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AERODYNAMIC PERFORMANCE PREDICTION OF A SHORT RANGE ROTORCRAFT

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ABSTRACT

High agility occurs at the boundaries of the performance where high vibratory loads are developed on the vehicle structure. This article presents a design optimization of short range rotorcraft while facing the tough weather conditions. Rotorcraft optimization has not yet reached the same maturity as aerodynamic optimization, and some potential reasons are well known. The use of design optimization for rotorcraft applications increases with the availability of improved analysis and more efficient algorithms. Especially for sensitivity calculations and further experimental verifications aerodynamic force optimization is a pre-requisite. The aerodynamic forces and structural loads acting on the rotor blades under extreme operating conditions are investigated by numerical methods. The rotor blade is designed using NACA 23012 airfoil and the aerodynamic force coefficients during the hovering and vertical climb are computed with significant accuracy. The objective of this analysis is to design a two/three seated rotorcraft by using single rotor (NOTOR) at low cost. It should possess the all weather operation capability for the emergency rescue purpose, condition like forest fire, floods, and other natural calamities.

Keywords: Unsteady Aerodynamics, NOTOR, Design optimization, Hovering, CFD.

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1. INTRODUCTION

The rotorcraft is an aircraft that uses rotating wing to provide lift, propulsion and control. The rotor blades rotate about a vertical axis and describing a disc in a horizontal or nearly horizontal plane. Aerodynamic forces are generated by the relative motion of blade surface with respect to the air [1]. The rotor should supply a lift to support the helicopter weight efficiently. Proficient vertical flight means a low power loading, because the installed power and fuel consumption of the rotorcraft are proportional to the power required [2]. The conventional rotors consist of two or more identical equally spaced blades attached to a central hub. In the proposed design, it consists of two rotor blades that are mounted in a hub. The uniform rotational motion of the blades is maintained usually by a shaft torque from the engine [5]. The lift and drag forces on these rotating wing produce the torque, thrust, and other forces and moment of the rotor.

The large diameter rotor is required for good aerodynamic efficiency of the rotating wing, which results in considerably more flexible blades [3]. Few rotorcrafts have a single main rotor but need a separate rotor to overwhelm the torque. It is the design that Igor Sikorsky settled on for hisVS-300 helicopter, and it has become the documented resolution for helicopter design, even though designs will vary. The helicopter rotor designs from Germany, and United Kingdom rotates counter clockwise except all other countries designs are rotate clockwise. It is difficult to compare the aerodynamic effects on the rotor between dissimilar designs, while the effects may evident on contradictory sides of each helicopter [6]. The torque is developed by the way of engine turns the rotor and produces an effect that reasons the body of the helicopter to turn in the contradictory direction of the rotor. To eradicate this effect, an anti-torque control must be used with adequate boundary of power accessible to allow the rotorcraft to continue its heading and offer yaw control.

NOTAR, an acronym for NO Tail Rotor, is a rotorcraft anti-torque method that reduces the use of the tail rotor on a helicopter [12]. Even if the conception took certain period to enhance, the NOTAR arrangement is simple in concept and delivers anti torque the similar way a wing improves lift by expending the Coanda effect (Fig 1). Adjustable pitch fan is bounded in the aft fuselage section instantly and is determined by the main rotor transmission. This fan powers low pressure air over two slots on the right side of the tail boom, initiating the downwash after the main rotor to hug the tail boom. It is creating lift and thus amount of anti-torque comparative to the amount of airflow from the rotor wash. This can be increased by a direct jet thrust which also delivers directional yaw control, and vertical stability [7]. The successful design of a rotorcraft perhaps helps to a greater extent than any other aerospace vehicle, on the tight integration of a variety of Aeronautical engineering disciplines.

