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Original Article

Theoretical Investigation on Effect of Helicopter Main Rotor Parameters in Required Power

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Abstract

The main rotor is the principal factor effecting helicopter performance and fuel consumption. There are many basic geometric parameters that constitutive the main rotor design. Radius and chord are among these basic geometric parameters. In this study, it is aimed to examine the effects of variation in radius and chord on required power at different flight conditions. Based on the design values of B0105 and S-76 from utility helicopter the group, the power calculations were made for the main rotor only when the radius and only the chord changed between +8% and -8%, and both parameters changed between +8% and 8%. These calculations were repeated for hover, 50 knots, 90 knots, 130 knots forward flights, and for sea level, 5000 ft, 10000 ft altitudes. With the variation of radius and chord, the cases that the maximum reductions and increases in required power were revealed. Results shows İncreasing the chord alone resulted in an increase in required power in all flight conditions. It has been observed that the combinations obtained by variation the radius and chord of maximum decrease and increase amount in the required power are different from according to the altitude, hover condition and forward flight velocity.

Keywords: Helicopter main rotor, Required power, Hover, Forward flight velocity, Blade radius and chord length

Helikopter Ana Rotor Parametrelerinin Gerekli Güçteki Etkisinin Teorik İncelenmesi

Özet

Ana rotor, helikopter performansını ve yakıt tüketimini etkileyen temel faktördür. Ana rotor tasarımını da etkileyen birçok temel geometrik parametre bulunmaktadır. Yarıçap ve veter bu temel geometrik parametreler arasındadır. Bu çalışmada, farklı uçuş şartlarında yarıçap ve veter değerlerinin değişimlerinin gerekli güçteki etkilerinin incelenmesi amaçlandı. Hafif sınıf helikopter grubundan B0105 ve S-76 helikopterlerinin tasarım değerleri baz alındı. Yalnızca yarıçapın ve yalnızca genişliğin %+8 ile %-8 arasında değiştiği ve her iki parametrenin de %+8 ile %-8 arasında değiştiği durumlarda gerekli güç hesaplamaları yapıldı. Bu hesaplamalar, hover, 50 knots, 90 knots, 130 knots ileri uçuşlarda ve deniz seviyesi, 5000 ft, 10000 ft irtifalar için tekrarlandı. Yarıçap ve veter uzunluğunun değişimi ile gerekli güçteki maksimum azalma ve artışların olduğu durumlar ortaya konuldu. Genişliğin artırılması, tüm uçuş koşullarında gerekli güçte artışa neden olurken, genişliğin azaltılması gerekli güçte azalmaya neden olduğu saptandı. Ancak sadece yarıçap değişiminin gerekli güçteki etkisi, irtifalara ve ileri uçuş hızlarına göre

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farklılık göstermektedir. Yarıçap ve genişliğin değiştirilmesi ile elde edilen kombinasyonların da gerekli güçteki maksimum azalma ve artış miktarları, irtifalara, askı durumu ve ileri uçuş hızlarına göre farklılık göstermektedir.

Anahtar Kelimeler: Helikopter ana rotor, gerekli güç, askı, ileri uçuş hızı, pal yarıçap ve veter uzunluğu

1. INTRODUCTION

The conceptual design process of a helicopter begins with planning combination changes from geometric parameters to achieve the best design. Parameter changes are decided based on the results of performance evaluations. Parameter selection decisions vary depending on which performance evaluation is intended; For example, while the minimum required power calculation is aimed at low speeds in one evaluation, the capacity to carry more loads may be important in another performance evaluation [1]. The main rotor design is the preliminary step of helicopter conceptual design. The main rotor is the most important subcomponent in helicopters as it provides lift, thrust and control [2]. Lift against gravity generates thrust to sustain cruise flight, and control forces for manoeuvres at different altitudes and velocity. The main rotor consumes most of the power produced by the motor. For these reasons, the main rotor is the factor in defining helicopter performance [3]. Among the basic parameters of the main rotor geometric design, there are radius, chord, rotor tip speed, angular velocity, blade section airfoil. There are many studies on helicopter main rotor design and optimization in the literature. Mihr Mistry and Farhan Gandy [4] studied a Uh-60 helicopter-like utility helicopter design values with 3 different total weights of 16000, 18300 and 24 000 lbs. They examined the power consumption of the helicopter with changes in the radius and angular velocity.

Nomenclature

$EASA$	European Aviation Safety Agency	V_i	Induced Velocity
CFD	Computer Fluid Dynamics	$Pi_{(hover)}$	Induced Power at Hover
V_{tip}	Tip Velocity	$P_{pr(hover)}$	Profile power at Hover
R	Radius	P_{pp}	Parasit Power
c	Chord	$PT_{(hover)}$	Total Power in Hover
σ	Solidity	$P_{pr(fwd)}$	Profile Power in Forward Flight
Ω	Angular velocity	$PT_{(fwd)}$	Total power in Forward flight
W	Gross Weight	$EFPA_{(ff)}$	Equivalent Flat Plate area in Forward Flight
T	Thrust	AR	Aspect Ratio
C_{d0}	Profile Drag Coefficient	ρ	Density
B	Tiploss factor	V_D	Thrust component of the induced velocity of the main rotor

They showed on graphs the relationships between power consumption with radius and angular velocity changes at different forward flight velocity, hover and 3 different altitudes. In their study, they investigated the cases where only the radius, only the angular velocity and both parameters were changed by changing the radius from +17% to −16%, and the angular velocity by ±11%. They achieved up to 14% reductions in required power at low gross weight and low speeds with a change in angular velocity alone, and up to 20% reductions in required power at high altitude and 24 000 lbs total weight with just a change in the radius. In combinations where the radius is increased and the angular velocity is decreased, they have provided reductions of up to 30% in required power at high altitude and 24000 lbs total weight. Kim Chul Koo [1].

