Preliminary Experimental Investigation on Autorotation Performance of Scale Model Helicopter in Vertical Manoeuvre

A. A. Wahab[♣]
Dept. of Aeronautical & Automotive Eng.,
Faculty of Mechanical Engineering,
University of Technology Malaysia
abas@fkm.utm.my

M. S. M. Ali[♠]
Dept. of Aeronautical & Automotive Eng.,
Faculty of Mechanical Engineering,
University of Technology Malaysia
sukriali@gmail.com

Abstract: This paper presents the results of the preliminary experimental investigation of reducing the steady rate of descent of a typical helicopter in vertical autorotation. Test data for two types of blades with different driving region areas were obtained. Results were summarized for zero collective pitch, same disk loading and same mass moment of inertia. The results of this preliminary test indicated that the expanding of the driving region area did reduce the steady rate of descent in vertical autorotation slightly and in agreement with the corresponding theoretical values. Further experimental investigation will be conducted looking for suitable driving region areas and collective pitch conditions that will give the reduction in the steady rate of descent significantly for ensuring safe landing condition.

Keywords: autorotation, driving region, rate of descent.

1. Introduction

Autorotation is the continuous rotation of a body in an airstreams without the supply of external power [1]. The good example of autorotation phenomena is maple seed falling from the tree. Even though no power supply is provided, the body of maple seed keeps rotating. This is because airstreams from velocity descent was extracted by maple seed to provided sufficient power that needed. Because of that, descending velocity when helicopter power system failure is important feature to sustain rotor rotating, then make a safe landing. Indeed, understanding the factor influences the descent velocity is necessary.

Ideal autorotation is defined as steady rate of descent when the ideal power is zero. Therefore, the total vertical velocity components descend velocity and induced wake velocity in the rotor plane is zero [2]. However, in real autorotation the descent rate occurs at higher rate than ideal autorotation. This is because, profile power also taken into consideration. Additional of total power mean more kinetics energy is needed to balance the power consume by the rotor blade. Then, helicopter will descent at the steady rate where the velocity is sufficient to produce enough energy rate.

It is important to prevent main rotor rotation from decay rapidly. This is because, it produces very high torque from each blade [3] and rate of potential energy is not enough to provide sufficient kinetics energy to the rotor. The main factor to rotor decay is high torque from the high angle of attack. Because of that it is important to reduce collective pitch immediately after power failure. Upward velocity from descent velocity will increase angle of attack then retarding rotational speed with effect the total of main rotor thrust. Decreasing thrust will increasing rate of descent then this situation will continue till very high descent velocity. At this point no more rotational speed because the blades are completely stalled.

Helicopter performs glide after power-off generate additional energy needed to main rotor. This will decreasing steady rate of descent with increasing forward flight. In low region of forward flight, hover manoeuvre create the highest steady rate of descent [4]. This is because contribution of external power to the main rotor is purely rate of potential energy which is function of vertical velocity. Because of that improvement in vertical autorotation is believed benefit also to forward flight autorotation.

[♣] Prof, Dr, Ir.

[♠] MEng. student

2. Methodology

The experimental set up for this project comprised of a model rotor, tower building, test rig and electrical equipment and software for collecting, recording and analyzing data. The model rotor equipped with controllable pitch system and having the specifications as shown in table 1 below.

Table 1: Model rotor specifications

SPECIFICATIONS	DIMENSION
No. of Blade	2
Airfoil	NACA 0012
Rotor diameter, R (m)	0.6
Hub Weight, M_H (kg)	0.316
One Blade Weight, M_b (kg)	0.077
Solidity, σ	0.053
Total mass moment inertia, i (kg/m^2)	0.01
Cord Length, c (m)	
1) Rectangular Blade	0.05
2) Quadratics Blade	$c=-\frac{0.12r^2}{R^2}+\frac{0.12r}{R}+0.03$, r is radial distance

The tower is 11.5 meter height in open area condition. The test rig consisting of an electric motor, safety net, sensor and rotor shaft was installed on the top of the tower. A guide wire from the centre of the shaft till the ground had been fixed vertically to prevent the blade from moving sideward. The ground end of the guide wire was fixed with spongy block to prevent the falling down blade from breaking. Video camera was used to measure the descent velocity. Photoelectric sensors had been used to count rotational speed of the model rotor along the drop test time. By using analogue to digital data acquisition system, LabView® user interface recorded and analyzed the data in the computer. The electrical schematics diagram and LabView® user interface are shown in Fig.1and 2 respectively.

