2.72/2.720 Elements of Mechanical Design – Sp 2024.v9

Lab: M8-11 or M2-5 (35-308) Lecture: MW 11.00-12.30 (3-442)

Required Text:	**Mechanical Engineering Design (Shigley/Mischke)**	**Prof. Martin Culpepper**	culpepper@mit.edu	35-237
Useful Texts:	Machinery's Handbook	**Tech Inst.: Wade Warman**	wwarman@mit.edu	35-112
	The Power of Habit (Duhigg)	**Tech Inst.: Pat McAtamney**	patmca@mit.edu	N51-144
	Design of Machinery (Norton)	**TA: Alejandro Martinez**	amart615@mit.edu	35-029
	Ultimate GD&T Pocket Guide 2nd Edition	**TA: Laura Rosado**	lmrosado@mit.edu	35-029

Advanced course on modeling, design, integration, and best practices for use of machine elements such as bearings, bolts, belts, flexures and gears. Modeling and analysis of the elements is based upon rigorous application of physics, mathematics and core mechanical engineering principles (solid mechanics, fluid mechanics, manufacturing, estimation, simulation, etc.). Principles are reinforced via (1) hands-on laboratory experiences wherein students conduct experiment and disassemble machines, and (2) a design project wherein students model, design, fabricate and characterize a mechanical system that is relevant to a real-world application. Students master materials via activities/quizzes that are directly related to, and coordinated with, the project deliverables. Student assessment is based upon mastery of course materials with emphasis on *proven ability* to synthesize, model and fabricate a design, subject to engineering constraints (e.g. cost, time, schedule). Students *must* master a set of key concepts to *pass* the class.

	Date	Lecture		Quizzes	Assignment due	Laboratories
01	2/05	**Introduction:**	Overview, modeling decision making			No Lab
02	2/07	**Design**	Process, FRs & decision making (2.007)	Q: Syllabus	Gurus & ME skill survey	
03	2/12	**Errors:**	Compliance (2.001) & vibration (2.003/004)			**Bootcamp: Design process**
04	2/14	**Errors:**	Thermal (2.005/006) & fabrication (2.008)		Lathe FRs & Gantt v1	Lathe TA, Sense making FRs
05	**2/20**	**Fatigue:**	Fatigue modeling (2.002) (TUESDAY)		Error budget estimates	**Bootcamp: 2.00X practical use**
06	2/21	**Constraints:**	Constraint design & bearing layouts (2.007)	Q: V&M → Shaft		Engineer toolbox/units/magnitude
07	2/26	**Constraints:**	Rolling/sliding bearing load/life (2.007)		FRs: Spindle	**Bootcamp: System models I:**
08	2/28	**Drives:**	Belt drives: Types, forces, selection (2.007)			Model: Fab/thermal/compliance
09	3/04	**Constraints:**	Flexures & alignment mechanisms (2.145)	Q: Constraint → Bearing	Peer Review I	**Bootcamp: System models II:**
10	3/06	**Spindle work:**	Group work on project			Model: Compliance, sensitivity
11	3/11	**Connections:**	Bolted joints (2.007)		FRs: Drives	**Coaching/mentoring:**
12	3/13	**Spindle work**	Group work on project			Presentation coaching (by appt)
13	3/18	**Drives:**	Leadscrew drive design	Q: Bolted joints → Bolts		**Design review I:**
14	3/20	**Project work:**	In-class x-axis design exercise		Gurus final & Gantt v2	**Spindle Assembly**
15	3/25	**Sp. Vacation:**	---	---	---	**Sp. Vacation**
16	3/27	**Sp. Vacation:**	---	---	---	
17	4/01	**Linkages:**	General design principles** (2.007)			**Graduate exams:**
18	4/03	**Project work:**	Group work on project			Oral exam on fundamentals
19	4/08	**Drives:**	Gears: Types, forces, selection** (2.007)			**Design review II:**
20	4/10	**Assessment:**	Practicum (team) modeling assessment	P1: Model accuracy	Peer Review II	**Cross-Slide Assembly**
21	4/15	**Patriot' Day:**	---			**Coaching/mentoring:**
22	4/17	**Project work:**	Group work on project			Smoke test advising (by appt)
23	4/22	**Actuators:**	Actuator selection** (2.007)		Model / CAD files	**Design review III:**
24	4/24	**Assessment:**	Engineering skills assessment (individual)	P2: Ugrads: Eng. Basics		**Assembly Smoke Test**
25	4/29	**Project work:**	Group work on project			**Graduate exams:**
26	5/01	**Project work:**	Group work on project		Peer Review III	Oral exam on gadget X
27	5/06	**Project work:**	Group work on project			**No lab:**
28	5/08	**Project work:**	Group work on project			Prep for demo day
29	5/13	**Last day:**	Demo day and "gadget" display!		Project & specifications	No Lab