calculated the required forces at hover, 60 knots and 150 knots forward flight velocity in the standard sea-level with ±10% variation in the radius, chord and angular velocity of the baseline rotor parameters of UH 1N helicopter. By taking into account other parameters affected by the change of these parameters such as solidity, blade tip speed, rotor disc area, calculations were made in 6 different cases. He concluded that an increase in width and angular velocity would generally result in an increase in required power at forward flight speeds. Stanislaw Kachel et al. [5] analyzed the results of the methods of modern helicopter designs. They examined the values of 70 different rotorcraft parameters in terms of EASA requirements. The values of the main rotor design parameters such as radius, chord, solidity, blade aspect ratio were examined. These parameters were compared with the values of small and large helicopters and attack, general purpose, light class, cargo helicopters separated according to their mission profile. In their article, they explained the basic mathematical optimization steps in the helicopter preliminary design phase. M F Afthon and MA Moelyadi [6] optimized the 5 blade design parameters of an unmanned helicopter to increase the power endurance and reduce the required power. These are root chord, taper location, taper ratio, pitch angle, tip twist angle parameters. They calculated thrust and power with BEMT theorem and CFD. As a result of the optimization, they achieved an optimum blade design that increased efficiency by 11% with a 9.4% reduction in required power. Joanne L. Walsh et al. [7] studied the optimization steps for helicopter suspension and minimum required power in forward flight. They presented a systematic evaluation of the interactions of rotor blade design variables. They compared their advanced rotor design optimization for military helicopters with rotor values designed with traditional approaches. In this study, it is aimed to calculate the effects of increases and decreases in the radius and chord length of the blade geometries on the main rotor of the two selected helicopters on the amount of power to be consumed in the main rotor under different flight conditions.

Table 1. Helicopter baseline parameters for Bo105 and S-76 helicopters

Baseline rotor parameters		B0105 helicopter	S-76 helicopter
Description	Unit	Value	value
Radius	ft	16	22
Number of Blades	-	4	4
Chord	ft	0.88	1.26
Angular velocity	rad/sec	44.4	30.7
Rotor solidity	-	0.07	0.07
Weight	Ibs	5511	10000
Airfoil	-	NACA0012	SC-1095R8

These calculations were repeated hover and three different forward velocity. Increases and decreases in required power were examined at partially low (50 knots) and partially high cruise speeds (90 knots-130 knots) and their values in different flight conditions were calculated. Another reason for choosing 50 knots and 130 knots forward flight velocity is the minimum power consumption and maximum forward flight speed of the BO105 helicopter. Three different situations are included in the calculations: sea level, 5000 ft and 10000 ft altitude. S76 and BO105 helicopters basic rotor parameter values taken from the literature [8-10] are shown in Table 1.

2. MATERIAL AND METHOD

The thrust force that with the rotation of the blades on the main rotor of the helicopter consisted, in the vertical direction to the rotor plane balances the weight of the helicopter and this balancing beside provides the required force in the forward direction in forward flight. The thrust required in the forward direction varies depending on the acceleration requirement in forward flight, the angular accelerations required in the maneuvers, and the parameters affecting the dynamic calculations such as the mass moment of inertia of the helicopter fuselage. In order for the rotor to make this movement, it must overcome the profile resistance and induced resistance forces formed in the blade in the case of hover, and in addition to these, the parasitic resistance forces in forward flight. (see Figure 1.)

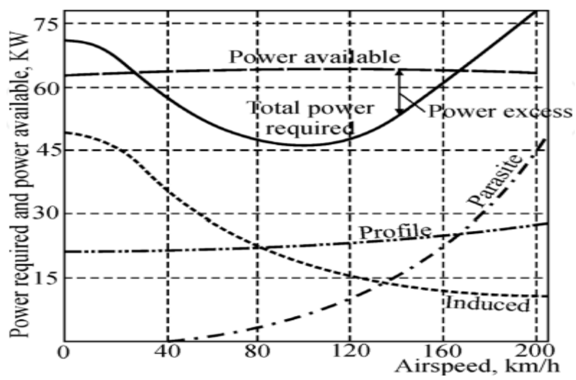

Figure 1. Power required and power available in straight and level flight.[11]

The power required the rotor to continue this movement is equal to the product of the torque on the rotor shaft and the rotational angular velocity of the rotor. The helicopter engine provides this power. The amount of power required by the helicopter is not just for the main rotor; for tail rotor, fuselage, other power-consuming mechanical and electronic components, there are also losses [12]. The thrust required in the rotor determines the torque value, which affects the amount of power required in the main rotor. The thrust that can be obtained depends on the rotor hub and blade design, rotor rotation speed and flight conditions. For blade design, airfoil selection, blade length and chord are important decision However, there are some limiting criteria for such design parameters. For example, strength and vibration problems caused by excessive shear stress, normal force, centrifugal force and bending moment values that will occur in the blade impose a limit on the blade's aspect ratio, rotor solidity and angular rotation values. While AR value is defined as the ratio of blade length to chord (or blade span ratio), stiffness is more related to the number of blades in the rotor. The aspect ratio should be between 15 and 20 for single main rotor helicopters [13]. The fact that the blade tip speed is below certain values of the Mach value is also related to the aerodynamic restrictions and the strength, vibration and noise problems that will be caused by the centripetal forces. If the blade tip speed is greater than the Mach number of 0.3, the compressible property of the air should be taken into account, while if this value is close to or higher than 1, undesirable aerodynamic flow conditions such as shocks occur in the helicopter [14]. That the helicopter flies at different altitudes, the change in air density, which is the most important factor, significantly affects the thrust that can be obtained and the amount of power required. Another situation that affects thrust and power calculations is that the air between the rotor plane and the ground creates additional lifting force like a pillow during the helicopter's flight close to the ground and especially in the hover [15]. This situation is mostly explained by the reduction of the blade end losses due to the ground effect of the vortices formed at the blade tips. The amount of power required by the helicopter in the main rotor varies according to the flight conditions. For example, the amount of power required for suspended position is greater than the amount required for forward flight at low speed. For each helicopter, forward flight is made at minimum power at a critical speed. Establishing the relations between the force, moment, power values in the helicopter main rotor and the rotor and especially the blade geometry (length, chord, section profile and making the calculations is according to the wing element momentum theorem. However, equations that are more reliable were obtained by making empirical corrections to these theoretical formulas with the data obtained from the experimental and field flight tests obtained after the helicopter design. Some of these, that are required to calculate the required power according to the helicopter main rotor design, presented in the literature and used in this study, are the equations in the range equations (2.1) to (2.17).

