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DESIGN OF AN ARMAMENT WING FOR A LIGHT CATEGORY HELICOPTER

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ABSTRACT - The objective of this research is to study the feasibility of an armament wing as a weapon carrier for a light category helicopter of 3000 kg class to increase the aerodynamic efficiency of the helicopter. Modern attack helicopters need better agility, maneuverability, and diving characteristics, higher 'g' capability and increased speed. Many conventional and non-conventional ways are being used to improve the helicopter performance; which includes use of auxiliary engines, propellers and wings etc. A wing improves overall lifting effectiveness with increased velocity and improve the decreasing effectiveness of the main rotor in extreme cases (high altitude/high speed/more weight).

To install a wing on a light category helicopter, the aerodynamic design of the wing was taken up during this project work. Parameter estimation was carried out through hand calculations and by using a simulation program. Firstly, enormous literature was studied to figure out the type of the wing to be used on the helicopter. The literature survey included the statistical analysis of various class of helicopters with wings. The statistical analysis helped in choosing the area of the wing.

The major work included the selection of aerofoil, wing dimensions and estimation of wing angles. Various aerofoils were compared to derive a lift of at least 10-15% of the helicopter All Up Weight. The best aerofoils were chosen based on the L/D ratio for different angle of attacks.

To assess the performance of the helicopter with wing, a simulation program in the form of optimizer was required to estimate the overall behaviour of the helicopter throughout the flight regime (different AUW, speeds and altitudes). Subsequently, it is used to optimize the wing parameters (Incidence angle and location of the wing). This program calculates the forces and moments on the aerodynamic surfaces with 3 Dimensional effects. The final optimization of wing parameters was based on the performance of the wing at different speeds and altitudes. The overall helicopter behaviour in terms of controls angle, Attitudes and power was also considered to choose the final wing configuration. This research work includes the comprehensive analysis of aerodynamic design process for a light-category helicopter.

KEYWORDS

1. HAL- Hindustan Aeronautics Limited
2. NACA- National Advisory Committee for Aeronautics
3. Km/h - Kilo meter per hour
4. M/h - Meter per hour
5. AOA - Angle of attack
6. AOI - Angle of Incidence
7. L/D - lift by Drag
8. AR - Aspect ratio
9. S - Area
10. b - Span
11. C_L- Coefficient of lift
12. C_D - Coefficient of drag
13. C_m - Coefficient of moment
14. ρ - Density
15. V- Velocity
16. Deg – Degree
17. Kmph- Kilometre per hour
18. V_Y- Velocity w.r.t. best rate of climb
19. V_H – Maximum cruising speed

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I. INTRODUCTION

The research was carried out for a light category helicopter of 3 tonne weight class. The helicopter meets the requirements of both military and civil operators.
The general characteristics of light category helicopter are: -

- Predominantly composite airframe with excellent crashworthy features.
- Composite main and tail rotor blades for excellent damage tolerance capability. Hinge-less rotor system for high agility and manoeuvrability of the helicopter.
- Advanced avionics suite with fully integrated smart multi-functional display and indigenously developed application software.
- Several dual redundant systems ensuring higher level of safety.

In this, we will introduce an armament wing in light category helicopter so that it can be used for attack/defence purposes and to increase the aerodynamic efficiency of the helicopter. In the coming period, there will be a wide improvement in helicopters regarding speed, range and other features. The basic features required for the attack helicopters are better agility, maneuverability and increased speed. Many ways have been implemented to improve the helicopter's performance which includes, the use of auxiliary engines, wings etc. But by installing the wing, the helicopter's overall lifting efficiencies with increased velocity and decreasing effectiveness of main rotor improves in extreme cases like high altitude, high speed etc.

II. LITERATURE SURVEY

The objective was to design the armament wing for light category helicopter. The basic requirement for designing the wing was the shape of the airfoil and airfoil nomenclature which was surveyed from 'Fundamental of Aerodynamics by John D Anderson. The shapes of all the standards NACA airfoils are generated by specifying the shape of the mean camber line and then wrapping a specified symmetrical thickness around mean camber line. The NACA identified various airfoils shapes like NACA 4 digit series, 5 digit series and 6 digit series with the logical numbering system.
To design an armament wing, the research was done to select the suitable airfoil series. Out of various series like 4 digit, 5 digit, 6 digit, 7 digit, NACA 4 digit series was selected because the higher digit series(5,6,7) have more thickness than 4 digit series which can increase the weight of the wing and that can be a drawback in the performance of the helicopter as it is a light category helicopter. The NACA 4 digit series have a suitable thickness for such category. NACA 4 digit series aerodynamics coefficients were referred from 'Theory of wing sections' by IRA H. Abott.
IHS Jane's, 'All the world's Aircraft Development and Production' was referred to compare the span and chord of the different attack helicopters to select the wing area and aspect ratio was decided based on the statistical analysis.
So based on the above literature survey, the airfoils series and wing parameters were decided for the further analysis and parametric studies.

