CEE 201L

Uncertainty, Design and Optimization

Spring 2024

Instructor: Henri Gavin  
henri.gavin@duke.edu  
133 Hudson

T.A.: Adan Cortez-Perez  
adan.cortezperez@duke.edu
Hana Thibault  
hana.thibault@duke.edu

Lecture: Mo We Fr 12:00 - 12:50  
115A Hudson

Recitation: Th 4:40 - 5:55  
115A Hudson

Office Hours: HG: Tu 4:30 - 5:30 and by appointment  
133 Hudson
AC: We 5:00 - 6:00 and by appointment  
132 Hudson
HT: Fr 1:30 - 2:30 and by appointment  
132 Hudson

Notes and assignments are available through the course website.

Website: [http://www.duke.edu/~hpgavin/cee201/](http://www.duke.edu/~hpgavin/cee201/)

Prerequisite: EGR 201L. Solid Mechanics or ECE 110L. Fundamentals of ECE

Academic Integrity: *The Duke Community Standard* applies.

Grading: 3 projects (30%); 8 homework (35%); 1 take home final (30%); ∞ participation: (5%)

BULLETIN DESCRIPTION


COURSE OBJECTIVES AND MEASURABLE OUTCOMES

Students successfully completing CEE 201L will be able to:

1. Identify, formulate, and solve engineering problems by:
   (a) formulating constrained optimization problems from broad design goals,
   (b) interpreting and assessing designs provided by solutions to constrained optimization problems, and
   (c) identifying possible obstacles to practical and successful implementations.

2. Design systems, components, and processes to meet desired needs within realistic constraints, (including economic, environmental, social, and safety constraints) by:
   (a) mathematically modeling the system to be designed,
   (b) defining design attributes to parameterize the design, and
   (c) intelligently iterating on the design to meet the desired objectives without violating constraints.

This course measures the students’ progress in meeting the above objectives by requiring students to:

1. understand procedures for numerical optimization and to apply these methods to diverse problems (homework and projects);
2. interpret constrained optimization as method for structural analysis using energy methods (homework and mid-term exam);
3. model uncertainties involved in system design and to propagate these uncertainties through optimized designs (homework and projects);
4. work in groups to design feasible and cost-effective systems to meet specific design goals (projects);
5. write programs (using Matlab) to analyze candidate systems and to utilize optimization-solvers in order to efficiently converge on optimal designs (projects); and
6. present methods and communicate findings in written project reports (projects).
COURSE POLICIES

- **The Duke Community Standard**
  Duke University is a community dedicated to scholarship, leadership, and service and to the principles of honesty, fairness, respect, and accountability. Citizens of this community commit to reflect upon and uphold these principles in all academic and non-academic endeavors, and to protect and promote a culture of integrity.

  To uphold the Duke Community Standard:
  
  - I will not lie, cheat, or steal in my academic endeavors;
  - I will conduct myself honorably in all my endeavors; and
  - I will act if the Standard is compromised.

- **Attendance:** Your engaging participation will make this course much more fun! Please be on time. Please keep your cell phones off.

- **Communication:** We will use e-mail for out-of-class communications related to the course. Start the subject line of any/all email to me with **CEE 201:**.

- **Extra-curricular and co-curricular activities:** In most cases extra-curricular and co-curricular activities conflicting with course commitments can be resolved easily. Just let me know beforehand.

- **Grading:** The TAs will grade your solutions to homework assignments. I will grade the projects and the take-home exams. See me (not the TA) about any grading issues before the last day of class.

HOMEWORK AND PROJECT REQUIREMENTS

- **Collaboration and Academic Integrity:** Collaboration with other students enrolled in the course is encouraged on homeworks and is required on projects. Present your own solutions in a way that makes sense to you. Copying will be considered a violation of the Duke Community Standard. The TAs may not solve homework problems for you. On each assignment, write and sign the reaffirmation, “I have adhered to the Duke Community Standard in completing this assignment.”

- **Neatness:** 15 of 100 points on each assignment are allocated to neatness.
  
  - Use **pencil**, preferably a mechanical pencil.
  - Write neatly and clearly.
  - Write your first and last **name**, the **course number**, the assignment number and the **due-date** in the upper right corner of the first page. Write the **page number** on each page (e.g., 3/6, means page 3 of 6)
  - Write out each **problem statement**. (i.e., Given=..., Find=..., Collaborators=...)
    
    For “Collaborators:” list the people with whom you worked on the problem.
    
    If there are no collaborators just write “none”.
  - Use a **straight edge** (your Duke ID card, a ruler, or a triangle) to draw straight lines.
  - Present solutions to problems in the **same order** as listed in the assignment.
    
