DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING, UNIVERSITY OF CALIFORNIA, IRVINE

Preliminary Examination Guidelines

I. Purpose of Exam

The Preliminary Exam establishes whether the Ph.D. Candidate has command of specified fundamental material in Applied Mathematics and one of five Topic Areas of mechanical and aerospace engineering. The Candidate must demonstrate capability to synthesize different elements of knowledge in the formulation and solution of open-ended problems and to exercise sound scientific scrutiny and judgment.

II. Format

The Preliminary Examination has two parts: **Applied Mathematics** and **Topic Area**. The Applied Mathematics examination is written; the Topic Area examination is oral. Each Candidate is required to take both parts. The Candidate must choose one of five available Topic Areas: Systems and Design, Dynamics and Controls, Fluid Dynamics, Solid Mechanics, or Thermal and Transport Sciences.

- **Applied Mathematics**: 150-minute written examination. See Appendix A for topics.

- **Topic Area**: 90-minute oral examination in one of the following subtopics:

    - Systems and Design.
    - Dynamics and Controls
    - Fluid Dynamics.
    - Solid Mechanics.
    - Thermal and Transport Sciences.

    Questions will be presented in writing to the student. See Appendices B – F for the topics in each Topic Area.

III. Preparation

The Preliminary Exam requires significant preparation. Good performance in classes alone does not guarantee good performance in the exam. Intensive and thorough review of the material, solving sample problems, and practice exam sessions with peers are highly recommended. The preliminary exam represents an excellent educational opportunity for the student to review and integrate undergraduate and graduate course material. In addition, it is very important that the Candidate practices and refines his/her presentation skills prior to the exam.

Attempting to take the exam without this level of preparation is not recommended.

IV. Schedule and Registration

The Preliminary Exam is offered in the Fall and Spring Quarters, at dates announced well in advance of the exam. Only students who have been formally admitted to the PhD program and have a PhD advisor on record are eligible to take the preliminary exam. All incoming graduate students who have been admitted to the PhD program and have previously received an MS degree must take the Preliminary Exam for the first time during the Fall Quarter of their second year in the program. If a second chance is required for the examination, it must be taken during the Spring Quarter of the second year. All incoming graduate students who have been admitted to the PhD program as MS/PhD students must take the Preliminary Exam for the first time in the Spring Quarter of their second year. If a second chance is required for the examination, it must be taken during the Fall Quarter of their third year. Students who do not take the Preliminary Exam in a timely fashion as defined above will not be considered to be in good academic standing and may not be allowed to continue in the Program.

The student together with the faculty advisor must petition for the Preliminary Exam at least six weeks prior to the start of the Exam period. Students should meet the requirements for "Demonstration of Oral English Proficiency for Teaching Assistant Employment" as described in the UCI Catalogue before petitioning for the Preliminary Exam. Petition forms are available at http://mae.eng.uci.edu/graduate/prelim_exam_form.pdf.

V. Examination Committees

The MAE Graduate Studies Committee chooses the Examiners, including exam chairs, for the five topical areas of the exam. At least four faculty members will constitute the examination committee for the Applied Math part. Three Examiners will be present during the Topic Area exam. The Candidate's faculty advisor should not be involved in any part of the exam.

VI. Grading

Each of the Examination parts will receive a separate pass or fail grade from the responsible faculty team. Any part failed in the first taking must be retaken. If any part is failed twice, the Candidate has failed the Preliminary Examination and may not continue for the Ph.D. degree. Candidates must pass both parts of the examination.

Appendix A: Applied Mathematics Topics

Textbooks

G -- Advanced Engineering Mathematics, by Greenberg, Prentice-Hall

C -- Linear System Theory and Design, by C-T Chen, Oxford Publishing, third Edition

H -- Applied Partial Differential Equations with Fourier Series and Boundary Value Problems, 4th Ed., Haberman, Prentice-Hall

F -- Partial Differential Equations for Scientists and Engineers, by S. J. Farlow, Dover paperback, 1993.

