HELICOPTER EXTERNAL NOISE PREDICTION AND CORRELATION WITH FLIGHT TEST

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SUMMARY

The helicopter external noise prediction requires consideration of many aerodynamic sources. Mathematical analysis procedures for predicting the main and tail rotor rotational and broadband noise have been presented. The blade slap and thickness noise contributions, which normally become important in extreme flight conditions, have not been analyzed during this investigation.

The aerodynamic and acoustical data from Operational Loads Survey (OLS) flight program have been used for validating the analysis and noise prediction methodology. For the long method of rotational noise prediction, the spanwise, chordwise, and azimuthwise airloading is used. In the short method, the airloads are assumed to be concentrated at a single spanwise station and for higher harmonics an airloading harmonic exponent of 2.0 is assumed. For the same flight condition, the predictions from long and short methods of rotational noise prediction are compared with the flight test results. The short method correlates as well or better than the long method.

The correlations at low-speed cruise and hover are fair. The correlations at high-speed and low-speed partial power descent conditions are poor. At high speed and partial power descent flight conditions, the blade slap contributions should be added to the external noise spectrum to improve correlations. Additional sources (i.e. main rotor wake tail rotor interaction and thickness noise) which will improve the correlation further should also be analyzed.

Further recommendations deal with the subject of extensive validation of the prediction procedures. Since the total helicopter noise is composed of contributions from several sources, errors made in calculating one source component might be offset by opposite errors in other source component calculations. Prediction procedures, therefore, should be correlated for several helicopter types and several flight conditions.

INTRODUCTION

The need for accurate helicopter external noise prediction is urgent. In the very near future, the external noise of the helicopters will be regulated. When the noise regulations are in effect, the success of a new helicopter design might well depend upon how accurately the external noise of the helicopter can be predicted. An inaccurate prediction procedure will require the external noise design goal for a new helicopter to be much below the required regulation limit, thereby unduly penalizing the design.

In the present state-of-the-art, the external noise of the helicopters cannot be predicted accurately for most flight conditions. For other flight conditions, such as low-speed cruise, external noise can be predicted only with moderate accuracy. The reason for this state of affairs is that typical helicopter external noise is composed of several components such as main rotor noise, tail rotor noise, broadband noise, blade slap at low-flight speed, blade slap at high speeds, interaction noise, etc. The aerodynamic sources of these noise components are different and sometimes unrelated. In order to predict the total external noise, therefore, separate analytical procedures for these sources need to be developed. The problem is further complicated by the fact that proper aeroacoustics analysis procedures for calculating the external noise from many of these sources are presently not available; hence, the external noise for some flight conditions cannot be accurately predicted.

A typical helicopter noise is produced by lift and drag forces at rotors, rotor interactions with turbulence, pressure discontinuity sources (i.e. those due to local shocks) and mass displacement monopole sources termed thickness noise. The noise component due to harmonic airloads on the blades is referred to as rotational noise. Rotor interactions with turbulence is nonharmonic source and is referred to as broadband noise. The term blade slap is used to describe the rotor thumping noise and is commonly attributed to both pressure discontinuities produced at high tip Mach numbers and occasionally due to blade vortex interactions.

Several rotor noise prediction methods are available for predicting the rotational noise, thickness noise, and blade slap noise (ref. 1 thru ref. 3). Recently, methods for predicting the broadband noise of helicopters have become available (ref. 4). While these methods address the prediction of individual noise components, the problem of predicting the total helicopter noise for specified flight conditions (for example, proposed noise regulation flight conditions) has not been resolved. In this paper, methods for predicting rotational and broadband noise components are presented. Two independent methods for predicting the rotational noise components have been developed. The short method uses the rotor airloads concentrated at a single span station and an airloading harmonic exponent. The long method utilizes spanwise, chordwise, and azimuthwise airload distribution for calculating the rotor external noise. An attempt has been made to predict the total external noise spectrum of the helicopter by combining the rotational and broadband noise component for both main and tail rotors. The correlations for several flight conditions are presented which indicate the accuracy of the noise prediction procedure for a given flight condition.

New concepts for predicting the rotor rotational and broadband noise components are not being proposed in this paper. The primary objective is, however, to address the prediction of the total helicopter noise spectrum. In this process, the simultaneous aerodynamic and acoustical helicopter flight test data have been used. The correlations carried out for several flight conditions point out the need for improving the correlation through additional analyses.