    Begin every problem on a new page that it can fit on the same page.
  - For partial credit, **describe** your thinking in words.
  - **Draw a box** around your final answer. Give the units for numerical answers.
  - **Scan** your solution set. Use: **PDF, b&w, 300 dpi, and high contrast settings**.
    
    Name your **.pdf** file ... **cee201-MyName-HW#-2024.pdf**
• **Programming:** Some homework assignments and all projects involve *matlab* programming. The TA and HPG can help with *matlab* can help. Also, read this. Include *your* code and any plots to your homework and project PDFs prior to submitting your work.

• **Submission of work:** Name your .pdf file ... cee201-MyName-HW#-2024.pdf. Upload your homework assignments and project reports to the CEE 201L Gradescope page by 5:00 pm on the due date. Please set your document scan settings to generate reasonably sized files ... less than 5MB. Low quality scans will be penalized 5 neatness points.

• **Short-term illness:** If illness or injury prevents you from attending class or meeting a deadline, read the university policy on short-term and long-term health issues, complete this secure on-line incapacitation form, and meet with or contact me within 48 hours to figure out a plan for your support and accommodation.

• **Extensions:** Every student can get one automatic *one-work-day homework extension*. To obtain the extension, simply send me an e-mail stating your extension request, with Cc to yourself, and with the subject line: CEE 201: *<your name>* extension request at least 24 hours before the deadline.

Automatic extensions are not available on projects or the final.

• **Late work:** Is not accepted except for illness or athletic notifications.

• **Group Project Peer Evaluation (optional):** For each project each student has the option to anonymously indicate the percent effort of each member of their group, including themselves, by submitting a *Project Cross Evaluation Form*. The project grade for group member $i$, $(g_i)$ will be apportioned according to the team project grade, $g$, and the contributions $c_i$ of team member $i$ to the project, as reported by any members of the group,

$$g_i = g - (100 - g) \left(1 - \frac{n}{m} \frac{1}{100} \sum_{i=1}^{m} c_i\right)$$

where the group has $n$ members and $m$ group members submit project cross-evaluation forms. For example, if a group earns a “B” (a grade $g$ of 85) and two of three group members anonymously submit a project cross-evaluation form, grades for members of the group will be assigned as follows:

<table>
<thead>
<tr>
<th>evaluated student</th>
<th>evaluating student</th>
<th>adjusted grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>“X”</td>
<td></td>
</tr>
<tr>
<td>Sue</td>
<td>“Y”</td>
<td></td>
</tr>
<tr>
<td>Tim</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bob</td>
<td>30</td>
<td>81.25</td>
</tr>
<tr>
<td>Sue</td>
<td>30</td>
<td>83.50</td>
</tr>
<tr>
<td>Tim</td>
<td>40</td>
<td>90.25</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>(3)(85.00)</td>
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</tbody>
</table>

so the individual student grades would be 81 for Bob, 84 for Sue, and 90 for Tim.

• **Homework answer keys:** will be posted on *Canvas* after homeworks are graded.
## COURSE SCHEDULE

