

# ME724 – Essentials of Turbulence

## 1 Instructor & TAs

### 1.1 Instructor

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### 1.2 Teaching Assistants

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## 2 Books and References

- **Main reference:** “Turbulent Flows” by Stephen B. Pope
- “Turbulence” by Uriel Frisch
- “A First Course in Turbulence” by Tennekes and Lumley
- “Statistical Theory and Modeling for Turbulent Flows” by P.A. Durbin

## 3 Pre-requisites

- Undergraduate Fluid Mechanics (Compulsory)
- Engineering Mathematics (Compulsory)
- Ability to program, perform data analysis (Compulsory)
- Advanced Fluid Mechanics (Not compulsory, but desirable)
- Familiarity with probability theory, tensor algebra and constitutive equations (Not compulsory, but desirable)

## 4 Schedule of Lectures (25 Lectures)

- Jan: 5, 8, 12, 15, 19, 22, 29
- Feb: 2, 5, 9, 12, 16, 19 (Midsem from 22nd – 27th Feb)
- March: 1, 4, 8, 11, 15, 18, 22, 29
- April: 1, 5, 12, 15

## 5 Course Contents

This is an introductory graduate-level course on turbulence, which will focus on fundamentals as well as applications of turbulence. The students will experience hands-on implementation of turbulence models in open source softwares like OpenFOAM.

Topic	Details	Lectures
Introduction	Examples of turbulence, Chaos, Attractors	1
Fundamental Fluid Mechanics	Navier Stokes Equations, Pressure Poisson Equation, Cartesian Tensor Notation, Strain and Vorticity Tensors	2
Hydrodynamic stability	Normal mode analysis, Kelvin-Helmholz Instability, Raleigh Criterion, Orr-Sommerfeld Equations	2
Statistical Description of Turbulent Flows	Random variables, probability distributions, random fields, probability and averaging	2
Mean flow equations	Reynolds equations, Reynolds stresses, mean scalar equation, gradient-diffusion equation and turbulent-viscosity, Mixing length models	2
Free Shear Flows	Round and Plane jets, similarity solutions, mechanisms for entrainment	2
Scales of Turbulent Motion	Vortex Dynamics, Energy cascade in isotropic turbulence, Kolmogorov's 2/3rds and 4/5ths law, Refined Similarity Hypothesis	4
Wall Bounded Flows	Channel Flow, Boundary Layers, Length Scales (+ units), Mixing Length Models, Matched Asymptotics, Log-law hypothesis, energy budget, Monin Obhukov Similarity	4
Turbulent viscosity models	Algebraic models, $k-\epsilon$ model, $k-\omega$ model, Spallart-Allamaras model, Model Constants	2
Reynolds stress models	Exact RST equations, pressure strain, Rotta's return to isotropy, Rapid distortion theory, wall functions, elliptic relaxation, $v^2 - f$ model	4
Turbulent Mixing	Passive scalar spectra, homogeneous vs inhomogeneous mixing	1
Stochastic methods	Langevin Equations for Turbulence, Dispersion of particles, Reaction	3
Direct Numerical Simulations	Numerical Methods, Spectral Methods, Convergence	1
Large Eddy Simulation	Filtering, Subgrid Stress, Smagorinsky model, Dynamic Smagorinsky, Wall Modeling	3

## 6 Logistics

<b>Time, venue etc.</b>	
No. of lectures:	25
No. of tutorials:	Around 3-4
Duration of each lecture:	1 hr 25 mins
Timing :	2:00pm – 3:25 pm, Tue and Fri
Venue :	LT301
Extra/Makeup classes and Tutorials:	May be held on Saturdays at a different venue
Office hours :	Please take appointment via email for doubts/clarifications.

