

GRADUATE PROGRAM POLICY

Mechanical Engineering

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1 Synopsis

Overview. The Department of Mechanical Engineering offers graduate programs leading to the degrees of Master's of Science in Mechanical Engineering (MSME), which can be pursued along two tracks (thesis or non-thesis), and the Doctor of Philosophy (PhD) in Mechanical Engineering. The Department also administers the Master's of Science in Robotics (MSR) Program. The graduate programs are designed to provide considerable flexibility in the selection of course work and specialization. Independent research is required for the PhD degree, as well as for both the MSME and MSR (thesis track) degrees, while the MSME and MSR non-thesis degree programs are appropriate for full-time and part-time students. For those students already enrolled in the Department's Bachelor's in Mechanical Engineering (BME) program, the Department also offers a 4+1 BME/MSME program that allows the student to complete both the BME and MSME degrees in five years of full-time study.

Admission to Program. Students are admitted into the graduate program for either a MSME or a PhD degree. The option of enrollment into the PhD program directly after the BME is available. For students with a Bachelor's degree in engineering the following minimum criteria will normally be applied:

1. A baccalaureate degree in mechanical engineering or in a closely related field of science or mathematics.
2. An undergraduate grade point average in engineering, science and mathematics courses of at least 3.0 on a 4.0 scale.
3. A minimum of at least three letters of strong support from former teachers or supervisors.
4. A minimum combined Quantitative and Verbal score of 308 (1200) on the Graduate Record Examination (GRE) aptitude Test. (Limited GRE waivers may be possible on a case-by-case basis.)
5. A minimum score of 600 on the Test Of English as a Foreign Language (TOEFL), at least 250 on the computer-based TOEFL, or at least 100 on the TOEFL iBT with a speaking score of 20. This test is not required of students whose first language is English and who have received an undergraduate or post-graduate degree from a College or University in which English is the sole language of instruction.

Admission to the graduate program is competitive. Those who meet stated requirements are not guaranteed admission, nor are those who fail to meet all of those requirements necessarily precluded from admission if they offer other appropriate strengths. For applicants with no prior training in engineering, the same minimum criteria will apply. In

addition, their records will be reviewed in relation to the intended program of study. Provisional status with specific remedial work may be a basis for acceptance of such applicants.

Advisement. A temporary academic advisor is assigned to new students when they are admitted to the Department. Students select their permanent advisor once they become familiar with the department, and are clear about their research interests. The permanent advisor will be someone whose interest matches the interest of the student insofar as possible. For students on Research Assistantships, the advisor directs their research and advises them on course selection.

2 MASTER of SCIENCE in MECHANICAL ENGINEERING (MSME)

The MSME program may be pursued under either a thesis option, or a non-thesis option. The program requires 30 credit hours of graduate level coursework, 6 of which must be Master's Thesis credits under the Thesis Option. Coursework must be completed with a grade point average of 3.0 or higher (see Graduate Catalog for relevant details). The course requirements are designed both to provide a balanced program in Mechanical Engineering, and to allow for a degree of specialization. Students should be able to complete all degree requirements, including the thesis if chosen, in 18 to 24 months of full-time study.

Students receiving departmental financial support (fellowship or teaching assistantship) cannot participate in the MSME program.

I Course Requirements

A Required MEEG courses (12 credits)

- (a) MEEG 690 Intermediate Engineering Mathematics
- (b) Three from the following list:

- MEEG 610 Intermediate Solid Mechanics
- MEEG 620 Intermediate Dynamics
- MEEG 621 Linear Systems
- MEEG 630 Intermediate Fluid Mechanics
- MEEG 640 Intermediate Heat Transfer
- MEEG 683 Orthopedic Biomechanics

Students may petition the Graduate Committee to substitute a more advanced (e.g., 800-level) course on the same topic for one of these required courses.

B Three additional graduate level mechanical engineering electives (9 credits)

Thesis-track. Under the Thesis track, 6 credits of MEEG 869 Master's Thesis must be completed toward requirement B.

Non-thesis track. Under the Non-Thesis track, any course listed in A(b) above, excluding those used to fulfill requirement A, can be used toward the 6 credits of requirement B. This 6 credit requirement can also be satisfied with MEEG 868 Research or Independent Study; the latter can be earned through the Graduate Student – Industry Partnership (GSIP) program.

**C Three additional elective graduate level courses
(9 credits)**

These must be courses in engineering, mathematics, science, another field related to the student's academic concentration. Courses must be selected with the documented approval of the department's Graduate Committee, which has the authority to decide on acceptable courses.

