EXPERIMENTAL RESEARCH ON HELICOPTER TAIL SHAKE PHENOMENON

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Abstract

Helicopter tail shake phenomenon is still remained as a long dragged issue that adversely affected the overall performance, occupants' comfortness and handling qualities of helicopter. This problem is more severe in modern helicopter as it needs to fly faster and with high manoeuvrability, causing rigorous interactional aerodynamic (I/A) related vibration problems. The objective of this present research is to improve basic understanding of the viscous unsteady flow phenomenon observed behind the helicopter tail part. A good understanding of this matter is necessary as a typical aspect of tail shake that it has unsteady random character, indicating that the wake induced excitation is in also unsteady of nature. For this, a wind tunnel test had been conducted with a rigid 14% model of generic Eurocopter 350Z helicopter in the Universiti Teknologi Malaysia – Low Speed Tunnel (**UTM-LST**) with a test section size of 2m x 1.5m x 5.8m and 288 km/hr maximum test wind speed. The model, supplied by Eurocopter France, is equipped with a motor that can rotate the main rotor up to 900 rpm during wind-on condition. Therefore, the wake analysis can be done 'with' or 'without' main rotor rotation which undoubtly can give a more comprehensive understanding on the wake induced. As the induced wake, which consequently causing tail to shake, differs with pitch and yaw angle, the wind tunnel test was performed in a range of -10^o to +10^o of pitch and yaw angle, respectively. The selected test wind speed was 40 m/s, which corresponds to a Reynolds number of 3.7 x 10^6. To investigate the characteristics of the induced wake, a mapping process was done at 3 different planes behind the model with each plane consists of 4 measurement points. With this, it is hope the collected data could help on the wake analysis that contributes to helicopter tail shake phenomenon. **DANTEC** single hotwire, type 55P01, was used to determine local turbulence level and velocity at each respectively point throughout all the tests. However, only static results and analysis will be discussed in this paper.

Keywords: Helicopter tail shakes phenomenon; unsteady flow; wake induced excitation

1. Introduction

This present paper aims to improve basic understanding on unsteady aerodynamic wake that contribute to helicopter tail shake phenomenon. The tail shake is partly due to the unsteady flow contributed from the main rotor assembly that hit the vertical tail which consequently causing the *tail shake phenomenon*. This shaking tail, besides influencing helicopter performance, will transmit vibrations to the cockpit and somehow will deteriorate the level of comfortness, as well adversely effect the crew efficiency. Interactional Aerodynamic (I/A) remains, despite a considerable effort by different companies over the last two decades [1], difficult to predict with confidence before the first flight of a new helicopter. General complexity of modern, compact helicopter design, associated with scaling difficulties, are contributing factors towards limited success in predicting I/A related vibration problems [1].

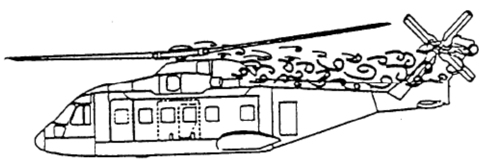


Fig. 1 Schematic of tail shake phenomenon [1]

2. Test Descriptions

This experimental study is based on a rigid scaled-down 1:7.126 generic model of Eurocopter helicopter. It is based on prototype of 350Z model and supplied by Eurocopter France. The model is equipped with only main motor i.e. no tail motor. Its length about 1.45m and is not dynamically scaled down i.e. any structural response of the model is not representing the actual structural response of real 350Z helicopter.

To determine wake characteristics which leads to tail shake, a mapping process was done at 3 different planes behind the model with each plane consists of 4 measurement points, respectively. Figure 2 shows the schematic diagram of the experimental set-up.

