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For additional information, please visit the AFIT website, www.afit.edu, or call:

Commercial: 937-255-3069
DSN: 785-3069
## CONTENTS

PREFACE ................................................................................................................................. 9  
Chapter 1 : Introduction ............................................................................................................. 11  
Chapter 2 : Admission and Registration Procedures ................................................................. 15  
  2.1 Admission to AFIT .................................................................................................................. 15  
  2.2 Department of Aeronautics and Astronautics Program Admission Requirements .............. 16  
  2.3 Part-Time Master’s Degree Program ...................................................................................... 17  
  2.4 Course Registration and Credit .............................................................................................. 17  
Chapter 3 : Degree and ABET Requirements ............................................................................. 19  
  3.1 General MS Degree Requirements ....................................................................................... 19  
  3.2 ABET Requirements .............................................................................................................. 20  
Chapter 4 : Program Guide ......................................................................................................... 21  
  4.1 Graduate Aeronautical Engineering (GAE) ........................................................................... 21  
    4.1.1 Introduction ...................................................................................................................... 21  
    4.1.2 Program Educational Objectives ...................................................................................... 21  
    4.1.3 Student Outcomes ............................................................................................................ 22  
    4.1.4 Program Elements ........................................................................................................... 22  
    4.1.5 Sample Program—18 Month GAE Thesis Student .............................................................. 26  
    4.1.6 Special Programs .............................................................................................................. 28  
      4.1.6.1 Air Force Joint AFIT/Test Pilot School (TPS) Programs ............................................... 28  
  4.2 Graduate Astronautical Engineering (GA) ............................................................................. 31  
    4.2.1 Introduction ...................................................................................................................... 31  
    4.2.2 Program Educational Objectives ...................................................................................... 31  
    4.2.3 Program Outcomes ........................................................................................................... 31  
    4.2.4 Program Elements ........................................................................................................... 32  
    4.2.5 Sample Program—18 Month GA Thesis Student ............................................................... 36  
  4.3 Graduate Space Systems (GSS) ............................................................................................. 38  
    4.3.1 Introduction ...................................................................................................................... 38  
    4.3.2 Program Educational Objectives ...................................................................................... 38  
    4.3.3 Program Outcomes ........................................................................................................... 38  
    4.3.4 Program Elements ........................................................................................................... 39  
    4.3.5 Degree Options ............................................................................................................... 42  
    4.3.6 Sample Program—18 Month GSS Thesis Student .............................................................. 44  
  4.4 Graduate Certificate Program in Space Systems .................................................................... 46  
    4.4.1 Introduction ...................................................................................................................... 46  
    4.4.2 Program Educational Objectives ...................................................................................... 46  
  4.5 Graduate Materials Science (GMS) ....................................................................................... 47  
    4.5.1 Introduction ...................................................................................................................... 47  
    4.5.2 Program Educational Objectives ...................................................................................... 47  
    4.5.3 Program Outcomes ........................................................................................................... 47  
    4.5.4 Program Elements ........................................................................................................... 48  
    4.5.5 Administrative ................................................................................................................ 50  
    4.5.6 Sample Program—18 Month GMS Thesis Student .............................................................. 51  
Chapter 5 : Resident PhD Program ............................................................................................. 53  
  5.1 Introduction ............................................................................................................................ 53  
  5.2 Admission Criteria ................................................................................................................. 54
PREFACE

The Department of Aeronautics and Astronautics, Air Force Institute of Technology (AFIT) provides educational expertise (through the doctoral level) in Aeronautical Engineering, Astronautical Engineering, Materials Science, Space Systems, Mechanical Engineering, and Engineering Mechanics. The major departmental effort is devoted to teaching and research in support of programs leading to the Master's degree in the first four of these program areas and Doctoral studies in any area of departmental activity. The Master of Science programs in Aeronautical Engineering and Astronautical Engineering are accredited by the Accreditation Board for Engineering and Technology (ABET). The North Central Association of Colleges and Universities accredits all other Master’s-level degree programs.

This brochure provides an introduction to the Department of Aeronautics and Astronautics, AFIT. It is intended to serve as a guide for students and faculty advisors in the preparation of education plans for graduate study in Aeronautical Engineering, Astronautical Engineering, Materials Science, and Space Systems.

The requirements and curricula specified in this edition of the brochure apply to all full-time students and to all part-time students admitted to the Master’s-level degree programs in Aeronautical Engineering (GAE), Astronautical Engineering (GA), Materials Science (GMS), and Space Systems (GSS) during the period of 1 May 2018 to 30 April 2019. Course descriptions and schedules are also provided in this brochure. Additional information on courses, programs, and admissions may be found in the AFIT catalog and the applicable departmental and program brochures.

Further questions regarding the departmental Master’s-level degree programs should be referred to the Department of Aeronautics and Astronautics, AFIT/ENY, as indicated below:

Mail: AFIT/ENY
2950 HOBSON WAY
WRIGHT-PATTERSON AFB, OH 45433-7765

Phone: Commercial: (937) 255-3069 or DSN: 785-3069

Office: Bldg 640, Room 349
(AFIT Graduate School of Engineering and Management)
CHAPTER 1: INTRODUCTION

The graduate program in Aeronautical Engineering was initiated in September of 1951. Since the passage of Public Law 733 by the 83rd Congress (1954), degrees have been authorized for conferral by the Commander of Air University on persons who meet all requirements established by the Air Force Institute of Technology. Programs within the Institute were first accredited by the Engineer's Council for Professional Development (ECPD) in 1955. The North Central Association of Colleges and Schools now accredits the Institute through the doctoral level. The Graduate School of Engineering and Management's program in Graduate Systems Engineering was the first one in the country that was accredited at the advanced level by the Accreditation Board for Engineering and Technology (ABET, formerly ECPD). Programs in Graduate Astronautical Engineering and in Graduate Aeronautical Engineering are also accredited by ABET. The programs in Graduate Space Systems and Materials Science are accredited through the North Central Association of Colleges and Schools.