III. ANALYSIS

- **THEORETICAL CALCULATIONS**

In the first step the wing forces were calculated which were required to improve the helicopter's performance .The 3-D forces and moments for a wing for different flight conditions were calculated by the airfoil theory. Aerodynamic coefficients of different NACA airfoils were used to calculate the forces and the moments generated by the wing in different flight regimes. By using the following formulas, aerodynamic forces and moments were calculated.

$L=1/2\rho v^2SC_l$ ---------- (1)
$D=1/2\rho v^2SC_d$ ---------- (2)
$M=1/2\rho v^2SC_m$ ---------- (3)

On comparing the dimensions of wing of few helicopters like Apache, Augusta, Bell etc., the average span and chord were considered. Using that span and chord, the approximate area of 2.737 m was considered for Light category helicopter.

- **SIMULATIONS:**

Simulation studies were also carried out to calculate to confirm the theoretical calculations. After confirming the trends and sensitivity w.r.t. different flight conditions, it was required to assess the performance of the helicopter with wing. The control angles, attitude and total power were estimated for different flight regimes i.e. hover, low speed handling, level flight. At sea level, the

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aerodynamic forces and moments were obtained at different angles for different speeds.
The prime objective of this study was to check the behaviour of the helicopter with wing for different flight regimes.

IV. PARAMETERIC STUDIES

- **EFFECT OF AEROFOIL**

The Aerodynamic forces and moments were calculated for different airfoils like NACA 4418, 4424, 4412 and 2412 considering respective aerodynamic coefficients (C_l, C_d, and C_m) at Mach 0 and Reynold's number one lakh. Angle of attack of wing was a resultant of wing incidence angle (AOI), helicopter angle of attack and helicopter pitch angle. Helicopter angle of attack changes with respect to flight regime. However, it is fairly accurate to assume the angle of attack of the helicopter same as the helicopter angle of attack in level flight.
It is observed that for all the airfoils, lift was increasing with AOA and with specific stall angle of attack. The general outcome of theoretical analysis is listed below:

- Drag increases with the increase in AOI and AOA as shown in Table1 & fig1.
- Lift due to armament wing increases with the increase in AOI and AOA as shown in table1 & fig.2.
- Pitching moment due to armament wing increases with the increase in the AOI and AOA as shown in Table1 & fig.3.

AOA (degree)	Cl	Cd	Cm
-5	-0.0718	0.00845	-0.1049
-4	0.0039	0.0078	-0.1044
-3	0.1512	0.00745	-0.1041
-2	0.2625	0.00715	-0.1038
-1	0.3734	0.00697	-0.1035
0	0.4833	0.00686	-0.1032
1	0.5842	0.00594	-0.1009
2	0.7055	0.00622	-0.1026
3	0.8214	0.00687	-0.1016
4	0.921	0.00722	-0.101
5	1.0254	0.00797	-0.0998
6	1.128	0.00884	-0.0998
7	1.2208	0.01036	-0.0954
8	1.2973	0.01288	-0.09
9	1.3676	0.01527	-0.0836
10	1.4317	0.01746	-0.0762

