helicopter is not dynamically stable and the pilot is supposed to give some inputs to control the helicopter. The required glide ratio for this condition should be high to allow the helicopter to remain in hover condition.

2. Literature review

Anh et al. (2011) proposed an optimum solution for helicopter blade design to improve the hover characteristics of a helicopter by using class function/shape function transformation to generate airfoil coordinates. This gave rise to a new blade shape which was considered in terms of design variables such as twist, taper ratio, and point of taper initiation, blade root chord, and coefficients of the airfoil distribution function. The author has reduced the required hover power by 7.4% and increased the figure of merit by 6.5%.

Qing et al. (2014) employed a method called as sequential quadratic programming to optimize the airfoil of a helicopter rotor blade (SC1095) under dynamic stall conditions. The author obtained an optimized airfoil having larger leading edge radius and camber using grid generation technology and employing Reynold's averaged Navier-Stokes equation along with implicit scheme of lower–upper symmetric Gauss–Seidel (LU-SGS) for predicting airfoil flow field and temporal discretization (Wang Qing et al. ,2014).

Renald et al. (2012) suggested an ingenious method called as Karmann-Treffz geometrical construction for finding the profile and the pressure distribution of the airfoil. This is easier than analyzing a cambered airfoil.

Cazangiu et al. (2014) used finite element analysis to show the mechanical behaviour of a rotor blade under hover conditions of a helicopter.

3. Methodology

According to NACA (National Advisory Committee for Aeronautics) designation a standard airfoil was selected and its simulation was done on Aerofoil 3.2 workbench (developed by Donald L. Ried) and important aerodynamic characteristics were noted in a tabulated form. The following steps were undertaken:

- **i.** Standard airfoil NACA0012 was selected for analysis.
- **ii.** This airfoil belongs to the NACA 4 and 5-digit series.
- **iii.** NACA 4-digit series was selected and the maximum camber thickness as a percent of chord thickness was selected as 12% and the maximum displacement of the chord line was taken as 0% and the chordwise position of the mean line was kept as 0%.
- **iv.** In the simulation workbench a slider was provided to change the angle of attack and obtain various aerodynamic characteristics on each point of the airfoil surface.
- **v.** At a particular angle of attack, the values of lift coefficient, drag coefficient, angle of zero lift, maximum thickness and aerodynamic center was generated by the simulator and the values were plotted in a tabulated form.
- **vi.** Due to effect of angle of zero lift (0^o in case of NACA0012) for a angle of attack of 5.04^o a new blade design having an asymmetrical camber shape.

The following steps were used to simulate a new asymmetrical blade design using Aerofoil 3.2 workbench:

- **i.** For the new blade NACA 5-digit series is selected. In this particular case the designation NACA 250xx was selected.
- **ii.** The slider provided in the simulation was moved in a manner such that NACA 250(6.1) airfoil was obtained.
- **iii.** In this airfoil the maximum camber thickness was 6.1% times the chord length. The camber line parameters were only applicable for the NACA 4-digit series hence other parameters remain unchanged.
- **iv.** Now by altering the angle of attack a new value of angle of zero lift was obtained which was not zero as obtained during the simulation of the NACA 0012.
- **v.** At the same angle of attack, the values of the values of lift coefficient, drag coefficient, angle of zero lift, maximum thickness and aerodynamic center was generated by the simulator and the values were plotted in a tabulated form.

To analyse the lift and drag forces during the hover flight of a helicopter the following steps were followed:

- **i.** The blade span was fixed as 36 feet taking a Sikorsky S-64 helicopter rotor blade as reference.
- **ii.** Assuming the maximum and minimum stream velocity of the air to be constant at 40m/s the altitude of the helicopter was varied at an interval of 30m.

iii. The lift and drag force was calculated by standard equation and the density of air at changing altitudes was taken into account.

iv. The lift and drag at corresponding altitudes were taken for both the airfoil configurations and recorded in a tabulated form.

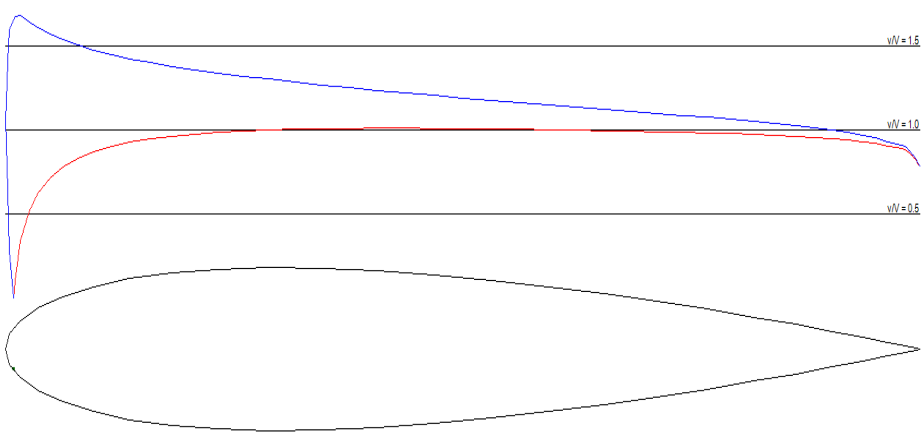
v. The lift by drag ratio also called as glide ratio was calculated and plotted against the altitude and some specific results were obtained.