At one time, the resident School of Engineering contained the Department of Mechanical Engineering, the Department of Aeronautical Engineering, and the Mechanics Department. In 1969, these were reorganized into two departments: the Aero-Mechanical Department, which emphasized various aspects of the mechanics of fluids (e.g., aerodynamics, heat transfer, propulsion, and fluidics) and the Department of Mechanics, which emphasized solid mechanics, aircraft structures, astrodynamics, and flight vehicle mechanics. A systems engineering activity was added to the Department of Mechanics in the 1970s. In 1977, these two departments were merged into the present single entity. This placed administrative control for three related curricula in aeronautics, astronautics, and systems engineering in the single department. In 1995, responsibility for the Space Operations Program was transferred to the department. In 2001, the department added the Aerospace and Information Operations Program. In 2002, a decision was made by the SECAF and the SECNAV to close the Aeronautical Engineering Department of the Naval Post Graduate School and begin sending all naval officers that require graduate education in aeronautical engineering to AFIT. The first naval officers to participate in that program took courses in the winter of 2003. In 2002, a decision was made by SECAF and CSAF to send some Air Force Majors selected as candidates for intermediate service school to AFIT for a Master’s degree and professional military education in-residence credit. Therefore, the Department of Aeronautics and Astronautics has developed a new graduate program in Systems Engineering (with specializations in Airborne Systems, C4ISR Systems, and Space Systems) to accommodate the Intermediate Development Education (IDE) (formerly Intermediate Service School) students. In 2003, the department combined the Space Operations and Aerospace with Information Operations Programs into the Space Systems Program. In 2007, the Systems Engineering programs were transferred to the Department of Systems and Engineering Management.

The programs of the resident Graduate School of Engineering and Management are a significant factor in graduate education in aeronautical and astronautical engineering in the United States. This scale of operation enables students in the resident Graduate School of Engineering and Management to select from a wider variety of courses and research topics than would be
available in smaller institutions. No programs leading to degrees in mechanical engineering or engineering mechanics are currently available, but students with interest in these disciplines may pursue them as a concentration within the Aeronautical Engineering Program.

The mission of AFIT’s Department of Aeronautics and Astronautics is to provide high-quality aerospace graduate education and to conduct world-class defense-focused research. The vision of the department is to achieve national recognition as the premier aerospace engineering department for producing defense-focused graduates and research.

Three major areas of expertise can be identified within the Department. These are: (1) Fluid Mechanics and Energy Transmission, (2) Solid Mechanics and Structures, and (3) Dynamics, Systems, and Controls.

(1) The Fluid Mechanics and Energy Transmission Division provides courses and opportunities for research in aerodynamics (compressible, incompressible, viscous and computational), propulsion (air-breathing, rocket, non-chemical, and alternative energy), and heat transfer (convection, conduction, and radiation).

(2) The Solid Mechanics and Structures Division provides course offerings and research programs covering such topics as applied mechanics (elasticity, plasticity, and continuum mechanics), structures (stability, shells, and finite element methods), structural dynamics (mechanical vibrations, wave propagation, and aeroelasticity), and structural materials (fracture mechanics, composite materials, and fatigue).

(3) The Dynamics, Systems, and Controls Division provides courses and research activities in aircraft flight mechanics (performance, stability, and control), astrodynamics (orbital mechanics and optimal trajectories), spacecraft attitude dynamics, systems (design and modeling of large scale systems, and weapons analysis), and robotics (manipulators, remote systems, and man-in-the-loop control).

As is true of the entire resident school, the faculty of the Department is approximately 50 percent military and 50 percent civilian. Approximately 10 percent of the AFIT students are officers from other services or allied countries or civilians.

Full-time programs leading to the Master of Science degree are typically six quarters long. Each student entering the department is assigned a class advisor who provides counseling in the selection of courses and in research opportunities within the department. The student selects a research topic and thesis advisor in the 2nd quarter and from that point on is expected to work closely with that member of the faculty both in research and in finalizing the plan of study.

Part-time students seeking a Master’s degree are advised by a single member of the department to become a candidate in one of the degree programs and to select a thesis advisor. From that point on, the thesis advisor guides the thesis research and recommends courses for the student. In administrative matters, the class advisor oversees the progress of the student throughout the program.
An advisory committee is appointed to assist each doctoral student in planning a program of study and developing a research area.

Each curriculum within the department is developed, monitored, and evaluated by a curriculum committee, selected by the department head. These committees provide the means for developing modifications in course offerings and research opportunities needed to support curricular requirements, and conversely, to provide the mechanism whereby developments in the sub-disciplines can be quickly reflected in curricular changes. The school and academic departments are headed by the Dean of the Graduate School of Engineering and Management and the department heads, respectively. The Department of Aeronautics and Astronautics has the following Master of Science (MS) degree programs:

**Aeronautics and Astronautics (AFIT/ENY)**
-- Graduate Aeronautical Engineering (GAE)
-- Graduate Astronautical Engineering (GA)
-- Graduate Materials Science (GMS - with ENP)
-- Graduate Space Systems (GSS)

Administrative processes for the institute are provided in AFIT Instructions (AFIT-I). Processes specific to the Graduate School of Engineering and Management are laid out in a series of EN Operating Instructions (ENOI). These ENOIs cover a wide variety of topics in detail and are referenced in this document. The ENOIs are available on the AFIT Intranet.
CHAPTER 2: ADMISSION AND REGISTRATION
PROCEDURES

2.1 Admission to AFIT

United States citizens wishing to attend graduate-level classes at AFIT, whether full-time or part-time, must first be admitted to the Graduate School of Engineering and Management. General requirements for admission are explained in the AFIT Catalog and on the AFIT web page. The application itself can be completed on-line at the AFIT web site. With the exception of officers in selected foreign military service who are sponsored by their government, foreign nationals are not eligible to attend AFIT and will not be admitted.