2.1 Calculation Procedure

1. The following equations are used for main rotor basic blade geometry calculations [13].

$$V_{tip} = \Omega R \tag{2.1}$$

$$A = \pi R^2 \tag{2.2}$$

$$\sigma = \frac{bc}{\pi R} \tag{2.3}$$

$$AR = \frac{R}{c} \tag{2.4}$$

2. The thrust coefficient is calculated by equation (2.5) [16].

$$C_T = \frac{T}{pR^2 \pi V_{tip}} \tag{2.5}$$

3. To for account losses due to tip vortex interactions, the tip loss factor is calculated by equation (2.6)[13]

$$B = 1 - \sqrt{2C_T} \tag{2.6}$$

4. Putting this value of in the equation of the power coefficient equation 2.7 Leads to:

$$B = 1 - \frac{\sqrt{2T(\rho R^2 V_{tip})^{-1}}}{b} \tag{2.7}$$

5. According to the momentum theorem, induced power is equal to the product of rotor thrust and induced velocity ($P_i = TV_i$). Taking into account the effect of tip loss factors, the equation $P_i = BTV_i$ is formed. For the aim of the present analysis, the vertical drag produced by the main rotor downwash on the fuselage and appendages is also disregarded. According to Glauert's hypothesis, the induced velocity and main rotor thrust are related by equation (2.8) [17].

$$V_i = \sqrt{\frac{T}{2\pi R^2 \rho V_D}} \tag{2.8}$$

$$V_D = \sqrt{(v_i - V\sin\alpha)^2 + (V\cos\alpha)^2} \tag{2.9}$$

6. That a hovering condition is analyzed, such that V = 0, D = 0, and T = W, a closed-form expression is obtained for the induced velocity from equation [18] (2.8). The induced power in the hover is calculated by equation (2.10). Newton Raphson approach is used for the V_D solution in forward flight.

$$P_{i(hover)} = \frac{1}{1-(\sqrt{2T(\rho R^2 V_{tip})^{-1}}\, b^{-1})} \frac{T}{\sqrt{2\pi R^2 \rho}} \tag{2.10}$$

7. In hover the profile power resulting from the blade profile drag is calculated by equation Assuming an average drag coefficient such as cdo from the BEM theorem and a constant veter length, the following equation can be obtained. (2.11).[13]

$$P_{pr(hover)} = 0.125\sigma Cd_o \rho A V_{tip}^3 \tag{2.11}$$

8. Equation 2.3 instead of solidity, equation 2.1 instead of $Vtip$, equation 2.2 instead of A

$$P_{pr(hover)} = 0.125 bcCd_0 \rho \Omega^3 R^4 \tag{2.12}$$

9. In the hover, the required power on the main rotor is calculated by equation (2.5).[13]

$$PT_{hover} = P_{i(hover)} + P_{p(hover)} \tag{2.13}$$

10. In forward flight the profile power resulting from the blade profile drag is calculated by equation. [13]

$$P_{pr(fwd)} = (1+4.3\mu^2)(P_{pr(hover)}) \tag{2.14}$$

11. The advanced ratio is calculated by equation (2.15).[13]

$$\mu = \frac{V_{fwd}}{V_{tip}} \tag{2.15}$$

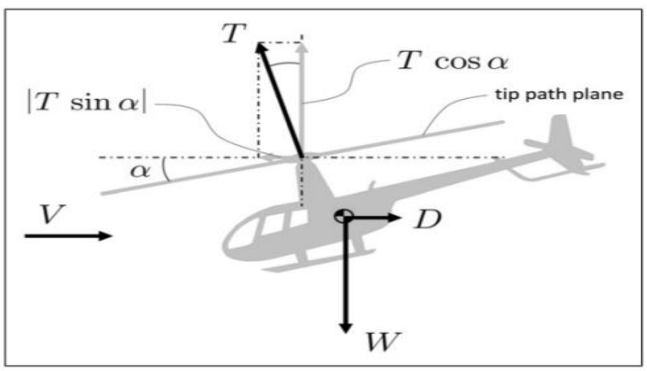

Figure 2. Side view of rotorcraft platform. [18]

12. Non-carrying body elements such as the main body, landing gear, main rotor head, engine hoods, vertical and horizontal tail, tail rotor head cause parasitic drag. Parasitic drag (D), measured parallel to but opposite to the direction of flight, also includes form drag and surface friction associated with these fuselage elements. The power required to create the $T\sin\alpha$ (see figure 2) component of the thrust is called the "parasite power". Equality (2.16) [13].

$$P_p = 0,5 pV_{fwd}^3 EFPA(ff) \tag{2.16}$$

$$PT_{fwd} = P_{pr} + P_i + P_p \tag{2.17}$$

In this study, blade tip losses were subsumed, but ground effect was not included in the calculations. These calculations were made for steady level. MATLAB and EXCEL programs were used to make the calculations and create the graphics.

3. RESULTS AND DISCUSSION

Fig.3 and Fig.4 shows the values obtained by calculating the required power in the main rotor at forward flight speeds of Bo105 and S-76 helicopters at sea level, 5000 ft, 10000 ft altitude. Figure 5 shows Experimental data describe the relationship between speed and total required power of the B0105 helicopter. The calculations are only the required power on the main rotor. The difference is that the required amount of power in the tail rotor is not included in the calculation. The required power in the main rotor accounts for a too amount of the total required power. Considering this situation, it is seen that the calculation is close to the experimental data.

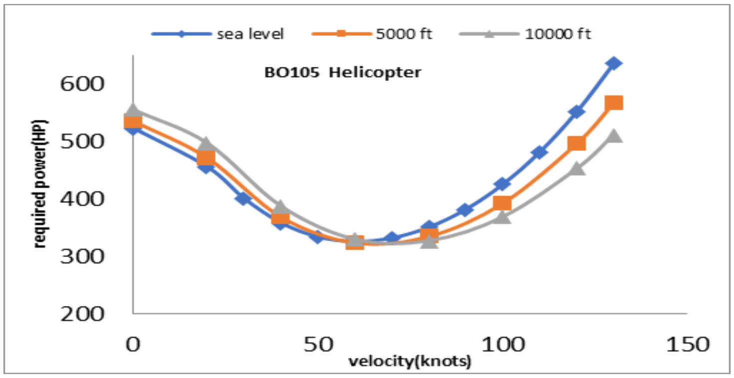

Figure 3. The required power calculation in the main rotor for the Bo105 helicopter baseline rotor in three different altitudes

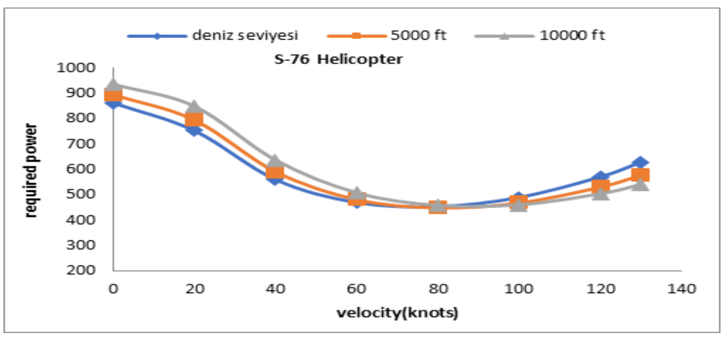

Figure 4. The required power calculation in the main rotor for the S-76 helicopter baseline rotor in three different altitudes

