

Understanding the Aeroacoustic Radiation Sources and Mechanism in High-Speed Jets

Dissertation

Presented in Partial Fulfillment of the Requirements for the Degree
Doctor of Philosophy in the Graduate School of The Ohio State
University

By

Michael Crawley, B.S.

Graduate Program in Department of Mechanical Engineering

The Ohio State University

2015

Dissertation Committee:

Mo Samimy, Advisor

Datta Gaitonde

James Gregory

Mei Zhuang

© Copyright by

Michael Crawley

2015

Abstract

Who reads a dissertation abstract?

This work is dedicated to Science ...

Acknowledgments

I should probably acknowledge someone here . . .

Vita

September 10, 1986 Born - Plano, Texas

2009 B.S. Mechanical Engineering,
University of Texas, Austin.

2009-present Graduate Research Associate,
The Ohio State University.

Publications

Research Publications

M. Crawley, C.-W. Kuo, and M. Samimy, “Identification of the Acoustic Response in the Irrotational Near-field of an Excited Subsonic Jet.” submitted to *International Journal of Aeroacoustics*.

M. Crawley, R. Speth, D. V. Gaitonde, and M. Samimy, “A Study of the Noise Source Mechanisms in an Excited Mach 0.9 Jet - Complementary Experimental and Computational Analysis.” AIAA Paper 2015-0736, *53rd AIAA Aerospace Sciences Meeting*.

M. Crawley, A. Sinha, and M. Samimy, “Near-field and Acoustic Far-field Response of a High-Speed Jet Forced with Plasma Actuators.” *AIAA Journal*, expected 2015.

M. Crawley and M. Samimy, “Decomposition of the Near-Field Pressure in an Excited Subsonic Jet.” AIAA Paper 2014-2342, *20th AIAA/CEAS Aeroacoustics Conference*.

M. Crawley, A. Sinha, and M. Samimy, “Near-field Pressure and Far-field Acoustic Response of Forced High-Speed Jets.” AIAA Paper 2014-0527, *52nd AIAA Aerospace Sciences Meeting*.

M. Crawley, H. Alkandry, A. Sinha, and M. Samimy, “Correlation of Irrotational Near-Field Pressure and Far-Field Acoustic in Forced High-Speed Jets.” AIAA Paper 2013-2188, *19th AIAA/CEAS Aeroacoustics Conference*.

H. Alkandry, **M. Crawley**, A. Sinha, M. Kearney-Fischer, and M. Samimy, “An Investigation of the Irrotational Near Field of an Excited High-Speed Jet.” AIAA Paper 2013-0325, *51st AIAA Aerospace Sciences Meeting*.

M. Crawley, M. Kearney-Fischer, and M. Samimy, “Control of a Supersonic Rectangular Jet Using Plasma Actuators.” AIAA Paper 2012-2211, *18th AIAA/CEAS Aeroacoustics Conference*.

Fields of Study

Major Field: Mechanical and Aerospace Engineering

Table of Contents

	Page
Abstract	ii
Dedication	iii
Acknowledgments	iv
Vita	v
List of Tables	viii
List of Figures	ix
1. Introduction	1
1.1 Motivation	1
1.2 Background	3
1.2.1 Components of Jet Noise	3
1.2.2 The Acoustic Analogy	4
1.2.3 Flow Control	4
2. Experimental Methodology	5
2.1 Anechoic Chamber	5
2.2 Data Acquisition	5
2.3 Localized Arc-Filament Plasma Actuators	5
3. Near-field Signature of Aeroacoustic Sources	6
4. Stochastic Estimation of Time-resolved Velocity Fields	7

List of Tables

Table

Page

List of Figures

Figure

Page

Chapter 1: Introduction

1.1 Motivation

The advent of the turbojet engine led to a transformation in both commercial and military aviation, allowing for much faster flight than previously possible with propellor-driven aircraft. However, the increased thrust of turbojets has come at great cost; significant acoustic radiation is generated by the rotating components (compressor, turbine, fan), by the combustion process, and ultimately by the free jet itself. On the commercial side, the escalating number of flights, encroachment of urban and residential areas near airports, and tightening of environmental regulations have combined to force airports to institute curfews, surcharges and flight path restrictions to combat noise pollution. For the military, hearing damage inflicted on nearby personnel (particularly on aircraft carriers) has necessitated the implementation of noise reduction concepts on tactical aircraft. During takeoff and landing, when acoustic radiation is most problematic to ground crew and surrounding urban and residential areas, the dominant noise source of the jet engine is the aeroacoustic radiation generated by the high velocity engine exhaust. This has spurred extensive research, spanning over six decades, into the aeroacoustic source mechanism in high speed, high Reynolds number jets.

