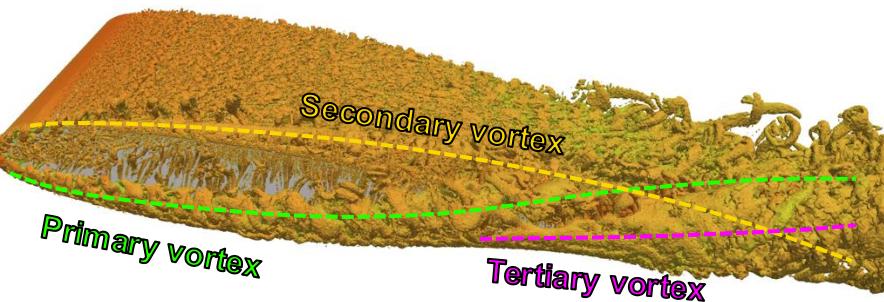
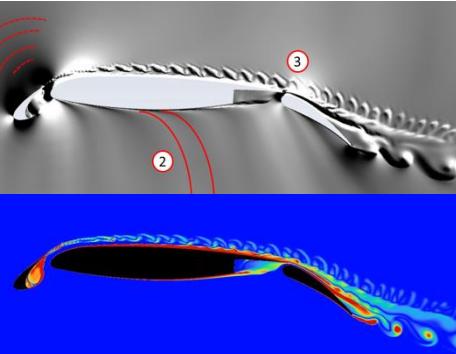
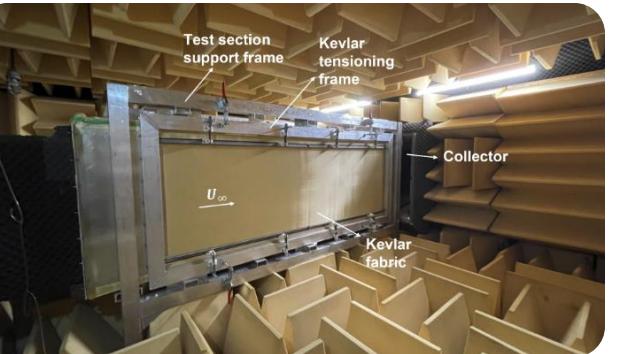
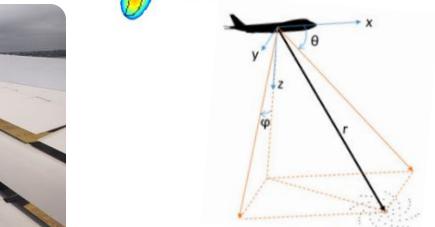
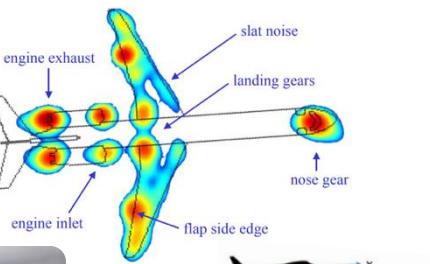
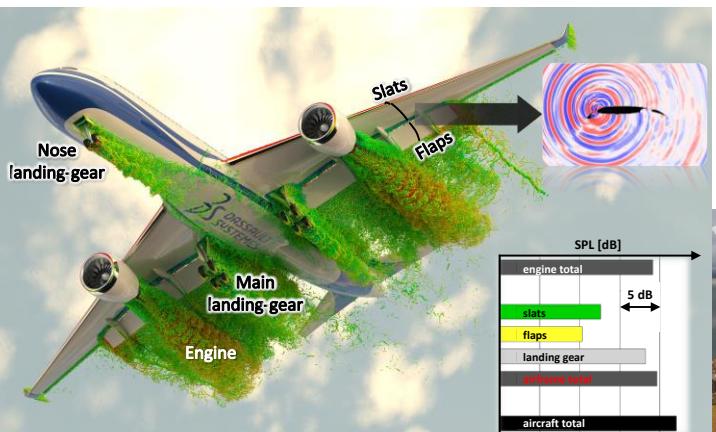
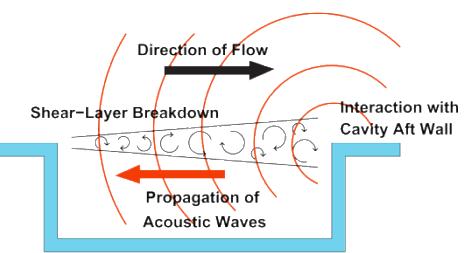




