MAE 623 – Conduction Heat Transfer

Instructor: Terence Musho, Ph.D., P.E.
Office: 727 ESB
Phone: (304) 293-3256
tdmusho@mail.wvu.edu
Office hours: MW 11:00am-noon. In person or Zoom.

Lecture: MWF 12:00 – 12:50 PM Room ESB-E851

Optional Text:
Heat Conduction, David Hahn (WVU eLibrary)
Heat Conduction using Green's Functions, J.V. Beck
Nano/Microscale Heat Transfer, Zhuomin Zhang (WVU eLibrary)
Inverse Heat Transfer: Fundamentals and Applications, M. Necat Ozisik

References:
Analytical Methods in Heat Conduction, Glen Myers
Introduction to Heat Transfer, F.P. Incropera. D.P. DeWitt, T.L. Bergman, and A.S. Lavine

Course Objectives: The objective of this course is to equip students with the advanced knowledge and skills needed to solve complex conduction heat transfer problems. The course begins with a review of foundational heat transfer concepts and progresses to advanced topics. Students will explore analytical methods for solving 1D, 2D, and 3D steady-state and transient conduction problems, with a focus on the Green's Function method. Additionally, the course covers specialized topics such as nanoscale heat conduction and the application of the Finite Element Method (FEM) to transient heat conduction challenges.

Grading:

Mid Term Exam	35%
Final Exam	35%
Homework	25%
In-Class Activities	5%

Class Rules:

- Attendance and Participation:
  - Regular attendance is expected. If you must miss a class, please notify the instructor in advance.
  - Active participation in class discussions, group work, and problem-solving sessions is encouraged.
  - Be punctual. Arriving late disrupts the class and can affect your understanding of the material.

- Respectful Environment:
  - Treat all classmates and the instructor with respect. Diverse perspectives and ideas are valuable to the learning process.
  - Constructive criticism is welcome, but it should be delivered in a professional and

respectful manner.

- Assignments and Deadlines:
  - Homework and assignments must be submitted by the specified deadlines. Late submissions will be penalized unless prior arrangements have been made.
  - If you encounter difficulties with an assignment, seek help early. Extensions may be granted in exceptional circumstances with advance notice.

- Academic Integrity:
  - All work submitted must be your own. Plagiarism, cheating, and other forms of academic dishonesty will not be tolerated and will result in disciplinary action.
  - Collaboration on homework is allowed where specified, but each student must submit individual work that reflects their understanding.

- Communication:
  - Check your university email regularly for updates or announcements related to the course.
  - Use office hours to discuss course material, seek clarification on assignments, or receive feedback on your progress.

- Technology Use:
  - Laptops and tablets are allowed in class for note-taking and accessing course materials. However, refrain from non-course-related activities during class.
  - Cell phones should be silenced or turned off during class sessions. In case of an emergency, step outside to take calls.

- Exams:
  - Exams will be closed-book unless otherwise stated. Ensure you understand the material and can apply it without external resources.
  - Academic integrity rules apply during exams. Any violation will be dealt with seriously.

- Accommodations:
  - If you require special accommodations due to a disability, please inform the instructor as early as possible. We will work together to ensure your needs are met.

- Professional Development:
  - This course is an opportunity to develop not only technical skills but also professional conduct. Approach your studies with seriousness and commitment.
  - Engage in discussions, presentations, and projects as if they were in a professional setting, practicing clear communication and ethical behavior.

Course Content:

1. **Introduction and Review of Heat Transfer**
   - **A. Modes of Heat Transfer**:
     - **Conduction**: Heat transfer through direct contact within a material or between materials.

        - **Convection**: Heat transfer through fluid motion, including natural and forced convection.
        - **Radiation**: Heat transfer through electromagnetic waves, without the need for a medium.
    - **B. Fundamental Mechanisms of Heat Transfer**:
        - **Atomistic Considerations**: Role of atomic vibrations, phonons, and electron transport in heat conduction.
        - **Material Considerations**:
            - Influence of alloy composition on thermal properties.
            - Temperature-dependent behavior of materials.
            - Effects of microstructure, such as grain boundaries and dislocations, on thermal conductivity.
2. **Introduction to Heat Conduction**
    - **A. Fourier's Law of Heat Conduction**:
        - **Mathematical Consideration of Linear PDEs**:
            - Introduction to the heat equation.
            - Boundary and initial conditions for solving PDEs.
    - **B. Steady Heat Conduction Solutions**:
        - **Solving PDEs Using Separation of Variables**:
            - Method of separating variables in PDEs to simplify complex heat conduction problems.
        - **2D and 3D Steady-State Examples**:
            - Examples of heat conduction in rectangular, cylindrical, and spherical coordinates.
            - Analysis of thermal gradients and temperature distributions.
3. **Fourier Analysis of Boundary Value Problems – Transient Conduction**
    - **A. Introduction to Fourier Series**:
        - **Orthogonal Functions**: Understanding the orthogonality of sine and cosine functions in the context of heat conduction.
        - Application of Fourier series to solve time-dependent heat conduction problems.
    - **B. Mathematical Treatment of Non-Homogeneous Boundary Conditions**:

    - Techniques for handling non-homogeneous boundary conditions in transient heat conduction problems.
  - **C. Solution Techniques**:
    - **Superposition Solutions**: Applying the principle of superposition to solve complex boundary value problems.
    - **Product Solutions**: Combining spatial and temporal solutions for transient problems.
    - **Duhamel's Theorem**: Using Duhamel's theorem to solve problems with time-dependent boundary conditions.
    - **Bessel Functions and Cylindrical Solutions**: Introduction to Bessel functions and their application in cylindrical coordinate systems.

4. **Green's Function Method – Transient Conduction**
   - **A. Green's Function Derivation**:
     - Conceptual understanding and mathematical derivation of Green's functions.
     - Application of Green's functions to solve transient heat conduction problems.
   - **B. 2D Transient Green's Function Solutions**:
     - Solving 2D transient heat conduction problems using Green's functions.
     - Examples in rectangular and cylindrical geometries.
   - **C. 3D Transient Green's Function Solutions**:
     - Extending Green's function solutions to 3D heat conduction problems.
     - Analysis of temperature fields in complex geometries.
5. **Numerical Analysis**
   - **A. ANSYS Finite Element Analysis (FEA) for Heat Conduction**:
     - **Hands-on Demonstration**: Practical session on setting up and solving heat conduction problems using ANSYS.
     - Introduction to meshing, boundary conditions, and solution techniques in FEA.
     - Interpretation of numerical results and validation against analytical solutions.
6. **Inverse Heat Transfer Methods**
   - **A. Techniques**:

        - **Inverse Heat Transfer Techniques**: Introduction to inverse methods for estimating unknown boundary conditions or material properties from temperature measurements.
        - **Conjugate Gradient Method**: Application of the conjugate gradient method to solve inverse heat conduction problems.
        - Case studies on real-world applications, such as thermal imaging and material testing.

7. **Micro/Nanoscale Conduction Heat Transfer**
    - **A. Quantized Heat Conduction**:
        - **Quantum Mechanical Considerations**: Understanding heat conduction at the quantum level, including phonon and electron transport.
        - **Heat Capacitance and Debye Temperature**: Analysis of specific heat at low temperatures and its relation to Debye temperature.
        - **Mean Free Path and Scattering Mechanisms**: Impact of phonon mean free path and scattering on thermal conductivity at the micro and nanoscale.
    - **B. Ballistic Thermal Transport Solutions**:
        - **Quantum Conductance**: Exploring thermal conductance in nanostructures and quantum wires.
        - **Small Gap Conduction and Dielectric Interactions**: Investigating heat transfer mechanisms in nanoscale gaps, including near-field radiation and dielectric effects.

TENTATIVE COURSE Schedule

Date	Topics	Notes
Week 1	Introduction to Heat Transfer Mechanisms of Heat Conduction in Solids	
Week 2	LCM, Semi-infinite Solids, Infinite Solids Separation of Variables Solution to PDE	
Week 3	Orthogonal Functions, Fourier Series Boundary Value Problems	Univ. Closed Sep. 2
Week 4	1D Transient Conduction Homogenous BC Example 1D Transient Conduction 1 NH BC Example	
Week 5	2D and 3D Steady State Conduction Example Superposition of Solutions Derivation	
Week 6	Superposition of Solutions Example Product Solution Example	
Week 7	Duhamel's Solution Example Bessel Functions	
Week 8	Introduction to Green's Functions, Naming Convention X22 GF Derivation	Fall Break Oct. 10-11
Week 9	X23 GF Example X30 GF Example	
Week 10	Radial GF Example Mid Term Exam	
Week 11	2D and 3D GF Example Time Partitioning GF Solution	
Week 12	Intro to Inverse Heat Transfer Conjugate Gradient Method	
Week 13	Finite Element Solution	
Week 14	No Class this Week	Fall Recess Nov. 23-Dec 1
Week 15	Micro/Nanoscale Heat Transfer Debye Derivation	
Week 16	Small Gap Considerations Quantum Conductance	Last Class Dec. 12
Week 17	Final Term Paper Due at Final Time	Winter Recess Dec. 21