Air Force personnel seeking an assignment to AFIT to obtain a graduate degree will be evaluated for eligibility only. The prospective officer student must also request assignment to AFIT through their assignment team at HQ AFPC; the prospective enlisted student must apply to HQ Air Staff. Sister Service members presently must also be evaluated for academic eligibility. All other qualified students will fall into one of the following admission categories: unconditional admission as a degree-seeking student; conditional admission as a degree-seeking student; unconditional admission as a non-degree-seeking student; or, conditional admission as a non-degree-seeking student. Students who are conditionally admitted (either degree-seeking or non-degree-seeking) for academic reasons may have that condition removed at the discretion of the department. Students who are conditionally admitted due to missing admissions documents (e.g., transcripts and/or GRE scores) must resolve deficiencies by providing missing documents and become unconditionally admitted by the end of the first quarter of study. Students admitted in non-degree status may request a change of status and be fully admitted into a degree program. The AFIT Catalog includes more details.

Students may transfer up to 12 credit hours of graduate credit from other accredited institutions. These 12 hours of credit may consist of courses taken before, during, or after residence at AFIT’s graduate school, but may not include any course submitted for any other degree. All courses transferred must carry a “B” or higher, and a thesis written under the direction of another school may not be transferred. The faculty advisor, the department head, and the Academic Standards Committee must approve the transfer credits. Neither the grades nor the credit hours pertaining to the transferred courses will be used in grade point average calculations except to remedy academic deficiencies. EN Operating Instruction 36-104 has additional information.

Students admitted in non-degree status may request a change of status and be fully admitted into a degree program. Students seeking a change of status must meet all the requirements of the program they wish to enter. A maximum of 12 credit hours earned while in non-degree-seeking status can be applied to a degree program.
Admission to the Graduate School of Engineering and Management does not guarantee admission to a specific degree program within the Department of Aeronautics and Astronautics. Additional requirements for admission to specific programs are described in the next section.

2.2 Department of Aeronautics and Astronautics Program Admission Requirements

The general requirements for admission to graduate programs within the Department of Aeronautics and Astronautics are as follows:

a. An ABET-accredited degree with appropriate major (except for the space systems program). Students with other prior degrees will be evaluated individually. A few students with other prior degrees, but with 36 credits in the engineering sciences and design disciplines, are approved each year for admission to graduate study in aeronautical and astronautical engineering.

b. A cumulative GPA of 3.0 (on a 4.0-point basis) in that degree. Students who do not meet this requirement will be considered on an individual basis. In general, students who have a GPA above 2.8 and a “B” average on the critical upper division engineering science courses may expect to be admitted. Applicants for graduate work in astronautical or systems engineering are expected to have a "B" average in all mathematics courses attempted, beginning with calculus.

c. Minimum scores on the GRE of 153 (verbal) and 148 (quantitative) are a requirement for admission to any of the graduate MS programs of the Graduate School of Engineering and Management. The Department may waive this requirement, but applicants should be aware that those admitted each year to the Department of Aeronautics and Astronautics have average GRE scores above the national averages for aeronautical engineers. Applicants are also encouraged to take the advanced test in engineering. An above-average score may offset marginal grades.

d. Entrance to the graduate Aeronautical or Astronautical Engineering Programs requires a Baccalaureate degree, which contains at least one course each in statics, dynamics, mechanics of materials, fluid mechanics, thermodynamics, circuits, a capstone design course, and suitable laboratory experience in the application of engineering principles. The applicant must also have 48 hours in mathematics (through differential equations) and basic science, one year of calculus-based physics, a course in chemistry and a course in computer programming. Normally, entrants will have a prior ABET-accredited degree in aerospace or mechanical engineering, or in engineering mechanics. Exceptions are made, however, subject to the above. For example, prior work in civil or materials engineering may qualify for a concentration in structures; prior study in chemical engineering may qualify for a program in propulsion; and students with degrees in electrical engineering may wish to concentrate in flight mechanics and controls. A student who lacks an ABET-accredited engineering degree will be admitted only if a review of records shows that all deficiencies can be removed including any deficiencies in the humanities and social sciences.

e. The Graduate Materials Science Program requires applicants to have an undergraduate degree in an engineering discipline or the physical sciences.
f. The Space Systems Program is much more interdisciplinary in nature than the other programs, and does not require an undergraduate engineering degree. A prospective student’s undergraduate program should include three quarters of calculus-based physics, and mathematics including calculus and differential equations.

2.3 Part-Time Master’s Degree Program

It is possible to earn an MS degree as a part-time student (course load less than 12 quarter hours per quarter). After admission in degree-seeking status and successful completion of 12 credit hours within the Graduate School of Engineering and Management, the student may apply in writing for candidacy to a graduate program (refer to ENO1 36-134). The request for candidacy must include an approved education plan that is developed with the aid of the student’s academic advisor. The student should apply for candidacy at least one year prior to graduation.

After admission to candidacy, the part-time student must complete at least eight quarter hours of graduate credit in four consecutive quarters. This requirement must be reflected on the education plan, which will be reviewed annually by the department. All academic work taken to fulfill program requirements, including transfer courses, must be completed within 26 consecutive quarters (6 1/2 years).

2.4 Course Registration and Credit

Students are responsible for registering for classes. A normal course load for degree-seeking students attending AFIT full-time is 12 to 16 quarter hours. Non-degree-seeking students will typically register for no more than eight quarter hours.

Registration for all students is accomplished during the open registration period, which normally begins by Monday of the third week of the quarter preceding the course offering, and extending to Friday of the first week of the quarter in which the course is offered. Students will receive various notifications advising them of registration dates. Registration is accomplished on-line by logging onto WebAdvisor and entering their courses through the registration screen. Students who do not have access to WebAdvisor must complete the AFIT Drop/Add Request Form. This form is available in the ENY office, on-line, and in the Registrar’s Office. Students are responsible for resolving all resultant scheduling conflicts and ensuring that they have the approval of their academic advisor.

Once a quarter begins, the student can drop courses only by submitting a properly-completed Drop/Add Request Form to the Registrar’s Office. Students may drop courses through week two of the quarter without the course showing up on the student’s academic record. Any student who drops a course during week three through the end of week five will receive the grade of "W". Students dropping courses during week six through the end of week seven will receive a grade of “WP” or “WF”.