NOISE GENERATING MECHANISMS

Lighthill has proposed aerodynamic mechanisms for the generation of sound (ref. 5). These mechanisms relate to fluctuations of mass, momentum, and momentum flux rates which can be related to the mathematical concepts of source, dipole, and quadrupole, respectively.

The rotational noise component from main and tail rotors is harmonic in nature and important in the low- to mid-frequency range. However, the broadband noise of main and tail rotors is nonharmonic and is due to external or rotor-generated turbulence at the rotor blades.

Blade slap, the most characteristic helicopter noise component, is produced during certain flight conditions and is a rotor thumping sound which is impulsive in nature and important in the mid- to high-frequency range. The operating conditions where blade slap is dominant are partial power descent and high-speed flight. Considerable research has been conducted in identifying the noise-generating mechanism of blade slap. Tangler (ref. 6) has shown a shocklike pressure discontinuity generated during blade vortex interactions and also during high transonic Mach number at the tip. Farassat (ref. 2) has shown the blade slap to be generated by a thickness source, and Schmitz and Boxwell (ref. 7) have found both the thickness- and shock-related peaks in their in-flight measurements of helicopter noise at high speeds.

THEORETICAL FORMULATION

In the present paper, the methodology for predicting the rotational and broadband noise components of the helicopter is presented. The calculation of blade slap or thickness noise contributions has not been attempted.

Long Method of Rotational Noise Prediction

The propogation of sound in a uniform medium is governed by the equation,

$$\frac{\partial^2 \rho}{\partial t^2} - c^2 \nabla^2 \rho = \frac{\partial Q}{\partial t} - \frac{\partial F_i}{\partial x_i} + \frac{\partial^2 T_{ij}}{\partial x_i x_j}$$

where,

ρ = perturbation density
c = velocity of sound in the medium
Q = mass per unit volume, per unit time introduced at $\vec{x}$ at time t,
F_i = the fluctuating external force field per unit volume of the medium
T_{ij} = the applied fluctuating stress tensor
x_i = position vector components

For rotational noise calculation, only the $\frac{\partial F_i}{\partial x_i}$ terms on the right-hand side need be considered. In the long method, the spanwise, chordwise, and azimuthwise airload distribution is considered. The rotor disc is divided into radial and azimuthal segments. Each segment is treated as a rotating source, and the doppler correction factors are introduced to account for any translational source motions.

Short Method of Rotational Noise Prediction

Again, the $\partial F_i/\partial x_i$ terms of the acoustical equations are considered. In the short method, the airloads are assumed concentrated at a single spanwise location and an air-loading harmonic exponent is used. This prediction procedure is valid only in far field (observer-to-hub location greater than 5-6 rotor diameters). The theoretical formulation is similar to the procedure in section 11.3 of Morse and Ingard (ref. 8).

Referring to figure 1 consider the coordinate system based on the helicopter. The origin of the coordinate frame coincides with hub center. The axis vertically downward is Z, X is the axis in longitudinal direction and perpendicular to the Z axis, and the Y axis is perpendicular to both X and Z. Let the location of the source (thrust) be a distance r_1 from the hub center. If the reference point is at azimuth Ψ_1, as measured from negative X axis, the source coordinates are $(-r_1\cos\Psi_1,\ r_1\sin\Psi_1,\ 0)$. The observer is at a distance r from the hub, and the observer coordinates are $(-r\sin\sigma\cos\Psi,\ r\sin\sigma\sin\Psi,\ r\cos\sigma)$.

The expression for the total sound pressure field can be written down as

$$\rho = \frac{1}{4\pi r} \sum_{n=1}^{\infty} (2nk_1\alpha_n) \Bigg\{ \sum_{\ell=o}^{\infty} \left(\beta_\ell F_t\cos\sigma + \delta_\ell \frac{nB-\ell}{nBM} F_d\right) \times J_{nB-\ell}(nBM\sin\sigma) \sin\left[nk_1(r-ct)+(nB-\ell)(\Psi+\pi/2)\right]$$

$$+ \sum_{\ell=o}^{\infty} \left(\beta_\ell F_t\cos\sigma + \delta_\ell \frac{nB+\ell}{nBM} F_d\right) \times J_{nB+\ell}(nBM\sin\sigma) \times \sin\left[nk_1(r-ct) + (nB+\ell)(\Psi+\pi/2)\right]\Bigg\}$$

