# QUALIFYING EXAMINATION GUIDELINES

# FOR

# PH.D. CANDIDATES

August 2006

Aerospace and Mechanical Engineering Department
College of Engineering
The University of Arizona
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**GENERAL REMARKS**

This booklet was prepared for the benefit of the student and should be read in conjunction with the Graduate Catalog and the booklet on the Graduate Programs in the Department of Aerospace and Mechanical Engineering. The purpose of this booklet is to help the student to prepare for the Ph.D. Qualifying Examination.

In order to continue their doctoral studies, all Ph.D. students are required to pass the Qualifying Examination. Students who received their M.S. degrees from The University of Arizona must take the examination during their ***second semester*** in residence; students who received their M.S. degrees elsewhere must take the examination during their ***third semester*** in residence. This examination is given twice a year, mid September and early February, in the following areas:

**Biomedical**
**Controls**
**Engineering Mathematics**
**Fluid Mechanics**
**Kinematics and Dynamics**
**MEMS**
**Nuclear Engineering**
**Reliability Engineering**
**Solid Mechanics**
**Thermal Sciences**

## Qualifying Examination

In order to continue their doctoral studies, all Ph.D. students are required to pass the Qualifying Examination. This examination is given twice a year, usually around the middle of September and the beginning of February. The written portions for the three subject areas will be administered as follows: **2 subjects on Monday and math on Tuesday. The oral portion will be on Thursday and Friday.** Students who completed the requirements for the M.S. degree in the AME Department must take the Qualifying Examination no later than their second semester in residence for the Ph.D. degree. Students who completed the requirements for the M.S. degree at another institution must take the Qualifying Examination no later than their third semester in residence for the Ph.D. degree. **A student is not eligible to register for dissertation units (AME 920) until the Qualifying Examination has been passed.**

There shall be at least two designated preparatory courses for each subject area of the Qualifying Exam. A candidate for admission to the PhD program may be exempted from the written part of the Qualifying Examination in any subject exam in which the student has earned grades in two of the designated preparatory courses for that exam, with grades no worse than one A and one B. A candidate may also be exempted from the written part of any subject exam if the student has, without being enrolled in the courses, taken the regularly scheduled final examination of two of the designated preparatory courses, and earned grades in those final exams equivalent to no worse than one A and one B.
Prior to taking the oral examination and no later than the end of the third semester of the candidate's enrollment in the PhD program, all candidates must earn exemption in the manner described in the above paragraph. If there are not two designated preparatory courses offered in a chosen subject area during the first year of a candidate's enrollment in the PhD program, then the examination committee for that subject area must prepare and conduct a written examination for that candidate. The same shall be done during the second year of a candidate's enrollment, if that candidate has not otherwise had two opportunities to either earn exemption or pass the exam.

A candidate may be exempted from the written and/or oral part of any subject exam in which the student has, at a previous attempt, passed that exam with a clear pass. A clear pass shall be any numerical score equal to or greater than 60% when the passing score is 50%.

The examination areas and designated courses are: Some areas have more than two courses identified. Only two of the courses will be required.

| | |
|---|---|
| **Biomedical Engineering** | **AME 566 and BME 511** |
| **Engineering Mathematics** | **AME 500A, AME 500B** |
| **Controls, Stability, and Optimization** | **AME 558, AME 554** |
| **Fluid Mechanics** | **AME 536A, AME 536B** |
| **Kinematics and Dynamics** | **AME 550, AME 553, AME 560** |
| **Micro Electromechanical Systems (MEMS)** | **AME 586, AME 589** |
| **Nuclear Engineering** | **NEE 588, NEE 586, AME 530** |
| **Reliability Engineering** | **AME 572,574,575,577** |
| **Solid Mechanics and Structures** | **AME 561, AME 564A** |
| **Thermal Sciences** | **AME 530, AME 532, AME 533** |

Each student must choose Engineering Mathematics and two other examination areas. For each area, the test consists of a closed-book, written portion of two-hours duration and an oral portion of one-hour duration. Material on the tests is at the Master level. The Associate Department Head to the Graduate Program selects two examiners in each area. Students planning to take the examination should obtain the booklet "Qualifying Examination Guidelines" from the department, Room N712. In this booklet, typical textbooks illustrating the topics covered and the level of the material are listed for each subject area.

In the event of failure, a second qualifying examination is generally granted the following Semester. **No more than two attempts to pass this examination are permitted within AME, even if the student transfers between Aerospace Engineering and Mechanical Engineering.** The student is notified by mail as soon as possible after the results of the examinations are decided.