17
CHAPTER 3:  DEGREE AND ABET REQUIREMENTS

3.1 General MS Degree Requirements

All of the MS degrees offered under the GA/GAE/GMS/GSS programs must adhere to the general requirements for the MS degree established by the AFIT Graduate School of Engineering and Management. A summary of these requirements follows. For more complete information and for the final authority on these requirements, the reader should consult Graduate School of Engineering and Management Operating Instruction (ENOI) 36-135, “Requirements for Award of the Master’s Degree.” Degree requirements are 48 credit hours; however, the 6-quarter in-residence MS program normally includes a minimum of 72 quarter hours (12 hours per quarter is considered full-time status). The requirement for 72 hours may be waived only by approval of the department head and the dean.

The general MS requirements are:

(1) Up to 12 quarter hours of graduate course work with a grade of "B" or better may be transferred in accordance with E NOI 36-104.

(2) The minimum residence requirement is three quarters as a full-time student (ENOI 36-135).

(3) The student must have attained a grade point average of at least 3.0 for all graded courses included in the student's approved program. At least 36 of the quarter hours of courses submitted for the degree must have been completed in residence (ENOI 36-135).

(4) As part of graduate credit for the GA/GAE/GMS/GSS degrees, the student must complete 12 credit hours of thesis research. The results of this research must be reported in an oral presentation and in a written document. A thesis grade of "C-" or better is required (ENOI 36-104, E NOI 36-135). (GSS students: see note at the end of Chapter 3 concerning "Thesis".)

(5) The 48 hours of graduate credit for the degree must satisfy the applicable program requirements. See Chapter 4 and/or Appendix F for program requirements.

(6) Degree requirements must be met within five years after the graduation of the student's class section (ENOI 36-135) or, for part-time students, within 6.5 years of the first degree-required course taken.

(7) No student is considered to have satisfactorily completed an approved program if there is an unresolved grade of "U," "F" or "I" in any course (ENOI 36-104).

(8) The student must be recommended for the degree by the Faculty Council of the Graduate School of Engineering and Management before the degree will be awarded (ENOI 36-135).


3.2 ABET Requirements

The Graduate Aeronautical Engineering (GAE) and Graduate Astronautical Engineering (GA) Degree Programs at AFIT are accredited at the Master’s level by the Accreditation Board of Engineering and Technology (ABET). Students requesting the degree of Master of Science in one of these programs must satisfy all ABET curriculum requirements for this level. The criteria for Master’s-level programs are fulfillment of the Baccalaureate-level general criteria, fulfillment of program criteria appropriate to the Master’s-level specialization area, and one academic year of study beyond the Baccalaureate level. The program must demonstrate that graduates have an ability to apply Master’s-level knowledge in a specialized area of engineering related to the program area. The Baccalaureate-level general criteria require that the student either enter the program with an accredited aeronautical or astronautical degree, or supplement his/her AFIT degree program with the course work necessary to complete undergraduate ABET requirements. Undergraduate requirements include: (a) one year of a combination of college-level mathematics and basic sciences (some with experimental experience) appropriate to the discipline; (b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study; and (c) a general education component that complements the technical content of the curriculum and is consistent with the undergraduate program and institution objectives. Each Baccalaureate program must also satisfy applicable Program Criteria as defined by AIAA. These latter criteria can be found in the sections dealing with the GA and GAE programs.

The Graduate Space Systems (GSS) Degree Program was developed to meet the needs of the Air Force for managers who could analyze space-related systems and make informed decisions on their development, use, and deployment. The North Central Association of Colleges and Schools accredits this program. This is a highly interdisciplinary program, including elements of astronautical engineering, systems engineering, operational analysis, and other branches of engineering and management. While the program is new enough that it does not yet have a “peer group” in the general technical community, the same standards of achievement and scholarship expected of any AFIT major are applied to the GSS program.

The Graduate Materials Science program (GMS) has not been ABET accredited. The North Central Association of Colleges and Schools accredits this program.
CHAPTER 4: PROGRAM GUIDE

4.1 Graduate Aeronautical Engineering (GAE)

Mission statement:  Produce graduates who are technically well prepared for their subsequent duties and responsibilities as aeronautical engineers in DoD organizations.

4.1.1 Introduction

The Graduate Aeronautical Engineering (GAE) program is a fully accredited program at AFIT leading to a Master of Science degree in Aeronautical Engineering. The GAE program is designed for students from all branches of the U.S. military services as well as students from allied foreign military services, civilians and part-time students. Most students (Air Force and Navy quota as well as Air Force Test Pilot School (AFTPS)) enter as a class in September (Fall Quarter). Other students enter in quarters as shown in the table below. Program duration is program dependent and is shown in the table below. The courses are primarily taught by the faculty of the Department of Aeronautics and Astronautics.

<table>
<thead>
<tr>
<th>Program</th>
<th>Length (mos.)</th>
<th>Start Qtr</th>
<th>Graduation Qtr</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF Quota</td>
<td>18</td>
<td>Fall</td>
<td>Winter</td>
</tr>
<tr>
<td>AF TPS</td>
<td>15</td>
<td>Fall</td>
<td>Winter</td>
</tr>
<tr>
<td>Navy Quota</td>
<td>18-24</td>
<td>Fall</td>
<td>Summer</td>
</tr>
<tr>
<td>Other (Civ., FNs, etc.)</td>
<td>18-24</td>
<td>Fall (typical)</td>
<td>Varies</td>
</tr>
</tbody>
</table>

Notes:
1. Air Force Test Pilot School students complete 15 months in residence and graduate at the end of the winter/summer quarter following their one-year test pilot school program.

2. Includes foreign nationals (FN), civilians in DAGSI programs, and special DoD programs.

4.1.2 Program Educational Objectives

1. Our graduates will make direct contributions as a practicing engineer in the area of aeronautical engineering.

2. Our graduates will effectively communicate, evaluate, monitor and administer aeronautical research and development programs.

3. Our graduates will solve new technological challenges to meet the needs of the Air Force and other DoD organizations.
4.1.3 Student Outcomes

1. GAE graduates will demonstrate the ability to perform independent research, resulting in substantial contributions to the field of aeronautical engineering.

2. GAE graduates will demonstrate the ability to effectively communicate complex ideas and concepts both orally and in writing.

