Feasibility Study on Improving of Helicopter Forward Flight Speed via Modification of the Blade Dimension and Engine Performance

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Abstract: The purpose of this paper is to study the feasibility on improving a 5-seaterr helicopter forward flight speed via applying the different combination between rotor and engine. The emphasis of this study is given to the increment in the main rotor number of blade from 3 to 4 blades and blade sizing at which to meet the better forward flight speed than the existing rotor design. The performance of the helicopter and the aerodynamic of rotor at steady and level flight was analysed by using the closed-form equation derived from the blade element theory (BET). The improvements in forward flight speed performance for every rotor-engine combinations were examined and detail documented in this paper. The percentage of improvements then was compared with the existing rotor data obtained from the helicopter flight manual and found that they were in good agreement.
Keywords: Aerodynamic, forward flight, helicopter, speed performance.

1.0 Introduction

Helicopter is designed to be well operating at different flight mission that requires the aircraft to fly at various flying modes (i.e.: hovering, vertical climb and descent, and different range of forward flight speed). Unlike the fixed-wing aircraft, the helicopter rotor requires to provide both propulsive and lifting forces. In term of flight performance, it is greatly influenced by rotor and fuselage aerodynamic and also engine performance. During forward flight, the disk of helicopter rotor is operated at two different environments i.e., high (closed to transonic) and low subsonic airspeed regime. The high subsonic regime normally occurred at the disk of the rotor at which the blade is advance to the flight direction (or advancing side) and the low subsonic regime however occurred at the disk at which the blade is retreat away to the flight direction (or retreating side). As the speed of flight is increased, it is difficult to operate the helicopter rotor blade below or closed to the blade stall angle. Blade stalling is among the factors that potential to restrict the forward flight speed of helicopter and it is caused by the asymmetrical loading that had generated between advancing and retreating rotor disk side [1]. The development of high speed helicopter by principal is to reduce the travelling time. There were 3 major areas that could be used to improve the helicopter flight speed (i.e., (i) *aerodynamics* such as good aerodynamics shape, (ii) *engine* such as powerful engine performance, and (iii) *structure* such as light and stiff structure). It was observed that in high forward speed of flight the 1) Compressibility effect, 2) Retreating blade stall and 3) Reverse flow region may restrict the forward flight speed [1].

To realize the helicopter with better flight speed, several design concepts were introduced, where, recently the helicopter was designed incorporated with an additional propulsive system as a pusher [2], tilted-rotor [3], tilted-wing [4], and fitted with additional fixed-wing. These concepts have successfully improved the helicopter flight speed but finally have encountered with economical conflict. After that, the new approach such as blade planform modification [5-9], flow control over the blade [10, 11], nose-droop concept [12] and variable diameter rotor [4] were introduced. These approaches seem more useful on improving the helicopter flight speed performance with less economical conflict. For the example the concept of blade planform modification (known as the British Experimental Rotor Program (BERP)) rotor that used by GKN-Westland Super Lynx helicopter was designed to meet the conflicting aerodynamic requirements of advancing and retreating blade [13]. Assembled with BERP rotor and improved engine performance, the new world absolute speed record for a conventional helicopter was achieved by a GKN-Westland Super Lynx in 1986 at speed of 400.87 km/h (previous record is 367km/h).

Nowadays, the helicopter at comparable gross weight can be designed with different number of blades. In this paper however, the 5-seater Eurocopter AS 355F2 [14] helicopter main rotor number of blade was increased from 3 to 4

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blades and four different combinations of rotor and engine was proposed to study its influence on the forward flight speed performance. The improvement in forward flight speed, the effects on the blade dynamic coefficients and retreating blade stall will considered and discussed with detail in this paper.

