

GRADUATE STUDY POLICIES AND PROCEDURES

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The following material has been prepared in order to aid students in planning their graduate study program in Aerospace and Ocean Engineering. Policies concerning admissions, degree requirements, examinations, etc., are included. The information contained herein is intended to supplement the information given in the Graduate Policies and Procedures and Course Catalog obtainable on the Graduate School web site. It is the student's responsibility to follow the policies and procedures presented in the Policies and Procedures and Catalog, and in this document. For an AOE graduate student, the degree requirements are defined by the AOE Graduate Study Policies and Procedures that are in effect at the start of the academic year in which the student files the Plan of Study.

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I. ADMISSION REQUIREMENTS AND PROCEDURES

Applications to the AOE Department's graduate programs are reviewed by the AOE faculty, who evaluate each applicant's suitability for the AOE graduate program, including an assessment of the applicant's ability to carry out scholarly work at the graduate level. A non-refundable application fee (\$75) is required of all applicants at the time the application is submitted. Admissions recommendations are made to the Graduate School on the advice of the AOE Graduate Committee. Admission to the AOE graduate program is granted by the Virginia Tech Graduate School upon review of the Graduate Committee's recommendations. More information regarding the online application can be accessed at the following link: <http://graduateschool.vt.edu/applying>.

The deadline for applications to begin graduate study in the Fall semester is December 30th and the deadline for applications to begin graduate study in the Spring semester is September 1st. International applicants must have a completed application on file with the AOE department by these dates in order to be considered for admission. Domestic applicants should adhere to these deadlines as well in order to ensure full consideration for financial assistance. All applications are reviewed and evaluated based on the applicant's past academic performance, research and work experience, recommendation letters, and test scores. Applicants are ranked accordingly and recommendations are periodically made concerning which applicants should be offered acceptance into the graduate program and, in some cases, assistantships. Acceptances and assistantship offers are based on many factors in addition to those mentioned previously. These additional factors include departmental needs in the indicated areas of interest and availability of research funds. The application review process can range from a few weeks to several months.

Virginia Tech does not discriminate against employees, students or applicants on the basis of race, color, sex, sexual orientation, disability, age, veteran status, national origin, religion, or political affiliation. The University is subject to titles VI and VII of the Civil Rights Act of 1964, Title IX of the Education Amendments of 1972, Sections 503 and 504 of the Rehabilitation Act of 1973, the Age Discrimination in Employment Act, the Vietnam Era Veteran Readjustment Assistance Act of 1974, Federal Executive Order 11246, Governor Allen's State Executive Order Number Two, and all other rules and regulations that are applicable. Anyone having questions concerning any of those regulations should contact the Equal Opportunity/Affirmative Action Office. The minimum requirements for admission established by the AOE Department are listed below (note that meeting these does not guarantee admission):

1. The applicant should have a Bachelor's degree, usually in Engineering, Mathematics, or Physics, from an accredited institution.
2. The applicant should provide evidence which shows genuine promise of success in graduate study such as a good academic record, especially in the Junior and Senior years, and satisfactory letters of recommendation. For regular status, a minimum average of B (3.0/4.0) or better is required. Averages below this value may be considered, on an individual basis, for provisional status, when there is additional evidence of achievement, such as work experience.

3. Scores of the General (Verbal, Quantitative, and Analytic) portion of the Graduate Record Examination (GRE) must be submitted for all applicants. More information can be found at the following link: <http://www.ets.org>.
4. All foreign applicants who have not earned a degree from an accredited English-speaking institution are required to take the Test of English as a Foreign Language (TOEFL). More information can be found at the following link: <http://www.ets.org>.
5. At the beginning of the Fall Semester, the AOE Department holds an orientation for new graduate students. This orientation provides an opportunity for new students to meet each other and the graduate program personnel. The orientation meeting also covers establishing a Plan of Study, as well as some administrative and logistical details.

II. FINANCIAL AID

A number of Graduate Assistantships and Fellowships are available. To be eligible for aid, an applicant should have at least a B (3.0/4.0) average for the last 60 hours of study. A student must maintain at least a 3.0 average (GPA) each semester at Virginia Tech to remain eligible for an Assistantship.

A. Graduate Assistantships

1. Graduate Assistantships are the most common form of financial assistance. For this type of assistance, the graduate student devotes a minimum of twenty hours per week to assigned duties, primarily research or instructional assistance, other than course work. Assistantships are targeted towards Ph.D. students and, to a lesser degree, thesis Masters students. Students on a Graduate Research Assistantship (GRA) will devote twenty hours per week towards research, while students on a Graduate Teaching Assistantship (GTA) will devote twenty hours per week towards instructional assistance (e.g., holding office hours, teaching a recitation section, creating homework and test problems, and grading assignments).
2. A student on a Graduate Assistantship must carry a minimum of 12 hours of course work and research hours per semester. Students may not register for more than 18 hours of coursework and research hours in a semester without prior approval from the Dean of the Graduate School. Normally, students will register for 12 hours of course work and research (including 3 or more hours of research) plus the 1-hour Graduate Seminar. Registration during summer sessions is not required unless the degree program is to be completed during a summer session.
3. Graduate Assistantship stipends typically start at a Step 8 on the stipend table for new Masters level students and Step 12 for new Ph.D. students. The Graduate Student Stipend table can be found at the following link: <http://graduateschool.vt.edu/financial/assistantships#Graduate%20Stipends>. Increases in a stipend depend on a student's experience, academic record, and past performance. Payment is on or near the 1st and 16th of each month, with the first payment of the academic year being on or near September 1.
4. All students with Graduate Assistantships have their tuition paid by the department or from a research grant or contract. Hence, students with Graduate Assistantships effectively have a tuition waiver. However, students are responsible for paying all comprehensive fees.
5. Students with Graduate Research Assistantships are evaluated at the end of each semester by the faculty Advisor for whom they are doing research. A student performing in an unsatisfactory manner will be apprised of the deficiency and instructed on how to improve performance. An additional unsatisfactory review could result in temporary or permanent loss of the Graduate Assistantship.
6. Students with Graduate Teaching Assistantships are evaluated at the end of each semester by the faculty member for whom they are providing instructional assistance. A student performing in an unsatisfactory manner will be apprised of the deficiency and

instructed on how to improve performance. An additional unsatisfactory review could result in temporary or permanent loss of the Graduate Assistantship.

