University of Illinois Urbana-Champaign
Department of Aerospace Engineering
Spring 2023

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. Because of the ongoing situation regarding the COVID-19 pandemic, the syllabus may be modified in substantial ways 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

Course Delivery

Lectures will generally be held on *MW 1-2:20pm* in *403B2 Engineering Hall*. Temporary adjustments are possible, and some are already planned. 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.

Online course materials (notes, homeworks), as well as grades, will be delivered through the course's **Canvas page**. Students should make sure to be enrolled in the page, and be set up to quickly receive Canvas announcements. *All important announcements will be communicated over Canvas*.

Students are required to follow the campus COVID-19 protocols and engage in appropriate behavior to protect the health and safety of the community. Significant modifications to the course delivery methods as a result of the changes in the COVID-19 situation are possible, and will be announced to students as necessary.

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 on 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 **11:59pm** (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 10% of the weight of the deliverable per day (prorated for the actual delay time; e.g., a 3-hour delay incurs a penalty of 1.25% of the total value of the deliverable). Students are responsible for submitting the assignments and project in a timely manner; if there are issues with Canvas, the deliverables should be submitted to the instructor over email.

The midterm will be completed in person during the regular lecture times. Students will not be allowed to communicate with each other or with the outside world during the quizzes. The midterms will be solved on paper, with access to any written material, but without access to computational tools.

Emergencies do happen, and everything is still more fluid than usual because of COVID-19; when faced with unavoidable obstacles, students should contact the instructor for any modifications to the submission schedules.

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 on an author's page 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 on the author's page 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 on an author's page at https://lewisgroup.uta.edu/FL%20books/Lewis%20optimal%20control%203rd%20edition%202012.pdf)

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.*

Respect and Growth in the Classroom

The effectiveness of every course is dependent upon creating a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all. Growing as a whole person is far more important than growing in a scientific discipline, and includes growing in respect and understanding of others. While everyone has different personalities and perspectives and it takes time to adapt to one another, maintaining an environment where everyone can freely and joyfully contribute is an explicit goal of the class.

The Aerospace Engineering department has a committee called Aero's Space to Belong. They offer office hours, one-on-one discussion, and a reporting process. In case of conflict that undermines anyone's sense of respect, self-respect, or belonging, every student should consider using these resources: https://aerospace.illinois.edu/diversity/reporting.

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, visit 1207 S. Oak St., Champaign, call 217-333-4603 (V/TTY), e-mail a message to disability@illinois.edu, or visit https://www.disability.illinois.edu. If a student is concerned that they have a disability-related condition that is impacting their academic progress, there are academic screening appointments available that can help diagnosis a previously undiagnosed disability. These may be accessed by visiting the DRES website.

Illinois law requires the University to reasonably accommodate its students' religious beliefs, observances, and practices in regard to admissions, class attendance, and the scheduling of examinations and work requirements. If there is a conflict between course deadlines and any religious observances, students should notify their instructor and follow the procedure at https://odos.illinois.edu/community-of-care/resources/students/religious-observances/ to request appropriate accommodations. These steps should be conducted in the first two weeks of classes.

Privacy and Reporting

The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University's Title IX Office. In turn, an individual with the Title IX Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options. A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: https://wecare.illinois.edu/resources/students. Other information about resources and reporting is available here: https://wecare.illinois.edu.

Any student who has suppressed their directory information pursuant to Family Educational Rights and Privacy Act (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See https://registrar.illinois.edu/academic-records/ferpa/ for more information on FERPA.

Campus Emergency Plan

The university's emergency response recommendations can be found at the following website: http://police.illinois.edu/safe/. Students should review this website and the appropriate campus building floor plans website within the first 10 days of class: http://police.illinois.edu/emergency-preparedness/building-emergency-action-plans/.

Modifications to the Syllabus

The instructor reserves the 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, beneficial adaptation to changing public health circumstances, accurate measurement of the students' success, and improvement of the students' educational outcomes. Any modifications will be transparently communicated to the students.