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Nonlinearity in Outdoor Propagation of High-Power Jet Noise: Measurement Results

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ABSTRACT

Noise measurements were conducted on a static run-up of a high-performance military aircraft to develop better noise models for this type of aircraft. This paper describes the measurement program and the resulting acoustic data. These measurements demonstrate nonlinear source and propagation effects from military jet aircraft. Moreover, these results serve as a comparative data set for the evaluation of nonlinear propagation models.

1. INTRODUCTION

Current environmental noise models used by the Department of Defense (DoD) to assess the impact of military aircraft operations are unable to deal with the new generation of fighter aircraft with high performance engines and vectored thrust capabilities. Their shortcomings have the potential to lead to restrictions in flight operations at airbases and within training airspaces. A new aircraft noise model, which takes advantage of today's computer computational capabilities, is needed to provide legally defensible noise assessments of current and future aircraft operations in protecting bases and airspaces for training purposes, and minimizing restrictions based on noise.

Detailed noise measurements from static jet run-up operations were collected for the evaluation of a proposed nonlinear propagation model. Several high-engine power conditions were measured during the study. This measurement is part of a joint effort by Wyle Laboratories, The Pennsylvania State University, and The University of Alabama to develop better noise models for military aircraft.

2. BACKGROUND

This measurement study is the second of a series on nonlinear propagation effects from military jets. The first field measurements[1] were performed using the Army Research Laboratory's Mobile Acoustic Source (MOAS) that provided high-amplitude periodic and broad-band waveforms. These MOAS measurements validated the proposed propagation model[2] for a simple acoustical source. The static jet run-up measurements provide the next step in the evaluation of the propagation algorithms by collecting noise data from a high-powered military jet, a highly complex acoustical source.

3. FIELD MEASUREMENTS

Static engine run-up measurements were conducted on the high-powered military aircraft at Edwards Air Force Base on 15 Sept. 2005. The primary objective of the measurements was to collect noise data along the maximum noise emission radial from the jet exhaust. Noise data were collected from 23 m to 305 m along five radials for five different engine conditions. Unfortunately, these measurements were secondary, and instrumentation set up time was severely limited.

A. Experimental Setup

Measurements were performed for five stable engine conditions: idle, cross bleed, intermediate, military, and afterburner powers. The microphone layout, shown in Figure 1, was positioned at the aft quadrant of the jet originating 7.6 m behind the jet nozzle exit. The setup consisted of five radial arrays with a total of 21 microphones. To capture the max noise emission radial microphone arrays of 115^{o}, 125^{o}, 135^{o}, and 145^{o} were used. The angles are relative to the aircraft heading, such that the jet exhaust is at 180^{o}. Measurements were also performed at angles of 90^{o} to determine if nonlinear characteristics were present in the direction of minimum noise emission. Both 6.35 mm (1/4”) and 12.7 mm (1/2”) microphones were placed at 23 m, 38 m, 61 m, 91 m, 152 m, and 305 m distances along each radial.

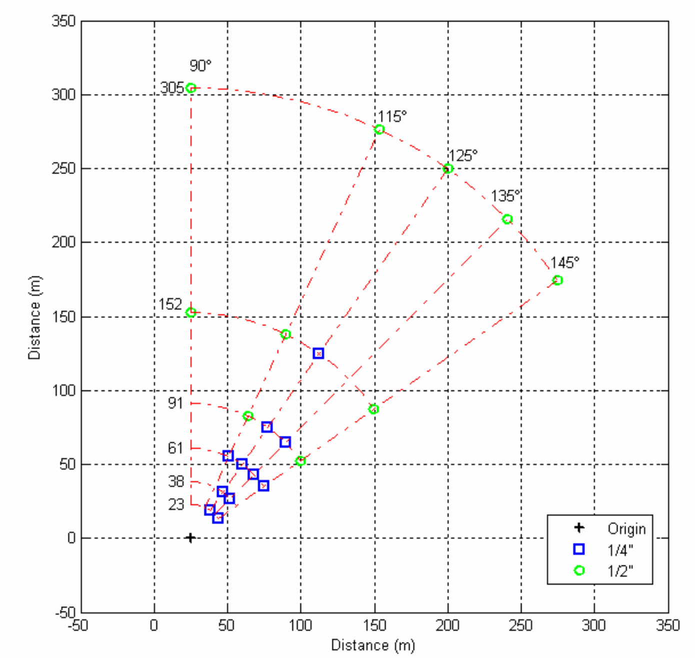

Figure 1: Microphone arrays used to study propagation effects as a function of engine condition and angle.

