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Continuum Mechanics with Applications
MAE 6020/AM 6020/CE 6720
Fall 2015

What is continuum mechanics?

Continuum mechanics is the study of how matter changes shape when it is pushed, pulled, stretched, squished or heated. Similarly, continuum mechanics tells us how much effort it will take to change the shape of both liquids and solids. Continuum mechanics will help you answer most of the really important questions in life including:

-Is toothpaste liquid or a solid?
-At what point does calculating the "change in length per unit length" no longer result in a quantity called strain?
-Under what conditions can you mechanically model human knee ligaments the same way you do steel?
-How many material parameters are required to fully characterize a transverse isotropic material?

If you took an undergraduate engineering course in Strength of Materials you were presented with a lot of equations. The course was designed to teach you what those equations mean and how to use them to describe material behavior. This course in continuum mechanics is designed to begin with VERY few assumptions, and show you where all of those equations come from.

More Technically: Continuum mechanics, or the mechanics of deformable bodies, is the study of the gross behavior of matter subjected to external forces and heat fluxes. Essentially it considers the fundamental concepts of stress, strain, and the constitutive or material models that relate these two. It does not consider atomic or other structure but rather assumes that matter is distributed continuously in regions of space. As a result it involves the consideration of matter at length scales just large enough such that individual molecules or atoms of a material appear. Continuum mechanics helps us answer important questions like:

Why should you care about continuum mechanics?

Continuum mechanics frames the fundamental background (think: prerequisites) for more advanced study in solid mechanics, fluid mechanics, thermal mechanics, and biomechanics, such as linear and nonlinear elasticity, plasticity, composite materials, micromechanics, nonlinear mechanics, and viscoelasticity. Additionally, most research in theoretical mechanics relies on the general principles of continuum mechanics, expressed using tensor analysis, to express and derive expressions for material models and predict experimental results. In short,

this course teaches the language of mechanics; understanding this language will provide students with the tools to tackle more advanced mechanics topics through self-study or other courses. *As a result, mastery of this fundamental material is essential for graduate engineers who will use mechanics in their research and/or profession*.

What are you going to learn?

-*Math*: index notation, scalars, vectors, matrices, tensors, tensor properties and operations, transformation laws, eigenvalues and eigenvectors, Cramer's Rule, tensor invariants, and tensor calculus.
-*Kinematics*: motion, displacement, deformation, simple shear, Lagrangian (material) and Eulerian (spatial) descriptions, velocity, acceleration, the material derivative, deformation homogeneity, deformation gradient, polar decomposition, stretch and rotation tensors, strain, deformation and strain tensors, linearizing strain, compatibility, kinematics of fluids, and rate of deformation and spin tensors.
-*Stress*: Cauchy stress principle, stress vector, Cauchy stress tensor, symmetry, equilibrium equations, Piola-Kirchoff stress tensors, and hydrostatic and deviatoric stresses.
-*Constitutive Equations:* Poisson's ratio, linear elastic materials, generalized Hooke's law, elastic stiffness tensor, isotropy, transverse isotropy, anisotropy, bulk modulus, material incompressibility, Cauchy-Navier equations, and boundary value problems.
-*Newtonian Viscous Fluid (2 classes)*: continuity, compressibility, conservation of mass, viscous stress tensor, Navier-Stokes equations.
-*Nonlinear Elasticity (2 classes):* strain energy density, strain energy density function, neo-Hookean, Mooney-Rivlin,

What are you going to learn to do?

-Demonstrate an understanding of continuum mechanics theory and when it can and should be applied (*Foundational Knowledge, Application*)
-Connect the theories of continuum mechanics to your background in (presumably undergraduate mechanics--like what you learned in a first course in Strength of Materials for instance), and your own research and interests (*Foundational Knowledge, Integration, Application*).
-Demonstrate an understanding of how linear algebra and tensor theory apply to continuum mechanics and how they can apply to other disciplines (*Foundational Knowledge, Application*).
-Evaluate other research literature for its adherence to fundamental concepts and assumptions of continuum mechanics, and use such concepts to understand what the authors have done (*Application, Foundational Knowledge, Learning How To Learn).*
-Succeed in this course while succeeding in adjusting to a new place, a new university, your other course(s), and/or the demands of your research (*Human, Learning How To Learn*).

