Mechanical Engineering

Degrees Offered

- Masters of Science, Mechanical Engineering (M.S.M.E.)
- Doctor of Philosophy, Mechanical Engineering (Ph.D.)

Educational Objectives of the Departmental Graduate-Level Programs:

1. To provide high quality advanced master-level and Ph.D. level education to graduate engineering students to enable successful careers in technology development, innovation and research, with depth and breadth in one or several areas of the mechanical engineering discipline.
2. To develop the capacity of graduates to conduct independent research and/or technology development and innovation, through original contributions to the mechanical engineering discipline and to disseminate the results of their scholarly work.
3. To instill in graduates the drive for leadership in technology development, innovation and research and to contribute to the advancement of the profession in a societal and economic context.

The outcomes of the graduate programs in Mechanical Engineering are as follows:

- Holders of graduate degrees will have an expert-level understanding of the advanced principles of mechanical engineering, which include mechanical systems design, system dynamics, solid mechanics, energy systems, engineering materials, automatic controls, mechatronics, and computational mechanics.
- Holders of graduate degrees will hold paramount the highest standards of ethical and professional responsibility in the practice of their profession to contribute to the well being of society and to the advancement of the mechanical engineering profession.
- Holders of Ph.D. degrees will have furthered original research contributions to the state of the art in their specific areas of expertise and will be able to develop innovative research in order to advance the frontiers of knowledge, secure sponsored research, and disseminate its findings through scholarly publications.

Thesis Based Master's Degrees

All the requirements for thesis based master's degrees (M.S.A.E., M.S.M.E. and M.S.M.S.&E.) in the MAE Department must be completed within eight years preceding the student's graduation. All students in these programs are required to engage in research, complete and successfully defend a master's thesis. They must identify a subject for their thesis research, form a three-member advisory and examining committee (AEC), and file a plan of study by the end of their second semester of enrollment in the graduate program. A minimum of twenty-four credit hours of coursework with a minimum overall GPA of 3.0/4.0 and six credit hours of M.S. thesis research are required for the thesis based master's degrees. Students must pass a final examination administered by their advisory and examining committee before being certified for the degree. All thesis based master's degree students have to comply with core requirements by selecting a "core area" taking two of the courses listed in that area, and in addition they have to comply with the mathematics requirements by taking two courses from an approved list. Four additional courses can be selected from a list of technical electives, or from the core and mathematics lists to complete the coursework requirements, with no more than three courses at the 400 level.

Ph.D. Degrees

The MAE Department offers Ph.D. Programs in Aerospace Engineering, in Mechanical Engineering and in Materials Science and Engineering. These programs require a minimum of eighteen credit hours of graduate level coursework plus a minimum of twenty-four credit hours of research. Students in the Ph.D. program must take and pass the Ph.D. Qualifier examination by the second semester of the program with a second attempt no later than the third semester in the program if necessary. After the qualifier examination, students are expected to produce a dissertation proposal and defend it before a five-member advising and examining committee (AEC). Subsequent the successful proposal defense, students must comply with the journal paper publication (or patent disclosure) requirement in order to attain Ph.D. Candidacy. Finally Ph.D. candidates must successfully defend a Ph.D. dissertation and submit it to WVU library through the ETD protocol to fulfill all the requirements for the degree.

Admissions

The applicant must first submit a completed an on-line application, application fee, and transcripts of all college work (directly from the institution) to the WVU Office of Admissions. Each applicant is required to complete an applicant information form and have three recent reference letters (using standard forms available from the department) sent directly to the department; at least two of the three references should be from the institution last attended.

Regular Admissions Requirements

Minimum requirements for admission as a regular student into the graduate programs of the department are summarized as follows:

- An applicant for admission into the M.S. or the Ph.D. degree program must have earned a grade point average (GPA) of 3.0 or better (out of a possible 4.0) in all previous college work if he/she holds a B.S. or M.S. degree, respectively, from an accredited or internationally recognized program, as stated above.
Curriculum Requirements

The Department of Mechanical and Aerospace Engineering (MAE) offers a direct track option from the bachelor of science (B.S.) to the doctor of philosophy (Ph.D.) degree for prospective qualified students holding a B.S. degree in an engineering discipline, materials science, mathematics, or applied sciences from an accredited undergraduate program or an internationally recognized program. This is an accelerated track that provides outstanding candidates the option of earning a Ph.D. degree in less than five years after graduating from an undergraduate program by engaging early in their Ph.D. dissertation research without having to complete a research thesis for a master of science (M.S.) degree. To qualify for the direct track degree option, a candidate must have earned a cumulative grade point average (GPA) of 3.5/4.0 or higher in his/her undergraduate studies and attain a minimum of seventy-fourth percentile in the quantitative section of the standardized Graduate Record Examination (GRE). Students who are pursuing an M.S. degree in the MAE department have also the possibility of transferring into the direct track option in their third semester in the program, provided that they earn a GPA of at least 3.75/4.0 and attain a minimum of seventy-fourth percentile in the quantitative section of the GRE by the end of their first two semesters of graduate studies at WVU. Students admitted into the direct track option are considered to be Ph.D. students in the MAE department.