**D At least one semester of MEEG 600 Seminar
(0 credits)**

Special arrangements can be made for part-time students to fulfill this requirement.

II Thesis Requirements

Students following the thesis-track demonstrate their ability to conduct scholarly research by compiling and defending a Thesis in front of a committee. The Thesis will have to be defended in front of a committee of at least two MEEG faculty members, chaired by the graduate advisor and including either a third full-time faculty or an external member with the prior approval of the graduate committee. The thesis is to be submitted to committee members at least two weeks in advance of the defense and shall meet the academic and professional standards set forth by the University. Upon acceptance of the thesis, the Committee recommends approval to the Department Chairperson.

III Learning Outcomes and Assessment

A Application of graduate-level mathematics (for both MSME tracks)

Outcome. The student will demonstrate the ability to apply graduate-level mathematics to the solution of engineering problems in at least two of the general areas of solid mechanics, fluid mechanics, dynamics and heat transfer.

Direct assessment. Student learning relative to this outcome is assessed by the student's course grades in: MEEG 610 Intermediate Solid Mechanics; MEEG 620 Intermediate Dynamics; MEEG 630 Intermediate Fluid Mechanics; MEEG 640 Intermediate Heat Transfer; and MEEG 690 Intermediate Engineering Mathematics.

Indirect assessment. A current and updated employment listing will serve as indirect evidence of student attainment of the learning goal.

B Conduct of research (for MSME thesis track)

Outcome. The student will demonstrate the ability to conduct, present and defend graduate-level research including literature review, motivation, methodology utilized, results, unique contributions, and conclusions generated.

Direct assessment. Student learning relative to this outcome is assessed by the quality of the written Master's thesis and performance in the thesis defense.

Indirect assessment. A current and updated employment listing will serve as indirect evidence of student attainment of the learning goal.

3 MASTER of SCIENCE in ROBOTICS (MSR)

The MSR program consists of 30 credit hours of graduate level coursework, and offers a Master's thesis track or a course-based only track. The curriculum consists of a core of six (6) required courses, and four (4) electives. The latter are selected from an approved list of graduate courses and are designed to provide the opportunity for specialization in particular academic subareas such as control, estimation, optimization, or machine learning. A student pursuing the Thesis option can request to count 6 credits of Master's Thesis towards the Required Course credits (requirement A below). A justification for the substitution of thesis credits for required course credits must be provided, and the student's request should be approved by the Graduate Program Director. Students interested in our full-time campus experience are able to complete all degree requirements below, including the optional thesis, in as little as 18 to 24 months. See admission requirements and application information below.

I Course Requirements

The MSR program requires thirty (30) credit hours of graduate level coursework, and offer a Master's Thesis or a course-based only track. Under the Master's Thesis track, six (6) of the thirty (30) total credits must be Master's Thesis credits. Coursework must be completed with a grade point average of 3.0 or higher.

A Required Courses (18 credits)

The following six (6) courses are required for the degree:

1. CISC 621 Algorithm Design and Analysis
2. MEEG 621 Linear Systems
3. MEEG 671 Introduction to Robotics
4. MEEG 678 Introduction to Autonomous Driving
5. CISC 642 Introduction to Computer Vision
6. MAST 632 Environmental Field Robotics

B Elective courses (12 credits)

Students can choose four (4) from the following pre-approved graduate electives.

- MEEG 620 Intermediate Dynamics
- CISC 681 Artificial Intelligence
- MEEG 677 Introduction to State Estimation
- CISC 684 Introduction to Machine Learning
- MEEG 698 Stochastic Optimal Control
- MEEG 894 Linear Feedback Control Design
- MEEG 877 Sensing and Estimation in Robotics
- MEEG 895 Game Theory and Mechanism Design
- MEEG 829 Applied Nonlinear Control
- MEEG 890 Nonlinear Programming

The list above is expected to grow as the program expands, with the approval of the program's Executive Committee. Still, the courses in this list give a student the opportunity to any of five academic concentrations:

Control: MEEG 621 (Linear Systems); MEEG 698 (Stochastic Optimal Control) or MEEG 894 (Linear Feedback Control Design); MEEG 829 (Applied Nonlinear Control)

Estimation: MEEG 621 (Linear Systems); MEEG 677 (Introduction to State Estimation); MEEG 877 (Sensing and Estimation in Robotics)

Artificial Intelligence: CISC 621 (Algorithms); CISC 684 (Machine Learning); CISC 642 (Computer Vision)

