



DEPARTMENT OF MECHANICAL ENGINEERING

QUALIFYING EXAMS

GUIDELINES AND FORMATS

May 2021 Exams

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## INTRODUCTION

The purpose of the doctoral qualifying examination (QE) is manifold: according to the faculty, the QE serves to

- 1) Ensure that the ME PhD student has maturity (cohesive and holistic view) in the disciplinary foundations of modern ME and closely-related disciplines
- 2) Ensure that the ME PhD student has depth in an area and the breadth expected of mechanical engineers
- 3) Ensure that the ME PhD student can think analytically and synthetically to construct rational and sound solutions to unfamiliar problems at an advanced level in engineering and engineering sciences
- 4) Ensure that the ME PhD student can communicate effectively (including ability to organize thoughts)
- 5) Ensure that the ME PhD student can respond reactively and cogently to questions or points raised in professional discussions and interactions
- 6) Enable ME faculty to collectively assess the students

## ADMINISTRATION

A student whose highest degree (at entry to the graduate program) is a Bachelor's degree, must take the QE (for the first time) no later than the end of 5 regular semesters (fall and spring). A student entering the graduate program with a Master's degree must take the QE (for the first time) no later than the end of 3 regular semesters (fall and spring). [Due to the cancellation of the May 2020 exams, students who would normally be expected to take the QE in Jan 2021 or May 2021 have the option of taking the QE one semester later than the expected time.](#)<sup>1</sup>

In rare and extraordinary circumstances, a student may be granted one extra semester by the Graduate Officer. [Students who have been impacted by the Covid-19 pandemic may petition for such an extension.](#) Petitions require a letter of support from the student's thesis supervisor. Students who wish to discuss sensitive matters should feel free to contact the Graduate Officer directly or via the Graduate Student Ambassador, Professor Betar Gallant.

The Qualifying Examinations are offered twice yearly (usually in January and May) over a one-week period. In order to be eligible to take the QE the student must have maintained a cumulative GPA of not less than 4.5 in the MIT graduate program. In addition, the candidate must have obtained 2 A's and 1 B or better in graduate-level

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<sup>1</sup> Covid-specific changes are marked in [blue](#).

MechE department classes at MIT<sup>2</sup>. For the academic year 2020-2021 (January and May 2021) the requirement of a cumulative GPA of not less than 4.5 in the MIT graduate program and the completion of at least 2 As and 1 B in graduate-level MechE Department classes at MIT are waived. For May 2021 all QE sessions will be virtual, using a computer, tablet, tablet stylus, Explain Everything, and Zoom. Additional buffer time will be built into the exam schedule to account for connectivity issues. Students who do not have the necessary equipment will be loaned equipment to prepare for and take the QE. More information is available below.

The QE consists of three components:

SQE: two subject examinations exploring the student's breadth of knowledge in selected MechE disciplines,

RQE (Part I): a subject examination exploring the student's depth of knowledge in the student's chosen area of research, and

RQE (Part II): an examination of the student's research skills.

The QE takes place over two days and is organized as follows:

Day 1: The student takes three subject examinations, each consisting of a 30-minute oral exam. Two of these exams will be in two subject areas selected by the candidate and will comprise the student's SQE. The third examination will be in the student's chosen area of research and will comprise Part I of the student's RQE.

Day 2: The student takes the Research Qualifying Examination-Part II, consisting of one 45-minute oral examination in the candidate's field of research that explores the student's research skills.

For the subject examinations, the student must pick 3 *distinct* areas from the approved lists below, choosing at least 2 from the C (core)-list and not more than 1 from the S (specialized)-list. The student must also indicate the one area that the RQE (Part-I and Part-II) is to be in. New subject areas may be added to these lists with one semester's advanced notice; existing subjects may be removed, but only with a minimum of two years' notice.

During Part II of the RQE the student will:

- Make a 25-min presentation of the student's original research (such as work for a previously completed SM thesis (at MIT or elsewhere) or initial work at MIT towards a doctoral thesis).
- Respond to questions on that research for 20 minutes.

The student's advisor can be present during the both parts of the RQE but is not permitted to participate in Part II of the exam. They may, however, participate in Part I of the RQE. The advisor can also participate in the SQE.

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<sup>2</sup> Exceptions may be granted by the Graduate Officer in the case of an incoming student with an SM degree, who may want to take the QE after one semester at MIT.

At least 2 weeks before the RQE, the student must provide the Graduate Office with a brief (approximately 100 word) abstract of the intended research presentation. This will help the faculty participating in the RQE anticipate and prepare for the specific knowledge domain(s) that may arise during each student's exam.