Aircraft Aeroacoustics

0860395

Dr. Hadar Ben-Gida
bengida@technion.ac.il



AA0860395 Course Overview

Objective:

- Provide students with a comprehensive understanding of the physical principles of aeroacoustic phenomena relevant to aircraft systems
- The student will learn to apply acoustic analogies, as well as analytical and empirical methods, to predict and analyze the noise characteristics of aircraft systems

Prerequisites:

- Compressible flow (84312)

Weekly hours:

- 3 lecture hours, Tue 14:30-17:30, Lady Davis, Room 371

3 academic credits

Office hours: Tue, before class (upon request)

TA: Ohad Katri

Schedule



Lecture time is 14:30-17:30,
at Room 371

Sun	Mon	Tue	Wed	Thu
26/10	27/10	28/10	29/10 Semester starts!	30/10
2/11	3/11 Itzhak Rabin Mem. Day	4/11 Lecture 1	5/11	6/11
9/11	10/11	11/11 Lecture 2	12/11	13/11
16/11	17/11	18/11 Lecture 3	19/11	20/11
23/11	24/11	25/11 Lecture 4	26/11	27/11
30/11	1/12	2/12 Lecture 5	3/12	4/12
7/12	8/12	9/12 Lecture 6	10/12	11/12
14/12 Hanukkah	15/12 Hanukkah	16/12 Lecture 7 Hanukkah	17/12 Hanukkah	18/12 Hanukkah
21/12 Hanukkah	22/12 Hanukkah	23/12 Lecture 8	24/12 Christmas Eve.	25/12 Christmas
28/12	29/12	30/12 Lecture 9 Tenth of Tevet	31/12	1/1/2026
4/1	5/1	6/1 Lecture 10	7/1	8/1
11/1 SciTech Forum	12/1 SciTech Forum	13/1 SciTech Forum	14/1 SciTech Forum	15/1 SciTech Forum
18/1	19/1	20/1 Lecture 11	21/1	22/1
25/1	26/1	27/1 Lecture 12	28/1	29/1 Semester ends!

Course Syllabus

- **Ch. 1 – Introduction to Aircraft Aeroacoustics**
- **Ch. 2 – Linear Acoustics**
- **Ch. 3 – Acoustic Analogies (Lighthill, Curle, FW-H)**
- **Ch. 4 – Unsteady Loading**
- **Ch. 5 – Airfoil Self-Noise**
- **Ch. 6 – Propeller and Rotor Noise**
- If time permits:
 - Aeroacoustics of high-lift devices, wingtip,...
 - Cavity noise