The intent of the qualifying examination is both (1) to evaluate the student's knowledge and understanding of the materials covered in the examination, and (2) to evaluate the candidate's potential to successfully complete a Ph.D. research program. Thus, while knowledge of the material and mathematical techniques covered in the individual examinations is important, the faculty look for much more than the ability to just memorize material. It is important that the candidate also have a good overall integrated understanding of the fundamentals of the material so that he/she can: properly relate the mathematical techniques and physical principles and apply these to engineering problems; apply the material to a wide range of situations including situations the student may not have previously seen; and be able to demonstrate the ability to think about problems in a logical and appropriate manner.

The topics to be covered in each examination area and typical textbooks covering these topics are in this booklet. The subcommittee responsible for each area prepared this information. Membership of each subcommittee appears under the subject heading. Students who have further questions should consult with the members of the subcommittees. **Copies of past examinations are available in AME N712**.

## BIOMEDICAL

### Professors Enikov, McGrath, Simon, VandeGeest, Wong, Wu

Computational activities in biomotor control, constitutive modeling of soft tissues, mass and fluid transport in soft tissues, finite-element analysis of the spine and cardiovascular system, models of the head and neck, orthopedic mechanics, evolution and adaptation of biosystems, microsensing, and design an devaluation of medical implants; biothermal science (bioheat and biomass transfer, cryobiology).

## REFERENCES

**TBA**

## CONTROLS

### Professors Arabyan, Enikov, Williams

Students are expected to understand the basic principles of controls, stability, and optimization, and be able to apply these principles along with the associated mathematical analysis techniques to practical problems. The following subjects should be studied:

**Stability:** Linearization of nonlinear systems (1, P10) (2, P109); eigenvalue stability criteria for linear continuous systems (2, Ch4) and discrete systems (3, Ch14); stability analysis using the methods of Liapunov (2, Ch4).

**Control:** Time domain analysis of linear systems (5, Ch7) (1, Ch3-5); state space design techniques for linear systems (1, Ch8) (5, Ch10); concepts in controllability and observability (3, Ch12) (2, Ch6) (4, Ch6); observer design for linear systems (1, Ch8); determination of controllable and reachable sets for nonlinear systems (2, Ch6) (e.g., linear systems subject to bounded control inputs).

**Optimization:** The general nonlinear programming problem for minimizing a function subject to equality and inequality constraints; necessary condition for a minimum (7, Ch2) (6, Ch1-4); numerical techniques (2, Ch3) (6, Ch5).

## REFERENCES


1. W. J. Grantham and T. L. Vincent, Modern Control System Analysis and Design, Wiley, 1990.

2. T.L. Vincent and W.J. Grantham, Nonlinear and Optimal Control Systems, Wiley, 1997.

3. W. L. Brogan, Modern Control Theory, Quantum, 1974.

4. D. Burghes and A. Graham, Introduction to Control Theory Including Optimal Control, Halsted Press, 1980.

5. B. C. Kuo, Automatic Control Systems, Prentice-Hall, 1982.

6. G. N. Vanderplaats, Numerical Optimization Techniques for Engineering Design: With Applications, McGraw-Hill, 1984.

7. T. L. Vincent and W. J. Grantham, Optimality in Parametric Systems, Wiley Interscience, 1981.

## ENGINEERING MATHEMATICS

**Professors Balsa, Ganapol, Kerschen, Madenci, Tumin**

**Students are expected to have mastered the basic concepts of differentiation and integration, infinite series and sequences, Fourier series, Laplace transforms, algebra of vectors and complex numbers, and ordinary differential equations in their undergraduate courses. Advanced concepts as well as the undergraduate concepts covered more in depth are generally considered in AME 500A and AME 500B, Advanced Engineering Mathematics.**

### Topics - AME 500A

### Physical Vectors and Second Order Tensors

***Ref. 1, Ch. 9, 14 – 16.*** **<u>Or</u>** ***Ref. 2, CH 9,10***
***Ref. 3, CH 1-6, 8***

Cartesian coordinates; Representation of vectors and second order tensors (basis, components, etc.)
Index notation and summation convention
Algebra of vectors (addition, multiplication by scalar, dot and vector products, magnitude, direction, orthogonality)
Geometric interpretation of vector algebra
Vector fields; Tensors and tensor fields
Coordinate transformation of vector and tensor components
Grad, div, curl; identities
Curves (tangent, normal, curvature, torsion, etc.) and surfaces (tangents, normal, curvatures, etc.); Parametric representations; Arclength; Element of surface
Line, surface and volume integrals; Integral theorems (Gauss, Stokes, etc.)
General orthogonal coordinate systems; Coordinate metrics; Element of volume; Unit vectors; Differential operators

