THE OHIO STATE UNIVERSITY
Mechanical and Aerospace Engineering

AAE 8802/ME 8518: Advanced Mathematical Methods
Fall 2018

Course Handout

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

Pre-requisites:
Graduate standing. Working knowledge of at-least one programming language is required.

Course Objectives:
The objective of this course is to introduce to the mechanical/aerospace engineering graduate students some important mathematical methods commonly used for conducting research. The methods are mainly derived from two core areas: (i.) differential equations and (ii.) applied linear algebra. To a lesser extent, some components will also be derived from statistics and probability theory. The course will focus more on the practice of mathematical methods, i.e. their implementational aspects rather than their theoretical aspects. From differential equations, we will consider series approximations, initial and boundary value problems, special functions and inverse methods. From linear algebra, we will consider vector spaces, approximation theorems, matrix algebra and decompositions. From probability theory, we will consider error analysis and estimation methods. Upon completion of this course, the student should be favorably situated to derive/design and analyze mathematical models from physical situations.

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):

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:	×		
(ae4) Propulsion:	×	**(as4)** Telecommunications:	×		
(ae5) Flight mechanics:	×	**(as5)** Space structures:	×	**(me2)** Work professionally in both thermal and mechanical systems areas:	×
(ae6) Stability and control:	×	**(as6)** Rocket propulsion:	×		
Mathematics: 50 %, **Engineering Sciences**: 50 %					

This course primarily covers professional component **me1**. In addition, there is some coverage of probabilistic analysis. There is also significant coverage 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.

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.	✓		

There will be high coverage for outcomes (**a**), (**e**) and (**k**) in this course. These outcomes will be assessed throughout the semester via regular homework assignments (to be completed by individual effort) and problems on exams.

Instructor: Mrinal Kumar (kumar.672@osu.edu). Office Location: E530 Scott Labs, Telephone: (614) 688-2884.

Office hours: `Mo-We 2-3 pm` @ Scott Labs and `Th 2-3 pm` @ ARC (Aerospace Research Center), room 174. Also welcome to come in any other time if I am available.

Teaching Assistant: `TBD`

Class meeting times: `Mo-We 11:10 AM - 12:30 PM`

Meeting location: `Scott Labs Room E105 (Bldg #148, 201 W 19th Ave)`
See here: https://www.osu.edu/map/

Textbooks/Software: Material will be derived from several textbooks and papers. Relevant books are listed below against the topic of concern. The student must also have access to at-least one programming language (e.g. MATLAB).

I. **Differential Equations**

(a) *Ordinary Differential Equations* by Philip Hartman, SIAM-Philadelphia (2002), ISBN: 978-0-898715-10-1. (available online through OSU library)

(b) *Ordinary and Partial Differential Equations, with Special Functions, Fourier Series, and Boundary Value Problems*, by Ravi P. Agarwal and Donal O'Regan, Springer New York (2009), ISBN: 978-0-387-79145-6. (available online through OSU library)

(c) *Elementary Differential Equations and Boundary Value Problems*, by William E. Boyce and Richard C. DiPrima, John Wiley & Sons, 3rd Ed. (1977), ISBN-10: 0-471-09334-3

(d) *Differential Equations, Dynamical Systems, and an Introduction to Chaos* by Morris W. Hirsch, Stephen Smale, and Robert L. Devaney, Elsevier Academic Press, 2nd Ed. (2004), ISBN: 0-12-349703-5 (available online as free pdf)

(e) *Ordinary Differential Equations and Dynamical Systems*, by Gerald Teschl, Graduate Studies in Mathematics, Volume 140, American Mathematical Society Providence, Rhode Island, 2010. (available online as free pdf)

II. **Linear Algebra**

(a) *Numerical Linear Algebra*, by Lloyd N. Trefethen and David Bau III, SIAM, 1st Ed. (Jun 1, 1997), ISBN-10: 0-89-871361-7, ISBN-13: 978-0-89-871361-9

(b) *Applied Numerical Linear Algebra* by James W. Demmel, SIAM-Philadelphia (1997), ISBN: 978-0-898713-89-3. (available online through OSU library)

(c) *Principles of Applied Mathematics: Transformation and Approximation*, by James P. Keener, Westview Press, Revised Ed. (2000), ISBN: 0-7382-0129-4