Topics

A. Linear Algebra

1. Vectors, norms, inner-products, orthogonality, adjoint operators, and their properties. G, Sections 9.1-9.5
2. Vectors spaces, linear independence, Wronskian, span and subspace, basis. G, Sections 9.6-9.9 Matrix Analysis
3. Matrices: determinant, inverse, domain, range, null space, rank. G, Chapter 10
4. Eigenvalues and eigenvectors. G, Sections 11.1, 11.2
5. Basic properties, diagonalization. G, Sections 11.2, 11.4
6. Properties of symmetric (Hermitian) matrices, positive (semi) definite matrices, etc. G, Sections 11.3) Ax = b and the Least Squares Problem
7. Basic definition, existence and uniqueness (rank conditions). G, Chapter 8 and Section 10.5
8. Solution by optimization. G, Sections 9.10

B. Ordinary Differential Equations And Dynamical Systems

9. Phase plane and its use to study second order ODE. G, Sections 7.2, 7.3
10. Solution to general LTI systems: first order form ($\dot{x} = Ax + Bu$), Leibnitz rule, the solution to the first order form. C, Section 4.2
11. Decoupling, diagonalization and modal forms. G, Section 11.5
12. LTV systems, state transition matrices and their properties. C, Section 4.5 Stability
13. General definitions. C, Chapter 5
14. LTI: eigenvalues and the complete picture. C, Sections 5.2-5.4
15. LTV systems and eigenvalues. C, Section 5.5 Nonlinear Dynamical Systems
16. Phase Portrait. G, Section 7.2
17. Equilibrium points, stability, linearization about equilibrium points, use of eigenvalues for

stability of equilibrium points. G, Section 7.3

18. Duffing equation. G, Section 7.6 Solving ODE's
19. Numerical solution: Euler's method. G, Section 6.2
21. Power series solution. G, Section 4.2
22. Frobenius solution (regular singular point). G, Section 4.3

C. Partial Differential Equations

23. From Physics to PDE: The linear 2nd-order diffusion equation, the Laplace and Poisson equations, the linear 2nd-order wave equation, and first-order linear and non-linear wave equation. Boundary conditions. H, Chapter 1 and 4. F, Lessons 1-4, 16, and 31-32.
24. Separation of variables, eigenvalue and eigenfunctions, superimposition principle. H, Chapters 2 and 4. G, Chapters 18 and 19. F, Lessons 5-8 and 26.
25. Fourier-series. H, Chapter 3. G, Chapter 17.
26. The Sturm-Liouville theorem, and generalize Fourier expansion. H, Chapters 5 and 8. G, Section 17.7-17.8. F, Lesson 9.
27. Multi-dimensional problems using separation of variables, double Fourier-series, Bessel functions, and Legendre polynomials. H, Chapter 7. G, Sections 4.4 and 4.6 and Chapter 20. F, Lessons 30 and 35.
28. Traveling waves, D'Alembert formula for the wave equation, vibration of finite strings, wave reflection at boundaries. H, Sections 12.1-12.5. G, Chapter 19 and Sections 18.4 and 20.4. F, Lessons 17-20.
29. Fourier transform and its application to the solution of PDEs. H, Chapter 10. G, Section 17.9-17.11. F, Lessons 11-12 and 21.
30. Laplace transform and its application to the solution of PDEs. H, Chapter 13. G, Section 18.4 and 20.4. F, Lesson 13.
31. Greens function method for solving Poisson equations, method of images. H, Section 9.5. F, Lesson 36.
32. Method of characteristics for 1st order linear and non-linear wave equations, the traffic flow equation, shock waves. System of linear first-order wave equations.. H, Chapter 12. F, Lessons 27-29.
33. Classification of 2nd-order partial differential equations. F, Lesson 23.

Appendix B: Systems and Design Topics

The Systems and Design Preliminary Exam is structured with two Parts as follows:

Part I – A 30-minute oral exam that will be taken by all students covering topics in System Modeling.