** = Depending on project progress, if teams are ahead of schedule, we will do these lectures

Detailed description of quizzes, assignments and methods for submission are posted here.

Important information about this syllabus

Culpepper has taught 2.000, 2.001, 2.008, 2.009, 2.145, 2.351J, 2.70, 2.75, 2.76 and 2.810 at MIT, none compare in terms of effort/time required to teach 2.72. He has been teaching 2.72 for over 15 years, and has learned things are least stressful for students/staff if policies/rules in the syllabus are followed AND students ask for help. If you don't ask for help, **you will end up** spending 20+ hours/wk on this class. Prof. Culpepper does not eat small children, and no students have ever gone "missing" after meeting him. The staff will work hard to make this a good experience for you, please be respectful and follow the content of the syllabus so that we can focus on helping you vs. dealing with extra work caused by non-compliance.

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 math/modeling content they are exposed to in engineering programs. This leads to a misperception that models and equations embody all engineering ability required to practice engineering. In mechanical design, models are critical, but not sufficient because your thoughts, decisions and actions must be based on:

(1) Understanding that engineering models are idealizations. The only thing that "perfectly" models a mechanical system is a physical embodiment of that system. Designers must understand the limits of modeling/simulation and gain the ability to judge whether a model is sufficiently accurate to give the information they seek. The process of "synthesizing-modeling-fabricating-testing" a prototype helps provide this insight. This is important because the construction of high-risk and high-performance systems is cost- and time-intensive.

(2) Mastery of:
(a) Concepts, principles, and design processes are necessary, but not sufficient, to practice mechanical design
(b) Mathematics, physics, and engineering modeling are necessary, but not sufficient, to practice mechanical design
(c) Practical skills and familiarity with best practices are necessary, but not sufficient, to practice mechanical design
(d) Teamwork, planning, and efficient time-management are necessary, but not sufficient, to execute a mechanical design project
The judicious use of (a), (b) and (c) is necessary to understand and apply the principles of mechanical design.

(3) Knowing "how to engineer." Most engineering theory classes teach you "about engineering fundamentals". Most engineering project classes enable you to "practice engineering fundamentals". 2.72 teaches you "how to engineer" something, with reliance upon your knowledge "about" engineering, and experience in "practicing engineering fundamentals."

2.72/2.720 Mechanical Design Project Description

"In theory there is no difference between theory and practice. In practice there is." --Yogi Berra

The project focuses on (i) understanding the role of concepts, principles, design process, best practices, math, physics, and modeling within mechanical design; and (ii) rigorous application of concepts, principles, design process, best practices, math, physics and modeling to realize a complex and high-quality design. You will learn by "doing" and gaining perspective via interaction with the staff.

