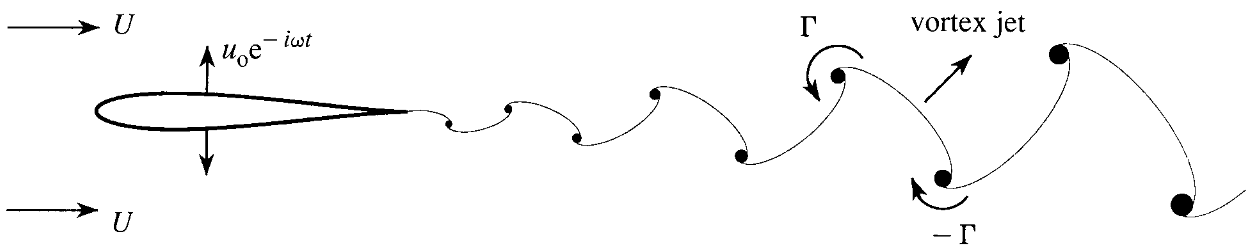
Thrust producing wake



ME542: ADVANCED FLUID MECHANICS

Fall 2012

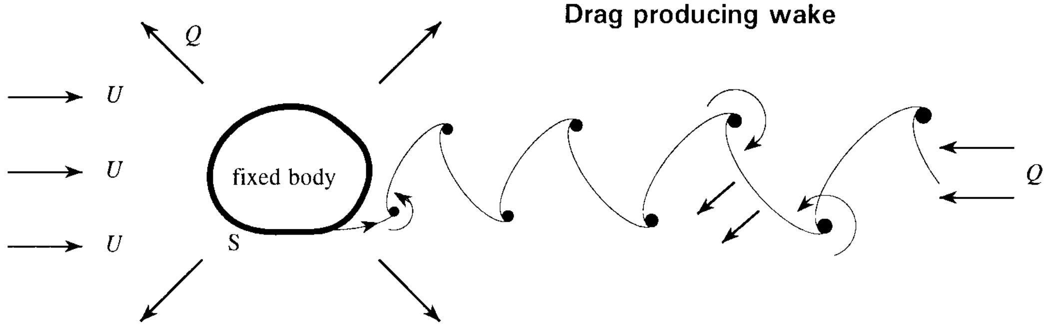
This course will consolidate your knowledge of fluid mechanics and help to develop a critical and mature approach to the subject. It supplies background preparation for more specialized courses on fluid mechanics, including acoustics and aeroacoustics. It starts with the general equations for a viscous compressible fluid and proceeds to selected topics in two and three dimensional incompressible fluid mechanics, as discussed in Chapters 1 - 4 of the instructor's text book *Hydrodynamics and Sound* (2007, Cambridge University Press).

The course is intended for advanced seniors and graduate students. Successful completion of the course will satisfy the ME graduate Math Qualifying requirement.

Prerequisites: Introductory knowledge of Fluid Mechanics and Multivariate Calculus (or instructor approval).
Day & Time: Tues and Thurs 6-8pm

Instructor: Michael Howe, Room EMA 218, mshowe@bu.edu

Drag producing wake



ENG ME 542 Advanced Fluid Mechanics

Instructor:

M. S. Howe
EMA 218
mshowe@bu.edu

This course is intended to consolidate your knowledge of fluid mechanics and to develop a critical and mature approach to the subject. It will supply the background preparation for more specialized courses on fluid mechanics, acoustics and aeroacoustics.

Outline syllabus:

Equations of motion. Selected topics in two and three dimensional incompressible fluid mechanics, as discussed in Chapters 1 - 4 of *Hydrodynamics and Sound* (M. S. Howe 2007, Cambridge University Press).

Prerequisites:

Introductory knowledge of Fluid Mechanics and Multivariate Calculus.

Textbooks:

Students of Fluid Mechanics should aim to build a library of classic texts. These are usually considered to be 'too difficult' for the average graduate, and most textbooks in use in American universities are simplifications that present interpretations and often misguided simplifications of the originals. Many valuable classics are now out of print, but are often available from libraries and online sources.