B. Supplemental Fellowships

Fellowships are available to supplement the Graduate Assistantship stipends of exceptionally well qualified students. Recipients of these fellowships are reviewed after each semester with regard to their academic and research progress and performance. A minimum GPA of 3.2 is required to retain a fellowship.

C. Other Fellowships

The AOE Department does not currently award Fellowships other than as supplements to Graduate Assistantships.

However, all graduate students are encouraged to apply for external support, when eligible and qualified. Information about such opportunities is posted on both the AOE and Graduate School web sites.

III. ESTABLISHING A PLAN OF STUDY

Each graduate student establishes an Advisory Committee which guides the student in defining their plan of study, advises the student concerning specific degree requirements, and evaluates the student's progress providing constructive feedback. The Chairperson of the Advisory Committee is the student's Advisor.

A. Areas of Specialization for Graduate Degrees

Multiple degrees and specializations are offered in AOE including, (i) M.S., M.Eng., and Ph.D. degrees in Aerospace Engineering, (ii) M.S. degree in Ocean Engineering, and (iii) Ocean Engineering option under the PhD in Aerospace Engineering. The areas of specialization are described below.

1. Aero-Hydrodynamics (M.S., and Ph.D. in Aerospace Engineering).
This area is concerned with the determination of forces and moments caused by the motion of an aerospace or ocean vehicle through a liquid or gaseous medium, and with the nature of the flow field around the vehicle and in its wake. This determination ranges from very low subsonic speeds through the speed of sound (transonic) to supersonic and hypersonic speeds. Both inviscid and viscous flow phenomena are significant. In addition, the study of internal flow fields associated with propulsion is a subset of this area.
Faculty: Adams, Alexander, Brizzolara, Choi, Coutier-Delgosha, Devenport, Gilbert, Lowe, Massa, Paterson, Pitt, Raj, Roy, Schetz, Srinivasan, Wang, Xiao, Young.
2. Dynamics, Control and Estimation (M.S., and Ph.D. in Aerospace Engineering).
The area of dynamics involves dynamic modeling and analysis for space, atmospheric, and ocean vehicles. The area of control and estimation involves the development and application of methods for vehicle guidance, navigation, and control.
Faculty: Black, Brizzolara, Farhood, Joerger, Patil, Philen, Psiaki, Ross, Sultan, Woolsey.
3. Structures and Materials (M.S., and Ph.D. in Aerospace Engineering).
This area involves development and application of methods for design and evaluation of aerospace and ocean structures. Principal subjects of study are structural analysis, computational mechanics, structural optimization, composite structures, smart structures, deployable structures, structural health monitoring, material science, machine learning, and multi-disciplinary analysis and optimization of aircraft, spacecraft, ships and satellites.
Faculty: Canfield, Gilbert, Kapania, Patil, Philen, Pitt, Seidel, Sultan, Wang.
4. Ocean Engineering (M.S. in Ocean Engineering, and Ph.D. as an option under Aerospace Engineering).
This area of engineering deals with all hardware systems (including ships, offshore petroleum and mineral exploration and production systems, naval systems, instrumentation associated with environmental and pollution data, detection and collection systems) that function on or within the sea.

Faculty: Alexander, Brizzolara, Brown, Coutier-Delgosha, Devenport, Gilbert, Paterson, Wang, Woolsey, Xiao.

5. Applied Physics (Ph.D. in Aerospace Engineering only).

This area is concerned with the application of classical and modern physics to the development of advanced aerospace instrumentation and vehicles. This is an interdisciplinary program. In addition to traditional subjects in aerospace engineering, students in this program also study subjects in applied physics, molecular dynamics, plasma physics, and electrical engineering.

Faculty: Adams, England, Lowe, Massa, Srinivasan.

6. Space Engineering (M.S., and Ph.D. in Aerospace Engineering).

This area is concerned with the multidisciplinary application of Aerospace, Electrical, Mechanical, and Systems Engineering (among others) to the development of advanced space instrumentation, vehicles, constellations, and space exploration systems.

Faculty: Adams, Black, England, Joerger, Psiaki, Srinivasan, Young.

B. Selection of Advisor

1. On the supplemental page of the application for admission, students should specify their principal area of interest from the six areas of specialization described in Section III.A. and indicate the names of AOE faculty members with whom they are interested in working.
2. For students entering on a Graduate Research Assistantship, the faculty member funding the research will generally serve as the student's Advisor. The student is expected to actively support the research program which is funding their GRA while also engaging in research supporting their degree. In many cases, the two research efforts overlap considerably.
3. Students entering on a Graduate Teaching Assistantship, or those entering without funding, have until the end of their first semester enrolled to mutually select an Advisor. As part of this selection process, the student is expected to proactively seek to attend research meetings of prospective Advisors with mutual research interests. Furthermore, the student should seek to actively engage in research whenever possible.
4. The Advisor will help establish the student's Plan of Study and, for students pursuing a thesis or dissertation, will serve as the student's research mentor. A student with a Graduate Research Assistantship who, in the course of the graduate program, selects a different Advisor must renegotiate the Assistantship agreement with the old Advisor and new Advisor, in communication with the Graduate Program Coordinator.
5. All full-time faculty members in the AOE department as well as AOE-affiliate faculty members who are employees of Virginia Tech are eligible to be M.S., M.Eng., and Ph.D. candidate Advisors. Faculty members from other departments may serve as Advisors if approved by the Department Head and the AOE Graduate Committee as AOE Affiliate Faculty.