The microphones used were ¼ in. Brüel & Kjaer 4939, ¼ in. G.R.A.S 40BF, and ½ in. Brüel & Kjaer 4190. Microphones were mounted perpendicular to the ground at a height of 1.8 m (6 ft) to correspond with the engine nozzle centerline. They were powered from Brüel & Kjaer Nexus 2690 microphone conditioning amplifiers. Pressure time histories were simultaneously recorded for each microphone using National Instrument PXI-4472 dynamic signal acquisition modules. For each stable engine condition, the data acquisition system recorded 30 seconds of acoustic data at a sampling rate of 96,000 Hz. Each channel used a 24 bit delta-sigma analogue to digital converter (ADC) and an anti-aliasing filter at ~ 44,100 Hz.

B. Measured Data

Table 2 provides a summary of the acoustical data collected during the measurement. 39 separate data runs were recorded with up to 21 microphones. Measurement of the cross bleed conditions had fewer microphones because of the set time constraint. Table 3 provides a general overview of the measured data with a list of the OASPL for each radial at 305 m. This table shows that the maximum emission angle shifts forward with increasing engine power. For idle power the maximum emission angle is 145^{o}, but for afterburner power the maximum emission angle is 125^{o}.

Table 2. Summary of Static Engine Run-up Noise Data

Engine Power Condition	Number of Data Samples
Idle	5
Cross bleed	4
Intermediate	3
Military	14
Afterburner	13

Table 3. Measured Overall Sound Pressure Levels

Engine Power Condition	Overall Sound Pressure Level at 305m (dB)				
	90	115	125	135	145
Idle	73.5	76.2	75.8	74.6	78.5
Crossblead			105	107	
Intermediate	98.8	112	116	117	117
Military	104	116	118	118	115
Afterburner	109	121	122	120	118

A sample of the acoustical data is described to highlight the nature of this measured data set. This sample involves data collected along the 125^{o} radial array with microphones located at 23 m, 61 m, 152 m, and 305 m. Time histories for cross bleed, intermediate, military, and afterburner are shown in Figures 2(a), 2(b), 3(a), and 3(b), respectively. In these figures, the closest microphone is shown on top and the most distance on the bottom. The scale changes with distance to account of the decrease in level. It is important to note the scales for cross bleed graph are smaller than for the graphs of the higher power settings because of the lower sound levels.

From these time snapshots, shocks can be seen for all of the engine power settings as expected from a jet exhaust. However, for afterburner power, shocks are more pronounced at 305 m compared to the other powers.

(a) (b)

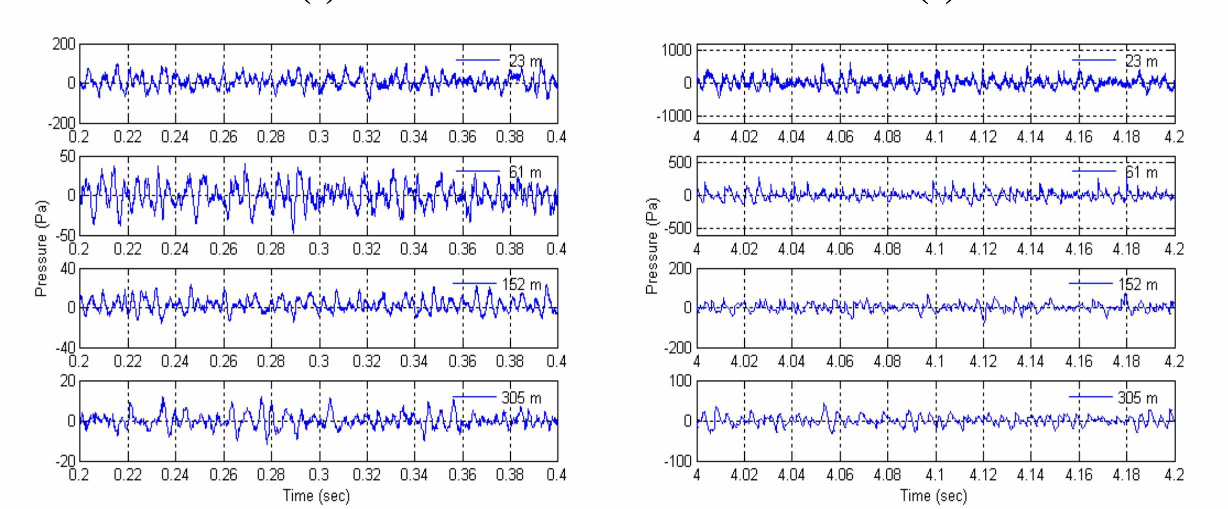

Figure 2: (a) Cross bleed engine power: pressure time history of 125° radial microphone array. (b) Intermediate engine power: pressure time history of 125° radial microphone array.

