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EFFECTS OF HELICOPTER HORIZONTAL TAIL CONFIGURATIONS ON AERODYNAMIC DRAG CHARACTERISTICS

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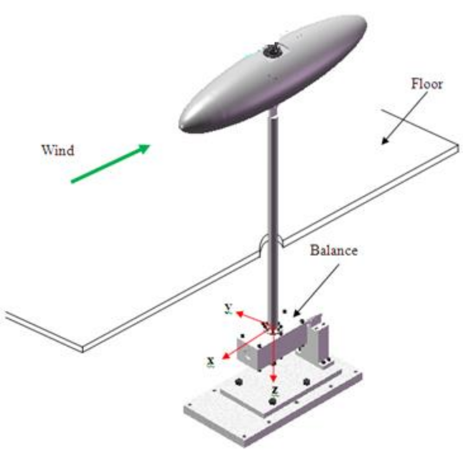
Graphical abstract



Abstract

Experimental aerodynamic investigations remain the subject of interest in rotorcraft community since the flow around the helicopter is dominated by complex aerodynamics and flow interaction phenomena. The objective of this study is to determine the aerodynamic drag characteristics of helicopter horizontal tail by conducting wind tunnel tests. To fulfil the objective, three of the most common helicopter horizontal tail configurations namely Forward Stabilizer, Low-aft Stabilizer and T-tail Stabilizer, were fabricated as a simplified scaled-down wind tunnel model mated with a standard ellipsoidal fuselage. The test wind speed for this experimental work was 30 m/s, determined from Reynolds sweep, which was corresponding to Reynolds number of 2.8 x 10^5. Wind tunnel tests were performed at various angle of attack ranging from -15^o to +15^o with 5^o interval. The results indicate that at zero yaw and zero pitch angles, Forward Stabilizer contributed the least drag coefficient at 0.277 implying the configuration could be the best for cruising flight segment. In contrast to T-tail Stabilizer, this configuration contributed the most drag coefficient at 0.303, which was 9% higher than the former. The T-tail Stabilizer was also found to be most sensitive to the change of angle of attack where the drag was drastically increased up to 131.35% at -15^o angle of attack compared to at zero angle of attack. These findings had successfully testified that the type of stabilizer configuration does significantly influence the aerodynamic drag characteristics of helicopter. Subsequently, the selection of stabilizer must wisely be done to have the best aerodynamic efficiency and performance for the helicopter.

Keywords: Aerodynamic drag, ellipsoidal fuselage, helicopter, stabilizer, wind tunnel

1.0 INTRODUCTION

Rotorcrafts are becoming an essential need as its demand, expediency and usage are increasing rapidly due to its unique ability to hover along with other fundamental movements in any direction [1].

The flow around a helicopter is dominated by complex aerodynamics and flow interaction phenomena [2]. This is further elaborated by Qing Wang and Qijun Zhao [3] stating that the rotor blades work at extraordinary serious unsteady environment compared with the fixed wing aircraft in normal forward flight and therefore its aerodynamic characteristics are more complex. Even though structural strength transpires to be an imperious portion in any aircraft design, for a rotorcraft the aerodynamics remains the most thought-provoking and abstruse impediment grappled by the aerodynamicists and designers even today [4]. As the aerodynamics of rotorcraft in forward flight, particularly at high advance ratios, are highly complex [5], it is a demand to do more investigations to gain better understanding on aerodynamic and performance of helicopter.

Due to the lack of experimental aerodynamic data on helicopter horizontal tail owing to confidential issue, this research aims to investigate the aerodynamic drag characteristic on the helicopter horizontal stabilizer tail. Although, numerical simulation is considered to be more advantageous when it comes to saving time and costs in comparison to conducting actual experiments [6], however simulation results are never exact. Since the helicopter horizontal stabilizer also plays a vital role and important component in the helicopter design process, it is hope that the open literature of this research work can benefit the rotorcraft community.

The horizontal tail is needed for longitudinal stability in which to be statically stable in longitudinal mode, the pitching moment derivative, Cm_{α} must be a negative value [7]. Consequently, the total drag of helicopter is increased due to the present of this horizontal tail. According to Ortega [8], a reduction of the helicopter's parasite drag will increase range, maximum speed and payload, as well as decreasing the vibration excitation and blade loads significantly [9]. Since parasite drag represents 40-50% of the total power requirement of a single rotor helicopter [10], therefore reduction of drag would significantly bring down the total power required. The fuel savings from the reduction of helicopter drag has stimulated many research efforts. Furthermore, current civilian and military requirements call for helicopters with high speed and long range capabilities, and therefore low drag is an important design criterion.