Teams of students will model, design, build, characterize and optimize the performance of a desktop lathe. Each team will design a 'group' lathe and must build one lathe. The construction of a lathe that meets functional requirements is a key element of receiving a *passing* grade. High-level functional requirements (FRs) may be provided and may include but are not limited to: (a) minimum repeatability for cutting; (b) material compatibility; (c) durability and damage-proofing. *FRs specified by course staff must be achieved*. Each team must also generate additional FRs that are necessary to reach a successful conclusion. It is the responsibility of each team to ensure they have a necessary and sufficient set of given/generated FRs. You must demonstrate an ability to set realistic, quantitative FRs and work toward them in a deterministic way. *If you build parts without a complete and justifiable list of FRs, and without having done a proper amount of modeling/design, you'll receive an F grade for that part.* We won't tell you all FRs/calculations you should have. We are happy to review them and give feedback. Determining your own FRs/calcs is an important learning experience and indicator of proficiency.

Documentation

"Documentation is not a step on a linear timeline, and certainly not the one at the end. One could argue documentation is a byproduct." — Ines Garcia

Repository / Revision Control & Media:

Each team will use an assigned, shared group Google drive folder. Groups must practice revision control according to this convention: documentname_v1.doc or systemmodel_v3.mcd. For CAD, we recommend that each part/drawing/assembly has a version number, however folder numbering (where only the folder that contains parts/drawings/assemblies) is an acceptable alternative. Groups must take pictures/video of parts, fabrication processes, assembly, and experiments as you go. This is important for documenting the fabrication process (i.e. presenting results at D-Lab) and may prove crucial in debugging any errors/mistakes.

Design Notebooks:

Each student must keep a PHYSICAL design notebook (we provide 1st one). Electronic notebooks are not allowed. These must be dedicated notebooks in which all your ideas, calculations, and records are stored. You must bring notebooks to all class events. Notebooks will be collected during the semester, without warning, and their grading will be a substantial part of the project grade. The notebook must be legible, organized, and always up to date. Notebooks MUST adhere to best practices - see guidelines on Canvas. Loose papers must be stapled or glued into personal notebooks. No pencil or erasable ink may be used. No class notes may be included.

Laboratory Schedules

You must attend all labs & reviews to pass the class - unless excused or you get permission from Prof. Culpepper ahead of time.

Lab Sessions:
Do not be late. These times are utilized to teach new methods, check progress and allow you to ask questions. Sometimes they may resemble recitations, sometimes hands-on labs and sometimes presentations. A good chunk of lab time will be spent helping you learn how to do practical engineering modeling that is useful. In 2.72, models inform what you design and build, NOT guesses or intuition. Guesses are easy, engineering requires effort, and so you need to become confident and disciplined so that you want/can do things the right way vs. the easy/dangerous/unprofessional way. *If you use guesses, or build and then model after the fact, you will be given a zero for that part/activity. At first students dislike this, but it gets easier and they come to appreciate it.* A valuable skill you will learn in 2.72 is to select/justify the best choice of a particular modeling method over the others, e.g. simulation vs. experiment vs hand calculations?

Design reviews (DR labs):
You'll give a presentation (~10 min presentation followed by ~15 min discussion) to the course staff during each assembly review. A large-screen display will be available (connects via HDMI or wifi). If your presentation laptop does not have an HDMI port, you must bring the appropriate adapter. We will not have a laptop for you to use (and suggest you bring a backup). Everyone must present their part of the project (even if there is no progress) and everyone must participate in the questions / discussion, or they won't earn credit for the meeting. Your team should (a) first tell us the purpose of the meeting, then (b) immediately show your Gantt chart to tell us if you are ahead / behind schedule (there is no such thing as 'on' schedule), and (c) other items you feel appropriate to make us understand how you engineered the parts properly and that they do what they were supposed to do. Relevant hardware deliverables should be brought to the meeting in a FINISHED state (not missing seals, or lubricant, or with untightened bolts, etc…). You should have back-up slides (when needed) to communicate detailed issues of significant import.

List of major parts to be provided and parts to be processed

Depending upon your design, there may be other minor parts that are not listed which you will be responsible for. If you have questions, please ask.