C. Selection of Advisory Committee

1. The student, in consultation with the Advisor, will identify additional candidates to serve on the Advisory Committee and invite them to serve. The advisory committee members are typically selected from the list of AOE faculty member and AOE-affiliated faculty members (see the complete list at <https://www.aoe.vt.edu/people/faculty.html>).
2. In special cases, which may occur when a student has significant research collaboration with external researchers, highly qualified persons who are not Virginia Tech faculty members may serve as Advisory Committee members, with approval of the Dean of the Graduate School and the Department Head. Graduate school approves individuals for graduate committee service on the basis of having earned the appropriate terminal degree and maintaining a record of scholarly productivity. An Advisory Committee may have at most one external committee member.
3. Committees for the M.S. and M.Eng., must satisfy the following requirements:
 - a. The Advisory Committee must consist of at least three members, at least two of whom must be AOE faculty members or AOE-affiliated faculty members. At least one committee member must be an AOE faculty member.
 - b. The Advisor (Chair) must be an AOE faculty member or AOE-affiliate faculty member who is an employee of Virginia Tech. Any AOE-affiliated faculty member or any VT faculty member can serve as a co-advisor. In rare cases, for off-campus student, an external committee member may serve as a co-advisor if the student receives regular advice for the member. (Add about process for adding non-VT)
4. Committees for the Ph.D. must satisfy the following requirements:
 - a. The Advisory Committee must consist of at least four members, at least three of whom must be AOE faculty members or AOE-affiliated faculty members. At least two committee members must be AOE faculty members.
 - b. The Advisor (Chair) must be an AOE faculty member or AOE-affiliate faculty member who is an employee of Virginia Tech. Any AOE-affiliated faculty member or any VT faculty member can serve as a co-advisor. In rare cases, for off-campus student, an external committee member may serve as a co-advisor if the student receives regular advice for the member.
 - c. The PhD Advisory Committee must have some breadth in their technical background. This is achieved by choosing the PhD Advisory Committee such that all members of the committee do not have **primary** research interest in a single area of expertise as defined in Appendix A.
 - i. Any advisory committee members from outside the AOE faculty must be assigned one primary area of expertise by the PhD Advisor. These committee members can then satisfy the breadth requirement if their primary research interest is different from the rest of the committee.

D. Duties of the Advisory Committee

The Advisory Committee's duties are to aid the student in establishing a Plan of Study and to approve the Plan of Study. Depending on the degree sought by the student, there are additional duties:

1. M.S. (Thesis) Advisory Committee members provide research guidance to the student as required, evaluate the M.S. Thesis and provide feedback, and attend, evaluate, and provide feedback during the M.S. Defense.
2. M.S. (non-thesis) and M.Eng. Advisory Committees attend the Final Examination as required by the Graduate School.
3. PhD Advisory Committee members provide (i) regular research guidance to the PhD student as the student develops their research contributions, and (ii) mentoring to the PhD student to help the student become part of the professional (academic and research) community. As described in Section VII. PATH TO PHD IN AOE, the committee has additional formal roles spanning the complete PhD program including in the:
 - a. Preliminary Examination
 - b. PhD Proposal and Plan of Research
 - c. PhD Pre-Defense
 - d. PhD Defense

In signing the Plan of Study, an Advisory Committee member commits to serve in each of these capacities. A faculty member is obligated to participate in all scheduled formal meetings of the Advisory Committee, to help support the research efforts of the student as required, and to support all activities specified in sections below.

1. The signatures of faculty members on a student's Plan of Study constitute approval of the plan by the faculty members and the indication that they are willing to serve on the student's Advisory Committee. It is the student's responsibility, however, to ensure that the plan satisfies all requirements. Any waivers of the requirements must be described in the Plan of Study and must be fully approved.
2. Every member of the Advisory Committee must approve any revision of the student's Plan of Study.

E. Plan of Study

The Plan of Study determines the student's course activities. It is important to establish a Plan of Study as early as possible to assure that, from the beginning of graduate study, all courses fit into a coherent program. Every course listed within a given Plan of Study should contribute to the student's overall educational objective.

1. Students should prepare their Plan of Study, in consultation with their Advisor(s) and Advisory Committees. Forms for the Plan of Study can be obtained from AOE Graduate Program Coordinator or from the AOE web site.
2. If an entering student's background is deficient in a technical area which the Advisory Committee considers essential for the student's program of study, the deficiency must be addressed in a manner which satisfies the Advisory Committee. This process may include formal course work to appear on the Plan of Study, additional course work that does not appear on the Plan of Study, or informal study and evaluation by the Advisory Committee.
3. All course work which appears on the Plan of Study must satisfy the following requirements when the Plan of Study is submitted and at the time of the Final Examination:

- a. Completed courses on the Plan of Study must have been taken within the previous five years.
- b. Courses yet to be taken must be completed within five years.
- c. In some cases, courses that do not satisfy these time requirements may be included on the Plan of Study through the Graduate School's Course Justification process.
4. The original Plan of Study and any subsequent revisions must be approved in the following sequence:
 - a. Advisor
 - b. Advisory Committee
 - c. AOE Graduate Program Director or Department Head
 - d. AOE Graduate Program Coordinator
 - e. Virginia Tech Graduate School
5. After all appropriate signatures (and Virginia Tech Identification Numbers for members of the Advisory Committee outside of the AOE Department) are obtained, the Plan of Study form is submitted to the AOE Graduate Program Coordinator who will submit it to the Graduate School. The Plan of Study must be submitted to the AOE Graduate Coordinator no later than the end of the second (2nd) academic semester for both Masters and PhD students. Students participating in the UG/G program, who plan to graduate in five years (four for BS plus one for MS), are encouraged to complete their Plan of study early in their fifth year.

IV. DEGREE REQUIREMENTS

A. Master of Science in Ocean Engineering Requirements: Thesis and Non-Thesis

1. A minimum of 30 credit hours is required.
 - For thesis students, up to 9 credit hours may be allotted for Research and Thesis (AOE 5994).
 - For non-thesis students, up to 6 credit hours may be allotted for Project and Report (AOE 5904).
2. A minimum of 15 credit hours (18 for non-thesis) of graded course work numbered 5000 and higher must be included in the Plan of Study. These credit hours do not include the AOE Seminar (AOE 5944), Research and Thesis (AOE 5994) hours, or Project and Report (AOE 5904) hours.
3. A maximum of 6 credit hours of 5974 and 5984 is allowed.
4. A maximum of 6 credit hours of approved 4000 level course work is allowed.
5. Up to 50% of the courses on the Plan of Study may be transferred from a graduate program at another institution, subject to the approval of the Advisory Committee. Substitution of a transferred course for a specific required course is subject to the approval of the Graduate Program Director or a designee, usually the responsible instructor. Each transferred course must have a grade of B (3.0/4.0) or better.
6. Breadth Requirement: All MS OE students are required to take at least one course each in the three disciplinary areas identified below.

Fluid Mechanics

- AOE 5104, Advanced Aero and Hydrodynamics;
- AOE 5124, Aero and Hydroacoustics;
- AOE 5144, Boundary Layer Theory;
- AOE 5304, Advanced Naval Architecture.

Dynamics and Control

- AOE 5334, Advanced Ship Dynamics;
- AOE 5444G, Advanced Dynamics of High-Speed Craft.