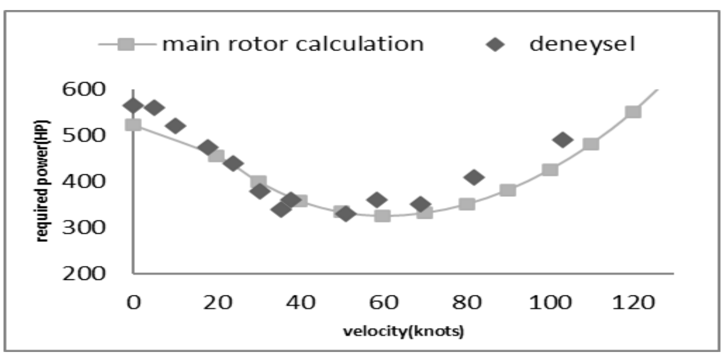

Figure 5. Trim power values for the Bo-105 baseline rotor (flight experimental data (Ref. 19)) as compared to main rotor required power calculations at sea level

3.1 BO105 Helicopter

3.1.1 Required power as a function of only radius

While the rotor radius of the Bo105 helicopter was 16 ft, this value was changed according to different values between 14.6 ft and 17.2 ft, and the change in the required power on the rotor was investigated. Power values are calculated as a function of R change only. No changes were made to the chord length. Fig.6a. Showing by reducing the radius at sea level, a reduction in all flight conditions is achieved. The maximum reduction in required power is 6.1% at 90 knots forward velocity. Increasing the radius resulted in increase at hover and 3 different forward flight velocity. Fig6b Shows Reducing the radius at 5000 ft altitude results in a reduction in required power at forward flight speeds of 90 knots and 130 knots, while resulting in increased at hover.

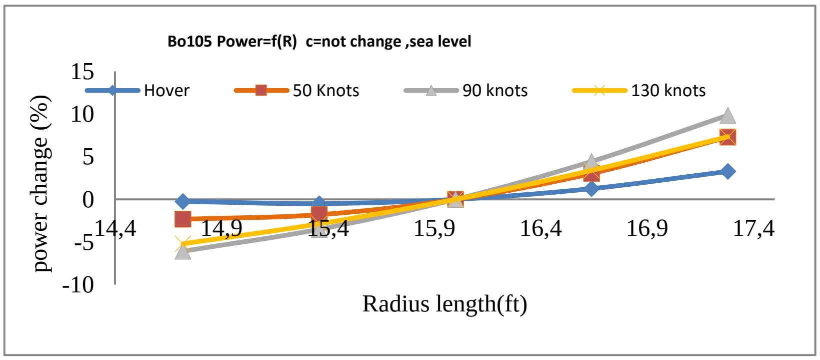

Figure 6a. standart sea level

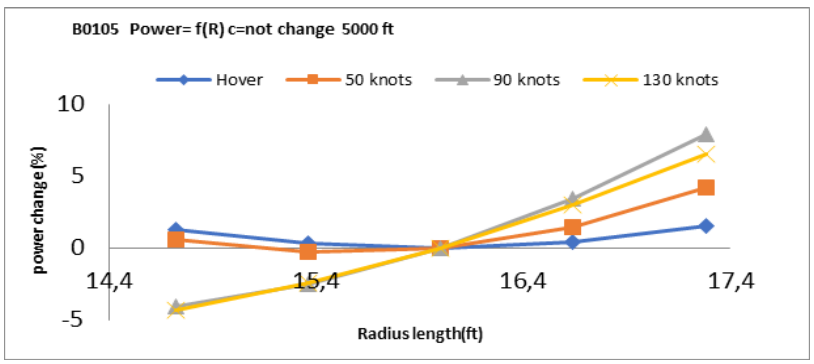

Figure 6b. 5000 ft altitude

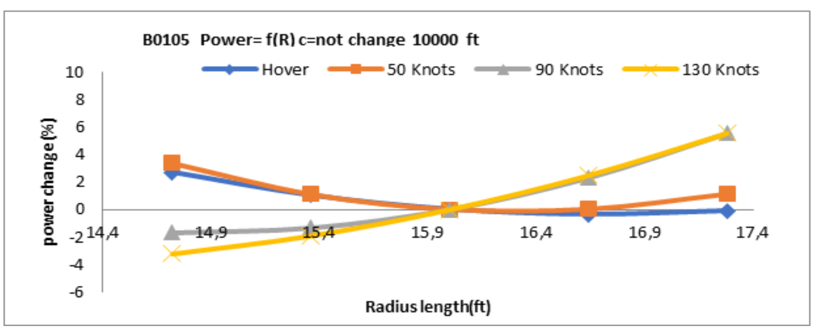

Figure 6c. 10000 ft altitude

5000 ft altitude results in a reduction in required power at forward flight speeds of 90 knots and 130 knots, while resulting in increased at hover. The maximum reduction in required power is 4.2% at a forward flight velocity of 130 knots. Fig6.c shows an increase in the radius 10000 ft results in a reduction in required power in the hover and an increase in required power at forward flight velocity. Increasing the radius by 4% (R=16.64 ft) results in a maximum reduction of 0.38% in required power in the hover. With a decrease in the radius, 90 and 130 knots forward. There is an increase in required power at flight velocity. The maximum reduction in required power is 3.7% at a forward flight velocity of 130 knots.
In general, the induced power decreases as the radius increases, but the profile power increases. The reduction provided by the induced power is equated with the increase in the profile power. The cases where the decrease in induced power outweighs the increase in profile power varies with altitude and forward flight velocity.

3.1.2 Required power as a function of only chord

Table 2 shows the percentage change in required power with chord variation for B0105 helicopter. In all cases where the chord length is reduced, the required power is reduced, while increasing the chord length causes an increase in the required power. As the chord length decreases, the aspect ratio decreases and the solidity increases. The maximum changes in required power at all altitudes are at 50 knots and 90 knots forward flight velocity. The maximum reduction in required power is 3.35% at sea level 50 knots flight velocity. As the altitude increased, the change in required power decreased.