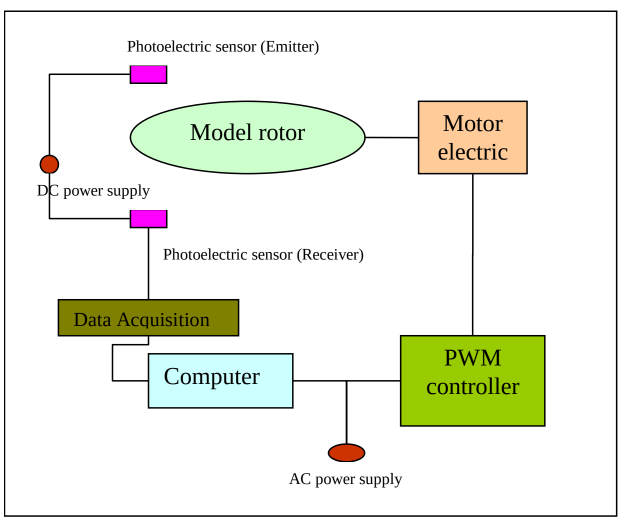

Fig. 1: Schematics diagram of electrical equipment

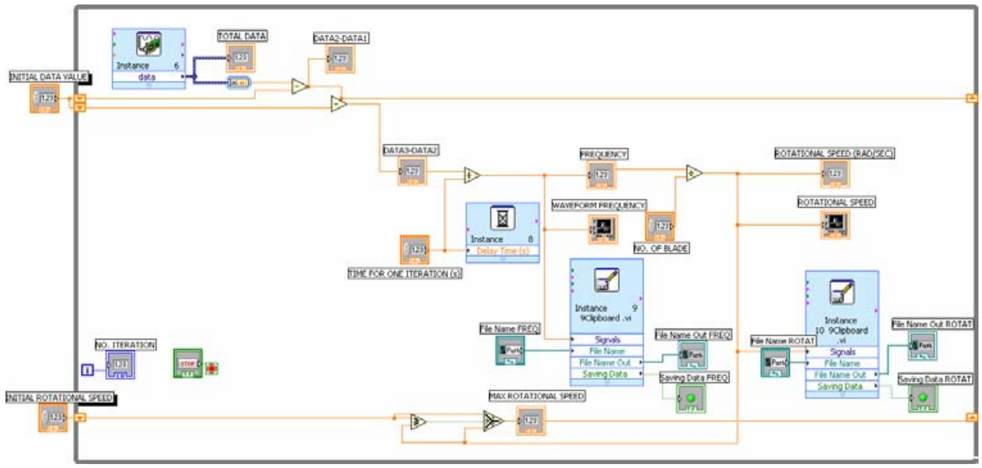

Fig. 2: LabView® block diagram

The experimental errors for the measurement of distant and time taken for descend velocity were found to be ±0.15m ±0.02sec respectively while the sensor detector and time interval measurement errors for rotational speed were found to be ±1 count and ±1µsec respectively. Then the error for descent velocity and rotational speed were then calculated as follow:

Descent velocity error ε_V and rotational speed error ε_Ω ,

$$\varepsilon_R = V\left(\frac{0.15}{S} + \frac{0.02}{t}\right) \quad (1)$$

$$\varepsilon_\Omega = \Omega\left(\frac{1}{N} + \frac{1x10^{-6}}{0.2}\right) \quad (2)$$

V Descent velocity
S Distance from the release point
t Time at certain point of distance
N Number of sensor detecting for 0.2sec

For every condition, the experiments were repeated four times and the average value and the percentage of precision uncertainty were calculated as follow:

Average descent velocity $\overline{V}$ and average rotational speed $\overline{\Omega}$,

$$\overline{V} = \frac{1}{4}\sum_{n=1}^{4} V_n \quad (3)$$

$$\overline{\Omega} = \frac{1}{4}\sum_{n=1}^{4} \Omega_n \quad (4)$$

n Number of experiment repetition
V_n Descent velocity at experiment number n

Ω_n Rotational speed at experiment number n

Percent of precision for average velocity $P_{\bar{V}}$ and average rotational speed $P_{\bar{\Omega}}$

$$P_{\bar{v}} = \frac{\frac{2S_{\bar{v}}}{\sqrt{4}}}{\bar{V}} x100\% \quad (5)$$

$$P_{\bar{\Omega}} = \frac{\frac{2S_{\bar{\Omega}}}{\sqrt{4}}}{\bar{\Omega}} x100\% \quad (6)$$

$S_{\bar{v}}$ Descent velocity standard deviation

$S_{\bar{\Omega}}$ Rotational speed standard deviation

3. Results and Discussion

The accuracy of the experiment was examined by using maximum error from the data and the precision of the average value for four repeated experiments. Analyzes gave the maximum error for descent velocity and rotational speed as 11% and 25% respectively. In addition to errors in the data analyzed, other inaccuracies are possible to occur in the test themselves. Friction between the model and the guide wire was a possible source of error, but there had been no evidence that the data were erratic because the entire test that were conducted under the same conditions would duplicate each other error. The percentage precisions of average values for the descent velocity and rotational speed were calculated to be 30% and 9% respectively. Then the total errors from this experimental were ±41% in descent velocity and ±34% in rotational speed measurements.