### Linear Algebra

***Ref.4, CH 1-6***

Scalars and vectors; Vector spaces
Algebra of vectors (addition, multiplication by scalar); Geometry in $\mathbb{R}^3$
Linear combinations; Linear independence/dependence; Basis; Dimension
Subspaces; Spans; Reduction of spanning set to basis
Linear functions on vector spaces; Matrices; Algebra of matrices (addition, multiplication by scalar, matrix multiplication, inverse, etc.)
Change of basis; Matrix similarity
Linear equations; Row operations; LU factorization
Null space and range (nullity, rank, etc.); Solvability
Eigenproblem; Generalized eigenproblem; Diagonalization; Jordan form
Inner product; Orthogonality; Complements
Adjoint operator; biorthogonality; Green's function
Eigenproblem for self-adjoint operators
Real quadratic forms; Rayleigh-Ritz

### Topics AME 500A continued

## Ordinary Differential Equations

***Ref. 1, Ch  1–4  <u>Or</u> Ref. 2, CH 1-5***
***Ref.4, CH, 5***

Classification of  ODE; Linear systems; Linearization about a solution
Solution of $d\mathbf{y}/dt = A\mathbf{y} + \mathbf{b}(t),\ A = const$ by matrix methods; Fundamental matrix
Power series solution about regular point
Series solution about singular point (Frobenius method); solution at infinity

## Topics - AME 500B

## Functions of a Complex Variable

***Ref. 1, Ch. 21 - 24 <u>Or</u> Ref. 2, CH 13-18***

Representation of complex numbers (ordered pair, $i-$notation, polar form, etc.)
Algebra of complex numbers (addition, product, roots, etc.)
The complex plane; geometric interpretation of algebra
Examples of functions  of a complex variable; Isolated singularities (poles)
Multi-valuedness; Branch points and cuts
Differentiation; Cauchy-Riemann equations
Contour integration; Cauchy integral theorem; Deformation of contour; Cauchy integral formula
Taylor and Laurent expansions
Cauchy residue theorem
Analytic continuation; Evaluation of real integrals by residues
Examples of inversion of transforms; Contour deformation; Asymptotic considerations

## Partial Differential Equations

***Ref. 5, CH 1-13***

First order linear, quasi-linear and nonlinear equations; method of characteristics; initial value problem
Second order equations in two variables; classification; normal forms; method of characteristics
Sturm-Liouville problem for second order equations (two-point eigenproblem); eigenfunction expansion.
Generalized functions (step, delta, etc); Green’s function for second order ODE’s,
Solutions of wave equation, diffusion equation and Laplace equation (finite domains, rectangular, cylindrical and spherical) using various techniques/boundary conditions
Solutions of wave equation, diffusion equation and Laplace equation (infinite domains) using various techniques/boundary conditions. Eigenproblem; Green’s function for PDE’s. Solutions by Fourier and Laplace transforms.

**References:**


1. M. Greenberg, Advanced Engineering Mathematics, 2nd edition, Prentice-Hall, 1998
2. E. Kreyszig, Advanced Engineering Mathematics, 9th edition, Willey & Sons, 2006
3. D. A. Danielson, Vectors and Tensors in Engineering and Physics, 2nd edition, Westview Press, 2003
4. G. Strang, Linear Algebra and its Applications, 4th edition, Brooks/Cole, 2006
5. R. Haberman, Applied Partial Differential Equations, 4th edition, Pearson Education, 2004

## FLUID MECHANICS

### Professors Balsa, Fasel, Jacobs, Kerschen, Wygnanski, Zohar

The candidate must (1) demonstrate an understanding of the fundamentals of fluid mechanics at the level of AME 536A and 536B and (2) be able to apply these fundamentals to the solution of problems. Topics that the candidate will be expected to know include:

