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Thickness Noise Analysis of an Uneven Helicopter Rotor Configuration

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ABSTRACT

In this paper, thickness noise of hovering helicopter is analyzed. Noise of helicopter caused by main rotor is calculated according to Formulation 1A derived from FW-H. Shape and configuration modification has been discussed as a noise reduction method including different airfoil and tapered tip. An uneven helicopter rotor configuration with modified shape is proposed, which has less noise than ordinary rotor configuration. Meanwhile, the thickness noise of uneven rotor has been analyzed when different modulation ratio and different modulation type including sine and cosine mode are selected. By analyzing different rotational rate, airfoil of blade, and numbers of blade, sound pressure level and noise spectra are calculated. In addition, the effect caused by different number of grid in the calculation is compared. By comparing with these calculation results data, it shows that the method used in this paper is proper. Some useful conclusions and advices are obtained consequently. These conclusions could be used as a direction for the helicopter's rotor acoustic design.

INTRODUCTION

Noise generated from helicopter has severe affect on the environment when helicopter is flying. Because of these affects, ICAO (international commercial aviation organization) makes some regulations rules for noise of helicopter. Within them, concrete noise requirements are proposed when helicopter is in takeoff, flying over and approach. So the reduction of helicopter noise is becoming more and more important.

Noise source of helicopter is consisted of rotor, tail rotor, and engine. Thickness dominates in rotor plane when velocity of helicopter is subsonic.

NOISE CALCULATION METHOD OF HELICOPTER ROTOR—FW-H FORMULATION

FW-H formulation is the basis of rotor noise calculation. It has apparent physical meaning so as to be used widely in calculation of rotor noise [1].FW-H formulation is shown as [2]:

$$\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2}-\frac{\partial^2}{\partial x_i^2}\right)p^{'}(\mathbf{x},t)=\frac{\partial}{\partial t}\left[\rho_0 v_n\delta(f)\right] -\frac{\partial}{\partial x_i}\left[pn_i\delta(f)\right]+\frac{\partial^2[T_{ij}H(f)]}{\partial x_i\partial x_j} \tag{1}$$

In equation (1), three items in the right denotes monopole, dipole and quad pole sound source. Farassat solve the FW-H formulation. He derived the solution-formulation 1A [3]. According to formulation 1A, rotor noise is mainly combined with thickness noise- $p_T^{'}(\mathbf{x},t)$ and loading noise- $p_L^{'}(\mathbf{x},t)$ when velocity is subsonic. The calculation of thickness noise is shown as:

$$4\pi\cdot p_T^{'}(\mathbf{x},t)=\iint\limits_{f=0}\left[\frac{\rho_0\dot{v}_n}{r(1-M_r)^2}+\frac{\rho_0 v_n\hat{r}_i\dot{M}_i}{r(1-M_r)^3}\right]_{ret}dS +\iint\limits_{f=0}\left[\frac{\rho_0 c v_n(M_r-M^2)}{r^2(1-M_r)^3}\right]_{ret}dS \tag{2}$$

In calculation for equation (2), the retarded time of small element of surface should be first solved. Then, by integral of rotor blade surface, the thickness noise can be attained. The elements of blade surface are shown as fig.3. The retarded time relates to the sound source transmission time. It can be obtained by solving the retarded time equation. Assuming the sound departing from sound source at τ reaches the receiver at t. The times-τ and t should satisfy the equation [15]:

$$t=\tau+\frac{r}{c_0} \tag{3}$$

In equation (3), r represents the distance form sound source to receiver and c0 is sound velocity in air. Provided that receiver coordination is (x_1, x_2, x_3) in fixed frame, its corresponding vector is denoted as **x**. let (y_1, y_2, y_3) is coordinate of some element of blade surface, its corresponding vector is **y**. So:

$$\mathbf{r} = \mathbf{x} - \mathbf{y} \tag{4}$$

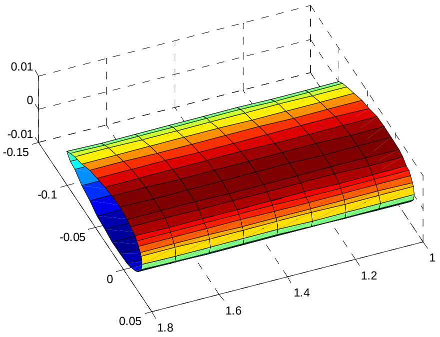


Figure.3 the elements of blade surface

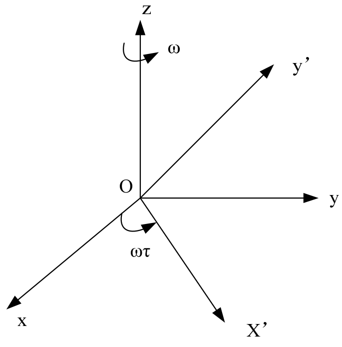


Figure.4 the fixed frame and blade frame

Because the blade is in rotation, blade frame should be use in calculation. The relation between the fixed frame (x'y'z') and blade frame (xyz) is shown as fig.4. In fig.4, ω is angle velocity of rotor, τ is the time elapsed.