LS = Leadscrew ***CF = Cross Feed*** ***HS = Head Stock*** ***TS = Tail Stock***

	Our responsibility (if using stock parts)	Your responsibility (at a minimum)
Spindle	• Housing blank • Shaft blank • Bearings	• Housing • Springs • End cap • Seals/grease • Shaft • Preload nut
Structure	• HS blank • TS blank • Structure tube (w/ starter slot)	• Carriage rails • Finished structure tube • Finished Tail stock • Finished Head stock
Z Axis Drive	• Bearings • LS preload washers • LS bearing seat • LS flange nut • Bearing preload nut • Lead screw • LS plate end cap • LS bushing • Handles	• Drive nut • LS flexure • Any modifications / replacements of parts we provided • Drive preload mechanism • LS preload nut • Thrust bearing
Carriage	• Handle • 2 Skirts & 1 bed	• Finished carriage • Carriage rail bushing flexure • Carriage rail bushings • Potting agent / mat'ls
Cross Feed (X-Slide)	• Tool holder • Handle • Oil fitting • Lead screw blank • Male dovetail • Female dovetail	• Thrust/radial bearings/preload • Gib • Gib adjustment • Nut (CAD = mounting section) • Finished lead screw
Misc.	• Chuck • Metrology fixtures (3-ball & runout) • 2 HSS & 2 carbide tools • ¼" Fasteners • Motor	• Safety shield for spindle drive • Wire for motor • Spindle drive components • Drivetrain components • Motor mount / tension system • Jigs or tools necessary for assembly, measurement, testing, etc.

2.720 for Graduate credit

2.720 is the graduate version of 2.72. This year, students will build a CNC version of the lathe that must cut steel (undergrads do a manual lathe that need only cut aluminum). To get grad student credit will require (a) additional functional requirements (e.g. cutting more or different materials) and (b) additional meaningful functionality, subassemblies, and/or components to be integrated into the lathe. Each graduate student project group must *set a 15 min meeting with Prof. Culpepper by the end of February* to propose how they will integrate CNC capability into their lathe (which CNC kits, general design, supportive calculations) and to propose a budget for the additions.

Rules & logistics for using the ME Manufacturing Shop

"Good plans shape good decisions. That's why good planning helps to make elusive dreams come true." --Lester Bittel

No exceptions to these rules without permission from Prof. Culpepper. Please do not ask the Technical Instructor.

Fabrication of parts for your lathe

Fabrication of quality parts requires time; be clear eyed about time you may need to make parts. This time is markedly reduced with proper, thoughtful planning and lack of procrastination. The **ME Mfg Shop (35-125)** is open Monday-Friday from 8:00 am to 4:30pm. Machining stops at 4.00pm, and cleanup commences. *Students must do all work on their spindle, headstocks, tail stocks, carriage, and flexures in the ME mfg shop*. If any of these parts are made/modified outside the 35 shop (without permission from Culpepper) this will be considered cheating. All other parts may be machined in other facilities as long as students have submitted, and have received approval on, a process plan prior to commencing machining of these parts. *The ME MakerWorkshop is not part of the ME Mfg Shop.*

Scheduling the use of machines/resources in the ME Mfg. Shop

Use of the machines/CMM must be scheduled in advance via the 2.72 slack channel. Use of the shop for non-machine use is at the discretion of the technical instructor. The waterjet must be scheduled with the Technical Instructor. CMM Training will be arranged by the course Technician in mid- to late March / early April. Only members from two teams may be in the shop at one time. The only exceptions are when a 3rd team needs to use the waterjet, CMM, or to run bench tests. If you are more than 15 min. late for an appointment, it will be cancelled, and you must meet with Prof. Culpepper to explain this prior to your group's further use of the shop.