  

<b>Assignments</b>	
Number of assignments :	Around 4-5 individual and 4 group assignments. You will be given around 3 weeks to attempt each.
Final Project:	1 final project, which needs to be presented before end of semester.
Assignment submission :	Assignments will be accepted <i>ONLY</i> as hard copies. Scanned assignments will <i>NOT</i> be accepted. Typing your assignments in Word/Latex is not required, as long as your handwriting and presentation is legible.
Due date :	Due date will be stated on the assignment and announced in class. The assignment has to be submitted before 5:30 p.m. on due date (a) in class or (b) in my office mailbox (my name is written on the mailbox) or (c) it can be slipped under my office door (Rm # 322 ME building).
Penalty for late submission :	You will receive 25% penalty on the assignment if it is submitted after due date. Late assignments will not be accepted after 2 days post due date. For example, if an assignment is due on, say, 15th Aug, then you will get a 25% penalty if you submit assignment on 16th Aug or 17th Aug. It won't be accepted 17th Aug, 5:30 p.m. onwards. Further grace period is possible only if you have some kind of medical emergency.

## Group Projects

You will receive individual as well as group assignments in this course. Each “group” can consist of *at most* 3 students, although you may also solve the group assignment by yourself if you wish.

Group work can be tricky, primarily because group members may not be able to contribute their time and effort to the project equally. On the other hand, group projects can be a great place to pool your resources and learn from each other. Communication between the members plays a vital role in ensuring the success of any group project. My advice would be to first understand the skill sets of your groupmates when you first meet. Before a group meets to brain-storm on a problem, each member should have thought through the problem individually. After the first group discussion, the problem should be divided between the members, as equally as possible. However, each member will be responsible for making sure that the whole problem is being solved correctly, and should take a close look at the assignment before submission. By the time the group is submitting the assignment, each group member should be able to solve the whole problem by themselves. I may conduct a viva to ensure this.

## Final Project

Final project will have to be done in groups of *at most* 2 students. Grades will be given on final presentation and report. Exact format of project topic allocation etc will be announced in the following lectures.

## 7 Penalties for copying assignments/exams

**Definition of “copying”** : You have “copied” if you have looked at your classmate’s assignment, mindlessly jotted down all or part of it, and then submitted your copy as a separate assignment/answer sheet.

Copying, whether it is for assignments, projects or exams, is a serious offense at IIT Bombay. Moreover, awarding marks for copied assignments/exams is very discouraging for students who are trying to attempt the problems by themselves. Therefore, copying will be taken *VERY* seriously in this class. In the case of assignments, while you may discuss the concepts in the problems with your classmates, you *MAY NOT* copy each other’s assignments.

**Penalty for copying:** It is actually fairly easy to find out whether an assignment/exam solution has been copied or not. You will get a zero for an assignment that we think you have even partially copied. If we find that, say, 3 students, A,B,C have copied a problem from each other, then *all 3 will be handed zeroes for the whole assignment*, regardless of who

solved the problem “originally”. You may contest the penalty in person after receiving your corrected assignments. Following types of arguments will not work:

- “*I attempted it myself, the other person copied it.*” (Sorry, allowing another person to copy is equally unacceptable.)
- “*Someone copied my assignment without my knowledge.*” (That’s too bad – you need to guard your assignment !).
- “*X,Y,Z also copied but did not receive the penalty.*” (We are not the police.)
- “*I have copied only part X of the assignment problem.*” (We don’t have time to cross-check sub-parts.)

## 7.1 Tutorial Format

We will mainly discuss concepts related to problems given in assignments.

## 7.2 Attendance Policy

Attendance will be taken every class. You are expected to be in class within 5 mins of the start time. You may *NOT* be allowed to fill in attendance if you arrive late. If you have attendance of 80% or below then you may lose a grade. If you have less than 50% attendance then you may get a DX grade automatically. You may also be reported to the Dean of Academic Affairs if your attendance is below 80%. However, the most important incentive for attendance is that the syllabus is vast, and therefore the subject matter is most easily grasped in class.

# 8 Grading

Points Breakup	
4-5 Individual Assignments	20%
4 Group Assignments	15%
1 Project	15%
4 Quizzes (30 mins each, best 3 out of 4 counted)	20%
Endterm	30%

Tentatively, the following grading policy will be used:

<b>Grades</b>	
AA	90-100%
AB	81-90%
BB	71-80%
BC	61-70%
CC	51-60%
CD	46-50%
DD	40-45%
FR	Below 40%
Audit Grade	40%-100%