where,

n = n^{th} acoustical harmonic

k_1 = wave number = $\frac{\omega_1}{c} = \frac{B\Omega}{c}$

c = speed of sound

B = number of blades

F_t = thrust force

F_d = drag force

β_ℓ = ℓ^{th} harmonic of thrust force for nonuniform flow

δ_ℓ = ℓ^{th} harmonic of drag force for nonuniform flow

α_n = n^{th} harmonic coefficient for fourier expansion of the forces

$J_n(\ )$ = the Bessel Functions

M = rotational Mach number defined at the effective radius where the thrust and drag force is located

If a helicopter carrying such a rotor moves through the air with velocity components (V_1, V_2, V_3), the following Doppler corrections can be made.

Let $s = \vec{r}-\vec{r}_1$

where,

$\vec{r}$ = observer position vector

$\vec{r}_1$ = source position vector

then

$$M_r = \sum_{i=1}^{3} \frac{V_i(\vec{r}-\vec{r}_1)_i}{cs}$$

and

$$C_1 = \sqrt{M_r^{\,2} + (1-M^2)}$$

$$C_2 = \frac{\dot{M}_r + \sqrt{M_r^2 + (1-M^2)}}{(1-M^2)}$$

The distance r in the acoustical equation is modified to $C_1 r$, and the argument of the Bessel function, $nBM\sin\sigma$, is modified to $C_2 nBM\sin\sigma$.

Broadband Noise Prediction Using Similarity Scaling

For prediction of broadband noise, an empirical technique using similarity scaling of measured data has been developed. The data base is obtained from model outdoor stand tests by Scheiman et al. (ref. 9) of NASA-Langley Research Center (LRC). These tests were conducted at zero lift conditions at hover mode. The model was a two-bladed rotor, 3.05 m (10 ft) in diameter, and the blade section was NACA 0012 of 0.424 m (16.7 in.) chord. The similarity laws derived include observer distance, rotor size, Mach number, and sound directivity parameter.

AH-1G FLIGHT TESTS

To gain experimental insight into helicopter rotor aerodynamic, dynamic, and acoustic environments, the Operational Loads Survey (OLS) flight test program was conducted on a Model AH-1G Cobra helicopter. The flight test was conducted in 1975 at Bell Helicopter Textron under U.S. Army sponsorship (ref. 10).

For the purpose of the OLS flight test, two AH-1G main rotor blades were modified and instrumented with surface-flow sensors, absolute pressure transducers, hot-wire sensors, semiconductor accelerometers, and strain gauges. The test helicopter with the instrumented rotor installed is shown in figure 2.

The aerodynamic instrumentation consisted of absolute pressure transducers and surface-flow and hot-wire sensors. These measurements were taken at five spanwise stations. The absolute pressure transducers measure static pressures and are located on upper and lower airfoil surfaces from leading to trailing edge. The surface-flow sensors consist of differential pressure transducers. Wire sensors are also located at five radial stations to measure leading-edge stagnation.

Acoustical instrumentation consisted of five microphones mounted on the helicopter and a ground-based microphone system to record flyover and flyby noise.

The flight program was made up of both low and high gross weight airspeed sweeps, high 'g' maneuvers, descents, and nap-of-the-earth (NOE) maneuvers.

NOISE PREDICTION CORRELATIONS

For the purpose of noise prediction correlation, the OLS flight program provides both the acoustical and aerodynamic data. The acoustical data for several critical conditions have been used for correlations. In addition, the chordwise, spanwise, and azimuthwise static pressure distributions for high-speed flight conditions have been used to provide the aerodynamic inputs to the long method for the rotational noise prediction program.

The correlations have been attempted for three important flight conditions, i.e. low-speed flight, high-speed level flight, and low-speed partial power descent conditions for Bell Model AH-1G. Additional correlations have been conducted for tie-down hover in ground effect for a Bell-manufactured medium helicopter.

