ME706 Acoustics and Aerodynamic Sound

Instructor:

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Prerequisites:

Familiarity with the elements of Fluid Mechanics; working knowledge of advanced undergraduate Engineering Mathematics (The reference textbook *Mathematical Methods for Mechanical Sciences* (MMMS) can be downloaded from the ME706 Blackboard website).

Textbook:

Howe, M. S. *Theory of Vortex Sound* (paperback), Cambridge University Press, 2003.

Course grading:

- One take-home examination
- One Project

This is a practical course dealing with the conversion of hydrodynamic (*rotational*) kinetic energy into the longitudinal disturbances we call sound. The first few lectures will review and develop basic background material and methods from the underlying theory of acoustics; they will serve as an introduction to acoustics for those new to the subject. Great care will be taken to discuss underlying fluid mechanical and acoustic concepts. A considerable number of practical sound generation problems occur at low Mach numbers (< 0.4) to which we confine ourselves. Many idealized hydrodynamic flows involving the production of sound by unsteady flow adjacent to solid boundaries are investigated ('vortex-surface' interactions) by the powerful and universal method of 'compact Green's function', which provides a routine procedure for estimating the sound and an easy identification of those parts of a structure that are likely to be important sources of sound. These interactions are simple enough for the student to acquire an intuitive understanding of the method of solution and of the underlying physics, and each student project will consist of a numerical determination of the sound produced by such a vortex-surface interaction.

Students are expected to:

- Exhibit a level of mathematical maturity roughly equivalent that derived from an advanced undergraduate course on 'Engineering Mathematics' (vector differential and integral calculus; partial differential equations; the 'repeated suffix' summation convention; Dirac δ-function, etc. Relevant review material will be found in MMMS).
- Independently study and attempt to solve problems at the end of each chapter of *Theory of Vortex Sound*. Some of these will be set as homework problems.

BOOKS

Students should aim to build a library of classic texts. Many of these are out of print, but are available in libraries or second hand (e.g. from: http://www.abebooks.com/).

Recommended classics:

Batchelor, G. K. 1967 *An Introduction to Fluid Dynamics,* Cambridge University Press.

Birkhoff, G. 1955 *Hydrodynamics – a study in logic, fact and similitude.* Dover publications (republication of edition published by Princeton University Press, 1950)

Birkhoff, G. and Zarantonello 1957 *Jets, wakes and cavities.* New York, Academic Press.

Durand, W. F. 1934. (editor) *Aerodynamic Theory*, 6 volumes. See especially volumes II and III. Second hand only.

Goldstein, S. 1960 *Lectures on fluid mechanics.* Interscience: New York. (out of print)

Gurevich, M. I. 1965 *Theory of jets in ideal fluids.* New York, Academic Press.

Lamb, Horace 1932 *Hydrodynamics* (6th. ed.). Cambridge University Press. (Also available from Dover; paperback version reprinted as a *Cambridge Classic* by Cambridge University Press, 1993). All serious students should have this!

Landau, L. D. and E. M. Lifshitz 1987 *Fluid Mechanics* (Second edition). Oxford: Pergamon.

Lighthill, James 1978 *Waves in Fluids.* Cambridge University Press.

Lighthill, J. 1986 *An Informal Introduction to Theoretical Fluid Mechanics.* Oxford: Clarendon.

Milne-Thomson, L. M. 1968 *Theoretical Hydrodynamics* (5th. edition). London: Macmillan. (Also available from Dover)

Prandtl, L. 1952 *Essentials of Fluid Dynamics.* London, Blackie and Sons. (out of print)

Sedov, L. I. 1965 *Two dimensional problems in hydrodynamics and aerodynamics.* New York: John Wiley.

Stoker, J. J. 1957 *Water Waves.* New York: Interscience Publishers.

For a review of elementary fluid mechanics:

Acheson, D. J. 1990 *Elementary Fluid Dynamics.* Oxford: Clarendon Press.

Books related to acoustics:

Baker, B. B. and Copson, E. T. 1969 *The Mathematical Theory of Huygens' Principle*, Second edition. Oxford University Press.

Crighton, D. G. Dowling, A. P., Ffowcs Williams, J. E., Heckl, M. and Leppington, F. G. 1992 *Modern methods in analytical acoustics* (Lecture Notes). Springer-Verlag: London.

Dowling, A. P. and Ffowcs Williams, J. E. 1983 *Sound and sources of sound.* Ellis Horwood (ISBN 0-85312-400-0).

Goldstein, M. E. 1976 *Aeroacoustics.* New York: McGraw-Hill.

Howe, M. S. *Acoustics of Fluid-Structure Interactions*, Cambridge University Press, 1998

Howe, M. S. *Hydrodynamics and Sound*, Cambridge University Press, 2006

Noble, B. 1958 *Methods based on the Wiener-Hopf Technique.* London: Pergamon Press.

Pierce, A. D. 1989 *Acoustics, An introduction to its principles and applications.* American Institute of Physics.

Rayleigh, Lord 1945 *Theory of Sound*, Volumes 1 and 2. New York: Dover.

Rough schedule

Lecture 1:

1.1. What is vortex sound?

1.2. Equations of motion of a fluid

Lecture 2:

1.3. Equation of linear acoustics

1.4. The special case of an incompressible fluid

Lecture 3:

1.5. Sound produced by an impulsive point source

1.6. Free space Green's function

Lecture 4:

1.7. Monopoles, dipoles and quadrupoles

1.8. Acoustic energy flux

Lecture 5:

1.9. Calculation of the acoustic far field

Problems 1

Lecture 6:

2.1. The acoustic analogy

2.2. Lighthill's v^8-law

Lecture 7:

2.3. Curle's theory

2.4. Sound produced by turbulence near a compact rigid body

Lecture 8:

2.5. Radiation from a noncompact surface
Problems 2
3.1. The influence of solid boundaries

Lecture 9:

3.2. The Helmholtz equation
3.3. The reciprocal theorem

Lecture 10:

3.4. Time-harmonic compact Green's function
3.5. Compact Green's function for a rigid sphere

Lecture 11:

3.6. Compact Green's function for cylindrical bodies
3.7. Symmetric compact Green's function

Lecture 12:

3.8. Low frequency radiation from a vibrating body
3.9. Compact Green's function summary and special cases
Problems 3

Lecture 13:

4.1. Vorticity and the kinetic energy of incompressible flow
4.2. The vorticity equation

Lecture 14:

4.3. The Biot-Savart law
4.4. Surface force in incompressible flow expressed in terms of vorticity

Lecture 15:

4.5. The complex potential
4.6. Motion of a line vortex

Lecture 16:

Problems 4
5.1. The rôle of vorticity in Lighthill's theory

Lecture 17:

5.2. The equation of vortex sound
5.3. Vortex-surface interaction noise

Lecture 18:

5.4. Radiation from an acoustically compact body
5.5. Radiation from cylindrical bodies of compact cross-section

Lecture 19:

5.6. Impulse theory of vortex sound
Problems 5

Lecture 20:

6.1. Compact Green's function in two-dimensions
6.2. Sound generated by a line vortex interacting with a cylindrical body

Lecture 21:

6.3. Influence of vortex shedding
6.4. Blade-vortex interaction noise in two-dimensions
Problems 6

Lecture 22:

7.1 Linear theory of vortex-airfoil interaction noise

7.2. Blade-vortex interactions in three dimensions

Lecture 23:

7.3. Sound produced by vortex motion near a sphere

7.4. Compression wave generated when a train enters a tunnel

Lecture 24:

Problems 7