Final Grading

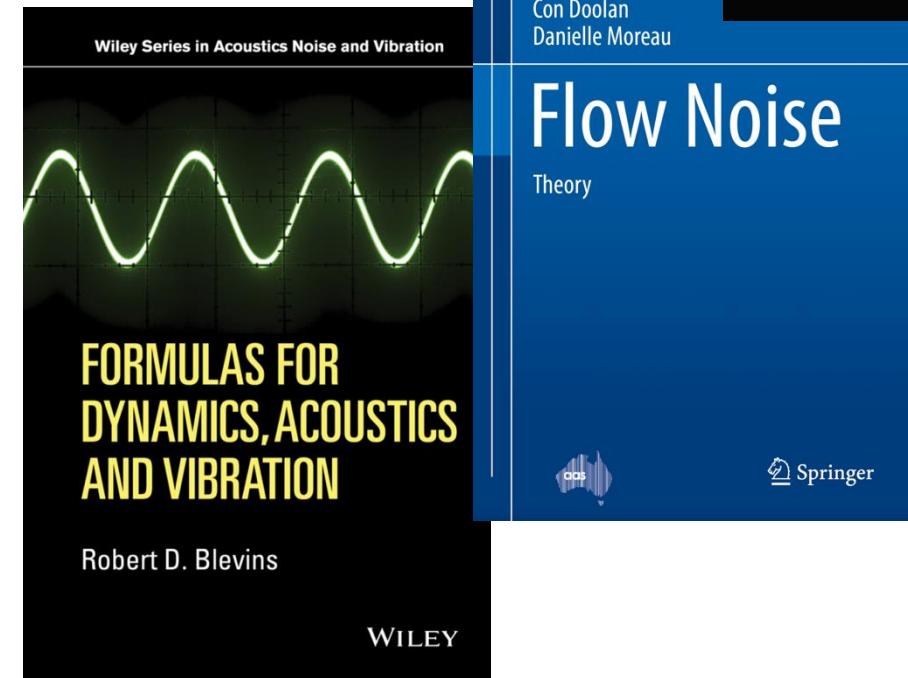


3 HW assignments: 70% (23%, 23%, 24%)

- Each HW assignment is due within 4 weeks (after being published)
- Require MATLAB/Python or any other suitable programming language
- Each HW assignment is to be submitted via *Moodle* (.zip file containing the **report + codes**)
- Each HW assignment includes **bonus points (+20/30) applicable only to the specific HW**
 - Final course grade can be up to 100
- Assignments:
 - **HW1** (23%) – Fundamentals in aeroacoustics (deadline: 02/12/2025)
 - **HW2** (23%) – Aircraft noise analysis (deadline: 30/12/2025)
 - **HW3** (24%) – Rotor noise prediction (deadline: 27/01/2026)
 - **Optional - HW4** – Airframe noise (deadline: 26/02/2026)
 - Can replace one HW assignment with the lowest grade (MAGEN)

Reference Material

- S. Glegg and W. Devenport. "Aeroacoustics of Low-Mach Number Flows". 2nd Edition, Elsevier Academic Press, 2024.
- C. Doolan and D. Moreau. "Flow Noise", Springer 2022.
- R. D. Blevins, "Formulas for Dynamics, Acoustics and Vibration". John Wiley & Sons, 2016



Chapter 1

Introduction to aircraft aeroacoustics

Sound and noise



Aircraft Aeroacoustics

Sound or noise?

Aircraft approach



Space shuttle launch



Jet noise



Helicopter



Drones



Sonic boom



Aircraft Aeroacoustics

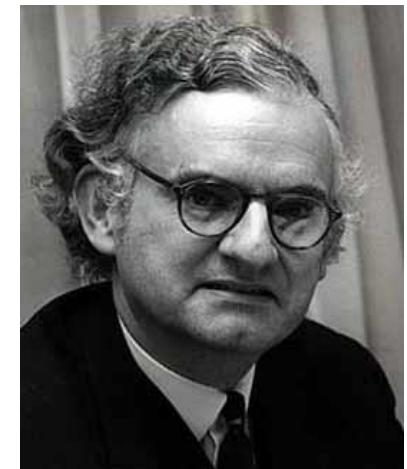
Definitions

□ Acoustics

- Scientific study of **sound** generation, propagation, and reception
- **Noise** is any unwanted or undesirable sound that is heard by a person, referred to as an observer in acoustics terminology

□ Aeroacoustics

- The study of **noise generation by air flows (flow-induced sound)**, and the way in which aerodynamic systems can be designed to minimize noise
- Subject born from Lighthill's paper on his theory of aerodynamic sound (1952) – “Lighthill's Acoustic Analogy”



Sir James Lighthill
(23 January 1924 – 17 July 1998)
A British applied mathematician

On sound generated aerodynamically
I. General theory
By M. J. LIGHTHILL
Department of Mathematics, The University, Manchester
(Communicated by M. H. A. Newman, F.R.S.—Received 13 November 1951)