**Control Volume Analysis**: All conservation laws (Ref. 2)

**Euler's Equations in Streamline Coordinates**, **Bernoulli's Equation** (Ref. 2)

**Dimensional Analysis and Similitude** (Ref. 3, pp. 175-209)

**Kinematics**: Stress and rate of strain tensors (Ref. 1, pp. 131-147, Ref. 3, pp. 63-84)

**Navier-Stokes Equations**: Derivation and assumptions involved (Ref. 1, pp. 147-173, Ref. 3, pp. 87-146).

**Potential Flow Theory** (Ref. 1, pp. 378-471, Ref. 3, pp. 471-579)

**Parallel and Nearly Parallel Viscous Flows**: Lubrication theory (Ref. 1, pp. 216-228, Ref. 3, pp. 148-172

**Low Reynolds Number Flow**: Stokes and Oseen approximations (Ref. 1, pp. 216-246, Ref. 3, pp. 660-704).

**Vorticity Dynamics** (Ref. 1, pp. 264-282, Ref. 3, pp. 324-357)

**High Reynolds Number Flows**: Boundary layers, jets, and wakes (Ref. 1, pp. 303-353, Ref. 3., pp. 581-657)

**Drag and Flow Separation** (Ref. 3, pp. 359-400)

### REFERENCES


1. G. K. Batchelor, Introduction to Fluid Mechanics, Cambridge University Press, 1980.
2. R. W. Fox and A. T. McDonald, Introduction to Fluid Mechanics, 3rd Ed., Wiley, 1985.
3. R.L. Panton, Incompressible Flow, 2nd Ed., Wiley, 1996.
4. M. Van Dyke, An Album of Fluid Motion, Parabolic, 1982.
5. C. Pozrikidis, Introduction to Theoretical and Computational Fluid Dynamics, Oxford, 1997.
6. Hermann Schlichting, Boundary Layer Theory, 7th Edition, New York: McGraw-Hill, 1979.

## KINEMATICS AND DYNAMICS

### Professors Arabyan and Nikravesh

Students are expected to have mastered the fundamentals of kinematics and dynamics up to the intermediate level and the basic concepts of mechanical vibration. Students are tested on understanding of theories, problem-solving skills, and application. The following topics have been highlighted to give the student a framework to prepare for the Qualifying Examination:

**Basic Concepts:** Newton's laws of motion, units, dimensions.

**Kinematics of Particles:** Rectilinear and curvilinear motion; coordinate systems; absolute and relative motion; rotating systems.

**Kinematics of Rigid Bodies:** Degrees of freedom; absolute and relative coordinates; generalized coordinates; constraints; translation and rotation of coordinate axes; Euler angles and Euler parameters; infinitesimal rotations, absolute and relative motions.

**Dynamics of Particles:** Work, kinetic energy, potential energy, conservative systems, linear impulse and momentum, angular impulse and momentum, friction, equations of motion, collision, conservation laws.

**Dynamics of Rigid Bodies:** Virtual displacement and virtual work; generalized forces; impulse and momentum; impact; Newton’s equations, Euler=s equations, Lagrange's equations, D'Alembert's principle; dynamics of constrained and unconstrained systems; holonomic and nonholonomic constraints; Lagrange multipliers.

**Vibration Theory:** Free vibration of a conservative system, forced vibration of a conservative system; damped vibration; natural frequencies and mode shapes of single- and multi-degree of freedom systems, linearization of equations of motion.

### REFERENCES


D. T. Greenwood, Principles of Dynamics, 2nd Ed., Prentice Hall, 1988.

P.E. Nikravesh, Computer-Aided Analysis of Mechanical Systems, Prentice-Hall, 1988.

J. H. Ginsberg, Advanced Engineering Dynamics, 2nd Ed., Cambridge University Press, 1995.

W. T. Thomson, Theory of Vibrations with Applications, 3rd Ed., Prentice Hall, 1988.

W. Weaver, S. P. Timoshenko, and D. H. Young, Vibration Problems in Engineering, 5th Ed., Wiley, 1990.

M.L. James, et al., Vibration of Mechanical and Structural Systems with Microcomputer Applications, 2nd ed., Harper Collins, 1994.