Table 1: C_l, C_d and C_m of NACA series 4412

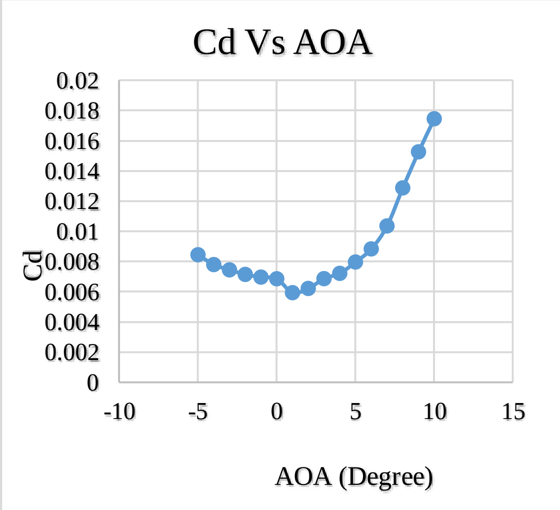

Figure1: Coefficient of Drag w.r.t AOA

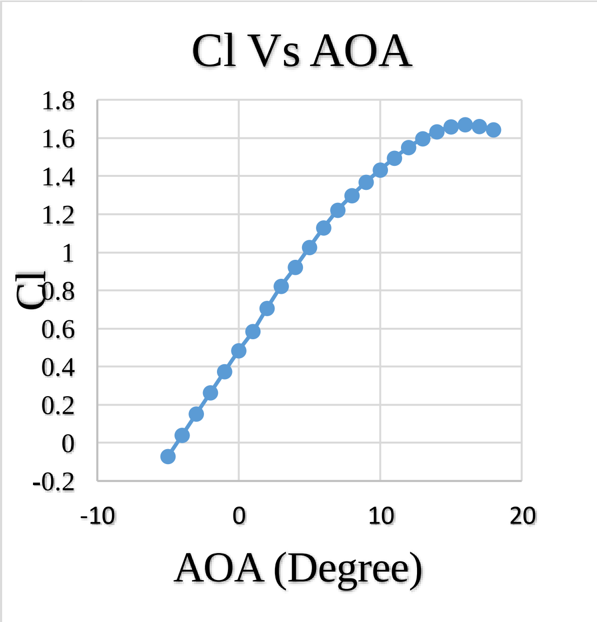

Figure2: Coefficient of lift w.r.t AOA

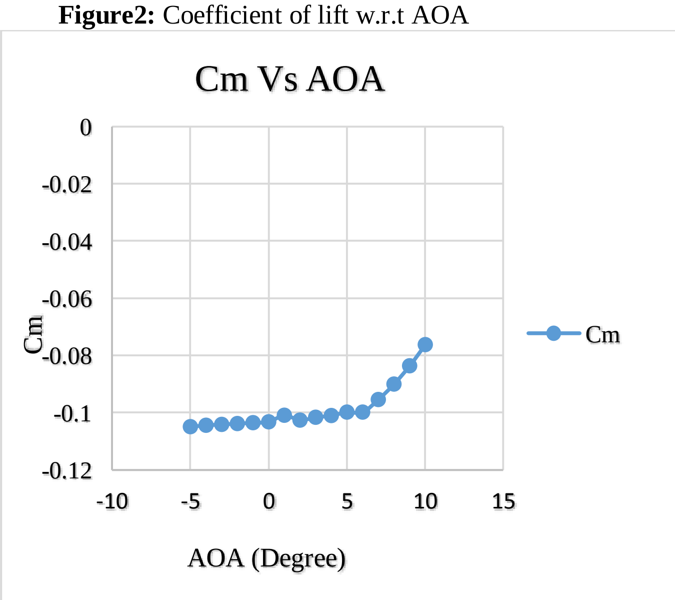

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Figure3: Coefficient of moment w.r.t AOA

The overall performance of the wing was based on following aspects:

- **LIFT TO DRAG RATIO:**

An efficient airfoil produce the lift with the minimum of drag i.e. the ratio of L/D is a measure of aerodynamic efficiency of the airfoil. The L/D ratio of the complete flight vehicle has an important impact on its flight performance. For e.g. the range of the vehicle is directly proportional to L/D ratio. The higher is the L/D, the more aerodynamically efficient is the airfoil. Calculation of L/D for different aerofoils is given in Table 2. The calculation was based on maximum flight speed of the helicopter (V_H) at sea level. Based on this, out of all the above airfoils, NACA 4412 had highest value of L/D ratio as shown in fig. 4.

- **THE MAXIMUM LIFT COEFFICIENT:**

An effective airfoil produce a high value of $C_{L.max}$ for a complete flight vehicle. The value of Cl increases linearly with the AOA until an AOA is reached when the wing stalls, the lift coefficient reaches a peak value, and then drops off as AOA is further increased. Therefore, NACA 4412 airfoil was resulting in the highest value of $C_{L.max}$.

