课程大纲
COURSE SYLLABUS

1.	**课程代码/名称** **Course Code/Title**	MAE5015 湍流 Turbulent Flows
2.	**课程性质** **Compulsory/Elective**	专业选修课 Subject-Elective
3.	**课程学分/学时** **Course Credit/Hours**	3 学分 / 48 学时 3 Credits / 48 Hours
4.	**授课语言** **Teaching Language**	英文 English
5.	**授课教师 Instructor(s)**	夏克青 XIA Ke-qing
6.	**先修要求** **Pre-requisites**	掌握基本的流体力学知识 Fluid mechanics background required

7. 教学目标 Course Objectives

湍流是自然界和各种工程应用中普遍存在的流体运动状态，也是非常具有挑战性的物理问题。本门课程将会介绍湍流的基本概念，例如湍流的时间和空间尺度、雷诺剪切应力、湍动能和能谱、能量级串等，并将这些知识应用到不同的湍流系统当中，具体包括均匀各向同性湍流、壁湍流、可压缩湍流和二维湍流。在本课程当中，学生需要阅读相关的经典文献和最新的研究综述，从而更好地了解湍流研究的现状和未来的发展趋势。

This course is to introduce the phenomena and theory of turbulence, a very common state of fluid motion in nature and engineering, and a very challenging physical problem. In this course, we will introduce a number of fundamental concepts about turbulence, such as the range of scales, Reynolds stress, the turbulence kinetic energy budget, and energy cascade. We focus on both understanding the fundamentals and the use of such knowledge in various kinds of turbulent flows. Specific flow phenomena addressed will include homogeneous isotropic flows, wall-bounded flows, compressible flows and two dimensional flow. Students will be required to explore classical and recent literature to study the development of turbulence research.

8. 教学方法 Teaching Methods

讲授 + 习题课 + 课程项目
Lecture + Tutorial + Project

9. 教学内容 Course Contents

Section 1	绪论（3 学时）： 湍流的基本特性，湍流的空间和时间尺度，分析湍流问题的基本方法，湍流研究进展回顾 Introduction (3 hours): The nature of turbulence, Length and time scales in turbulent flows, Basic methods for analysis of turbulence, An overview of recent development

Section 2	流体运动方程（3 学时）： Navier-Stokes 方程的张量形式，压强的作用，被动标量，涡量方程，流体的拉伸和旋转，欧拉场和拉格朗日场 The equations of fluid motion (3 hours): Navier-Stokes equations in tensor form, The role of pressure, Conserved passive scalars, The vorticity equation, Rates of strain and rotation, Eulerian and Lagrangian fields
Section 3	概率描述方法（3 学时）： 随机变量的特征，耦合随机变量，随机过程，统计取样，概率和平均 The statistical description (3 hours): Characterization of random variables, Joint random variables, Random processes, Statistical sampling, Probability and averaging
Section 4	平均流动方程（3 学时）： 雷诺方程，雷诺应力，平均标量方程，梯度扩散，湍流粘度假设 Mean-flow equations (3 hours): Reynolds equations, Reynolds stresses, The mean scalar equation, Gradient-diffusion, Turbulent-viscosity hypotheses
Section 5	湍流动能和湍流动力学（3 学时）： 湍动能，湍动能方程，涡动力学 Kinetic energy budget and turbulent dynamics (3 hours): Kinetic energy, Kinetic energy equation and energy budget, Vortex dynamics
Section 6	能谱（3 学时）： 相关函数和结构函数，波数空间的能谱，谱传递，傅立叶模态的演化 The spectral descriptions (3 hours): Correlations and structure functions, Spectra in wave number space, Spectral transfer, The evolution of Fourier modes
Section 7	能量级串和相似性（3 学时）： 能量级串，Kolmogorov 假设，局部各向同性，均匀各向同性湍流，2/3 律和 4/5 律，间歇性 Energy cascade and scale similarity (3 hours): Energy cascade, Kolmogorov’s hypotheses, Local isotropy, Homogeneous isotropic flow, Inertial range, The two-thirds and four-fifths laws, Intermittency
Section 8	自由剪切流（3 学时）： 湍流射流、湍流尾流、混合层、热羽流