**MEMS – Micro Electromechanical Systems**

**Professor Enikov, Wong, Zohar**

Students completing Micro Electromechanical Systems option are expected to demonstrate understanding of the basic scientific principles, theories, and techniques used in the design and synthesis of MEMS. These include:

- *Micro-machines (device)*
  1. *Working principles of micro-transducers:* sensing and actuation principles; electrostatics and electromagnetic forces; piezoresistivity and piezoelectricity; electrochemical, electrical, optical, mechanical, and thermal transducers. Scaling laws*:* Trimmer's force scaling formalism applied to electrostatic, electromagnetic, inertial and capillary forces. Scaling of heat-flux (thermal conductivity and convection
- *Micro-machining (technology)*
  1. *Scientific principles of microsystem design and fabrication:* atomic structure of matter, ions, ionization, molecular interactions, basic gas kinetic theory, doping and diffusion in semiconductors, plasma physics concepts, electrochemistry (electrolysis and electrodynamics), quantum physics concepts
  2. *Micro-fabrication techniques:* bulk and surface micro-machining (wet and dry etch techniques), common semiconductor processes used in MEMS (CMOS), LIGA, UV LIGA, soft lithography. Bio-film deposition techniques. Packaging and electronic interface of MEMS devices.
- *Micro-mechanics (science)*
  1. *Solid Mechanics of Micro-structures:* static and dynamic bending of thin plates, beams and membranes, resonance and damping, thermo-elasticity. Examples of MEMS devices utilizing these structures (accelerometers, pressure sensors, tuning fork oscillators), thermal actuators.
  2. *Fluid mechanics in Micro-structures:* viscous flows, continuity, momentum and energy conservation in micro-scale flows. Surface tension, capillary effects – implication to micro-pumps. Electro-kinetic flows. Examples of MEMS devices utilizing these structures (micro-pumps, micro-mixers, separation micro-devices)
  3. *Heat transfer in micro*-devices: general principles of heat conduction, Fourier Law, Netwon's cooling law (convection cooling in fluids). Dimensionless numbers and their relevance to micro-scale systems. Thermodynamic potentials. Heat transfer in multi-layered structures Examples of MEMS devices utilizing these structures (micro heat sinks, micro reactors, micro heaters)

References:


1. S. A. Campbell, *The Science and Engineering of Microelectronic Fabrication*, $2^{nd}$ Ed., Oxford Univ. Press, 2001.
2. M. Madou, *Fundamentals of Microfabrication*, CRC Press, 1997.
3. J. W. Gardner, *Microsensors: Principles and Applications,* John Wiley and Son, Ltd., 1994.
4. T. Fukuda and W. Menz, Eds., *Micro Mechanical Systems: Principles and Technology*, Handbook of Sensors and Actuators, Vol. 6, Elsevier, 1998.
5. S. D. Senturia, *Microsystem Design,* Kluwer Academic Publishers, 2002.
6. T.-R. Hsu, MEMS and Microsystems: Design and Manufacture, Mc-Graw Hill, 2001

## NUCLEAR ENGINEERING

**Professor Ganapol, Li, Williams**

The Nuclear Engineering option in the AME graduate program is designed to give the aero or mechanical engineering graduate student fundamental knowledge of the application of nuclear processes in engineering. The basic nuclear processes will include nuclear physics, radioactivity and charged and neutral particle interactions with matter. The application of these nuclear processes will include nuclear reactor theory and stability, power production and fuel cycles, contemporary and advanced reactor designs, experimental nuclear science and radioactivity management in the biosphere.

The following topics will be covered:

Nuclear Physics:
Liquid drop and shell models of the nucleus
Fundamental quantum mechanics of the nucleus
Radioactive decay (beta, alpha, gamma) and nuclear stability
Nuclear fission and fusion
Particle interactions with matter

Reactor Physics:
Nuclear cross sections
Neutron flux and current
Basic neuton transport theory
Neutron diffusion theory (one group)
Nuetron slowing down theory
Criticality
Multigroup theory and heterogeneous reactors

Reactor Control:
Reactivity and reactor kinetics
Optimization concepts
Reactor stability
Control rod blackness theory

Reactor designs:
Light water reactors (BWRs, PWRs)
Liquid Metal Reactors (LMFBRs, PbBi's)
Pebble Bed Modular Reactors (PBMRs)
Generation IV concepts

Power production:
Fission energy conversion
Two phase flow
Steam cycles
Heat exchangers
Conversion to electricity
Fuel Cycles:
Reactivity optimization, BOC loading, EOC Loading

Experimental nuclear science:
TRIGA reactors, Counters, Experimental techniques

Waste Management:
Current concepts

## RELIABILITY ENGINEERING

**Professor Kececioglu and Shkarayev**

The student will be expected to do the following:

Define the basic terms and perform operations of probability and statistics theory.

Define the fundamental concepts of reliability**,** maintainability and testing theory and apply them to real-life problems. In particular, the student will be expected to define and apply times-to-failure distributions; failure rates; early, useful, and wear-out life reliability; reliability apportionment; reliability growth; failure modes, effects, and criticality analysis; accelerated, accept-reject, sequential, Bayesian, and nonparametric testing; quantification of the maintainability of equipment, reliability and availability of maintained equipment, spares provisioning, sixteen preventive maintenance strategies, life-cycle costing, maintainability prediction, etc.