3. GAE graduates will be able to perform research that provides substantial and tangible value to the DoD.

4.1.4 Program Elements

(1) Core Aeronautical Engineering
(2) Mathematics (2)
(3) Specialty Sequences (2)
(4) Independent Investigation (i.e. thesis)
(5) Electives
(6) 48 graduate quarter hours, minimum

(1) Core Aeronautical Engineering

CORE AERONAUTICS: Each student who graduates with a Master of Science in Aeronautical Engineering must have a broad foundation in the theoretical and applied aspects of the fundamental disciplines of aeronautical engineering. The department offers courses in five aeronautics disciplines: 1) aerodynamics, 2) aircraft stability and control, 3) air breathing or rocket propulsion, 4) structures/materials and 5) air weapons. A complete list of the courses that comprise each discipline are contained in Appendix B. The department requires that a master’s student take at least one department-offered course from any three of the five disciplines. Those courses may be taken as part of a specialty sequence, as part of the ABET core, or simply as elective courses.

ABET CORE: Certain general program outcomes and professional components for Aeronautical Engineering are specified by the Accreditation Board for Engineering Technology (ABET). Specific course topics are determined by the lead society for ABET, the American Institute of Aeronautics and Astronautics (AIAA). The ABET general criteria are largely satisfied in any undergraduate engineering program while the specific topics are usually covered only in an aerospace or aeronautics undergraduate program. Prior to beginning the GAE program, the student with his/her faculty advisor’s assistance, based on undergraduate transcripts will identify any deficiencies in the general/specific core aeronautical engineering areas. Students identified as having core aeronautics deficiencies may satisfy the requirements either by taking remedial undergraduate courses or by taking appropriate courses from the list below. ABET general program requirements include competency in designing and conducting aeronautical (wind tunnel)-based experiments, which can be satisfied by taking AERO 517 Fluid Measurements Lab. ABET also requires a design experience and AIAA further specifies design of an aeronautical system, component or process. Either AERO 585 Aerospace Systems Design,
MENG 585 Air-breathing Engine Design, or AERO 620 Helicopter Mission Performance and Handling Qualities will satisfy the design requirement. Completion of the following courses satisfies both general and specific ABET guidelines:

a. Aerodynamics: AERO 534 Aerodynamic Fundamentals
c. Structures: MECH 545 Aerospace Structural Analysis
d. Propulsion: MENG 501 Aerospace Propulsion
e. Materials: MATL 545 Mechanical Properties of Materials
g. Aeronautical Lab: AERO 517 Fluid Measurements Lab

Students with a Bachelor of Science in Aeronautical Engineering have sufficient background so that most or all of these courses can be waived. Students with other undergraduate degrees frequently lack this background.

(2) Mathematics

The second element of the GAE curriculum is mathematics. Each student must complete at least two graduate level courses containing a major emphasis in mathematics or statistics. This requirement can be satisfied by taking two courses offered by the Mathematics department or one course from the Mathematics department plus a second course approved by the Aeronautics department. Such approved second courses can also be used simultaneously in satisfying other degree requirements, such as in sequences.

Department-approved Math substitute courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>AERO 551</td>
<td>Numerical Methods for CFD</td>
</tr>
<tr>
<td>MECH 620</td>
<td>Systems Optimization</td>
</tr>
<tr>
<td>MECH 622</td>
<td>Functional Optimization and Optimal Control</td>
</tr>
<tr>
<td>MECH 712</td>
<td>Nonlinear Oscillations</td>
</tr>
<tr>
<td>ASYS 525</td>
<td>Linear Systems Analysis</td>
</tr>
<tr>
<td>ASYS 625</td>
<td>Non-Linear Systems Analysis and Control</td>
</tr>
</tbody>
</table>

The particular math courses each student takes are based upon background and area of specialization. Nearly all students take math courses that cover topics in advanced calculus, complex variables, Fourier series and boundary value problems, linear algebra, numerical methods, and probability/statistics. MATH courses popular among students in the Graduate Aeronautical Engineering program include (but are not limited to) MATH 508, MATH 509, MATH 511, MATH 513, MATH 521, and STAT 583.

(3) Specialty Sequences

The third element of the Graduate Aeronautical Engineering curriculum is comprised of the specialty sequences. Each student is required to take two specialty sequences. Each of these
three-course sequences form a coherent body of knowledge in a particular area and provide the student with a strong theoretical background for thesis work and post-graduation assignments.

Air Force Ed Codes: Full-time Air Force military students entering AFIT are assigned an advanced level education specialty code (Ed Code). This code reflects the current requirements and availability of officers in each specialty. The system of Ed Codes is used by the Air Force to determine both the number of students and the type of advanced level education for each student. For such Air Force students, one sequence is normally dedicated to meeting Air Force requirements for specialized education, while the second sequence is left to the student's choice.

Over the last few years, Air Force quota students have been entering the GAE program with the following Ed Codes:

<table>
<thead>
<tr>
<th>Ed Code</th>
<th>Specialty</th>
</tr>
</thead>
<tbody>
<tr>
<td>4AAY</td>
<td>Aeronautical Engineering – Aerodynamics</td>
</tr>
<tr>
<td>4ABY</td>
<td>Aeronautical Engineering – Air Weapons</td>
</tr>
<tr>
<td>4AGY</td>
<td>Aeronautical Engineering – Structural Analysis</td>
</tr>
<tr>
<td>4AEI</td>
<td>Aeronautical Engineering – Rocket Propulsion</td>
</tr>
<tr>
<td>4AEY</td>
<td>Aeronautical Engineering – Air-breathing Propulsion</td>
</tr>
<tr>
<td>4AFY</td>
<td>Aeronautical Engineering – Stability and Control</td>
</tr>
<tr>
<td>4AYY</td>
<td>Aeronautical Engineering – General</td>
</tr>
<tr>
<td>4B*Y</td>
<td>Aerospace Engineering</td>
</tr>
<tr>
<td>4MBB</td>
<td>Mechanical Engineering – Fluid Mechanics</td>
</tr>
<tr>
<td>4MBY</td>
<td>Mechanical Engineering – Structural Dynamics</td>
</tr>
<tr>
<td>4MFY</td>
<td>Mechanical Engineering – Structural Materials</td>
</tr>
<tr>
<td>4MHB</td>
<td>Mechanical Engineering – Control Systems</td>
</tr>
<tr>
<td>4MYY</td>
<td>Mechanical Engineering – General</td>
</tr>
</tbody>
</table>

For the specialty codes listed above, Air Force students must take at least one sequence in the associated specialty.