Design: MEEG 620 (Dynamics); MEEG 671 (Intro to Robotics); MAST 632 (Environmental Field Robotics)

Optimization: CISC 621 (Algorithms); MEEG 895 (Game Theory and Mechanism Design); MEEG 890 (Nonlinear Programming)

Graduate-level independent study can substitute for up to six (6) graduate elective credits along a non-thesis degree track. Such substitutions, as well as any choice of electives that is not included in the above list, need to have the written (hard copy or electronic) approval of the program's Executive Committee. Independent study activities can take place outside the campus, in the context of semester-long internships with approved industry or government partners, but always under the supervision and oversight of a faculty member from

the participating academic units, who will be ultimately responsible for assigning a grade for the course. To facilitate academic assessment, all independent study courses receiving credit toward MSR degree requirements (including those available through the Graduate Student – Industry Partnership (GSIP) program) should lead to a tangible deliverable, including but not limited to a technical report, a research poster, or a prototype.

II Thesis Requirements

For those students following the MSR Thesis-Track, the thesis requirements are very similar to those for MSME, namely: At the completion of the thesis research, candidates for the MSR thesis-track degree must defend their thesis orally in front of a committee of at least three members, two of which being full-time faculty members and one serving as the committee chair, and a third full-time faculty or an external member, with the prior approval of the program's Executive Committee. The thesis is to be submitted to committee members at least two weeks in advance of the defense and shall meet the academic and professional standards set forth by the University. Upon acceptance of the thesis, the committee recommends approval to the Mechanical Engineering Department Chairperson.

III Learning Outcomes and Assessment

Graduates of this program will be able to demonstrate different technical skills depending on their specialization through elective course selection. These skills may cover different aspects of design, analysis, simulation, and control of robotic systems. Yet all graduates should be able to demonstrate competency relative to the following three program learning outcomes.

A Ability to derive mathematical models of robotic systems

Outcome. Ability to derive mathematical models of typical robotic systems, analyze their dynamic behavior, and design standard controllers.

Direct assessment. Student learning relative to this outcome is assessed by the students course grades in: MEEG 621 Linear Systems; MEEG 671 Introduction to Robotics; MEEG 620 Intermediate Dynamics; MEEG 698 Stochastic Optimal Control; MEEG 894 Linear Feedback Control Design; MEEG 829 Applied Nonlinear Control.

B Ability to simulate robotic behavior

Outcome. Ability to simulate robotic behavior in industry-standard software environments —e.g., Robot Operating System (ROS), Webots, etc.

Direct assessment. Student learning relative to this outcome is assessed by the student's course grades in: MEEG 678 Introduction to Autonomous Driving; MEEG 671 Introduction to Robotics; CISC 642 Introduction to Computer Vision.

C Familiarity with robotic systems deployment

Outcome. Familiarity with implementation issues of robotic deployment in real-world environments.

Direct assessment. Student learning relative to this outcome is assessed by the student's course grades in MAST 632 Environmental Field Robotics.

4 Bachelor's/Master's (4+1) in MECHANICAL ENGINEERING (BME/MSME)

The 4+1 BME/MSME degree program is offered to highly-qualified undergraduate students already enrolled in the BME degree program. This program allows the student to earn both the BME and the MSME degree in 5 years of full-time study in Mechanical Engineering at the University of Delaware. Students should apply in the spring of their junior year.

I Course Requirements

The MSME portion of this degree follows the course requirements of the non-thesis track of the MSME degree. The differences of the 4 + 1 degree, compared to the non-thesis track MSME degree, are the following:

- Students first complete all the required credits for the BME.
- Students take two 600-level technical electives as part of the requirements for the BME degree. These courses are to be chosen from the course requirements for the MSME degree and will also count towards their 4 + 1 degree requirements.
- Students complete an additional 24 credits of coursework to meet the course requirements for the MSME degree
- Students must achieve a 3.0 Grade Point Average (GPA) (a B average) in their graduate work to earn the 4 + 1 degree.

II Learning Outcomes and Assessment

A Application of graduate-level mathematics

Outcome. The student will demonstrate the ability to apply graduate-level mathematics to the solution of engineering problems in at least two of the general areas of solid mechanics, fluid mechanics, dynamics and heat transfer.

Direct assessment. Student learning relative to this outcome is assessed by the student's course grades in: MEEG 610 Intermediate Solid Mechanics; MEEG 620 Intermediate Dynamics; MEEG 630 Intermediate Fluid Mechanics; MEEG 640 Intermediate Heat Transfer; and MEEG 690 Intermediate Engineering Mathematics.