How can you succeed in learning?

Succeeding in this class will be easy if you continue to do the things you have learned to do to be successful. Those are:

Come to class ready to learn (work): Class is the best time for you to ask questions, to firm up and demonstrate your understanding, to communicate with your peers, and learn new material. But learning is work. So come ready to work.

Do your homework, with help from your peers and me: Collaborative learning is almost always more successful than individual learning. If you get stuck, you should ask for help. If you don't get stuck, it never hurts to make sure you are on the right track. Just make sure you understand the questions and their solutions.

Read your textbook and other materials: Reading your textbook in advance of class will help tremendously with your understanding of what we are going to cover in class. Additionally, web resources will provide another approach to the same topics that you can consult before, during, or after the time we cover it in class.

Ask questions: If you don't completely understand something, your peers and I are your best resource. If you don't want to ask in class, come meet me, ask another student, or make an anonymous post on collab. Just make sure you ask it.

What resources are available to help you?

Instructor: Jason R. Kerrigan (jrk3z@virginia.edu)
Office 1: MEC 327
Phone: 434-297-8049 (7-8049)
When: Mondays and Wednesdays (generally)
Meet with me about homework, course content, being a graduate student, or life in general:
-10:30-11:45 Mondays and Wednesdays
-By appointment (made by email)

Office 2: Center for Applied Biomechanics, 4040 Lewis & Clark Dr, UVA Research Park (Near CHO Airport)
Phone: 434-924-7519 (4-7519)
When: Tuesdays, Thursdays, and Fridays (generally)
Meet with me about homework, course content, being a graduate student, or life in general:

-By appointment (made by email)

Class:
Mondays and Wednesdays 2:00-3:15 PM
Mechanical and Aerospace Engineering Building (MEC) Room 341

Web Materials:
www.continuummechanics.org
www.ocw.mit.edu

Textbook:
Introduction to Continuum Mechanics, 4th Edition, paperback by W. M. Lai, D. Rubin, E. Krempl. Butterworth-Heinemann (Elsevier); Burlington, MA. 2010. ISBN978-0-7506-8560-3.

Electronic Course Materials:
https://collab.itc.virginia.edu search once you get there for Continuum Mechanics 2015

How will we evaluate your learning?

Concept Checks-(10%)-We will begin the majority of the classes with a question (or 2 or more) that aim to assess your comprehension of what was covered in the previous class(es) and the assigned reading prior to the class. Concept checks will be performed using www.questionpress.com/kerrigan so you will need to bring a web enabled device (with a fully charged battery) to class every time. We will immediately and together review the answers to the questions and have a brief discussion. These will be graded with the following rubric:
-0 points: answer no questions
-1 point: answer some of the questions
-2 points: answer all of the questions
-3 points: get all of the questions right

Homework-(25%)-Much of this course is focused on mathematical descriptions and derivations. You will develop and refine your understanding of these principals through practicing them by solving problems in homework assignments. Since some of these will be challenging, it is expected that you will seek out assistance from your peers and from me. Much like what you will encounter the rest of your life, your work will be graded by your peers. To ensure that everyone is grading the same, and that it is clear to you how your work will be assessed, we will grade each part (a, b, c, d…) of each problem using the following rubric:

Points	Title	Details
0	Blank	No attempt made
1	Not Blank	Something is written, but it has very little to do with the problem, or is incomplete. Or, the answer is given without sufficient work to clearly show how the answer was obtained
2	Right Track	Proper application of the principles, but substantial errors in execution result in an implausible result.
3	Close	Everything looks right, but a small error results in an incorrect, but plausible, result.
4	Right	Proper principles and execution. Arrived at the correct result.