	NACA2412	NACA4418	NACA4415	NACA4412	NA
AOA (degree)	L/D	L/D	L/D	L/D	L/D
-5	-15.372	-7.626	6.342926	-8.49704	15
-4	-14.923	4.911	5.361596	5.051282	7.
-3	-13.362	18.303	17.74485	20.2953	2.
-2	-11.65	31.913	30.19016	36.71329	12
-1	-5.677	45.546	44.33333	53.57245	24
0	-2.448	58.739	55.68151	71.28319	34
1	6.307	74.253	70.59163	98.35017	42
2	9.716	87.779	96.44345	113.4244	47
3	**13.704**	100.788	108.2982	119.5633	54
4	17.748	107.838	117.2917	127.5623	62
5	22.816	114.726	119.1415	128.6575	62
6	27.119	115.384	119.1585	127.6018	69
7	31.707	114.363	116.6532	117.8378	69
8	32.64	109.034	111.1353	100.722	6
9	27.561	101.76	100.834	89.56123	68
10	23.195	91.79	90.48714	81.99885	67

Table2: L/D Ratio for different airfoils at different AOA (degree)

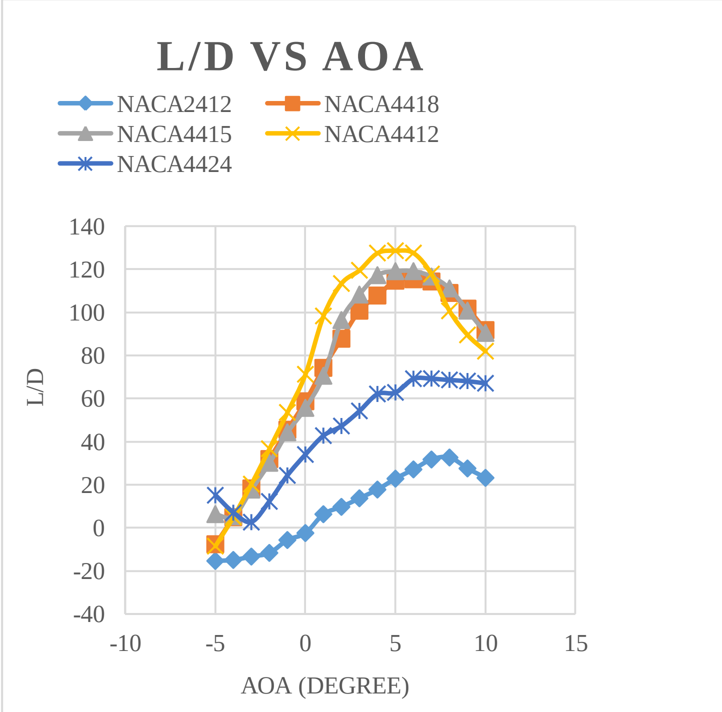

Figure 4: Comparison of different airfoils

- **EFFECT OF ASPECT RATIO ON WING**

The induced drag coefficient for a finite wing with general lift distribution is inversely proportional to aspect ratio. The primary design factor for minimizing the induced drag is the ability to make the aspect ratio as large as possible.

$$AR = b^2/S$$

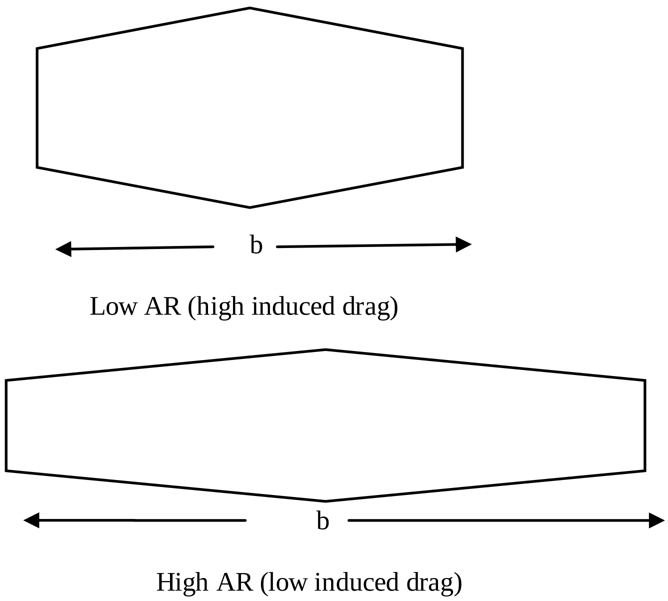

Figure 5: Schematic of high and low aspect ratio wings

During this research, the wing area and aspect ratio (Fig: 5) was decided based on the statistical analysis of contemporary helicopter. The wing dimensions are given below:
Wing Span: 3.9 m
Tip chord: 0.526 m
Root Chord: 0.878 m
Area: 2.737m
Aspect Ratio: 5.555