2.0 Methodology

The aerodynamic environment of helicopter rotor in forward flight is very complex as the rotor is subjected to free dynamic flapping, lagging and pitching motion. The unsteady on aerodynamic environment has leads to the complexity on both the rotor aerodynamic and performance analysis. To closely analyze the aerodynamic loads (e.g.; rotor thrust, lift and drag coefficient, induced velocity and rotor disc loading) and dynamic coefficients (e.g.; lateral and longitudinal flapping coefficient, pitching, sectional blade angle of attack, collective pitch and rotor coning angle) acting on 25 sections of blade element, the closed form equation of blade element theory (BET) was used [15].

The total thrust, T as represented in Eq. 1 shows that the amount of thrust force developed by the rotor will affect by the presence of N number of blade [16,17]. The increments in rotor blades drag, ΔH however influenced both by the presence of N number of blade and airfoil profile drag, $\overline{C}_d$.

$$T = \frac{N}{2\pi}\int_0^{2\pi}\int_0^{R}\frac{\Delta L}{\Delta r}\,dr\,d\Psi \tag{1}$$

$$\Delta H = \left(\Delta D - \Delta L\frac{U_P}{U_T}\right)\sin\Psi - \Delta L\beta\cos\Psi \tag{2}$$

$$\Delta D = \frac{1}{2}\rho U_T^2\overline{C}_d c\Delta r \tag{3}$$

$$\Delta L = \frac{1}{2}\rho U_T^2 a\left(\theta_o + \theta_{tw}\frac{r}{R} + \frac{U_P}{U_T}\right)c\Delta r \tag{4}$$

where U_p is the perpendicular velocity, U_T is the tangential velocity, a is airfoil lift curve slope (for Onera 209 airfoil, a=5.232/rad), r is radial blade station, Ψ is azimuth angle and θ_{tw} is blade twist angle.

The helicopter main rotor blade flapping coefficient (i.e.; longitudinal flapping, a_n and lateral flapping, b_n), rotor coning angle, a_o and the cyclic pitch coefficient (i.e.; longitudinal cyclic, B_1 and lateral cyclic, A_1) as a function of blade azimuth angle can respectively be modelled using Eq. 5 and Eq. 6. By allowing the blade to freely flapping about its rotational axis, this phenomenon permit both the blade at advancing and retreating side to produce equal amount of lift force to encounter the asymmetry of flow field generated in both rotor blade sides.

$$\beta(\Psi) = a_0 - \sum_{n=1}^{\infty}\left(a_{n_s}\cos n\Psi - b_{n_s}\sin n\Psi\right) \tag{5}$$

The blade pitch (or feathering) motion can be described as the Fourier series [18]

$$\theta(r,\Psi) = \theta_o + \frac{r}{R}\theta_{tw} - A_1\cos\Psi - B_1\sin\Psi \tag{6}$$

where, in forward flight, the value of the collective pitch θ_o increase with increasing in forward flight speed.

Based on the performance study, the total power P_T for the forward flight is influenced by profile power, P_o induced power, P_i and parasite power, P_p as given in Equation 2.1.

$$P_T = P_o + P_i + P_p + P_c \tag{7}$$

The profile profile power, P_o induced power, P_i and parasite power, P_p in general, are influenced by the blade solidity, σ airfoil profile drag, C_{do} and the rotor thrust coefficient, C_T advanced ratio, μ and the helicopter fuselage drag, *f*. Directly, the total power presented in non-dimensional form as the total power coefficient, C_{PT} empirically can be written as:

$$C_{P_T} = C_{p_o} + C_{P_i} + C_{P_p} + C_{P_c} = \frac{kC_T^2}{2\mu} + \frac{\sigma C_{d_o}}{8}\left(1 + K\mu^2\right) + \frac{1}{2}\left(\frac{f}{A}\right)\mu^3 + 0 \qquad (8)$$

where thrust coefficient, C_T; solidity, σ; equivalent flat plat area, f; advanced ratio, μ; induced power, P_i; profile power, P_o; parasite power, P_p and climb power, P_c. This performance equation (Eq. 8) are incorporated with numerical value of K = 4.7, the empirical correction to account for a multitude of aerodynamic phenomena mainly those resulting from tip losses and nonuniform inflow, κ = 1.15 and the constant momentum induced velocity were used [18].