This work is an experimental research aiming to determine the drag contribution of the most three common helicopters horizontal tail configurations which are the forward stabilizer, low-aft and T-tail stabilizer [11]. For forward mounted stabilizer, the horizontal stabilizer is mounted forward on the tail rotor which normally the stabilizer is attached near the helicopter center of gravity. For low-aft stabilizer, it is mounted low down near the end of the tail. And for T-tail stabilizer, the horizontal stabilizer is mounted at the top of the vertical fin which will make the stabilizer to move away from the rotor wake for most flight conditions.

2.0 METHODOLOGY

This study is to analyze the effects of helicopter horizontal tail configurations on aerodynamic drag characteristics by conducting wind tunnel test. For that, a standard ellipsoid shape was chosen as the fuselage with the ellipsoidal ratio of 4.485 [13]. Many researches use this standard helicopter model to avoid confidential issue and ease for results verification with other journals, as shown in Figure 1 [14].

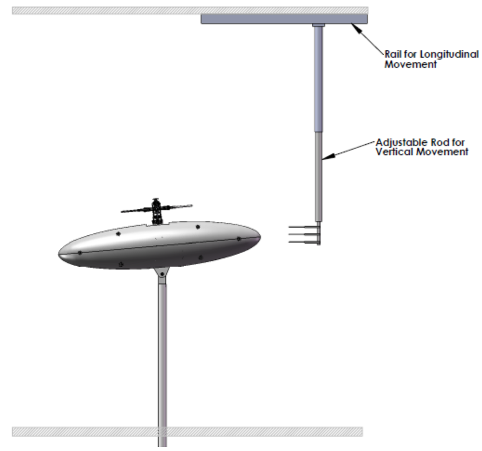


Figure 1 Schematic diagram of experimental works with a standard ellipsoidal helicopter fuselage [14]

In determining the size of model, the blockage ratio had been considered where the ratio of the frontal area of the model to the wind tunnel cross-sectional area must be less than 0.1 [15].

Wood had been chosen as the material for the model due to ease of fabrication and availability factor at Aerolab, Universiti Teknologi Malaysia.

The experiments were conducted in UTM-LST wind tunnel facility at Aeronautical Laboratory (Aerolab), Universiti Teknologi Malaysia. The test section is 2.0m (W) x 1.5m (H) x 5.8m (L) with the maximum wind speed of 80 ms^{-1} [16].

The wind tunnel tests were conducted for three different horizontal stabilizers as shown in Figure 2, Figure 3 and Figure 4, respectively.

Figure 2 Ellipsoidal fuselage mated with Forward stabilizer

Figure 3 Ellipsoidal fuselage mated Low-aft stabilizer

Figure 4 Ellipsoidal fuselage mated with T-tail stabilizer

The model was supported by a single strut system where it supports the pitching movement during wind tunnel testing. The center of gravity location is not an issue for this kind of experiment as the test was solely aimed to measure the aerodynamic drag force. Each configuration of tail stabilizer was run at variations angle of attack ranging from -15^{O} to 15^{O} with intervals of 5^{o}. For each angle of attack, 100 data were taken in 10 seconds i.e the sampling frequency was 10 Hz. Hysteresis and repeatability tests were also conducted to check the data reliability.

The well-established MICROCRAFT 6-component balance with high accuracy was used for the measurement of the aerodynamic loads. The balance is capable to determine the six aerodynamic loads namely lift force, drag force, side force, pitching moment, yawing moment and rolling moment.

The Reynolds sweep had been run for 5 different wind speeds ranging from 10 m/s to 50 m/s at zero angle of attack and yaw angles to determine at which wind speed the aerodynamic coefficients become independent of wind speed [17]. Based on the Reynolds sweep result, the wind speed of 30 m/s was selected to be the test wind speed which is corresponding to 2.8 x 10^5 Reynolds number.

Aerodynamic load data were captured during this kind of test. However, the present of the model in the test section had actually reduced the area through which the air must flow. From the Continuity and Bernoulli's equations, this increases the velocity of the air around the model [17]. Because the air is speeded up around the model, the forces and moments become larger, and if no correction is applied, the aerodynamic coefficients will be overestimated.

The ratio of the 'frontal area' of an article to the stream cross-sectional area is effectively zero in most actual operations. In wind tunnel tests, this ratio is called Blockage Ratio reflecting the relative size of the test article and the test section. It is usually chosen in the range of 0.01 to 0.10 [15]. In this experiment, the model frontal area was 0.017 m^2, giving the blockage ratio of 0.0057

Essentially, the blockage correction can be obtained based purely from the Continuity Equation which is expressed as [18]:

Air density x *velocity* x *area* = a constant

Since the air density does not change significantly at low speeds, the equation can be rewritten as follow:

velocity x *area* = a constant

If S = tunnel cross section area
A = model frontal area

Then around the model, the air has to flow through the remaining area *S- A*, which is:

$$V_{true} \times (S-A) = V_{indicated} \times S$$

Or $$V_{true} = (V_{indicated} \times S) / (S-A) \quad (1)$$

Where $V_{indicated}$ = is the speed in the test section upstream of the influence of the model.