Structures and Materials

- AOE 5024, Vehicle Structures;
- AOE 5074, Advanced Ship Structural Analysis.

7. Math Requirement: All MS Students are required to take at least one course (of three credits or more) focused on graduate-level mathematics, statistics, or numerical methods. A sample list of courses satisfying this requirement is given in Appendix B. The MS Advisory Committee can approve other courses that have majority of their learning outcomes on advanced mathematics, statistics, or numerical methods.
8. Non-thesis MS OE students must take at least two of the following courses:

- AOE 5074, Advanced Ship Structural Analysis;
- AOE 5084, Submarine Design;
- AOE 5304, Advanced Naval Architecture;
- AOE 5314, Naval and Marine Engineering System Design;
- AOE 5324, Principles of Naval Engineering;
- AOE 5334, Advanced Ship Dynamics;
- AOE 5444G, Advanced Dynamics of High-Speed Craft.

B. Master of Science in Aerospace Engineering Requirements: Thesis and Non-Thesis

1. A minimum of 30 credit hours is required.
 - For thesis students, up to 9 credit hours may be allotted for Research and Thesis (AOE 5994).
2. A minimum of 15 credit hours (18 for non-thesis) of graded course work numbered 5000 and higher must be included in the Plan of Study. These credit hours do not include the AOE Seminar (AOE 5944), Research and Thesis (AOE 5994) hours, or Project and Report (AOE 5904) hours.
3. A maximum of 6 credit hours of 5974 and 5984 is allowed.
4. A maximum of 6 credit hours of approved 4000 level course work is allowed.
5. Up to 50% of the courses on the Plan of Study may be transferred from a graduate program at another institution, subject to the approval of the Advisory Committee. Substitution of a transferred course for a specific required course is subject to the approval of the Graduate Program Director or a designee, usually the responsible instructor. Each transferred course must have a grade of B (3.0/4.0) or better.
6. Breadth Requirement: All MS AE students are required to take at least one course each in three out of the four disciplinary areas identified below.

Fluid Mechanics

- AOE 5104, Advanced Aero and Hydrodynamics;
- AOE 5114, High Speed Aerodynamics;
- AOE 5124, Aero and Hydroacoustics;
- AOE 5135, Vehicle Propulsion;
- AOE 5144, Boundary Layer Theory.

Dynamics and Control

- AOE 5204, Vehicle Dynamics and Control;
- AOE 5744, Linear Systems Theory;
- AOE 5754, Applied Linear Systems;
- AOE 5774, Nonlinear Systems Theory;
- AOE 5234, Orbital Mechanics.

Structures and Materials

- AOE 5024, Vehicle Structures;
- AOE 5034, Mechanical and Structural Dynamics;

- AOE 5054, Stability of Structures;
- AOE 5064, Structural Optimization.

Applied Physics

- AOE 5174, Introduction to Plasma Science;
- AOE 5xxx, Advanced Spacecraft Propulsion;
- AOE 5654, Introduction to Space Science I: The Solar Wind and Magnetosphere;
- AOE 5664, Upper Atmosphere and Ionosphere;
- ECE 5194, Remote Sensing: Principles and Techniques.

7. Math Requirement: All MS Students are required to take at least one course (of three credits or more) focused on graduate-level mathematics, statistics, or numerical methods. A sample list of courses satisfying this requirement is given in Appendix B. The MS Advisory Committee can approve other courses that have majority of their learning outcomes on advanced mathematics, statistics, or numerical methods.
8. Non-thesis MS AE students must take at least two additional graduate courses in AOE. See Appendix C for suggestions of courses to take for a specialization in (i) Fluid Mechanics, (ii) Dynamics, Controls, and Estimation, (iii) Structures and Materials, and (iv) Space Engineering.

C. Master of Engineering Requirements

1. The M. Eng. degree is a non-thesis degree. However, each candidate is required to prepare a paper, the subject and outline of which must be approved by the student's Advisor and Advisory Committee. The purpose of this paper is to develop and demonstrate the student's ability to plan and carry out projects or problems relating to engineering practice. This project is carried out under the auspices of a special project (AOE 5904, Project and Report).
2. A minimum of 30 credit hours is required, of which 3-6 credit hours must be allotted for AOE 5904.
3. A minimum of 18 credit hours (including 5974 and 5984) of graded course work numbered 5000 and higher must be included in the Plan of Study.
4. A maximum of 6 credit hours of approved 4000 level course work is allowed.
5. A maximum of 6 credit hours of 5974 and 5984 is allowed.
6. Up to 50% of the courses on the Plan of Study may be transferred and are subject to approval of the Advisory Committee. Substitution of a transferred course for a specific required course is subject to the approval of the Graduate Program Director or a designee, usually the responsible instructor. Each transferred course must have a grade of B (3.0/4.0) or better.
7. All M. Eng. candidates are required to take:
 - AOE 5404, Applied Numerical Methods;
 - AOE 5104, Advanced Aero-Hydrodynamics;
 - AOE 5024, Vehicle Structures;

- AOE 5204, Vehicle Dynamics and Control; and
 - One additional AOE graduate course. If a student has previously taken, while an undergraduate or student elsewhere, any of the specific required AOE courses above or equivalent, that course must be replaced with another AOE graduate course acceptable to the Advisory Committee. A student will not be allowed to repeat a course from Virginia Tech or one that is equivalent from another institution for a grade.
8. The project described in requirement (1) may be carried out in conjunction with other students in the same program (e.g., a design project with several students of varied interests).