Provisional Admissions

An applicant not qualifying for the admission status of regular graduate student, either due to marginally insufficient grade point average or GRE performance, incomplete credentials, or inadequate academic background, may be admitted as a provisional student at the discretion of the Admissions Committee of the department. Requirements for attaining regular student status must be stated in a letter of admission. Provisional students must sign a contract, which lists in detail all requirements that have to be met for attaining regular student status, typically no later than the end of the first semester at WVU.

All of the graduate degree programs offered by the department require the student to attain an overall grade point average of 3.0 or higher both in all the courses required for the degree program and in all the courses taken at WVU in order to meet graduation requirements. The cumulative grade point average (GPA) is calculated on the basis of courses only, and excludes credit for research, for which the received grade can be either S (satisfactory), or U (unsatisfactory). Note: A grade of U in research is equivalent to a grade of F in a regular course and it can decrease drastically the GPA of a graduate student.

Doctoral Admissions

ADMISSION TO DOCTOR OF PHILOSOPHY PROGRAM

To be eligible for admission into the doctor of philosophy degree program with a major in aerospace or mechanical engineering, a candidate must hold or expect to receive (by the enrollment date) a M.S. degree in an engineering discipline from an institution which has an ABET accredited undergraduate program in engineering or an internationally recognized program in engineering (except for students qualified for the direct track to Ph.D. degree option, described below). Qualified candidates holding a M.S. degree in applied sciences can also be considered for admission into the Ph.D. program.

ADMISSION TO THE DIRECT-TRACK TO PH.D. DEGREE OPTION

The Department of Mechanical and Aerospace Engineering (MAE) offers a direct track option from the bachelor of science (B.S.) to the doctor of philosophy (Ph.D.) degree for prospective qualified students holding a B.S. degree in an engineering discipline, materials science, mathematics, or applied sciences from an accredited undergraduate program or an internationally recognized program. This is an accelerated track that provides outstanding candidates the option of earning a Ph.D. degree in less than five years after graduating from an undergraduate program by engaging early in their Ph.D. dissertation research without having to complete a research thesis for a master of science (M.S.) degree. To qualify for the direct track degree option, a candidate must have earned a cumulative grade point average (GPA) of 3.5/4.0 or higher in his/her undergraduate studies and attain a minimum of seventy-fourth percentile in the quantitative section of the standardized Graduate Record Examination (GRE). Students who are pursuing an M.S. degree in the MAE department have also the possibility of transferring into the direct track option in their third semester in the program, provided that they earn a GPA of at least 3.75/4.0 and attain a minimum of seventy-fourth percentile in the quantitative section of the GRE by the end of their first two semesters of graduate studies at WVU. Students admitted into the direct track option are considered to be Ph.D. students in the MAE department.

Curriculum in Master of Science in Mechanical Engineering

A candidate for the M.S. degree in mechanical engineering must comply with the rules and regulations as outlined in the WVU Graduate Catalog and the specific requirements of the Statler College and the Mechanical and Aerospace Engineering Department.

Program Requirements

All M.S. degree candidates are required to perform research (except those pursuing the coursework-only degree option) and follow a planned program of study. The student’s research advisor, in conjunction with the student’s Advising and Examining Committee (AEC) will be responsible for determining the plan of study appropriate to the student’s needs. The underlying principle of the planned program is to provide the students with the necessary support to complete their degree and prepare them for their career.

Curriculum Requirements

A minimum cumulative GPA of 3.0 is required in all courses.

Course Requirements *

A minimum of 60% of courses must be from 500 level or above.
<table>
<thead>
<tr>
<th>Thesis Option (30 credit hours)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Electives (6 credit hours)</td>
<td></td>
</tr>
<tr>
<td>Mathematics Requirements (6 credit hours)</td>
<td></td>
</tr>
<tr>
<td>Additional Courses (12 credit hours) - Any BIOM, CE, CHEM, CPE, CS, EE, IENG, MAE, MATH, MINE, PNGE, PHYS, SENG, or STAT courses 400-799, as approved by the student’s AEC</td>
<td></td>
</tr>
<tr>
<td>MAE 697 Research (6 credit hours)</td>
<td></td>
</tr>
<tr>
<td>Written Research Proposal</td>
<td></td>
</tr>
<tr>
<td>Thesis</td>
<td></td>
</tr>
<tr>
<td>Final Oral or Written Examination</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Problem Report Option (33 credit hours)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Electives (6 credit hours)</td>
<td></td>
</tr>
<tr>
<td>Mathematics Requirements (6 credit hours)</td>
<td></td>
</tr>
<tr>
<td>Additional Courses (18 credit hours) - Any BIOM, CE, CHEM, CPE, CS, EE, IENG, MAE, MATH, MINE, PNGE, PHYS, SENG, or STAT courses 400-799, as approved by the student’s AEC</td>
<td></td>
</tr>
<tr>
<td>MAE 697 Research (3 credit hours)</td>
<td></td>
</tr>
<tr>
<td>Written Research Proposal</td>
<td></td>
</tr>
<tr>
<td>Formal Written Report or Professional Report/Paper</td>
<td></td>
</tr>
<tr>
<td>Final Oral or Written Examination</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coursework Option (33 credit hours)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Electives (18 credit hours)</td>
<td></td>
</tr>
<tr>
<td>Mathematics Requirements (6 credit hours)</td>
<td></td>
</tr>
<tr>
<td>Additional Courses (9 credit hours) - Any BIOM, CE, CHEM, CPE, CS, EE, IENG, MAE, MATH, MINE, PNGE, PHYS, SENG, or STAT courses 400-799, as approved by the student’s AEC</td>
<td></td>
</tr>
<tr>
<td>Comprehensive Exam (Written or Oral)</td>
<td></td>
</tr>
</tbody>
</table>