Process plans for parts that you will make/modify

Before you fabricate a part, you must create a process plan. To get you in the habit, you must meet with the Technical Instructor to discuss how to make the parts for the spindle and cross slide before machining any of them. You must schedule a meeting ahead of time via e-mail. Everyone who will work on the part must attend the meeting. You must have a process plan (see Appendix A) for each part you make (in the spindle/cross slide) before meeting the Technical Instructor and must keep each version of this plan in your machining guru's design notebook. The first couple times you should expect to need multiple process plan revisions, schedule accordingly. When you fabricate ANY part in the ME mfg. shop, you MUST show the approved process plan and prints to the Technical Instructor. Prints and process plans must have English units, dual dimensioning is encouraged. You don't need a meeting for parts beyond the spindle/cross slide, but when machining ANY parts; the instructors reserve the right to ask to see your process plans prior to machining.

At a minimum, your group must bring the following to meetings with the Technical Instructor:

a) **2D printed CAD drawing with all dimensions and tolerances (hand sketches are not allowed)**
b) **Complete process plan wherein the following are laid out in bullet-point form:**
   i. Major steps, in order, that you will take to make the part (incl. fixturing, locating/alignment, and measurement steps)
   ii. Tooling that you will need for every operation
   iii. Measurement tools that you will need for every operation
   iv. Questions / uncertainties
   v. Revisions/lessons from past meetings with the Technician that are relevant to the new plan (to show learning, i.e. grading)
c) *(Waterjet parts only)* **Properly scaled DXF on USB stick**

The Technical Instructor must sign off on the top of each Process Plan for the spindle and cross slide. For each part that is made, the relevant Process Plan must be brought to the relevant D-Lab meeting. Process plans will be graded and supporting info (such as notes, engineering drawings) must be stapled to the plan. Your group will need to schedule meetings for:

Item:	Meeting Duration to Expect:	Meeting Deadline:
Spindle shaft, housing, end caps	1 hr	By 3pm on 03/04
Flexures (lead screw, carriage rail)	1 hr – design approval & set time to cut part	By 3pm on 04/03
Belt safety shield	1 hr – design approval & set time to cut part	By 3pm on 04/12

Measurement tools in the shop

In addition to the stocked measurement tools in the shop, you will have access to special purpose tools that were purchased for this class. See the Technical Instructor to check them out. They must remain in the shop while in use and must be returned immediately when you are done with them. Additional portable measurement tools (calipers, micrometers) may also be available at Office Hours.

Tool:	Example Use:
Telescoping bore gauges	Inner diameter measurements (e.g. spindle bearing bores)
2x digital micrometers	Measuring spindle shaft diameters
4x dial indicators capable of resolving 0.0001"	Indicating/centering cylindrical pockets and holes

Design Verification Tests / Experiments

What you must measure as part of your tests and experiments

"Experience does not ever err; it is only your judgment that errs in promising itself results which are not caused by your experiments" --Leonardo da Vinci

You will be responsible for generating the design of your experiment, modeling/understanding/estimating the errors in your experiment, *understanding how 'good' your data is*, and creating the hardware that is required for you to measure:

1. Spindle error motions (dx, dy, εx, εy, as a function of θz) on the shaft and on a part in the chuck
2. Carriage error motions (dx, dy, εx, εy, εz as a function of z) as it travels along the z axis, or
3. Cross feed (x-slide) error motions (dy, dz, εx, εy, εz as a function of x) as it moves long the x axis

You must use the designated Coordinate-Measuring Machine (CMM) to characterize items 2 and 3. You may check out a 3-ball metrology fixture (consisting of three finely polished balls attached to a plate) to make measurements. This fixture should be mounted to the part to be characterized, with the centroid of the balls located at a point of interest. By measuring the position of each ball, you may identify the 3D location and orientation of the triangle connecting the three ball centers, and thus obtain the position and orientation of the attached part in the current state. This data, taken at multiple locations, may then be used to calculate error motions.

You must create a model that calculates error motions (items 2 and 3) given center points for the 3 balls. Bring this to the CMM training (check it gives reasonable results first) and measurement sessions so that you may plug in your data and see results. You may use the model to see how sensitive the measurement set up is (very important) and you may ask for a report on the CMM characteristics from the TA (includes a basic characterization of the CMM's capability).