Table 2. Effect of chord change of Bo105 helicopter on required power value

Bo105 Helicopter			Chord length change (%)			
	Altitude	Velocity (knots)	0.92c	0.96c	1.04c	1.08c
required power change(%)	sea level	Hover	-2.02	-1.01	1.01	2.02
		50	-3.35	-1.67	1.67	3.35
		90	-3.30	-1.65	1.65	3.30
		130	-2.34	-1.17	1.17	2.34
	5000 ft	Hover	-1.70	-0.85	0.85	1.70
		50	-2.85	-1.42	1.42	2.85
		90	-3.03	-1.52	1.52	3.03
		130	-2.26	-1.13	1.13	2.26
	10000 ft	Hover	-1.41	-0.70	0.70	1.41
		50	-2.36	-1.18	1.18	2.36
		90	-2.72	-1.36	1.36	2.72
		130	-2.15	-1.07	1.07	2.15

3.1.3 Required power as a function of Radius and chord

The required power changes as a function f(R, c) in the hover of the Bo105 helicopter are shown in Fig.7a. Fig7b. and Fig7c. for three different conditions (sea level, 5000 ft and 10000 ft altitudes), respectively. Fig7.a Shows In the Bo105 helicopter, when the radius were reduced at sea level by 1.94% and the chord is reduced by 7.9%, a maximum reduction in required power of 2.21% is obtained. These values are the combination of R is value of 15.69 ft and c is value of 0.815 ft. The maximum increase in required power is approximately 5.10% in combinations where the radius and chord are increased by 8%. Fig7.b shows when the radius was increased at 5000 ft altitude by 4.93% and the chord is decreased by 7.8%, the maximum reduction in required power by 1.9% is obtained. These values are the combination of R is 16.79ft and c is value of 0.82. In the combination of the radius and chord are increased by 8%, there is an increase in the required power by 3.71%. Fig7.c shows when the radius is increased at 10000 ft altitude by 4.93%

and the chord were decreased by 4.31%, a maximum reduction of 1.82% in required power is obtained. These values are the combination of R is value of 16.79 ft and c is value of 0.84. The maximum increase in required power is 3.66% in the combination of the radius is reduced by 8% and the chord is increased by 8%.

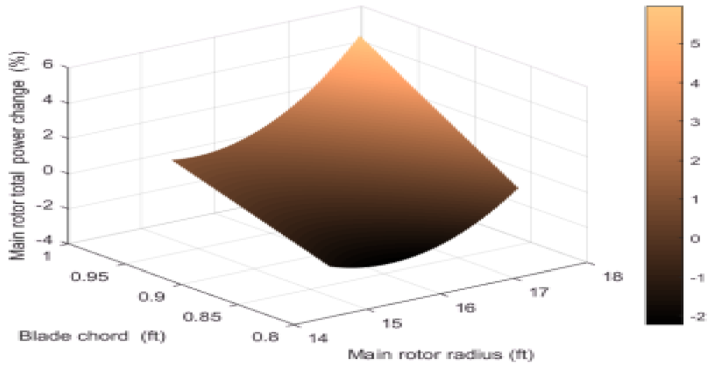

Figure 7a. Sea level

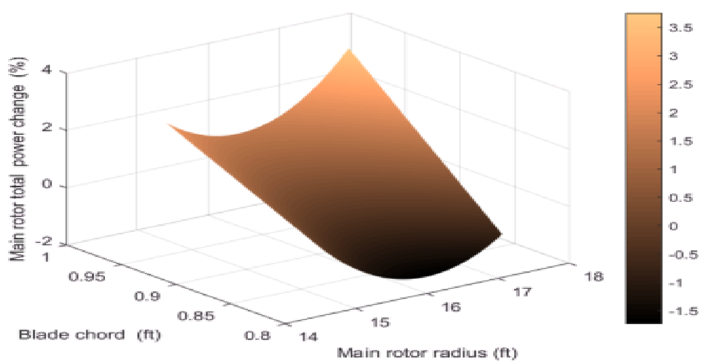

Figure 7b. 5000 ft altitude

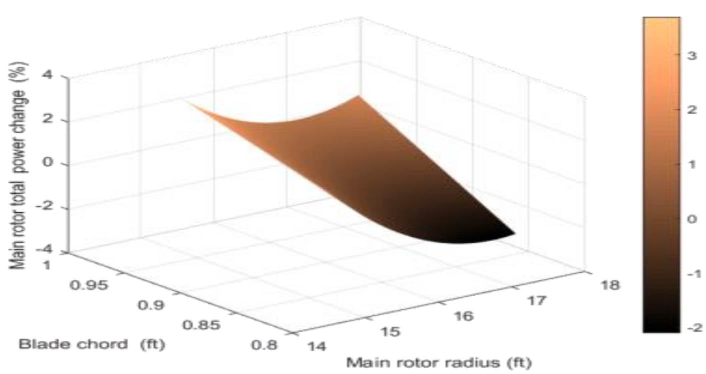

Figure 7c. 10000 ft altitude

Figure 7. Required power variation for hover with radius and chord change of Bo105 helicopter

Table 3 shows the radius and chord combinations selected for three different situations and the changes in the required power in these combinations. These situations are the minimum required power, the maximum required power and the other selected combinations that decrease required power.
There are many combinations of R and c that the required power decreases and increases in the rotor. The combinations of R and c, where the maximum decreases in the required power, vary according to the altitudes and flight speeds. For hover state, the maximum decrease in required power was obtained with the radius decreases at sea level with that the radius increases at other altitudes. In 50 knots forward velocity sea level, when the R value is reduced by 6% and the c value by 8%, the required power decreases by 4.85%.

