ME/AERSP 524
Turbulence and Applications to CFD: DNS and LES

(Companion course: AERSP/ME 525. Turbulence and Applications to CFD: RANS

Listed title, Fall 2005: Although the working title is as per the top of the page, the title listed by the university is "Homogeneous Turbulence." The official title changes will come in the Spring 2006 offering of Aersp/ME 525 and beyond (see bottom of page, "Phase-in Schedule").

Description and changes: The structure and content of this course, and its companion course Aersp/ME 525, have been modified from previous offerings to teach turbulence in context with its application so computer simulation. This course will emphasize applications to direct numerical simulation (DNS) and large-eddy simulation.(LES), while 525 will emphasize applications to Reynolds averaged Navier-Stokes (RANS) simulation. Both courses will teach a overlapping fundamentals (see outline). ME/Aersp 524 sill go more into scale separation and interscale dynamics, as necessary to understand DNS and LES, and subfilter modeling as required in LES. Aersp/ME 525 will go more into single point representations and closures, and its simulation. Both courses will require three computer projects from the student in order to teach physics and applications concurrently with elements high-performance computing.

Time/place: TR 1:00-215 PM, 214 Hammond building

Teacher: James G. Brasseur
205 Reber Building (Mechanical Engineering)
865-3159 (office); brasseur@psu.edu.

Primary Texts: J Mathieu and J Scott, Introduction to Turbulent Flow, Cambridge University Press 2000 (ISBN 0-521-77538-8, paperback) and SB Pope, Turbulent Flows, Cambridge University Press 2000 (ISBN 0-521-59886-9, paperback). These are paperback and not too expensive, so I would like for you to add both texts to your library. If you can only afford one, look at both in the library and decide. Other texts will be placed on reserve.

Math: Cartesian tensors and vector notations are used interchangeably. I shall provide reference texts in the library.

COURSE EVALUATION

Miscellaneous out of class assignments based on the reading: 10%

Computer Project I with Report: 20%

Computer Project II with report: 20%

Computer Project III coordinated with II, and Final Report – 30%: Preparation of a technical report that coordinates knowledge from computer project II with new knowledge from computer project III as well as a review of selected recent references.

Final Presentation – 15%: Oral presentation of computers projects III and II. Typically the presentation should be 20 minutes with 5 minutes allotted for class questions.

Class Participation – 5%: Designated students will ask questions following the oral presentations to stimulate class discussion.

PHASE-IN SCHEDULE

Fall 2005	ME/AERSP 524:	Turbulence and Applications to CFD: DNS and LES
Spring 2006	AERSP/ME 525:	Turbulence and Applications to CFD: RANS
Spring 2007	ME/AERSP 524:	Turbulence and Applications to CFD: DNS and LES
Spring 2007	AERSP/ME 525:	Turbulence and Applications to CFD: RANS
Spring 2008	ME/AERSP 524:	Turbulence and Applications to CFD: DNS and LES

...etc.

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	OUTLINE FOR ME/AERSP 524= **(bolded ⇒ common material in ME/AERSP 524 and AERSP/ME 525)**
3-4 lectures	**1. INTRODUCTORY CONCEPTS** • **Stability and transition to turbulence** • **Basic characteristics of turbulence and classes of turbulent flows** • **Approaches of measurement and analysis: experiment vs. computation** **2. BASIC SCALING OF TURBULENCE (Ch 1, Tennekes & Lumley + Kolmogorov)** • **Scaling arguments and basic concepts of mixing, Reynolds number, etc.** • **Basic Kolmogorov theory (spectral subranges, $k^{-5/3}$, etc.)** • **The basic three scales of turbulence: large-eddy, Taylor, Kolmogorov**
1 week to complete	COMPUTER PROJECT I: KINEMATIC TURBULENCE FROM ASSEMBLY OF FOURIER MODES • Understanding the concept of turbulence length scales: integral vs. inertial vs. dissipation range • Understanding physical space vs. scale space (Fourier space)
4 lectures	**3. DECOMPOSITIONS OF FLUCTUATING TURBULENCE VARIABLES** • **Physical space: means + fluctuations, correlation, moments, pdf** • **Scale space: Fourier decomposition** **4. STATISTICAL EQUATIONS OF MOTION** • **Reynolds average vs. Favre average** • **Equation for mean velocity** • **Equations for Reynolds stress, component KE, and TKE** • **Reductions for homogeneous and isotropic turbulence** • **The closure problem**
2-3 lectures	5. KINEMATIC REPRESENTATIONS OF TURBULENCE SCALE DECOMPOSITION • Physical space: the two-point correlation • Scale space: the Fourier spectral energy tensor and the energy and dissipation spectra • The integral scale, Taylor microscale and Kolmogorov scale revisited
3 lectures	6. PSEUDO-SPECTRAL DIRECT NUMERICAL SIMULATION (DNS) OF HOMOGENEOUS TURBULENCE • The Fourier-transformed Navier-Stokes equation • Pseudo-spectral solution of the Navier-Stokes equation with periodic boundary conditions
2 weeks to complete	COMPUTER PROJECT II: DNS OF DECAYING ISOTROPIC TURBULENCE • Pseudo-spectral code provided to the students • Physical Space: decay of TKE and dissipation-rate, pdfs of energy, dissipation-rate,

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	enstrophy • Fourier Space: decay of energy and dissipation spectra, transfer spectrum
3 lectures	7. LARGE-EDDY SIMULATION (LES) DECOMPOSITION IN PHYSICAL SPACE • The theoretical two-scale decomposition vs. the actual three-scale decomposition • The LES equations and the closure problem
2 lectures	8. SUBFILTER SCALE (SFS) MODELS • Smagorinsky and dynamic Smagorinsky models • Similarity and mixed models • Deconvolution and other "resolved subfilter scale" (RSFS) models
3 weeks to complete	COMPUTER PROJECT III: LES OF DECAYING ISOTROPIC TURBULENCE • Break class into groups • Each group adds different SFS models to the DNS code and modifies filtering for use as LES code • Analysis of decaying turbulence with different SFS models and different types of explicit filtering • The role of aliasing error and explicit vs. implicit filtering
3-4 lectures	9. UNDERSTANDING LES IN SCALE SPACE • LES decomposition in Fourier space • Triadic dynamics in context with LES
2 lectures	10. PREDICTIONS AND NUMERICAL ISSUES IN APPLIED LES • Truncation, aliasing, roundoff error, and numerical dissipation • Gridding, regularity, and complex geometries of real systems • Boundaries: boundary conditions and special difficulties
5 classes	IN-CLASS STUDENT PRESENTATIONS OF COMPUTER PROJECTS III WITH II

27-30 TOTAL CLASSES