D. Doctor of Philosophy Requirements (beyond B.S.)

1. A minimum of 90 credit hours beyond the B.S. degree are required.
2. A minimum of 30 hours of Research and Dissertation (AOE 7994) must be included on the Plan of Study. All Ph.D. students must register for dissertation credit in accordance with the amount of time devoted to dissertation research. For example, a full-time research load would be 12 credit hours of dissertation credit, and would require a minimum of 40 hours per week of work devoted to research.
3. A minimum of 30 credit hours of graded course work numbered 5000 or above must be included. Up to 6 credit hours of 4000-level course work is allowed if approved by the PhD Advisory Committee.
4. A maximum of 9 credit hours of Independent Study (5974) and Special Study (5984) may be included.
5. A minimum of two consecutive semesters of full-time enrollment must be spent in residence at the Blacksburg campus (or with prior approval at some designated off-campus graduate center).
6. Up to 15 credits of course work on the Plan of Study may be transferred from another university and is subject to the approval of the PhD Advisory Committee. Each transferred course must, (i) have a grade of B (3.0/4.0) or better, (ii) have been earned while in good standing in graduate status, and (iii) have been graduate courses at the institution where the student took the courses. Courses that are double-counted for both an undergraduate and graduate degree for students in Virginia Tech's UG/G Program are subject to the grade requirements for transfer courses.
7. All Ph.D. candidates are required to have taken or be enrolled in all of the courses on the Plan of Study by the semester in which the student presents the PhD Pre-defense.
8. AOE Course Requirement: All PhD candidates are required to take at least six AOE Courses. All graduate courses with an AOE number are considered AOE courses. Any graduate course taught by an AOE faculty will also be considered an AOE course for this requirement. All courses on the list of Breadth courses (see below) can count towards both the AOE Course Requirement and the Breadth Requirement.
 - a. Students may use transfer courses to satisfy this requirement. Substitution of a transferred course for a specific AOE course from the graduate course catalogue is subject to the approval of the Graduate Program Director on the recommendation

of the responsible instructor. The student may request that a transfer course not listed in the graduate course catalogue be used to satisfy an AOE course requirement if the course is typically taught in an Aerospace or Ocean Engineering program. The Graduate Program Director will approve it on the recommendation of the PhD Advisory Committee.

9. Breadth Requirement: All PhD candidates are required to take at least one course each in three out of the four disciplinary areas identified below.
 - a. The student must have taken or be enrolled in at least two of the three disciplinary breadth courses by the semester in which the student takes the PhD Preliminary Examination.
 - b. Students may use transfer courses to satisfy this requirement. Substitution of a transferred course for a specific course listed below is subject to the approval of the Graduate Program Director on the recommendation of the responsible instructor. The student may request that a transfer course not listed below be used to satisfy a breadth requirement if the course is transferred from an Aerospace or Ocean Engineering program and primarily covers the breadth area. The Graduate Program Director will approve it on the recommendation of the AOE Graduate Committee.

Fluid Mechanics

Sample course list:

- i. AOE 5104, Advanced Aero and Hydrodynamics;
- ii. AOE 5114, High Speed Aerodynamics;
- iii. AOE 5124, Aero and Hydroacoustics;
- iv. AOE 5135, Vehicle Propulsion;
- v. AOE 5144, Boundary Layer Theory;
- vi. AOE 5304, Advanced Naval Architecture.

Dynamics and Control

Sample course list:

- i. AOE 5204, Vehicle Dynamics and Control;
- ii. AOE 5744, Linear Systems Theory;
- iii. AOE 5754, Applied Linear Systems;
- iv. AOE 5774, Nonlinear Systems Theory;
- v. AOE 5234, Orbital Mechanics;
- vi. AOE 5334, Advanced Ship Dynamics;
- vii. AOE 5444G, Advanced Dynamics of High-Speed Craft.

Structures and Materials

Sample course list:

- i. AOE 5024, Vehicle Structures;
- ii. AOE 5034, Mechanical and Structural Dynamics;
- iii. AOE 5054, Stability of Structures;
- iv. AOE 5064, Structural Optimization;
- v. AOE 5074, Advanced Ship Structural Analysis.

Applied Physics

Sample course list:

- i. AOE 5174, Introduction to Plasma Science;
- ii. AOE 5xxx, Advanced Spacecraft Propulsion;
- iii. AOE 5654, Introduction to Space Science I: The Solar Wind and Magnetosphere;
- iv. AOE 5664, Upper Atmosphere and Ionosphere;
- v. ECE 5194, Remote Sensing: Principles and Techniques.

10. Math Requirement: All PhD candidates are required to take at least one course (of three credits or more) focused on graduate-level mathematics, statistics, or numerical methods. A sample list of courses satisfying this requirement is given in Appendix B. The PhD Advisory Committee can approve other courses (including transfer courses) that have majority of their learning outcomes on advanced mathematics, statistics, or numerical methods.

V. MASTER OF SCIENCE PROCEDURES

The policies and procedures given below apply to both on-campus and off-campus graduate students and are intended to aid the student in working more effectively toward a degree under the supervision of the Advisor and Advisory Committee.

A. Master of Science Thesis

1. Proposal: Each graduate student working toward the M.S. (with thesis) degree is encouraged to write a short (around 3 pages without figures) research proposal stating the subject and general objectives of the proposed degree research. A prospective committee member may require the proposal before agreeing to serve.
2. Thesis Registration.
 - a. All thesis M.S. students must register for thesis credit in accordance with the amount of time devoted to thesis or dissertation research. For example, a full-time research load would be 12 credit hours of thesis or dissertation credit, and would require a minimum of 40 hours per week of work devoted to research.
 - b. Students are required to register for thesis credit in accordance with that fraction of time devoted to research, regardless of the total thesis hours accumulated.
3. Final Review of Thesis. The student must have an Advisor-approved draft copy of the thesis or dissertation in the hands of each member of the MS Advisory Committee at least two weeks before the scheduled Final Examination for the M.S. degrees. Failure to comply with this requirement will likely delay the Final Examination.
4. Requirements for thesis preparation can be found at the following link: <http://etd.vt.edu>.

B. Master of Science Final Examination

Master of Science Final Examination is scheduled through the Graduate School at <https://ess.graduateschool.vt.edu>. The request to schedule the examination must include the time, date, building and room number, title of the MS thesis (for students completing a MS Thesis), and the names and signatures of the MS Advisory Committee. The request is due in the Graduate School at least two weeks before the examination date requested.

1. Each candidate is required to pass an oral Final Examination administered by the MS Advisory Committee.
 - a. For the M.S. with thesis, the requirement includes a public presentation of the thesis. That presentation is followed immediately by a closed oral examination, which is primarily a thesis defense.
 - b. For the M.S. without thesis, the examination is a comprehensive exam closed to the public. The format of the examination is at the discretion of the Advisory Committee.
2. On the basis of the candidate's performance in the examination (and the quality of the thesis, if appropriate), the MS Advisory Committee will determine whether the student has passed or failed.

- a. A majority vote of the examining committee is required for the candidate to pass. In this event, the committee may, at its discretion, require minor thesis revisions and/or inform the candidate of areas of weakness revealed by the examination.
- b. If the MS Advisory Committee decides that the candidate has failed the examination, it shall recommend:
 - i. When the examination may be repeated (at least one semester, or 15 weeks, later).
 - ii. If necessary, major thesis revisions, and additional research and/or course work.