The correlations are shown in figures 3 through 7. Figure 3 is the correlation for the long method of rotational noise prediction. The spanwise and azimuthwise airloads from the Operational Loads Survey flight program were used to calculate main rotor noise at the ground microphone. Since tail rotor airloads information was unavailable, tail rotor noise was calculated using the short method and was added to the predicted main rotor noise. The overall spectrum compares favorably with the flight test noise spectrum. There is as much as 13 to 15 decibels deviation at moderate frequencies. This deviation could be explained by the fact that this condition corresponds to high-speed level flight (84.9 m/s or 165 knots) where blade slap contributes to the total helicopter noise, and also by the fact that a mechanism for blade slap is not included in the prediction procedure.

Figure 4 depicts the same flight condition, although the short method of rotational noise prediction has been used. An air-loading harmonic exponent of 2.0 was also used.

Low-speed cruise flight condition is shown in figure 5. The flight corresponds to 30.9 m/s (60 knots) level flight. Deviations in the mid-frequency range cannot be explained logically.

Figure 6 is the correlation for the 33.4 m/s (65 knots), 2.03 m/s (400 ft/min) partial power descent flight condition. Deviations in the mid-frequency region appear; however, there are more significant deviations in the high-frequency region. The high-frequency deviations could be explained in terms of blade slap being produced due to blade vortex interactions in a partial power descent flight condition.

Correlations for tie-down hover conditions shown in figure 7 have been carried out in terms of dBA.

CONCLUSIONS

The correlations are carried out for four important flight conditions - low-speed cruise, high-speed cruise, low-speed partial power descent, and hover. For the same flight condition, the short method correlates as well as or better than the long method. This could be explained by numerical errors associated with approximating the rotor disc into discrete segments, and also by the fact that high-frequency airloads are hard to define and extract from the flight data.

The correlations at high-speed and low-speed partial power descent conditions are poor. Under these conditions, high-speed blade slap and low-speed blade vortex interactions are present. Adding the blade slap contributions to the predicted noise should improve the correlation.

The correlations at low-speed cruise and hover is fair, which might indicate that the noise sources have been correctly identified and correctly analyzed.

RECOMMENDATIONS

The present state-of-the-art of the noise prediction technology is poor. For the correlations attempted, deviations as much as 12 dBA were present. Some of the deviations could be reduced by adding the blade slap and main rotor wake tail rotor interaction noise components to the predicted noise. The noise sources for high-speed and low-speed blade slap are presently being researched amd analysis procedures will soon be available. It is recommended that workable analysis procedures for calculating the blade slap and main rotor wake tail rotor interaction noise components be developed.

The next recommendation deals with the subject of extensive validation of the external noise prediction procedures. The total noise of helicopters is composed of several components. When comparing predicted and flight-measured noise spectrums, it is possible to draw wrong conclusions regarding the degree of correlation. The errors in predicting a one source noise component might be compensated by errors in predicting some other source. It is therefore recommended that noise prediction procedures be extensively correlated for several conditions and for several helicopter types before being used in a design iteration cycle.

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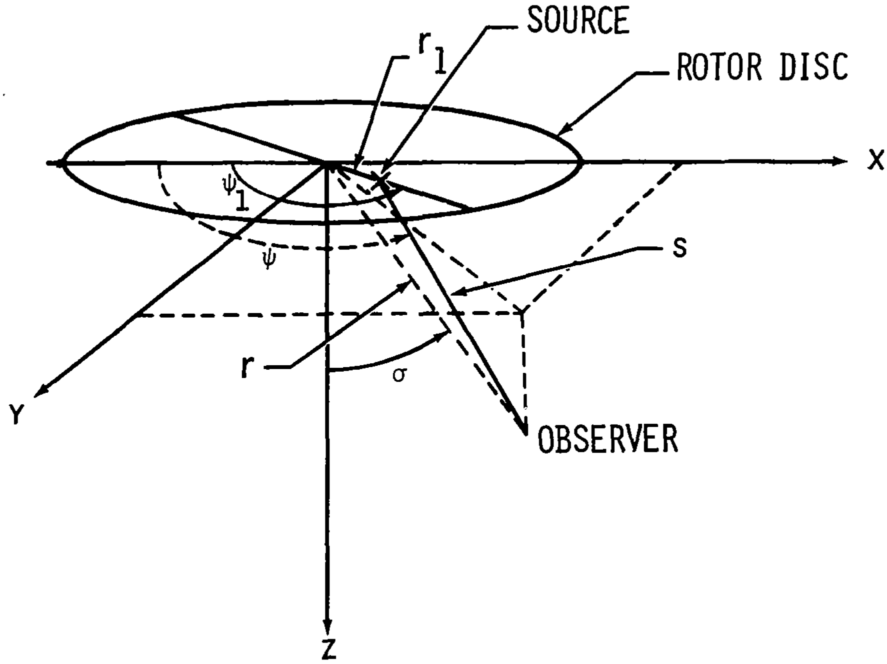

Figure 1.- Theoretical formulation.