Table 1 and 2 depict the configuration of blade [19], engine and combination between blade and engine used for analysis. The selection of new turboshaft engine, the Allison 250-C47B engine for Eurocopter AS 355F2 helicopter was made primarily based on the slightly high output shaft rotational speed.

Table 1: Current and New Configuration of Eurocopter AS 355F2.

Eurocopter AS 355F2		
	***Blade* [19]**	***Engine***
Current configuration	**Radius: 5.345m Chord : 0.35m Airfoil: Onera 209 Number of blade: 3**	**Allison C250-20F Power: 450 shp Ω output: 6016 rpm**
New configuration	**Radius: 4.80m Chord : 0.31m Airfoil: Onera 209 Number of blade: 4**	**Allison C250-47B Power: 650 shp Ω output: 6317 rpm**

Table 2: Combination between Blade and Engine.

Design Approach				
Combination	***Rotor***		***Engine***	
	Current	***New***	***Current***	***New***
(A)	√		√	
(B)	√			√
(C)		√	√	
(D)		√		√

3.0 Result and Discussion

Table 3.0 concludes the result of analysis of the Eurocopter AS 355F2 helicopter with different rotor-engine combination. According to the Table, the cruising speed performance of this particular aircraft has improved by applying the different combination between rotor and engines. Modifying the blade dimension by reducing the blade radius about 10.19% and chord about 11.4% (combination (C)) improve the maximum cruising speed by about 6.687%. To realize a better forward flight speed, a better performance engines were used. The selection of the engine was based on the same manufacturer, C250 engine family and slightly higher engine shaft rotational output. Two Allison C250-47B was chosen to replace the Allison C250-20F engines that are currently used by Eurocopter AS 355F2 helicopter. Using this new engine, the cruising speed performance has abruptly been increased. This is apparently revealed by using the combination

(B) and (D). By using combination (B), the cruising speed has improved up to 28.09%. This increment however, requires a slightly higher collective pitch control (16.79), longitudinal flapping (-7.669°), lateral flapping (1.623°) angle, and longitudinal cyclic input of about 14.44 ° to trim the aircraft.

Combination (D) is the combination between new rotor configuration and new engine performance. Increment up to 33.54% and equal to 89.67 m/s on cruising speed was observed. As combination (B), a slightly higher collective (20.62°) are required to ensure the helicopter are flying at steady and level flight. As the forward speed is increased the production of reverse flow area also increases. The higher dynamic flapping on both lateral and longitudinal axis and collective pitch are required to produce enough of moment about centre of gravity to balance or trim the helicopter.

From the aerodynamic analysis, the effect of compressibility at advancing side is not taken into account, however the blade angle of attack at retreating side are carefully checked. The static stall of this particular airfoil is 14°. Fig. 3.0 (a) to Fig. 3.0 (h) shows the distributions of sectional main rotor blade angle of attack and blade lift during forward flight. From these Figures, the large blade angle of attack is found occurring at outer portion and the reverse flow area at inner portion of the blade span. It was found also that the higher speed of flight will generate the bigger reverse flow area.

TABLE 3.0: Dynamic coefficient and performance table of Eurocopter AS 355F2 helicopter with Different Blade-engine Combinations

Combination	Manual[14]	(A)	(B)	(C)	(D)
VNE (m/s)	77.22	73.87	92.48	77.80	95.80
Max. cruise speed (m/s) at MCP	61.67	67.15	86.01	71.64	89.67
% of max. cruise speed compared with combination (1) rotor.	-	0	+28.09	+6.687	+33.54
Collective pitch required (Deg.)	-	15.64	16.79	18.10	20.62
Angle of tip path plane, TPP (Deg.)	-	-5.91	-9.67	-6.72	-10.50
Longitudinal cyclic pitch (Deg.)	-	9.05	14.44	12.07	17.67
Lateral cyclic pitch (Deg.)	-	0	0	0	0
Longitudinal flapping	-	-3.91	-7.67	-4.72	-8.497
Lateral flapping (Deg.)	-	1.62	1.62	1.71	1.70

