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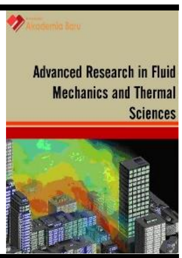

Experimental Work on Unsteady Helicopter Rotor Hub Wakes

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ABSTRACT

Helicopter tail shake phenomenon is a topic of main distress for the rotorcraft industry since it adversely affects the overall performance, occupants' comfort and handling qualities of helicopter. This research work is intended to investigate the unsteady aerodynamic wake characteristics induced by the helicopter rotor hub that lead to this tail shake phenomenon by executing a wind tunnel campaign. The experiments were carried out in the UTM wind tunnel with a test section of 2m (width) x 1.5m (height) x 5.8m (length) with the maximum wind speed of 80m/s. Dynamic pressure measurements inside the wake due to the effect of helicopter advance ratios and pylon configurations were performed. The dynamic analysis conducted through the power spectral density and **r**oot-**m**ean-square methods, has successfully managed to quantify the frequency and the amplitude of unsteadiness of the hub wakes that lead to the tail shake problem. The analyses tell that by employing pylon to the rotor hub, it could significantly reduce the wake unsteadiness up to 99.31%. Subsequently the findings of this research have potential to minimize this long running problem that undoubtedly could benefit the entire growing helicopter industry.

1.Introduction

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 [1]. According to Qing and Zhao [2], the helicopter rotor blades work at higher unsteady aerodynamic environment compared to the fixed wing aircraft, making its aerodynamic characteristics are more complex. The flow field is characterized by its inherent complexity including effects of fluid–structure interference, shock–boundary layer interaction, and dynamic stall [3]. It is one of the Interactional Aerodynamics (I/A) problems and remains, despite a considerable effort by different companies over the last two decades, difficult to predict with confidence before the first flight of a new helicopter [4]. Moedersheim and Leishman [5] had done some total pressure

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measurements on the rotor wake but the advance ratios of the works, which is the ratio of flight velocity to the product of rotor rotation speed and main rotor blade radius, were only up to 0.3. Consequently, it is quite low for the hub wake to influence the flow environment in the vicinity of tail parts. As the aerodynamics of rotorcraft in forward flight, particularly at high advance ratios, are highly complex [6], it is a demand to do the investigations at higher advance ratios. Based on research done by Roesch and Dequin [7], the problems have become more critical due to higher drag and reduced performance owing to the low energy wake induced by the hub wake.

Experimental works have been recognized as well-testified instrumentation to conduct the research [8, 9]. Hassan *et al.,* [10] affirming that wind tunnel testing is known for providing a wealth of information that the designer can access to gain an in-depth understanding of the design's behavior. This research work is intended to quantify the unsteadiness of hub wake with regards to the advance ratios and pylon configurations. The experiments were conducted in the Universiti Teknologi Malaysia's low-speed closed-return wind tunnel as shown in Figure 1.