(a) (b)

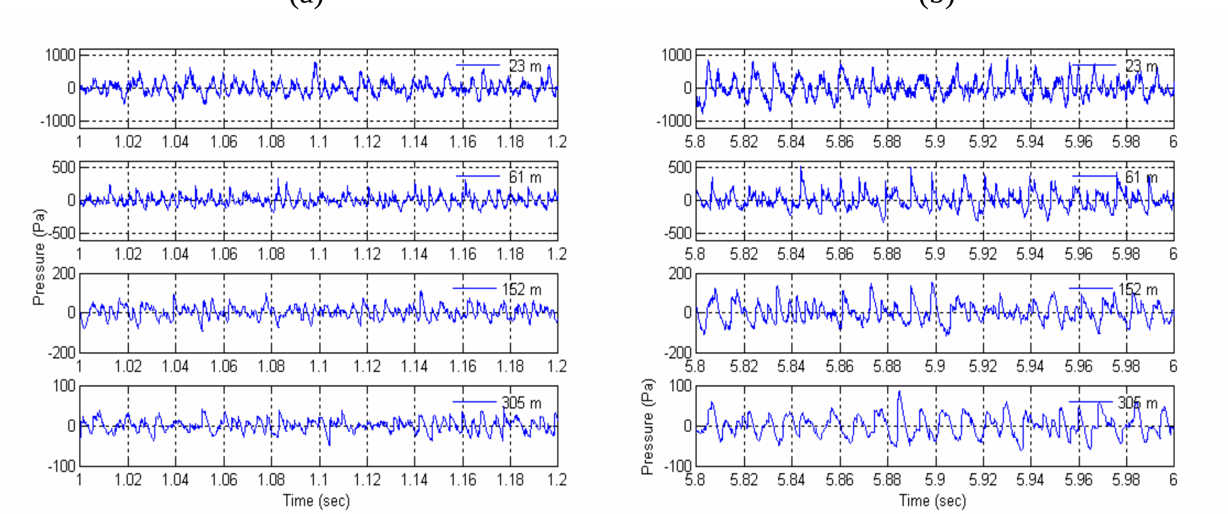

Figure 3: (a) Military engine power: pressure time history of 125° radial microphone array. (b) Afterburner engine power: pressure time history of 125° radial microphone array.

The flat, C, and A-weighted overall sound pressure levels of the 125 radial microphones for each engine power conditions presented are shown in Table 3. Frequency data processing was restricted to spectral resolution no finer than one-third octave bands. For the one-third octave bands, the time data was divided into 86 data blocks using 50% overlapping. A Hanning window was applied to each data block and a Fast Fourier Transform (FFT) was performed with 65,536 spectral lines, frequency resolution of ~ 1.5 Hz. For each data block the autospectrum was calculated from the FFT results. The auto spectrum of the 86 data blocks was then averaged. The total energy of each one-third octave band was found by summing each spectrum found in the band. One-third octave band plots for cross bleed, intermediate, military, and afterburner are shown in Figures 4(a), 4(b), 5(a), and 5(b) respectively.

Table 3: Overall Sound Pressure Level of 125° Radial.

Engine Power Condition	Weighting	Overall Sound Pressure Level of 125 Radial (dB)			
		75 ft	200 ft	500 ft	1000 ft
Idle	Flat	97	90	82	76
	C	96	88	82	75
	A	89	82	74	66
Cross bleed	Flat	125	117	110	105
	C	125	117	110	105
	A	117	109	102	96
Intermediate	Flat	138	129	121	116
	C	138	129	121	116
	A	129	124	113	107
Military	Flat	140	132	125	118
	C	140	132	125	118
	A	132	126	117	110
Afterburner	Flat	143	136	128	122
	C	143	135	127	122
	A	134	128	118	111

For the lower power conditions, the ground interference effect is obvious for bands 27 through 29. As the power increases the effect of ground interference is reduced, which indicates an increase in the size of the noise source.

Ambient conditions during the measurements were conducive to making outdoor measurements. Wind conditions were calm with temperatures ranging from 13.0 - 16.5 °C and humidity ranges of 45 - 56%.

