Helicopter Linear Noise

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Abstract

FOLLOWING Ffowcs-Williams and Hawkings' theory,[1,2] the three-dimensional quasi-steady full-potential rotor flow analysis code ROT22, adapted from Jamesons' FLO22 code, is run in conjunction with the Farassat Noise code and the linear noise made by rotor blade in hover investigated. For the case considered, the study, while it confirms the earlier finding that the blade volume displacement is a dominant source of helicopter noise, contradicts a previously drawn conclusion namely that the blade tip loading makes a significant contribution to the overall noise. The thickness noise is further compared with the one calculated from the Schmitz-Yu code.[8] It is shown that the inclusion of blade profile curvature in the calculations improves the negative peak amplitudes overpredicted by a Schmitz-Yu study.

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According to the Ffowcs-Williams and Hawkings theory,[1,2] the linear acoustic pressure p' produced at a point x fixed in space, at any time t by a moving aerodynamic surface is given by[3]

$$4\pi p(x,t) = \frac{1}{a_0}\frac{\partial}{\partial t}\int_{f=0}\frac{a_0\rho_0 v_n + \ell_r}{r|1-M_r|}\mathrm{d}S + \int_{f=0}\frac{\ell_r}{r^2|1-M_r|}\mathrm{d}S \tag{1}$$

where a_0 is the speed of sound in the undisturbed medium (taken as 340.85 m/s); $\rho_0 = 1.225$ kg/m^3, the fluid density of the undisturbed medium (taken at 60° F); v_n is the local normal velocity at the blade surface; ℓ_r is the force per unit area in the radiation direction r acting on the fluid at the body surface, defined by $\ell_r = p_{ij}n_j\hat{r}_i$, $r = x - y$, where y is the position of the source on the blade; p_{ij} the compressive stress tensor at the blade surface relative to the undisturbed medium; n_j ($j=1,2,3$), the unit normal at the blade surface element area dS; $\hat{r}_i$ the unit vector in the radiation direction, $r = |r|$; M_r the local Mach number in the radiation direction defined by $M_r = v_i\hat{r}_i/a_0$; v_i the local fluid velocity; and [ ] indicates that the integrand is evaluated at the retarded time τ, $\tau = t - r/a_0$. The integrals are taken over the surface of the blade $f=0$ and the other symbols used have their usual meaning.

The model example studied here is that of a single straight untwisted untapered 1/7th-scale UH-1H NACA0012 profile rotor blade with parameters: blade outer radius $R_0 = 1.045$ m, blade inner radius $R_i = 0.151$ m, and blade chord $c = 0.0762$ m. (It may be remarked here that a two-bladed rotor system in hover simply duplicates in one revolution the results of a single blade.) The surface normal velocities v_n in Eq. (1) are obtained kinematically. The loading distribution ℓ_r, in the case of full-potential theory, is given by $\ell_r = (p - p_0)n_i\hat{r}_i$ where p is the local fluid pressure and p_0 the fluid pressure at infinity. The fluid pressure distribution over the blade surface for a given tip Mach number (TMN) is obtained from the pressure coefficient (C_p) distribution, defined by

$$C_p = \frac{2}{\gamma M_z^2}\left(\frac{p}{p_0} - 1\right) \tag{2}$$

where γ is the ratio of specific heats, M_z the sectional Mach number given by $M_z = \omega z/a_0$, ω the constant angular velocity of the blade, and z the spanwise coordinate. The surface C_p distribution was obtained from the ROT22 code. The C_p distribution, in any case, consisted of 21 subdistributions corresponding to the 21 spanwise computational stations, each subdistribution containing 41 chordwise values. For consistency, the C_p subdistribution at the tip section of the blade was obtained by linear extrapolation from the two subdistributions closest to the tip, located at distances of 1.3 and 3.9 cm from the tip.

The noise integrals in Eq. (1) are evaluated for a single rotor using the Farassat code. The code is modified to accommodate the 22×41 C_p distribution received from the ROT22 code. Also changed in the code was the use of a uniform expression in evaluating the loading noise integrands, of the precise value of r in computing the retarded times τ, and of the smaller-size time steps for more accurate calculation of the time-differentiated terms. The pressure at the tip end, after Farassat and Martin,[5] was assumed uniform across the whole section, taken equal to the minimum surface pressure at the tip section. Other details of computation and of some salient features of ROT22 and of the Farassat code may be found in Ref. 4.