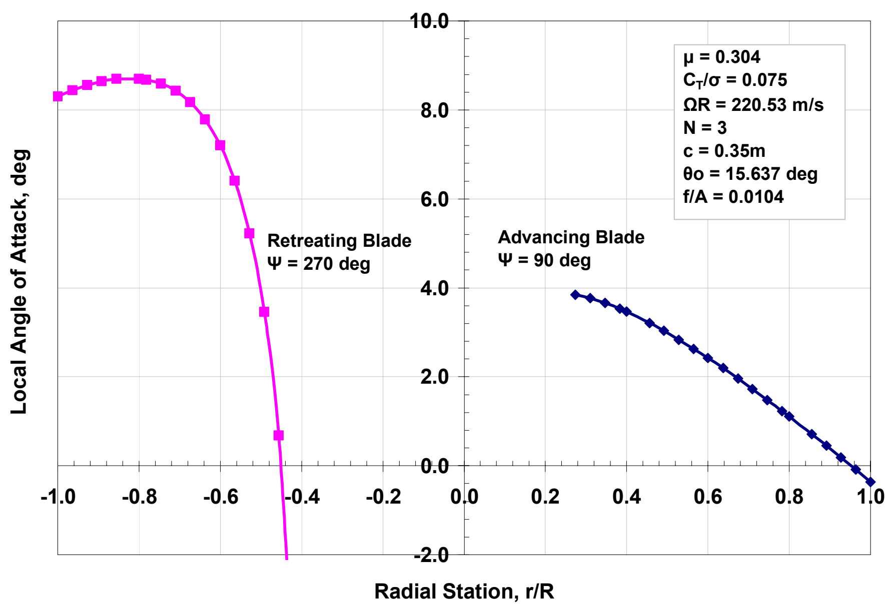

Fig. 3.0 (a): Local blade angle of attack measured at advancing and retreating blade side of Combination A.

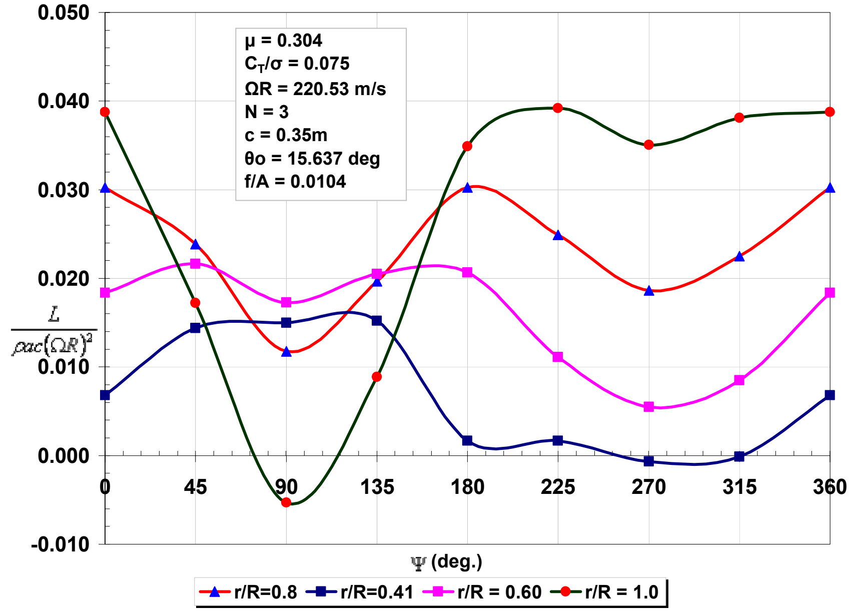

Fig. 3.0 (b): Sectional blade Lift of Combination A.