**Total Hours**

<table>
<thead>
<tr>
<th>MATHEMATICS REQUIREMENTS FOR ALL OPTIONS (6 CREDIT HOURS)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Select two of the following (at least one course with MATH prefix):</td>
<td></td>
</tr>
<tr>
<td>MATH 420 Numerical Analysis 1</td>
<td></td>
</tr>
<tr>
<td>MATH 441 Applied Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MATH 456 Complex Variables</td>
<td></td>
</tr>
<tr>
<td>MATH 521 Numerical Analysis</td>
<td></td>
</tr>
<tr>
<td>MATH 522 Numerical Solution of PDE</td>
<td></td>
</tr>
<tr>
<td>MATH 541 Modern Algebra</td>
<td></td>
</tr>
<tr>
<td>MATH 543 Linear Algebra</td>
<td></td>
</tr>
<tr>
<td>MATH 545 Number Theory 1</td>
<td></td>
</tr>
<tr>
<td>MATH 551 Real Variables 1</td>
<td></td>
</tr>
<tr>
<td>MATH 555 Complex Variables 1</td>
<td></td>
</tr>
<tr>
<td>MATH 560 Introduction to Dynamical Systems and Applications</td>
<td></td>
</tr>
<tr>
<td>MATH 563 Mathematics Modeling</td>
<td></td>
</tr>
<tr>
<td>MATH 564 Intermediate Differential Equations</td>
<td></td>
</tr>
<tr>
<td>MATH 567 Advanced Calculus</td>
<td></td>
</tr>
<tr>
<td>MATH 568 Advanced Calculus</td>
<td></td>
</tr>
<tr>
<td>MATH 573 Graph Theory</td>
<td></td>
</tr>
<tr>
<td>STAT 513 Design of Experiments</td>
<td></td>
</tr>
<tr>
<td>STAT 545 Applied Regression Analysis</td>
<td></td>
</tr>
<tr>
<td>STAT 561 Theory of Statistics 1</td>
<td></td>
</tr>
<tr>
<td>STAT 562 Theory of Statistics 2</td>
<td></td>
</tr>
<tr>
<td>MAE 515 Analytical Methods in Engineering</td>
<td></td>
</tr>
<tr>
<td>MAE 623 Conduction Heat Transfer</td>
<td></td>
</tr>
<tr>
<td>MAE 633 Computational Fluid Dynamics</td>
<td></td>
</tr>
<tr>
<td>MAE 640 Continuum Mechanics</td>
<td></td>
</tr>
<tr>
<td>MAE 645 Energy Methods in Applied Mechanics</td>
<td></td>
</tr>
</tbody>
</table>
**TECHNICAL AREA COURSES FOR THESIS OR PROBLEM REPORT OPTIONS (6 CREDIT HOURS)**

Select two courses in a single core technical area from the following:

**Area A: Fluid Mechanics and Aerodynamics (FMA)**

- MAE 532 Dynamics of Viscous Fluids
- MAE 624 Convection Heat Transfer
- or MAE 636 Fundamentals of Turbulent Flow

**Area B: Thermal Sciences and Systems (TSS)**

- MAE 521 Advanced Thermodynamics 1
- MAE 532 Dynamics of Viscous Fluids
- MAE 624 Convection Heat Transfer

**Area C: Dynamics and Controls (D&C)**

- MAE 642 Intermediate Dynamics
- or MAE 653 Advanced Vibrations
- MAE 660 Feedback Control in Mechanical Engineering

**Area D: Solid Mechanics and Design (SMD)**

- MAE 543 Advanced Mechanics of Materials
- MAE 641 Theory of Elasticity 1
- or MAE 653 Advanced Vibrations

**Area E: Materials Science (MS)**

- MAE 580 Crystallography and Crystals
- MAE 583 Thermodynamics and Kinetics of Materials
- MAE 649 Microscopy of Materials

**TECHNICAL AREA COURSES FOR COURSEWORK OPTION (18 CREDIT HOURS)**

**Required Courses**

- MAE 521 Advanced Thermodynamics 1
- MAE 532 Dynamics of Viscous Fluids
- MAE 543 Advanced Mechanics of Materials
- MAE 580 Crystallography and Crystals
- MAE 653 Advanced Vibrations
- MAE 660 Feedback Control in Mechanical Engineering

* Students who do not hold a baccalaureate degree in mechanical engineering will be required to take a set of undergraduate mechanical engineering courses above and beyond the minimum coursework requirements in order to overcome deficiencies in the mechanical engineering area.