Part II – A 60-minute oral exam in which the student answers systems engineering and design questions in one of the following subtopic areas of his/her choice (chosen prior to the exam so that the appropriate examiners are present for the exam)

1. Robot Kinematics
2. Micro- and Nano- Systems
3. Biorobotics

Note that students taking the exam a second time must take Part II in the same subtopic area, unless approval has been given by the MAE Graduate Advisor.

Part I: System Modeling

Part I of the Systems and Design exam is a 30 minutes exam that will test the student's ability to present and illustrate their understanding of a system model. Before the exam, students are required to choose three models to study from the two chapters specified below. The student must inform the committee which three models they have chosen to study three weeks prior to the exam. The committee will then base Part I of the exam on one of the models, with the selected model revealed at the beginning of Part I of the preliminary exam session. The student will be asked to present the chosen model and analyze the resulting equations within a design framework.

Please select three models from the following two chapters:

Astrom KJ and Murray RM. *Examples in Feedback Systems: An Introduction for Scientists and Engineers*. (2^{nd} ed.) Princeton University Press. [Chapter 3: System Modeling and Chapter 4: Examples]

Optional references

Feedback Systems: An Introduction for Scientists and Engineers, 2nd Ed, Astrom KJ and Murray RM
A good reference for understanding first and second order system responses is "Review of First- and Second-order System Response" found at:

https://stuff.mit.edu/afs/athena/course/2/2.151/www/Handouts.html

Relevant UCI courses are MAE 157, 200A, 241, and 270, but it is not required to take these courses for this part of the SED prelim. It is expected that students may be able to master the exam material through independent study.

PART II: Systems and Design - Robot Kinematics Topics

Textbooks

1. J. J. Craig, Introduction to Robotics: Mechanics and Control (3rd Edition), Prentice Hall, 2004 [Craig]
2. L. W. Tsai, Robot Analysis: The Mechanics of Serial and Parallel Manipulators, Wiley-Interscience, 1999 [Tsai]
3. B. Siciliano and O. Khatib, *Springer Handbook of Robotics*, Springer, 2008 [Handbook]

Topics

1. Rotation matrix, homogeneous transforms, Lie groups. Handbook 1; Craig 2; Tsai 2

2. Angular velocity, spatial velocity, Lie algebras. Handbook 1; Craig 5; Tsai 4, 5

3. Rotation axis and Screw axis, Cayley's formula, matrix exponential. Handbook 1, Tsai 2

4. Force-Torque and Velocity-Angular velocity screws. Handbook 1, 3; Craig 5, Tsai 6

5. Derivation of kinematics equations. Handbook 1, 3; Craig 3, Tsai 2, 3

6. Solutions to direct and inverse kinematics. Craig 3, Tsai 2, 3

7. Jacobian and Virtual Work. Handbook 3; Craig 5, Tsai 6

8. Workspace and manipulability. Craig 1, 8; Tsai 1, 4, 5

PART II: Systems and Design - Micro- and Nano- Systems Topics

Textbooks

1. Madou, M. J. (2012). *Fundamentals of Microfabrication and Nanotechnology.* (3rd ed.) CRC Press. [FMN]
2. Ville Kaajakari (2009). *Practical MEMS*: Analysis and design of microsystems, MEMS sensors, electronics, actuators, rf mems, optical mems, and microfluidic systems. Small Gear Publishing [PMEMS]
3. Stephen D. Senturia (2004). *Microsystem Design*. (2nd ed.) Springer. [MSD]

Topics

Students are expected to take a sequence of courses composed of MAE 249 “Microsensors and Actuators” (introducing physical modalities of sensors and actuators as well as signal processing), MAE 252 “Fundamentals of Microfabrication” (introducing techniques for nano- and micro manufacturing), and MAE 247 “Microsystems Design” (introducing general principles for simulation and design of multi-physics microsystems). It is recommended that students take all three of these classes in sequence, and it is required that students specializing in Micro- and Nano- Systems take at least two of these classes before the prelim exam.