Exams-(30%)-It is important for you to be able to demonstrate your understanding of the theories and background of the mathematical formulations we will discuss during class and you will practice in your homework. Three times during the semester we will have in-class exams. Since your homework assignments are focused on your ability to solve problems, these exams will evaluate your conceptual understanding of the material we cover and how it relates to mechanics.

Research Paper Investigations-(15%)-Your ability to succeed as a graduate student and enter the professional world hinges on your ability to obtain, understand, evaluate, critique, and apply research (papers) that you find in the public domain. Some would say that the purpose of graduate coursework is really to help you learn the foundational knowledge you will need to begin doing this, and to teach you how to learn the remaining foundational knowledge on your own. As a result, in each course of your graduate career, you should gain more tools and continue to polish your ability to be critical of previous research. While it will be challenging to completely understand, analyze, and critique theoretical mechanics research without mastery of the entirety of the material you will learn in this course, we will periodically review and discuss papers throughout the semester to begin working on this important skill and to help identify directions in our course. Initially the papers will be chosen for you and tasks will range from group discussion to very short thinking and writing assignments. At the end of the semester, you will need to complete a short written technical review of a paper that contains an application of theoretical mechanics to solve a problem. You will be asked to teach your audience about the authors' work. Much like what you will encounter for the rest of your life, your work on this assignment will be assessed by both your peers (do they understand your explanation) and me.

Final Exam-(20%)-We will use the three hour final exam period to assess your learning in this course. This assessment will involve both solving problems and demonstration of your understanding of the conceptual nature of the mathematical material.

What else do you need to know?

-*Homework*: Late homework will not be accepted. Specific instructions are included with each homework to facilitate grading. You are encouraged to work with your classmates, and thus homework does not require an honor pledge.
-*Missing Class*: If you need to miss class for some reason, send me an email in advance to be excused from concept checks, and to get details about what you are going to miss.
-*Grading Scale*: This course will use the following grading scale:

A+: 97-100	B+: 87-89. $\overline{9}$	C+: 70-79. $\overline{9}$
A: 93-96.$\overline{9}$	B: 83-86. $\overline{9}$	C: Below 70
A-: 90-92. $\overline{9}$	B-: 80-82. $\overline{9}$	

I reserves the right to adjust (down) the lower bounds of each of these ranges. However, the upper bounds will remain unchanged.

-*Your Own Work*: You are expected to work with your peers on your homework. However, you are expected to turn in your own work. If you choose to copy someone else's work, you will have problems demonstrating your understanding on exams.
-*Professional and Academic Integrity:* I trust that throughout your career at UVA, you will exhibit the highest standards of ethics, integrity and personal responsibility. As a result, I expect that you will fully comply with all of the provisions of the UVA Honor System. In addition to pledging that you have neither given nor received unauthorized aid on exams and assignments, your signature also affirms that you have not knowingly represented as your own any opinions or ideas that are attributable to another author in published or unpublished notes, study outlines, abstracts, articles, textbooks, or web pages. In other words, I expect all work with your name on it to be your work, and that references are cited appropriately. Breaking this trust agreement will not only result in zero credit for the assignment in question and referral to the UVA Honor Committee, but it will also jeopardize your future as a professional engineer. Don't let yourself down. It is not worth it.
-*Learning Needs*: If you have learning needs that have been evaluated by the Learning Needs and Evaluation Center (LNEC) or the Student Disability Access Center (SDAC), I will be happy to accommodate them and help you accordingly. You must, however, provide documentation from LNEC/SDAC within the first two weeks of the semester or whenever you are evaluated, but at least one week before an exam.

Schedule/Calendar

The course schedule/calendar is on the collab site here and will be updated regularly so you should check there often.