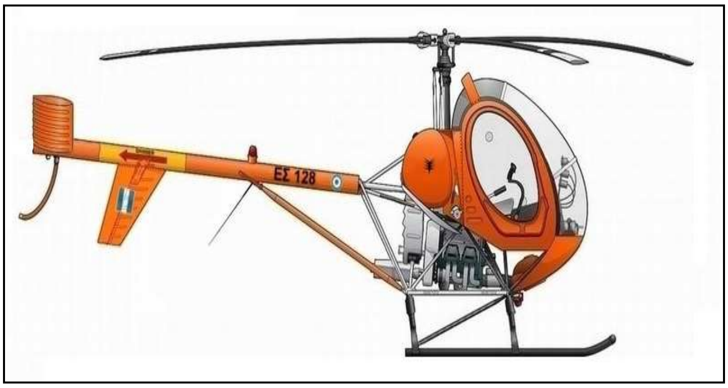


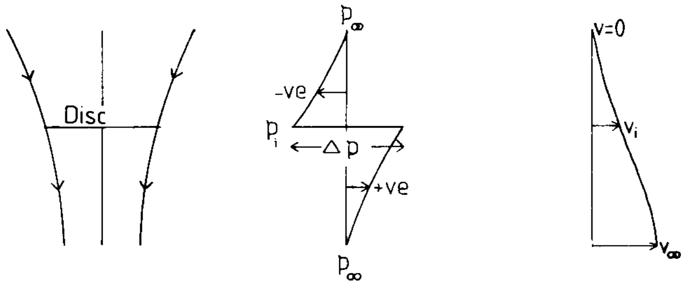
Fig 1. Rotor craft with single main rotor design

An example is the design of slender and flexible beam like main rotor system. Even in the normal operating conditions they undergo elastic deformations in bending and torsion that can be beyond the limits of linear beam theories [11]. The main observation of this study about helicopter operations is that "it is ten times more likely to be involved in an accident than a fixed wing aircraft". A root cause for the high rate of helicopter accidents is statistically the loss of pilot control. The reason might be the fact that today high-attained performances with the helicopters are forcing these machines to operate closer to the limit of their capabilities. Particularly, in the developing countries, helicopter accident becomes most common one, because of poor handling and tough weather conditions. During the tough weather conditions, the aerodynamic capabilities of the rotorcrafts won't allow them to operate successfully. Therefore, the proposed design will overcome this setback and offer sufficient details to operate at any conditions [20].

2. MOMENTUM THEORY FOR HOVERCRAFT

The rotorcraft rotor produces an ascending thrust by driving a column of air downwards over the rotor plane. A connection among the lift produced and the velocity are interconnected to the air that can be obtained by the laws of conservation of mass, momentum and energy [9]. The energy conservation, in the method of Bernoulli's equation is applied to earlier and after the disc along the flows. Using the hypothesis of incompressible flow analysis, along the inflow line,

$$p_\infty = p_i + \frac{1}{2}\rho v_i^2 \quad (1)$$



(a) Flow field (b) Pressure (c) Velocity

In equation (1), 'ρ' is the air density, and using the Actuator disc concept for rotor in hover the outflow becomes

$$p_i + \Delta p + \frac{1}{2}\rho v_i^2 = p_\infty + \frac{1}{2}\rho v_\infty^2 \quad (2)$$

By the momentum conservation, the thurst, 'T' on the disc is equivalent to the complete rate of increase of axial momentum of the air. (i.e.,) $T = \rho A v_i v_\infty$. Here, A - disc area, Δp - thrust per unit area and $v_\infty = 2v_i$. Thus the half velocity communicated to the air occurs above the disc and half below the disc. The relation between the thrust (Here Lift) and the velocity v_i is,

$$T = 2\rho A v_i^2 \quad (3)$$

The the induced velocity is known as,

$$v_i = \sqrt{\frac{T}{2\rho A}} = \sqrt{\frac{w}{2\rho}} \quad (4)$$

The work done on the air is denoted by its change in kinetic energy per unit time in equation (3). It is identified as the induced power of the rotor and it can be written as,

$$p_i = T v_i = T^{3/2} \big/ \sqrt{2\rho A} \quad (5)$$

And Thrust coefficient, $C_T = T/\rho A(\Omega R)^2$, Power coefficient : $C_P = P/\rho A(\Omega R)^3$

