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AN EMPIRICAL MODEL FOR THE IN-FLIGHT NOISE DIRECTIVITY OF AN F-16C

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1. INTRODUCTION

A directional, spectral F-16 noise source model has been prepared for use in single-event noise prediction models. The model is based on F-16C flyover measurements conducted at Edwards Air Force Base in 1991 by the U.S. Air Force Armstrong Laboratories. Those measurements, originally collected for incorporation into NOISEMAP's data base,[1] consisted of 12 flyovers at various engine power settings. Each flyover was in a straight line at a nominal altitude of 1,000 feet above the ground. Tape recordings of noise were made on a microphone array centered under the flight track, and aircraft position was recorded via radar. Directivity patterns were developed by adjusting the measured time history according to direction to the aircraft, propagation time, spherical spreading, air absorption, and (at low elevation angles) lateral attenuation. The model has been prepared in two forms: sets of Fourier coefficients from which the one-third octave band spectra can be computed at arbitrary angle, and tables of spectra at various angles from which a user can interpolate to arbitrary angle.

2. FLIGHT TEST DATA

The flight tests were conducted on 3 June 1991, at Edwards AFB, California. Twelve passes were flown: three at afterburner (92% core rpm plus burner, 350 to 400 kts), two at full military power (91% rpm, 280 to 320 kts), three at approach power (82% to 83% rpm, 160 to 220 kts), two at intermediate power (86% rpm, 220 kts) and two at maximum endurance power (76% to 78% rpm, 235 kts). Each pass was level, at 1,000 feet above the ground, in a straight line, and at constant power. Speeds are nominal; the aircraft accelerated at the higher power settings. Conditions were maintained for a distance of at least one to two nautical miles before and after the center of the microphone array.

Aircraft position was documented on radar, with the tracking data (position and speed) supplied at 1/4-second intervals. Meteorological conditions were measured at the site. Wind speed was below 12 knots for all passes.

Six microphones were deployed. Two were at a center reference position under the flight track, 10 feet from each other. Four others were placed 1,000 feet from the center: one uptrack, one downtrack, one to the left, and one to the right. Noise data were reduced to yield one-third octave spectra in bands 17 through 40 (50 Hz to 10,000 Hz) at 1/4- or 1/2-second intervals.

3. DEVELOPMENT OF DIRECTIVITY PATTERNS

Directivity patterns were developed in the form of one-third octave band spectra at a distance of 1,000 feet from the aircraft, at various angles θ ($0° =$ forward) relative to the aircraft's longitudinal axis. In accordance with customary practice for airport/airbase noise modeling, it was assumed that noise is axisymmetric, i.e., it does not depend on the angle about the roll axis, and that the longitudinal axis is aligned with the flight path. It was also assumed that the effective source location is at the aircraft's reported coordinates.

A set of reference angles was defined at 5-degree increments from $\theta = 5°$ to 175°. At each value of θ for a given flyover and microphone the following procedure was followed:

1. The aircraft position and time corresponding to that value of θ was identified.
2. Propagation time from the aircraft to the microphone was computed, based on ambient sound speed, and added to aircraft time to yield arrival time.
3. The spectrum at the arrival time was interpolated from the measured noise data.
4. The spectrum at 1,000 feet was obtained by adding inverse square law spreading, air absorption at the measured ambient conditions,[2] and (at elevation angles below 15 degrees) NOISEMAP's lateral attenuation model.[3] These effects were applied as additions to the measured noise, yielding the source noise.

This procedure was followed for each angle, microphone, and flight condition. No adjustments for Doppler shift were applied: frequencies were as measured at the ground, which is the appropriate propagating frequency for air absorption.

The application of NOISEMAP's simple lateral attenuation model was an approximation. However, the low angles at which it was applied corresponded to longer distances (one mile or more) at which signal-to-noise ratio was less than ideal. Measured directivity patterns were interpolated to these smaller angles, as well as to 0 and 180 degrees for which there were no data.

At larger distances (corresponding to θ near 0° and 180°) and high frequencies (above 5000 Hz) this procedure yielded unrealistically high source levels. This is because it does not account for the production of high frequencies from nonlinear steepening. There is no simple way to account for this phenomenon. Therefore, the current model is limited to one-third octave bands at 5000 Hz and below.

This procedure was applied to all flights for afterburner, full military power, intermediate power, and approach power, and to all six microphones for each pass. For a given flight condition, differences from pass to pass and from microphone to microphone were small. Accordingly, the average across all microphones from one flight for each condition was selected for final analysis. The choice was arbitrary, and any other pass would yield the same result.

4. USER FORMAT OF MODEL

Use of these directivity patterns in a noise model requires the ability to compute spectra at arbitrary angle, in a convenient format. Two forms of user model were prepared: Fourier coefficients and look-up table.