4. Case Study

The following case study is done for comparing the lift by drag ratio or the glide ratio at different altitudes for a newly designed asymmetrical blade (NACA 250(6.1)) using NACA 0012 as a baseline airfoil.

The simulation of both these airfoils have been done and their aerodynamic profile and properties have been listed in the case study.

4.1. Standard Baseline Airfoil (NACA 0012)



(Figure 1. Standard Blade Design for Baseline Airfoil (NACA 0012))

Figure 1. shows an illustration of the shape of a standard baseline airfoil having NACA0012 designation. The red and blue curves indicate the distribution of Mach number over the lower and upper surface of the blade respectively. This is a symmetrical airfoil design which is used for a stable lift produced for the flight of the helicopter. All the calculations and simulations have been done on Airfoil 3.2 workbench and accordingly the specifications are tabulated in table 1.

NACA 0012	
Angle of Attack	5.04^{o}

Lift Coefficient	0.595
Drag Coefficient	0.405
Angle of Zero Lift	0.00°
Maximum Thickness	0.12
Aerodynamic Centre	x/c=0.2566 y/c=-0.0011

(Table 1. Specifications for NACA 0012)

4.2. Important Formulae

i. NACA Four-Digit Series:

The first digit specifies the maximum camber (m) in percentage of the chord (airfoil length), the second indicates the position of the maximum camber (p) in tenths of chord, and the last two numbers provide the maximum thickness (t) of the airfoil in percentage of chord. For example, the NACA 2415 airfoil has a maximum thickness of 15% with a camber of 2% located 40% back from the airfoil leading edge (or 0.4c). Utilizing these m, p, and t values, we can compute the coordinates for an entire airfoil using the following relationships:

a) Pick values of x from 0 to the maximum chord c.
b) Compute the mean camber line coordinates.

$$\mathbf{y_c = \frac{m}{p^2}(2px - x^2)} \qquad \textbf{x=0 to x=p}$$

$$\mathbf{y_c = \frac{m}{(1-p)^2}\{(1-2p) + 2px - x^2\}} \qquad \textbf{x=p to x=c}$$

Where,

x = coordinates along the length of the airfoil, from 0 to c (which stands for chord, or length)

y = coordinates above and below the line extending along the length of the airfoil,

t = maximum airfoil thickness in tenths of chord (i.e. a 15% thick airfoil would be 0.15)

m = maximum camber in tenths of the chord p =position of the maximum camber along the chord in tenths of chord.

c) Calculate the thickness distribution above (+) and below (-) the mean line

$$y_t = \frac{t}{0.2}(0.2969\sqrt{x} - 0.1260x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4)$$

d) Determine the final coordinates for the airfoil upper surface (x_U, y_U) and lower surface (x_L, y_L) using the standard relationships.

$$x_U = x - y_t \sin\theta$$

$$y_U = y_c + y_t \cos\theta$$

$$x_L = x + y_t \sin\theta$$

$$y_L = y_c - y_t \sin\theta$$

$$where\ \theta = arc\tan\left(\frac{dy_c}{dx}\right)$$

ii. Lift

$$L = C_L \frac{\rho}{2} SV^2$$

iii. Drag

$$D = C_D \frac{\rho}{2} SV^2$$

iv. Mach Number

$$M = \frac{u}{c}$$

4.3. New Blade Design

Using symmetrical blade design results in zero lift condition when the angle of attack of the airfoil is 0°. This is a dangerous condition as at times the angle of attack on the could become zero due to pitch control of the blades. This causes no aerodynamic lift on the blade and thus would lead in loss of power of the helicopter. To avoid such a situation, we will incorporate an asymmetrical airfoil design. The asymmetrical airfoil has a higher coefficient of lift than the symmetrical airfoil. On asymmetrical airfoils, the top edge is shaped