- **EFFECT OF WING INCIDENCE ANGLE AND SPEED**

Parametric studies were carried to optimize the wing incidence angle at different speeds. The primary aim was to get the lift of at least 10-12% of the all up weight. That amounts to be around 3000 to 4000 N. This criteria was important from getting higher speed point of view. It is also worth to be noted that helicopter in this weight range being designed for Indian conditions may not require very high speed.
Another criteria was to get better range and endurance and to check the wing performance from V_Y (velocity w.r.t best rate of climb) to V_H (maximum cruising speed). This range of speed covers the Best Range and Best Endurance speed. It was also required to have lesser control angles, power and similar pitch attitude of the helicopter compared to the helicopter without wing. In addition to all these facts, the wing lift should also increase with speed and not flattened out or stalled.
There was also a drastic reduction in the amount of lift being calculated by simulation studies compared to theoretical (hand calculations) calculations. This can be attributed to the 3-D effects of wing itself and interference effect of wing with other helicopter components. However, the overall aerodynamic sense regarding the ratio of lift and drag was same for simulation studies and theoretical calculations.
From Table- 3 and Fig: 6, it was clear that the lift force increases with increase in incidence angle. The design target of 3000N-4000 N was only visible with AOI of 10 deg and above.
Considering everything mentioned above, the wing incidence can be chosen as 12 to 15 deg. The wing with 12-15 deg of incidence angle would off-load the rotor in the speed range of V_Y (velocity w.r.t best rate of climb) to V_H (maximum cruising speed) However, 12-15 deg of wing would have higher control angle and power requirement at V_H.
Another fact which might be critical during the installation of wing with weapons on the helicopter is the ground clearance. At this point, it is quite premature to decide anything on the wing incidence angle based on the ground clearance.

Overall, a wing with 12-15 deg of incidence angle would give benefit in the range of V_Y with a penalty in V_H. Alternatively, using a wing with 0 deg incidence angle would have no loss ad no benefit in the entire flight regime. However, this is not recommended.
All in all, it is recommended to use 12-15 deg of wing incidence angle for a light category helicopter of 3000 kg weight category.

AOI (degree)	5	8	10	12	15
SPEED (kmph)					
120	1460.183	1819.153	2032.426	2212.392	2413.25
160	2084.83	2719.737	3087.212	3484.163	3893.389
200	2199.814	3129.055	3710.383	4330.251	5123.222
240	1624.481	2933.649	3695.146	4534.428	5574.334

Table 3: Lift (Newton) at different AOI at various speed

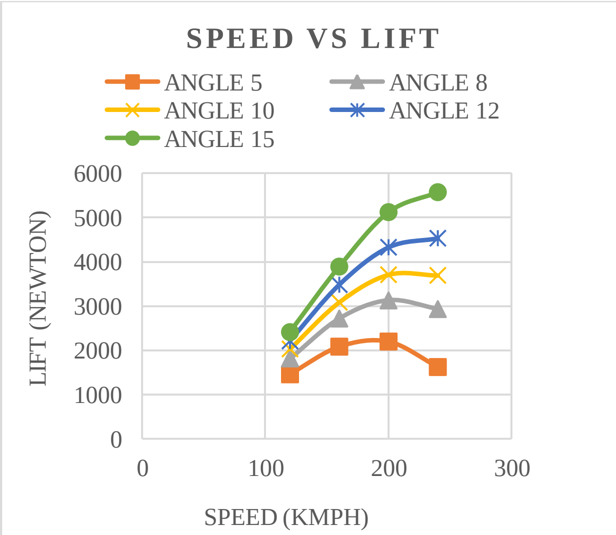

Figure 6: Effect of AOI and speed

AOI (degree)	0	5	8	10	12	15
SPEED (kmph)						
120	-1.408	-1.483	-1.516	-1.553	-1.495	
160	-0.8	-0.895	-0.926	-0.877	-0.931	-0.781
200	0.726	0.631	0.677	0.691	0.669	0.761
240		2.867	2.886	2.947	3.037	3.241

Table 4: Main Rotor Collective cyclic (degree)

