

THE OHIO STATE UNIVERSITY
Mechanical and Aerospace Engineering

AAE 8820: Robust Multivariable Control with Applications
Autumn 2017

Course Handout

NOTE: Modifications to this syllabus may be required during the semester. Any changes to the syllabus will be announced in class.

Catalog Course Description: Advanced concepts for robust control of uncertain dynamic systems with applications. Credits: 3

Pre-requisites: 5620 (620), 5621 (621) or equivalent. Working knowledge of at-least one programming language is required, e.g. MATLAB[®].

Course Objectives: By the end of this course, you should be able to do the following:

- have a solid grasp of linear algebra tools central to the analysis and design of robust control systems,
- understand and compute the \mathcal{H}_2 and \mathcal{H}_∞ norms and their role in characterizing system stability and performance,
- understand the notion of a system's internal stability and apply various tests to evaluate it,
- apply the principles of linear fractional transformations and structured singular value analysis (μ synthesis)
- pose and solve \mathcal{H}_2 and \mathcal{H}_∞ control problems.

Contribution of course to meeting the professional component (ABET): The table below describes the contribution of this course to development of specific components of professional growth as described in the ABET program criteria. The components have been divided into three streams: aeronautical (ae), astronautical (as) and mechanical (me): There is high coverage for professional components

Aeronautical	Astronautical	Mechanical
(ae1) Aerodynamics: ×	(as1) Orbital mechanics: ×	(me1) Apply principles of engineering, basic science & mathematics (inc. multivar. calculus & differential eqns) to model, analyze, design & realize physical systems, components or processes: ✓
(ae2) Aerospace materials: ×	(as2) Space environment: ×	
(ae3) Structures: ×	(as3) Attitude determination and control: ✓	(me2) Work professionally in both thermal and mechanical systems areas: ×
(ae4) Propulsion: ×	(as4) Telecommunications: ×	
(ae5) Flight mechanics: ✓	(as5) Space structures: ×	
(ae6) Stability and control: ✓	(as6) Rocket propulsion: ×	
Engineering Design: 20% Mathematics: 40 %, Engineering Sciences: 40 %		

(ae5) and (ae6). In addition to the program criteria described above, this course will also contribute to the development of proficiency in the subject of numerical methods and the use of computational tools to solve engineering problems.

Relationship of course to program outcomes (ABET): This course will meet several program outcomes as described in the ABET criteria, described in the table below. There will be high coverage for outcomes (a), (c), (e) and (k) in this course. These outcomes will be assessed throughout the semester via homework assignments (to be completed by individual effort) and selected problems on exams. In

Program outcome	Met?	Program outcome	Met?
(a) an ability to apply knowledge of mathematics, science, and engineering	✓	(b) an ability to design and conduct experiments, as well as to analyze and interpret data	×
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	✓	(d) an ability to function on multidisciplinary teams	×
(e) an ability to identify, formulate, and solve engineering problems	✓	(f) an understanding of professional and ethical responsibility	×
(g) an ability to communicate effectively	×	(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	×
(i) a recognition of the need for, and an ability to engage in life-long learning	✓	(j) a knowledge of contemporary issues	×
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	✓		

addition, there is low coverage for outcome (i), which will be assessed through homework.

Instructor: Mrinal Kumar (kumar.672@osu.edu). Office Location: E530 Scott Labs, Telephone: (614) 688-2884. Office hours: M, W 3-4 PM. Also welcome to come in any other time if I am available.

Teaching Assistants: None.

Class meeting times: M-W, 10:05 - 11:55 AM

Meeting location: Scott Labs E103

Textbook/Software: There is no official textbook for this course. Material will be gathered from a number of sources and reading material will be provided. The following books are notable references for the topics considered in this course and can be used as supplemental reading material.

1. *Essentials of Robust Control*, by Kemin Zhou and John C. Doyle, Publisher: Prentice Hall, 1999.
2. *Robust Control of Uncertain Dynamic Systems: A Linear State Space Approach*, by Rama K. Yedavalli, Publisher: Springer, 2014, ISBN: 978-1-4614-9131-6.
3. *Robust Control Design with MATLAB®*, by D.-W. Gu, P. Hr. Petkov and M. M. Konstantinov, Publisher: Springer, 2005, ISBN: 978-1-85233-983-8.
4. *Linear Robust Control*, by Michael Green and David J. N. Limebeer, Publisher: Dover, 2012, ISBN: 978-0-4864-8836-3
5. *Robust Process Control*, by Manfred Morari and Evangelos Zafiriou, Publisher: Prentice Hall, 1989, ISBN: 978-0-1378-2153-2

Note: You are not required to buy any of the above books.