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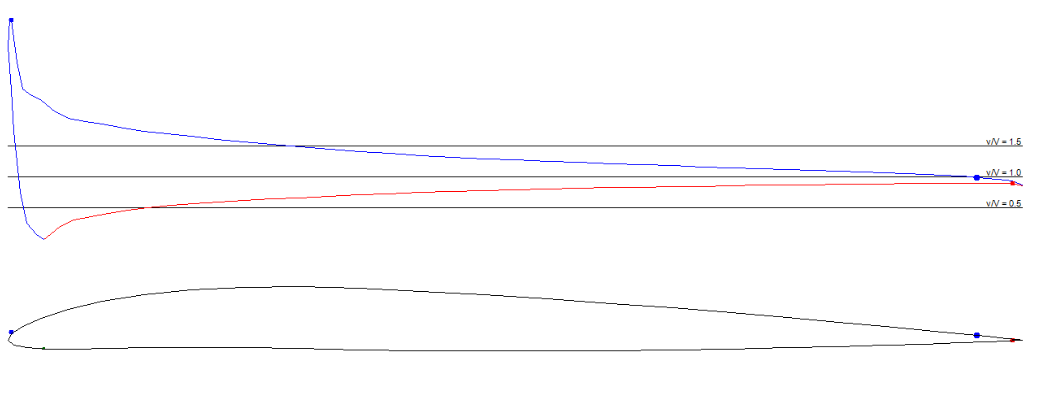
differently than the bottom edge, which changes the way air flows over it. This causes the air to move faster, which creates more lift.



(Figure 2. New Blade Design with Plot of Mach number Distribution)

Figure 2. Shows the aerodynamic profile of the new blade having an asymmetrical profile. The red and blue curve indicates the Mach number distribution over the upper and lower surface of the airfoil. The angle of attack has been taken as 1.54o and by simulation some aerodynamical values have been tabulated in table 2.

NACA 250(6.1) (for maximum camber thickness 6.1% of chord length)	
Angle of Attack	1.54^{o}
Lift Coefficient	1.328
Drag Coefficient	0.0145
Angle of Zero Lift	-1.530^{o}
Maximum Thickness	0.061
Aerodynamic Centre	x/c=0.2533 y/c=-0.0005

(Table 2. Specification for Blade NACA 250(6.1))

4.4. Calculations

These calculations are performed to test the lift and drag force obtained at different altitudes of the helicopter. As the altitude increases there is some change in the density of air. The first result that should be obtained from these calculations is that the lift force should be sufficient to lift the helicopter. This force is generated for single blade. Considering a heavy lift helicopter six blade rotor is used to generate an enormous lift.

I. Case 1(At 30m distance from the ground)

The helicopter is assumed to be in hover flight condition and is 30m vertically above the ground. At this condition the following assumptions have been made:

Minimum Free stream velocity=40m/s

Maximum Free Stream Velocity=40m/s

Chord length=4.0 feet

Altitude=30m

Density=1.22kg/m^3

Rotor span=36 feet

Area=13.37 m^2

The lift and drag is calculated as follows:

$$Lift = C_l \frac{\rho}{2} S V^2$$

= (1.328)*(1.22/2)*13.37*(40)^2

= 17.32KN

$$Drag = C_D \frac{\rho}{2} S V^2$$

= (0.0145)*(1.22/2)*13.37*(40)^2

= 0.189KN

Similarly, six cases have been considered in which the helicopter altitude is varied by a progressive interval of 30m from the ground. The chord length, maximum and minimum free stream velocity and the blade span is assumed to be the same in all the cases. The density of air changes in every case and is mentioned in each case. Air density is taken at 25°C air temperature.

II. Case 2(At 60m distance from the ground)

Density of air=1.2142kg/m^3

$$Lift = C_l \frac{\rho}{2} SV^2$$

= (1.252)*(1.2178/2)*13.37*(40)^2

= 16.25KN

$$Drag = C_D \frac{\rho}{2} SV^2$$

= (0.0110)*(1.2178/2)*13.37*(40)^2

= 0.142KN

III. Case 3(At 90m distance from the ground)

Density of air =1.2178kg/m^3

$$Lift - C_l \frac{\rho}{2} SV^2$$

= (1.204)*(1.2142/2)*13.37*(40)^2

= 15.68KN

$$Drag = C_D \frac{\rho}{2} SV^2$$

= (0.0108)*(1.2142/2)*13.37*(40)^2

= 0.140KN

IV. Case 4(At 120m distance from the ground)

Density=1.2107 kg/m^3

$$Lift = C_l \frac{\rho}{2} SV^2$$

= (1.140)*(1.2107/2)*13.37*$(40)^2$

= 14.76 KN

$$Drag = C_D \frac{\rho}{2} SV^2$$

= (0.0104)*(1.2107/2)*13.37*$(40)^2$

= 0.134 KN

V. Case 5(At 150m distance from the ground)

Density=1.2071 kg/m^3

$$Lift = C_l \frac{\rho}{2} SV^2$$

= (1.139)*(1.2071/2)*13.37*$(40)^2$

= 14.70 KN

$$Drag = C_D \frac{\rho}{2} SV^2$$

= (0.0104)*(1.2071/2)*13.37*$(40)^2$

= 0.134 KN

VI. Case 6(At 180m distance from the ground)

Density of air =1. 2036 kg/m^3

$$Lift = C_l \frac{\rho}{2} SV^2$$

= (1.139)*(1.2036/2)*13.37*$(40)^2$

= 14.66 KN

$$Drag = C_D \frac{\rho}{2} SV^2$$

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$= (0.0104)*(1.2036/2)*13.37*(40)^2$