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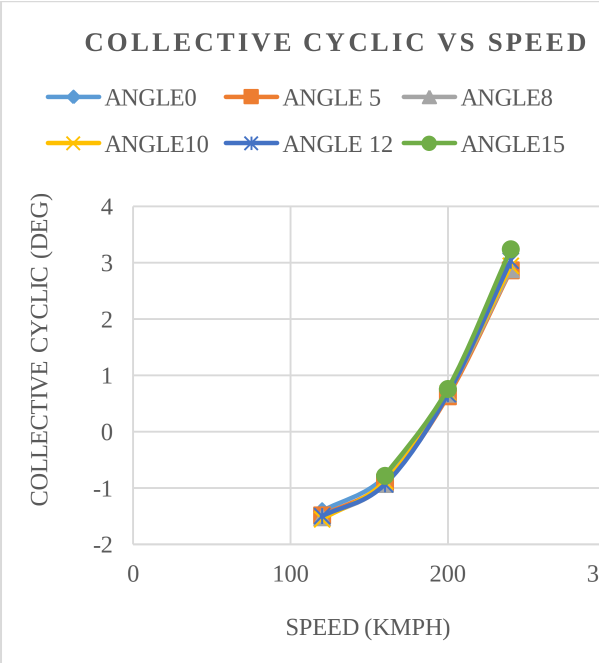

Figure 7: Main rotor collective cyclic Vs speed

The Main Rotor collective requirement decrease with increase in the wing incidence angle from V_Y and again increases at V_H (Table: 4&Fig: 7).

AOI (degree)	ANGLE0	ANGLE 5	ANGLE8	ANGLE10	ANGLE12	ANGLE15
SPEED						
120	1.655	1.803	1.887	1.937	1.966	1.999
160	1.577	1.838	1.988	2.087	2.184	2.28
200	1.517	1.904	2.137	2.231	2.369	2.571
240		1.897	2.206	2.382	2.512	2.811

Table 5: Main Rotor Lateral cyclic (degree)

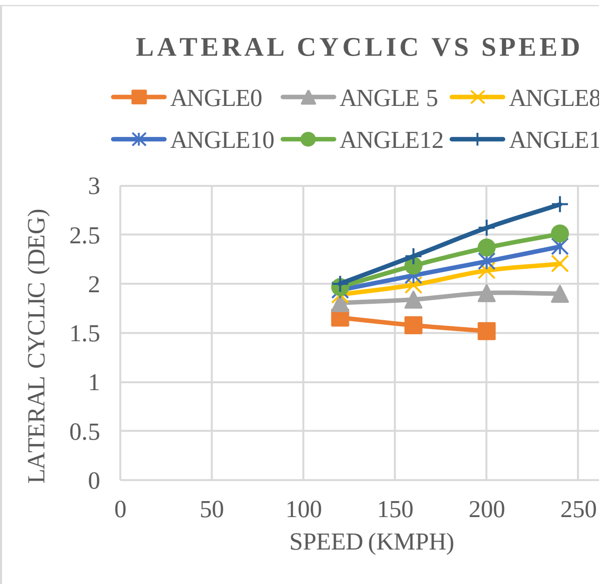

Figure 8: Main rotor lateral cyclic Vs speed

The Main Rotor lateral cyclic requirement increase with higher incidence angle, however it is within the limits. (Table:5&Fig: 8).

AOI (degree)	0	5	8	10	12	15
SPEED (kmph)						
120	-1.972	-1.944	-1.928	-1.917	-1.97	
160	-2.576	-2.506	-2.479	-2.489	-2.453	-2.531
200	-3.718	-3.615	-3.578	-3.495	-3.438	-3.396
240		-4.947	-4.896	-4.847	-4.802	-4.788

Table 6: Main rotor longitudinal cyclic (degree)

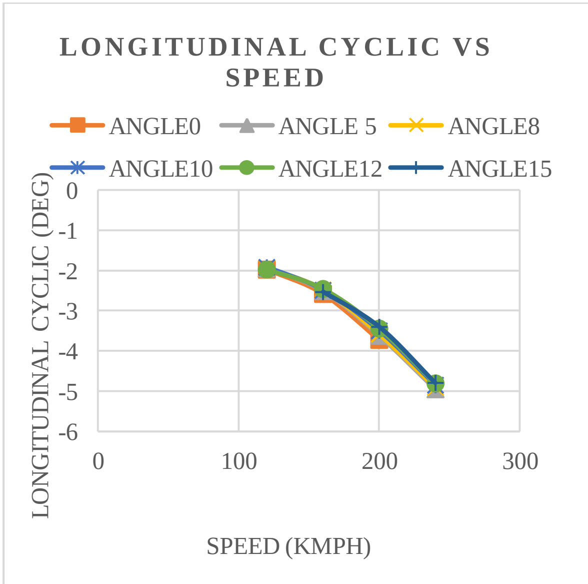

Figure 9: Main rotor longitudinal cyclic Vs speed

The Main Rotor longitudinal cyclic requirement decreases with increase in wing incidence angle which is beneficial (Table: 6&Fig: 9).

