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HIGH SPEED ROTOR THICKNESS NOISE

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Introduction

One of the major sources of tone noise from high speed rotors is caused by blade thickness effects. For instance on a typical helicopter the approach noise levels are dominated by tail rotor tone noise and predictions suggest that this is primarily due to the blade thickness. The theoretical prediction of this effect was developed by Hawkings and Lowson (1) and in this paper this theory is compared with experimental results acquired using model rotor blades of different thicknesses.

Since the thickness noise source is significant it is desirable from a theoretical viewpoint to use thin blades. However other design criteria limit how much the blade thickness can be reduced, thus restricting the associated noise benefits. Therefore this paper suggests the use of blades tapered in thickness towards the tip to obtain the maximum noise reduction within the design constraints. The attenuations which may be obtained using these blades is evaluated theoretically.

Basic Theory

Before discussing the experimental results the noise mechanisms associated with the rotor will be described.

The overall noise levels generated by the rotor are influenced mainly by two effects - thickness noise and unsteady force noise. These two sources have different mechanisms and radiate principally in different directions; therefore each will be described in turn, and the details of the prediction methods which have been used to calculate their respective levels will be outlined.

Thickness noise is generated purely by the physical dimensions of the blade and propagates mainly in the plane of the rotor disc. It is independent of thrust and its relative level is proportional to the blade thickness. Therefore, as is the case for the tests described in this paper, if the blade thickness is doubled then the resultant noise produced increases by 6dB.

Unsteady force noise is described by Lowson and Ollerhead (2)-and depends on the fluctuations of blade loads which occur during each blade cycle. In general unsteady force noise is more omnidirectional than thickness noise and peaks at an angle away from the rotor disc plane.

Two different prediction programs have been used to calculate the contribution from these two source mechanisms. The thickness noise program is based on Ref.(1) and may be used for both the near and far fields. The unsteady force noise program is based on Ref.(2) and only applies in the acoustic far field. This presented an area of uncertainty since the measurements described below were recorded in the near field of the rotor (¾ of a rotor diameter from

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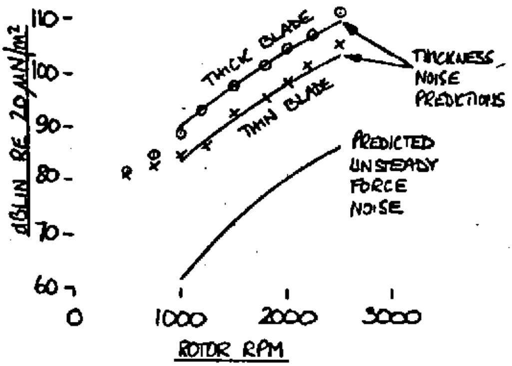

Figure 1. Comparison of Measured and Predicted dB(LIN) Levels vs Rotor RPM; 2° Pitch; Measurements in Rotor Tip Path Plane.

⊙ Thick blade measurements

✖ Thin blade measurements

the rotor axis). However corrections were made using the results given in Ref. (2), Figs.15 and 16. These show first that unsteady force noise is effectively symmetrical about the disc plane in the near field and secondly that there should be a correction in the order of +12dB applied to the predicted levels to account for near field effects. These corrections have been applied and dramatically improve the correlations between the predictions and measured results.

Experimental Results

In this section the results will be presented of an experiment which was undertaken to evaluate the effect of blade thickness on a model 0.61m radius, 0.13m chord, single bladed rotor. Two blades were tested in turn, with thickness to chord ratios of 6% and 12% respectively. Three measurement locations were used at 74°, 90° and 106° to the rotor axis and the rotor speed was varied between 500 RPM (V_T = 31.9 m/sec) and 3000 RPM (V_T = 191.6 m/sec). The pitch settings tested were 2°, 6° and 10°, and the rotor thrust was monitored in each case.

In general the agreement between the experimental results and the predicted levels is good, and typified by the two sets of data shown in Figs.1 and 2. In Fig.1 the measured and predicted levels are shown for the thick and thin blades as a function of rotor RPM. This data was measured in the tip path plane using the 2° blade pitch setting. At this condition thickness noise is expected to dominate and very good agreement between theory and experimental data has been found. Although these results only show the dB(LIN) levels, equally good agreement was also obtained between the measured and predicted spectra.