Air Force students with the educational code 4AYY (Aeronautical Engineering-General) are free to choose their primary sequence from the list shown under "Course Sequences." Students with 4MYY (Mechanical Engineering-General) must choose at least one of the following sequences: Propulsion, Structural Analysis, or Structural Materials.

Air Force students with the educational code 4B*Y (Aerospace Engineering) choose their program (GA or GAE) and their sequences after consultation with their advisor and the supervisor of their next assignment.

In all cases, the second sequence (student's choice) may be taken in an area outside the Ed Code specialty. Students also may select their second sequence from those listed with other programs, such as "Advanced Astrodynamics" (GA program).
(4) Independent Investigation

The fourth element of the Graduate Aeronautical Engineering program is an independent investigation of a problem of current DoD interest, conducted and documented by the student, with supervision of the faculty. The investigation is presented as a formal thesis and the thesis carries 12 credit hours.

Chapter 7 explains the thesis polices procedures, and requirements for AFIT and the Department of Aeronautics and Astronautics.

(5) Electives

Students have the opportunity to take supporting courses and elective courses and seminars covering current technical developments and DoD projects. Electives are also used to make up for undergraduate deficiencies and failed courses, prepare for future assignments, increase depth in a specialty, develop an additional specialty, or pursue individual interests by taking courses not normally found in an aeronautical engineering program. One area of growing importance in DoD is Systems Engineering. Some students may consider taking electives in this area, e.g., SENG 520 and/or SENG 620, or pursuing a certificate in Systems Engineering, a group of five courses including a capstone course that can be replaced with Aircraft Design or Engine Design. ENV administers the Certificate program, and specific information regarding that program should be addressed to ENV.
### 4.1.5 Sample Program—18 Month GAE Thesis Student

**Master of Science in Aeronautical Engineering**  
September - March (18 Months)

#### Short Term Review (4 weeks)
- Mathematics
- Dynamics
- Aeronautics
- Computers

#### 1st Quarter
**Fall**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXXX xxx</td>
<td>MATH I</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Core/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Core/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Core/Elective</td>
</tr>
</tbody>
</table>

**Total Credit Hours:** 13-16

#### 2nd Quarter
**Winter**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXXX xxx</td>
<td>MATH/Math Substitute</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Core/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Core/Sequence I/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Core/Sequence II/Elective</td>
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</tbody>
</table>

**Total Credit Hours:** 13-16

#### 3rd Quarter
**Spring**

<table>
<thead>
<tr>
<th>Course</th>
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</tr>
</thead>
<tbody>
<tr>
<td>XXXX xxx</td>
<td>MATH/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence I</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence II</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Elective/Core</td>
</tr>
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</table>

**Total Credit Hours:** 13-16

#### 4th Quarter
**Summer**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credit Hours</th>
</tr>
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<tbody>
<tr>
<td>AERO 799</td>
<td>Thesis Research</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence I/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence II/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Core/Elective</td>
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**Total Credit Hours:** 14-16
<table>
<thead>
<tr>
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<th>Course Code</th>
<th>Course Type</th>
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</thead>
<tbody>
<tr>
<td>5th Quarter</td>
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<td>AERO 799</td>
<td>Thesis Research</td>
<td>3-7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>XXXX xxx</td>
<td>Sequence I/ Elective/Core</td>
<td>3-4</td>
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<td></td>
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<td>XXXX xxx</td>
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<td></td>
<td></td>
<td>9-15</td>
</tr>
<tr>
<td>6th Quarter</td>
<td>Winter</td>
<td>AERO 799</td>
<td>Thesis Research</td>
<td>3-6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TENY 799</td>
<td>Thesis Completion</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>XXXX xxx</td>
<td>Elective</td>
<td>3-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>XXXX xxx</td>
<td>Core/Sequence</td>
<td>3-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21-26</td>
</tr>
</tbody>
</table>

**TOTALS** 72-94

**Program Notes**

1. This program layout is typical for a full-time 18-month student. For longer programs, additional department approved electives may be taken. In such programs, the thesis research is typically accomplished in the final three quarters.

2. In addition to curriculum requirements specified for the degree, a minimum course load of 12 credit hours per quarter (average) is required for full-time DoD students.

3. Technical electives may be selected from any program in the Graduate School of Engineering and Management.

4. A student lacking adequate preparation in humanities and social sciences must use electives to correct these deficiencies in order to earn the ABET designated degree. Taking courses at other DAGSI Universities can satisfy these deficiencies and other enhancements.
4.1.6 Special Programs

4.1.6.1 Air Force Joint AFIT/Test Pilot School (TPS) Programs

A special program is offered in the department in which the participating students are awarded dual diplomas: (1) an MS in Aeronautical Engineering from AFIT, and (2) a diploma from the United States Air Force Test Pilot School (AFTPS). The special joint AFIT/TPS program is only available to students who have been selected for admission to TPS. Degree requirements: same as listed in section 4.1.4.