MAE 6020: 2015 CALENDAR

M/W SCHEDULED CLASSES:

M/W Date	Will we have class?	Detail
26-Aug	yes	
31-Aug	yes	
2-Sep	yes	
7-Sep	NO CLASS	Need To Make Up
9-Sep	yes	
11-Sep	YES	FRIDAY CLASS! 9:00AM MEC 215
14-Sep	yes	
16-Sep	yes	
18-Sep	YES	FRIDAY CLASS! 9:00AM MEC 215
21-Sep	yes	
23-Sep	yes	
25-Sep	YES	FRIDAY CLASS! 9:00AM MEC 215
28-Sep	yes	
30-Sep	yes	
5-Oct	NO CLASS	UVA Reading Day
7-Oct	NO CLASS	Need To Make Up
12-Oct	yes	
14-Oct	yes	
19-Oct	yes	Note this change as of 9/30
21-Oct	yes	Note this change as of 9/30
26-Oct	NO CLASS	Need To Make Up
28-Oct	NO CLASS	Need To Make Up
2-Nov	yes	
3-Nov	YES	TUESDAY 8:00AM Class MEC 205
4-Nov	yes	
6-Nov	YES	FRIDAY CLASS! 9:00AM MEC 215
9-Nov	NO CLASS	Need To Make Up
11-Nov	NO CLASS	Need To Make Up
16-Nov	yes	
18-Nov	yes	
23-Nov	yes	
25-Nov	NO CLASS	Thanksgiving Break
30-Nov	yes	
1-Dec	YES	TUESDAY 8:00AM Class MEC 205
2-Dec	yes	
7-Dec	yes	
11-Dec	FINAL EXAM	2:00-5:00 PM, MEC341

OUR PLAN:

Date	Class Number	Topic	To Prepare for THIS Class You Should:	HW Info
26-Aug	1	Introduction		HW1 Assigned
31-Aug	2	Course Overview	Read Ch 1, Read Syllabus, Complete HW1	HW1 Due, HW2 Assigned
2-Sep	3	Mathematical Preliminaries	Read Ch 2.1-2.15, Review Linear Algebra, Complete HW2	HW 2 Due, HW3 Assigned
9-Sep	4	Mathematical Preliminaries	Read Ch 2.1-2.15, Review Linear Algebra	
11-Sep	5	Mathematical Preliminaries	Read Ch 2.16-2.32, Review Vector Calculus	HW3 Due, HW 4 Assigned
14-Sep	6	Mathematical Preliminaries	Read Ch 2.16-2.32, Review Vector Calculus	
16-Sep	7	Kinematics	Read Ch3.1-3.5	
18-Sep	8	Kinematics	Complete HW4, Read Ch 3.6, 3.18-3.19	Homework 4 Due
21-Sep	9	Kinematics	Read Ch 3.20-3.21, Appendix 3.2-3.3,	Homework 5 Assigned
23-Sep	10	Exam 1	Study your notes, the slides, HW3/HW4, and Ch2	
25-Sep	11	Kinematics		
28-Sep	12	Kinematics	Complete HW5, Read Sec 3.20-Sec 3.26	Homework 5 Due
30-Sep	13	Kinematics	Grade HW5, Read Sec 3.27, 3.28, 3.30, 3.7-3.10	Graded HW 5 Due, HW6 Assigned
12-Oct	14	Kinematics	Read Sec 3.11-3.17	
14-Oct	15	Kinematics	Review Ch 3. Complete HW6	Homework 6 Due
19-Oct	16	Stress	Complete RP1	Read and think about RP1
21-Oct	17	Stress		Hand out Exam 2 (Takehome)
2-Nov	18	Stress		Exam 2 Due in Class
3-Nov	19	Stress		
4-Nov	20	Stress		
6-Nov	21	Stress		
16-Nov	22	Linear Elastic Solid		
18-Nov	23	Linear Elastic Solid		
23-Nov	24	Exam 3		
30-Nov	25	Linear Elastic Solid		
1-Dec	26	Newtonian Viscous Fluid		
2-Dec	27	Newtonian Viscous Fluid		
7-Dec	28	Nonlinear Elasticity		