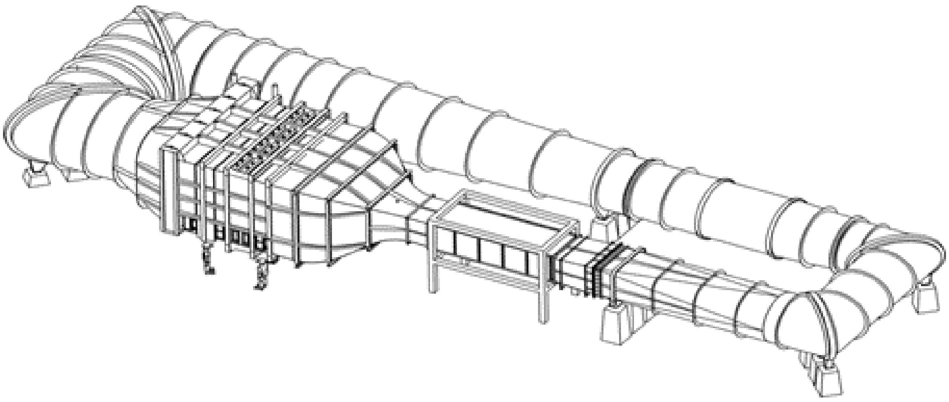

Fig. 1. Schematic layout of Universiti Teknologi Malaysia's wind tunnel

2. Methodology

The selected model for this wind tunnel test campaign was a standard ellipsoidal fuselage with the axes ratio of longitudinal to lateral axes is 4.485 [11]. The model is selected as there were previous studies on this model which providing accessible data for comparison. Furthermore, the ellipsoidal fuselage avoids geometric complexity and simplifies the interactions with the wake [11].

Waard and Trouvé [4] explained the helicopter tail shake phenomenon is being an interaction between the aerodynamic excitation and the structural response. However, this experimental work was only on the aerodynamic excitation part, in which the work concentration was on the hub wakes as it is believed to be the major contributor of the tail shake phenomenon [12]. According to Cassier *et al.,* [13], the tail shake phenomenon is caused by the wake shedding from the main rotor head and cowlings, striking the vertical fin. This permits the tail shake investigation to be conducted by using the blade-stubs configuration [14]. Blade-stubs configuration is a combination of main-rotor-hub assembly with shorter blades. Blade-stubs configuration also has advantage to avoid all dynamic constraint such as instability, Eigen mode and track adjustment.

For the main rotor configuration, this research works opted for a single main rotor configuration as De Waard and Trouvé [4] emphasized that the helicopter tail shake phenomenon is a recurring phenomenon on single main rotor helicopter configuration. Figure 2 features the model for this wind tunnel campaign.

Fig. 2. Blade-stubs configuration with single main rotor design

Figure 3 shows the schematic drawing of the model with the basic dimensions.

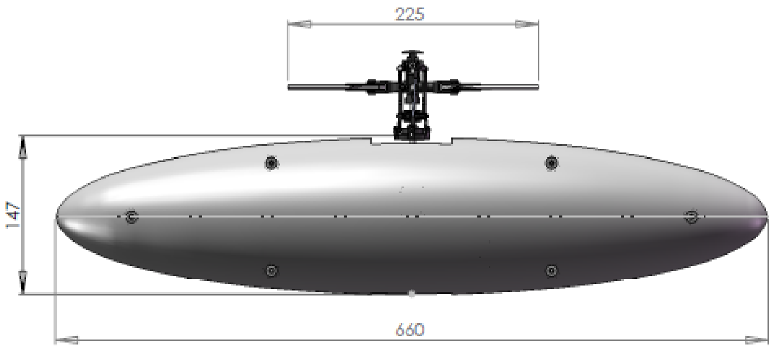

Fig. 3. Schematic drawing of the model (dimension in mm)

2.1 Angle of Attack

Obviously, the helicopter's angle of attack influences the trajectory of main-rotor-hub assembly's wake to the vertical tail. According to Ishak *et al.,* [15] where experimental works were done on a generic 14% scaled-down helicopter model, the data congregated had shown the turbulence intensity of the wake behind the helicopter during forward flight was generally higher when the model was at negative angle of attack (-ve α), compared to at nose up (+ve α) configuration. The results are agreeable with Waard and Trouvé [4] which found the tail shake worse at negative angle of attack. Furthermore, the cruising flight, where normally the longest flight segment occurs, also happens at nose down configuration. Therefore, the test configuration for this research was decided to be at negative angle of attack. However, for this publication, only results at angle of attack of -5^o (α = -5^o) would be highlighted.

2.2 KULITE Miniature Dynamic Pressure Transducer XCL-072

In order to have minimum blockage, the dynamic pressure transducer should be very small in size. For that, KULITE miniature dynamic pressure transducers type XCL-072-10PSID with diameter of 0.075´´ had been selected to be used in this research. They are pressure differential type with maximum pressure range of 10 psi (700 mbar).