The loading pressure-time histories with and without the tip loading effect are shown in Fig. 1. It is seen that the amplitudes of the tip loading, although increasing with increasing TMNs, are really small. Since, as also confirmed by the results of Ref. 4, the contribution made by total surface loading to overall noise is secondary in effect, one reaches a conclusion that is at variance with that of Farassat,[5] namely that "...tip noise is significant at all speeds,...the tip dipole noise should be included in linear acoustic calculations."[5]

The decibel differences due to tip loading effect based on overall noise curves are given in Table 1. Also given in Table 1 are the corresponding decible differences obtained from Fig. 3 of Ref. 5. Comparison between the two sets of values shows

Table 1 Decible difference in overall noise due to tip loading

TMN	This study	Ref. 5
0.6	1.7	3.52
0.8	1.27	2.92
0.88	0.92	2.83

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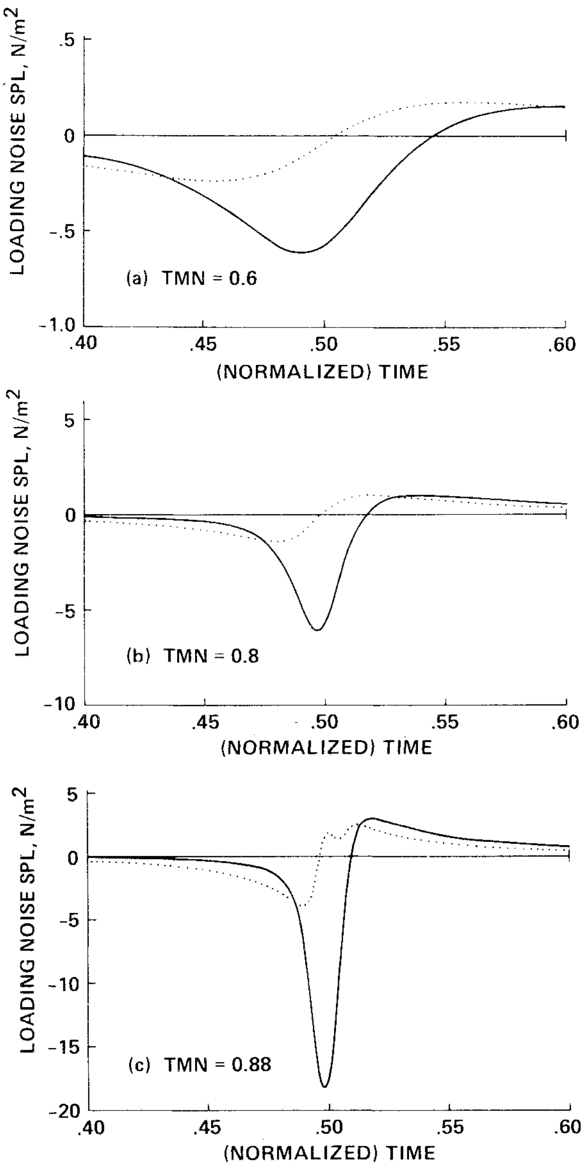

Fig. 1 Loading noise pressure-time curves (a) to (c), for assessment of tip loading effect (dotted line, without tip loading; solid line, with tip loading; observer distance = $3R_0$).

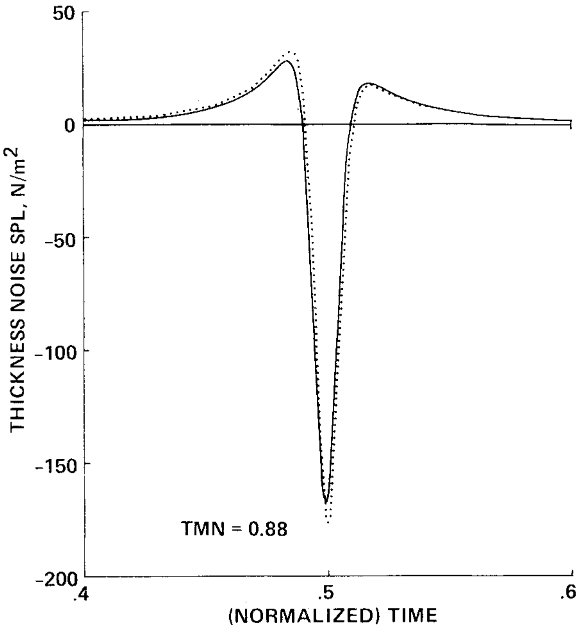

Fig. 2 Effect of blade profile curvature on thickness noise (dotted line, without profile curvature, Schmitz-Yu code; solid line, with profile curvature; observer distance = R_0).

that the decibel differences obtained by Farassat and Martin[5] are too high by, at least, a factor of 2. The reason for this discrepancy is seen in the tip end pressures employed by Farassat and Martin, which are 56-94% larger than those predicted by the full-potential theory. It may be remarked in passing that the tip end pressures used by Farassat and Martin were obtained from Garabedian and Korn's two-dimensional transonic aerodynamics program and that the tip section pressures given by a two-dimensional theory can be larger than those predicted by a three-dimensional theory.[6,7]

Figure 2 compares the thickness noise as predicted by the Schmitz-Yu code for TMN 0.88 at observer distance = 3 R_0 with the corresponding results obtained from the Farassat code. The Schmitz-Yu code neglects the effect of profile curvature on noise, and the present calculation was performed to assess this effect. The results show that, for the cases studied, the inclusion of the profile curvature can improve the overpredicted[8] peak negative pressures by 7 to 8%.

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