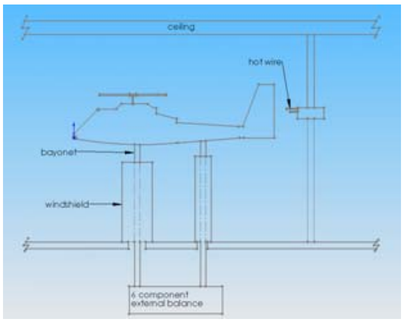


Fig. 2 Schematic diagram of experimental set-up

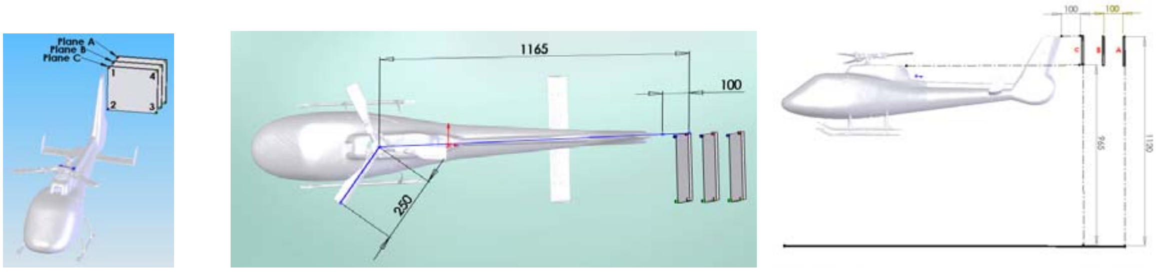
The location of the planes as follows:

i) Plane A (300 mm behind the end of tail part)
ii) Plane B (200 mm behind the end of tail part)
iii) Plane C (100 mm behind the end of tail)

For each plane, the hotwire be positioned at 4 different positions:

i) Point 1 (z=1120 mm, x= Plane A@B@C, y=0)
ii) Point 2 (z= 965 mm, x= Plane A@B@C, y=0)
iii) Point 3(z=965 mm, x= Plane A@B@C, y=250 mm)
iv) Point 4 (z=1120 mm, x= Plane A@B@C, y=250 mm)

Note : •z direction is in vertical axes. The distance shown is taken from test section floor.
•y direction is in lateral axes. The distance shown is taken from centre of test section to left side



(a) (b) (c)

Fig. 3. Hotwire Mapping Planes: (a) 3D-View (b) Plan-View (c) Side-View

** All dimension in mm*

DANTEC single hotwire, type 55P01 was used for determining local turbulence level and velocity at each respectively point. Altogether 2 hotwires from this type had been used throughout all the tests. Beforehand, each wire individually had undergone velocity calibration process. This due to fact that each wire has its own characteristics i.e would have different calibration slope.

Fig. 4. Hotwire during velocity calibration process

Fig. 5. Single hotwire type 55P01

In principle, both wires should give the same results for the same point location. To confirm this, experiments had been conducted for several random points and results show the difference between the two hotwires at only less than 5%. This small difference is acceptable as the wake is unsteady in nature [1].

In addition, to confirm the chosen of sampling frequency and number of samples have no effect on the results, two hot wire set-up files had been initialised:

Table 3. Hotwire set-up files

	Set-up 1	**Set-up 2**
Sampling Frequency (Hz)	600	25 000
Number of samples	32 768	150 000

Table 4 shows the results obtained. It can be concluded for static results, the sampling frequency and number of samples has a mere influence on the static average data. *However, further dynamic analysis indicates that they have prominent influence on data collection for frequency and power spectral density analysis.*

Table 4. Turbulence Level at Plane C for V=50 ms^{-1} and main rotor rpm 300

Point	Turbulence Level (%)	
	Set-up 1	**Set-up 2**
2	11.484	11.420
4	0.242	0.231

Even though the blade could be assumed as not the source of wake excitation for tail shake [2], test was still need to be conducted with blade i.e short blade, which is only at one-third of original blade length (0.25m in radius). This is because without blade, the physical end of sleeve tip would become different which consequently will influence the wake characteristics.