Indirect assessment. A current and updated employment listing will serve as indirect evidence of student attainment of the learning goal.

5 PHD in MECHANICAL ENGINEERING

The PhD program in Mechanical Engineering consists of 33 credits of graduate level coursework plus 9 credits of Doctoral Dissertation. The PhD program is designed to allow for considerable flexibility in course selection and specialization of study. Course work must be completed with a cumulative grade point average of 3.0 or higher (see Graduate Catalog for relevant details). In addition, the student must pass the Qualifying Examination, Candidacy Examination and fulfill the teaching requirement prior to completing the dissertation requirements. The PhD should be obtainable in four years of full-time study after entering the program. There is no foreign language requirement for the PhD.

I Course Requirements

A Five MEEG courses at 600 or higher level (15 credits)

At least three of these courses shall be selected from the following list:

- MEEG 690 Intermediate Engineering Mathematics
- MEEG 610 Intermediate Solid Mechanics
- MEEG 620 Intermediate Dynamics
- MEEG 630 Intermediate Fluid Mechanics
- MEEG 640 Intermediate Heat Transfer
- MEEG 683 Orthopedic Biomechanics
- MEEG 621 Linear Systems

B Five additional graduate courses in engineering, science or mathematics (15 credits)

Of these five electives, at least three courses (9 credits) must be at the 800 level.

C At least one additional graduate course in mathematics (3 credits)

MEEG 690 cannot be used to satisfy this requirement. Unless the course is offered by the Department of Mathematical Sciences, electives intended to satisfy this requirement should typically require approval of the Graduate Committee.

**D At least three semesters of MEEG 600 Seminar
(0 credits)**

Special arrangements can be made for part-time students to fulfill this requirement.

**E Credit Waiver for Master's in Mechanical Engineering or a relevant field
(up to 12 credits)**

In recognition of graduate degree experience, up to a maximum of 12 credits out of the 33 required credits can be waived for a student who is entering the PhD Program with a previously awarded Master's degree in Mechanical Engineering or a relevant field. The relevance of a Master's degree is determined by the Graduate Curriculum Committee (GCC) and the student's advisor after the student enrolls in the PhD program. To consider a Master's degree relevant, evidence must be provided regarding graduate coursework and/or research experience that is sufficiently similar to the Master's degree requirements at UD. In the case where 12 credits are waived, requirements A, B and C would be appropriately reduced, provided that at least 9 out of the remaining 21 credits are in Mechanical Engineering, with the remainder in engineering, mathematics, or science. In case the Master's degree is deemed not sufficiently similar to a Master's degree in Mechanical Engineering, the GCC and the student's advisor will, based on the prior graduate coursework evidence provided, determine the number of credits to be waived, and the appropriate reduction in requirements A, B and C . All students are responsible for organizing their course plan in consultation with their thesis advisor such that they are well prepared for the PhD qualifying examination, and that they fully undertake the coursework needed for their research.

**F MEEG 969 Doctoral Dissertation
(9 credits)**

In order to proceed to MEEG 969 students must complete all course requirements and have candidacy. An individual course can be used to meet more than one of the requirements provided the total number of credits is at least 33. MEEG 868 cannot be used toward these requirements.

Students will submit their list of completed courses, including any approved requests for credit waivers, to the Dissertation Committee at the time of their candidacy exam (see below). Upon approval, it will enter into the candidate's file. Deviations from the proposed plan must be approved by the Dissertation Committee. A copy of the course plan must be sent to the University Office of Graduate Studies.

II Dissertation Requirements

A dissertation is required which demonstrates the student's ability to conduct independent research. A Dissertation Committee is selected by the advisor and approved by the Department Chairperson. This committee will also serve as the student's Candidacy Examination Committee. At least three Mechanical Engineering Department faculty members and at least one external faculty member (from another department or institution) will serve on the Dissertation Committee. The Committee will be chaired by the research advisor, who must be a regular full-time member of the Department of Mechanical Engineering Faculty. During the course of the research, the student will periodically review progress with the Committee.

The student must orally present the dissertation before the Dissertation Committee at an open defense. The student shall supply final draft copies of the dissertation to members of the Committee at least two weeks before the oral defense. The dissertation must meet the academic and professional standards set forth by the University.