2.3 Wake Pressure Rake

The wake rake, which houses the KULITE dynamic pressure transducers, is designed in such a way to achieve minimal flow blockage, and yet be sufficiently rigid to withstand the extreme unsteady wake induced by rotor rotation. Subsequently a dedicated wake rake consists of a square array of 9 pressure tubes had been designed and fabricated. The intervals of the pressure tubes were 25 mm to be similar with Lee and Brown [16]. Figure 4 shows the designed wake rake housing nine KULITE pressure dynamics transducers during the wind tunnel test.

Fig. 4. The designed wake pressure rake at UTM tunnel

2.4 Pylon Configurations

In this research program, five test configurations were investigated which are

i. No Pylon Configuration
ii. Ellipsoidal Pylon (Single Height) Configuration
iii. Rectangular Pylon (Single Height) Configuration
iv. Ellipsoidal Pylon (Double Height) Configuration
v. Rectangular Pylon (Double Height) Configuration

Figure 5 shows each pylon configuration mated to the ellipsoidal fuselage model, respectively.


(a) No Pylon Configuration


(b) Ellipsoidal Pylon (Single Height)


(c) Rectangular Pylon (Single Height)


(d) Ellipsoidal Pylon (Double Height)


(e) Rectangular Pylon (Double Height)

Fig. 5. Pylon configurations

2.5 Pressure Measurements

With the aid of wake rake housing KULITE dynamic pressure transducers, the mapping of pressure was conducted at the downstream of main-rotor-hub assembly. Figure 6 illustrates the schematic diagram of this experimental work.

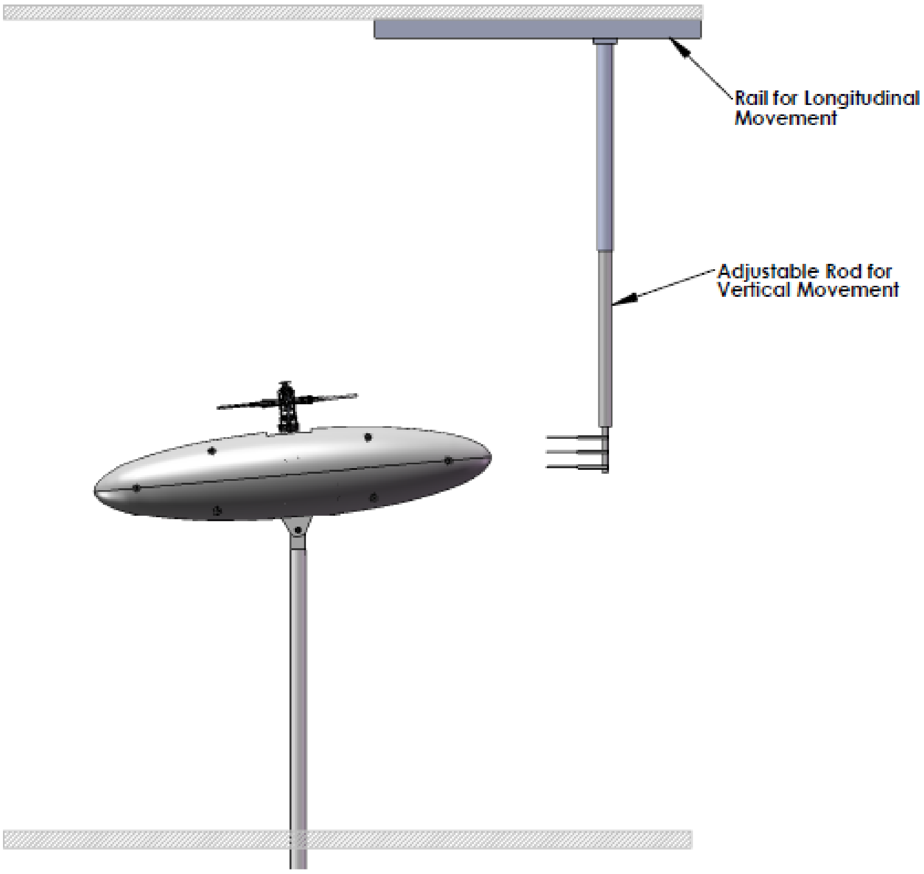

Fig. 6. Schematic diagram of pressure mapping

The rig is installed with a rail allowing the longitudinal movement of the wake pressure rake, and the adjustable rod is for the vertical movement. With these movements, bigger area mapping can be covered which possibly could cater more comprehensive information. Altogether 45 measurement points had been covered through this mapping process.