Attendance/Other expectations: Students are expected to attend all lectures although there are no penalties for missing classes. Any activity that acts as a distraction for other students (e.g. talking on phone/texting/Rubik's cube/juggling etc.) is not permitted while class is in progress.

Course outline: The table below provides a tentative weekly schedule for this course. Please note that the table is meant only as a guideline *and there may be significant variations depending on several factors*, e.g. how easily the introductory material is grasped by the class, allowing me to proceed to more advanced topics.

Material	Week #	HW Due?	Comments
Introduction, linear algebra, linear systems	1	×	
	2	✓	
\mathcal{H}_2 and \mathcal{H}_∞ spaces, system stability and performance	3	✓	Labor day week
	4	×	
	5	✓	
Characterization of system uncertainty, notion of robustness	6	✓	
	7	×	Exam 1 (take-home)
Linear fractional transform, μ synthesis	8	×	Autumn break
	9	✓	
	10	✓	
\mathcal{H}_2 optimal control	11	×	
	12	✓	
\mathcal{H}_∞ control	13	✓	
	14	×	Thanksgiving week
Applications.	15	✓	
	16	×	Exam 2 (take-home)

Grading policy: All HW assignments are to be completed individually. You are encouraged to discuss assigned problems with fellow students, but you must turn in your own work. Shared computer programs will not be considered for evaluation. Details of grade distribution:

- **Homework Assignments:** 50%
- **Take-home exams (2):** 50%.
 - **Assigned: Week 7 (F), Due back: Week 8 (W)**
 - **Assigned: Week 16 (M), Due back: Week 16 (W)**

Late assignment policy: You are allowed to turn in 1 assignment late without penalty (your 1st late submission). The 2nd late submission will incur a penalty of 25% and 50% the 3rd onwards.

Grading scale:

Score	Grade	Score	Grade	Score	Grade	Score	Grade	Score	Grade
> 92	A	> 86	B+	> 76	C+	> 66	D+	< 59	E
> 89	A-	> 82	B	> 72	C	> 62	D		
		> 79	B-	> 69	C-	> 59	D-		

The above table represents a guideline for letter-grade allocation. In borderline cases, I reserve the right to assign a grade different from the grade derived from the table above. Such an assignment will be based on the progressive performance of the student in the course. For example, a student ending up with a final score of 85 may be awarded an A- (instead of B+) if her performance has progressively improved over the course of the semester.

Academic Misconduct: It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term “academic misconduct” includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct at <http://studentconduct.osu.edu>

Accommodation for Students with Disabilities: Students with disabilities that have been certified by the Office for Disability Services will be appropriately accommodated and should inform the instructor as soon as possible of their needs. The Office for Disability Services is located in 098 Baker Hall, 113 W. 12th Avenue; Phone: 292-3307, TDD 292-0901, VRS 429-1334; <http://www.ods.ohio-state.edu/>

Grievances and Solving Problems: According to University Policies, if you have a problem with this class, you should seek to resolve the grievance concerning a grade or academic practice by speaking first with the instructor or professor. Then, if necessary, take your case to the department chairperson, college dean or associate dean, and to the provost, in that order. Specific procedures are outlined in Faculty Rule 3335-7-23. Grievances against graduate, research, and teaching assistants should be submitted first to the supervising instructor, then to the chairperson of the assistant's department.

Counseling Services: As a student you may experience a range of issues that can cause barriers to learning, such as strained relationships, increased anxiety, alcohol/drug problems, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may lead to diminished academic performance or reduce a student's ability to participate in daily activities. The Ohio State University offers services to assist you with addressing these and other concerns you may be experiencing. If you or someone you know are suffering from any of the aforementioned conditions, you can learn more about the broad range of confidential mental health services available on campus via the Office of Student Life Counseling and Consultation Services (CCS) by visiting ccs.osu.edu or calling (614) 292- 5766. CCS is located on the 4th Floor of the Younkin Success Center and 10th Floor of Lincoln Tower. You can reach an on-call counselor when CCS is closed at (614) 292-5766 and 24 hour emergency help is also available through the 24/7 National Prevention Hotline at 1-(800)-273-TALK or at suicidepreventionlifeline.org

Diversity: The Ohio State University affirms the importance and value of diversity in the student body. Our programs and curricula reflect our multicultural society and global economy and seek to provide opportunities for students to learn more about persons who are different from them. We are committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters sensitivity, understanding, and mutual respect among each member of our community; and encourages each individual to strive to reach his or her own potential. Discrimination against any individual based upon protected status, which is defined as age, color, disability, gender identity or expression, national origin, race, religion, sex, sexual orientation, or veteran status, is prohibited.

Copyright: The materials used in connection with this course may be subject to copyright protection and are only for the use of students officially enrolled in the course for the educational purposes associated with the course. Copyright law must be considered before copying, retaining, or disseminating materials outside of the course.