Momentum Theory for Vertical Climb: A flow diagram for the rotor in vertical climb with upward velocity V_c is shown above. Based on the Bernoulli's equation as previously, now for the inflow [8] condition,

$$P_\infty + \frac{1}{2}\rho V_c^{\,2} = P_i + \frac{1}{2}\rho (V_c + \nu_i)^2 \qquad (6)$$

The outflow equation becomes,

$$p_i + \Delta p + \frac{1}{2}\rho (V_c + \nu_i)^2 = p_\infty + \frac{1}{2}\rho (V_c + \nu_\infty)^2 \qquad (7)$$

Also the thrust by momentum conservation equation is written as,

$$T = \rho A (V_c + \nu_i)\nu_\infty \qquad (8)$$

The connection among the induced velocity in hover and vertical climb is agreed by

$$\nu_h^{\,2} = (V_c + \nu_i)\nu_i \qquad (9)$$

For ν_i in terms of ν_h consumes the result,

$$\frac{\nu_i}{\nu_h} = -\frac{V_c}{2\nu_h} + \sqrt{\left\{\left(\frac{V_c}{2\nu_h}\right)^2 + 1\right\}} \qquad (10)$$

The induced velocity drops as climbing speed increases, dropping asymptotically towards zero for high rates of climb. For low rate of climb, ν_i will be similar to $(\nu_h - V_c/2)$. The power required, or total work done by the lift produced is,

$$P_i = T(V_c + \nu_i) \qquad (11)$$

Where, TV_c - is the work done on the rotor and $T\nu_i$ - is the work done on the air. The TV_c and $T\nu_i$ are represented by the induced velocity. Compare P_i to the value in hover and by means of equation (10) gives,

$$\frac{P_i}{P_h} = \frac{P_i}{T\nu_h} = \frac{V_c}{\nu_h} + \frac{\nu_i}{\nu_h} = \frac{V_c}{2\nu_h} + \sqrt{\left\{\left(\frac{V_c}{2\nu_h}\right)^2 + 1\right\}} \qquad (12)$$

Hence, the induced power rises with climb speed. At high rates of climb, P_i approaches to the climb work done TV_c only [10]. For small rates, it is nearly

$$P_i \approx P_h + TV_c/2 \qquad (13)$$

Now the momentum theory of its over-simplified depiction and the nature of the outflow beneath the rotor are mathematically expressed. The location of the tip vortex from a blade, when the next blade passes by is originated to be lower in climb than in hover [17]. It varies to the upwash at the blade tips for small rates of climb the power required is less than power for hovering.

FORCE DISTRIBUTION OVER THE ROTOR BLADE

Rotational velocity increases linearly with radius and most part of the lift is generated in the outer section of the blade [5]. The lift increases in the inner section by twisting the blade pitch angle and decreases with the radius [12]. The primary considerations in the blade force prediction are as follows (Fig 2),

- Blades are affected by centrifugal force due to rotation and lifting force (leads to rotor coning)
- Coning effect generates large moments at the blade roots
- Use of articulated rotor heads [14]