The MechE department faculty as a whole review each student's performance in the qualifying examinations and make decisions regarding passing, being allowed to repeat the exams, or failing. Prior to review by the department faculty, scores are assigned by the exam committees for each student for each exam taken, with a score of 7/10 being a pass. Passing the QE requires passing Part II of the RQE, as well as any 2 (or more) of the 3 subject area examinations. In the case of borderline failing performance, other aspects of student performance in the graduate program, any special circumstances that may have adversely affected student performance in the exam, as well as the best interest of the student are typically taken into account in making the decision. Advisors who are not in MechE are also invited to these meetings, but they cannot participate in decision-making.

Candidates who are permitted to repeat all or part of the exams must do so the next time they are offered; additional time may be granted under extraordinary circumstances. In no case is a candidate allowed to repeat more than once.

### **PREPARING FOR THE QE**

Although preparation for any exam is a matter of personal style and preference, we provide here some information that could be helpful in placing this process in a better context. Along these lines, always keep in mind, that, over both attempts, the historical failure rate of this exam is on the order of 2%. In other words, *the primary objective of the exam is not to fail you but to make you a better Mechanical Engineer via the preparation process.*

#### What faculty are looking for:

The faculty are looking for the students taking the exam to demonstrate maturity, depth and breadth, ability to think analytically and synthetically, communicate effectively and respond to questions reactively.

The exam question is just the vehicle for this investigation. Your task is to use the problem to demonstrate the above qualities: explain how you understand the problem and ask for any clarifications; sketch how you approached the problem, stating any fundamental principles you will be using; state any assumptions you will be making and clearly justify them; proceed with the solution. Proposing and defending reasonable approximations is acceptable. Proposing solutions that violate fundamental engineering principles (e.g. second law of thermodynamics) is not acceptable.

For Part II of the RQE, an explicit charge to the faculty is to assess your ability to complete an excellent thesis. It is therefore important that you convey the ability to master your area of research including the relevant literature, the ability to perform and defend

research in the field, and have thoroughly thought about the feasibility and relevance of future steps.

Preparation strategies:

Solving past exam problems can be very helpful but it is not sufficient. You need to be comfortable with all material associated with each subject exam. Studying in groups and practicing oral exams can be very beneficial, especially if you have no experience in that exam format. If you are not able to join a study group, contact GAME for help. The MechE Communication Lab (<https://mitcommlab.mit.edu/meche/>) can be very useful for helping with your RQE Part II presentation.

A document detailing workflows, resources and contingency planning for the May 2021 exam (which will be virtual) can be found [here](#). The Department will provide tools (e.g. tablets) to anyone who needs them well in advance of the exam (links for requesting equipment on loan can be found in the above [link](#)). A workshop on how to collaborate using Explain Everything can be found [here](#) (MIT login required; after clicking on the link, go to [mit.zoom.edu](https://mit.zoom.edu) and sign in to access the recording). Practice sessions for checking equipment, connectivity and workflows will be arranged for all participants towards the end of the Spring semester.

## SUBJECT EXAM LISTS AND DETAILED DESCRIPTIONS

### Core subject areas: C-List

The subject or subjects most suitable for preparation for these exams are included in parentheses.

Dynamics (2.032)

Fluids (2.25) *or* Hydrodynamics (2.20), *not both*

Heat Transfer (2.55 or 2.51+2.52J)

Machine Design (2.72) *or* Product Design (2.744 or 2.739J), *not both*

Manufacturing (2.810)

Micro and Nano Engineering--Theory (2.37)

Solid Mechanics (2.071) *or* Structures (2.080J), *not both*

Stochastic Dynamical Systems (2.122)

System Dynamics & Controls (2.140 and 2.151)

Thermodynamics (2.42)

### Specialized subjects/fields: S-List

Acoustics (2.066)

Biomechanical Engineering (2.795J or 2.798J)

Computational Engineering (2.097J or 2.29)

Micro and Nano Engineering--Experiment (2.675), *cannot be chosen* with Micro and Nano Engineering--Theory

Optics (2.71 or 2.717)

Robotics (2.120), *cannot be chosen with* System Dynamics & Controls

Below we provide detailed descriptions of each subject exam.

## ACOUSTICS

**Faculty Contact:** Professor N. Makris

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period.