III Qualifying Examination

The purpose of the qualifying examination is to assess the aptitude of a doctoral student in the early stages of the program. A student must be enrolled in the PhD program, have a minimum GPA of 3.2 and a minimum of 12 graduate coursework credits to complete the qualifying exam. The qualifying exam will consist of three parts:

- (a) a research aptitude exam based on the student's research interest area
- (b) one math exam (based on the content in MEEG 690)
- (c) one mechanical engineering topic exam (based on undergraduate-level mechanical engineering and the content in one of the core courses, MEEG 610, MEEG 620, MEEG 630, MEEG 640)

Part (a) will be offered between the end of the first semester and the end of the second semester of study and will:

- (i) Include a 2-3 page report reviewing and summarizing typically 3 or 4 published peer-reviewed articles from the literature, in the student's research interest area. The articles will be selected by the student's advisor and no more than one of them shall have been authored by the advisor.
- (ii) Include a 20 minute oral presentation of the above described report, followed by a period of questioning related to the selected papers.
- (iii) Be graded by a committee of at least three faculty members, including the student's research advisor and two other faculty members, not advising the student, appointed by the department chair. The criteria for grading will be established by the faculty and provided to the student ahead of the exam.

Parts (b) and (c) will be written exams, offered in early June and must be taken at the first opportunity after the completion of 12 graduate coursework credits toward the

PhD. In judging student performance on this examination, the faculty has three options: (i) outright passing, (ii) giving a second chance, and (iii) outright failing. If the student is given a second chance, the faculty will specify the parameters for taking and passing the second chance exam. These decisions will be made in a faculty meeting held as soon as possible following the grading of the exams. There will be no third chance given. A student who ultimately fails the Qualifying Examination is not eligible to continue in the PhD program, but may apply to change his/her matriculation to the MSME program.

IV Candidacy Examination

The PhD Candidacy Examination must be taken within one and a half years of successful completion of the Qualifying Examination and at least one year prior to the dissertation defense. The student will prepare a comprehensive, written research proposal and defend it orally before the Candidacy Examination Committee (the composition of which is specified in §II). The Candidacy Examination is intended to test the student's ability to synthesize knowledge in the formulation of an independent research proposal. Performance is judged by the Candidacy Examination Committee, and any additional requirements they wish to impose must be satisfied before the student is admitted to candidacy. Additional requirements could include, but are not limited to: taking additional coursework, modifying the written research proposal, and defending the revised proposal before the Candidacy Examination Committee. Satisfactory completion of any additional requirements must be approved by the student's Candidacy Examination Committee.

V Teaching Requirement

The ability to communicate effectively is an essential skill for all PhD graduates. Therefore, all PhD students are required to fulfill a teaching requirement, which consists of serving as a Teaching Assistant (TA) for one or two semesters, depending on the assignment. Students are expected to continue to be actively involved in their research while serving as a TA.

International graduate students are required to take International Teaching Assistant (ITA) training through the University's English Language Institute (ELI) prior to their first semester as a graduate student. Training and assessment are part of the University's requirements for the proficiency of international TAs. A final decision on how to resolve any deficiency is made by the Graduate Curriculum Chair in consultation with the student's thesis advisor and the Department Chair.

Teaching Assistant positions are assigned by the Graduate Curriculum Chair in advance for the upcoming semester. Students are encouraged to submit their preferences for specific TA positions early to facilitate the process. Although every effort is made to satisfy these requests, students should recognize that this might not be possible in all cases. In addition, the educational needs of the Department may require the Graduate Curriculum Chair to ask students to fill specific TA positions.

VI Learning Outcomes and Assessment

A Application of graduate-level mathematics

Outcome. The student will demonstrate the ability to apply graduate-level mathematics to the solution of engineering problems in at least two of the general areas of solid mechanics, fluid mechanics, dynamics and heat transfer.

Direct assessment. Student learning relative to this outcome is assessed by the student's performance on the written PhD Qualifying exam.

Indirect assessment. A current and updated employment listing will serve as indirect evidence of student attainment of the learning goal.

B Conduct of research

Outcome. The student will demonstrate the ability to conduct, present and defend graduate-level research including literature review, motivation, methodology utilized, results, unique contributions, and conclusions generated.

Direct assessment. Student learning relative to this outcome is assessed by the quality of the written dissertation and performance in the dissertation defense.

Indirect assessment. A current and updated employment listing will serve as indirect evidence of student attainment of the learning goal.

C Planning of graduate-level research

Outcome. The student will demonstrate the ability to propose and present relevant graduate-level research including the description of importance of a problem, a literature review of potential topics where unique contributions can be made and anticipated methodology.

Direct assessment. Student learning related to this outcome is assessed by performance on the Candidacy Examination.

Indirect assessment. A current and updated employment listing will serve as indirect evidence of student attainment of the learning goal.