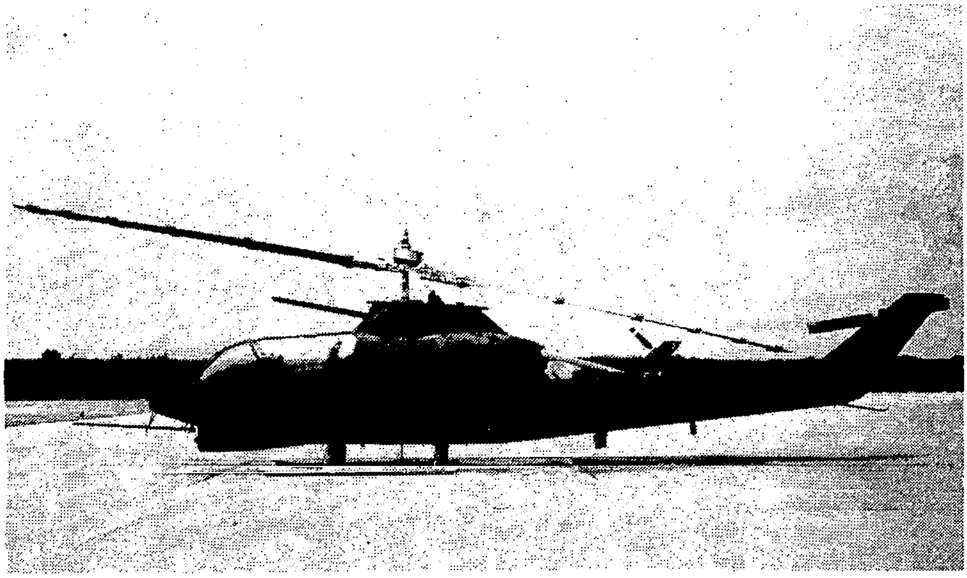

Figure 2.- AH-1G for Operational Loads Survey (OLS) flight test.

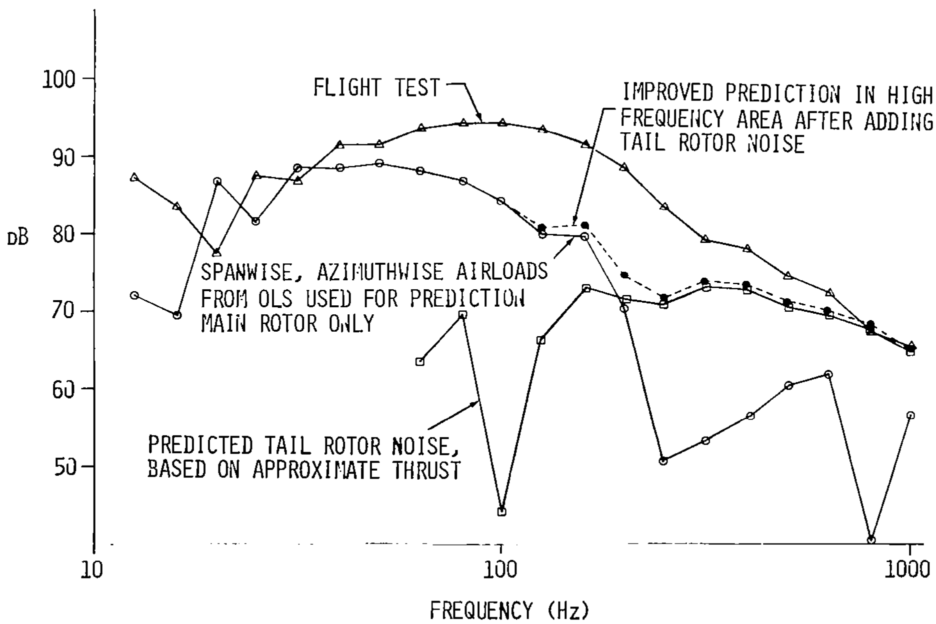

Figure 3.- Third octave sound pressure level. Correlation of long rotational noise prediction method. AH-1G flight at 84.9 m/s (165 knots).