AOI (DEGREE)	0	5	8	10	12	15
SPEED(KMPH)						
120	-0.656	-0.782	-0.854	-0.9	-1.033	
160	-1.057	-1.213	-1.26	-1.648	-1.846	-1.608
200	-1.081	-1.401	-1.443	-1.627	-1.389	-1.659
240		0.695	0.116	-0.097	-0.094	0.177

Table 7: Tail Rotor collective cyclic (degree)

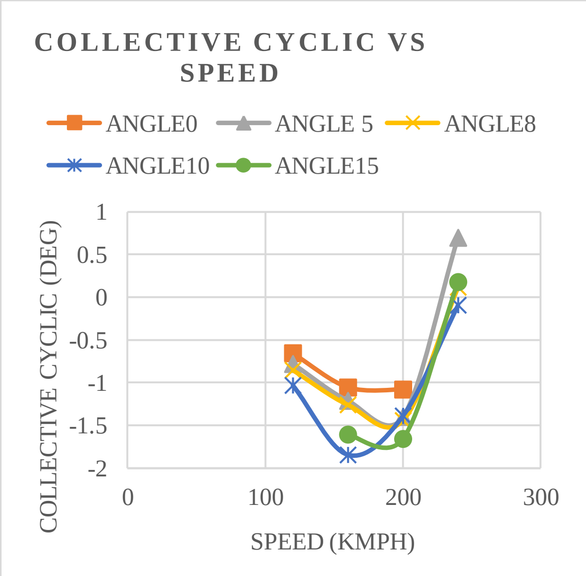

Figure10: Tail rotor collective cyclic Vs speed

The Tail rotor collective requirement was more lift with higher incidence angles at lower speeds. No general trend was observed at higher speeds. (Table:7&Fig:10).

AOI (degree)	0	5	8	10	12
SPEED (kmph)					
120	284.854	281.542	280.372	279.83	283.909
160	321.856	318.172	317.792	319.162	315.689
200	427.456	424.733	428.441	429.209	427.303
240	588.8	599.836	597.239	597.689	605.1

Table 8: Power required (KW) at different AOI

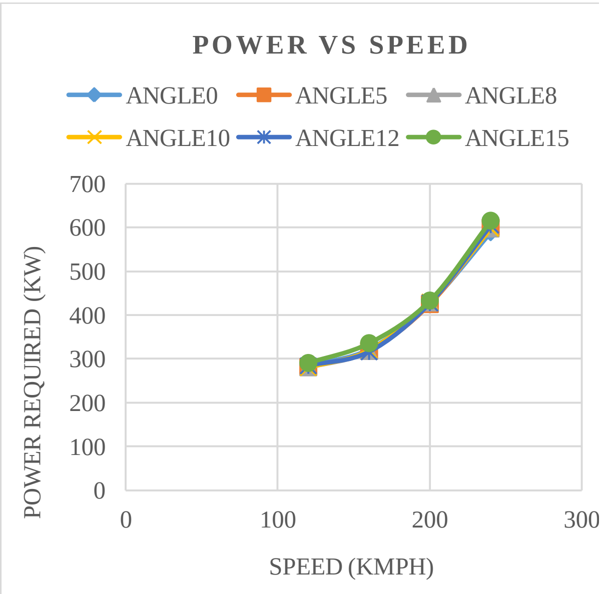

Figure 10: Power required Vs Speed

The Power requirement was less with higher wing incidence angle at lower speeds and higher at high speeds with higher incidence angles. (Table: 8 & Fig:10).

- **EFFECT OF WING ALONE**

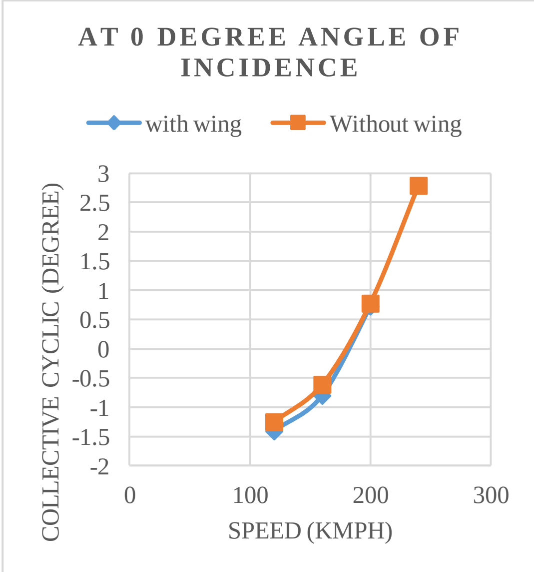

Fig.11: Main Rotor Collective cyclic Vs Speed (0 deg wing incidence)

