ME 397 Design of Complex Engineering Systems

Mechanical Engineering Department, The University of Texas at Austin
Spring 2008, TTh 9:30 – 11 AM, ETC 7.111

Instructor

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Course Description and Goals

In this course, students will have the opportunity to learn to negotiate solutions to *complex* engineering design problems that may involve multiple disciplines, multiple scales, uncertainty, computationally expensive simulation models, and multiple objectives. Upon completion of this course, each student should be able to:

- Characterize and formulate complex engineering design problems by identifying appropriate objectives, constraints, design variables, and coupled parameters.
- Understand the impact of problem formulation on computational tractability, solution quality, and opportunities for collaboration and distribution of design activities.
- Formulate and solve multiobjective decisions. Explore tradeoffs between multiple objectives and generate Pareto sets of solutions.
- Identify and apply suitable search techniques (e.g., optimization algorithms, designed experiments, basic metamodeling techniques) based on problem characteristics and desired solution quality.
- Evaluate complex engineering systems with properly formulated and partitioned simulation models and understand the relationship between model fidelity, computational expense, and problem solution methods.
- Critically evaluate and validate the results of simulations and design/optimization/search processes.
- Identify and mathematically model sources of uncertainty and variability. Implement appropriate computational methods and decision support protocols to evaluate and minimize the impact of uncertainty and variability on performance parameters.
- Partition a multidisciplinary or multiscale problem into sub-problems, manage the interfaces between them, and negotiate systems-level solutions.
- Write a project report in a form suitable for publication as a refereed conference (or journal) paper and present his/her work orally in a manner suitable for a broad technical (conference) audience.

Topics

(1) Introduction to Complex Engineering Systems Design Methodology. (2 lectures)

- Factors that contribute to complexity: multiple objectives, uncertainty, multiple disciplines, multiple scales, concurrency.
- Examples of complex engineering systems.

(2) Simulation-Based Design of Complex Engineering Systems. (7 lectures)
- Modeling and simulation to support design.
  - Model fidelity vs. expense.
  - Validation of models.
- Optimization methods and algorithms.
  - Problem formulation, including identification of objectives, constraints, and design variables.
  - Overview of gradient-based optimization techniques: linear and non-linear programming.
  - Overview of exploratory techniques: genetic algorithms, simulated annealing.
  - Validation and verification of solutions.
- Design of experiments and metamodeling.
  - Alternative experimental designs, including factorial, fractional factorial, and Latin Hypercube designs.
  - Metamodeling methods, including response surfaces and kriging.
  - Applications of designed experiments and approximate models for design space exploration.

(3) Multiobjective Decision-Making and Optimization. (3 lectures)
- Pareto sets and tradeoffs.
- Basic multiobjective formulations: weighted sum, compromise programming, etc.
- Utility theory.
- Satisficing methods and goal programming.

(4) Uncertainty and Robust Design (6 lectures)
- Sources of uncertainty. Representation of uncertainty.
- Propagation and estimation of uncertainty. Monte Carlo method, designed experiments, worst-case (Taylor series) analysis.
- Robust design principles and methods.
- Design flexibility with robust design methods.

(5) Introduction to Multidisciplinary and Multiscale Design Methods and Challenges (3 lectures)
- Overview of multidisciplinary and multiscale design problem formulations. Issues of coupling, decomposition, and collaboration.
- Robust design for multidisciplinary applications.
- Game theory.

Grading

		Total
Design Project		45%
Project Proposal	10%	
Final Project Report	30%	
Final Project Presentation	5%	
Assignments		30%
Design Journal		20%
Attendance, participation, peer evaluations, etc		5%
		100%

Textbook

There will ***not*** be a required textbook in this course. Specific references will be provided.

Additional References

It is beneficial to purchase or obtain access to an engineering optimization reference book. The following texts are recommended:

- Papalambros, P. Y., and D. Wilde, 2000, *Principles of Optimal Design*, *2nd Edition*, Cambridge University Press, Cambridge, UK.
- Belegundu, A. D. and T. R. Chandrupatla, 1999, *Optimization Concepts and Applications in Engineering*, Prentice Hall, Upper Saddle River, NJ.

