Fluid Mechanics II – Advanced Topics:

1. **Fluid Kinematics**

Construction of flow from specified distribution of rate of dilatation and vorticity: The multipole expansion, Canonical vorticity distributions: Examples include straight line vortex, Circular line vortex (the Frankel-Norbury family of vortex rings), vortex sheet, the Hamiltonian structure of Point vortices.
Flow field with zero vorticity and dilatation everywhere (Incompressible potential flows): Introduction to velocity potential, Properties and examples of potential flows, Complex variable formulation for potential flows (Method of Images, the Riemann sphere), Velocity potential in multiply connected domains

2. **Equations of motion**

The Cauchy and the Navier Stokes equations
Non-dimensionalization of equations of motion, Dimensionless parameters
Equations in the rotating reference frame, Coriolis force, the Taylor-Proudman Theorem, Geostrophic flows, Inertial waves
Microscopic interpretation of transport properties: Temperature and pressure dependence of shear viscosity (liquids and gases), The concept of bulk (volume) viscosity
Conditions for Incompressibility
The no-slip boundary condition

3. **Unidirectional flows**

Impulsive motion of an infinite flat plate (Rayleigh's first problem) – Introduction to momentum diffusion; the two-plate problem; relation between the one plate and two plate problems.
Internal and external flows driven by an impulsively rotated cylinder (Fourier-Bessel expansions).
Steady Flows in a rotating reference frame - the Ekman spiral, Ekman pumping and the Tea-Leaf paradox.
Steady and pulsatile pipe flow - Perturbation approaches for small and large frequencies, I

4. **Nearly unidirectional flows: low Reynolds numbers**

Low-Reynolds number lubrication flows: the sliding block problem, Analysis of the normal approach of rigid cylinders, spheres and drops, The Reynolds Lubrication equation, Gravity and surface tension-driven spreading of thin film on a flat substrate, Centrifugal spreading (Spin-coating).

5. **Fully three-dimensional (Stokes) flows: low Reynolds numbers**

Introduction to spherical-harmonics-based solution of the Stokes equations, Solution for a translating particle/drop in Stokes flow, Drag for anisotropic bodies, the Boussinesq-Scriven Interfacial boundary condition, Thermo-capillary migration, Principle of dynamic reversibility for Stokes flows.
Motion of particles in rotating fluids, Wave-drag on floating particles.

6. Non-Newtonian Fluid Rheology

Maxwell model for linear viscoelasticity, Contrasting Newtonian and viscoelastic flow phenomena, non-linear constitutive models: the upper convected Maxwell and Oldroyd-B models for dilute polymer solutions, Microstructural responses in weak and strong flows, the retarded motion expansion.
Viscoplastic fluids – The squeeze-flow paradox.

7. Large-Reynolds-number flows

Potential flow theory for slender bodies of revolution.
Singular perturbation concepts at small Re and the Laminar wake, Scaling arguments for Turbulent wakes.
The Origin of Lift (2D aerofoil theory), Effect of finite span on tip vortices, Wake behind a Lifting body.
Axisymmetric and Planar jets, Scaling arguments for Turbulent jets.
Large-Reynolds-number gravity currents.
The Laminar boundary layer and related topics: Boundary layer hypothesis and singular perturbation at large Reynolds number, the Blasius boundary layer, Drag coefficient v/s Re curve for streamlined bodies, Scaling arguments for the turbulent boundary layer.
The Falkner-Skan solutions: effect of ambient pressure-gradient.
Flow past bluff bodies: Boundary layer separation.
Drag coefficient v/s Re for bluff bodies; Laminar-Turbulent transition and the drag crisis.
Jeffery-Hamel flow: Breakdown of Boundary-layer hypothesis and solution multiplicity as function of Re.

8. Natural and Forced convection

Relevant dimensionless parameters (the Grashof and Rayleigh numbers), the inertial and viscous convection regimes, the Rayleigh Benard and double diffusive problems.
The self-similar Laminar (buoyant) plume, scaling arguments for the turbulent plume.
Forced convection: Heat and Mass transfer from drops at small and large Peclet numbers, the Nusselt vs Peclet scalings for the exterior and interior problems.
Acoustic streaming.

9. The Bernoulli theorem

Open Channel flows (Subcritical vs Supercritical flows), Convergent-Divergent Nozzle: 1D compressible flows,
Volumetric oscillations of a bubble (the Rayleigh-Plesset equation), Shape oscillations of a bubble, Bjerknes forces, Sound propagation through two-phase bubbly flows.

10. Hydrodynamic stability