Perform reliability assessments using unique methods and distributions; e.g., Monte Carlo simulation; have knowledge of the normal, lognormal, exponential, Weibull, extreme value, gama and beta distributions.

## REFERENCES


A. H. S. Ang and W. Tang, Probability Concepts in Engineering Planning and Design, Vol. II, Wiley, 1984.

K. C. Kapur and Lamberson, Reliability in Engineering Design, Wiley, 1977.

D.B. Kececioglu, Reliability Engineering Handbook, Vols. 1 and 2, 2002, Destch Publications

D. B. Kececioglu, Reliability and Life Testing Handbook, Destch Publications, Vols 1 and 2, 2002.

D.B. Kececioglu, Maintainability, Availability and Operational Readiness Engineering, Destech Publications, Vol. 1, 2003.

## SOLID MECHANICS

**Professors Enikov, Madenci, Shkarayev, Simon, Missoum, Wu**

The subjects listed here were selected for their fundamental nature. The examination will address the advanced student, whose mastery of the fundamentals allows their application to non-trivial situations. The lists of courses and textbooks are given to suggest the level of knowledge that is expected. The list is intended only as a guide.

## COURSES

The following is a list of major areas and courses offered at The University of Arizona that are relevant to them:

| | |
|---|---|
| Finite Element Analysis | AME 461, AME 561 or equivalent |
| Mechanics of Deformable Solids (I) | AME 564A or equivalent |
| Mechanics of Deformable Solids (II) | AME 564B or equivalent |

*If the above courses are not taught due to cancellation, an equivalent may be taken

## REFERENCES

The following textbooks are suitable sources for information on the given subjects:


Y. C. Fung, <u>Fundamentals of Solid Mechanics</u>, Prentice Hall, 1965.

S. P. Timoshenko and J. N. Goodier, <u>Theory of Elasticity</u>, McGraw Hill, 1970.

A. Mendelson, Plasticity: <u>Theory and Applications</u>, Macmillan, 1968.

R. D. Cook, D. S. Malkus, and M. E. Plesha, <u>Concepts and Applications of Finite Element Analysis</u>, John Wiley and Sons, 1989.

Y.C. Fung, A First Course in Continuum Mechanics, Prentice-Hall, latest edition.

## THERMAL SCIENCE

**Professors Chan, Jacobs, Li, McGrath, Ramohalli, Tumin, Wright, Zohar**

In addition to familiarity with the following subjects, the candidate is expected to be able to integrate theoretical tools and basic physical principles in simple applications. Familiarity with the course content of AME 533 (Heat Transfer), 530 (Advanced Thermodynamics), and 532 (Convective Transport Phenomena) is required. References are given as suggestions to indicate the level of the material covered.

**Thermodynamics:** Energy balances in closed and open systems; second law applications and derivations of limiting trends in systems; state principles and equations of state; applications to cycles (Ref. 1).

**Convection:** Physical driving mechanisms; laminar and turbulent regimes; forced and free convection; internal and external flows; uni-directional solutions; boundary layer approximations; scaling; asymptotic limits of high and low Prandtl numbers (Ref. 2).

**Conduction:** Fundamentals of heat conduction; Steady, 1-D conduction; Steady, multi-dimensional conduction; Transient conduction with steady boundary conditions; Transient conduction with time dependent boundary conditions. (Ref. 3).

**Radiation:** Definitions of radiative properties and fluxes, characteristics of blackbody radiation, basic laws (Planck's Law, Wien's Law, the Stefan-Boltzmann Law, Kirchhoff's Law), view factors, radiative exchange between diffuse, gray surfaces in an enclosure. (Ref. 4, Ch 1, 2, 5-7).

## REFERENCES


1. A. Bejan, Advanced Engineering Thermodynamics, 3rd Edition, Wiley, 2006

2. W. M. Kays and M. E. Crawford, Convective Heat and Mass Transfer, 4th Edition, McGraw-Hill, 2005.

3. M.N. Oziski, Heat Conduction, 2nd Edition, Wiley Interscience, 1993.

4. R. Siegel and J. Howell, Thermal Radiation Heat Transfer, 4th Edition, Taylor & Francis, 2002. (Chapters 1,2,5,6 and 7)