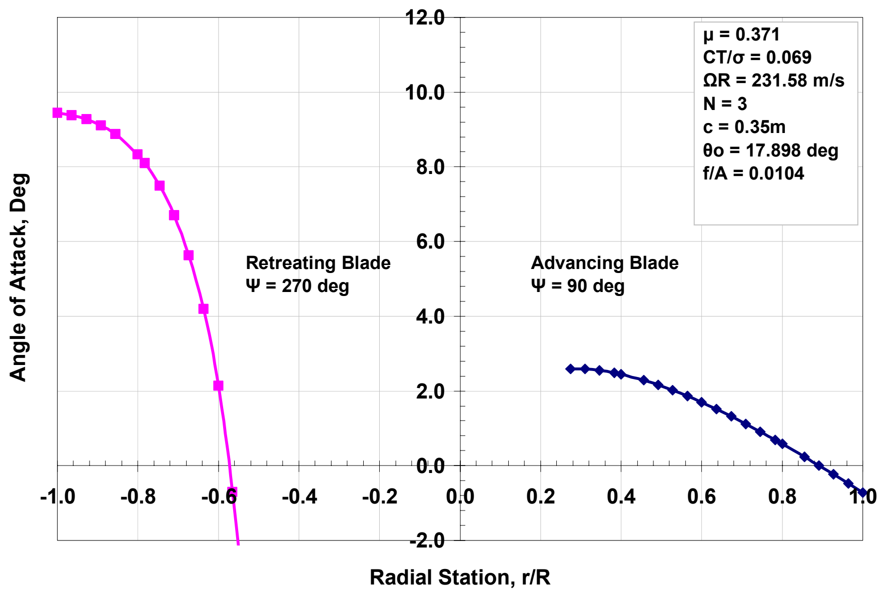

Fig. 3.0 (c): Local blade angle of attack measured at advancing and retreating blade side of Combination B.

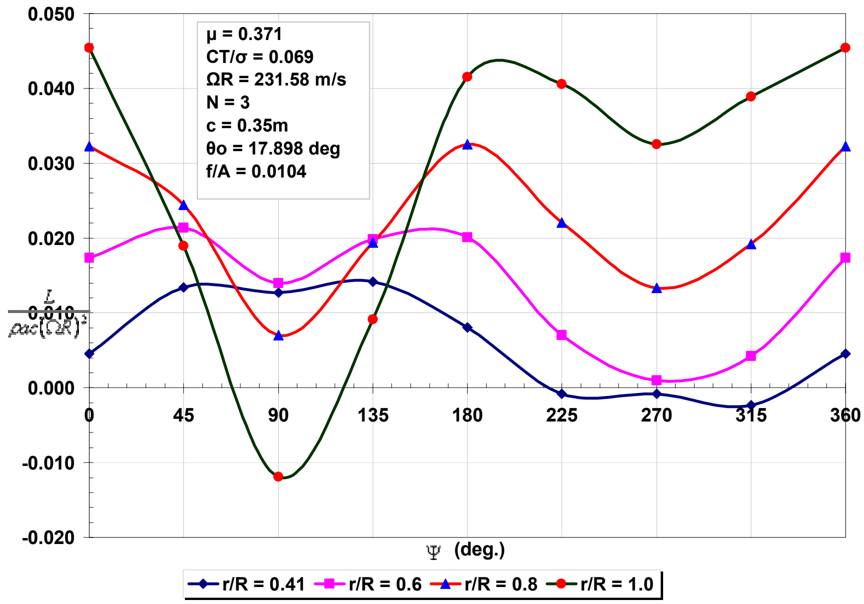

Fig. 3.0 (d): Sectional blade Lift of Combination B.