Group budgets for experimental setup

"It's clearly a budget. It's got a lot of numbers in it." --George W. Bush

Each group may spend up to $200 (grad groups get extra for the CNC) to purchase materials for their lathe, including but not limited to:

Preload washers   Rails   Bushings   Epoxy   Seals   Etc…

Learning to work to stringent budget requirements is part of being a good machine designer. *If you go over budget, your course grade drops 1 level*. You have two options for ordering parts:

1. Order parts on your own and submit reimbursements. Be sure to obtain a tax-exempt form from the course admin (show this at the store to avoid tax) as MIT does not reimburse tax. Reimbursement requests are due to the course admin by 05/17.

2. Request parts via the course admin (see order link on Canvas). Please note that it will take 1 business day for processing in addition to ground shipping time; express shipping will not be available.

Incomplete requests or requests with errors cannot be processed. We strongly encourage vendors other than McMaster to reduce cost. Please do not expect orders to be placed on weekends/evenings. *Reimbursement requests (see order link on Canvas) are due to the course admin by 05/17.*

Gantt Chart

Your group must have a Gantt chart with major milestones & design lab meetings. You have 1 opportunity to revise the Gantt chart (see "Gantt v2" on syllabus). This sometimes is necessary when students adjust their expectations for timing of tasks as they gain experience.

Group Gurus

Your group must assign people to be RESPONSIBLE for the administration and conduct of specific tasks. *Gurus DO NOT do all of the type of work under their Guru area*. They are to be your 'experts' that facilitate the work of their teammates in the area for which they have a Guruness. Groups must make tentative assignments the 1st week and will be allowed to make changes once more (see syllabus Gantt v2 deadline). All Gurus MUST serve as a 'Deputy' Guru for another position. Due to limits on time/space, only one person from each group may be trained in FEA. Only one person may be Budget/Scheduling Guru and then, only as a 'Deputy'.

- **Modeling** Guru (caretaker of parametric model)
- **FEA** Guru (to be trained in FEA modeling)
- **Measurement** Guru
- **CAD** Guru
- **Fabrication** Guru
- **Budget/Scheduling** Guru (orders, budget, etc)

Absences and wellness

"He who has health has hope and he who has hope has everything." – Arabian Proverb.

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" mechanical designer/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 you are overwhelmed or need help, know that Prof. Culpepper is very open to discussing your situation and working with you to make necessary and reasonable adjustments*.

Lecture and reading quizzes: If a student misses a lecture due to COVID/sickness, the TAs or Prof. Culpepper will catch them up via zoom. Reading quizzes may be excused, i.e. reading of material will be verified verbally by questioning during the catch-up session.

Group work: Students in quarantine may not gather with their group members to work on the project. We know this may be disruptive, and the staff will make accommodations for the group to minimize disruptions and enable as much collaboration as possible. Should a student need to quarantine, the student, their group, and course staff will make a plan that addresses group work during the quarantine period.

Practicum and qualifying quizzes: If a student misses a qualifying quiz, they will be schedule for a make-up after they return, with suitable time to prepare given the circumstances.

Design review labs: If a student is out with COVID/sickness and able to participate via zoom, they may do so. If they are unable to participate, they will make arrangements to meet with one of the staff to review their portion of the project, with suitable time to prepare given the circumstances.

Labs: If a student misses a lab (other than design review) due to COVID/sickness, the TAs or Prof. Culpepper will catch them up via zoom.

Assignments: Students that test positive for COVID/sickness may ask for additional time to complete assignments. The staff will be very supportive in this regard. This will be worked out between the student and Prof. Culpepper

Grading

In school, we learn that mistakes translate into bad grades. This unfortunate lesson gets burned into our brains, and we go through life shunning challenges that might end in failure. Mark Frauenfelder

GRADING *(We may introduce unannounced 'spot-checks' that will be graded as part of the project grade)*			
Project and team activities	Quizzes	Labs	Peer/staff reviews
30	45	20	05

3 Quiz types: Qualifying (theory understanding), Reading (preparation for lecture) and Practicum (practical understanding).