1. **Fabrication and Characterization Techniques**: UV lithography [FMN v.2 Ch 1,2], dry etching [FMN v.2 Ch. 3] & [PMEMS Ch.1], properties/characteristics of single crystal Si [FMN v.1 Ch.4] & [PMEMS Appendix F], wet bulk micromachining [FMN v.2 Ch 4], PVD, CVD, and surface micromachining [FMN v.2 Ch 7,10] & [PMEMS Ch 1]), conductivity measurements, capacitive measurements [PMEMS Ch 6, 8], profilometry, microscopy (Optical, SEM), Proximal Probes (STM, AFM) [all in FMN v.3 Ch 6], X-ray Analysis [FMN v.1 Ch 2].
2. **Principles of Sensing and Actuation**: fundamentals of capacitive actuation [PMEMS Chs15,], fundamentals of capacitive sensing [PMEMS Ch 6], Accelerometers [PMEMS Ch 3, Appendix B], Gyroscopes [PMEMS Ch 22], Pressure Sensors [PMEMS Ch 13], micro resonators [PMEMS Ch 20]), commercial multi-user fabrication processes, multi-physics modeling, and signal processing.
3. **Microsystems’ Design**: Scaling laws [FMN v.3 Ch 1,7] & [PMEMS Ch 14], beams as micromechanical springs [PMEMS Ch 4], thermal/piezoelectric actuation [PMEMS Ch 14, 16, 17], Multiphysics sensing thermal/ piezoelectric/ piezoresistive/ magnetic [PMEMS Ch 5, 7], Microfluidics [PMEMS Ch 23], system’s modeling through conjugated power variables/lump element models [MSD Ch 5], photolithography mask design.

PART II: Systems and Design – Biorobotics

Textbooks

1. Winter, D (2009). *Biomechanics and Motor Control of Human Movement*. (4th ed.) Wiley. [BMC, Chapters 2, 3, 5, 6, 8-10]
2. McMahon, T (1984). *Muscles, Reflexes, and Locomotion*, Princeton University Press [MRL, Chapters 1, 3, 6-8]
3. Burdet, E, Franklin, DW, Milner, TE (2013). *Human Robotics.* MIT Press [HR, Chapters 2-8, 11]
4. Popovic, M (2019). *Biomechatronics*. (1st ed.) Academic Press. [BM, Chapters 2, 3, 9, 10, 12]
5. Rosen, J (2020). *Wearable Robotics* (1st ed). Academic Press. [WR, Chapters 1, 11, 19, 23]

Topics

To supplement their study of the above material, it is suggested that students take at least two courses chosen from MAE 286 Design for Human Movement, MAE 250 Biorobotics, and BME 220 Sensory Motor Systems. Specific topics covered include:

1. **Muscle Mechanics and Motor Control**: muscle mechanics and physiology [MRL 1, 3, 6] [HR 3, 4], [BMC 9], muscle models (Hill model [MRL 1], [BMC 9]), somatosensation [HR 2] [MRL 6], multi-joint kinematics, dynamics, and impedance [HR 5, 6], motor control and learning [MRL 6] [HR 5, 6, 7, 8], neural control of locomotion [MRL 7].
2. **Kinematics, Kinetics, and Energetics**: biomechanical data processing and analysis [BMC 5, 10], principles of inverse dynamics [BMC 5, 8] [BM 2], mechanics of locomotion [MRL 8], mechanical work/energy/power, efficiency [BMC 6], metabolic energy expenditure [BMC 6].
3. **Robotic Rehabilitation Systems**: robotic actuator types [BM 3], designs, control, and limitations of exoskeletons and prosthetic devices [WR 1, 11, 19, 23][BM 9, 10], robotic therapy approaches [HR 11][BM 12].