VI. MASTER OF ENGINEERING PROCEDURES

The policies and procedures given below apply to both on-campus and off-campus graduate students and are intended to aid the student in working more effectively toward a degree under the supervision of the Advisor and Advisory Committee.

A. Master of Engineering Report

1. Proposal: Each graduate student working toward the M.Eng. degree is encouraged to write a short (around 3 pages without figures) project proposal stating the subject and general objectives of the proposed project. A prospective committee member may require the proposal before agreeing to serve.
2. A final draft copy of the project report must be in the hands of each member of the Advisory Committee at least one week before the scheduled final examination for the M. Eng. degree. If a student report is part of a larger report submitted by several students, the entire report must be submitted to the Advisory Committee for each student involved.
3. Requirements for report preparation are the same as those for thesis or dissertation preparation, and can be found at the following link: <http://etd.vt.edu>. The final report should be uploaded to <https://vtechworks.lib.vt.edu> and the link provided to the Graduate Program Coordinator.

B. Master of Engineering Final Examination

Master of Engineering Final Examination is scheduled through the Graduate School at <https://ess.graduateschool.vt.edu>. The request to schedule the examination must include the time, date, building and room number, and the names and signatures of the MEng Advisory Committee. The request is due in the Graduate School at least two weeks before the examination date requested.

1. Each candidate is required to pass a comprehensive oral Final Examination (closed to the public) administered by the Advisory Committee. Presentation of the project report is part of the examination.
2. On the basis of the candidate's performance in the examination and the quality of the project report, the Advisory Committee will determine whether the student has passed or failed.
 - a. A majority vote of the examining committee is required for the candidate to pass. In this event, the committee may, at its discretion, require minor revisions in the project report and/or inform the candidate of weaknesses revealed by the examination.
 - b. If the Advisory Committee decides that the candidate has failed the examination, it shall recommend:
 - a. When the examination may be repeated (at least one semester, or 15 weeks, later);
 - b. If necessary, major revisions of the project report, and additional project and/or course work.

VII. Path to PhD in AOE

The policies and procedures given below apply to both on-campus and off-campus graduate students and are intended to aid the student in working more effectively toward a degree under the supervision of the Advisor and the PhD Advisory Committee. The key assessment steps in the Path to PhD are the Preliminary Examination, the Proposal and Plan of Research, the Pre-Defense, and the Defense (Final Examination).

A. Preliminary Examination

To assess a student's fundamental disciplinary knowledge and potential to complete a defensible doctoral dissertation in a reasonable time and with reasonable mentorship, each PhD student must take a Preliminary Examination no later than the third semester of their PhD program. To be eligible, the student's GPA, based on the courses in the Plan of Study must be 3.0 or greater and the student must have a properly formulated PhD Advisory Committee and have filed an approved Plan of Study. The student must have taken or be enrolled in at least two of the three disciplinary breadth courses by the semester in which the student takes the examination. The process for the examination is as follows:

1. The PhD Preliminary Examination can be taken at any point during the semester that is mutually agreed upon by the student and the PhD Advisory Committee. The examination is scheduled through the Graduate School at <https://ess.graduateschool.vt.edu>. The request to schedule the examination must include the time, date, building and room number, and the names and signatures of the committee. The request is due in the Graduate School at least two weeks before the examination date requested.
2. The PhD Advisory Committee will choose an Examination Chairperson other than the PhD Advisor.
3. The student will provide a short written technical document to the PhD Advisory Committee at least four weeks before the exam date. This document is intended to provide technical context for the exam. It will not be formally assessed by the committee. The student may consult with the advisor to develop this initial document and may use the student's existing research abstract or paper if suitable material exists.
4. The Examination Chairperson will provide the student one or two relevant paper(s), related to the technical document, within a week. The Examination Chairperson will also provide a cover letter establishing expectations for the student's independent study and for the subsequent oral examination. The student will study the provided paper(s), and any additional related papers chosen by the student, in order to understand and evaluate the papers' contributions in the context of the student's prior coursework.
5. The student will prepare an independent study report (around five pages, excluding figures) describing the student's independent study, and submit this document to the PhD Advisory Committee within two weeks of receiving the assigned papers. The report should summarize the work(s), identifying strengths and weaknesses of the contribution(s) with supporting analysis. The report must be prepared independently by the student (i.e., without input from the advisor or others). A copy of the report is filed with the AOE Graduate Program Coordinator.

6. The student also prepares a presentation summarizing the independent study. The presentation should take 10-20 minutes (not including the time required to answer questions from the committee). The presentation must also be prepared independently.
7. During the presentation, the PhD Advisory Committee members will ask the student questions on the assigned paper(s), student's report, and student's presentation, and will include questions on related fundamental disciplinary concepts.
8. The Preliminary Examination involves the PhD Advisory Committee's assessment of the independent study report, the oral presentation on the scheduled exam date, and the student's response to questions from the committee either during the oral presentation or in the question and answer portion of the oral exam. An assessment rubric for the examination will be provided to the students.
9. The Examination Chairperson collects the committee feedback based on the assessment rubric and provides a copy to the Graduate Program Coordinator. The Examination Chairperson also creates a summary of the committee feedback and provides the feedback to the student and the PhD Advisor. For the student to pass the Preliminary Examination, there must be no more than one negative vote.
10. A student who fails the Preliminary Examination on their first attempt will be allowed to retake the examination once in the following semester.

B. PhD Proposal and Plan of Research

To ensure the PhD topic and plan are feasible, technically sound, and qualify as PhD-Dissertation-level research, each PhD student will present a PhD Proposal to the PhD Advisory Committee no later than two semesters after the Preliminary Examination. The proposal can be presented at any point during the semester that is mutually agreed upon by the student and the committee. The proposal will consist of a written document and a presentation.

1. Written document shall consist of the following:
 - i. preliminary literature review and background summary, and may include any preliminary research by the student;
 - ii. a proposal overview (around 10 pages, excluding figures) to identify gaps in the current literature, proposed work in the context of these gaps, research methods, expected results, potential impact of the work, a timeline, and risk mitigation plans; and
 - iii. a one-page proposal summary, including schedule and tentative research products, to serve as the first draft of the Plan of Research.

The written document will be given to the PhD Advisory Committee two weeks prior to the scheduled presentation. The student can consult with their advisor in formulating the proposal details.

