ACADEMIC  Aggie Honor Code: “An Aggie does not lie, cheat, or steal, or tolerate those who do.”

INTEGRITY: Upon accepting admission to Texas A&M University, a student immediately assumes a commitment to uphold the Honor Code, to accept responsibility for learning, and to follow the philosophy and rules of the Honor System. Students will be required to state their commitment on examinations, research papers, and other academic work. Ignorance of the rules does not exclude any member of the TAMU community from the requirements or the processes of the Honor System. For additional information please visit: www.tamu.edu/aggiehonor/

AMERICANS WITH DISABILITIES ACT (ADA) POLICY STATEMENT: The Americans with Disabilities Act (ADA) is a federal antidiscrimination statute that provides comprehensive civil rights protection for persons with disabilities. Among other things, this legislation requires that all students with disabilities be guaranteed learning environment that provides for reasonable accommodation of their disabilities. If you believe you have a disability requiring an accommodation, please contact the Disability Services (disability.tamu.edu) in Room B118 of Cain Hall or call 845-1637.

INSTRUCTOR: Dr. Devesh Ranjan
OFFICE: ENPO 311 PHONE: 979-458-3580
E-MAIL: dranjan@tamu.edu (grades cannot be discussed via e-mail or telephone)
OFFICE HOURS: TR 2:00-3:30 PM or by appointment*
*Note that I try to be very good about responding to emails promptly. If you have a quick question, send me an email.

GRADING POLICY: Homework 25% 90 ≤ A ≤ 100; 80 ≤ B < 90
Mid-Term Exam 20% 70 ≤ C < 80; 60 ≤ D < 70
Final Examination 20% F < 60 (lower bounds may or may not be adjusted to student advantage. Adjustment is not certain and may not occur).
Group Project 25% adjusted to student advantage.
Oral Exam 10% is not certain and may not occur.

HOMEWORK: Homework will be assigned in class on a regular basis. Feel free to discuss the problems with your fellow classmates, but be sure to turn in an individual assignment. The due date for the homework will be announced in class. No late assignments will be accepted after the solutions have been posted on the e-learning website.

EXAMINATIONS: There will be a seventy five in class examinations during the semester, and a two-hour/ take-home final at the end of the semester. Unexcused absences will result in a grade of zero for missed examinations.

PREREQUISITES: MEEN 344–Fluid mechanics

SUGGESTED BOOKS

COURSE CONTENT: The development of turbulence models requires much experimental input and increases the need for detailed experiments to provide verification in different flows. The purpose of this course is to introduce the fundamental principles, formulations and mathematical techniques associated with different measurement techniques used in turbulent flow analysis. Some of the key measurement techniques which will be discussed in this class are: hot-wire/hot-film anemometry, laser anemometry, Laser Doppler Velocimetry, Particle Image Velocimetry, Planar Laser Induced Fluorescence. A brief introduction to the LabVIEW programming will be given in the class.

PROJECT: One team project will be assigned by the end of the sixth week. You can choose your own group members (group size < 3). The formal written and oral presentation will constitute a significant part of your grade. The project assessment guidelines will be discusses during the seventh week of the semester.
MEEN 637 - Turbulence Measurement & Analysis

Topics to be discussed in class

**Governing Fluid Mechanics Equations**
- Conservation of mass, momentum, and energy
- Navier-Stokes equation
- Reynolds averaged Navier-Stokes equation
- Orr-Sommerfeld equation

**Pressure Instrumentation**
- Manometers & Pressure transducers
- Static pressure measurement
  - Pressure taps
  - Flush mounted probes
  - Pressure sensitive paint
- Impact pressure measurement
  - Pitot probe
  - Dynamic impact pressure probes
  - Multi-hole pressure probes

**Hot-wire/Hot-film Anemometry**
- Governing equations for heat transfer
- Constant temperature anemometer systems
- Calibration for temperature, velocity, density, and yaw
- Modal decomposition of measured voltage into meaningful quantities
- Conditions where decomposition can be simplified
- Wall shear stress measurements using hot-films

**Laser Anemometry**
- Two-spot (L2F or Time of Flight) anemometry

**Laser Doppler Anemometry (LDA or LDV)**

**Particle Image Velocimetry (PIV)**
- Doppler Global Velocimetry (DGV)

For all cases examine:
- Flow reversals
- Fringe bias
- Velocity bias
- Optical consideration
- Seed considerations

**Reynolds Stress Tensor Measurement**
- Hot-wire/Hot-film anemometry
  - 1 Sensor
  - 2 Sensors
  - 3 Sensors
- Laser Anemometry
  - L2F
  - LDA (1-D, 2-D, and 3-D)
  - PIV
  - DGV

Advantages and Disadvantages

**Temporal-Spectral Analysis of Data**
- Mean velocity
- Turbulence Intensity

**Auto-correlations**
- Cross-correlations
- Spectra (wavenumber and frequency)
- Coherence
- Wavelet Analysis

Implementation using:
- Hot-wire/Hot-film anemometry
- Laser anemometry

**Computer Implementation of Data Acquisition & Analysis**
- LabView Programming
- Analog-Digital conversion
  - Mean velocity & turbulence intensity
  - Sampling rate
  - Number of samples
  - Gaussian error distribution assumption
  - Statistical criterion
  - Turbulence criterion
- Calculation of temporal-spectral quantities
  - Spectral analysis
    - Fast Fourier Transform (FFT)
    - Spectra
    - Cross-Spectra
    - Coherence
    - Aliasing
- Calculation of Auto-correlation and Cross-correlation

**Measurement of Coherent Structures (Chaos)**
- Conditional Sampling
- Coherence measurement
- Spectral measurement
- Correlation coefficients

**Turbulence Induced Phenomena**
- Turbulence induced accelerations
- Later transfer of momentum (mixing)
- Turbulence production
- Turbulence kinetic energy
- Turbulence dissipation
- Turbulence length scales & energy cascade
- Which and how can these be measured?

**Vorticity**
- Mean vorticity
- Vorticity fluctuations

**Density Field Measurements**
- Planar Laser Induced Fluoroscence
- Chemistry intensive techniques
- Shadowgraphy and Schlieren techniques
- Importance of Calibration
- Image analysis