The effect of wing on helicopter was compared with the helicopter without wing for angle of incidence of 0 degree, 12 degree and 15 degree (Fig 11, 12 & 13). It can be seen that the wing with 12-15 deg wing incidence angle is beneficial in the forward speed. The collective control requirements are high with 12-15 deg of wing incidence angle at maximum level flight speed.

The wing with 0 deg wing incidence angle also gives benefit in the forward speed range without any penalty at maximum level flight speed.

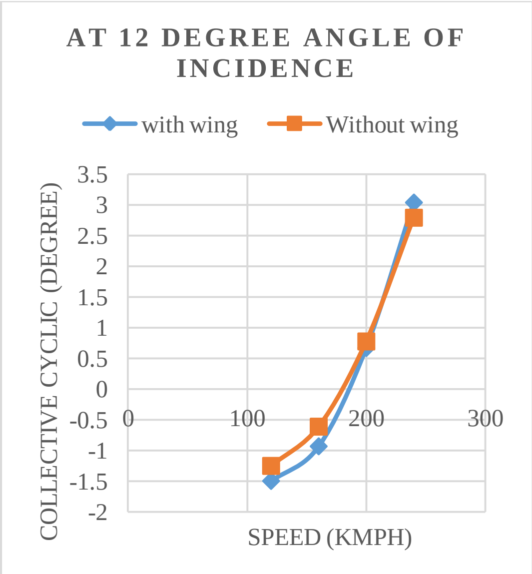

Fig.12: Main Rotor Collective cyclic Vs Speed (12 deg wing incidence)

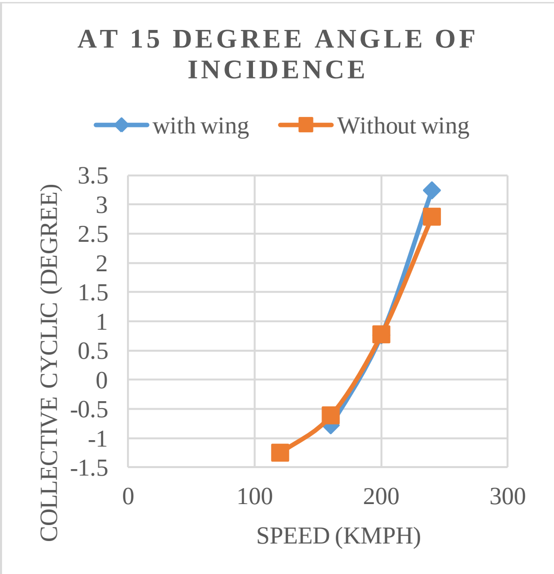

Fig.13: Main Rotor Collective cyclic Vs Speed (15 deg wing incidence)

V. CONCLUSIONS

1. For installation of armament wing in Light category helicopter, NACA 4412 airfoil was found suitable on the basis of L/D ratio. This was providing maximum lift and minimum drag.
2. The wing incidence angle was selected to be 12-15 degree based on the benefits only at lower speeds. This type of wing can be used when slight reduction in maximum level flight speed in acceptable.
3. The wing incidence of 0 deg incidence angle gives benefit in terms of helicopter power and control angles at lower speeds without any loss at maximum level flight speed with. This type of wing would serve the purpose of weapon carrier with improvement in overall helicopter range and endurance.
4. Control angle and Power requirements were less with wing on the helicopter compared to the helicopter without wing.
5. Power requirement reduces with higher wing incidence angles at the speed range of V_Y to V_H.
6. Decrease in maximum level flight speed or higher power requirement at maximum level flight speed was observed.
7. Increase in Range and Endurance is expected by installing a wing on the light weight Helicopter of 3000 kg class.
8. Wing location can be chosen slightly forward to the C.G. of the helicopter to get higher nose up moment to reduce negative pitch angle of the helicopter.

VI. REFERENCES

- IHS Jane's, all the world's Aircraft Development and Production. Editor in chief: Paul Jackson FRAES.
- "Theory of wing sections" by IRA H. ABOTT and ALBERT E. VON DOENHOFF, Research engineer NASA.

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