Air Force TPS: Each year the Air Force TPS Selection Board selects two or more Air Force officers for this combined program. The selected students enter AFIT residency in September or January, and in five quarters (15 months) complete their AFIT course work. The Air Force students also complete a large portion of the thesis requirement while in-residence. The students leave in December/June without their AFIT degree and enter TPS at Edwards AFB starting in January/July. While at TPS the students design and fly a flight test program that is subsequently incorporated into their MS thesis. Upon successful completion of the 1-year program at TPS and a successful defense of their AFIT thesis, the students are awarded the MS Degree in Aeronautical Engineering.
Sample Program--Air Force TPS Program

Aeronautical Engineering
(15 Months)

Short Term Review (4 weeks)
September/December/June
Mathematics
Dynamics
Aeronautics
Computers

<table>
<thead>
<tr>
<th>1st Quarter</th>
<th>Credit Hours</th>
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</thead>
<tbody>
<tr>
<td>XXXX xxx MATH I</td>
<td>4</td>
</tr>
<tr>
<td>XXXX xxx Core/Elective</td>
<td>3-4</td>
</tr>
<tr>
<td>XXXX xxx Core/Elective</td>
<td>3-4</td>
</tr>
<tr>
<td>XXXX xxx Core/Elective</td>
<td>3-4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13-16</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2nd Quarter</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXXX xxx MATH/Math substitute</td>
<td>4</td>
</tr>
<tr>
<td>XXXX xxx Sequence I</td>
<td>4</td>
</tr>
<tr>
<td>XXXX xxx Core/Sequence II/Elective</td>
<td>3-4</td>
</tr>
<tr>
<td>XXXX xxx Core/Elective</td>
<td>3-4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14-16</strong></td>
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</table>

<table>
<thead>
<tr>
<th>3rd Quarter</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
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<td>3-4</td>
</tr>
<tr>
<td>XXXX xxx Sequence I</td>
<td>3</td>
</tr>
<tr>
<td>XXXX xxx Sequence II</td>
<td>4</td>
</tr>
<tr>
<td>XXXX xxx Elective/Core</td>
<td>2-4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12-15</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4th Quarter</th>
<th>Credit Hours</th>
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</thead>
<tbody>
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<td>3</td>
</tr>
<tr>
<td>XXXX xxx Sequence I</td>
<td>4</td>
</tr>
<tr>
<td>XXXX xxx Sequence II/Elective</td>
<td>3-4</td>
</tr>
<tr>
<td>XXXX xxx Elective</td>
<td>3-4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13-15</strong></td>
</tr>
</tbody>
</table>
5th Quarter

<table>
<thead>
<tr>
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<th>Description</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>AERO 799</td>
<td>Thesis Research¹</td>
<td>4</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Elective/Core</td>
<td>3-4</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence II/Elective/Core</td>
<td>3-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-12</td>
</tr>
</tbody>
</table>

6th Quarter

<table>
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<tr>
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<th>Description</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
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<td>AERO 799</td>
<td>Thesis Research¹</td>
<td>4-12</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Elective/Core</td>
<td>3-4</td>
</tr>
<tr>
<td>TENY 799</td>
<td>Thesis Completion</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19-28</td>
</tr>
</tbody>
</table>

Program Notes

1. Thesis credits are for the Air Force program only and are continued in the AF TPS program. At completion of the GAE program, 12 credit hours are awarded for the thesis. Naval officers will substitute a sequence course or technical elective.

2. In addition to curriculum requirements specified for the degree, a minimum course load of 12 credit hours per quarter (average) is required for full-time DoD students.

3. Technical electives may be selected from any program in the Graduate School of Engineering and Management.
4.2 Graduate Astronautical Engineering (GA)

4.2.1 Introduction

The Graduate Astronautical Engineering (GA) program is designed to provide astronautical engineering specialists for the Air Force. Astronautical engineering is dedicated to the design, testing, and development of spacecraft, missiles, launch vehicles, and related systems. In the traditional program, students enter as a class in September and graduate in 18 months. This ABET accredited program leads to a Master of Science in Astronautical Engineering.

4.2.2 Program Educational Objectives

This program provides the student with a broad education in the scientific and engineering disciplines associated with Astronautical engineering. Our Program Educational Objectives are to provide graduates who:

1. Make direct contributions to the area of astronautical engineering as practicing engineers.
2. Successfully evaluate, monitor, and administer astronautical research and development projects.
3. Use their AFIT education to approach and solve new technological challenges to meet the needs of the Department of Defense.

4.2.3 Program Outcomes

1. Graduates of the GA program will be able to apply sound engineering principles to solve Air Force and Department of Defense problems.
2. Graduates of the GA program will be able to communicate technical information, via oral presentations and written documents, to a wide range of audiences, including engineering professionals and senior military officers.
3. Graduates of the GA Program will understand the principles of orbital mechanics. Graduates will be able to describe Keplerian motion, major perturbations to Keplerian motion, and be able to plan orbital maneuvers.
4. Graduates of the GA program will be prepared to describe and discuss significant aspects of the space environment and their effect on Earth-orbiting spacecraft.
5. Graduates of the GA program will be able to model spacecraft attitude dynamics and synthesize control laws to control spacecraft attitude. Graduates will understand transformations due to coordinate frame translation and rotations.
6. Graduates of the GA program will have a basic understanding of modern communication principles as they relate to satellite communications. Graduates will recognize methods of modulation, multiplexing, and encoding. Graduates will be able to perform simple link margin analyses needed to establish initial design requirements.

7. Graduates of the GA program will be prepared to describe essential features of rocket propulsion including: performance parameters, propellant types, rocket staging, and fluid mechanics as it pertains to rocket propulsion.

8. Graduates of the GA program will be able to conduct basic analyses of space structures including deformation from tension, torsion, shear, and bending.

9. Graduates of the GA program will have a basic understanding of the remote sensing process, and be able to recognize key concepts relating to optical systems, imaging, spatial and spectral resolution, and atmospheric absorption and scattering.

4.2.4 Program Elements

The GA curriculum is built around five principal elements:

(1) Core Courses
(2) Mathematics
(3) Specialty Sequences
(4) Thesis
(5) Elective Courses

Full-time quota officers are required to complete an average of 12 credit hours per quarter over the duration of their program. Typical master’s programs are six quarters, so students should plan to complete a minimum of 72 credit hours, including 12 hours of thesis credit. Students who are not DoD sponsored full-time quota students may complete the degree with as few as 48 graduate credit hours, but it should be recognized that this case presumes an appropriate undergraduate degree (ABET accredited degree in astronautical or aerospace engineering).

(1) Core Courses

Each student who receives a Master of Science in Astronautical Engineering must have a foundation in the theoretical and applied aspects of the fundamental areas of astronautical engineering. These areas, and associated program outcomes, are specified by the Accreditation Board for Engineering Technology (ABET). Expected outcomes include competency in orbital mechanics, space environment, spacecraft attitude determination and control, telecommunications, space structures, space-related design, and rocket propulsion. A course in sensor systems is also required for all Air Force students.