3. Results

The sampling rate for the data acquisition in this experimental work was 5 kHz with duration of 60 seconds, thus bringing up to 300 000 data for each measurement point. Data of pressure were analyzed through the static and dynamic analyses, respectively. However, owing to the page limitation of this publication, not all the results are presented in this paper. Figure 7 shows one of the test configurations that had been conducted during this wind tunnel campaign.

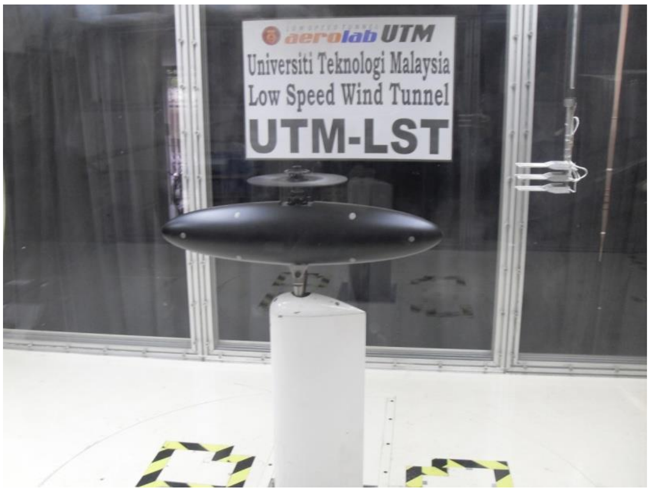

Fig. 7. Pressure mapping for No Pylon Configuration

3.1 Pressure Contours

Figure 8 to Figure 10 designate the distribution of the mean total pressure coefficient, Cp_o at mid-side plane for various pylon configurations at the highest advance ratio i.e. the rotor rotation (Ω) is 1200 rpm with the freestream speed of 30m/s. They indicates there is region where the total pressure coefficient is greater than 1 which is tally with the statement made by Roesch and Dequin [7], stating that dynamic pressure 20% (depending on the shape and configuration) above free stream level can be found in the high speed flow field region where the hub is located. In addition, experimental work by Moedersheim and Leishman [5] had also found the Cp_o could be as higher as 1.35 at the vicinity of tail parts. Subsequently, these literatures [5,7] have justified the findings of this research works.

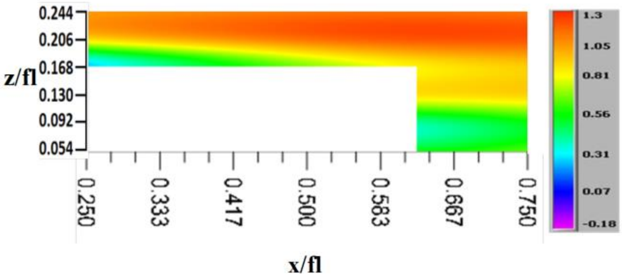

Fig. 8. Distribution of Cp_o for No Pylon Configuration

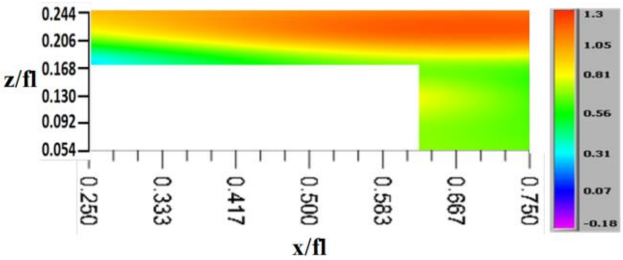

Fig. 9. Distribution of Cp_o for Ellipsoidal Pylon (Double Height)