V_{true}= is the actual speed around the model

The the aerodynamic drag coefficient C_D, is written as:

$$C_D = \frac{F_x}{0.5\rho V_{true}^2 A} \quad (2)$$

Where *A* is the model reference area for calculating aerodynamic coefficient.

To have the corrected C_D value, substitute Eq. (1) into Eq. (2). Now Eq. (2) becomes:

$$C_D = \frac{F_x}{0.5\rho\left(\frac{V_{indicated}S}{S-A}\right)^2 A}$$

$$C_D = C_{D\,indicated}\left(\frac{S-A}{S}\right)^2 \quad (3)$$

Since the blockage ratio (ratio of frontal area of model to frontal area of test section) in this experiment was small which only 0.57%, the second-order terms can be ignored [18], and then the final equation for the corrected drag coefficient become:

$$C_D = C_{D(indicated)} (1 - 2A/S) \quad (4)$$

where $C_{D(indicated)}$ was the drag obtained from the wind tunnel test.

3.0 RESULTS AND DISCUSSION

Figure 5 to Figure 7 depict the results of the experimental works done. The results show a typical pattern for drag coefficient characteristic during angle of attack sweep [17]. All the graphs show that the lowest drag happened at zero angle of attack which is agreeable with previous researcher [19]. The graphs are also in a good agreement with each other, telling that the aerodynamic drag would be increased when the angle of attack was changed to either in positive or negative sweep. However, it is noted that the changes were not identical. This could be explained as the models were not in a symmetrical form in vertical plane. Consequently during pitch up and pitch down attitude, the area exposed to the wind was different denoting unsymmetrical drag contribution during angle of attack sweep.

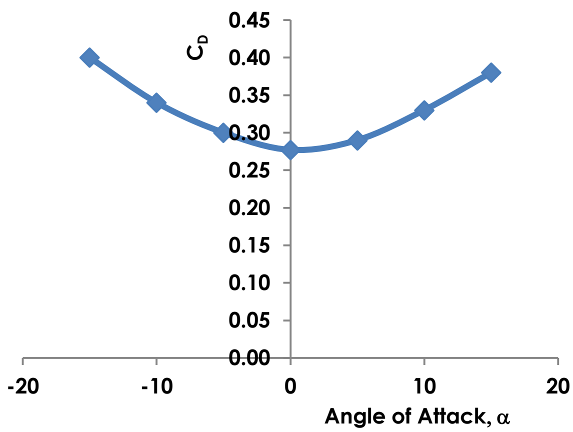


Figure 5 Characteristics of drag coefficient during α sweep for Forward stabilizer

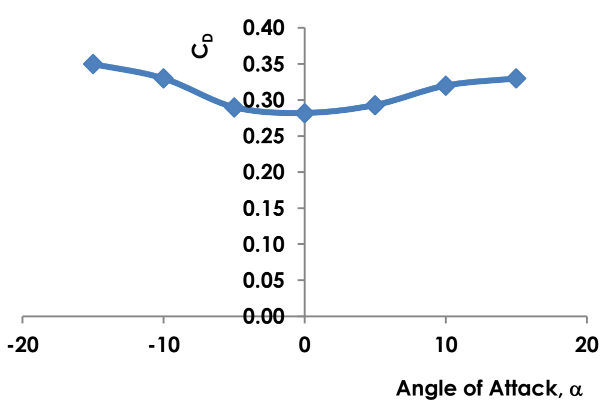


Figure 6 Characteristics of drag coefficient during α sweep for Low-aft stabilizer

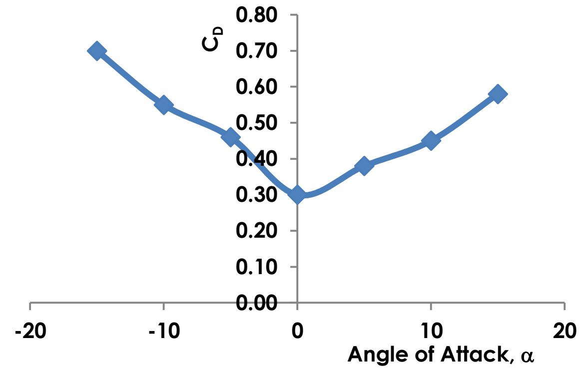


Figure 7 Characteristics of drag coefficient during α sweep for T-tail stabilizer

Since the angle of attack for the model was adjusted manually using inclinometer, it is admitted that there could be small discrepancy for the actual value of angle of attack. However the discrepancy is so small as the manual changing of angle of attack had been done in extremely caution manner and therefore, did not affect the overall results.