**Final Examination**

M.S. students following the thesis or problem report option must prepare a written research proposal. The proposal must be approved by the student's AEC at least one semester prior to the final oral examination.

All students, regardless of option, are required to pass a final oral or written examination, administered by their AEC, covering the thesis or problem report and/or related course material.
The students request for the comprehensive exam for students in the Coursework Only degree option must be filed at least four weeks in advance of the desired date of the exam. The comprehensive exam for students in the Coursework Only degree option must be passed at least 3 weeks before graduation.

**Suggested Plan of Study**

The plan below illustrates the Thesis Option. It is important for students to take courses in the order specified as much as possible; all prerequisites and concurrent requirements must be observed. A typical M.S.M.E degree program that completes degree requirements in two years is as follows.

**First Year**

<table>
<thead>
<tr>
<th></th>
<th>Fall</th>
<th>Hours</th>
<th>Spring</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Area Course</td>
<td>3</td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Math Course</td>
<td>3</td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Additional Course</td>
<td>3</td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Second Year**

<table>
<thead>
<tr>
<th></th>
<th>Fall</th>
<th>Hours</th>
<th>Spring</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional Course</td>
<td>3</td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>MAE 697</td>
<td>3</td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total credit hours: 30

**Curriculum in Doctor of Philosophy – Mechanical Engineering**

A candidate for the Ph.D. degree with a major in mechanical engineering must comply with the rules and regulations as outlined in the WVU Graduate Catalog and the specific requirements of the Statler College and the Mechanical and Aerospace Engineering Department.

**Program Requirements**

The doctor of philosophy degree with a major in mechanical engineering is administered through the college's interdisciplinary Ph.D. program. The research work for the doctoral dissertation must show a high degree of originality on the part of the student and must constitute an original contribution to the art and science of mechanical engineering.

All Ph.D. degree candidates are required to perform research and follow a planned program of study. The student's research advisor, in conjunction with the student's Advising and Examining Committee (AEC) will be responsible for determining the plan of study appropriate to the student's needs. The underlying principle of the planned program is to provide the students with the necessary support to complete their degree and prepare them for their career.

The doctoral courses of study are selected to fit the particular interests and objectives of the student, with proper attention given to broadening related areas of study. The research work for the doctoral dissertation may entail a fundamental investigation into a specialized area or a broad and comprehensive study in a related subject.

All students pursuing a Ph.D. degree in the MAE department are expected to engage in research and complete and successfully defend a Ph.D. dissertation. They should identify a subject for their Ph.D. dissertation, form a five-member advisory and examining committee, and file a plan of study by the end of their second semester of enrollment in the graduate program. At least one member of the graduate faculty from outside the department is required to serve on the advisory and examining committee.

**Curriculum Requirements**

A minimum cumulative GPA of 3.0 is required in all courses.

- **Course Requirements**

  - **Technical Area Courses**
    - Select one course in the relevant core technical area from the following:**
      - **Area A: Fluid Mechanics and Aerodynamics (FMA)**
        - MAE 532: Dynamics of Viscous Fluids
        - MAE 624: Convection Heat Transfer
        - MAE 636: Fundamentals of Turbulent Flow
      - **Area B: Thermal Sciences and Systems (TSS)**
        - MAE 521: Advanced Thermodynamics 1
        - MAE 532: Dynamics of Viscous Fluids
MAE 624 Convection Heat Transfer

Area C: Dynamics and Controls (D&C)

MAE 642 Intermediate Dynamics
MAE 653 Advanced Vibrations
MAE 660 Feedback Control in Mechanical Engineering

Area D: Solid Mechanics and Design (SMD)

MAE 543 Advanced Mechanics of Materials
MAE 641 Theory of Elasticity 1
MAE 653 Advanced Vibrations

Area E: Materials Science (MS)

MAE 580 Crystallography and Crystals
MAE 583 Thermodynamics and Kinetics of Materials
MAE 649 Microscopy of Materials

Mathematics Requirements

Select two of the following (at least one course with MATH prefix):

MATH 420 Numerical Analysis 1
MATH 441 Applied Linear Algebra
MATH 456 Complex Variables
MATH 521 Numerical Analysis
MATH 522 Numerical Solution of PDE
MATH 541 Modern Algebra
MATH 543 Linear Algebra
MATH 545 Number Theory 1
MATH 551 Real Variables 1
MATH 555 Complex Variables 1
MATH 560 Introduction to Dynamical Systems and Applications
MATH 563 Mathematics Modeling
MATH 564 Intermediate Differential Equations
MATH 567 Advanced Calculus
MATH 568 Advanced Calculus
MATH 573 Graph Theory
STAT 513 Design of Experiments
STAT 545 Applied Regression Analysis
STAT 561 Theory of Statistics 1
STAT 562 Theory of Statistics 2
MAE 515 Analytical Methods in Engineering
MAE 623 Conduction Heat Transfer
MAE 633 Computational Fluid Dynamics
MAE 640 Continuum Mechanics
MAE 645 Energy Methods in Applied Mechanics
CHE 531 Mathematical Methods in Chemical Engineering
EE 463 Digital Signal Processing Fundamentals
EE 465 Introduction to Digital Image Processing
EE 515 Linear Control Systems
EE 517 Optimal Control
IENG 518 Technology Forecasting
IENG 553 Applied Linear Programming
PHYS 461 Thermodynamics and Statistical Mechanics
PHYS 611 Introduction to Mathematical Physics