When the model rotor was released, it will keep rotating because of its initial rotational impulse. However, the rate of rotational speed was decreased by the effect of profile drag on the blade. This situation was depicted in Fig 3. For the first few seconds, the rate of rotor speed decay was high due to insufficient kinetics energy of the model rotor to counter the decelerating torque that was produced by the blade drag. However, the blade angle of attack was increased when the model rotor falling down due to upward velocity. This condition had made the lift vector to tilt forward to the leading edge thus creating accelerating torque. The area on the blade that experiencing the tilting forward lift vector was called driving region. The first driving region created was on the blade root then spreading to the tip depending on the descending velocity. Fig.3 also shows that the rate of rotational speed decay first decreased with falling time and then became constant at the last few seconds. At this condition, the accelerating torque from the driving region was equal to the decelerating torque from the driven and stall region.

Fig 3 also shows that the rectangular and the quadratics blades exhibited similar pattern of rate of rotational speed decay. In the first few seconds of drop test, slightly different value in rotational speed measurement was indicated. However, after one seconds of drop test, the blade with quadratics geometry gave rotational speed better than rectangular blade shape. Therefore, it was approved that at a typical time the driving region was developed higher at the centre of the blade. Then, by manipulated the area it can improve the performance of the vertical autorotation in term of rotor rotational speed. The experiment also shown rectangular blade was first achieved in steady rotational speed at 2.5sec then 3.5sec for quadratics blade. However, the quadratic blade gave better rotational speed about 3 rad/sec compare to rectangular blade about 2.6 rad/sec. Fig.3 shown an improvement about 15% rotational speed can be achieved when using blade with quadratic shape.

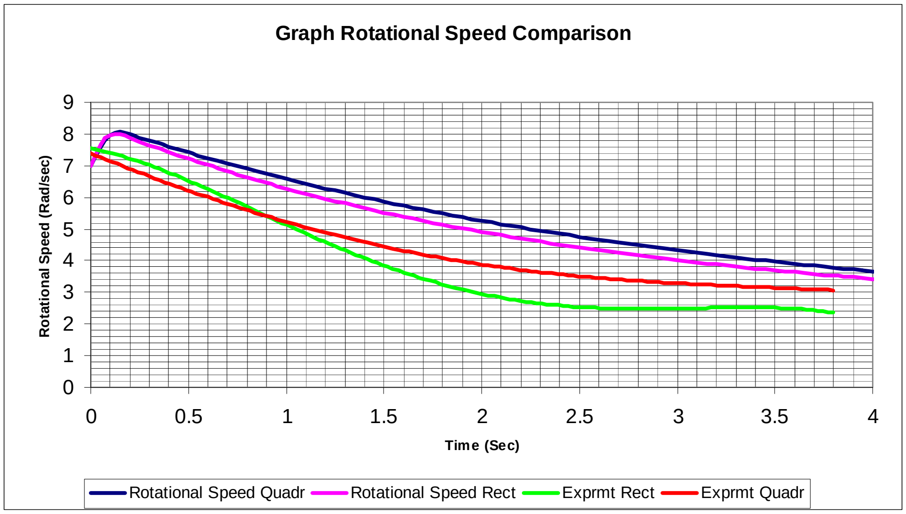

Fig.3: Theoretical and experimental rotational speed comparison with two types of blade

As mention earlier, data from rotational speed has 36% total error. That means from Fig.3 the line which was presented experimental value can be shift upward or downward until 36% increment. Comparison between theoretical and experimental gave 17% and 23.5% lower of steady rotational speed for quadratics rectangular blades respectively. The figure also has shown some increment at very beginning of the test drop when theoretical analysis was used. This was believed due to theoretical assumptions has been used where the summation of torque was taken from the axis of rotation. In the real case the blade root was not on the centre of the rotation but at some distance from the axis of rotation. Then there was some reduction in driving region area which decreased the rotational speed that can be produce. In theoretical analysis both type of blade had constant rotational speed after four seconds drop and quadratics blade still shown higher rotational speed about 6% increments.

The rate of descent of the model rotor was mainly due to the thrust can be produced at a given rotational speed. Because of that the behaviour of this parameter related to the behaviour of the rotational speed. As can be seen from Fig.4, line slope at the first few seconds was high. This was because at zero collective pitch, only a very small angle of attack can be produced from the resultant velocity. Then, a downward forces of weight was dominated which made the model accelerated. However when the model was descending, increase in upward velocity was increased the value angle of attack on the blade then produced more thrust. That proved why the rate of descent velocity was getting lower. Then the condition continued until constant descent velocity was experienced which means autorotation steady rate of descent has been achieved.