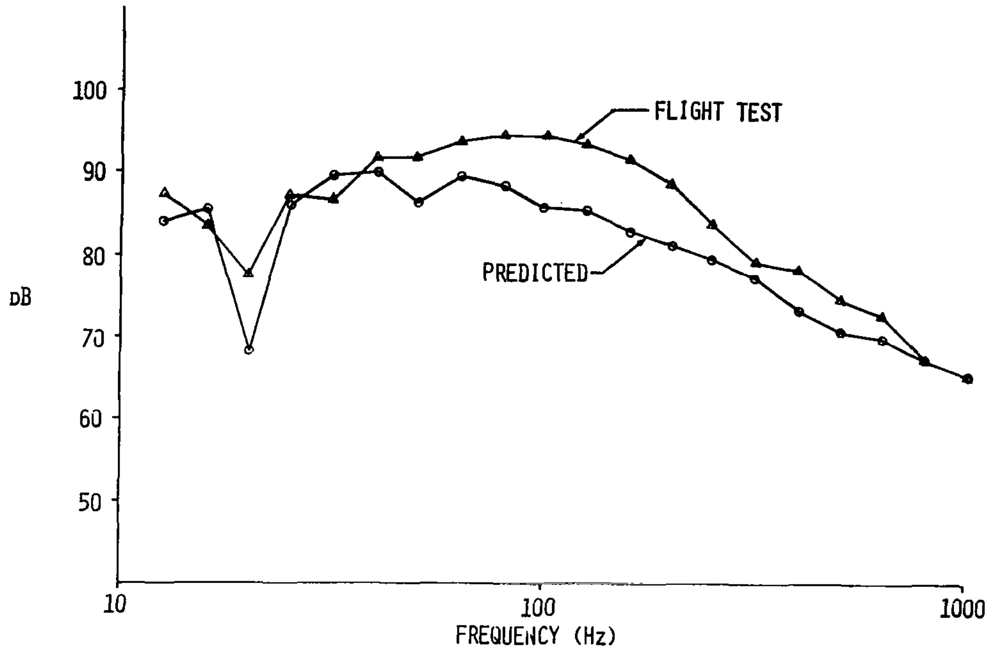

Figure 4.- Third octave sound pressure level. Correlation of short rotational noise predictions method. AH-1G flight at 84.9 m/s (165 knots).

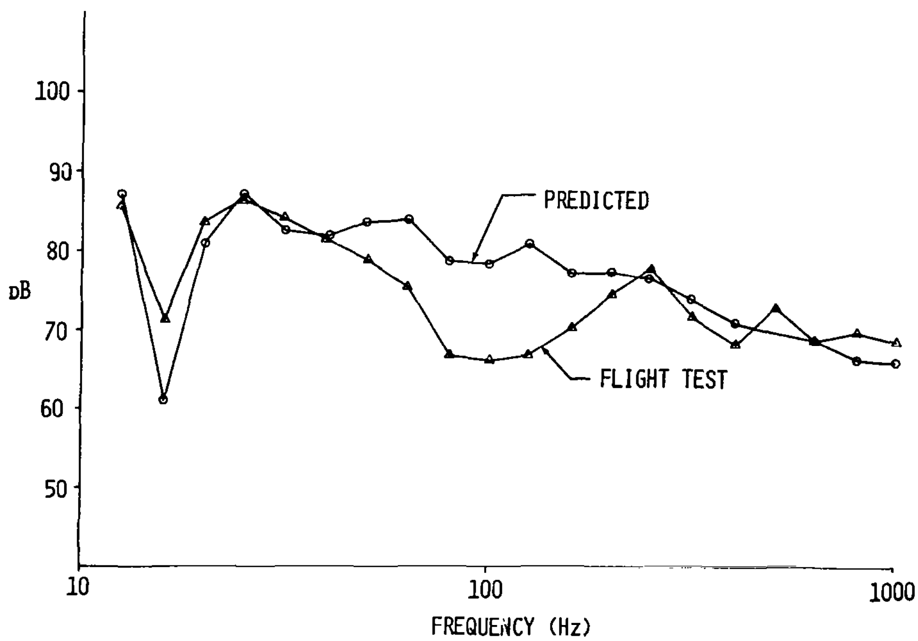

Figure 5.- Third octave sound pressure level. AH-1G flight at 30.9 m/s (60 knots).