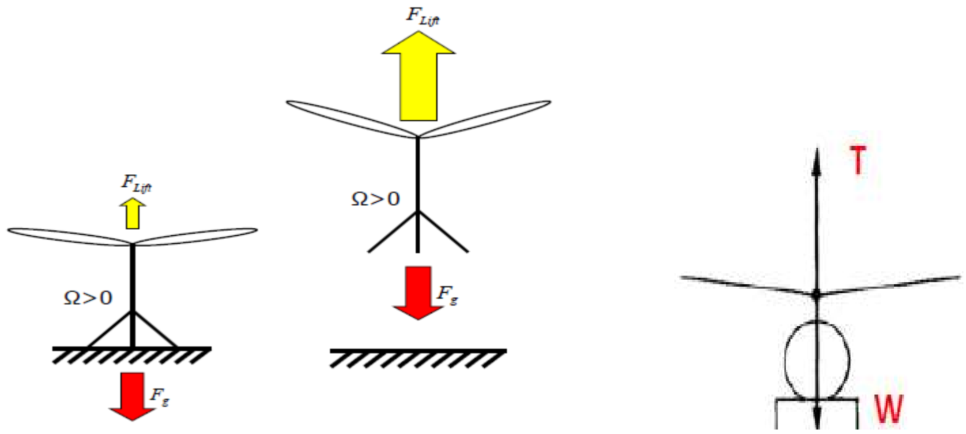


Fig 2. Forces on the rotor head and hovering layout

For standardization purposes, it is assumed that a stationary hover in a no-wind condition. During hovering flight, a helicopter maintains a constant position over a selected point, usually a few feet above the ground [16]. For a helicopter to hover, the lift and thrust produced by the rotor system act straight up and must equal the weight and drag, which act straight down. While hovering, you can change the amount of main rotor thrust to maintain the desired hovering altitude [9]. This is done by changing the Angle of Attack (AoA) of the main rotor blades and by varying power, as needed. In this case, thrust acts in the same vertical direction as lift and the forces on the blades do not vary as they turn.

3. SELECTION OF AIRFOIL

The Airfoils are developed mostly by Trial and error. In 1930s, NACA developed a family of mathematically defined airfoils. It comprises of 4-digit, 5-digit and 6-digit series. An airfoil-shaped body moves through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift [15]. Subsonic flight airfoils have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge. Often with asymmetric camber Foils of similar function are designed with water as the working fluid are called hydrofoils [7]. Here, Airfoil Designation – NACA 23012 is selected based on the initial parametric studies to meet the aerodynamic performance requirements. Its designation as,

- **2 –** Amount of camber in terms of relative magnitude of design C_L
- **30 –** The distance from the Leading edge to the location of maximum camber.
- **12 -** Section thickness in percent of chord.

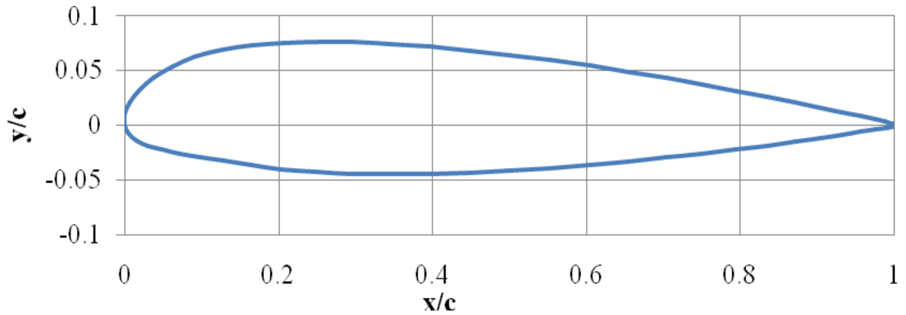


Fig 3. Constructed NACA 23012 Airfoil in the solver

As a continuation of the investigation recently completed of a large family of related airfoils (reference 1), two new series of related airfoils have been built and tested in the variable density tunnel [18]. The original investigation indicated that the effects of camber in relation to maximum lift coefficients are more pronounced when the maximum camber of the mean line of an airfoil section occurs at the forward position.

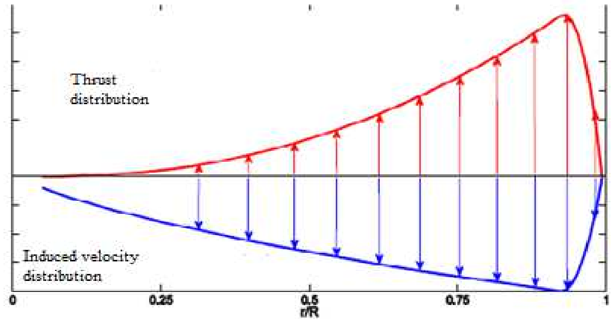


Fig 4. Distribution over a symmetrical blade with constant pitch angle

AEROFOIL DESIGN USING CATIA

The design parameters are obtained by the comparative study of different rotorcrafts which are similar to the proposed design and they are analyzed statistically. The popular designs considered are as follows,

(i). Md explorer and emergency medical helicopter, (ii). Md 520N, (iii). Rotorway exec 162 FA.

