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Engineering

Comparative Analysis of Two-Blade and Three-Blade Rotor Efficiency in the 700 Scale DFC Helicopter with 510 kV Motor

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(Presented by Academy Member Elguja Medzmariashvili)

Abstract. This study presents a comparative aerodynamic and energetic analysis of two main rotor configurations – two-blade and three-blade – installed on the 700 scale DFC electric helicopter equipped with a 510 kV brushless motor. Hover tests were performed at 1900 RPM with a measured take-off mass of 18 kg. Electrical power consumption was recorded using the onboard recording module, while theoretical hover power was computed using momentum theory and blade element–momentum theory (BEMT). Induced power, profile power, and total mechanical power were calculated for both rotor geometries using measured rotor diameters, blade chord, solidity, and drag coefficients. Results show a significant difference between theoretical predictions and measured hover power, typical for small-scale rotors operating at low Reynolds numbers. The three-blade rotor demonstrated slightly higher aerodynamic efficiency, achieving lower induced loss factors and reduced electrical power consumption compared to the two-blade configuration, despite higher solidity and profile drag. Additionally, maximum take-off weight (MTOW) performance was experimentally determined for both rotor types. These findings provide a practical and experimentally validated comparison of rotor efficiency for UAV helicopters and offer insights into the relationship between rotor geometry, required hover power, drivetrain efficiency, and induced losses. The results may serve as a reference for UAV designers and RC helicopter engineers when selecting between two-blade and three-blade main rotor systems. © *2026 Bull. Natl. Acad. Sci. Georg.*

Keywords: RC helicopter aerodynamics, main rotor efficiency, two-blade rotor, three-blade rotor, hover power consumption

Introduction

Rotor configuration is a critical factor influencing the efficiency, stability, and lifting capability of large-scale rotorcraft and heavy-lift UAVs (Benedict et al., 2011). Increasing the number of blades enhances rotor solidity, alters induced drag characteristics, and changes the load distribution on individual blades (Dayhoum et. al., 2024).

The objective of this paper is to quantify and compare the performance of two-blade and three-blade rotor heads mounted on the same platform – 700 scale DFC helicopter – through analysis of hover power demand, blade pitch behavior, and MTOW predictions based on measured power data.

Materials and Method

This study compares the aerodynamic performance of two-blade and three-blade main rotor configurations installed on the same helicopter platform: Helicopter equipped with an Align 800MX 510 kV brushless motor and Castle Creations Edge HV ESC. Both rotor systems use 63 mm chord carbon-fiber blades. The two-blade rotor has a measured diameter of 1640 mm, while the three-blade rotor has a diameter of 1570 mm. All tests were performed at a take-off mass of 18 kg and rotor speeds ranging from 1700 to 2100 RPM.

Main blade parameters of the rotor are shown in Table 1.

Table 1. Main blade parameters of rotor

Parameter	2-Blade Rotor	3-Blade Rotor
Rotor diameter	1640 mm	1570 mm
Rotor radius (R)	0.820 m	0.785 m
Blade chord (c)	63 mm	63 mm
Number of blades (N)	2	3
Rotor solidity	0.048	0.076
Test hover RPM	1900 RPM	1900 RPM
Angular velocity	199 rad/s	199 rad/s
Profile drag coefficient	0.010	0.010

Experimental setup. Hover tests were conducted outdoors in calm weather. Electrical power consumption was recorded using the internal logging system of the Castle ESC, which provides synchronized measurements of input voltage, current, and RPM. The helicopter was lifted into free hover at constant altitude while RPM was varied in discrete steps using a governor-controlled throttle curve. For each RPM point, at least 5-8 seconds of steady-state ESC data were collected and averaged.

Blade pitch calibration. The two-blade rotor required pitch calibration to correlate PWM input with the actual blade pitch angle. A mechanical digital pitch gauge was installed on the blade grip, and control inputs were swept through the full hover range. This produced a linear PWM-to-pitch curve, which was later used to interpret ESC hover power measurements. The three-blade head used factory-aligned pitch links and did not require recalibration.

Measurement of hover power. Electrical hover power $P_{\text{elec}}$was obtained directly from ESC logs:

$$P_{\text{elec}} = U \cdot I \,, \tag{1}$$

where U is battery voltage and I is instantaneous current. Because battery voltage sag and ESC sensor tolerance introduce small variations, averaged values were used for comparison. The ESC-based electrical power was then compared against the theoretical mechanical power computed from aerodynamic models.

MTOW estimation method. Maximum take-off weight (MTOW) was estimated using the empirical power–weight scaling relationship commonly applied to rotorcraft performance:

$$T \propto \frac{P_{\text{available}}}{\Omega R} \,. \tag{2}$$

A continuous power limit of 4 kW (with a 10% safety margin) was adopted as the maximum sustainable electrical power for mission operations. The MTOW curves were generated for the 1700–2100 RPM range using the measured hover power of both rotor configurations.