2. During the presentation (20-30 minutes, not including questions), the PhD Advisory Committee will:
 - i. review and assess the student's research goals, timelines, and methods;
 - ii. review and assess the student's progress in research tasks to date, including adequacy of preliminary results; and
 - iii. provide guidance to the student concerning the proposed research program, based on these assessments.

3. An amended one-page proposal summary document, updated after the PhD Proposal presentation, will serve as the Plan of Research to guide further work. Like the Plan of Study, a copy of the Plan of Research is provided to the Graduate Program Coordinator and can be updated as needed with committee approval.

C. PhD Pre-defense

To ensure the student's plan for completing their PhD Dissertation meets the PhD Advisory Committee's expectations, each PhD student will present a PhD Pre-defense no later than four months before the expected final defense. The student must have taken or be enrolled in all of the courses on the Plan of Study by the semester in which the student presents the pre-defense. The pre-defense can be presented at any point during the semester that is mutually agreed upon by the student and the committee. The pre-defense will consist of a written document and a presentation.

1. The student must provide a legible draft of the PhD Dissertation to the PhD Advisory Committee at least two weeks prior to the scheduled pre-defense. The draft dissertation must:
 - i. be at least 70% complete, based on the work described in the PhD Plan of Research;
 - ii. include the complete introduction, literature survey, background, and technical details;
 - iii. include some final results, explicitly stating the novel contributions;
 - iv. describe any remaining work that is planned and the expected outcomes; and
 - v. report the status of any archival publications to be included in the final version. A typical draft dissertation would describe at least two major research products (each corresponding, for example, to a publication) as well as all front and end matter.
2. The student must provide a concise presentation (30-45 minutes) to the PhD Advisory Committee describing current research results, continuing research plans, and the dissertation status. The presentation should include a one-slide summary of
 - i. the student's archival publications;
 - ii. the status of the dissertation;
 - iii. any pending experiments, simulations, analysis, etc.; and
 - iv. a schedule for completing the remaining work.
3. The PhD Advisory Committee will consider the student's research progress, in the context of the original/updated PhD Plan of Research, and will provide guidance concerning the ongoing research program and the proposed timeline. The committee will also approve any changes to the Plan of Research necessary at this time.

D. PhD Defense (Final Examination)

Each PhD student is required to take an oral Final Examination which is the Defense of the PhD Dissertation.

1. The PhD Defense is scheduled through the Graduate School at <https://ess.graduateschool.vt.edu>. The request to schedule the examination must include the time, date, building and room number, title of the PhD Dissertation, and the

names and signatures of the PhD Advisory Committee. The request is due in the Graduate School at least two weeks before the examination date requested.

2. A complete PhD Dissertation Document (following Graduate School guidelines) must be provided to the PhD Advisory Committee in its final form at least 2 weeks before the Defense. Furthermore, the document must be uploaded to the Graduate School exam portal and checked for similarity. Requirements for dissertation preparation can be found at the following link: <http://etd.vt.edu>.
3. The final examination will be conducted by the PhD Advisory Committee and will include a presentation of the dissertation research by the candidate and a questioning period, both open to the public (following Graduate School guidelines). Subsequently a closed-door oral examination is conducted by the Advisory Committee.
4. The PhD Advisory Committee may suggest corrections to be incorporated into a revised version of the dissertation to be approved in accordance with the Graduate School (i.e. in the ETD approval portal).
5. On the basis of the Final Examination, quality of PhD Dissertation and the candidate's overall academic record, the examining committee will make a recommendation as to the acceptance of the PhD Dissertation and the awarding of the Ph.D. degree. For the candidate to pass, there must be no more than one negative vote.

VIII. FINAL PROCEDURES

1. An application for degree must be submitted on HokieSpa on or before October 1st for a Fall degree completion date or March 1st for a Spring degree completion date.
2. At least three weeks prior to the final exam, the student must submit the request to be admitted to the final exam to the Graduate School. Students must be registered for at least three credit hours in the semester they plan to complete the final examination or defense. If the final examination or defense is to take place near the beginning of a new term, a candidate may apply for Start-of-Semester Defense Exception (SSDE) which allows them to register for only one credit. The form is available on graduate school website and must be submitted to the Graduate School at least three weeks prior to the date of the final exam.
3. Final fees are charged to the student's account by the University Bursar once the form(s) have been submitted. Fees must be paid in full in order for a student's degree to be awarded.
4. The final examination card is available in the final exam system to the student's Advisor prior to the day of the examination. The card must be electronically signed by the Advisory Committee and submitted to the Graduate School immediately following the examination.
5. Required examinations are administered during regular academic semesters or sessions, i.e., between the first day of classes for a given semester or session and ending with the last official day for examinations. Permission to schedule an examination in the time between sessions may be granted if an explanation of special circumstances requiring that scheduling is made to the Dean's office of the Graduate School by the student's Advisor. Scheduling of examinations between semesters/terms does not alter ETD submission or approval deadlines. If a student is unable to complete all requirements by the ETD submission or approval deadlines, the student will be required to submit the SSDE Request Form to defend in the following term.
6. A final version of the thesis or dissertation must be uploaded to the Graduate School system in PDF form (<http://etd.vt.edu>) within two weeks after the final examination. The ETD is electronically approved by the PhD Advisory Committee in the graduate school system.
7. Each student is encouraged to publish the thesis or dissertation. However, such plans should be discussed with the student's Advisor with particular attention given to authorship, procedure, and journal of interest.

IX. CONTINUOUS EVALUATION OF THE PROGRESS OF GRADUATE STUDENTS

1. Graduate student grades are reviewed each academic term by the AOE Graduate Committee, the Department Head, and the Graduate School. Students whose graduate GPA falls below 3.0 are warned that they are performing below the acceptable standard and must improve. Normally, students are allowed one semester in which to raise their GPA to 3.0 before any formal action is taken. If adequate improvement is not made during this grace period, students may be dropped from the degree program, depending upon the severity of academic deficiency.
2. The work performance of each student supported on a Graduate Assistantship is reviewed each academic term by the student's Advisor and, if necessary, by the Department Head. If the performance has been substandard, then the student may be warned that improvement is required, or, if circumstances warrant, the student may lose the Assistantship.