<table>
<thead>
<tr>
<th>Week</th>
<th>Dates</th>
<th>Topic</th>
<th>Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/10-1/12</td>
<td>Design: innovation, analysis, evaluation, iteration, and optimization;</td>
<td>[3] ch.1</td>
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<tr>
<td></td>
<td></td>
<td>design parameters, cost functions, safety constraints, and failure probability</td>
<td>[3] ch.2</td>
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<tr>
<td></td>
<td></td>
<td>safety factors, uncertainty, and risk. matlab</td>
<td>[44]</td>
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<tr>
<td></td>
<td></td>
<td>due 1/19</td>
<td><strong>HW 1:</strong> matlab language skills and debugging</td>
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<td>2</td>
<td>1/15</td>
<td><em>Martin Luther King Day</em></td>
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<td></td>
<td>1/16-1/19</td>
<td>Constrained Optimization: inequality constraints and penalty methods</td>
<td>[12] [43] [13] [17]</td>
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<td></td>
<td></td>
<td>random search and simplex methods</td>
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<td></td>
<td>due 1/26</td>
<td><strong>HW 2:</strong> Constrained Optimization: search methods</td>
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<tr>
<td>3</td>
<td>1/22-1/26</td>
<td>Constrained Optimization: LP, QP, gradient, Hessian, and KKT</td>
<td>[14] [15] [16] [17]</td>
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<td></td>
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<td>equality constraints, binding and non-binding inequality constraints</td>
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<td>Sensitivity of cost to constraint relaxation and parameter variation</td>
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<td>application to least squares fitting and minimum total potential energy</td>
<td>[19] [20] [21]</td>
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<td></td>
<td></td>
<td>due 2/2</td>
<td><strong>HW 3:</strong> Constrained Optimization: gradient methods</td>
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<tr>
<td>4</td>
<td>1/29-2/2</td>
<td>Uncertainty: Aleatory and Epistemic uncertainty and their sources.</td>
<td>[1] ch.1</td>
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<tr>
<td></td>
<td></td>
<td>Axioms of Probability; union, intersection, mutually exclusive, collectively exhaustive, independence, conditional and total probability, Bayes' Rule</td>
<td>[22]</td>
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<td></td>
<td>due 2/9</td>
<td><strong>HW 4:</strong> Uncertainty: rules of probability</td>
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<td>5</td>
<td>2/5-2/9</td>
<td>Uncertainty: random variables, histograms, and empirical distributions.</td>
<td>[1] ch.3</td>
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<td>Bernoulli sequences, Binomial, Poisson and Gaussian distributions, return periods</td>
<td>[22]</td>
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<tr>
<td></td>
<td></td>
<td>uniform, triangular, normal, log-normal, exponential, Rayleigh, Laplace,</td>
<td>[27]:1-21</td>
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<td></td>
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<td>extreme value distributions, sums &amp; ratios of normal &amp; lognormal random variables</td>
<td>[1] ch.4:160-180</td>
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<td></td>
<td>due 2/16</td>
<td><strong>HW 5:</strong> Uncertainty: probability distributions</td>
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<tr>
<td>6</td>
<td>2/12-2/16</td>
<td>Uncertainty: joint distributions, Monte-Carlo simulation, variance of proportions, propagating correlated uncertainty, least squares fitting and error analysis, parameter and model covariance</td>
<td>[27]:22-40</td>
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<tr>
<td></td>
<td></td>
<td>due 2/23</td>
<td><strong>HW 6:</strong> Uncertainty: monte carlo simulation and regression</td>
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<td>7</td>
<td>2/19-2/23</td>
<td>Uncertainty: sample statistics, method of moments and maximum likelihood, confidence intervals, quantiles, hypothesis testing, aleatory and epistemic uncertainties.</td>
<td>[23] [1] ch.6</td>
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<td>due 3/1</td>
<td><strong>HW 7:</strong> Uncertainty: confidence intervals and hypothesis testing</td>
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<tr>
<td>8</td>
<td>2/26-3/1</td>
<td>Design-based engineering analysis of networks and stock-flow systems: trusses, power grids, water supplies, ecology, and basketballs</td>
<td>[24]</td>
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<tr>
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<td>due 3/8</td>
<td><strong>HW 8:</strong> Computer aided engineering analysis of network and stock-flow systems</td>
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<tr>
<td>9</td>
<td>3/4-3/8</td>
<td>Design-based analysis and optimization of electrical power networks, LP as a SQP</td>
<td>[41] [42]</td>
</tr>
<tr>
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<td></td>
<td>due 3/22</td>
<td>Project 1: Generate and distribute enough electrical power to meet uncertain demand</td>
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<tr>
<td>10</td>
<td>3/11-3/15</td>
<td><em>Spring Break</em></td>
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<tr>
<td>11</td>
<td>3/18-3/22</td>
<td>Design-based analysis and optimization of structures</td>
<td>[41] [42]</td>
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<tr>
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<td>due 3/29</td>
<td>Project 2.1: Optimize a 2D statically determinate truss.</td>
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<td>due 4/5</td>
<td>Project 2.2: Truss failure and correlation analysis.</td>
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<tr>
<td>13</td>
<td>4/1-4/5</td>
<td>Rainfall, stream-flow, aquifer and reservoir storage, transpiration, evaporation</td>
<td>course notes</td>
</tr>
<tr>
<td>14</td>
<td>4/8-4/12</td>
<td>Treatment for suspended solids, biological, and petro-chemical pollutants</td>
<td>course notes</td>
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<td>due 4/12</td>
<td>Project 3.1: Provide enough clean drinking water.</td>
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<tr>
<td>15</td>
<td>4/15-4/19</td>
<td>In-class project work</td>
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<td>due 4/19</td>
<td>Project 3.2: Water supply failure and correlation analysis.</td>
</tr>
<tr>
<td>16</td>
<td>4/22-4/24</td>
<td>Other kinds of design optimization with uncertainty.</td>
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<td></td>
<td>due 4/30</td>
<td><strong>TAKE HOME FINAL</strong> due at 5:00 pm</td>
</tr>
</tbody>
</table>
References


[38] Petsos, Henry, *Design Paradigms, Case Histories of Error and Judgment in Engineering*, Cambridge Univ. Press,