A theory is initiated, based on the equations of motion of a gas, for the purpose of estimating the sound radiated from a fluid flow, with rigid boundaries, which as a result of instability contains regular fluctuations or turbulences. The sound field is that which would be produced by a stationary source moving with constant velocity U in a uniform free stream. The basic equation is $\rho_0 \partial_t p + p_0 - \partial p / \partial x = 0$, where ρ is the density, ∂ the velocity vector, p_0 the compressive stress tensor, and a_0 the velocity of sound outside the flow. The quadrupole strength density may be expressed in terms of the velocity fluctuations, and the theory is applied to the case of two-dimensional potential solutions. In it, the intensity depends crucially on the frequency as well as on the strength of the quadrupoles, and as a result increases in proportion to a high power, near the right-hand edge of the spectrum. The theory is also applied to the case of a source emitting energy from kinetic to acoustic in based on fluctuations in the flow of momentum across fixed surfaces, and it is explained in §2 how this accounts both for the relative inefficiency of the process of conversion and for the analogy with U . It is shown in §7 how the efficiency is also increased, particularly for the sound emitted forwards, in the case of fluctuations convected at a not negligible Mach number.

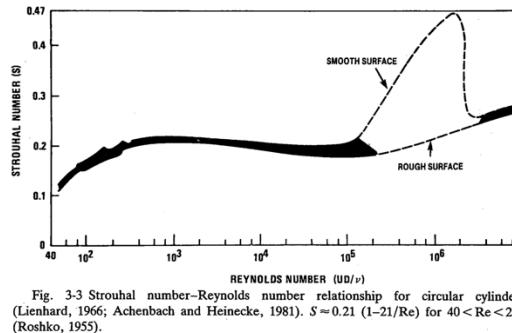
1. INTRODUCTION

The subject of this paper is sound generated aerodynamically, that is, as a by-product of an airflow, as distinct from sound produced by the vibration of solids. The airflow may contain fluctuations as a result of instability, giving at low Reynolds

Simple example

□ Flow around a cylinder

- Low Mach number
- Formation of von Kármán vortex street
- Tonal sound can be generated at the vortex shedding frequency
 - Vortices generate an unsteady force on the cylinder surface, generating a dipole sound source, also known as the Aeolian tone
- $St \sim 0.2$ over a large range of Re numbers



Reynolds
number

Mach
number

$$Re = \frac{\rho U_\infty D}{\mu} = 69,000 U_\infty c$$

$$M = \frac{U_\infty}{c} = 0.003 U_\infty$$

Strouhal
number

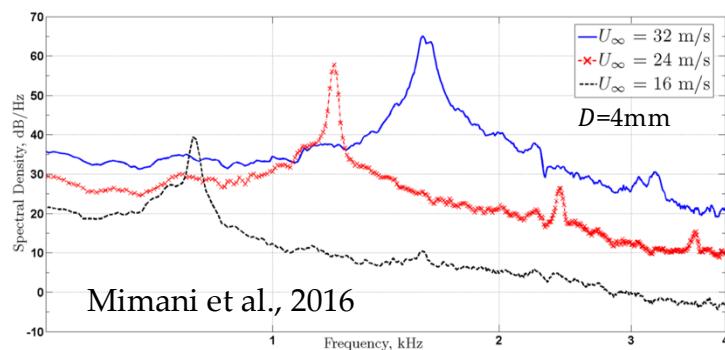
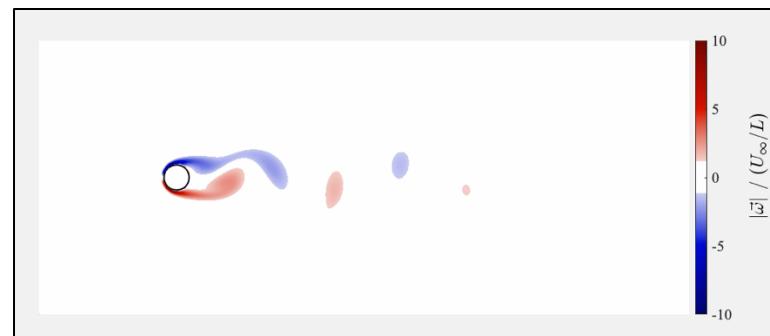
$$St = \frac{fD}{U_\infty}$$