= 0.133 KN

5. Result and discussions

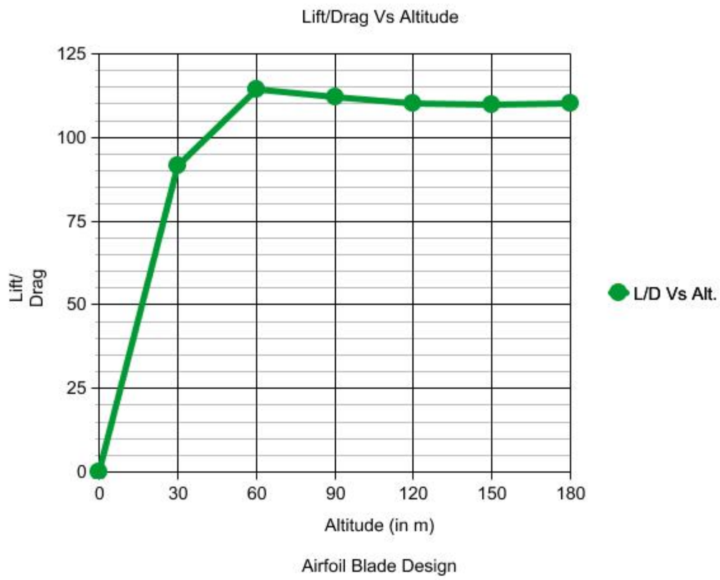
Airfoil Designation / Parameter	NACA 0012	NACA 250(6.1)					
Altitude	30 m	30 m	60 m	90 m	120 m	150 m	180 m
Density of Air	1.22*	1.22	1.2178	1.2142	1.2107	1.2071	1.2142
Lift(KN)	12.24	17.32	16.25	15.68	14.76	14.70	14.66
Drag(KN)	0.120	0.189	0.142	0.140	0.134	0.134	0.133

(Table 3. Results for blade design)

*Density of Air in kg/m^3

The results indicated in table 3. compares the lift and drag forces at various altitudes of the helicopter hover condition. The lift and drag reduces over a range of increasing altitude. The lift is more and the drag is less for NACA 250(6.1) as compared to NACA 0012 for a height of 30m. Further simulations show the same result hence it is not repeated in the result table.

Figure 3. shows the variation of the lift by drag ratio or the glide ratio with increasing altitude of the helicopter. It keeps increasing for a altitude range of 0 to 60m and then attains a constant value afrom 60m to 180m.



(Figure 3. Plot of Glide Ratio Vs Altitude)

7. Conclusion and Future Scope

Observing the result table, it can be noted that the lift capacity for the new blade is greater than the original blade design. Also the drag force is much smaller which ensures good lift for the helicopter. Hence theoretically the results obtained are feasible and acceptable and can be considered for practical testing and subsequent use in the helicopter. Observing the graph, it can be seen that the lift of the blade increases with increasing altitude and gradually becomes constant after 60m altitude. The glide ratio has a maximum value of 114.43 when the altitude is in the rang0e of 60m to 65m when the helicopter is in hover condition.

The airfoil NACA 250(6.1) can be tested practically in a wind tunnel as a result of which practical data can be obtained and compared with the theoretical data obtained in this paper. This airfoil profile can be used in a heavy lift helicopter (Sikorsky Sky Crane or Chinook) as it can generate the sufficient amount of lift required for the helicopter in hover condition.

References

1. Ngoc Anh Vu , Jae Woo Lee and Jung Il Shu, “Aerodynamic design optimization of helicopter rotor blades including airfoil shape for hover performance” in Chinese Journal of Aeronautics, 2013,26(1) 1–8.
2. Wang Qing, Zhao Qijun and Wu Qi on “Aerodynamic shape optimization for alleviating dynamic stall characteristics of helicopter rotor airfoil” in Chinese Journal of Aeronautics, (2015),28(2) 346–356

3. C.J.Thomas Renald, K.Sathiyalingam, V.Satheesh Kumara S.Shanavas and T.Govindasamy on “An Alternate Approach For Geometrical Construction Of Subsonic Airfoil With Numerical Investigation” in Procedia Engineering 38 (2012) 1758 – 1763.
4. Diana Cazangiu, Gabriel Dima, Razvan Dragan and Ileana Rosca on “Structural Analysis of the Main Rotor Blade For A Light Helicopter - Case Of Hovering Flight Mode” in Fascicle of Management and Technological Engineering Issue #1, 63-66.