Topics for the written exam in the PhD admission

AE 1: Dynamics and controls

I. Classical Control Theory

- Open-loop and closed-loop control systems, unity negative feedback control systems.
- Response of higher order systems to standard and generic inputs in Laplace and time domains, concept of partial fractions.
- Concept of system stability and connection with its response, asymptotic and bounded-input bounded-output stability, role of characteristic roots in stability, Routh's criterion for absolute and relative stability analysis, including unknown parameter-based stability.
- Concept of root locus and its application to proportional control system analysis.
- Concept of frequency domain and frequency response, response representation using Bode, Nyquist and Nichol's plots, closed-loop system analysis using frequency response attributes, Nyquist stability analysis.
- Transient and steady-state response concept, tracking control task and closed-loop error constants, integral control option for tracking, transient response and role of derivative action.
- PI controllers and lag compensators for tracking control tasks, PD controllers and lead compensators for transient response control tasks, PID controllers and lag-lead compensators for complex control tasks.
- Closed-loop performance specifications, gain and phase margins as design specifications, use of root locus, Bode plots, Nyquist plots and Nichol's plots in closed-loop control design, design rules, methodologies and guidelines for different types of control tasks.

II. Modern Control Theory

- Time domain representation of dynamical systems, basics of time response of higher order linear systems, algebraic perspective for dynamical system response.
- Vector spaces, concept of linear independence, basis vectors and dimension, linear transformations.
- Solution of linear algebraic systems, concept of kernel and image spaces, concept of eigenvalues, eigenvectors and eigenspace.
- Diagonal and Jordan forms, characteristic equation, operator form of linear dynamical systems, analytic functions of square matrices and Cayley-Hamilton theorem.

- Dynamical system response in a vector space, representation of linear dynamical systems in the state-space, various canonical forms.
- Concept of fundamental matrix and state transition matrix, solution of homogeneous and nonhomogeneous systems, evaluation of matrix exponential.
- Energy based stability hypothesis, Lyapunov's theorem of stability, concept of phase plane and state-trajectory based stability analysis.
- Controllability of dynamical systems, regulator problem and full state feedback control structure, pole placement design technique, tracking control structures, optimal control system using Linear Quadratic Regulator (LQR), output feedback control concept.
- Concept of observability and its role in control, full and reduced order observers, observer controllers.

AE 2: Aerodynamics

I. **Basic Fluid Mechanics:**

- Conservation laws: Mass, momentum, and energy (Integral and differential form)
- Dimensional analysis and dynamic similarity

II. **Potential flow theory:**

- Sources, sinks, doublets, line vortex, and their superposition
- Elementary ideas of viscous flows, including boundary layers.

III. **Airfoils and wings:**

- Airfoil nomenclature; Aerodynamic coefficients: lift, drag, and moment
- Kutta- Joukowski theorem
- Thin airfoil theory, Kutta condition, starting vortex
- Finite wing theory: Induced drag, Prandtl lifting line theory
- Critical and drag divergence Mach number.

IV. **Compressible Flow:**

- Basic concepts of compressibility
- One-dimensional compressible flows
- Isentropic flows, Fanno flow, Rayleigh flow
- Normal and oblique shocks
- Prandtl-Meyer flow
- Flow through nozzles and diffusers.

V. **Special Topics:**

- Shock-boundary layer interaction
- Wind tunnel testing
- Measurements and visualization techniques.

AE 3: Propulsion

I. Thermodynamics

- Thermodynamic systems and processes
- Properties of pure substances, behavior of ideal and real gases
- Zeroth and first laws of thermodynamics
- Calculation of work and heat in various processes
- Second law of thermodynamics
- Thermodynamic property charts and tables, availability and irreversibility
- Thermodynamic relations.

II. Fluid Mechanics

- Fluid properties
- Fluid statics
- Forces on submerged bodies
- Stability of floating bodies
- Control-volume analysis of mass, momentum and energy
- Fluid acceleration
- Differential equations of continuity and momentum
- Bernoulli's equation
- Dimensional analysis
- Viscous flow of incompressible fluids
- Boundary layer, elementary turbulent flow, flow through pipes, head losses in pipes, bends and fittings
- Basics of compressible fluid flow.

III. Application of thermodynamic and fluid mechanics concepts to air breathing and non-air breathing engines.

- Air and gas compressors
- I.C. engines and gas turbine cycles
- Impulse and reaction principles
- Velocity diagrams
- Steam and gas turbines

AE 4: Structures

I. Concepts of stress and strain:

- Three-dimensional transformations
- Mohr's circle
- Principal stresses
- Three-dimensional Hooke's law
- Plane stress and strain.

II. Concept of strain energy

- Castigliano's principles.
- Statically determinate and indeterminate trusses and beams
- Elastic flexural buckling of columns

III. Structural Dynamics:

- Free vibrations of undamped and damped 1-degree of freedom systems.
- Forced vibrations of undamped and damped 1-degree of freedom systems.

IV. Finite element methods:

- Basics of weak formulation and shape functions.
- Formulation and solution using 1-dimensional finite elements.

V. Composite materials:

- Constitutive equations for a composite lamina.
- Classical lamination theory for laminates.