The experiment results also shown rate of descent for the blade with rectangular shape having lower velocity at the first few seconds compared to other. It was believed due to higher profile drag on the quadratics blade compare to rectangular blade. This situation was true when referring back to rotational speed of quadratic blade in Fig.3. When the rotational speed was lower, the thrust can be produced also lower than the rectangular blade. Then gave higher velocity descent value compare to rectangular blade. However after one seconds drop test, lower descent value was experienced by the quadratics blade. At this condition, it has shown using quadratics blade only useful if the descent velocity was at least 5.4 m/sec. This was because driving region took effect on the expanding area after this velocity value. For this experiment condition, the steady rate of descent for the model rotor using quadratic blade can be reduced about 6% from 7.2m/sec to 6.8m/sec.

Theoretical analysis using BEMT with nun uniform circularly loading gave the similar pattern of descent velocity compare to the experimental. However because of the error in the measurements during the experiment and assumption that were used in the theoretical analysis, higher descent velocity was expected. Because of 41% error on experimental, the value on the line at Fig.4 can be shift upward or downward as much that error value. The different between theoretical results compare to experiment results were 52.5% and 55.6% for rectangular blade and quadratic blade respectively. If that error were taken into account, the minimum value of steady rate of descent for quadratics blade is about 3.536m/sec. Then the different values reduced to 14.6% between the experiment and the theory analyzes. This percent of difference then can be reduced in theoretical analysis when about 5% assumption error is taken into account.

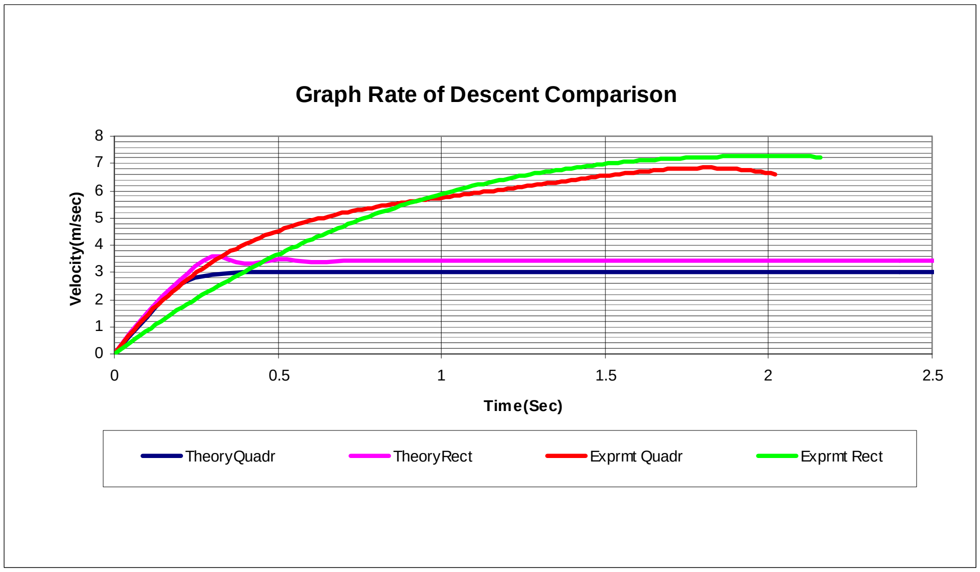

Fig.4: Theoretical and experimental rate of descent comparison with two type of blade

4. Summary

From an experimental investigation of rectangular blade and quadratics blade shape in the analysis of autorotation performance of model helicopter in vertical manoeuvre, the results shown that quadratics blade shape is the best choice. However, for safe autorotation landing the rate of descent for this blade was still high. Improvement of this matter can be made if additional positive collective pitch is used rather than zero collective pitch for this experiment.

Acknowledgment

This study sponsored by *Pembangunan Tabung Perindustrian* (PTP) University of Technology Malaysia.

References

[1] Skews, B. W., 1998. Autorotation of Polygonal Prisms with an Upstream Vane, *Journal of Wind Engineering*, 73: 145-158.
[2] Heyson, H. H., 1975. A Momentum Analysis of Helicopters and Autogyros in Inclined Descent with Comments on Operation Restrictions, *NASA Technical Note*, NASA TN D-7917
[3] Yeow, A., and Lee, N., 1985. Optimal Landing of a Helicopter in Autorotation. Master Thesis. Stanford University.
[4] Gessow, A., 1950. An Analysis of The Autorotative Performance of a Helicopter Powered by Rotor-Tip Jet Units, *NASA Technical Note*, NACA TN 2154