**AE 6370 –** **Optimization for the Design of Engineered Systems**

**Hours:** 3-0-3

**Catalog Description (25 words or fewer):**

Introduction to optimization, optimization problem formulations for engineering design, algorithms for constrained nonlinear programming, multiobjective and multidisciplinary optimization, and robust design optimization.

**Prerequisites:**

None

**textbooks:**

The material is based primarily on course notes; however, the following textbooks are representative of those that may be required or recommended as resources at the discretion of the instructor:

1. Vanderplaats, G.N., Multidiscipline Design Optimization, Vanderplaats Research and Development, 2007.
2. Nocedal, J. and Wright, S.J., Numerical Optimization, 2nd edition, Springer, 2006.
3. Arora, J.S., Optimum Design, 3rd edition, Academic Press, 2012.

**Course Objectives:**

Achieve proficiency with optimization fundamentals including specification of problem statements and necessary and sufficient conditions for optimality. Develop understanding of representative gradient-based and gradient-free algorithms for constrained optimization of nonlinear problems. Develop understanding of how nonlinear programming algorithms can be used as enablers for broader engineering design problems including multidisciplinary optimization, multi-objective optimization, and robust design optimization.

**Learning Outcomes:**

Students will be able to:

1. Write formal optimization problem statements for simple mathematical example problems and more complex engineering design problems
2. Explain necessary and sufficient conditions for optimality in order to understand whether a proposed solution could be or is a local optimum
3. Recommend or select a relevant optimization algorithm based on the features of a particular problem
4. Create a computational implementation of a relevant algorithm
5. Leverage designs of experiments and surrogate models of the objective function and/or constraints to reduce the computational cost of the optimization search process
6. Run an optimization algorithm, understand whether and how it has converged, and interpret the results
7. Illustrate and explain optimization search patterns with contour plots and similar visualizations
8. Apply optimization to multidisciplinary, multi-objective, and robust design problems

**Grading:**

Assignments: 15%

Midterm Exams(2): 40%

Final Exam: 45%

**Learning Accommodations:**

If needed, we will make classroom accommodations for students with documented disabilities. These accommodations must be arranged in advance and in accordance with the ADAPTS office (http://www.adapts.gatech.edu).

**Topic Outline**

1. **Introduction (2 hrs)**
   1. Need for numerical optimization in engineering design
   2. Review of multivariate calculus fundamentals
2. **Unconstrained Optimization (10 hrs)**
   1. Necessary and sufficient conditions for a local optimum
   2. Line search algorithms
      1. Zeroth order (Powell’s method, univariate search)
      2. First order (steepest descent, conjugate gradient, BFGS, etc.)
      3. Second order (Newton’s method)
   3. Direct search algorithms (random walk, coordinate pattern search, etc.)
   4. Normalization approaches and convergence criteria
3. **Constrained Optimization (10 hrs)**
   1. Challenges of constraints; activity, feasibility
   2. KKT necessary conditions
   3. Indirect methods and penalty functions (interior, exterior, augmented Lagrangian, etc.)
   4. Linear programming and the simplex method
   5. Direct methods (SLP, MoFD, generalized reduced gradient method, SQP, etc.)
4. **Metaheuristic Optimization (5 hrs)**
   1. Metropolis algorithm and simulated annealing
   2. Binary representation (decimal/binary conversion, Hamming distance, Gray codes)
   3. Genetic operators and algorithms (selection, crossover, mutation, replacement)
   4. Particle swarm algorithms
5. **Multi-Objective Optimization (2 hrs)**
   1. Partial ordering and Pareto dominance
   2. Aggregate objective function (AOF) approach
   3. -constraint method
   4. Normal boundary intersection (NBI) and related methods
   5. Multi-objective genetic algorithms (NSGA-II, etc.)
6. **Multidisciplinary Optimization (4 hrs)**
   1. Multidisciplinary analysis (MDA): partitioning, interaction, coupling, consistency
   2. Design Structure Matrices (DSM)
   3. Fixed-point iteration (Gauss Seidel)
   4. Single-level MDO architectures (MDF, IDF)
   5. Multi-level/hierarchical MDO architectures (CO, ATC)
7. **Designs of Experiments and Surrogate Models (4 hrs)**
   1. Full and fractional factorial designs
   2. Space filling designs (LHC, minimax and maximin, maximum entropy, uniform)
   3. Multiple linear regression models: polynomials and radial basis functions (RBFs)
   4. Nonlinear regression models: artificial neural networks (ANN) and Gaussian processes
   5. Assessing fit quality: error measures, validation sets, cross-validation, overfitting
   6. Regularization methods
8. **Robust Design Methods (3 hrs)**
   1. Taguchi methods
   2. Probabilistic methods in robust design; approaches for uncertainty propagation
   3. Reliability-based design optimization (RBDO)
9. **Bayesian Global Optimization (2 hr)**
   1. Philosophical approach involving Bayesian surrogate models
   2. Expected improvement criterion
   3. Efficient Global Optimization (EGO)

**Exams and Reviews: 3 hr**

**Total Course Hours: 45 hr**