Research

MAE 797 Research

Any BIOM, CE, CHE, CHEM, CPE, CS, EE, IENG, IH&S, MAE, MATH, MINE, PNGE, PHYS, SAFM, SENG, or STAT courses 500-799
Students who do not hold a baccalaureate degree in mechanical engineering are required to take a set of undergraduate mechanical engineering courses above and beyond the minimum coursework requirements in order to overcome deficiencies in the area. For these students, a minimum of fifty-four hours of coursework and thirty hours of independent research beyond a bachelor’s degree, or eighteen hours of coursework and twenty-four hours of independent research beyond an M.S. degree are required.

** PhD students who also earn their MS degree in the MAE Department are expected to select the third core course in their technical area.

Examinations

QUALIFYING EXAM
All students must take and pass a written qualifying examination. Normally, the qualifying examination is given no later than one semester after completion of eighteen credit hours toward the doctoral degree. This examination is designed to assess the basic competency of students in the mechanical engineering field to determine whether or not they have sufficient knowledge to undertake independent research.

The Ph.D. qualifying examination is the method of assessing whether the student has attained sufficient knowledge of the discipline and supporting fields in order to undertake independent research or practice. Students are required to pass a qualifying examination administered by the department which tests for a minimum level of proficiency expected of all students in a given area. It is expected that students will take the qualifying exam during their first or second semester of enrollment in the Ph.D. program; however, it is required that full-time students pass the qualifying examination no later than the end of the third semester of enrollment in their Ph.D. program. Students admitted in the direct track from B.S. to Ph.D. degree option are expected to take the qualifying exam by the end of their fourth semester of enrollment in the MAE graduate program.

CANDIDACY EXAMINATION
In order to be admitted to candidacy, the student must pass a candidacy exam, which is designed to evaluate the student’s overall ability to engage in high-level research.

As the student progresses, his or her advisory and examining committee is charged with evaluating the student’s competency in the specific area of study through the assessment of a dissertation proposal for the research to be completed and the evaluation of the student’s plan of study and associated coursework. After these requirements are completed, the student is formally admitted to candidacy for the Ph.D. degree. Only at this point can a student be called a doctoral candidate; admission to the graduate program for the purpose of pursuing the Ph.D. degree is not equivalent to becoming a Ph.D. candidate. Doctoral candidates are allowed no more than five years to complete the remaining degree requirements after admission to candidacy. An extension of time can be obtained only by repeating the qualifying and candidacy examinations and meeting any other requirements specified by the student’s advisory and examining committee.

A student who has successfully completed all coursework, passed the qualifying examination, and successfully defended the research proposal is defined as one who is a candidate for the Ph.D. degree.

FINAL EXAMINATION
At the completion of the dissertation research, candidates must prepare a dissertation and pass the final oral examination (defense) administered by their AEC.

In order to complete the Ph.D. requirements, a student must pass a final oral examination on the results embodied in the dissertation. This examination is open to the public and, in order to evaluate critically the student's competency, may include testing on material in related fields, as deemed necessary by the AEC. In addition, since the Ph.D. degree is primarily a research degree that embodies the results of an original research proposal and represents a significant contribution to scientific literature, the student must submit a manuscript on this research to the AEC.

Suggested Plan of Study
It is important for students to take courses in the order specified as much as possible; all prerequisites and concurrent requirements must be observed. A typical doctoral degree program that completes degree requirements in three years is as follows. The Ph.D. degree signifies that the holder has the competence to function independently at the highest level in the chosen field. Hence, the number of years involved in attaining or retaining competency cannot be readily specified, nor can an exact program of study be defined.
First Year

<table>
<thead>
<tr>
<th>Course Type</th>
<th>Fall Hours</th>
<th>Spring Hours</th>
<th>Total Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Area Course</td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Math Course</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>MAE 797</td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

Second Year

<table>
<thead>
<tr>
<th>Course Type</th>
<th>Fall Hours</th>
<th>Spring Hours</th>
<th>Total Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional Course</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>MAE 797</td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

Third Year

<table>
<thead>
<tr>
<th>Course Type</th>
<th>Fall Hours</th>
<th>Spring Hours</th>
<th>Total Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAE 797</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Total credit hours: 42

**JOURNAL PAPER PUBLICATION REQUIREMENT FOR ALL PHD STUDENTS:**

Beginning with all PhD students admitted for the summer or fall of 2016 and thereafter, every Ph.D. student, prior to his/her dissertation defense, will be required to provide written documentation that they have received formal proof of submission of either:

a.) At least one manuscript, generally co-authored with their research supervisor and about some portion of their PhD dissertation research, to an archival journal for publication, or

b.) At least one patent disclosure, also generally about some portion of their PhD dissertation research.