For y-some point of blade surface, if the coordinate is (y_1,y_2,y_3) in blade frame, then its corresponding coordinate $(y_{1\tau},y_{2\tau},y_{3\tau})$ in fixed frame is [4]

$$\begin{bmatrix} y_{1\tau} \\ y_{2\tau} \\ y_{3\tau} \end{bmatrix} = \begin{bmatrix} \cos\omega\tau & -\sin\omega\tau & 0 \\ \sin\omega\tau & \cos\omega\tau & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} \tag{5}$$

When helicopter is hovering, retarded time equation of some point in blade surface can be represented as equation (6). For simplification, the feathering and pitch of blade are ignored. At the same time, the rotation of blade is considered.

$$\begin{aligned} &c_0(\tau - t) + \{[x_1 + (y_1\cos\psi + y_2\sin\psi)]^2 \\ &+[x_2 - y_1\cos\psi + y_2\sin\psi]^2 \\ &+[x_3 - y_3]^2\}^{1/2} = 0 \end{aligned} \tag{6}$$

In equation (6), ψ is equal to $\omega\tau$. When velocity is subsonic, the equation has only a solution. The equation (6) is analyzed by Newton iteration. But if the change of slope about root of the equation is small, the time consuming is much more. So, in this paper, dichotomy is used to solve the equation.

THICKNESS NOISE OF UNEVEN CONFIGURATION

Uneven configuration is that the angle spacing between two neighbored blades is uneven in rotor plane. Even configuration with five blades is compared with uneven configuration in figure5.

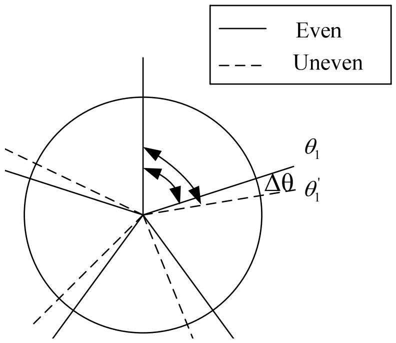


Figure.5 Even configuration vs. uneven configuration

Provided that the position of some blade is θi in even configuration, the modulated position with sine mode in uneven configuration is [5]

$$\theta_i' = \theta_i + \Delta\theta_m \sin(m\theta_i) \tag{7}$$

In equation (7), Δθ represents the maximal angle change between neighbored blades. If let

$$b = \Delta\theta_m \tag{8}$$

So, Δθi, the angle position change of the ith blade, can be represented by equation (9) according to modulation mode. m is the number of times the modulation cycle is repeated in one revolution of the rotor [6]