		Free shear flow (3 hours): Turbulent jets, Turbulent wakes, Mixing layers, Thermal plumes
	Section 9	壁湍流（3 学时）： 槽道流，管道流，近壁剪切，摩阻律，壁粗糙度，混合长 Wall-bounded shear flows (3 hours): Channel flow, Pipe flow, The near-wall shear stress, The friction law, Wall roughness, The mixing length
	Section 10	边界层（3 学时）： 平均速度剖面，内标度和外标度，指数律层，湍流猝发和湍流结构 Boundary Layers (3 hours): Mean velocity profiles, Inner and outer scalings, Logarithmic layer, Turbulent bursts and structures
	Section 11	可压缩湍流（3 学时）： 可压缩效应，密度涨落，激波，激波和湍流的相互作用 Compressible turbulence (3 hours): Effects of compressibiltiy, Density fluctuations, Shock wake, Shock-turbulence interactions
	Section 12	二维湍流（3 学时）： 二维流动，能量反级串，涡拟能级串 Two dimensional turbulence (3 hours): Two dimensional flow, Inverse energy cascade, Enstrophy cascade
	Section 13	湍流扩散（3 学时）： 湍流的拉格朗日描述，相对扩散，单粒子扩散，双粒子扩散，Richardson 维象论 Turbulent Dispersion (3 hours): Lagrangian characteristics of turbulence, Relative dispersion, Single particle dispersion, Pair dispersion, Richardson’s phenomenology
	Section 14	湍流研究进展：理论（3 学时）： Kolmogorov 理论回顾，多分形模型，壳模型，临界现象，重整化群方法 Recent development in turbulence I: Theory (3 hours): Revisit Kolmogorov theory, Multifractal model, Shell model, Critical phenomena, Renormalization group method
	Section 15	湍流研究进展：实验（3 学时）： 高雷诺数实验，现代湍流研究中的实验技术和设备

		Recent development in turbulence II: Experiment (3 hours): High Reynolds number experiments, Modern techniques and facilities in turbulence research
	Section 16	湍流研究进展：模拟和计算方法（3 学时）： RANS 方法，大涡模拟方法，直接数值模拟 Recent development in turbulence III: Modelling and simulation (3 hours): Reynolds-averaged Navier-Stokes approaches, Large-eddy simulation, Direct numerical simulation

10. 课程考核 Course Assessment

课堂表现 10% + 平时作业 20% + 课程项目 30% + 测验 40% (20%×2)
Class Performance 10% + Assignments 20% + Project 30% + Tests 40% (20%×2)

11. 教材及其它参考资料 Textbook and Supplementary Readings

教材/Textbook

Turbulent Flows by S.B. Pope (2000, Cambridge University Press).

参考书目/Supplementary readings

1. *A First Course in Turbulence* by H. Tennekes and J.L. Lumley (1972).
2. *Statistical Fluid Mechanics (Vols. 1–2)* by A.S. Monin & A.M. Yaglom (1971, 1975).
3. *Lectures in Turbulence for the 21st Century* by William K. George (2013).
4. *A Voyage Through Turbulence* edited by P.A. Davidson, Y. Kaneda, K. Moffatt and K.R. Sreenivasan (2011).
5. *An Introduction to Turbulent Flow* by J. Mathieu and J. Scott (2000).
6. *Turbulence: an Introduction for Scientists and Engineers* by P.A. Davidson (2004).
7. *Turbulence: the Legacy of A.N. Kolmogorov* by U. Frisch (1995).
8. *The Physics of Fluid Turbulence* by W.D. McComb (1990).