This publication requirement will have to be satisfied prior to scheduling the defense of the Ph.D. Dissertation.

**Major Learning Outcomes**

**MECHANICAL ENGINEERING**

The MAE Department is committed to deliver high quality education and research experience to all graduate students in order to enable them to achieve success in their careers, though the following Learning Goals:

- Expertise, depth and breadth in a chosen field of mechanical engineering.
- Capacity to engage in original research, advanced technological discovery and innovation in order to advance the frontiers of knowledge in the science of the mechanical engineering discipline.
- Capacity of effective high level communication in order to document, disseminate and transfer knowledge of the science of the mechanical engineering discipline in educational, research or applied workplace settings.
- Appreciation and understanding of the role of the science of mechanical engineering discipline in a global and societal context.

**COURSES**

**MAE 515. Analytical Methods in Engineering. 3 Hours.**

PR: Consent. Index notation for determinants, matrices, and quadratic forms; linear vector spaces, linear operators including differential operators; calculus of variations, eigenvalue problems, and boundary value problems.

**MAE 521. Advanced Thermodynamics 1. 3 Hours.**

PR: MAE 321 or MAE 426. First and second laws of thermodynamics with emphasis on entropy production and availability (exergy); Maxwell’s relationships and criteria for stability; equations of state and general thermodynamic equations for systems of constant chemical composition.

**MAE 525. Heavy Duty Vehicle Emissions. 3 Hours.**

PR: Graduate student standing in engineering or instructor consent. Present research and development of advanced heavy-duty engines and their use in vehicle powertrains. Study emissions formation and control from existing and developing heavy-duty vehicle system designs using conventional and hybrid propulsion systems.

**MAE 526. Advanced Internal Combustion Engine. 3 Hours.**

PR: MAE 425 with a minimum grade of C- or consent. An intermediate to advanced examination of internal combustion engine thermochemical processes, instrumentation, diagnostics, data analysis and modeling, with focus on preparing the student for advanced engine research.
MAE 528. Introduction to Fuel Cell Technology. 3 Hours.
PR: Graduate student standing in engineering or consent. Fuel cells definition, types and application areas, thermodynamics of fuel cells, introduction of electrochemistry, Nerst Potential, Butler-Volmer and Tafel equations, experimental techniques, computational techniques, fuel cell materials, fuel processing and storage, stack, and system design.

MAE 531. Fluid Mechanics 1. 3 Hours.

MAE 532. Dynamics of Viscous Fluids. 3 Hours.
PR: Consent. Derivation of and exact solutions for the Navier-Stokes equations; laminar boundary-layer theory, similarity solutions, and integral methods.

MAE 534. Fluid Flow Measurements. 3 Hours.
PR: MAE 336 or Consent. Principles and measurements of static and dynamic pressures and temperatures, velocity, and Mach number and forces. Optical techniques and photography. Design of experiments. Review of selected papers from the literature. (2 hr. lec., 3 hr. lab.).

MAE 543. Advanced Mechanics of Materials. 3 Hours.
PR: Consent. Shear flow and shear center; curved beams; unsymmetrical bending, energy methods in structural analysis; theories of failure; instability of structures; beams on elastic foundation.

MAE 561. Satellite Navigation. 3 Hours.
PR: MAE 411 and MAE 460 or consent. Examination of various segments of the Global Positioning System. Applications, error sources, and advanced methods for mitigating these errors sources. Estimation procedures, algorithms, and GPS processing will be introduced and utilized.

MAE 565. Artificial Intelligence Techniques in Mechanical and Aerospace Engineering. 3 Hours.
Introduction to solving complex problems in mechanical and aerospace engineering using genetic (evolutionary) algorithms, fuzzy logic-based modeling and control, and artificial neural networks.

MAE 580. Crystallography and Crystals. 3 Hours.
Introduction to the principles of structure of materials, and theory and applications of diffraction and imaging techniques for materials characterization using X-ray diffraction and transmission electron microscopy (TEM).

MAE 583. Thermodynamics and Kinetics of Materials. 3 Hours.
Fundamental concepts of thermodynamics and kinetics of materials. Classical thermodynamics. Examples of the application of thermodynamic concepts to the analysis of material systems.

MAE 594A. Seminar. 1-6 Hours.
Special seminars arranged for advanced graduate students.

MAE 621. Advanced Thermodynamics 2. 3 Hours.
PR: MAE 521 or Consent. Thermodynamics of multi-component inert and reacting systems; equilibrium analysis; introduction to irreversible processes involving diffusion and chemical kinetics; application of concepts to heterogeneous systems.

MAE 623. Conduction Heat Transfer. 3 Hours.
PR: MAE 423 or Consent. Analytical and numerical solutions of steady and non-steady heat conduction problems in one-, two-, and three dimensional bodies; solution of linearized equations; applications include extended surfaces, moving surfaces, moving heat sources, and instrumentation techniques.

MAE 624. Convection Heat Transfer. 3 Hours.
PR: MAE 423 or Consent. Laminar and turbulent flows in forced and free convection systems; external and internal flows with application to heat exchanger design; introduction to aerodynamic heating.