Project, Assignments, Design Journal, and Related Items

Project. Students will form groups of 2-3 and apply topics learned in the course to a graduate level design project. Students are encouraged to pick projects based on their own graduate research or interests. The instructor will be available for advice on project selection and scoping. The project should have a significant computer simulation component, and it should present opportunities for multidisciplinary, multiscale, and/or robust design. Example of previous design projects will be discussed in class, and written reports will be available for review. Projects are evaluated based on a project proposal, final project report, and final project presentation. The final project report and presentation will be *in a form suitable for a peer-reviewed journal or conference paper and presentation*; it is anticipated that some of the projects will lead to such publications. *Students will gain significant experience with writing and presenting research suitable for a technical audience.*

Design Journal. As a student, you will be expected to maintain a Design Journal for documenting observations, reflections, and insights on your project and/or the complex systems design methodology presented in class. Seven brief entries of 200-500 words will be expected, plus a 1000-2000 word final entry in which you critically evaluate what you have learned in this course. Guidelines and suggestions for topics will be provided in class.

Assignments. Four homeworks will be assigned. The homework assignments will require interpretation and application of lecture content for (a) a pre-specified sample problem, and/or (b) the student's design project. The intention is to encourage critical thinking and consistent, gradual development of the project throughout the semester.

Attendance, Participation, Peer Evaluations. Attendance in class is mandatory and monitored with periodic roll calls. Notify the instructor **in advance** if you must be absent for a legitimate reason. The instructor also monitors your participation in class and includes this assessment in your final grade, along with the results of peer evaluations of your participation in team project activities.

Assigned Reading. Please read (or at least skim) the assigned reading material before coming to class. Even a brief review of the material will greatly enhance your understanding of material presented in lecture. A reading list will be provided.

Deadlines and Penalties. *All assignments must be submitted on time.* Assignments are due before the beginning of class on the designated day. Unless prior approval is obtained from the instructor, late assignments will be penalized 10% or one letter grade *per day*.

Prerequisites

Graduate standing in engineering or related discipline or consent of the instructor. Students should be familiar with the following topics at an ***undergraduate*** level:

- design methodology. Students should be able to identify and implement the major phases of task clarification, conceptual design, and embodiment/detail design.

- engineering science. To complete their projects, students will benefit from familiarity with two or more major subject areas, such as thermal/fluid systems, solid mechanics, dynamic systems and controls, materials science, electrical systems, or manufacturing.
- computer-aided design and computer aided engineering.
- statistics and calculus through partial differential equations.
- engineering optimization. Familiarity with basic engineering optimization (e.g., ME 397 – Design Optimization and Automation) will be beneficial but not required. A substantial introductory review of engineering optimization will be provided.

Adding/Dropping the Course

An engineering student must have the Dean's approval to add or drop a course after the fourth class day of the semester or after the second class day of a summer term. Adds/Drops are not approved after the fourth class day, except for a good cause such as documented evidence of an extenuating non-academic circumstance (e.g., health or personal problems) that did not exist on or before the fourth class day. Applications for approval to drop a course after the fourth class day should be made in the Office of Student Affairs, ECJ 2.200.

Course/Instructor Evaluation

All students will have the opportunity to evaluate the course and instructor using the standard MEC (Management and Evaluation Center) form during the last week of classes. An intermediate survey will also be conducted by the instructor during the semester. Constructive feedback is encouraged at any time via personal discussions or email.

Academic Integrity

Academic dishonesty will not be tolerated in this course. Penalties are likely to include a grade of F for the activity and/or for the course. Ask your instructor if you have any questions about expectations for a particular activity. You are encouraged to discuss any aspect of the course with classmates and project team members, but remember the following rules:

- Do not plagiarize the work of others by copying from the web, other students, previous students, articles, or other sources (aside from compiling work from your teammates for group project activities) without properly referencing your sources.

Blackboard

The instructor will post lecture slides, assignments, and other handouts and interesting links on the blackboard web site. Please logon at http://courses.utexas.edu. The web site is password-protected. Site activities will include exchanging email, engaging in class discussions and chats, and exchanging files. In addition, electronic class rosters will be a component of the site. Students who do not want their names included in these electronic class rosters must restrict their directory information in the Office of the Registrar, Main Building, Room 1.

Special Needs

The University of Texas at Austin provides upon request appropriate academic adjustments for qualified students with disabilities. For more information, contact the Office of the Dean of Students at 471-6259, 471-4641 TDD or the College of Engineering Director of Students with Disabilities at 471-4321.