

# Final Exam Prep

## Lecture



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## Outline

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What Have We Learned

Topics and Problems

Examples

# What Have We Learned

Topics:

- Dimensional Analysis, Balance Laws
- Potential Flow, Boundary Layers, Lift and Drag
- CFD Theory and Usage
- Nozzles, Shock Waves
- Fan and Turbine Analysis

Wide range of fluid dynamics:

- Incompressible and Compressible
- Inviscid and Viscous
- Theory, Computation, and Experiment
- Applications: wind tunnels, aircraft, propellers, wind turbines, flow around an island, running in the rain, mobula rays, airfoils, multi-element airfoils, jet engines, vortex rings, sonic boom, car aerodynamics, fans, hot air balloons, meteors, supersonic projectiles, sprinklers, pumps, balloon in a car, sailing, sports ball aerodynamics

Emphasis on:

- Open-ended Problems
- Computation
- CFD Usage
- Applications
- True Principles. Connection between Spiritual and Secular.

# Topics and Problems

## Dimensional Analysis

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- Re, Ma, Fr, St, pressure/lift/drag/power coefficient
- Forming nondimensional groups
- Similitude

## Types of Problems:

- Form nondimensional equations
- Recognize common groups and what they mean
- Similarity analysis (i.e., translate drag from wind turbine to full scale)

## Balance Laws and Control Volumes

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- rate of accumulation = rate of inflow - rate of outflow + rate of production
- mass balance
- linear momentum balance
- Bernoulli's Equation (energy)

## Types of Problems:

- define appropriate control volumes
- mass/momentum balances and Bernoulli's equation

## Potential Flow

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- Laplace's equation
- Basic solutions
- Superposition of solutions
- Kutta-Joukowski Theorem
- D'Alembert's Paradox

## Types of Problems:

- Calculate velocity and pressure fields from basic solutions (and superpositions of solutions)
- Understand D'Alembert's Paradox
- Compute lift based on circulation

## Boundary Layers

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- Boundary Layer Thickness
- Displacement Thickness
- Momentum Thickness
- Laminar and Turbulent
- Blasius Solution (and Schlichting empirical formulas)
- Momentum Integral Boundary Layer Equation
- Transition and Separation

## Types of Problems:

- Compute boundary layer thicknesses
- Understand differences between laminar and turbulent profiles
- Use Blasius and Schlichting formulas
- Compute skin friction drag
- Understand transition and separation

## Lift and Drag

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- Circulation
- Skin friction drag. Pressure drag.  
Lift-dependent drag. compressible drag (later)
- Integral Methods
- Tabular Methods
- Downwash



## Types of Problems:

- Understand difference in different forms of drag, how they arise, how shape and flow conditions affect them, and how they might be computed.
- 2D and 3D lift/drag coefficients

## CFD

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- Common problems
- Theory
- Verification and Validation
- Richardson extrapolation
- $y^+$
- RANS/LES/DNS

## Types of Problems:

- CFD Concepts
- $y^+$  calculation
- Richardson extrapolation calculation

## Compressible Flow

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- Thermodynamics
- Energy Equation
- Speed of Sound
- Total/Stagnation Properties
- $f(M)$  mass balance equation
- over/under expanded
- compressible drag
- Normal shock waves
- oblique shock waves

## Types of Problems:

- Thermodynamic relationships
- compute speed of sound
- compute total properties
- nozzle analyses including nozzles with normal shocks
- normal/oblique shock calculations
- compressibility drag for simple shapes

## Turbomachines

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- Pump vs a turbine
- Torque and rotation
- Velocity triangles
- Angular momentum balance

## Types of Problems:

- Identify a pump vs a turbine
- Radial flow rotor analysis
- Axial flow rotor analysis
- Torque, Power, mass flow, work per unit mass

## Examples

- 7-48: dimensional analysis
- 5-36: control volume
- 6-69: potential flow
- 9-21: boundary layer thickness
- 9-52: skin friction drag
- 11-70: nozzle/shock
- 12-50: turbomachine