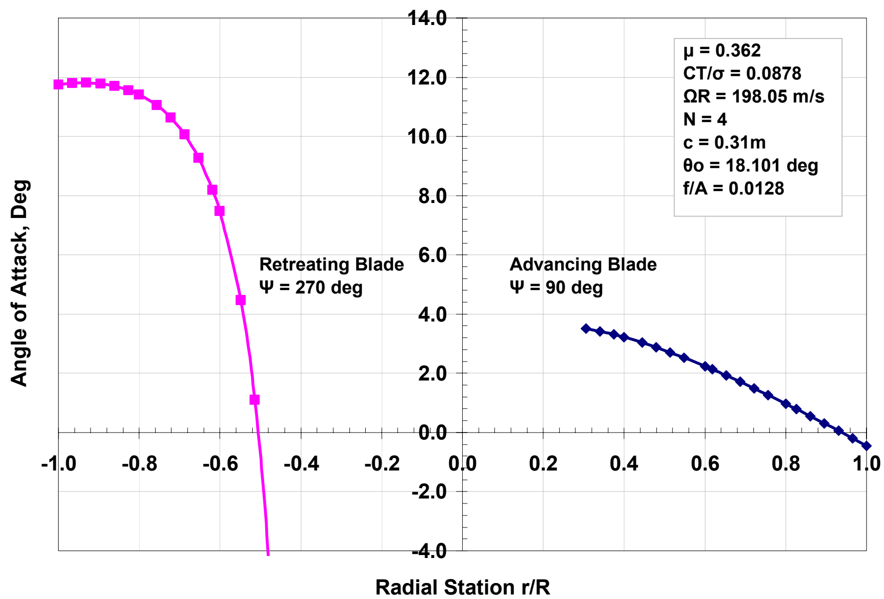

Fig. 3.0 (e): Local blade angle of attack measured at advancing and retreating blade side of Combination C.

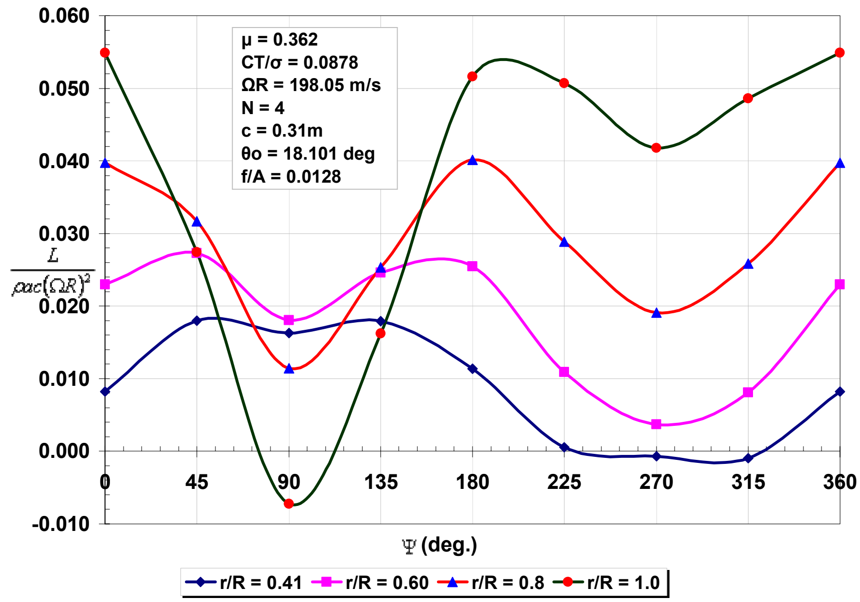

Fig. 3.0 (f): Sectional blade Lift of Combination C.