In Fig.2 the results are shown for a pitch setting of 10°, with measurements taken 16° in front of the rotor tip plane. This is the area where unsteady force is expected to dominate and good agreement has again been obtained between theory and experiment. The spectral content of the measured and predicted results at high pitch settings in general also show good agreement, except for the measurements behind the rotor. In these cases the first harmonic is predicted correctly but the higher harmonics tend to be overpredicted signif-

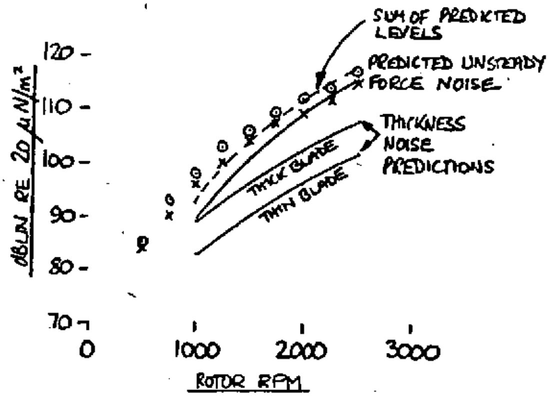

Figure 2. Comparison of Measured and Predicted dB(LIN) Levels vs Rotor RPM; 10° pitch; Measurement at 16° to Tip Path Plane.

icantly and no explanation has been found for this discrepancy.

The most important conclusion from these experiments is that blade thickness noise has been shown to dominate in the tip path plane and is predicted correctly by the theoretical model given in Ref.(1).

Tapered Rotor Blades

Since blade thickness noise dominates the noise radiated in the tip path plane, it is especially important that thin rotor blades should be used. However design criteria often limit the minimum thickness of the blade, but do allow the blades to be tapered in thickness along their span. This results in a significant noise reduction since the blade tip is more efficient at producing thickness noise than the inboard blade stations.

The attenuations which can be obtained using tapered blades has been calculated using the formulation for thickness noise given in Ref.(1). The results of this theoretical study are given in Fig.3 which shows the attenuation for rotor harmonics as a function of the spanwise location at which the tapering on the blade starts. This diagram shows that the majority of the attenuation which may be obtained using tapered blades is achieved by using a taper which starts at 60% of the blade span.

Conclusion

In this paper the importance of blade thickness noise on high speed rotors has been demonstrated both experimentally and theoretically. In general very good agreement has been found between the measured levels of rotor noise close to the plane of the rotor and the prediction schemes given in Refs.(1) and (2) providing that near field corrections are applied.

Since in-plane rotor noise is important, especially on helicopter tail rotors, thin rotor blades should be used to minimise the noise output. However

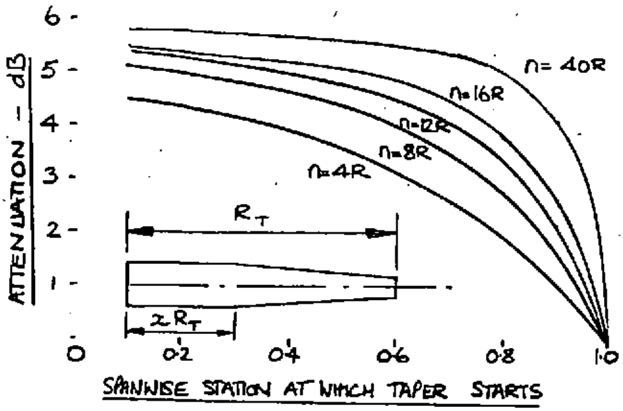

Figure 3. Attenuation of Rotor Harmonics Using Thickness Tapered Blades. Inboard Thickness = 12% Tip Thickness = 6% of Chord.

this is not always possible and so it is suggested that rotor blades which are tapered in thickness towards the tip should be used as an alternative. The attenuation which can be obtained from the tapered blade considered is between 4 and 5 dB providing the tapering starts at 60% of the blade span.

References

(1) D.L. HAWKINGS and M.V. LOWSON, 1974, Journal of Sound and Vibration, 36(1), p 1-20 "Theory of Open Supersonic Rotor Noise".

(2) M.V. LOWSON and J.B. OLLERHEAD, 1969, Journal of Sound and Vibration, 9(2), p 197-222 "A Theoretical Study of Helicopter Rotor Noise".