MAE 625. Radiation Heat Transfer. 3 Hours.
PR: MAE 423 or consent. Classical derivation of black body radiation laws; gray body and non-gray analysis; radiant properties of materials, radiant transport analysis, specular-diffuse networks, gas radiation, thermal radiation measurements; analytical, numerical solutions, and study of selected publications. (3 hr. lec.).

MAE 631. Gas Dynamics. 3 Hours.

MAE 633. Computational Fluid Dynamics. 3 Hours.
PR: MAE 532 or equivalent. Finite difference methods; convergence and stability; Navier-Stokes equations; discretization methods; grid distribution; solution of difference equations; pressure coupling; application to conduction/convection, boundary layers, and recirculating flows; introduction to general purpose CFD codes.

MAE 635. Turbomachinery. 3 Hours.
PR: MAE 320 or Consent. Flow problems encountered in design of water, gas, and steam turbines, centrifugal and axial flow pumps and compressors, design parameters.
MAE 636. Fundamentals of Turbulent Flow. 3 Hours.
PR: MAE 532 or consent. Statistical theories of turbulence and recent applications. Basic experimental data and length and time scale analysis. Application of semi-empirical theories to pipe, jet, and boundary-layer flow.

MAE 637. Multiphase Flows. 3 Hours.
PR: MAE 331. Particle dynamics including particle-particle and particle-surface interactions; fluidized bed concepts; mathematical models and numerical methods as applied to multiphase flows; design and instrumentation pertaining to multiphase units.

MAE 640. Continuum Mechanics. 3 Hours.
PR: MAE 242 and MAE 243. Mathematical preliminaries including index notation; analysis of stress; analysis of deformation; fundamental laws, field equations, and constitutive equations; application to fluids and solids.

MAE 641. Theory of Elasticity 1. 3 Hours.
PR: Consent. Cartesian tensors; plane stress and plane strain; 2-D problems in Cartesian and polar coordinates; stress and strain in 3-D; general theorems; torsion of noncircular sections.

MAE 642. Intermediate Dynamics. 3 Hours.

MAE 643. Inelastic Behavior of Engineering Materials. 3 Hours.
PR: MAE 543 or Consent. Characterization and constitutive relations of engineering materials; nonlinear elasticity, plasticity, viscoelasticity and creep; numerical implementation.

MAE 644. Fracture Mechanics. 3 Hours.
PR: MAE 641. Linear-elastic and elastic-plastic fracture mechanics; fatigue, dynamic, and creep crack growth; fracture mechanics models for composite materials.

PR: Consent. Variational principles of mechanics and applications to engineering problems; principles of virtual displacements, minimum potential energy, and complementary energy, Castigliano's theorem, Hamilton's principle. Applications to theory of plates, shells, and stability.

MAE 646. Advanced Mechanics of Composite Materials. 3 Hours.
PR: MAE 446 or Consent. Manufacturing, testing, and diagnostics of composite materials. Anisotropic plates with cutouts. Inelastic behavior of polymer matrix composites. Analysis of advanced composites such as metal matrix, ceramic matrix, and textile.

MAE 648. Experimental Stress Analysis. 3 Hours.
PR: Consent. Strain gage techniques and instrumentation; stress analysis using optical methods such as photoelasticity and interferometric techniques; NDE and NDT or problems involving stress analysis. (2 hr. lec., 3 hr. lab.).

MAE 649. Microscopy of Materials. 3 Hours.

MAE 650. Mechanical Metallurgy. 3 Hours.
PR: MAE 244 or Consent. Elastic behavior and plastic theory. Dislocation theory. Strengthening mechanisms and fracture. Mechanical properties from materials testing including tension, torsion, fracture toughness, fatigue, and creep.

MAE 652. Advanced Kinematics of Mechanisms. 3 Hours.
PR: MAE 452 or Consent. Analytical synthesis of mechanisms with up to five accuracy points; Burmester curve theory and path curvature theory; force and moment balancing of mechanisms; computer-aided dynamic analysis of mechanisms and inverse dynamic analysis.

MAE 653. Advanced Vibrations. 3 Hours.
PR: Consent. Dynamic analysis of multiple degree-of-freedom discrete vibrating systems; Lagrangian formulation; matrix and numerical methods; impact; mechanical transients.

MAE 654. Advanced Machine Design. 3 Hours.
PR: Consent. Design for extreme environments, material selection, lubrication and wear, dynamic loads on cams, gears, and balancing of multiengines and rotors, electromechanical components.

MAE 656. Advanced Computer Aided Design. 3 Hours.
Geometric modeling; finite element meshing; design approaches, case studies using CAD principles; projects utilizing state-of-the-art CAD packages. (2 hr. lec., 3 hr. lab.).

MAE 660. Feedback Control in Mechanical Engineering. 3 Hours.
PR: Consent. Emphasis on design of control systems using classical, frequency domain, and time domain methods; advanced mathematical modeling of physical systems, compensation, stabilization, pole placement, state estimation; extensive use of computerized design tools, especially Matlab.