Fig. 6 Model with short blade

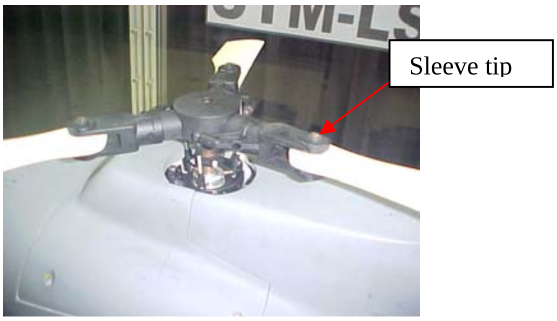


Fig. 7. Main rotor hub assembly

Dynamic similarity is not need to be considered in these aerodynamics tests [2,3]. Nevertheless, it is necessary to have the same flow field around the main rotor hub devices. For this, main rotor rpm is taken to keep the same blade tip velocity [2]. As the actual main rotor rpm for normal operation is about 300 rpm, the main rotor rpm for wind tunnel test must be at 900 rpm, since the short blade is only at one-third of original blade length. By doing this, the same value of Ωr will be kept.

$\Omega r_{\text{short blade}} = \Omega r_{\text{original blade}}$ where Ω = blade rotation (rpm) r = blade radius (m)

3. Results and discussion

The blade setting angle for this test is -6.5^0 and the main rotor rotates in counter-clockwise direction. The blade setting angle (for normal operating pitch angle range) and rotating direction of main rotor are not an issue here as the blade is assumed not to be the source of wake excitation for tail shake. To confirm this, a test was run with different blade setting angles and opposite direction of main rotor rotation, and the turbulence level readings obtained was then compared.

Table 5. Turbulence level (%) at Point 2, Plane B at V = 40 m/s

	Blade angle -6.5^0 Counter clockwise rotation direction	Blade angle -1.5^0 Clockwise rotation direction
Main rotor rotation (0 rpm)	8.664	8.771
Main rotor rotation (900 rpm)	9.354	9.370

Results show in Table 5 confirm this assumption could be made.

Even though the hot wire could also give reading on local velocity, the results presented here will be only on turbulence level (*velocity fluctuation*) as it is the indicator of wake intensity. *However, as due to very limited allowable pages for this paper, only static results would be presented here.*

Figure 8 shows the model be mounted in UTM-LST's test section.

(a) (b)

Fig. 8. Model during testing in UTM-LST: (a) Front view (b) Rear view

3.1 Model at zero pitch and yaw angles, V = 40 m/s

To study how the wake behaves in responding the increasing of main rotor rpm, main rotor rpm sweep test was conducted.

Table 5. Turbulence Level (%) for Plane C

Point	Main Rotor Rotation (rpm)			
	0	300	600	900
1	6.409	6.890	7.451	8.541
2	10.392	11.420	11.25	11.124
3	0.234	0.248	0.300	0.604
4	0.198	0.231	0.223	0.220

From Table 5, it can be concluded that for all points, the minimum turbulence level always happens when there is zero main rotor rotation. At Point 1 and 3, the wake increases with main rotor rpm, vice versa for point 2 and 4, the wake is about steady, indicating no influence of main rotor rpm at these two points.

As high wake demonstrate at Point 1 and 2, further investigation be done on these points at Plane B, also at zero pitch and yaw angle. This is to study how the wake evolved from Plane C to Plane B.

Table 6. Turbulence Level (%) for Plane B

Point	Main Rotor Rotation (rpm)	
	0	900
1	0.416	1.027
2	8.632	9.354

Compare to Plane C's results, the wake intensity is lower at Plane B. This is predicted as Plane B is located further downstream.

For further investigating on the contribution of main rotor assembly towards turbulence level at Point 2, Plane B, the main rotor assembly was taken out. Table 7 obviously tells without the main rotor assembly, the turbulence level drops drastically. Hence special attention need to focus on it since reduction of the unsteady wake triggered by it could significantly reduce tail shake.

Table 7. Wake contributors at Point 2, Plane B

Turbulence Level (%)		
No main rotor assembly	With main rotor (0 rpm)	With main rotor (900 rpm)
7.607	8.632	9.354

To study the effect of free stream velocity, Re. Sweep had been conducted from 10 m/s to 40 m/s at zero pitch and yaw angles for model. Figure 9 displays its result.

