Physical sources of sound in laminar and turbulent jets

S. Sinayoko  A. Agarwal  R. D. Sandberg

17th AIAA/CEAS Aeroacoustics Conference
Portland – 8 June 2011
Introduction

Aim
To understand the physical sources of jet noise.
Introduction

Aim
To understand the physical sources of jet noise.

Motivation
- By-pass ratio is limited
- Find alternative strategies
Introduction

Aim
To understand the physical sources of jet noise.

Motivation
- By-pass ratio is limited
- Find alternative strategies

Methods
- Non-radiating base flow sources
- DNS
Introduction

Aim
To understand the physical sources of jet noise.

Motivation
- By-pass ratio is limited
- Find alternative strategies

Previous work
Single frequency algorithm

Methods
- Non-radiating base flow sources
- DNS
Introduction

Aim
To understand the physical sources of jet noise.

Motivation
- By-pass ratio is limited
- Find alternative strategies

Methods
- Non-radiating base flow sources
- DNS

Previous work
Single frequency algorithm

Objectives of the presentation
- Multiple frequency algorithm
- Sources in a laminar jet
- Sources in a turbulent jet
Part I

Non-Radiating Base Flow (NRBF) Sources
NRBF sources definition

\[ f_i = - \frac{\partial}{\partial x_j} \left( \rho \tilde{v}_i \tilde{v}_j \right) ' \]

\[ \tilde{v}_i = \frac{\rho v_i}{\bar{\rho}} \]
Flow decomposition

Space-time domain

\[ q' = w \ast q \]

Wavenumber-frequency domain

\[ Q' = W \times Q \]

Filter window

\[
\begin{cases}
1 & \text{if } |k| = |\omega|/c_\infty \\
0 & \text{otherwise}
\end{cases}
\]
Part II

Sound sources in a laminar jet
Flow description

Pressure field
Pressure in Fourier domain ($\omega = 1.2$)
Pressure in Fourier domain ($\omega = 1.2$)

Pressure $P_{1.2}(\mathbf{k})$

Gaussian filter $W(\mathbf{k})$
Pressure in Fourier domain ($\omega = 1.2$)

Decomposition

Radiating pressure

$P'_{1.2} = WP$
Pressure in Fourier domain ($\omega = 1.2$)

Decomposition

Radiating pressure

$$P'_{1.2} = WP$$

Non-radiating pressure

$$\overline{P}_{1.2} = (1 - W)P_{1.2}$$
\[ p' = p'_{1.0} + p'_{1.2} + p'_{2.2} \]
$$p' = p'_{1.0} + p'_{1.2} + p'_{2.2}$$

$$\bar{p} = p - p'$$
NRBF sources

Axial NRBF source $f_z$ at $\omega = 1.2$
NRBF sources

Radial NRBF source $f_r$ at $\omega = 1.2$
Source validation

Profile along $r = 20D$
Source identification: shear-noise

\[ f_{zz} = -\frac{\partial}{\partial z} (\bar{\rho} \bar{v}_z \bar{v}_z)' \approx -2 \frac{\partial}{\partial z} \left( \rho_\infty \bar{v}_z \bar{v}_z'' \right)' \]
Part III

Sound sources in a turbulent jet
Flow analysis

Full density field
Flow analysis

Full density field

Density field, modes 0 and 1, $|St_D| < 4$
Flow decomposition: $n = 0, St_D = 0.5$
Flow decomposition: \( n = 0, \ St_D = 0.8 \)
Flow decomposition: $n = 0, St_D = 1.45$
Flow decomposition: $n = 0, 0.5 \leq |St_D| < 4.0$
Flow decomposition: \( n = 1, \, 0.5 \leq |St_D| < 4.0 \)
NRBF sources: $St_D = 0.5$
NRBF sources: $St_D = 1.1$
NRBF sources: $St_D = 1.45$
NRBF sources: $St_D = 2.55$
Qualitative validation: $n = 0, \ St_D = 1.1$
Conclusion

1. Algorithm to compute the NRBF sources at multiple frequencies
2. In laminar jet: linear shear noise term is major source
3. NRBF decomposition and sources for a fully turbulent jet
   - wavepackets
   - monopole
   - vortex pairing
Acknowledgements

Thank you!

Engineering and Physical Sciences Research Council