While progress has been made in the field of aeroacoustics, both experimentally [4, 6, 5] as well as theoretically [1], understanding of jet noise sources and their radiation mechanisms remains incomplete [2]. This is due to the large number of interrelated parameters (e.g. Reynolds number, temperature ratio, acoustic Mach number, nozzle geometry, et cetera) as well as the large disparity in the associated length and time scales of the turbulent phenomena and the radiated noise. Simulations of controlled free shear layers have suggested that there is significant potential for noise reduction, on the order of 11 dB in some cases [Wei 2006]. However, these simulations relied on non-physically defined actuation (that is, forcing was applied over a defined region by arbitrary energy, momentum, and body force terms), and a physical interpretation of the forcing parameters was not immediately clear to the researchers. Current noise-mitigation technologies for free jets have largely been applied in an adhoc fashion, due to our incomplete understanding of the aeroacoustic sources. Fully realizing this maximum noise reduction potential will require a much more detailed understanding of the mechanism (or mechanisms) by which free jets radiate to the far-field.

It is generally agreed that the dominant noise sources are related to the large-scale turbulent structures present in the mixing layer of the jet.

TO DO:

- Explain purpose of this particular work

1.2 Background

1.2.1 Components of Jet Noise

A simplified model of the noise generation process in stationary free jets can be found in Fig. [INSERT FIGURE]. This model is based off of the work of Tam et al

[4, 5], who observed that the far-field spectra could be represented as a combination of two similarity spectra based on polar angle of the observer, regardless of jet Mach number or temperature. At observer angles close to the jet downstream axis, the spectra exhibited a clearly defined spectral peak (F -spectrum), whereas at sideline or upstream angles the spectra were broadband (G -spectrum).

Additional noise source mechanisms have been identified for supersonic jets. In imperfectly expanded jets, shock cells are produced in the jet. As turbulent structures pass through these waves, the sharp pressure gradients cause them to emit acoustic radiation. This is observed directly in the far-field as a broad-band amplification at high frequencies, referred to simply as broad-band shock-associated noise (BBSAN). In stationary or subsonic airframes this radiation can generate a feedback loop, whereby the noise travels upstream to the nozzle exit, excites the initial shear layer, and produces new structures at the same frequency. A high-amplitude, narrow-band tone (screech noise) is the end result of this feedback loop. Lastly, supersonically-convecting (relative to the ambient) large-scale structures (which exist in supersonic and heated jets) produce high-amplitude, strongly-directional acoustic radiation towards aft angles. This Mach wave radiation can be explained by a wavy-wall analogy (Tam again?). In the present work, the jet is unheated and subsonic; as such these noise sources are not present and therefore neglected throughout the rest of this work.

TO DO:

- Create simplified figure of free jet showing high frequency versus low frequency radiation (based off of Tam 2008)

- Explain Tam’s ”two-component” source model, with additional experimental evidence?

1.2.2 The Acoustic Analogy

By rearranging the Navier-Stokes equations, Lighthill [3] was able to transform the governing equations for fluid dynamics into an inhomogeneous convected wave equation. In this acoustic analogy, the source term comprises Reynolds stress, shear stress, and density fluctuation terms (commonly referred to as *Lighthill’s stress tensor*). As this formulation is exact (aside from the assumption of a constant sound speed), complete knowledge of the source field will yield an exact solution for the acoustic far field. In practical applications (e.g. high-speed, turbulent jets) however, the full source field cannot be measured using current experimental capabilities nor simulated with sufficient fidelity, thereby requiring certain simplifications.

1.2.3 Flow Control

Chapter 2: Experimental Methodology

2.1 Anechoic Chamber

2.2 Data Acquisition

2.3 Localized Arc-Filament Plasma Actuators

Chapter 3: Near-field Signature of Aeroacoustic Sources

Chapter 4: Stochastic Estimation of Time-resolved Velocity Fields

Bibliography

- [1] Marie Cabana, Vronique Fortun, and Peter Jordan. Identifying the radiating core of lighthill’s source term. *Theoretical Computational Fluid Dynamics*, 22:87–106, 2008.
- [2] P. Jordan and Y. Gervais. Subsonic jet aeroacoustics: associating experiment, modelling and simulations. *Experiments in Fluids*, 44:1–21, 2008.
- [3] M. J. Lighthill. On sound generated aerodynamically. i. general theory. In *Proceedings of the Royal Society of London: Series A, Mathematical and Physical Sciences*, volume 211, pages 564–587. The Royal Society, 1952.
- [4] Christopher K. W. Tam, Golebiowski, Michel, and J. M. Seiner. On the two components of turbulent mixing noise from supersonic jets. In *2nd AIAA/CEAS Aeroacoustics Conference*, volume AIAA Paper, 1996.
- [5] Christopher K. W. Tam, K. Viswanathan, K. Ahuja, and J. Panda. The source of jet noise: Experimental evidence. *Journal of Fluid Mechanics*, 615:253–292, 2008.
- [6] K Viswanathan. Scaling laws and a method for identifying components of jet noise. *AIAA Journal*, 44(10):2274–2285, 2006.