**Disciplinary Scope:** Students are expected to be well-versed in the topics covered in the subject listed below.

**Most suitable subject for preparation:** 2.066

## BIOMECHANICAL ENGINEERING

**Faculty Contacts:** Professor Peter T. So

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period.

**Disciplinary Scope:** This exam covers the mechanics of biological systems, from single molecules to whole tissues, as well as biologically-relevant topics in transport and fluid flow. Students are expected to be well-versed in the topics covered in one of the two subjects below.

**Most suitable subject(s) for preparation:**

2.795J: Fields, Forces and Flows in Biological Systems

or

2.798J: Molecular, Cellular and Tissue Biomechanics.

## COMPUTATIONAL ENGINEERING

**Faculty Contact:** Professor P. Lermusiaux

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period.

**Disciplinary Scope:** A significant number of graduate students in the Mechanical Engineering Department perform research with a strong focus on computational engineering, in particular including the development of numerical methods and tools. More specifically, the subtopics in computational engineering include i) computational fluid dynamics, ii) computational solid mechanics, iii) numerical methods to solve partial differential equations and algebraic equations, iv) molecular-level simulation and v) optimization/parameter estimation.

Students are expected to be well-versed in the topics covered in one of the two subjects listed below.

**Most suitable subject(s) for preparation:**

2.097: Numerical Methods for Partial Differential Equations  
or  
2.29: Numerical Fluid Mechanics

## DYNAMICS

**Faculty contact:** Professor T.R. Akylas

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The Dynamics qualifying examination is at the level of the elementary graduate subject 2.032. Emphasis is placed on understanding basic dynamics principles and how they are applied to specific problems. The main topics include:

- Kinematics
- Momentum principles
- Principle of virtual work and Lagrange equations
- Three-dimensional rigid body dynamics
- Stability of steady motion
- Gyroscopic problems
- Vibrations of discrete and continuous systems

**Most suitable subject for preparation:** 2.032

## FLUID MECHANICS

**Faculty contacts:** Professors D.P. Hart and G.H. McKinley

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The topics and scope of this examination will be based on the subject 2.25.

**Most suitable subject for preparation:** 2.25

## HEAT AND MASS TRANSFER

**Faculty Contact:** Professor E. N. Wang

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The purpose of this examination is to evaluate the candidate's depth in and understanding of the fundamental principles of heat and mass transfer. The student is expected to recognize, formulate, and solve problems and applications involving conduction, convection, radiation, mass diffusion, and phase change. S/he should be able to determine temperature distributions inside solid bodies, to predict heat transfer and mass transfer rates at solid-fluid interfaces for all types of flow conditions, to estimate radiation heat exchange between solid surfaces, and to evaluate the performance of heat and mass exchangers.

The examination will be based on material closely related to the graduate subject Advanced Heat and Mass Transfer (2.55 or alternatively 2.51+2.52).

**Most suitable subject(s) for preparation:** 2.55 or 2.51+2.52J

### Recommended Textbooks

A. F. Mills, *Heat Transfer*, 2<sup>nd</sup> ed., Prentice Hall, 1997.

J.H. Lienhard IV and J.H. Lienhard V, *A Heat Transfer Textbook*, 3<sup>rd</sup> ed., Phlogiston Press, 2001. Also see <http://web.mit.edu/lienhard/www/ahtt.html>.

## HYDRODYNAMICS

**Faculty contact:** Professor A. Techet

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** Equations governing conservation of mass and momentum. Similitude and model testing. Ideal vortical and potential flows in two and three dimensions, including the concepts of lift and added mass. Lifting-surface theory for steady, unsteady, and cavitating hydrofoils. Real (viscous) laminar and turbulent flows, Reynolds stresses, laminar and turbulent boundary layers. Rudiments of linearized free-surface waves, including wave kinematics, superposition, dispersion, energy density and group velocity, and the effect of finite water depth. Water wave loads and motions of bodies in waves, ship wave resistance. Hydrodynamics of slender bodies. Application to floating and submerged vehicles.

**Most suitable subject for preparation:** 2.20

## MACHINE DESIGN SUBJECT EXAMINATION

**Faculty contact:** Professor A. Winter

**Exam Format:** The exam will consist of one 30-minute oral examination. The student will receive the question and any associated hardware three days before the qualifying exams. One double-sided summary sheet will be allowed in the oral exam; no additional materials or multimedia aids (other than colored chalk) will be permitted. The student will present their solution on the blackboard, which will typically include calculations, 2D and 3D sketches of systems and components, and additional on-the-fly analysis to address the reviewers' questions. It is critical that students can discuss physical principles on the blackboard to articulate their thought process. A significant component of this exam will be investigating students' ability to do this.