X. ATTENDANCE AT DEPARTMENTAL LECTURES

1. The AOE Department has a regularly scheduled Graduate Seminar (AOE 5944). Resident AOE graduate students who are enrolled for at least 9 credit hours are required, in addition, to register for this one credit seminar each semester and to attend the weekly lectures. This seminar includes presentations by students, faculty, and visiting lecturers. The seminar serves the graduate student by broadening the student's background, improving the perspective on engineering research, and informing the student of the types of work in progress in government, industry, here and at other universities. The seminar is a pass-fail course whose only requirement is to attend the lectures. In order to pass, a student may miss no more than three lectures in a semester. In exceptional circumstances, a faculty Advisor may excuse a student's absence by notifying the faculty member organizing the seminar course.
2. Every AOE graduate student completing an M.S. degree with thesis or a Ph.D. dissertation makes a public presentation of the research. Although some of these presentations may be given at the Graduate Seminar, many are not. AOE graduate students are strongly encouraged to attend as many of these degree research presentations as possible.

APPENDIX A

Faculty Area of Expertise for establishing technical breadth in a PhD Advisory Committee

1. Fluid Mechanics

Primary Faculty: Alexander, Brizzolara, Choi, Coutier-Delgosha, Devenport, Lowe, Paterson, Pitt, Raj, Roy, Schetz, Xiao, Young

Secondary Faculty: Adams, Gilbert, Massa, Patil, Srinivasan, Wang

2. Dynamics and Control

Primary Faculty: Black, Farhood, Joerger, Psiaki, Ross, Sultan, Woolsey

Secondary Faculty: Brizzolara, Patil, Philen

3. Structures and Materials

Primary Faculty: Canfield, Gilbert, Kapania, Patil, Philen, Seidel, Wang

Secondary Faculty: Pitt, Black, Sultan

4. Applied Physics

Primary Faculty: Adams, England, Massa, Srinivasan

Secondary Faculty: Lowe, Paterson, Pitt

APPENDIX B

Sample of approved courses focused on Mathematics, Statistics, or Numerical Methods:

1. AOE 5404, Applied Numerical Methods;
2. AOE 5434G, Advanced Introduction to Computational Fluid Dynamics;
3. AOE 5734, Convex Optimization;
4. AOE 6145, Computational Fluid Dynamics;
5. AOE 6174, Computational Plasma Dynamics;
6. AOE 6314, Advanced Dynamics;
7. AOE 6444, Verification and Validation in Scientific Computing;
8. ESM 5734, Introduction to the Finite Element Method;
9. ESM 5744, Energy and Variational Methods in Applied Mechanics;
10. ESM 6714, Applied Tensor Analysis;
11. ESM 6734, Finite Element Analysis;
12. MATH 5225, Real Analysis
13. MATH 5235, Complex Analysis;
14. MATH 5424, Numerical Linear Algebra;
15. MATH 5425, Applied Partial Differential Equations;
16. MATH 5465, Numerical Analysis;
17. MATH 5474, Finite Difference Methods for Partial Differential Equations;
18. MATH 5484, Finite Element Methods for Partial Differential Equations;
19. STAT 5044, Regression and Analysis of Variance;
20. STAT 5104, Probability and Distribution Theory;
21. STAT 5434, Applied Stochastic Processes;
22. STAT 5444, Bayesian Statistics;
23. STAT 5525, Data Analytics;
24. STAT 5616, Statistics in Research;
25. STAT 5664, Applied Statistical Time Series Analysis for Research Scientists.

APPENDIX C

Sample List of Courses for MS AE Specializations

Fluid Mechanics

This area is concerned with the determination of forces and moments caused by the motion of an aerospace or ocean vehicle through a liquid or gaseous medium, and with the nature of the flow field around the vehicle and in its wake. This determination ranges from very low subsonic speeds through the speed of sound (transonic) to supersonic and hypersonic speeds. Both inviscid and viscous flow phenomena are significant. In addition, the study of internal flow fields associated with propulsion is a subset of this area.

Sample course list:

- AOE 5024, Vehicle Structures
- AOE 5104, Advanced Aero and Hydrodynamics
- AOE 5114, High Speed Aerodynamics
- AOE 5124, Aero and Hydroacoustics
- AOE 5135, Vehicle Propulsion
- AOE 5144, Boundary Layer Theory
- AOE 5204, Vehicle Dynamics and Control
- AOE 5404, Applied Numerical Methods
- AOE 5434G, Advanced Introduction to Computational Fluid Dynamics

Dynamics, Control and Estimation

The area of dynamics involves dynamic modeling and analysis for space, atmospheric, and ocean vehicles. The area of control and estimation involves the development and application of methods for vehicle guidance, navigation, and control.

Sample course list:

- AOE 5024, Vehicle Structures
- AOE 5104, Advanced Aero and Hydrodynamics
- AOE 5204, Vehicle Dynamics and Control
- AOE 5744, Linear Systems Theory
- AOE 5754, Applied Linear Systems
- AOE 5774, Nonlinear Systems Theory
- AOE 5234, Orbital Mechanics
- AOE 5404, Applied Numerical Methods
- AOE 5734, Convex Optimization

Structures and Materials

This area involves development and application of methods for design and evaluation of aerospace and ocean structures. Principal subjects of study are structural analysis, computational mechanics, structural optimization, composite structures, smart structures,

structural health monitoring, material science, machine learning, and multi-disciplinary analysis and optimization.

Sample course list:

- AOE 5024, Vehicle Structures
- AOE 5034, Mechanical and Structural Dynamics
- AOE 5054, Stability of Structures
- AOE 5064, Structural Optimization
- AOE 5104, Advanced Aero and Hydrodynamics
- AOE 5204, Vehicle Dynamics and Control
- AOE 5404, Applied Numerical Methods
- ESM 5734, Introduction to the Finite Element Method
- ESM 5744, Energy and Variational Methods in Applied Mechanics

Space Engineering

This area is concerned with the multidisciplinary application of Aerospace, Electrical, Mechanical, and Systems Engineering (among others) to the development of advanced space instrumentation, vehicles, constellations, and space exploration systems.

Sample course list:

- AOE 5024, Vehicle Structures
- AOE 5104, Advanced Aero and Hydrodynamics
- AOE 5174, Introduction to Plasma Science
- AOE 5204, Vehicle Dynamics and Control
- AOE 5234, Orbital Mechanics
- AOE 5404, Applied Numerical Methods
- AOE 5654, Introduction to Space Science I: The Solar Wind and Magnetosphere
- AOE 5664, Upper Atmosphere and Ionosphere
- AOE 5xxx, Advanced Spacecraft Propulsion