↓

Sheeding
frequency

$$f = \frac{St U_\infty}{D}$$

LBM, $Re=100$, $St=0.17$



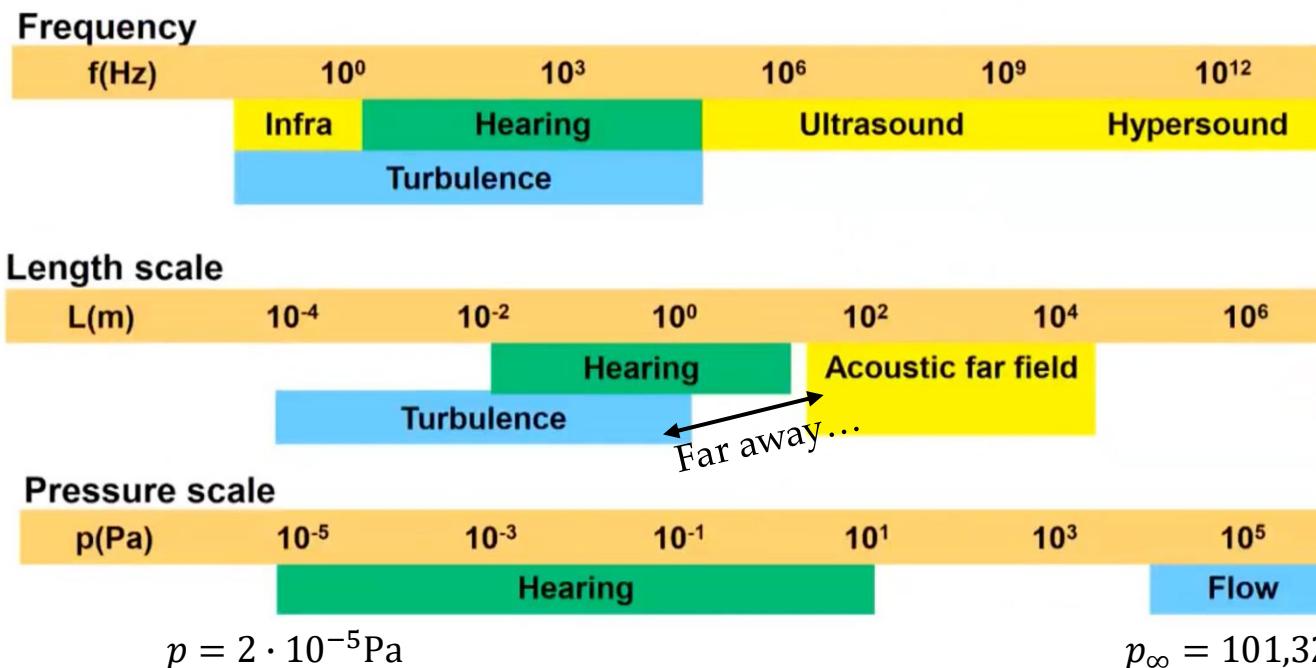
Mimani A., Prime Z., Moreau D., and Doolan C. (2016) "An experimental application of aeroacoustic time-reversal to the Aeolian tone." The Journal of the Acoustical Society of America 139(2), 740-763.

Standard atmosphere – sea level (SL)

density:	$\rho_{SL} = 1.225 \text{ kg/m}^3$
pressure:	$p_{SL} = 1.0132 \times 10^5 \text{ Pa}$
temperature:	$T_{SL} = 288.15 \text{ K}$
speed of sound:	$c_{SL} = 340.3 \text{ m/s}$
viscosity:	$\mu_{SL} = 1.79 \times 10^{-5} \text{ kg/m-s}$

Scientific Challenge

- The design of low-noise aircraft systems needs good knowledge of aeroacoustics
- Reduction of development time can be obtained by using common rules-of-thumb, relatively simple theories, and computational aeroacoustic (CAA) simulation
- **Main challenge – disparity of *length* and *energy* scales**



Acoustic wavelength

$$\lambda = \frac{c_0}{f}$$

Frequency (Hz)	1	10	100	1000	10,000
Wavelength (ft)	1128	112.8	11.28	1.128	0.1128 (1.3 in.)
Wavelength (m)	343	34.3	3.43	0.343	0.0343 (34.3 mm)