Table 3. Required power variation of radius and chord combinations for different flight conditions

B0105		max Power Reduction				other combination				max power increment			
altitude	velocity (knots)	R	c	HP	%	R	c	HP	%	R	c	HP	%
sea level	Hover	0.98R ↓	0.92c ↓	-11.55	-2.21	0.97R ↓	0.96c ↓	-7.27	-1.39	1.08R ↑	1.08c ↑	26.66	5.1
	50	0.94R ↓	0.92c ↓	-16.21	-4.85	0.98R ↓	0.96c ↓	-8.68	-2.6	1.08R ↑	1.08c ↑	39.49	11.83
	90	0.92R ↓	0.92c ↓	-32.47	-8.51	0.94R ↓	1.06c ↑	-11.17	-2.93	1.08R ↑	1.08c ↑	54.37	14.25
	130	0.92R ↓	0.92c ↓	-44.22	-6.97	0.96R ↓	1.02c ↑	-12.84	-2.02	1.08R ↑	1.08c ↑	66.01	10.4
5000 ft	Hover	1.49R↑	0.92c ↓	-10.18	-1.90	0.98R ↓	0.94c ↓	-6.27	-1.17	1.08R ↑	1.08c ↑	19.28	3.60
	50	0.98R ↓	0.92c ↓	-9.94	-2.94	0.98R ↓	0.96c ↓	-5.49	-1.62	1.08R ↑	1.08c ↑	27.05	8.00
	90	0.92R ↓	0.92c ↓	-22.49	-6.28	0.94R ↓	1.02c ↑	-9.99	-2.79	1.08R ↑	1.08c ↑	42.57	11.89
	130	0.92R ↓	0.92c ↓	-34.26	-6.04	0.94R ↓	0.94c ↓	-27.41	-4.83	1.08R ↑	1.08c ↑	53.89	9.50
10000 ft	Hover	1.49R ↑	0.96c ↓	-10.09	-1.82	0.99R ↓	0.98c ↓	-0.61	-0.11	0.98R ↓	1.08c ↑	20.28	3.66
	50	1.02R ↑	0.93c ↓	-8.33	-2.38	1.02R ↑	0.96c ↓	-4.91	-1.40	0.92R ↓	1.08c ↑	17.72	5.06
	90	0.94R ↓	0.92c ↓	-13.08	-3.82	0.96R ↓	0.96c ↓	-7.92	-2.31	1.08R ↑	1.08c ↑	31.36	9.16
	130	0.92R ↓	0.92c ↓	-24.75	-4.84	0.94R ↓	1.04c ↑	-9.02	-1.77	1.08R ↑	1.08c ↑	42.60	8.34
Radius and chord change : ↑ for increase , ↓ for decrease					(-) no change								

3.2 S76 Helicopter

3.2.1 Required power as a function of only radius

While the rotor radius of the S-76 helicopter was 22 ft, this value was changed according to different values between 20.2 ft and 23.8 ft, and the change in the required power on the rotor was investigated. Power values are calculated as a function of R change only. Fig.8a. shows with the reduction of the radius at sea level, the required power decreases at forward flight speeds of 90 knots and 130 knots, while causing an increase in other flight situations. With increasing radius, there is an increase in required power in all flight situations. Maximum changes in required power occur at a forward flight speed of 130 knots. Maximum reduction in required power is 5.60%. Fig.8b. shows reducing the radius at 5000 ft altitude results in a reduction in required power at 90 knots and 130 knots forward flight velocity, and an increase in required power at hover and 50 knots forward flight velocity. With the increase in the radius, the required power increases at 90 knots and 130 knots forward flight velocity. The maximum reduction in required power is 4% at 130 knots velocity. Fig.8c. shows At 10000 ft, reducing the radius results in reduction in required power at 130 knots, while hover causes an increase in required power at a forward flight velocity of 50 knots and 90 knots. By increasing the radius, the required power is reduced at hover and at 50 knots forward flight velocity. The maximum reduction in required power is 2.8% with the increase in the radius.

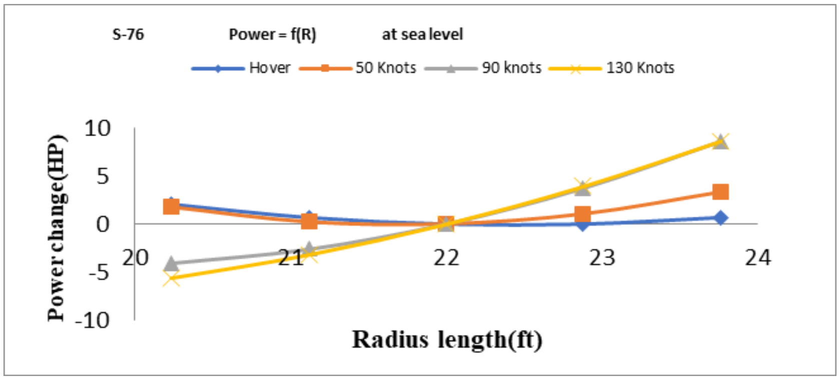

Figure 8a.sea level

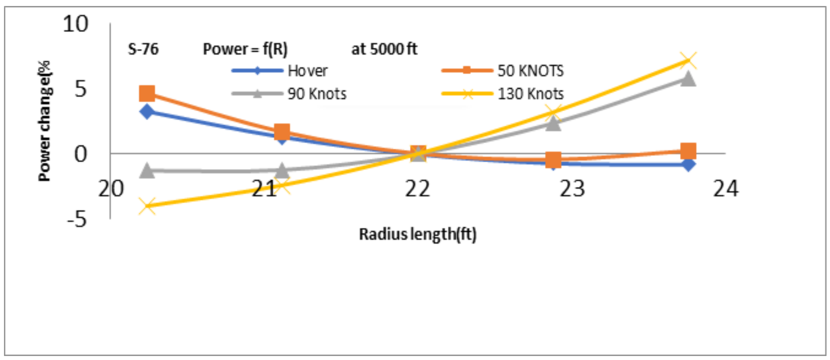

Figure 8b. 5000 ft

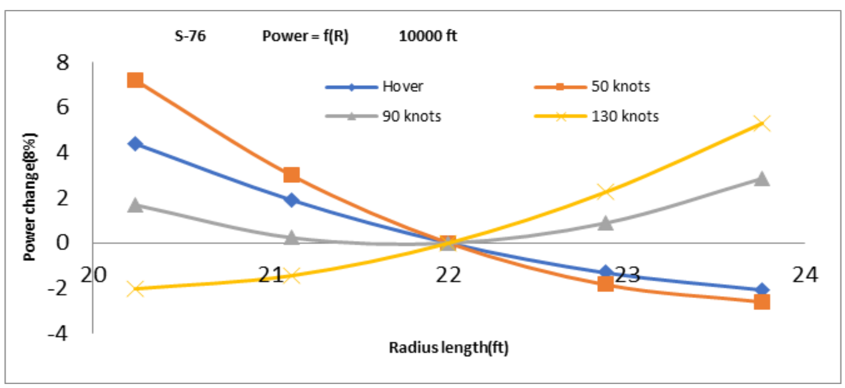

Figure8c. 10000 ft

Figure 8. Required power variation radius of S76 helicopter in different flight conditions

3.2.2 Required power as a function of only chord

While the chord length the S-76 helicopter was 1.26 ft, this value was changed according to different values between 1.16 ft and 1.36 ft, and the change in the required power on the rotor was investigated. Table 4. shows in all cases that the rotor blade chord length of the S-76 helicopter is reduced, the required power reduction is obtained. The maximum reduction in the required power amount is 3.48 at sea level, at a forward flight speed of 90 knots. The increase and decrease in the chord length and the amount of change in the required power are equal.