(a) (b)

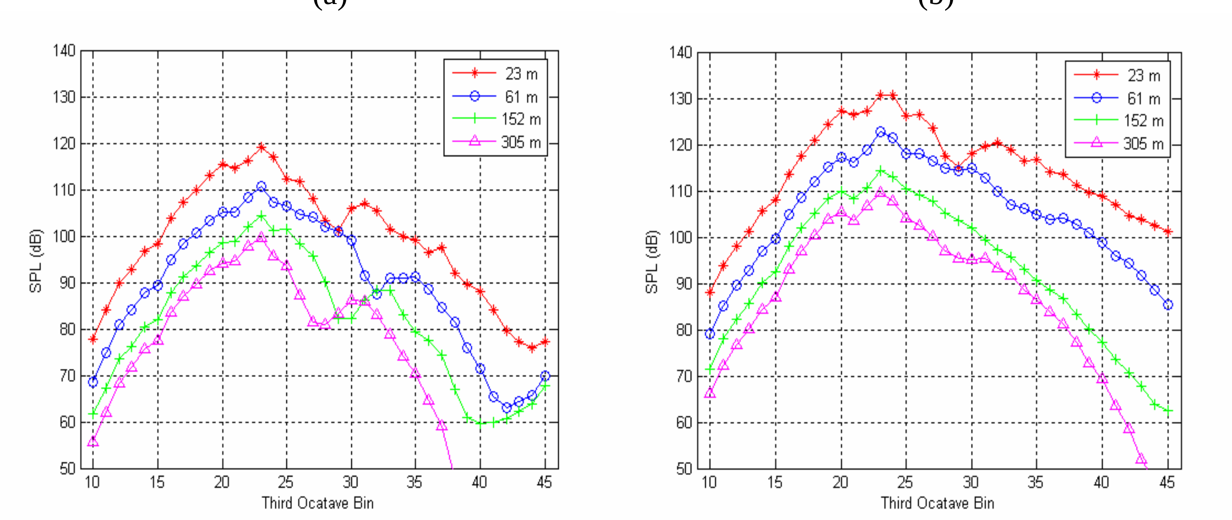

Figure 4: (a) Cross bleed engine power: one-third octave bands for 125° radial microphone array (b) Intermediate engine power: one-third octave bands for 125° radial microphone array.

(a) (b)

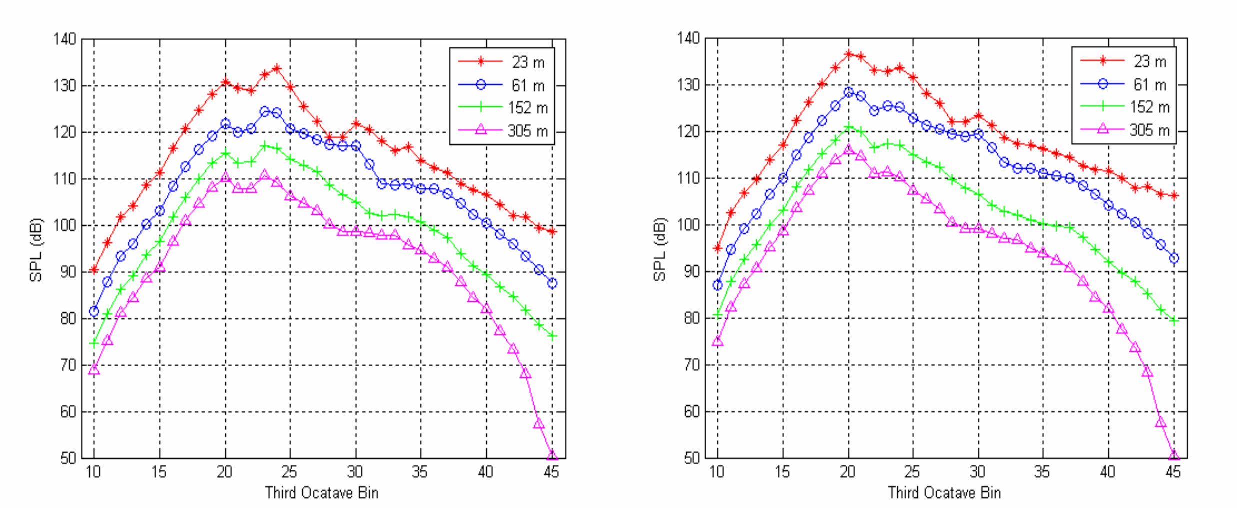

Figure 5: (a) Military engine power: one-third octave bands for 125° radial microphone array. (b) Afterburner engine power: one-third octave bands for 125° radial microphone array.

4. SUMMARY

As part of the development of a new noise model, detailed acoustical data measurements from static high-power military jet run-up operations were collected for the evaluation of a proposed nonlinear propagation model. The measurements focused on the rear quadrant where the jet noise emission is loudest. Several high power engine conditions were measured during the study. This measured data provides a comprehensive dataset to validate newly developed non-linear propagation models.

ACKNOWLEDGEMENTS

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