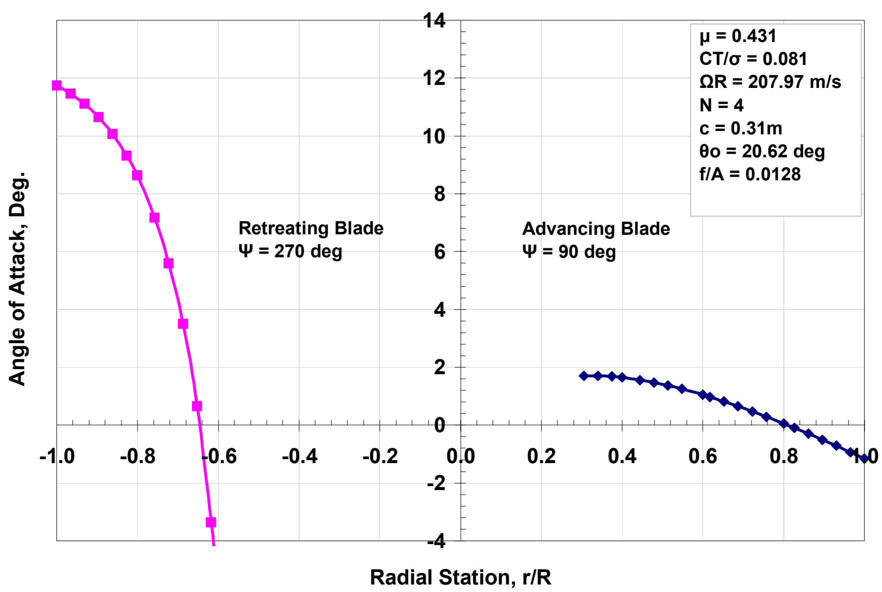

Fig. 3.0 (g): Local blade angle of attack measured at advancing and retreating blade side of Combination D.

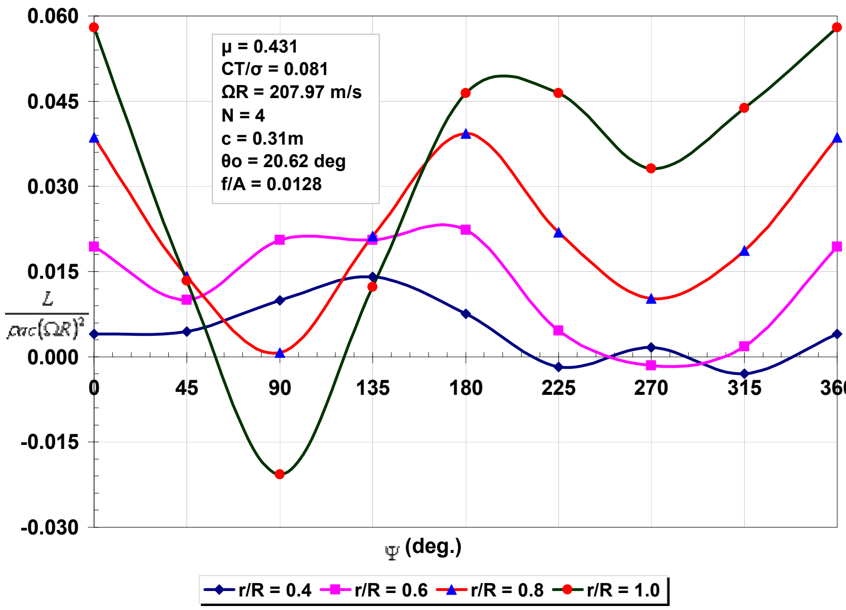

Fig. 3.0 (h): Sectional blade Lift of Combination D.

4.0 Conclusion

The forward flight speed of Eurocopter AS 355F2 helicopter was studied based on the different rotor-engine combinations. Assessments were performed by using the closed-form equation from blade element theory. From the study, it was found that there were two possible approaches can be used on improving the Eurocopter helicopter forward flight speed;

i. Increase its number of blade from 3 to 4 blades
ii. Use the high performance engine

From this study, by increasing the main rotor number of blade from 3 to 4 blades or by using combination B, will improve forward flight speed by about +28.09%. For rotor-engine combination, combination C is suggested; this is because of combination D generates the large reverse flow area at retreating blade side. The large ratio between reverse flow to the rotor area will cause the helicopter become unstable.

5.0 Acknowledgement

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