Reading Quizzes – Approximately 5 minutes long and cover assigned reading. We drop 2 of your lowest reading quiz scores. You may be excused from reading quizzes if you ask ahead of time for a justifiable reason (out of town for interview, have MIT sport event participation, etc…) or have a letter from S^3.

Qualifying Quizzes – Test your theory understanding. Engineers must understand what they are doing or they are dangerous, therefore no group will be given parts unless all team members have passed (grade >80%) the Qualifying Quiz for corresponding parts. E.g. you must demonstrate understanding of shear-moment diagrams before we give you material for the spindle.

Personal practicum Quiz – Test your practical understanding and ability to show you have done/can do something useful as a real engineer vs. operating as an applied mathematician that can only do problem sets and think about engineering.

Appendix A: Class software resources for modeling

"All models are wrong, but some are useful" – George Box.

First order modeling
(modeling order of magnitude and trends)
– Mandatory –

It is expected that you'll be doing your first order modeling in your notebooks and/or a formatted spread sheet. We will provide you with an engineering notebook during the first week. Microsoft Excel (available via ist.mit.edu), or Google sheets may be used when you need to quickly crunch numbers. You may elect to use other software for quick calcs, but keep in mind that the staff will be able only be able to offer feedback on spreadsheets, & for detailed calcs we will only be able to offer feedback on, and grade, MathCAD models.

Detailed parametric component and system modeling
(modeling performance – design links)
– Mandatory –

The detailed modeling and optimization in your project require a powerful modeling tool that is also well-suited for documenting and sharing your work. All groups will need to utilize MathCAD for detailed modeling (e.g. HTMs) of components and the machine system. You may obtain free access to MathCAD express via download from their website: https://www.mathcad.com. Their website has videos and pdfs to guide you through the installation. If you have any issues with installation, or with access to a computer, please contact Prof. Culpepper directly. Although we understand that many people are fond of MATLAB, MATLAB will not be accepted for use in the project. After you install MathCAD, we will provide you with a license to upgrade the basic version to MathCAD Prime by Feb. 14th.

Computer Aided Drafting
(modeling geometry)
– Mandatory –

All 2.72 geometric modeling must be done in SolidWorks. Prof. Culpepper will be running SolidWorks 2023 and all CAD files provided will be accessible to that version. You may obtain SolidWorks (see also below for FEA) for free at ist.mit.edu. If you have any issues with installation, please contact the IST helpdesk. If you have issues with access to a computer, please contact Prof. Culpepper directly.

Finite Element Analysis
(modeling complex multi-dimensional problems)
– Mandatory –

All 2.72 FEA work must be done in SolidWorks FEA. You may obtain SolidWorks and its FEA plug-in/add-in for free at ist.mit.edu. If you have any issues with installation, please contact the IST helpdesk. If you have issues with access to a computer, please contact Prof. Culpepper directly.

GANTT Charts
(modeling your time)
– Student choice –

You can make your own GANTT chart in a spreadsheet, or there are software programs that you may do to use this. The method used is up to your group. If you are looking for a free tool, you may wish to check out the following (not endorsed or required) : https://www.ganttproject.biz/ . There are other free tools like this; we will leave it up to you to select one. Just make sure it is possible to share info between group members and to readily show the staff your project plan during discussions/meetings.

Appendix B: Template for 2.72/2.720 Process Plan

All process plans (even first attempts/early versions) must be included in Machining Guru notebook for grading.

Process Plan	Group #:	Part Name:	Version:
Revision Date:		Group Members in Attendance:	
Approval Date:			
Application of previous lessons learned:			

#	Task & Questions	Machine	Tooling	Measurement
00				
01				
02				
03				
04				
05				
06				
07				
08				
09				
10				
11				
12				
13				