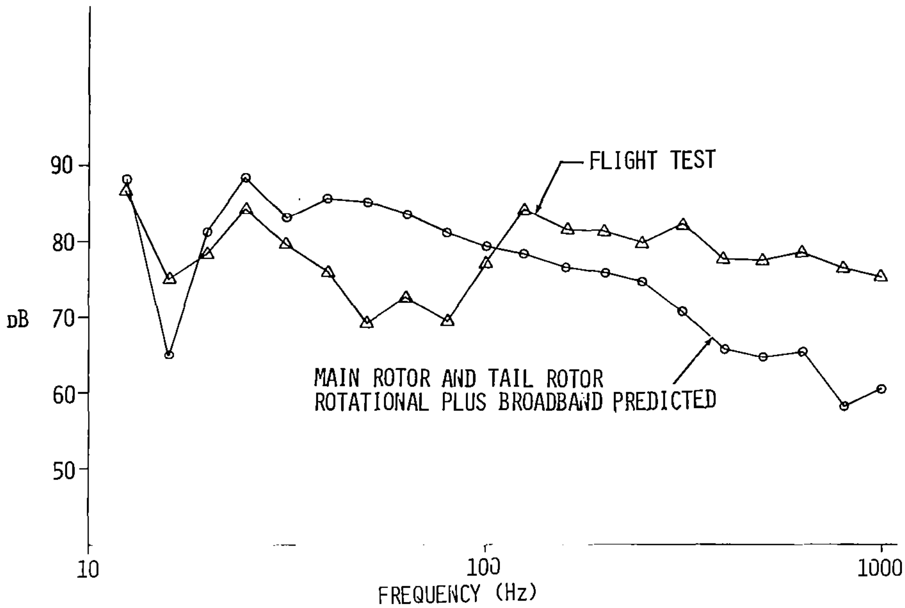

Figure 6.- Third octave sound pressure level. AH-1G at 33.4 m/s (65 knots). Partial power descent at 2.03 m/s (400 ft/min).

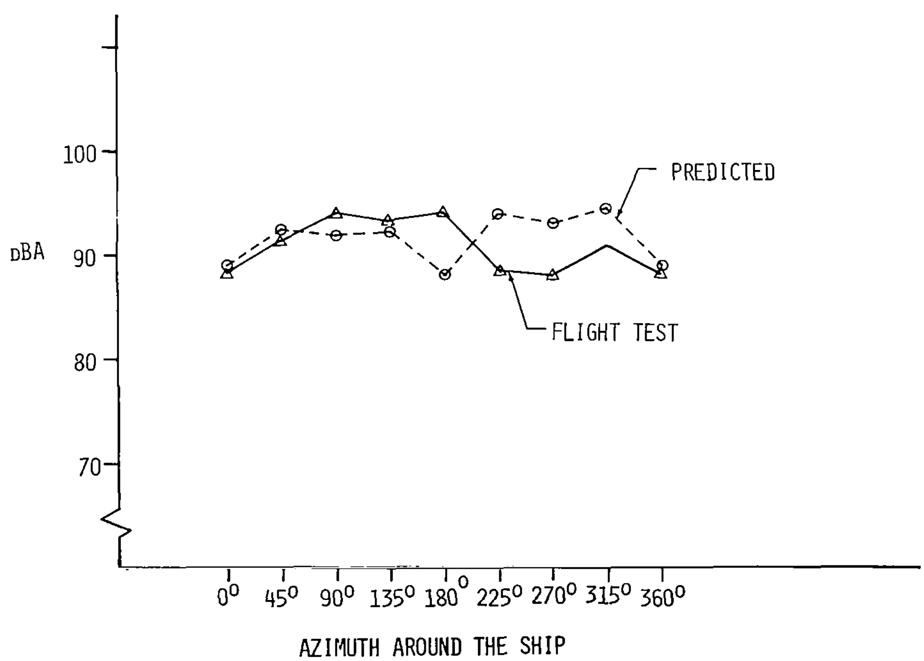

Figure 7.- Correlation of dBA for Bell medium helicopter in tie-down hover. Microphone at 61 m (200 ft) skid height 6.1 m (20 ft).