Appendix C: Dynamics and Control Topics

Kinematics and Dynamics (Ref. 1, relevant course MAE 241)

- Particle kinematics and dynamics (Ch. 2, 3)
- Rigid body kinematics and dynamics (Ch. 7, 8)
- Rotation matrix and parametrizations. SO(3)
- Angular velocity
- Inertia matrix
- Newton-Euler equations
- Holonomic and nonholonomic constraints (Section 6-3)
- Lagrangian dynamics (Ch. 6)

Dynamical Systems and Control (relevant courses MAE 270A, 170)

- Benefits of feedback control (Ref. 2, Ch. 3)
- Linear control design using transfer functions via Root locus and Bode plots (Ref. 2, Ch. 4 and 5)
- Approximate linearization of nonlinear systems (Ref. 3, Ch. 2)
- Solution of $\dot{x} = Ax + Bu$ for linear time-invariant (LTI) and time-varying cases (Ref. 3, Ch. 4)
- Controllability and observability: definitions; tests for LTI system (Ref. 3, Ch. 6 and Ref. 5)
- Minimal state space realization for LTI system (Ref. 3, Ch. 7 and Ref. 5)
- Set point regulation via linear state feedback (Ref. 3, Ch. 8 and Ref. 5)
- Asymptotic tracking via linear state feedback (Ref. 3, Ch. 8 and Ref. 5)
- Observer design (Ref. 3, Ch. 8, and Ref. 5)

Optimization (Ref. 4, relevant course MAE 206)

- Theory
- Necessary and sufficient conditions for unconstrained minimization (Ch. 7)
- Necessary and sufficient conditions for constrained minimization (Ch. 11)
- Methods
- Steepest descent and Newton's method (Ch. 8)
- Penalty method for constrained optimization (Ch. 13)

References:

1. D. T. Greenwood, Principles of Dynamics, 2nd ed., Prentice-Hall, 1988.
2. Franklin, Powell, Emami-Naeini, Feedback Control of Dynamic Systems, Addison-Wesley, 1986 or equivalent undergraduate controls text.
3. C. T. Chen. Linear System Theory and Design, 3rd ed., Oxford University Press, 1999.
4. D. G. Luenberger and Y. Ye, Linear and Nonlinear Programming, 3rd ed., Springer, 2008.
5. R.A. Williams and D.A. Lawrence. Linear State Space Control Systems, Wiley Publishing.

Appendix D: Fluid Dynamics Topics

Textbooks

K & C -- P.K. Kundu and I.M. Cohen, *Fluid Mechanics Third Edition*, Academic Press, 2004. L & R – H. W. Liepmann and A. Roshko, *Elements of Gasdynamics*, Dover, 2002.

M-T -- L.M. Milne-Thomson, *Theoretical Hydrodynamics*, Dover 1996. S -- M.A. Saad, *Compressible Flow*, Prentice Hall, 1993.

V & K -- W. G. Vincenti and C. H. Kruger, *Introduction to Physical Gas Dynamics*, Krieger 1975. W -- Frank M. White, *Viscous Fluid Flow, Third Edition*, McGraw Hill 2006.

Topics

1. **Conservation laws and non-conservative forms**. Navier-Stokes equations, Euler equations, potential flow equations, including viscous potential flow. Nondimensional groupings of parameters, the incompressible limit, the inviscid limit. Energy and Entropy equations for both incompressible and compressible flows. K & C, Chapters 1, 2, 4; M-T, Chapters II, III.

2. **Use of non-primitive variables.** Kinematics, streamlines, planar and axisymmetric stream functions, velocity potential; key issues in vector calculus; generalized Bernoulli equation; vorticity dynamics; circulation, Kelvin's circulation theorem, Crocco's vorticity theorem; vortex lines, vortex tubes, vortex stretching; Kelvin's minimum energy theorem. K & C 3, 4, 5; M-T I, IV, IX, XIII

3. **Use of complex variables.** Complex potential. Irrotational flows: sources, sinks, doublets, irrotational vortex; wedge flows, corner flows and stagnation point flows; flow past circular cylinders with and without circulation; lift force and Kutta- Joukowsky lift theorem. K & C 6; M-T V, VI, VII, VIII.

4. **Method of images**. Vortex-vortex interactions, vortex-wall interactions. K & C 6; M-T VIII, XIII.