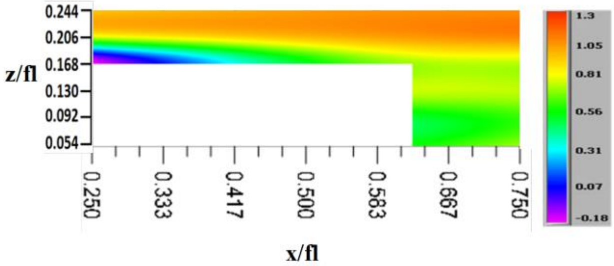

Fig. 10. Distribution of Cp_o for Rectangular Pylon (Double Height)

Apparently Figure 8 yields higher Cp_o fluctuations at the vicinity of vertical tail, compares to when pylon was mated to the main-rotor hub (Figure 9 and Figure 10). This concludes that employing pylon could reduce flow unsteadiness which in turn could minimize the tail shake problem.

3.2 Dynamic Analysis

The Power Spectral Density (PSD) analysis is used to determine the frequency of each component in the wakes, its amplitude (energy) which may quantify the unsteadiness and the dominant frequency which significantly influence the wake characters. The Root-Mean-Square (RMS) analysis is similar to the PSD analysis but the measured parameter is in the form of fluctuations. Figure 11 and Figure 12 indicate the point locations for the PSD and RMS analyses.

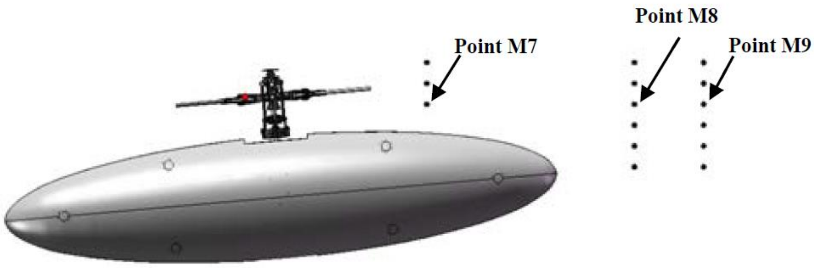

Fig. 11. Point designations for No Pylon Configuration

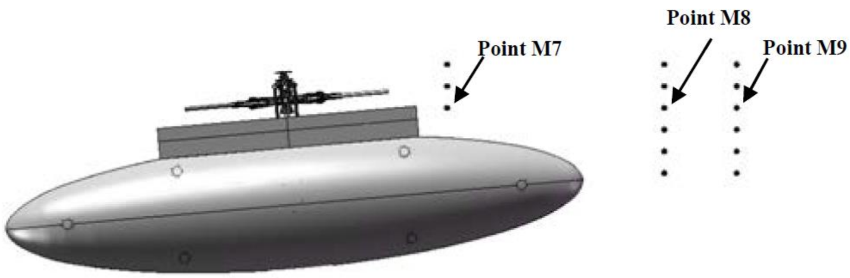

Fig. 12. Point designations for Ellipsoidal/Rectangular Pylon (Double Height) Configuration

Figure 13 and Figure 14 depict the PSD and RMS analyses for point M7 at No Pylon Configuration at rotor rotation,Ω = 1400 rpm (= 23.33 Hz) and V_∞=20 ms^{-1}. Both Figure 13 and Figure 14 agree that the most dominant frequency happens at 46.67 Hz marked by A. The 46.67 Hz is equivalent to two times of rotor rotation velocity, Ω = 23.33 Hz i.e. 2Ω. This particular frequency is strongly believed to be the frequency of hub wake, where justification will be made in the Figure 15. The 93.34 Hz peak (shown by B) comes from the harmonic of the 46.67 Hz i.e. 46.67 x 2 = 93.34 Hz, where aharmonic of a wave is a component frequency of the signal that is an integer multiple of the fundamental frequency. Noticeable at this harmonic frequency, the energy had been decreased.