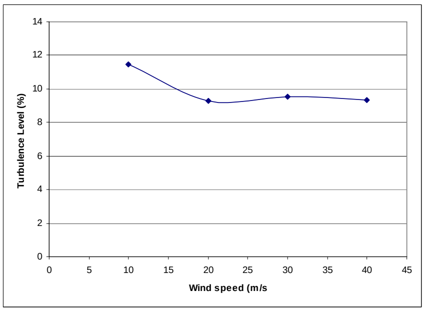


Fig. 9. Turbulence level at Reynolds sweep with main rotor 900 rpm (Point 2, Plane B)

The graph shows that above 20 m/s, the turbulence level, at this specific location, become independent of free stream velocity. This also indicates the 40 m/s test wind speed selected for this experiment is *appropriate*.

3.2 Model undergoing pitch and yaw sweep (-10^o to +10^o)

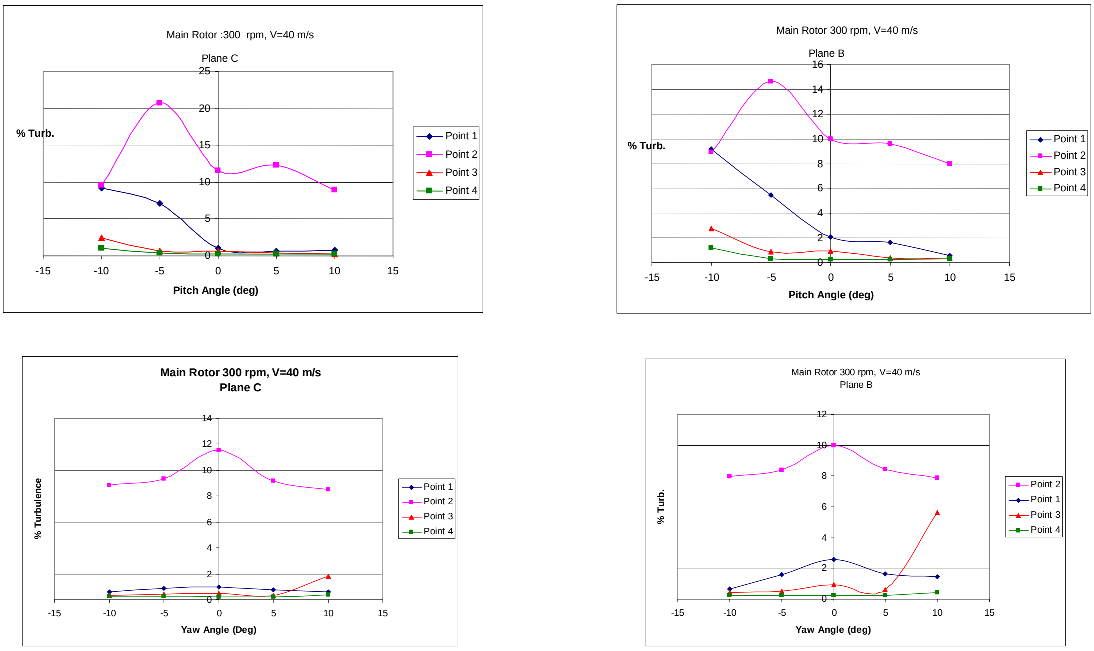


Fig. 10. Turbulence level characteristics during pitch and yaw sweep

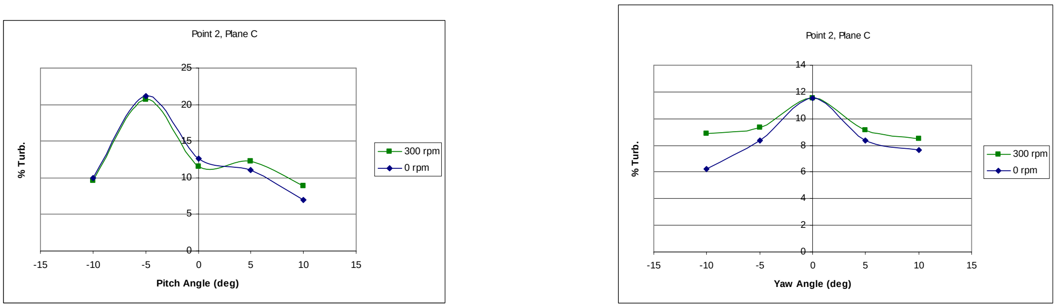


Fig. 11. Effects of without main rotor rotation during pitch and yaw sweep

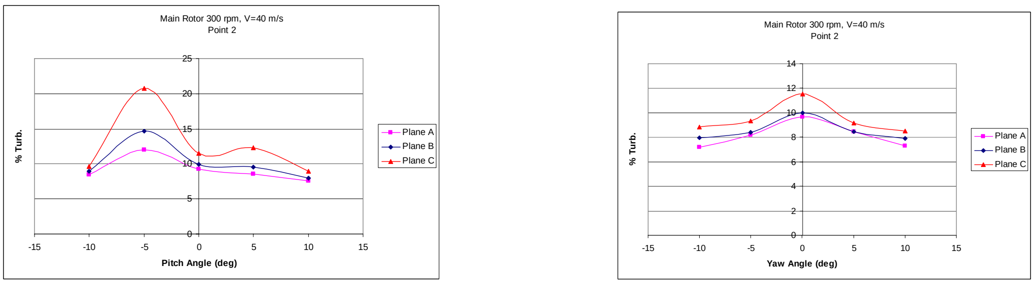


Fig. 12. Turbulence level at different planes during pitch and yaw sweep

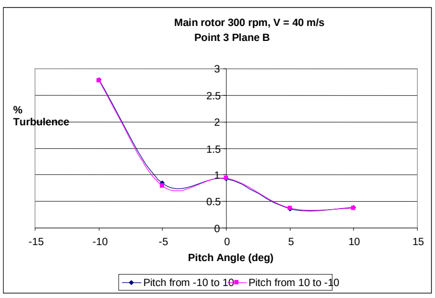


Fig. 13. Hysterisis study on pitch sweep

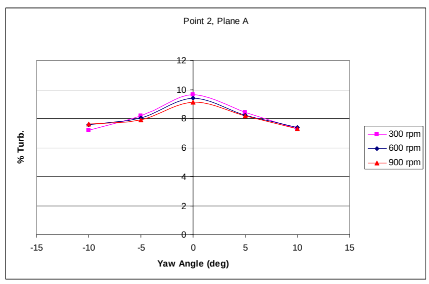


Fig. 14 Effects of main rotor rpm sweep at Plane A

Figure 10 translates the wake behaves non-linear towards pitch and yaw sweep. This is most probably due to rotation of main rotor and unsymmetrical shape of the above part and lower part, as indicated in Figure 15. For pitch sweep, it shows higher turbulence level happens at nose down configuration, compared to nose up configuration. This finding is tally with what had been reported by NLR report [1].

Fig. 15. Side plane of the model

Figure 11 depicts the wake characteristics without main rotor rotation. Surprisingly, at zero and –ve pitch angle, the turbulence level suddenly starts becoming higher for without main rotor rotation configuration.

Figure 12 tells for the same pitch and yaw angles, the wake recedes as it moves further downstream.

Figure 13 also shows the hysterisis of this experiment was really good. For this, the model at first was pitch from angle -10^0 to 10^0, with angle interval of 10^0. And then it was repeated again but with opposite sweep angle i.e. started from 10^0 to -10^0.

Figure 14 depicts turbulence level is at the most when model is at zero pitch and yaw angles at Plane A. Interestingly at this plane, turbulence level seems inversely with main rotor rpm.

4. Conclusion

This paper has presented the wake characteristics behind the tail part of a generic 350Z Eurocopter helicopter. Some interesting and important findings had been reported throughout the paper e.g. hazardous tail shake likely to happen at during nose down attitude, compared to at nose up attitude of the helicopter. Based on this initial experimental investigation, the most severe wake is happening when the model is nosed down to -5^0. Therefore, it is advisable that this model not to fly at this specific pitch angle to avoid vigorous tail shake. Nevertheless, further investigation on dynamic analysis is compulsory for a better understanding of this unsteady aerodynamic wake.

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