(d) *Matrix Analysis for Scientists and Engineers*, by Alan J. Laub, SIAM (Dec 29, 2004), ISBN-10: 0-89-871576-8, ISBN-13: 978-0-89-871576-7

(e) *Matrix Analysis*, by Roger A. Horn and Charles R. Johnson, Cambridge University Press; 2 edition (Oct 22, 2012), SBN-10: 0-52-154823-3, ISBN-13: 978-0-52-154823-6

III. **Probability Theory**

(a) *Basic Probability Theory*, by Robert B. Ash, Dover Publications New York (2008), ISBN-10: 0-486-46628-0, ISBN-13: 978-0-486-46628-6. (available online as free pdf)

(b) *Probability and Random Processes*, by Geoffrey Grimmett and David Stirzaker, Oxford University Press USA, 3rd edition (Aug 2, 2001), ISBN-10: 0-19-857222-0, ISBN-13: 978-0-19-857222-0

(c) *Probability, Random Variables and Stochastic Processes*, by Athanasios Papoulis and S. Unnikrishna Pillai, McGraw-Hill Europe, 4th edition (Jan 1, 2002), ISBN-10: 0-07-122661-3, ISBN-13: 978-0-07-122661-5

(d) *Probability and Random Processes: With Applications to Signal Processing*, by Henry Stark and John W. Woods, Publisher: Prentice Hall, 3rd edition (Aug 3, 2001), ISBN-10: 0-13-020071-9, ISBN-13: 978-0-13-020071-6

(e) *Introduction to Probability*, by Dimitri Bertsekas and John N. Tsitsiklis, Publisher: Athena Scientific; 2nd edition (July 15, 2008); ISBN-10: 1-88-652923-X, ISBN-13: 978-1-88-652923-6

Course outline: The table below provides a tentative weekly schedule for the material covered in this course:

Topic	Material	Week #	Assignment Due?
Differential Equations	Classification, key examples, analytical solutions	1	×
	Solution of initial value problems	2	✓
	Power Series Solutions	3	✓
	Method of Frobenius	4	×
	Partial Differential Equations	5	✓
	BVP, Sturm-Liouville theory	6	✓
Linear Algebra	Basic matrix algebra	7	× (Test 1)
	Versions of $Ax = b$: normal equations, least squares	8	×
	Spectral theory of matrices	9	✓
	Vector spaces	10	✓
	Approximation in Hilbert space	11	✓
	Proper orthogonal decomposition and ROM	12	× (Test 2)
Applied Probability	Set Theory Recap, Random Variables	13	×
	Conditional Probability, Expectations	14	✓
	Stochastic Discretization: Monte Carlo	15	✓
	Maximum Likelihood Estimation	16	×

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.

Grading policy: Because of the nature of the subject, course evaluation will be based on homework problems, an end-term project and take-home exams. All homework assignments are to be completed individually. You are encouraged to discuss assigned problems with fellow students, but must turn in your own submission. Shared computer programs will not be considered for evaluation. No collaboration is permitted in the take-home tests! The following are the details of grade distribution:

- **HW assignments** (8 - 10) : 10%
- **Mid-term tests** (2): 50%
- **End term exam**: 40%

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

Make-up exam policy:You must obtain permission from the instructor well in advance if you require to re-schedule your mid-term or end-term exam due to unavoidable circumstances. It may be difficult to accommodate last moment requests.

Grading scale:

The table below represents a guideline for letter-grade allocation. However, in borderline cases, I reserve the right to assign a grade different than the one resulting from the table above. Such an assignment will be based on the progressive performance of the student in the course. For example, a

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

student ending up with a final score of 85 may be awarded an B+ (instead of B) if her performance has progressively improved over the course of the semester. A lower grade *may* similarly result.
Note: A C- will not be a qualifying grade for critical tracking courses. In order to graduate, students must have an overall GPA and an upper-division GPA of 2.0 or better (C or better). Note: a C- average is equivalent to a GPA of 1.67, and therefore, it does not satisfy this graduation requirement. For more information on grades and grading policies, please visit: http://www.registrar.ufl.edu/catalog/ policies/regulationgrades.html

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.

Prepared by: Mrinal Kumar 13^{th} December, 2018