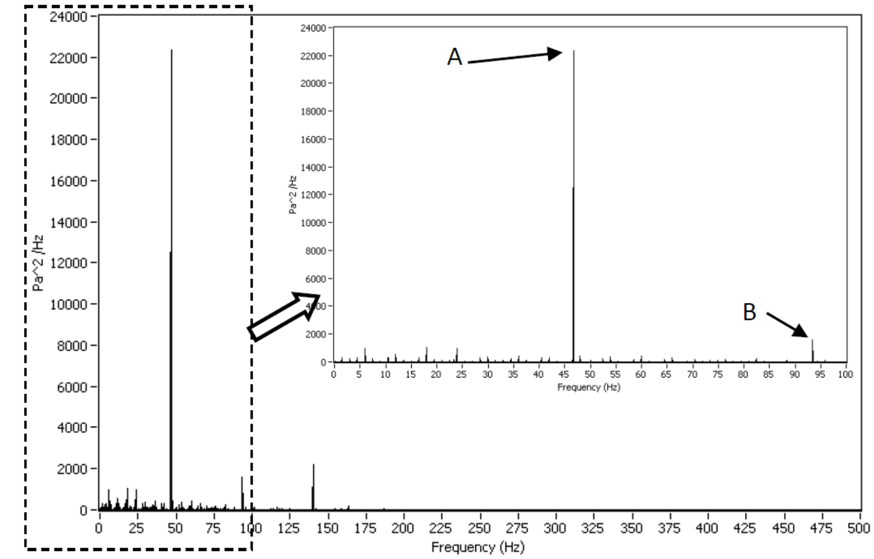

Fig. 13. PSD analysis at point M7

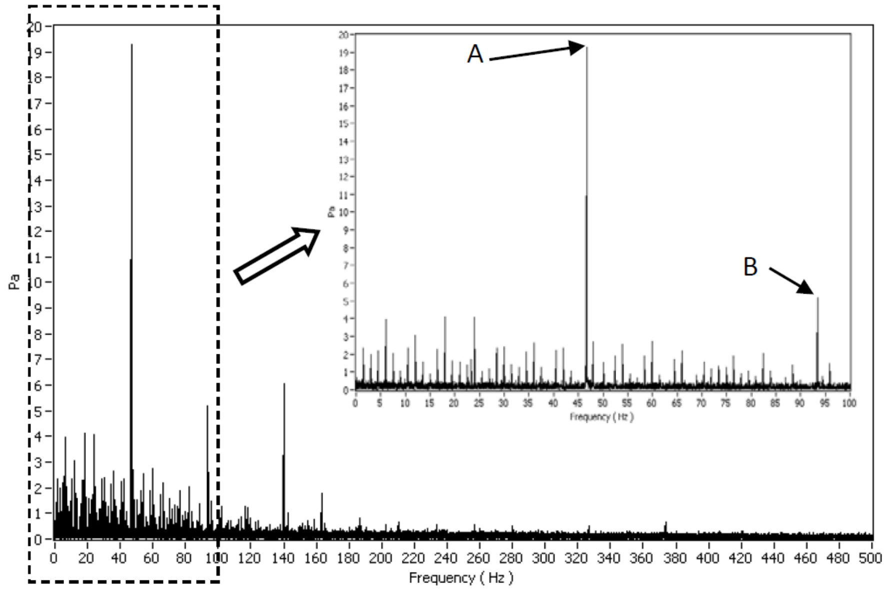

Fig. 14. RMS analysis at point M7

Figure 15 shows the Power Spectral Density (PSD) analysis for Point M7 to examine the dominant frequency for each respective pylon configurations. Figure 15 depicts the dominant frequency happened at 2Ω for the all cases. However, the flow's energy at this frequency had been decreased with the pylon configurations, which is a testament that the main-rotor-hub assembly wake happens at this particular frequency. Table 1 indicates the PSD values at 2Ω frequency for each respective pylon configurations. It obviously concludes that mating pylon to to the rotor hub could significantly minimise the energy of unsteady wake.