Table 4. Effect of chord change of Bo105 helicopter on required power value

S-76 Helicopter			Chord length change (%)			
	Altitude	Velocity (knots)	0.92c	0.96c	1.04c	1.08c
	sea level	Hover	-1.54	-0.77	0.77	1.54
		50	-2.83	-1.41	1.41	2.83
		90	-3.48	-1.74	1.74	3.48
		130	-3.13	-1.56	1.56	3.13
	5000 ft	Hover	-1.28	-0.64	0.64	1.28
required power change(%)		50	-2.33	-1.16	1.16	2.33
		90	-3.07	-1.54	1.54	3.07
		130	-2.88	-1.44	1.44	2.88
	10000 ft	Hover	-1.05	-0.52	0.52	1.05
		50	-1.87	-0.94	0.94	1.87
		90	-2.64	-1.32	1.32	2.64
		130	-2.64	-1.32	1.32	2.64

3.2.3 Required power as a function of Radius and chord

Fig.9a. Shows In the S-76 helicopter When the radius is increased at sea level by 3.81% and the chord is decreased by 7.85%, a maximum reduction of 1.76% in required power is obtained. These values are the combination that R= 22.84 ft and c= 1.16. Fig.9b. Shows When the radius is increased at 5000 ft altitude by 4.31% and the chord is decreased by 7.69%, a maximum reduction of 2.18% in required power is obtained. These values are the combination of R= 22.95 ft and c= 1.16 ft. Fig.9c. In the S-76 helicopter, when the radius is increased at 10000 ft altitude by 6.22% and the chord is decreased by 6.75%, the maximum reduction in required power by 2.94% is obtained. These values are the combination of R= 23.37 ft and c= 1.18 ft.

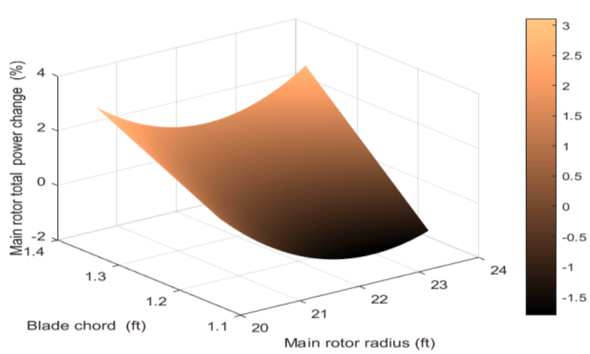

Figure 9a. Sea level

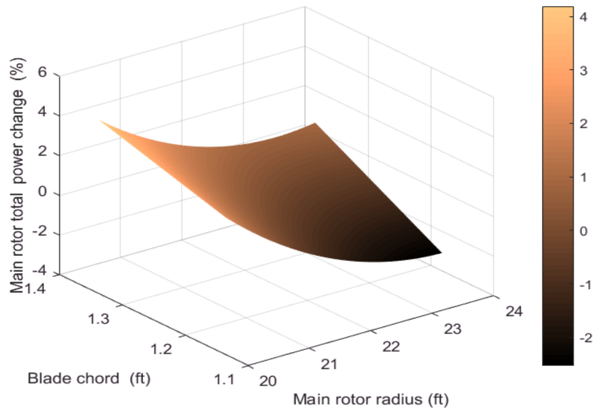

Figure 9b. 5000 ft altitude

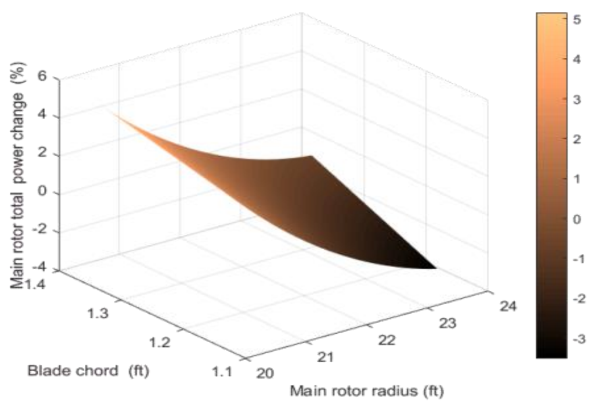

Figure 9c. 10000 ft altitude

Figure 9. Required power variation for hover with radius and chord change of Bo105 helicopter

Table 5 shows in order to reduce the required power in the rotor, R value is 2% and c value is 8 % at sea level 50 knots forward flight velocity, R value is 8% and c value is 8% at 90 knots velocity, R value is 8% and c value is % at 130 knots velocity. It is seen from Table.3 that 8 should be reduced. However, for minimum fuel consumption in 50 knots forward flight at 5000 ft altitude, the R value should be increased by 2% and the chord value should be decreased by 7%.

When the radius length R (Radius) value is reduced by 8% and the width c (chord) value is reduced by 8% in the Bo105 helicopter blade, when the new values are taken, it is calculated that the required power amount in the rotor will decrease by 44 HP by approximately 6.97%.When the radius length R value and width c value are reduced by 8% and the width c value is reduced by 8% in the S-76 helicopter blade, it is calculated that there will be a 49 HP reduction in the required power amount in the rotor, approximately 7.93%.

Table 5. Required power variation of radius and chord combinations for different flight conditions

