2.145 / 2.147 Design of Compliant Mechanisms, Machines & Systems – Fall 2023

Lab: T 12.30 - 3.30 (5-233) | Lecture: MW 11.00 - 12.30 (35-308)

Required Text: Readings from selected texts/articles/documents | **Prof. Martin Culpepper** culpepper@mit.edu 35-237

Design, modeling and integration of compliance into systems that enable performance which is impractical to obtain via rigid mechanisms. Students learn multiple strategies (pseudo-rigid body modeling, topology synthesis, freedom and constraint topology) to engineer compliant mechanisms for modern mechanical systems. Emphasis is placed upon the use of first principles to optimize planar and spatial kinematics, stiffness, energy storage/release, load capacity, efficiency and integration with actuation/sensing. Students apply the preceding to synthesize concepts, optimize them via computational models and test prototype(s) for prototype-based mechanical problem sets and a term project. Mechanical problem sets and projects are drawn from areas that include biological systems, prosthetics, energy harvesting, precision instrumentation, robotics, space-based systems and others.

Date		Lecture	Reading quiz	Mini project	Laboratories
01	09/06	Fundamental issues, concepts, principles; elements/systems			- No lab -
02	09/11	Boot camp: Practical application of 2.001, 2.002 and 2.003		Engineering bootcamp worksheet	Engineering bootcamp I
03	09/13	Boot camp: Practical application of 2.005, 2.007 & 2.008			Units, magnitudes, basics
04	09/18	Approach: Constraint-based design [Theory]	Blanding		Engineering bootcamp II
05	09/20	Approach: Constraint-based design [Examples]			Decision making
06	09/25	Approach: Constraint-based design [Practice]			CBD
07	09/27	Project work and coaching sessions			Flexure building blocks
08	10/02	Approach: Freedom and constraint topology [Theory]	Hopkins		Lect: Approach: FACT
09	10/04	Project work session (on your own) [Jury Duty]		CBD: Satellite or CBD examples	[Examples]
10	10/09	No class [Student holiday]			- No Lab -
11	10/11	Approach: Freedom and constraint topology [Practice]			
12	10/16	Approach: Pseudo-rigid body modeling [Theory]	Howell		FACT
13	10/18	No class [MC at ISAM]		FACT: Screw motions	Screw drive & AFM stage
14	10/23	Approach: Pseudo-rigid body modeling [Examples]			PRBM
15	10/25	Project work and coaching sessions			Lect.: [Practice] 4 bar/airfoil
16	10/30	Approach: Topological synthesis methods (overview)	Kota (Ext Cr)		Optional:
17	11/01	Modeling: Stiffness matrices I	SM		Project coaching session
18	11/06	Modeling: Stiffness matrices II		PRBM: Robot gripper	MODELING
19	11/08	Modeling: FEA			Stiffness matrices
20	11/13	Analysis & optimization: Energy			Optional:
21	11/15	Project work and coaching sessions			Project coaching session
22	11/20	Project work and coaching sessions			MODELING
23	11/22	Analysis & optimization: Kinematics & elastomechanics			Energy
24	11/27	Analysis & optimization: Dynamics			MODELING
25	11/29	Project work and coaching sessions		ENERGY: Bi-stable mechanism	Motion, stiffness, vibrations
26	12/04	Integration: Sensors and actuators			CASE STUDY
27	12/06	Integration: Fabrication, assembly & calibration			Microtome actuators/sensors
28	12/11	Project work and coaching sessions		BIOMIMETIC: Insect skeleton	- No lab -
29	12/13	Final day of class, recap & share projects			

GRADING

Mini projects / Assignments	Reading/in class quizzes	Labs	Practical assessment
50	20	25	05

Teaching philosophy

"The man who sets out to carry a cat by its tail learns something that will always be useful and which never will grow dim or doubtful." --Mark Twain

Many students misunderstand the purpose of the modeling content they are exposed to. This leads to a misperception that equations embody all abilities required to practice engineering. Models are critical, but your decisions and actions must be based on:

(1) Understanding that engineering models are idealizations of real systems. The only thing that "perfectly" models a real system is a physical embodiment of that system. The process of "synthesizing-modeling-fabricating-testing" a prototype helps to provide this insight.

(2) Mastering how to judiciously *combine* a, b and c… vs relying on them alone:
(a) Concepts, principles and design processes are necessary, but not sufficient alone
(b) Mathematics, physics and engineering modeling are necessary, but not sufficient alone
(c) Practical skills and familiarity with best practices are necessary, but not sufficient alone

Project design notebooks

Each student must keep a design notebook. Notebooks will be collected without warning. Notebooks must adhere to best practices guidelines. No 3-ring binders or digital notebooks will be accepted and class notes may not be included.

Useful texts (not necessary to purchase for this class)

1. Topology optimization of compliant mechanisms; Xianmin Zhang, Benliang Zhu
2. Handbook of compliant mechanisms; Larry Howell, Spencer Magleby, Brian Olsen
3. Compliant mechanisms: Design of flexure hinges; Nicolae Lobontiu
4. Designing compliant mechanism suspensions; Thorsten Schrader
5. Flexures: Elements of elastic mechanisms; Stuart Smith
6. Exact constraint machine design using kinematic processing; Douglass Blanding
7. Principles/techniques for designing precision machines; Layton Hale
8. A treatise on the theory of screws; Robert Ball
9. The Art of Flexure mechanism design; Florent Cosandier, Simon Henein, Murielle Richard, Lennart Rubbert

Lab sessions

Labs may resemble recitations, sometimes design reviews, sometimes case studies, and sometimes hands-on labs. Much of lab will focus on applying theory in practice. You must attend all labs to pass the class, unless you're pre-approved or excused by Prof. Culpepper.

Use of the Maker Workshop

You may make components for your assignments and project in any shop you choose. The Maker Workshop is available for any MechE student, or student in a MechE class. HOWEVER, respect the student mentors and strive to make judicious use of the facility. Be respectful of their time, the materials they have in the shop, and the tools/machines. If you break something accidentally… it happens when you are learning engineering - just make sure to let them know so they can take care of the problem and get reimbursed for expenses from the class.

Excused absences due to COVID and other

If a student misses a lecture, lab or presentation due to COVID, Prof. Culpepper will work with them to create a plan to make up the work. If a student misses a quiz, they will be scheduled for a make-up after they return, with suitable time to prepare. Students that test positive for COVID may ask for additional time to complete assignments. This will be worked out between the student and Prof. Culpepper

Your physical and mental well-being

An MIT education is analogous to training for the Olympics. No athlete believes that being trained as an amateur will help them win a medal. This course is training you to become an "elite" engineer, and sometimes that means making you work in ways that will stretch you… ways that don't seem obvious as to how they will prepare you to do engineering work that you have not done before. This is a rigorous course in which you'll be expected to demonstrate that you've mastered the material and are capable of operating on your own to realize designs that meet requirements. With that said, your physical and mental well-being are of utmost importance. Just as an athlete can over-train, students can be overwhelmed, burn-out and be stressed in ways that are not helpful. There is no shame in admitting this if it happens to you. If so, know that Prof. Culpepper is very open to discussing your situation and working with you to make necessary and reasonable adjustments.