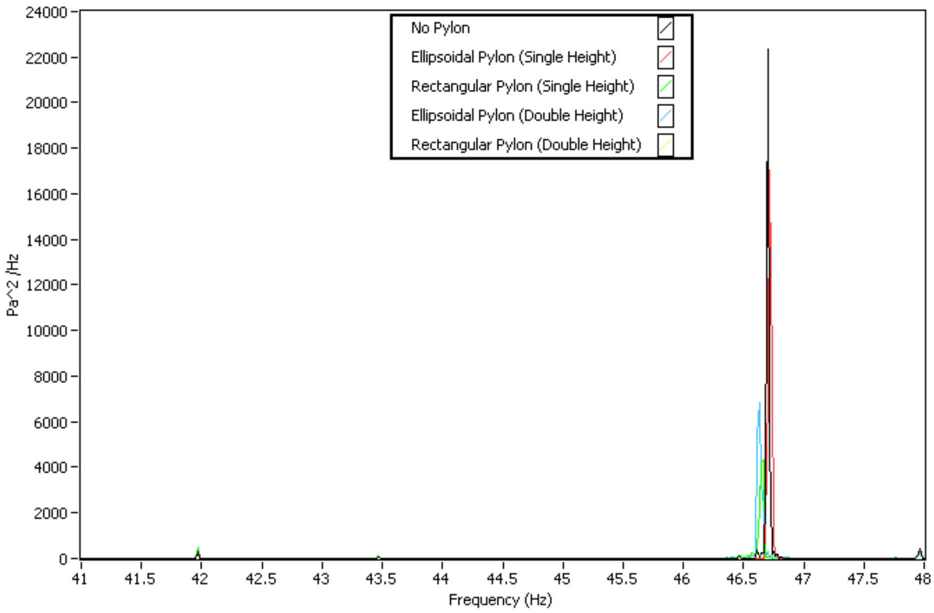

Fig. 15. PSD analysis for point M7 at different pylon configurations

Table 1
PSD for each pylon configurations for Point M7

Configurations	PSD (Pa^2/Hz)	% Reduction
No Pylon	22334	
Ellipsoidal Pylon (Single Height)	17025	23.77
Rectangular Pylon (Single Height)	4336	80.59
Ellipsoidal Pylon (Double Height)	6858	69.29
Rectangular Pylon (Double Height)	153	99.31

4. Conclusions

The aim of this research work which is to examine the unsteady aerodynamic wake characteristics triggered by the helicopter's rotor hub has been successfully accomplished. The data congregated from PSD analysis has successfully determined the frequency of hub wakes and its amplitude correspondingly. PSD analysis indicates the frequency of hub wakes is found to be the multiple integer of the rotor rotation velocity i.e $n\Omega$, where n depends on the helicopter's rotor hub design. In this research work, the frequency of hub wakes is found to be at 2Ω. This finding is unambiguously essential as it tells the frequency of hub wakes depends on the rotor rotation velocity, Ω. Thus, the problem-solving on this tail shake issue is not a straight-forward process since Ω is continuously varied throughout the entire flight segment.

PSD analysis has also successfully shown that by employing pylon to the rotor hub, it could lead to significant reduction of wake amplitude ranging from 23.77% up to 99.31%, depending on the shape of pylon. Subsequently, employing a pylon may help minimize the tail shake problem.

Findings also reveal that the pylon does modify the structure and trajectory of the hub wakes. Five pylon configurations have been tested in this research program and each configuration yields different pressure contours. Therefore, it could be concluded that hub wakes are very sensitive to the shape of pylon.

For future works, it is proposed to record the main rotor position corresponding to the hub wake since this would allow the wake data to be correlated with the position of main rotor. It would then be possible to track the wake's age and the evolution of major features of the wake flow.

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