5. **Mappings.** Joukowsky transformation, flows around plates and elliptical cylinders. 2D airfoils: lift and drag; Kutta condition; theorem of Schwarz and Christoffel, flows with steps, channel flows with area changes and branches. K & C 6, 15; M-T VI, X

6. **Free surface flows.** Impinging jets; flow through an orifice. M-T XI

7. **Flow stability.** Biot- Savart Law for vortical flows; vortex sheets; Linear perturbation analysis for hydrodynamic stability, Kelvin-Helmholtz instability, Rayleigh-Taylor flow, gravity waves, centrifugal instability; dispersion relations. K & C 7, 12; M-T XIII, XIV, XV.

8. **Water (gravity) waves.** Deep-water and shallow-water limits, group velocity. K & C 7; M-T XIV, XV.

9. **Axisymmetric potential flow around bodies of revolution**. K & C 6; M-T 6; XVI, XVII, XVI,

XVII.

10. **Viscosity.** Stress and strain tensors, Newtonian fluids and coefficient of viscosity; Navier-Stokes equations for heat-conducting, compressible fluid; nondimensional groupings of parameters. Boundary conditions. Diffusion of vorticity. W 1, 2. 2.

11. **Exact solutions.** Couette, Poiseuille Taylor-Couette flows. Unsteady flows: Stokes first and second problems; Duhamel integrals. Similarity. Jeffrey-Hamel flow, separation. W 3.

12. **Low-Reynolds-number flows.** Stokes flow, Oseen approximation; lubrication theory. W 3.

13. **Laminar boundary layers.** High-Reynolds-number flows over plates and wedges, Blasius and Falkner-Skan similar solutions, stagnation-point flow; integral methods, momentum and displacement thicknesses; axisymmetric flows. Boundary layers with suction and blowing. Compressible boundary layers: Crocco and Busemann integrals, Howarth and Dorodnytsin transformations. W 4, 7.

14. **Free shear flows.** Viscous jets, wakes, and mixing layers. W 4, 7.

15. **Stability of laminar flows.** Linear theory of small disturbances, Orr-Sommerfeld equation and solutions; transition to turbulence. W 5.

16. **Turbulent flows.** Vorticity equation, vortex stretching; Concept of time-averaging, elementary statistics (mean, variance, correlation, spectrum), Reynolds-averaged Navier-Stokes equations (RANS), modeling of terms, derivation and explanation of the turbulent kinetic energy equation; turbulent pipe flow, law of the wall; turbulent boundary layer, mixing-length theory. W 6.

17. **One-dimensional steady flow.** Isentropic flow, area change and choked flow, friction, heat addition; normal shocks. Rayleigh and Fanno lines. L&R 2; S 5, 6.

18. **One-dimensional, unsteady flow**. Isentropic waves, travelling shocks, contact surface, shock-tube problem; method of characteristics, Riemann invariants; onedimensional and spherical acoustics. L&R 3; S 9.

19. **Two-dimensional compressible flow.** Oblique shocks; Prandtl-Meyer isentropic waves; method of characteristics, Riemann invariants; wave reflections and interactions. L&R 4; S 7, 9.

20. **Compressible potential flow.** Small perturbations in subsonic, transonic, and supersonic regimes, slender-body linearized supersonic aerodynamics, Prandtl- Glauert similarity rule; underexpanded and overexpanded flows through converging/ diverging nozzles (internal and external flow). L&R 8; S 8.

21. **Thermodynamic couplings.** The perfect gas law, physical significance of cp and cv, their dependence on molecular structure and temperature. K & C 1; W 7.

22. **Kinetic theory of gases.** Derivation of Navier-Stokes equations for monatomic gas; pressure forces at wall; use of Krook model to determine Newtonian relationship between viscous stress and strain. V & K 1, 2, 9.

23. **Elementary engineering flows.** Theoretical and practical knowledge of elementary engineering flows, from low to high Reynolds numbers: flow around cylinder, sphere, plate, airfoil, finite wing; orifice flow. K & C 9, 15; W 3, 4.