Sl.No	Parameters	Values
1	Cabin max width	1.24 (m)
2	Main rotor diameter	7 .6 (m)
3	Tail rotor diameter	1.24 (m)
4	Main rotor disc	46 (m^2)
5	Length of fuselage	6.50 (m)
6	Tail rotor disc	1.3 (m^2)
7	Weight empty	230 (kg)
8	Length of rotor turning	8.60 (m)
9	Height to top of main rotor head	2.40 (m)
10	Skid track	1.80 (m)
11	Max T/O weight	480 (kg)

Table 1: Computed and Analyzed Design Parameters

By means of the upper and lower surface co –ordinates the computational model is developed with the 60 cm chord and 5 m span. The rotor blade model is prepared using the part design tool exists in the CATIA design software.

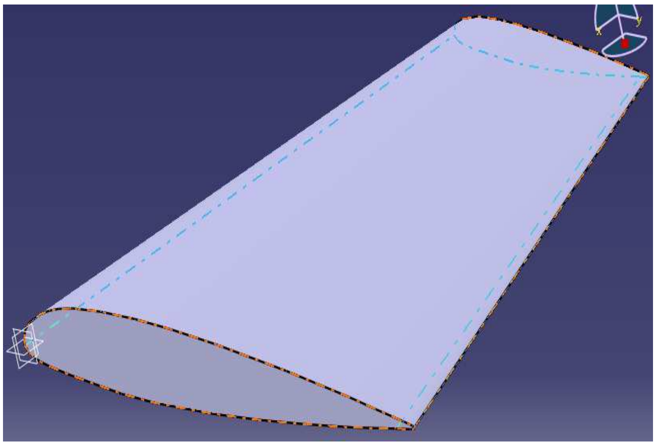


Fig 5. CATIA Model prepared using NACA –23012 airfoil

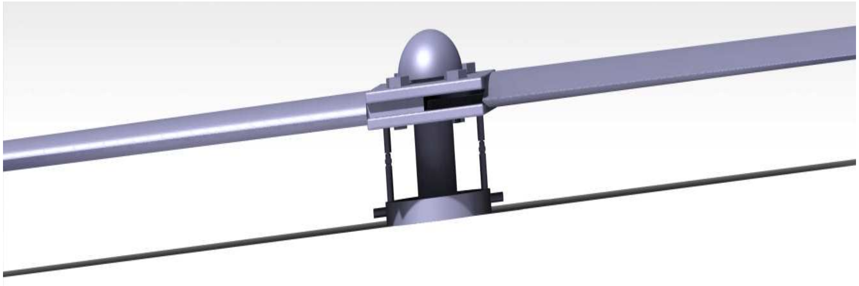


Fig 6. Assembled rotor blades with hub, bracket and pins

The two rotor blades and other assembly parts including the hub have been designed separately and combined together using part assembly module.

4. CFD ANALYSIS

The designed blade model is meshed with tetrahedral hybrid elements using the HYPERMESH tool. Energy equation has been enabled to identify the turbulent kinetic energy characteristics. Density based solver is used since the Mach number is high enough to consider the compressibility effects. Ideal gas assumption has been used for density parameter. At the inlet boundary of the control volume, the velocity magnitude is 240 m/s. In the upper surface the pressure is low and on lower surface pressure is high. Kinetic energy input value is taken as 0.1, density ρ =1.225kg/m^3. The rotational speed option has been enabled with the Velocity of 50 rad/sec and the Mesh spacing is 0.1.