**Topics/Scope:** For the Machine Design exam, students are expected to have a deep and thorough understanding of material taught, incorporated, and practiced in the undergraduate design courses offered in MIT's MechE dept. All students are expected to have an understanding of basic machine elements, how to model and optimize them, and how they are best used to create functional mechanical systems. All students should be familiar with standard elements, for example bolts, gears, bearings, shafts, structural elements/sub-systems, actuators, sensors, drives, linkages and springs/flexures. Typical questions focus on:

- System-level thinking/reasoning of the solution trajectory
- Elucidating functional requirements and design constraints
- Free-body diagrams
- Power and information flow
- Structural loops, metrology
- Conceptual design of machine elements or systems
- Modeling, sizing, and selection of machine elements and actuators
- Synthesis, modeling, and design of machine systems
- Questions about how a given element or system functions
- Contrast/compare the strengths and weaknesses of elements and systems
- Sensitivity analysis of parametric relationships
- Practical issues in mechanical system design, for example, cost vs. performance, consideration of alternate machine elements, safety, design verification testing, fabrication, and manufacturability

**Most suitable subject for preparation:** 2.72

**Other courses that reinforce the principles often found in this exam:** 2.007, 2.737, 2.75, 2.76, 2.77

**Books useful for review**

- Mechanical Engineering Design by Shigley and Mischke

- Precision Machine Design by Slocum
- Fundamentals of Design available free on [web.mit.edu/2.75](http://web.mit.edu/2.75)

## MANUFACTURING

**Faculty contact:** Professor T. Gutowski

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The doctoral qualifying exam in Manufacturing requires a graduate-level understanding of the material contained in the undergraduate subject 2.008. An important component is how materials behave in manufacturing processing conditions. This includes elements of solid mechanics found in 2.001 and elements of fluid mechanics and heat transfer found in the undergraduate courses 2.005 and 2.006. All students are expected to have an understanding of basic manufacturing processes. This would include at least machining, casting, injection molding, thermoforming, sheet metal forming, and polymer and metal additive manufacturing. This understanding of manufacturing processes should go beyond the physics and include the issues of cost, variation, quality, time and rate. It is also important that the candidate understands the relationship between design and manufacturability, and between design, manufacturability and system design. All students should have a basic familiarity with standard systems configurations such as transfer lines, flow lines, job shops, assembly systems, and manufacturing cells.

The manufacturing exam also requires familiarity with tools that can prove useful for characterizing system problems. These include SPC and reliability (MTTF, MTTR, zero buffers, infinite buffers). All of these elements will need to be integrated in order to analyze real problems and give insights into the fundamental mechanisms, as well as the potential trade offs between alternatives.

**Most suitable subject for preparation:** If you have not taken 2.008 or an equivalent, a recommended preparatory graduate subject is 2.810.

## MICRO AND NANO ENGINEERING

### Theory (C-list)

**Faculty contact:** Professor N.G. Hadjiconstantinou

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The topics and scope of the exam are closely aligned with those covered in the graduate subject Fundamentals of Nanoengineering 2.37.

**Most suitable subject for preparation:** 2.37

### Experiment (S-list)

**Faculty contact:** Professor Jeehwan Kim

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The topics and scope of the exam are closely aligned with those covered in the graduate subject 2.675.

**Most suitable subject for preparation:** 2.675

## OPTICS

**Faculty Contact:** Professor G. Barbastathis

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period.

### **Disciplinary Scope:**

#### Geometrical Optics

- Ray theory, thick/thin lenses, ray propagation matrices
- Optical systems: primate eye, telescope, microscope (4-f systems)
- Aberrations, simple aberration correction methods

#### Physical Optics

- Wave equation, plane & spherical wave solutions
- Light propagation in matter, polarization
- Optical resonators, optical gain, lasers
- Fresnel & Fraunhofer diffraction
- Interference/interferometers, diffraction gratings, holography
- Coherent/incoherent image formation (point spread functions, optical transfer functions, diffraction limit)

#### Fourier Optics

- Frequency analysis, bandwidth, sampling, space-bandwidth product
- Spatial filtering, convolutions & correlations
- Inverse problems, resolution

### **Most suitable subject(s) for preparation:**

2.71/2.710 or 2.717

## PRODUCT DESIGN

**Faculty contact:** Professor W. Seering

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** This exam covers material at the advanced undergraduate level.