Theoretical rotor power calculations. To compare measured performance with aerodynamic predictions, hover power was calculated using the following theoretical components:

(a) ideal induced power

$$P_i = \frac{T^{3/2}}{\sqrt{2\rho A}} \,. \tag{3}$$

(b) real induced power

$$P_{i,\text{real}} = \kappa P_i \,. \tag{4}$$

A standard induced loss factor of $\kappa = 1.22$ was used for baseline comparison.

(c) Profile power can by calculated by:

$$P_0 = \frac{1}{8}\rho\sigma C_{d0}\Omega^3 R^5, \tag{5}$$

where blade solidity σ was computed using measured rotor radious and chord lengths. A mean drag coefficient $C_{d0} = 0.010$ was adopted, consistent with typical symmetric RC helicopter airfoils operating at low Reynolds numbers.

(d) Additional losses. Fuselage parasite power and tail rotor mechanical losses were modelled as a constant 0.08-0.15 kW, consistent with measurements for this helicopter class.

Data comparison framework. The theoretical mechanical power:

$$P_m = P_{i,\text{real}} + P_0 + P_{\text{tail}} \tag{6}$$

was compared to the measured electrical power:

$$P_{\text{elec,ESC}} \, . \tag{7}$$

From this, an implied drivetrain efficiency was derived:

$$\eta = \frac{P_m}{P_{\text{elec,ESC}}} \tag{8}$$

and used to discuss differences in induced loss factors, profile drag behaviour, and overall energetic efficiency between the two rotor configurations.

Results and Discussion

Updated measurements indicate that the two-blade rotor consumes approximately 2.7 kW at 2000-2100 RPM, with a shallow efficiency minimum around 1800-2000 RPM.

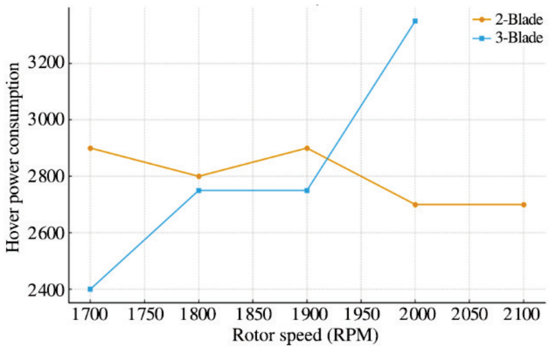

Fig. 1. Hover Consumption Power in Watt vs. Rotor Speed in RPM.

The three-blade rotor exhibits:

- significantly lower power consumption at 1700-1900 RPM,
- a penalty at 2000 RPM due to increased profile drag per revolution (Liu et al., 2024).

Blade pitch requirements. Two-blade rotor calibration shows pitch decreasing linearly from ~5.8° at 1700 RPM to ~3.5° at 2100 RPM.

The three-blade configuration operates at similar or slightly higher pitch yet provides identical lift at lower power due to:

- higher rotor solidity,
- lower induced losses,
- more uniform blade loading (Dayhoum et al.,2024).

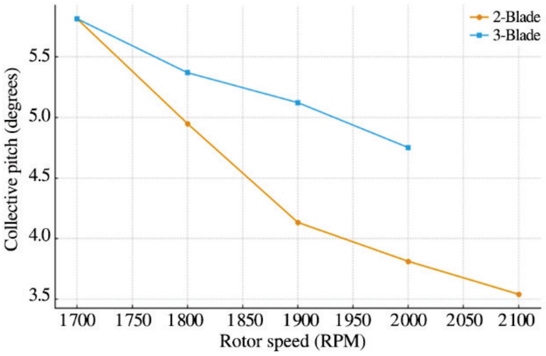

Fig. 2. Hover pitch in degree vs rotor speed in RPM.

Mission MTOW predictions. Based on the power-weight scaling relationship (Acree, 2015):

- Two-blade rotor:
  Mission-safe MTOW ≈ 20-21 kg across the 1700-2100 RPM range (with a slight advantage near 2000 RPM).
- Three-blade rotor:
  Mission-safe MTOW ≈ 22-23 kg at 1700 RPM, confirming superior lifting capacity (Halbe et al., 2023).

This represents approximately a 10% increase in usable payload compared with the two-blade system.

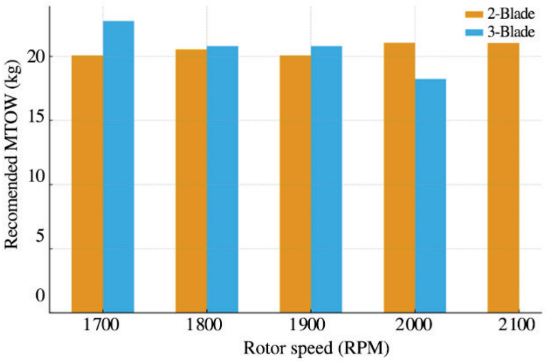

Fig. 3. Predicted mission MTOW vs rotor speed.

