University of Illinois at Urbana Champaign
Department of Aerospace Engineering
Spring 2020

AE 504: Optimal Aerospace Systems

4 credit hours

This syllabus is not an exhaustive description of all details of the course; the students are free to contact the instructor with any additional questions or concerns at any time.

Instructor

Melkior Ornik (mornik@illinois.edu)
Office: 319H Talbot
Office hours: Monday after class, or whenever agreed upon otherwise (online section: over Skype)
Contact: most easily by e-mail, but students are also welcome to come to the office whenever needed

Lecture Times

Lectures will generally be held on *MW 9-10:20am*. Temporary adjustments are possible, and many are planned: see tentative course outline. Attendance is *not* mandatory – students are welcome to adjust their course experience to their learning style, as long as doing so does not disturb learning styles of the others.

Course Description

AE 504 serves to provide multiple answers to a single question: *How to achieve an objective in the best way possible?* Posed in this way, such a question is vague, not well-defined, and there is no clear path towards solving it. The narrative of this course will be to resolve all of the above three issues: define a formal framework of optimization on finite- and infinite-dimensional spaces (the latter in particular focusing on spaces of control signals for a dynamical system), discuss common notions of cost associated with an objective or – of particular interest to aerospace applications – a system trajectory, and provide the theory necessary to approach questions of cost-minimization.

Formally, AE 504 is an introductory graduate course to optimization and optimal control. It is a mathematically oriented course – while aerospace applications serve to provide examples and a "story" for many of the course topics, they do not drive the course narrative, and the chosen topics are standard for optimization and optimal control courses throughout mathematical and engineering communities. The course, however, is not fully mathematically rigorous, primarily due to the breadth of the material combined with the lack of time. In it, we will cover – among other topics – standard finite-dimensional optimization notions such as KKT conditions and duality, discuss methods for solving particularly structured problems (e.g., convex, linear), and – on the side of control – explore dynamic programming, linear quadratic regulation, calculus of variations, and Pontryagin's maximal principle. By the end of the course, students will gain familiarity with the frameworks of optimization and optimal control, and will be able to solve basic optimization and optimal control problems.

Assignments and Grading

The deliverables for the course will consist of 5 homework assignments, a midterm covering the finite-dimensional optimization segment of the course, and a final project focused on optimal control. The weights for the deliverables will be distributed as follows:

Homework 1: 5%
Homework 2: 5%
Homework 3: 5%
Homework 4: 5%
Homework 5: 20%
Midterm: 25%
Final project: 35%

Additional extra credit may be offered during the semester, but should not be counted on.

The homework assignments and, particularly, the midterm will largely follow the material covered in the lectures. The final project will require students to produce work related to a topic in optimal control, based on (a) literature review, (b) students' independent research, or (c) a novel application of previous concepts to an aerospace application.

The final grades for the course will be calculated by the following formula: A-/A/A+ = 90-100, B-/B/B+ = 80-89.99, C- /C/C+ = 70-79.99, D-/D/D+ = 60-69.99, F = 0-59.99, where the "-" modifier will be assigned to those grades with the unit digit 0-1 (e.g., 91.87 = A-) and "+" modifier to those grades with the unit digit 8-9 (e.g., 78.02 = C+). The grades will not be rounded up, rounded down, nor "curved".

Submission of Deliverables

Homework assignments and final projects will be due at **noon** (Central time) of the deadline dates indicated by the instructor (see tentative course outline for predicted dates). Late submission of a particular deliverable, if not agreed with the instructor, will be penalized at the rate of 15% of the weight of the deliverable per day (prorated for the actual delay time; e.g., a 2-hour delay incurs a penalty of 1.25% of the total value of the deliverable).

Assignments should be submitted to the course Compass 2g page. Students are responsible for timely submission of the assignments. If there are issues with the page, students are welcome to submit the assignments to the instructor by e-mail.

Emergencies do happen; when faced with unavoidable obstacles, students should contact the instructor for any modifications to the submission schedules or the midterm timing.

Prerequisites and Literature

There is no required text for the course. With possible small exceptions intended for independent study, all new topics required for success in homework assignments and midterms will be discussed during the lectures. Students are required to have knowledge of linear algebra, ordinary differential equations, and multivariate calculus. Basic knowledge of control theory is also required. AE 352 is a formal prerequisite for the course.