Students are expected to have a deep and thorough understanding of material taught in the undergraduate design courses. Typical questions may focus on

- design of machine elements and the systems in which they are used;
- questions about how a given system functions and about the strengths and weaknesses of the system; and
- issues that must be understood when developing a product. Among these are, for example, product quality, product cost, product safety, manufacturability, product architectures, customer needs, product specification, concept generation, concept selection, concept testing, and prototyping.

**Most suitable subject(s) for preparation:**

Undergraduate: 2.007, 2.72, 2.009

Graduate: 2.744, 2.75, 2.739

**Textbooks useful for review:**

- Mechanical Engineering Design by Shigley and Mischke
- Product Design and Development by Ulrich and Eppinger

## SOLID MECHANICS

**Faculty contact:** Professor L. Anand

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The purpose of this examination is to evaluate the candidate's depth in and understanding of the fundamental principles and applications of solid mechanics of engineering materials. The student is expected to recognize, formulate, and solve problems involving: kinematics of deformation, stress, and balance principles. Isotropic linear elasticity and isotropic linear thermal elasticity. Variational and energy methods. Linear viscoelasticity. Small-strain elastic-plastic deformation. Mechanics of large deformation; nonlinear hyperelastic material behavior. Foundations and methods of deformable-solid mechanics, including relevant applications.

**Most suitable subject for preparation:** 2.071

## STOCHASTIC DYNAMICAL SYSTEMS

**Faculty contact:** Professor M. Triantafyllou

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The purpose of this examination is to evaluate the candidate's depth in and understanding of the fundamental principles and applications of stochastic dynamical systems. The student is expected to recognize, formulate, and solve problems involving: Response of systems to stochastic excitation with design applications. Linear time-invariant systems, convolution, Fourier and Laplace transforms. Probability and statistics. Event space, random variables, expectation, conditionals. Discrete and continuous random variables, derived distributions. Stochastic processes, auto-correlation. Stationarity and ergodicity, power spectral density. Systems driven by random functions, Wiener-Khinchine theorem. Sampling and filtering. Short and long term statistics, statistics of extremes. Problems from various areas of mechanical engineering, including mechanical vibrations and statistical linearization, statistical mechanics, and system prediction/identification.

**Most suitable subject for preparation:** 2.122

## STRUCTURAL MECHANICS

**Faculty contact:** Professor D. Parks

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** Fundamental concepts of structural mechanics with applications to marine, civil, and mechanical structures. Residual stresses. Thermal effects. Analysis of beams, columns, tensioned beams, trusses, frames, arches, cables, and shafts of general shape and material, including composites. Elastic buckling of columns. Exact and approximate methods, energy methods, principle of virtual work, introduction to computational structural mechanics.

**Most suitable subject for preparation:** 2.080J

## SYSTEM DYNAMICS AND CONTROLS, ROBOTICS

### **System Dynamics and Controls Option (C-list)**

**Faculty contact:** Professor K. Youcef-Toumi

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The exam is to cover material at the advanced undergraduate level, typically covering what is in corresponding MIT undergraduate subjects. The questions may also touch upon basic material in introductory / core graduate subjects.

**Most suitable subject(s) for preparation:** 2.140 and 2.151.

### **Robotics Option (S-list)**

**Faculty contact:** Professor H. Asada

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The exam is to cover material at the advanced undergraduate level, typically covering what is in corresponding MIT undergraduate subjects. The questions may also touch upon basic material in introductory / core graduate subjects.

**Most suitable subject(s) for preparation:** 2.120

## THERMODYNAMICS

**Faculty contact:** Professor W. Cheng

**Exam format:** The exam will consist of one 30-minute oral examination. The student will have 30 minutes to review the question(s) prior to the oral questioning period. The exam is closed book.

**Topics/Scope:** The purpose of this examination is to evaluate the student's understanding of the fundamental principles of engineering thermodynamics and how to use them to model engineering systems. *The exam focuses on single-component equilibrium thermodynamics.* Students are expected to have a graduate level knowledge of the undergraduate contents of thermodynamics subjects. In particular, those thermodynamics focused topics covered in 2.005+2.006 or equivalent subjects. These include the 1st and 2nd Laws, the rules governing mass and energy conservation, entropy balance, properties of substances, the analysis and design of power and propulsion systems, refrigeration and energy conversion.

**Most suitable subject for preparation:** 2.42

**Recommended Textbooks:**

2.005 and 2.006 Class Notes by Cravalho et al.  
Moran and Shapiro, 6<sup>TH</sup> ed., Wiley.