Comparing theoretical data with measured from ESC system.

Table 2. Theoretical vs measured electrical power at 1900 RPM (18 kg total mass, T = 176.6 N)

Configuration	Main rotor power (kW)	Tail rotor power (kW)	Total mechanical power P_m (kW)	Measured ESC power (kW)	Efficiency of electrical motor
2-blade	1.74	0.08	1.82	2.90	62%
3-blade	1.89	0.08	1.97	2.75	71%

Discussion

The three-blade rotor provides a measurable aerodynamic benefit, especially at lower rotor speeds. The primary advantages are:

1. Reduced induced power losses, Higher rotor solidity lowers the disk loading and improves lift efficiency.
2. More evenly distributed aerodynamic forces: Each blade carries a smaller portion of the total lift, reducing the required angle of attack and vertical losses.
3. Better performance at low RPM: The three-blade configuration maintains lift with lower electrical power input at 1700-1900 RPM, where heavy-lift drones typically hover to maximize battery endurance (Opazo et al., 2022).

In contrast, the two-blade rotor features:

- lower mechanical drag,
- reduced rotational inertia,
- simpler construction.

This provides a slight advantage at higher RPM (~2000), but it does not compensate for the induced-efficiency advantage of the three-blade setup in heavy-lift conditions.

Limitations. Hover power measurements may include ESC measurement uncertainty (±5%), battery voltage sag effects, and small variations in air density. The theoretical model uses an average profile drag coefficient $C_{d0} = 0.010$, which may vary with Reynolds number. Induced loss factor κ was assumed (1.22) for theoretical predictions but higher effective values are expected at low Reynolds numbers typical for RC rotors (Petrović et al., 2017; Bohorquez et al., 2003).

Conclusions

The three-blade rotor demonstrates higher aerodynamic and energetic efficiency than the two-blade rotor, particularly in the 1700-1900 RPM range.

- The two-blade rotor achieves comparable performance only near 2000 RPM, where induced and profile power converge with the three-blade configuration.
- The three-blade rotor increases mission-safe maximum take-off weight (MTOW) by approximately 2 kg (≈10%), offering greater lifting capability for payload-oriented operations.
- For long-duration hover, inspection missions, and operations where energy efficiency is critical, the three-blade configuration provides clear operational advantages.
- The two-blade configuration remains suitable for lightweight or cost-sensitive missions, where mechanical simplicity, reduced component count, and ease of maintenance are desired, consistent with standard rotorcraft design guidelines (Federal Aviation Administration, 2019).

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ინჟინერია

ორ- და სამფრთიანი როტორის ეფექტიანობის შედარებითი ანალიზი, მე-700 კლასის DFC შვეულმფრენში 510 kV ძრავით

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წინამდებარე კვლევა წარმოადგენს ორ- და სამფრთიანი მთავარი როტორის კონფიგურაციების აეროდინამიკურ და ენერგეტიკულ შედარებით ანალიზს, რომლებიც გამოყენებულია მე-700 კლასის DFC ელექტრო შვეულმფრენზე, რომელიც აღჭურვილია 510 kV ელექტროძრავით. ექსპერიმენტული გამოცდები ჩატარდა დაკიდების რეჟიმში, 1900 ბრუნი/წთ ბრუნვის სიხშირეზე და 18 კგ აფრენის მასის პირობებში. ელექტრული სიმძლავრის მოხმარების აღრიცხვა მოხდა საბორტო მონაცემთა ჩაწერის სისტემით, ხოლო დაკიდების რეჟიმისთვის საჭირო თეორიული სიმძლავრე გამოითვალა იმპულსური თეორიისა და ფრთის ელემენტ–იმპულსური თეორიის (BEMT) გამოყენებით. ორივე კონფიგურაციისთვის შეფასდა ინდუცირებული და პროფილური დანაკარგები ექსპერიმენტულად გაზომილი გეომეტრიული და აეროდინამიკური პარამეტრების საფუძველზე. შედეგებმა აჩვენა განსხვავება თეორიულ და ექსპერიმენტულ მონაცემებს შორის, რაც დამახასიათებელია მცირე მასშტაბის როტორებისთვის დაბალი რეინოლდცის რიცხვების პირობებში. სამფრთიანმა როტორმა აჩვენა ოდნავ უფრო მაღალი ეფექტიანობა და ნაკლები ელექტრული სიმძლავრის მოთხოვნა ორფრთიან კონფიგურაციასთან შედარებით. ასევე, ექსპერიმენტულად განისაზღვრა ორივე როტორის მაქსიმალური აფრენის მასა (MTOW). მიღებული შედეგები წარმოადგენს პრაქტიკულ საფუძველს უპილოტო და რადიომართვადი შვეულმფრენების როტორული სისტემების არჩევისთვის, ენერგოეფექტიანობისა და აეროდინამიკური დანაკარგების გათვალისწინებით.

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