The course material will partly follow the following textbooks:

- *Convex Optimization*, Stephen Boyd and Lieven Vandenberghe
  (a version can be found online at http://web.stanford.edu/~boyd/cvxbook/)
- *Dynamic Programming and Optimal Control*, Dimitri P. Bertsekas
  (some copies have been reserved for the course in the Engineering Library)
- *Calculus of Variations and Optimal Control Theory: A Concise Introduction*, Daniel Liberzon
  (a version can be found online at http://liberzon.csl.illinois.edu/publications.html)
- *Optimal Control*, Frank L. Lewis, Draguna Vrabie, and Vassilis L. Syrmos
  (a version can be found online at http://www.uta.edu/utari/acs/)

While the above textbooks will be useful for the course, the material covered will be significantly smaller than the union of those four books. *Students are not required to purchase any textbooks or other materials.*

Academic Integrity

Students are welcome to work together both on their homework assignments and final projects. Students are, however, required to write solutions and projects on their own *and* respond to any subsequent questions on the material posed by the instructor, whether in person or over e-mail. The answers to the instructor's questions may play a role in the grade assigned to the student.

Students are expected to work entirely alone on the midterm, making use solely of the materials allowed by the instructor.

Students are required to familiarize themselves with the University's Academic Integrity Policy and Procedure, available at http://studentcode.illinois.edu/article1/part4/1-401/, and abide by that policy in full.

Accommodations

To obtain disability-related academic adjustments and/or auxiliary aids, students that require special accommodations must contact the instructor and the Disability Resources and Educational Services (DRES) as soon as possible. Students are welcome to contact the instructor at any time with any accommodation-related needs. To contact DRES you may visit 1207 S. Oak St., Champaign, call 217-333-4603 (V/TTY), or e-mail a message to disability@illinois.edu.

Tentative Course Outline *(situation as of Jan 21)*

Week	Topic	Monday	Wednesday
1: Jan 20-24	Introduction to finite-dimensional optimization	No class (MLK Day)	Regular class
2: Jan 27-31	Examples; Introduction to constrained optimization	**No class, make-up: Tuesday, Jan 28, 8:30-9:50am**	Regular class **Homework 1 given**
3: Feb 3-7	Constrained optimization; Lagrange multipliers	Regular class	Regular class **Homework 1 deadline**
4: Feb 10-14	KKT conditions; Duality; Convexity	Regular class	Regular class
5: Feb 17-21	Convex optimization; Linear programming;	Regular class	Regular class **Homework 2 given**
6: Feb 24-28	Numerical methods	Regular class	Regular class **Homework 2 deadline**
7: Mar 2-6	Intro to discrete-time control systems; multi-step optimization	Regular class	**Midterm**
8: Mar 9-13	Discrete-time linear quadratic regulator	Regular class	Regular class
9: Mar 16-20		No class (break)	No class (break)
10: Mar 23-27		No class	No class
11: Mar 30-Apr 3	Dynamic programming; Bellman equation	8:30-9:20am, 9:30-10:20am	8:30-9:20am, 9:30-10:20am **Homework 3 given**
12: Apr 6-10	Calculus of variations; Pontryagin's maximal principle	8:30-9:20am, 9:30-10:20am	8:30-9:20am, 9:30-10:20am **Homework 3 deadline**
13: Apr 13-17	Linear quadratic regulator	8:30-9:20am, 9:30-10:20am **Homework 4 given**	8:30-9:20am, 9:30-10:20am
14: Apr 20-24	Minimum-time control; bang-bang	8:30-9:20am, 9:30-10:20am **Homework 4 deadline**	No class
15: Apr 27-May 1	Optimal control in aerospace	8:30-9:20am, 9:30-10:20am **Homework 5 given**	8:30-9:20am, 9:30-10:20am
16: May 4-8	Extra time; potential advanced topics	Regular class	Regular class **Homework 5 deadline**
– : May 14	**Project deadline**		

Modifications to the Syllabus

The instructor reserves the sole right to modify any and all parts of this syllabus throughout the semester. All modifications will be made solely in the interest of time scheduling, accurately measuring the students' success, and improving the students' educational outcomes.