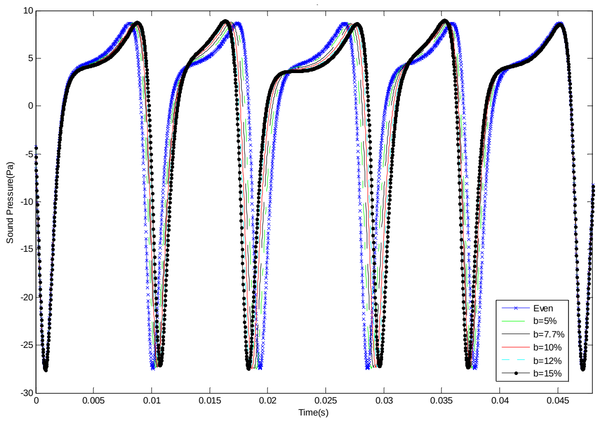
For sine mode,

$$\Delta\theta_i = b\sin(m\theta_i) \tag{9}$$

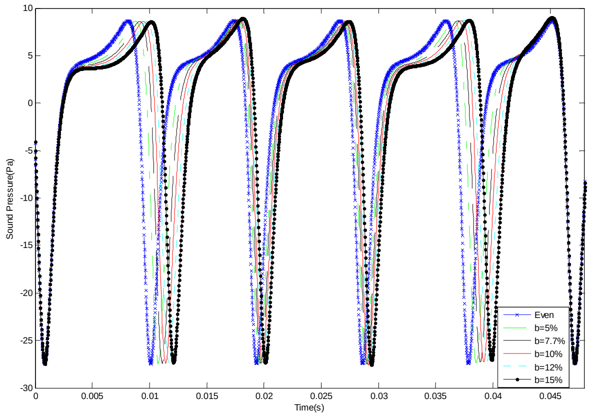
For cosine mode,

$$\Delta\theta_i = b\cos(m\theta_i) \tag{10}$$

In this paper, the thickness noise of a rotor with 5 blades is calculated according to equation (2) for even and uneven configuration. The calculation rotor model is like the rotor of UH-1, which is a 1/4 scale two-bladed untwisted model rotor with a rectangular platform and NACA0012 airfoil section. The length of blade is 1.829m, and chord length is 0.1334m. The rotation speed is 1296rpm. The observer position is in plane of the rotor. The distance between observer and center of hub is 3m. Time history of thickness noise for sine modulation mode and cosine modulation mode is plotted in figure 7. The reference signal is noise of even spacing configuration of rotor with 5 blades.



(a) thickness noise in sine modulation mode



(b) thickness noise in cosine modulation mode

Figure 6 thickness noise time history of two modulation mode with different modulation ratio

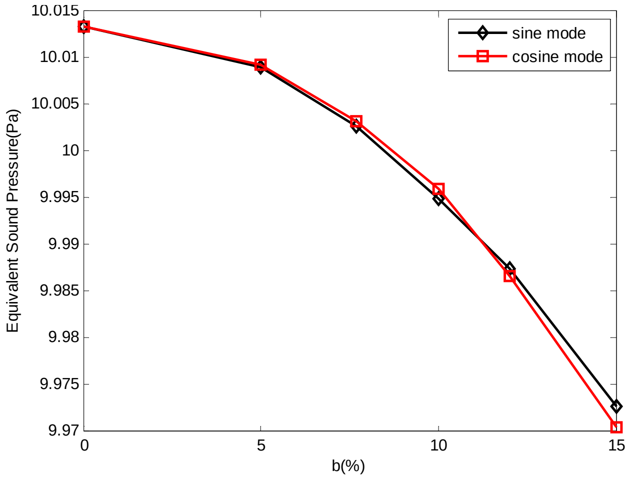


Figure 7 the variation of equivalent value of sound pressure with modulation ratio

The result in figure 7 shows that the two modulation modes have effect on equivalent value of sound pressure. With increase of modulation ratio, the equivalent value of sound pressure decreases. The spectrum of thickness noise of uneven configuration is compared with the one of even configuration in figure 8 and 9.

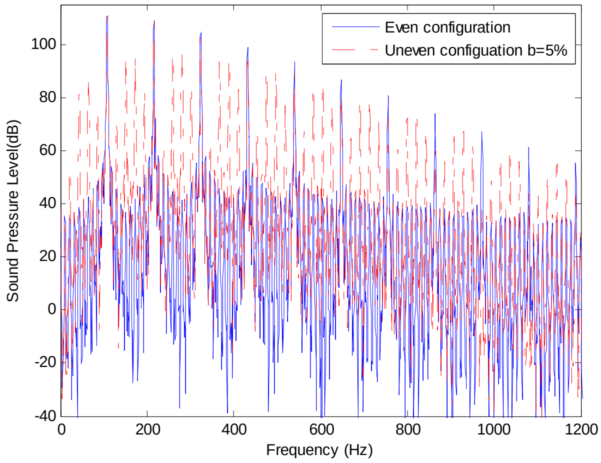


Figure 8 the spectra comparison between uneven configuration in sine mode and even configuration

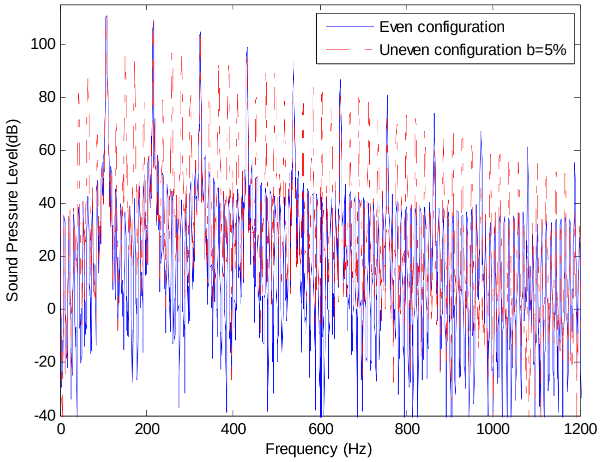


Figure 9 the spectra comparison between uneven configuration in cosine mode and even configuration