MAE 662. Robot Mechanics and Control. 3 Hours.
Kinematic and dynamic behavior of industrial robot manipulators; formulation of equations of motion for link joint space and end effector Cartesian space; path planning and trajectory motion control schemes.
MAE 663. Instrumentation in Engineering. 3 Hours.
PR: Consent. Theory of instrumentation suitable for measuring rapidly changing force, pressure, strain, temperature, vibration, etc.; computerized acquisition, analysis, and transmission of data; methods of noise reduction. (2 hr. lec., 3 hr. lab.).

MAE 686. Materials Science and Engineering Seminar. 1 Hour.
Mandatory seminar series for all materials science and engineering (MS&E) majors. Recent developments in materials science and engineering.

MAE 687. Materials Engineering. 3 Hours.
A study of materials engineering fundamentals emphasizing semiconductor, polymer, metal, and ceramic/cementitious material systems. Mechanical and physical properties, theoretical aspects, testing, design criteria, manufacturing, and economics of material systems. Laboratory testing and evaluation. (Equivalent to CE 687, CHE 687, EE 687, MINE 687, and IMSE 687.).

MAE 691. Advanced Topics. 1-6 Hours.
PR: Consent. Investigation of advanced topics not covered in regularly scheduled courses.

MAE 693A-Z. Special Topics. 1-6 Hours.
A study of contemporary topics selected from recent developments in the field.

MAE 694. Seminar. 1-6 Hours.
Special seminars arranged for advanced graduate students.

MAE 695. Independent Study. 1-6 Hours.
Faculty supervised study of topics not available through regular course offerings.

MAE 697. Research. 1-15 Hours.
PR: Consent. Research activities leading to thesis, problem report, research paper or equivalent scholarly project, or a dissertation. (Grading may be S/U.).

MAE 721. Fundamentals of Combustion. 3 Hours.
PR: MAE 321 or MAE 426. Thermodynamics, chemical kinetics, and diffusion of reacting gases; laminar and turbulent flames; flame stability and ignition.

MAE 733. Perfect Fluid Theory. 3 Hours.
PR: Consent. Conformal mapping including Schwarz-Christoffel and Joukowski transformations. Inviscid flows over airfoils, spheres, cones, wedges, and bodies of revolution. (3 hr. lec.).

MAE 741. Theory of Elasticity 2. 3 Hours.
PR: MAE 641. Complex variable methods, stress couples, nonlinear elasticity, numerical methods, potential methods, boundary value problems, and various special topics.

MAE 743. Theory of Elastic Stability. 3 Hours.
PR: Consent. Stability of discrete mechanical systems, energy theorems, buckling of beams, beam columns and frames, torsional buckling, buckling of plates and shells, and special topics.

MAE 744. Theory of Plates and Shells. 3 Hours.
PR: MAE 543 or Consent. Classical and modern theories of plates; dynamic response, nonlinear effects, and exact and approximate solutions of plates; application to rectangular and circular plates; membrane shells; shells with bending stiffness.

MAE 760. Advanced Topics in Control Theory. 3 Hours.
PR: MAE 660 or MAE 465. State feedback through eigenstructure assignment; Observers and Kalman filters; multiple-model adaptive estimation and control; parameter estimation; direct and indirect model-reference adaptive-control algorithms; introduction to neural networks.

MAE 790. Teaching Practicum. 1-3 Hours.
PR: Consent. Supervised practice in college teaching of Benjamin M. Statler College of Engineering and Mineral Resources courses. Note: This course is intended to insure that graduate assistants are adequately prepared and supervised when they are given college teaching responsibility. It will also present a mechanism for students not on assistantships to gain teaching experience. (Grading will be S/U.).

MAE 791. Advanced Topics. 1-6 Hours.
PR: Consent. Investigation of advanced topics not covered in regularly scheduled courses.

MAE 793A. Special Topics. 1-6 Hours.
A study of contemporary topics selected from recent developments in the field.

MAE 795. Independent Study. 1-9 Hours.
Faculty supervised study of topics not available through regular course offerings.

MAE 797. Research. 1-15 Hours.
PR: Consent. Research activities leading to thesis, problem report, research paper or equivalent scholarly project, or a dissertation. (Grading may be S/U.).

MAE 798. Thesis or Dissertation. 1-6 Hours.
PR: Consent. This is an optional course for programs that wish to provide formal supervision during the writing of student reports (698), or dissertations (798). Grading is normal.
MAE 799. Graduate Colloquium. 1-6 Hours.
PR: Consent. For graduate students not seeking coursework credit but who wish to meet residency requirements, use the University's facilities, and participate in its academic and cultural programs. Note: Graduate students who are not actively involved in coursework or research are entitled, through enrollment in their department's 699/799 Graduate Colloquium to consult with graduate faculty, participate in both formal and informal academic activities sponsored by their program, and retain all of the rights and privileges of duly enrolled students. Grading is S/U; colloquium credit may not be counted against credit requirements for masters programs. Registration for one credit of 699/799 graduate colloquium satisfies the University requirement of registration in the semester in which graduation occurs.