

University of Illinois at Urbana Champaign
Department of Aerospace Engineering
Spring 2019

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: Wednesday 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 *MWF 9-9:50am*. Temporary adjustments are possible, and some 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.

Grading

The deliverables for the course will consist of 3 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: 10%
Homework 3: 20%
Midterm: 30%
Final project: 35%

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.

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 (pro rated 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 Vrabe, 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. *The 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 11*)

Week	Topic	Monday	Wednesday	Friday
1: Jan 14-18	Introduction to finite-dimensional optimization	Regular class	8:35-9:50am	No class
2: Jan 21-25	Examples; Introduction to constrained optimization	No class (MLK Day)	8:35-9:50am	8:35-9:50am HWK 1 GIVEN

3: Jan 28-Feb 1	Constrained optimization; Lagrange multipliers	No class	8:35-9:50am	Regular class HWK 1 DEADLINE
4: Feb 4-8	KKT conditions; Duality; Convexity	Regular class	Regular class	Regular class
5: Feb 11-15	Convex optimization; Linear programming;	Regular class	Regular class	Regular class
6: Feb 18-22	Numerical methods	Regular class	Regular class	Regular class
7: Feb 25-Mar 1	Intro to discrete-time control systems; multi-step optimization	Regular class	8:35-9:50am MIDTERM	Regular class
8: Mar 4-8	Discrete-time linear quadratic regulator	Regular class	Regular class	Regular class
9: Mar 11-15	Dynamic programming; Bellman equation	Regular class	Regular class	Regular class HWK 2 GIVEN
10: Mar 18-22		No class (break)	No class (break)	No class (break)
11: Mar 25-29	Calculus of variations	Regular class	Regular class	Regular class HWK 2 DEADLINE
12: Apr 1-5	Pontryagin's maximal principle	Regular class	Regular class	Regular class
13: Apr 8-12	Linear quadratic regulator	Regular class	Regular class	Regular class
14: Apr 15-19	Minimum-time control; bang-bang	Regular class	Regular class	Regular class HWK 3 GIVEN
15: Apr 22-26	Optimal control in aerospace	Regular class	Regular class	Regular class HWK 3 DEADLINE
16: Apr 29-May 3	Extra time; potential advanced topics	8:35-9:50am	No class	No class (finals)
- : May 9	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.