Velocity & Pressure Contours: Computational Fluid Dynamics (CFD) tool is used to compute the Lift and Drag forces acting on the blades under extreme operating conditions. The contours of velocity magnitude presented in Fig (7) is indicating that the tip velocity is M = 0.79 for the given input of 50 rad/sec rotational speed.

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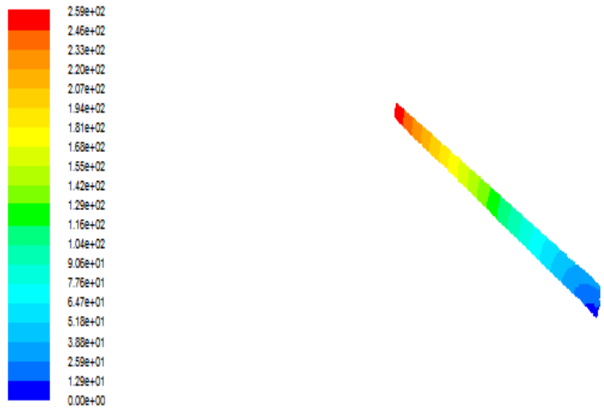

Fig 7. Contours of Velocity Magnitude (m/s)

The Fig (8) shows the rate of change of static pressure with respect to the span wise position of the blade. Many airfoils have been compared for the different camber of the blade to meet the design requirements. Then the tip speed has been calculated to ensure the existence of shocks. Once the blade area is determined, rotor radius can be calculated based on the blade performance after calculating tip speeds.

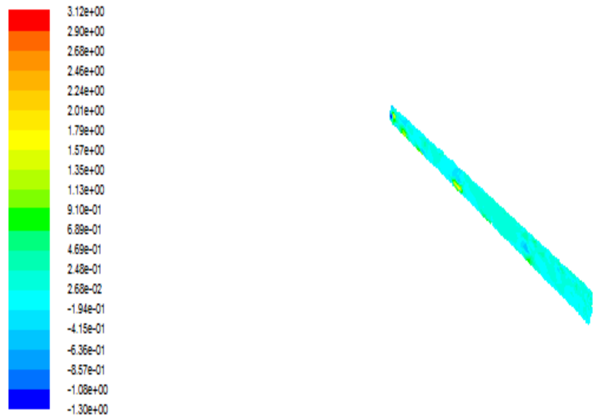

Fig 8. Contours of Static Pressure (Pa)

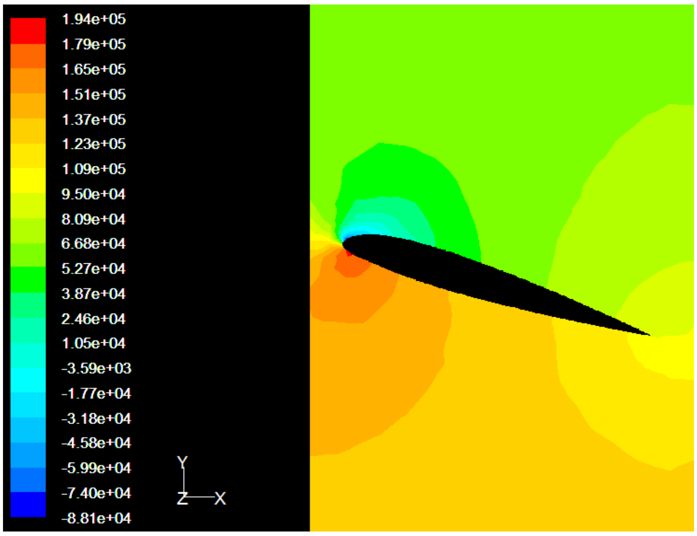

Fig 9. Contours of static pressure at 17 degree AoA

Fig (9) illustrates the stall characteristics of the rotor blade and above the 17° AoA the lift magnitude starts to diminish. When the blade slashes crosswise an airstream, there is a flow of air both over and under the blade. This profile shows that the air passes over the blade has to travel more distance and air passes under the blade is short. At the lower pressure side, the fluid is having higher velocity (i.e.,) the pressure difference between the air above and below the blade. Hence the lift force is created from the pressure difference between the sections. This lift force acts in the upward direction owing to the blade contour.