Appendix E: Solid Mechanics Topics

Textbooks

BJ -- Beer and Johnston, *Mechanics of Materials*, McGraw-Hill, 2005.

CTS -- Sun, *Mechanics of aircraft structures,* John Wiley & Sons, New York, 1998.

THGM -- Megson, Aircraft structures for engineering students, Butterworth- Heinemann, 2007. FT -- Fung and Tong, Classical and computational solid mechanics, World Scient., 2005.

MM -- Mase and Mase, *Continuum mechanics for engineers,* CRC, 2nd Ed., 1999.

DI -- Daniel and Ishai, Engineering mechanics of composite materials, Oxford University Press, 2006. KKC --Chawla, Composite materials: Science and engineering, Springer, 1998.

Topics

1. **Basic concepts of mechanics of structures**. Introduction to stress, strain and elastic behavior; torsion. Bending; shear stress in beams and shafts; M and V distribution in statically determinate and indeterminate beams. Shear flow in thin-walled beams (including multi-celled sections). Transformation of stress and strain (Mohr circle). Von Mises yielding criterion. Buckling of columns and simply supported plates. Elastic energy. Concepts of statical determinacy and indeterminacy. Solution of trusses and frames via displacement and force methods. *BJ, Ch. 1-11. THGM, Ch. 6.1-6.6.*

2. **Mechanics of composite materials**. Classifications of composite materials based on matrix chemistry and shape of the reinforcement. Common reinforcement and matrices for polymer matrix composites (PMC), metal matrix composites (MMC) and ceramic matrix composites (CMC). Elastic behavior of anisotropic materials. Stiffness of an orthotropic lamina: micro and macro mechanics. Strength of an orthotropic lamina: micro and macro mechanics. The shear-lag model for short fiber composites. Stiffness and strength of multidirectional laminates. The effect of temperature and humidity. Common experimental techniques for composite structures. *DI, Ch. 1-10. KKC, Ch. 1-8.*

3. **Basic concepts of Linear Elastic Fracture Mechanics**. Stress concentration and Griffith theory. Stress intensity factor. Strain energy release rate. Fracture toughness. *CTS, Ch. 6.3-4.* Fatigue failure. CTS, Ch. 6.5-6.

4. Fundamental mathematical concepts. Scalars, vectors and higher-order tensors. Indicial notation. Kronecker delta tensor; permutation tensor. Scalar (dot) product; cross product. Transformation of cartesian tensors. Principal values and principal directions of symmetric second-order tensors. Vector identities in tensor notation. Gauss and Stokes theorems. MM, Ch. 2. FT, Ch. 2.1-3.

5. **The stress tensor**. Alternate stress measures, Cauchy, first Piola, and second Piola stress tensors. Principal stresses and directions. Plane stress. Mohr's circle. Hydrostatic and deviatoric components of stress. Octahedral shearing stress. *MM, Ch. 3. FT, Ch. 3.1- 3.11.*

6. **Kinematics**. Material and spatial coordinates. Lagrangian and Eulerian description. Deformation gradients. Stretches of line, area and volume. Finite strain tensors (Green and Cauchy strain tensors). Strain rates. Material derivatives of line, area and volume elements. Infinitesimal strain and its geometric interpretation. Rotations. *MM, Ch.4. FT, Ch. 4.1-6, 4.9, 16.1-6.*

7. **Fundamental conservation laws**. Conservation of mass (continuity). Conservation of linear momentum. Conservation of angular momentum. Conservation of energy. First and second Piola-Kirchhoff stress tensors. Second law of thermodynamics and restriction on elastic properties. Invariance. *MM, Ch. 5. FT, Ch. 5, 16.7.*

8. **Constitutive equations**. Elasticity: generalized Hooke's law; isotropic elastic materials; symmetry considerations; relation among elastic properties. Plasticity: yield surface; flow rules for isotropic and kinematic hardening. *MM, Ch. 6. FT, Ch. 6.1-12.* Basic notions of viscoelasticity (Maxwell, Voigt and Kelvin models). *FT, Ch. 1.*