The engineering text *Mathematical Methods for Mechanical Sciences* can be downloaded from the ME 542 Website.

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.

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

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

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:

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

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

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

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.

Course Assessment:

(i) **Class participation/Homework (30%)**

Students will be asked to discuss and make class presentations of selected homework problems.

(ii) **Project (35%)**

This will usually involve a numerical application of fluid mechanical theory developed in the lectures to a model flow or fluid-structure interaction. The results will be documented in a short project report.

(iii) **Final Examination (35%)**

Takehome examination.

Students are expected to:

- Acquire 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. Review material will be found in MMMS).
- Independently study and attempt to solve problems at the end of each chapter of *Hydrodynamics and Sound*. Some of these will be set as homework problems and used in class discussions.

Rough course syllabus:

Text: *Hydrodynamics and Sound*, Howe 2007, CUP.

Lecture 1: T, 4 Sep
Math preliminaries.
1.1 The fluid state
1.2 The material derivative
1.3 Conservation of mass: equation of continuity

Lecture 2: R, 6 Sep
1.4 Momentum equation
1.5 The energy equation
1.7 Boundary conditions
Problems 1

Lecture 3: T, 11 Sep
2.1 Ideal fluid
2.2 Kelvin's circulation theorem
2.3 The velocity potential

Lecture 4: R, 13 Sep
2.4 Motion produced by a pulsating sphere
2.5 The point source
2.6 Free space Green's function

Lecture 5: T, 18 Sep
2.7 Monopoles, dipoles and quadrupoles

Lecture 6: R, 20 Sep
2.8 Green's formula

Lecture 7: T, 25 Sep
2.9 Determinancy of the motion
2.10 The kinetic energy

Lecture 8: R, 27 Sep
2.11 Problems with spherical boundaries
2.12 The Stokes stream function

Lecture 9: T, 2 Oct
2.13 The incompressible far field
2.14 Force on a rigid body

Lecture 10: R, 4 Oct
2.15 Sources near solid boundaries
2.16 Far field Green's function

Lecture 11: R, 11 Oct
2.17 Far field Green's function for cylindrical bodies
2.18 Symmetric far field Green's function

Lecture 12: T, 16 Oct
3.1 Complex representation of fluid motion
3.2 The circular cylinder

Lecture 13: R, 18 Oct
3.3 The Blasius force and moment formulae
3.4 Sources and line vortices

Lecture 14: T, 23 Oct
3.5 Conformal transformations

Lecture 15: R, 25 Oct
3.5 Conformal transformations (2)

Lecture 16: T, 30 Oct
3.6. The Schwarz-Christoffel transformation

Lecture 17: R, 1 Nov
3.7. Free streamline theory

Lecture 18: T, 6 Nov
3.8 The Joukowski transformation
3.9 The Joukowski airfoil

Lecture 19: R, 8 Nov
3.12 Unsteady thin airfoil theory

Lecture 20: T, 13 Nov
4.1 The vorticity equation

Lecture 21: R, 15 Nov
4.2 The Biot-Savart law

Lecture 22: T, 20 Nov
4.3 Examples of axisymmetric vortical flow

Lecture 23: T, 27 Nov
4.4 Some viscous flows

Lecture 24: R, 29 Nov
4.5 Force on a rigid body

Lecture 25: T, 4 Dec
4.7 Vortex-Surface interactions

Lecture 26: R, 6 Dec
Review

Lecture 27: T, 11 Dec
Review

Sample topics for discussion and review

- Role of Green's formula in Fluid Mechanics.
- The incompressible far field.
- Force on a rigid body in incompressible flow.
- The Kirchhoff vector and applications.
- The Kutta-Joukowski condition.
- Leading edge suction.
- The Schwarz-Christoffel transformation.
- Free streamline theory.
- Separation.
- Sedov's method.
- Unsteady thin airfoil theory.
- Creeping flow.
- Boundary layer theory.
- The Kirchhoff vector force formula.
- Vortex-Surface interactions.