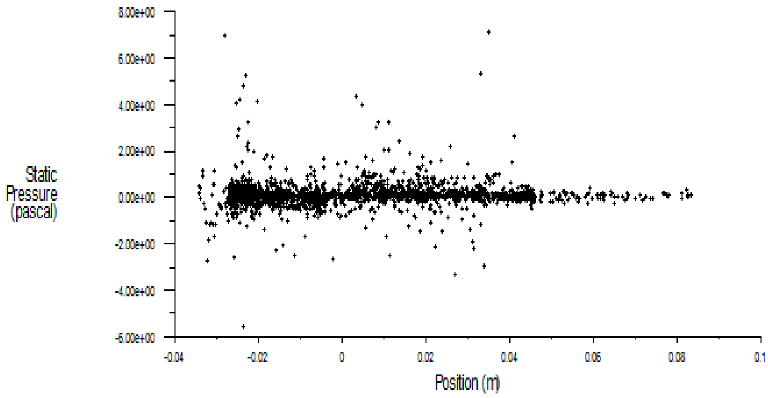

Fig 10. Static Pressure Variations from Root to Tip of the blade

The blade profile design is modified according to the rotor performance. The weight is acting downwards at the center of gravity. The lift force acts at the center of gravity as well but upwards. The drag force acts opposite to the direction of motion of the rotor blade. From the Fig (10), the blade attains the maximum lift and minimum drag at stall conditions.

5. RESULTS AND DISCUSSION

Sl.No	AoA	Total Lift (N)	Total Drag (N)	C_L	C_D
1	0	2635.88	76.5945	0.149	0.043
2	3	8452.26	106.36022	0.479	0.0602
3	9	8656.69	186.077	0.49	0.0105
4	12	27454.27	503.24314	1.5	0.0285
5	15	35732.39	787.28632	2.02	0.0446
6	17	41791.13	1029.0625	2.369	0.0583
7	20	49638.61	1427.017	2.813	0.0808
8	23	20449.83	837.86543	1.15	0.0474

Table 2: Aerodynamic Coefficients Vs AoA

The amount of forces acting on the rotor blades are computed using CFD Analysis with appropriate boundary conditions. Because of the mass of the blades, a weight force is acting downwards at the center of gravity of the blades. A separate blade is considered and the lift force value is computed for it. This design does not require a tail rotor because the main rotor alone is sufficient to produce lift and control moments [17].When compared to other helicopters, this design carries low initial material cost, low in maintenance cost, good fuel efficiency and easy handling in all weather operations. Lift force on the blades are approximately equal to 70 KN.

6. CONCLUSIONS

In this article, an attempt is made to design and fabricate a NOTOR helicopter. The dynamic forces are estimated for the speed of the rotor is 477 rpm and obtained nearly 70 KN lift and is three times greater than the helicopter weight. The lift generated by the tail rotor is ignored in this analysis as it is considered to be very small in comparison to that generated by the main rotor blades. Using generalized design parameters from the dimensional analysis, design of the rotor blade is finalized depending on the size of the vehicle [19]. The airfoil is analyzed by a CFD tool and obtained a favorable co- efficient of lift. Then the selection of material will play an important role in the role of NOTOR. It has been proved that the methodology incorporated is capable for predicting the helicopter aerodynamic characteristics. The designed blade setup will be tested in a wind tunnel to verify the results with numerical simulation before the fabrication process. A full scale model will be developed to prove the easy handling of pilot at any weather conditions. Significant rotorcraft performance benefits can be achieved by implementing retreating blades. Initial experimental and computational demonstrations have yielded encouraging results. Validation experiments are planned at full scale helicopter rotor blade to demonstrate aerodynamic benefits and control system performance.