B0105		max Power Reduction				other combination				max power increment			
altitudes	velocity (knots)	R	c	HP	%	R	c	HP	%	R	c	HP	%
sea level	Hover	1.04R ↑	0.92c ↓	15.16	-1.76	1.04R ↑	0.95c ↓	-9.48	-1.1	1.08R ↑	1.08c ↑	23.85	2.77
	50	1R(-)	0.92c ↓	-14.18	-2.83	0.98R ↓	0.94c ↓	-10.1	-2.01	1.08R ↑	1.08c ↑	35.72	712
	90	0.92R ↓	0.92c ↓	-30.82	-6.63	0.94R ↓	1.06c ↑	-6.46	-1.39	1.08R ↑	1.08c ↑	61.22	13.17
	130	0.92R ↓	0.92c ↓	-49.79	-7.93	0.96R ↓	1.02c ↑	-15.76	-2.51	1.08R ↑	1.08c ↑	79.38	12.65
5000 ft	Hover	1.04R ↑	0.923 ↓	19.49	-2.18	1.06R ↑	0.96c ↓	-13.23	-1.48	0.93R ↓	1.08c ↑	33.08	3.70
	50	1.04R ↑	0.92c ↓	-16.69	-3.18	1.06R ↑	0.96c ↓	-9.08	-1.73	1.08R ↑	1.08c ↑	17.58	3.35
	90	0.96R ↓	0.92c ↓	-17.59	-3.88	0.94R ↓	1.02c ↑	-3.60	-0.79	1.08R ↑	1.08c ↑	44.73	9.86
	130	0.92R ↓	0.92c ↓	-35.61	-6.17	0.94R ↓	0.94c ↓	-29.15	-5.05	1.08R ↑	1.08c ↑	62.80	10.87
10000 ft	Hover	1.04R ↑	0.93c ↓	27.50	-2.94	1.07R ↑	0.95c ↓	-27.22	-2.91	0.92R ↓	1.06c ↑	46.96	5.02
	50	1.06R ↑	0.94c ↓	-23.03	-4.12	1.02R ↑	0.96c ↓	-11.58	-2.07	0.92R ↓	1.08c ↑	47.93	8.57
	90	1R(-)	0.92c ↓	-11.95	-2.64	0.96R ↓	0.96c ↓	-4.06	-0.90	1.08R ↑	1.08c ↑	28.67	6.33
	130	0.92R ↓	0.92c ↓	-21.69	-4.02	0.94R ↓	1.04c ↑	-4.10	-0.76	1.08R ↑	1.08c ↑	47.07	8.72

Radius and chord change : ↑ for increase , ↓ for decrease (-) no change

4. CONCLUSION

This paper examines effect and possible reductions in rotor power requirement over a range of airspeed, and operating altitude achieved by using variation in rotor radius and chord. Only in all cases that C decreases (hover, forward flight) the required power is decreased. With the increase of the C value, the required power increases. Results similar to those obtained in the study of Kim C. K. [1] were obtained from the literature. Therefore, the following conclusion can be reached: in order to reduce the required power, it is necessary to reduce the chord length, provided that it remains within the strength limits. The effect of only the change of the radius on the required power differed according to the altitudes and velocity. In general, for both helicopters, only at forward flight speeds of 90 and 130 knots, the reduction of the required power in the rotor can be achieved by reducing the R. That the combinations obtained with the R and C changes are examined, the following results are obtained: For the Hover, the maximum decrease in the required power in the main rotor depending on the altitude is between 1.82%-2.21% for the Bo105 helicopter, and 1.76%-2% for the S-76 helicopter. It occurs in the range of 94. These maximum reductions can be achieved by increasing R and decreasing C at altitudes of 5000 ft and 10000 ft for both helicopters. In other words, by changing the R and C values, the reduction in the amount of power required in the rotor for hover can be achieved more in the S-76 helicopter than in the Bo105 helicopter. By changing the R and C values, the maximum reduction in the required power in the rotor at forward flight speeds is obtained in the range of 2.38%-8.51% in the Bo105 helicopter for different situations (different velocity values and altitudes), this range is in the S-76 helicopter 2.64-7.93%. This study is important in two respects. The first is that it shows that fuel savings can be achieved when the helicopter blades we will design are made according to the correct values for the determined purposes. The second is the possibility that blade designs that change according to these calculations when smart materials are used effectively are an initial study in terms of power optimization. As a continuation of this study, the calculations can be repeated by taking into account the ground effect. The results obtained can be compared by analyzing the effect of blade design parameters on the required power with Computer Fluid Dynamics (CFD).

REFERANSLAR

[1] Kim, C. K. (1985), 'The Effects Of Parameter Variation On Helicopter Performance', Naval Postgraduate School.

[2] Rohin K. M., Berend G. v. d. W., Christoph G. Balzarek (2021), 'Linearly variable chord-extension morphing for helicopter rotor blades', CEAS Aeronautical Journal, 55.

[3] Johnson, W. (1994), 'Helicopter Theory', Dover Publications Inc New York, p:278-310.

[4] Mihir M., Farhan G. (2014), Helicopter Performance Improvement with Variable Rotor Radius and RPM, Journal of The American Helicopter Society, 59, 042010.

[5] Stanisław K., Robert R., Jakub K. (2021), 'Review of Modern Helicopter Constructions and an Outline of Rotorcraft Design Parameters', Problems Of Mechatronics Armament, Aviation, Safety Engineering, 12, 3 (45), 27-52.

[6] Afthon M. F., Moelyadi M. A. (2020), 'A Study in Aerodynamic Optimization of UAV Helicopter Rotor-Blades Planform in Vertical Motion', International Journal of Aviation Science and Engineering, Volume 2, Issue 1, June, 1-8

[7] Joanne L. W., Gene J. B., Michael F. R. (1987), 'Optimization Methods Applied to the Aerodynamic Design of Helicopter Rotor Blades', Journal of The American Helicopter Society, 34-44.

[8] Even A. F. (1978), 'Aerodynamic Design of the Sikorsky S-76 SPIRIT™ Helicopter', Journal of The Helicopter Society, 15-17.

[9] Hasan I. (2007), 'Helikopter Ön Tasarım Otomasyonu', İstanbul Technical University.

[10] https://en.wikipedia.org/wiki/MBB_Bo_105

[11] Constantin R., Michael T. (2017), 'Helicopter Flight Physics', DOI: http://dx.doi.org/10.5772/intechopen.71516

[12] Mustafa Cavcar (1992), 'Helikopter Taşımacılığında Yakıt Sarfiyatı Minimizasyonu Açısından Tasarım ve Performans Analizi', İstanbul Technical University

[13] Layton, Donald M. (1984), 'Helicopter Design Manual', Naval Postgraduate School, Monterey, California.

[14] Stephen Glenn Kee (1983), 'Guide for Conceptual Helicopter Design', Naval Postgraduate School Monterey, California.

[15] Mehmet Ş., Nilay S. U., Dilek F. K. (2016), 'Model Helikopter Döner Kanat Sistemi İçin Yer Etkisi Durumunda Performans ve Akış Araştırması', VI. Ulusal Havacılık ve Uzay Konferansı.

[16] Seddon, J. (1990), 'Basic helicopter aerodynamics', BSP Professional Books, Oxford.

[17] Johnson W. (1994), 'Helicopter Theory', New York: Dover Publications, Inc., Pp. 299–300.