It is found that the spectra is altered obviously form the figure 8 and 9. However，analysis about figure 3 shows that the decrease of thickness noise caused by uneven configuration is limited. So, some others methods should be used. For example, the blade can be twisted and the tip of blade can be tapered or swept back. In addition, thin airfoil section and decreasing number of blades can be adopted in possible condition. Moreover, decrease of rotate speed do good to alleviate noise. The thickness noise time history comparison with different airfoil section is shown in figure 11. The thickness noise time history comparison between tapered tip and ordinary tip without tapered tip with different airfoil section is shown in figure 11.

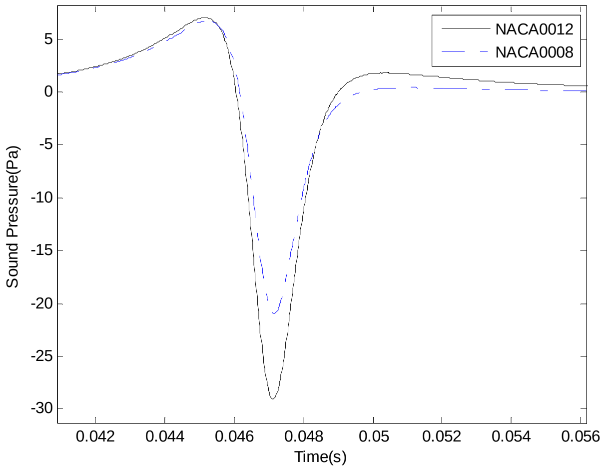


Figure 10 effect on noise caused by airfoil

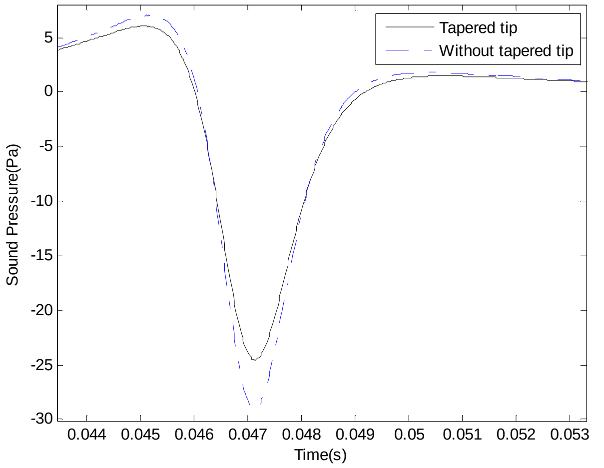


Figure11 effect on noise caused by tapered tip

Furthermore, because the variation of curvature near the leading edge of blade is large, so adequate grids are needed to get calculation precision. Spline interpolation is used to add numbers of grid near the leading edge. After interpolation, the thickness noise is compared with the one without interpolation in figure12.

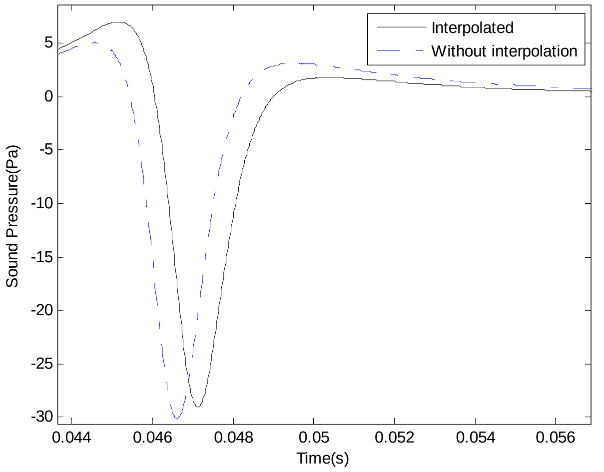


Figure 12 the noise comparison between interpolation and without interpolation

CONCLUSION

Uneven configuration can be used to decrease the thickness noise of rotor. Furthermore, uneven configuration with tapered blade tip and thin airfoil section can also help to control the noise. Calculation based on FW-H formulation can satisfy the requirements of analysis. In noise calculation, adequate grid numbers are needed to ensure the precision. Considering other affects caused by uneven configuration, low ratio of modulation is advised.

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