REFERENCES

[1] Ashwani K. Padthe, Peretz P. Friedmanny, and Dennis S. Bernsteinz, “Actuator Saturation in Individual Blade Control of Rotorcraft”, 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, pp 23 - 26 , April 2012.

[2] Dimitri J. Mavriplis, Zhi Yang Y, and Nathan Mundis Z, “Extensions of Time Spectral Methods for Practical Rotorcraft Problems”, 50th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, pp 09 - 12 , January 2012.

[3] Nawee Butsuntorn and Antony Jameson, “Time Spectral Method for Rotorcraft Flow with Vorticity Confinement”, 26th AIAA Applied Aerodynamics Conference, pp18 - 21, August 2008.

[4] Hassan Nagib, John Kiedaisch, and David Greenblatt, “Effective flow control for rotorcraft application at flight mach numbers”, American Institute of Aeronautics and Astronautics, pp 11-14, 2001.

[5] Lorber. P, McCormick. D, Anderson. T, “Rotorcraft Retreating Blade Stall Control”, United Technologies Research Center, pp 19-22, June 2000.

[6] Reddy. U.C. and Komerath. N.M. “3d Velocity Field Measurement in Large-Scale Rotor Flows”, 25th AIAA Applied Aerodynamics Conference, pp25 - 28, June 2007.

[7] Mohammad Zain. Z, Mohamad. N, Mohamad Ali. Z , “Redesign Of De Bothezat Helicopter : The Way Forward ForThe Rotorcraft Industry”, 43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials, pp.22-25, April 2002.

[8] Andrew M. Wissink, “A Parallel Newton-Krylov Method for Rotorcraft Flow field Calculations”, American Institute of Aeronautics and Astronautics, pp. 12-15, 1997.

[9] Li Liu, Peretz P. Friedmann and Dan Patt, “Simultaneous Vibration and Noise Reduction in Rotorcraft– Practical Implementation Issues”, 46th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference, pp.18 – 21, April 2005.

[10]. Chen1. C.L, Ya-Chi Chen and Bing Chen, “High Fidelity Multidisciplinary Tool Development for Helicopter Quieting”, 25th AIAA Applied Aerodynamics Conference, pp 25 - 28, June 2007.

[11] Gault, D.E., "A Correlation of Low-Speed, Airfoil-Section Stalling Characteristics with Reynolds Number and Airfoil Geometry", NACA TN 3963, pp.3 -8, March 1957.

[12] Seddon. J –Basic Helicopter Aerodynamics (BSP Prof. Book), pp.6 – 23, 1990.

[13] Greenblatt, D. and Wygnanski. I., “Parameters affecting dynamic stall control by oscillatory excitation”, AIAA Paper 99-3121, 17th AIAA Applied Aerodynamics Conference, pp.12 -28, July 1999.

[14] Hassan. A. and Munts E, “Transverse and Near Tangent Synthetic Jets for Aerodynamic Flow Control”, AIAA Paper 2000-4334, Applied Aerodynamic Conference, Denver, pp 14 – 17, August 2000.

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[15] Hites, M.H., "Scaling of High-Reynolds-Number Turbulent Boundary Layers in the National Diagnostic Facility", Ph.D. Thesis, Illinois Institute of Technology, pp.4-11, 1997.
[16] Hites, M., Nagib, H., Bacher, T., and Wygnanski, I., "Enhanced Performance of Airfoils at Moderate Mach Numbers Using Zero-Mass Flux Pulsed Blowing", AIAA Paper 2001-0734, 39th Aerospace Sciences Meeting and Exhibit,Reno, pp. 12-15, Jan 2001.
[17] Seifert, A. and Pack, L. G, "Oscillatory excitation of unsteady compressible flows over airfoils at flight Reynolds numbers", AIAA Paper 99-0925, 37th Aerospace Sciences Meeting and Exhibit, Reno, pp.11-14, 1999.

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