Table 1 indicates the percentage of maximum drag with respect to zero pitch attitudes. It shows the T-tail Stabilizer was very sensitive to the change of angle of attack where the drag was abruptly increased up to 131.35% compared to at zero angle of attack. Contrarily for the Low-aft Stabilizer, it was the least sensitive to the change of pitch attitude.

Table 1 Percentage of drag coefficient increment at maximum drag (at $\alpha = -15^o$)

Configurations	%Delta C_D
Low aft Stabilizer	24.11
T-tail Stabilizer	131.35
Forward Stabilizer	45.13

Nevertheless, the drag coefficient for this study was found to be slightly higher than the drag coefficient done by Ishak *et al.* [17], as the reference area used in computing the drag coefficient for the latter was the main rotor area.

Figure 8 tells the drag coefficient for T-Tail configuration at zero yaw and zero pitch angles is the highest. This could be explained as more surface of this kind of stabilizer is exposed to the wind load compared to the other two tail configurations. Interestingly, both Forward and Low-aft stabilizers denote about the same drag value at the zero pitch attitude. This could be due to their locations are located directly behind the fuselage, in which the fuselage restrained the stabilizers against the vigorous upcoming wind. That also could explain why T-Tail configuration contributes the highest aerodynamic drag for all pitch attitude.

Figure 8 also concludes that the drag characteristics for T-Tail configuration changes more drastically towards angle of attack, implying this configuration is the most sensitive to the change of pitch attitude. This could be due to its physical appearance which is entirely exposed to the free stream velocity. Oppositely, the drag characteristics of Low-aft Stabilizer show the least sensitive to the change of pitch attitude. Since its location is directly located behind the fuselage, the stabilizer was immersed inside the fuselage wake. Therefore the velocity of the wind seen by the stabilizers was less than the free stream velocity. In turn, the dynamic pressure experienced by the stabilizer was much lower and thus contributing to a lesser drag. Therefore it could be anticipated that Low-aft Stabilizer is more suitable for high speed mission such as for attack helicopter. Subsequently the T-Tail stabilizer could be convenience for low speed missions such as for transporting heavy goods.

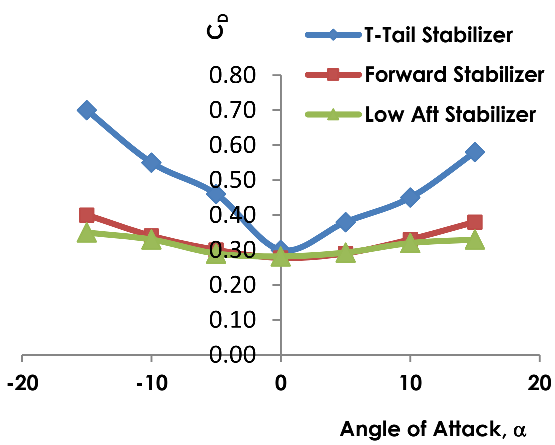


Figure 8 Comparison of drag coefficient characteristics between stabilizers during α sweep

Table 2 shows comparison of the drag coefficient at the extreme pitch attitude of the tested models. It can be seen that the maximum drag coefficient happened at negative pitch attitude for the all three configurations. This finding furnishes important information as it tells the aerodynamic drag getting worsen at negative pitch attitude compared to positive pitch attitude. Table 2 also depicts that T-tail Stabilizer configuration contributes the most drag at the extreme pitch attitudes. Nevertheless, T-tail Stabilizer may have advantages in terms of practicality and flight stability as it is away from the rotor wake for most flight conditions.

Table 2 Comparison of drag coefficient values at extreme pitch attitude

Configurations	Angle of Attack	
	-15°	15°
Low aft Stabilizer	0.350	0.330
T-tail stabilizer	0.701	0.580
Forward Stabilizer	0.402	0.380

4.0 CONCLUSION

The experimental works conducted in this study had successfully pointed out that the present of different tail part configurations does influence the aerodynamic drag characteristics, in which the finding is in favour with other publications [20, 21]. Hence, selection of stabilizer configuration must be done extremely careful to have the best aerodynamic efficiency and performance. Results depict that Forward stabilizer could be the best for cruising flight segment as it contributes the least aerodynamic drag. Contrarily to T-Tail configuration, it denotes the highest aerodynamic drag at extreme pitch attitude of the flight, which the finding was found to be in good agreement with the works done by Zabaroulla [11]. Although the results were for a simplified scaled-down wind tunnel model with no main rotor rotating, the findings could enhance the understanding on contributions of horizontal tail stabiliser towards aerodynamic drag characteristics. For future works, further investigations with different fuselage shape and with main rotor rotating are required to have better conclusion on aerodynamic drag characteristics contributed by stabilizer.

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