9. **Small deformation elasticity**. Navier's equations. Boundary value problems. Specified displacement and traction boundary conditions. Potential energy for hyperelastic solids. Uniqueness of solutions. Plane elastic waves (shear and dilational wave speeds). Two-dimensional problems: plane stress and plane strain. Airy's stress function in cartesian and polar coordinates. *FT, Ch. 7.1-4, 7.8, 9.1-3.*

10. **Principle of virtual work**. *FT, Ch. 10.7.*

11. **Basic notions of the Finite Elements method**. One and two-dimensional problems with one-dimensional elements (e.g. frames). Shape functions. Assembling global matrices. THGM, *Ch. 6.7-6.8.*

Appendix F: Thermal and Transport Sciences Topics

Preliminary Exam Format and Instructions

Paper Presentation and Exam

• The student is asked to prepare for a 15-minutes presentation on a research paper, which will be selected by the committee and announced 2 weeks before the exam, with no more than 15 slides

• The presentation is expected to include the following as an example

- Summary of approach and major findings
- Critique and/or support of approach and major findings
- Recommendations for future work or improvements

• The presentation will be interrupted by the committee, and the exam can last up to 80 minutes

• The examiners will ask questions on the paper and fundamentals of thermal/transport science

• For the fundamentals, study guide materials are provided in the next section

• The evaluation criteria will include the following aspects: Understanding of Paper, Critique of Work, Fundamental Questions, and Communication Skills

Preliminary Exam Study Guide Materials

Recommended Books

1. MSB&B – Moran, M.J., Shapiro, H.N., Boettner, D.D., & Bailey, M.B., Fundamentals of Engineering Thermodynamics, Ninth Edition, John Wiley & Sons, 2014.
2. IDB&L – F.P. Incropera, D.P. DeWitt, T.L. Bergman and A.S. Lavine, Fundamentals of Heat and Mass Transfer, Sixth Edition, John Wiley & Sons, 2006.

Related Topics

1. Basic concepts of thermodynamics: Energy, Forms of energy, Closed and open systems, Equilibrium and state, Thermodynamic properties of a system (U, V, m, T, P, etc.), Entropy and enthalpy, Reversible/irreversible processes, Energy storage modes (translation, vibration, rotation, and electron), Partition function and its relevance to the thermodynamic properties. MSB&B, Ch. 2-6.

2. Laws of thermodynamics and power systems: First/second/third law, First/second law analysis, Cycle analysis (e.g., Otto, Diesel, Brayton, and Rankine cycles...), Ideal/real refrigeration cycle,

Combustion process, Analysis of reacting systems. MSB&B, Ch. 8-10, 13.

3. Gas mixtures, chemical equilibrium and thermodynamic relations: Gas-vapor mixtures, Requirement for equilibrium, Chemical equilibrium, The Maxwell Relation, Thermodynamic relations involving enthalpy, internal energy, and entropy. MSB&B, Ch. 11-14.

4. Basic definitions and conservation of heat/mass transfer: Conduction, convection, and radiation, Fundamentals of mass transfer, Energy equation and special forms of the energy equation, Differential equations of mass transfer. IDB&L, Ch. 1.

5. Conduction heat transfer: Heat conduction equations, Lumped system formulation, Boundary conditions, Interface boundary condition. Simple analytical solutions of the conduction energy equation for steady & unsteady problems, IDB&L, Ch. 2-5.

6. Convection heat transfer: Forced vs. free convection, Laminar vs. turbulent flow, Internal vs. external flows, Dimensional analysis: characteristic quantities, dimensionless groups: Re, Pr, Ec, Nu, Gr, St, Order of magnitude scaling and negligible terms. IDB&L, Ch. 6- 9.

7. Radiation heat transfer: Fundamental physics of thermal radiation, Intensity, Black body radiation, Radiation properties of surfaces, Radiation exchange between gray-diffuse surfaces, Radiation exchange between surfaces using network method. IDB&L, Ch. 12,13.