In the Fourier coefficient format, a Fourier series was fit to each directivity pattern. Because of left–right symmetry, these are cosine series. Tables of coefficients, up to 20th order, are provided, together with the conventions for the series used. Coefficients up to 20th order is the highest credible order for the model, considering the 36 samples (5-degree increments from 0° to 180°) to be approximately the Nyquist rate for that order. Fewer terms can be used if desired. In addition to the coefficients and rules, FORTRAN subroutines performing the Fourier coefficients have been prepared.

In the look-up table method, the Fourier coefficient method is exercised to yield a simple table of spectra at θ increments; increments may be as small as 1 degree. Table generation is embodied in an executable program that operates on an Intel-based PC or compatible. The user selects the θ increment and whether octave band or one-third octave band spectra are to be tabulated.

5. IN-FLIGHT VERSUS STATIC DIRECTIVITY

Figures 1 and 2 show typical in-flight directivity patterns from the current model, at full military power and afterburner, respectively. Each figure shows the data for all flights at each condition, and also shows the corresponding directivity obtained from static runup. The directivities follow the expected patterns, with lobes in the 120° to 150° range. Both static and in-flight patterns are similar in this regime. In the lateral and forward quadrants, however, in-flight levels are up to 10 dB higher than static runup levels. This is due to forward flight and Doppler shift effects. Static runup data are often used as a source of directivity patterns. This can be adequate in many applications, but the differences shown in Figures 1 and 2 should be considered when doing so.

References

[1] C.L. Moulton, "Air Force Procedure for Predicting Aircraft Noise Around Airbases: Noise Exposure Model (NOISEMAP) User's Manual", Wyle Research Report WR 89-20, also AAMRL-TR-90-011, February 1990.

[2] American National Standard Method for the Calculation of the Absorption of Sound by the Atmosphere, ANSI S1.26-1978 (ASA 23-1978), June 1978.

[3] J.D. Speakman and B.F. Berry, "Modeling Lateral Attenuation of Aircraft Flight Noise", *Inter-Noise 92 Proceedings*, 1992.

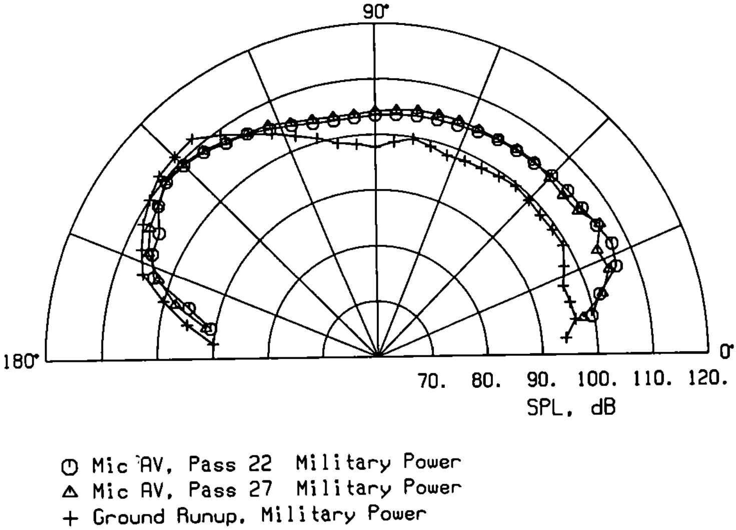

Figure 1. In-Flight and Ground Runup Directivity (A-Weighted SPL), Military Power.

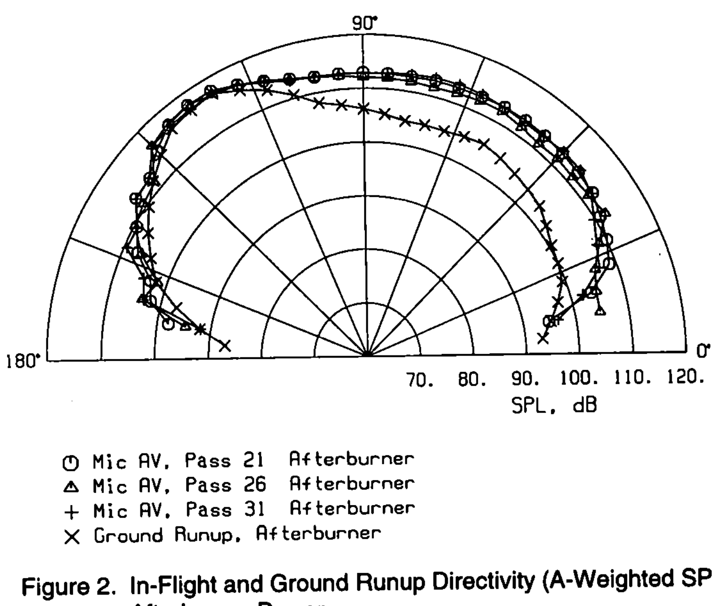

Figure 2. In-Flight and Ground Runup Directivity (A-Weighted SPL), Afterburner Power.