Not all master’s students are required to take courses in each of these areas to complete the GA program. Prior to beginning their program, it is the dual responsibility of the student and faculty advisor to identify areas in which the student’s undergraduate degree does not satisfy ABET core requirements and to ensure their graduate program will cover any deficiencies. Faculty advisors
will evaluate undergraduate transcripts to determine the applicability of undergrad courses in meeting requirements, and will prepare an ABET degree form to document that each student will meet all ABET requirements upon satisfactory completion of their education plan.

In addition to meeting ABET core requirements, students are required to meet all GA Core requirements listed below. These classes can be used to simultaneously meet other degree or ABET requirements. Students are strongly encouraged to take as many of the ABET courses as possible even if they have taken undergraduate courses in these areas. The graduate courses often go beyond similar undergraduate courses in these subject areas, and are designed to provide a strong academic foundation for anyone planning a career in a space-related field.

**GA Core Requirements:**

a. A course in orbital mechanics; ONE of the following courses:
   - MECH 532 – Introductory Space Flight Dynamics
   - MECH 731 – Modern Methods of Orbit Determination
   - MECH 732 – Advanced Astrodynamics
   
   *Note: This course also satisfies the ABET orbital mechanics requirement. Also, completion of an introductory orbital mechanics class (such as MECH 532) is a prerequisite for ASYS 631.*

b. A course in spacecraft attitude determination and control;
   - MECH 632 – Intermediate Space Flight Dynamics
   
   *Note: This course along with ASYS 565 satisfies the ABET requirement for spacecraft attitude determination and control*

c. A course in sensor systems;
   - ASYS 521A – Space Remote Sensing, or PHYS 521 – Space Surveillance

d. A course in linear systems;
   - ASYS 525 – Linear Systems Analysis
   
   *Note: This course is a prerequisite course for ASYS 565*

e. A course in three-dimensional kinematics and analytical mechanics;
   - MECH 521 – Intermediate Dynamics
   
   *Note: This course is a prerequisite course for MECH 632*

**ABET Core Requirements (as applicable)**

a. A course in orbital mechanics; satisfied by GA Core requirements above

b. A course in space environment; PHYS 519 – Space Environment
c. A course in spacecraft attitude determination and control; ASYS 565 – Control and State
Space Concepts and MECH 632 – Intermediate Space Flight Dynamics (satisfied by GA
Core requirements above)

d. A course in telecommunications; EENG 571 – Satellite Communications

e. A course in space structures; MECH 500 – Fundamentals of Solid Mechanics or MECH –
545 Aerospace Structural Analysis

f. A course in space-related design; ASYS 631 – Spacecraft Systems Engineering

e. A course in rocket propulsion; MENG 530 – Chemical Rocket Propulsion or MENG 531 –
Space Propulsion and Power

(2) Mathematics

The second element of the GA curriculum is mathematics. Each student must complete at least
two graduate-level mathematics courses. The particular courses each student takes are based
upon background and area of specialization.

Nearly all students take math courses that cover the following topics: Advanced calculus,
complex variables, Fourier series, Laplace transforms, boundary value problems, linear algebra,
numerical methods, and probability/statistics. Two courses specifically designed to cover most
of these topics are: MATH 511 – Methods of Applied Math I and MATH 513 – Methods of
Applied Math II. Other math classes suited to the GA program include MATH 521 – Linear
Algebra, and MECH 712 – Nonlinear Oscillations/MATH 605 – Nonlinear Ordinary
Differential Equations. Students planning on taking MECH 731 who have not had an
undergraduate probability course may consider taking a graduate course in probability such as
STAT 527 – Introduction to Probability.

(3) Specialty Sequences

The third element of the GA curriculum is comprised of the specialty sequences. A specialty
sequence, three or more courses in length, is an integrated presentation of a specific technical
specialty. Each program must contain two specialty sequences.

For Air Force Students: Each full-time Air Force student entering AFIT is assigned an advanced
level education specialty code (Ed Code). One of the specialty sequences required for the degree
must match the academic specialty code assigned to the student. The second may be in any
technical area. This code reflects the current requirements and availability of officers in each
specialty. The system of Ed Codes is used by the Air Force to determine both the number of
students and the type of advanced level education for each student. Students typically enter the
GA program with one of the following Ed Codes:
The minimum credit hours permitted in a 7-quarter program is 84.

Annually by the Department of Aeronautics and Astronautics.

To the student's next assignment, or for any other academically sound purpose. Any student approval of their academic advisor. Chapter 6 is a list of all specialty sequences offered

Problem of current DoD interest, conducted and documented by the student, with

Thesis

The second sequence is not required to match the education code, and students may select the second sequence from those listed with other programs/departments, subject to the approval of their academic advisor. Chapter 6 is a list of all specialty sequences offered annually by the Department of Aeronautics and Astronautics.

(4) Thesis

The fourth element of the GA program, the thesis, is an independent investigation of a problem of current DoD interest, conducted and documented by the student, with supervision by the faculty. Theses by previous GA students have been theoretical, experimental, and/or numerical. Topics for these theses are sometimes suggested by Air Force organizations.

Chapter 7 explains the thesis policies, procedures, and requirements for AFIT and the Department of Aeronautics and Astronautics.

(5) Elective Courses

Electives may be used to establish another specialty area, to take courses particularly pertinent to the student's next assignment, or for any other academically sound purpose. Any student with deficiencies in the social sciences and humanities or other areas must use electives to eliminate these deficiencies in order to qualify for the ABET accredited degree. The minimum credit hours permitted for full-time Air Force quota officers in a 6-quarter program are 72. The minimum credit hours permitted in a 7-quarter program is 84.

<table>
<thead>
<tr>
<th>Ed Code</th>
<th>Specialty</th>
<th>Required Primary Sequence</th>
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<tbody>
<tr>
<td>4B*Y</td>
<td>Aerospace Engineering</td>
<td>Any</td>
</tr>
<tr>
<td>4ECY</td>
<td>Astronautical Engineering - Guidance and Control</td>
<td>Mechanics and Control of Space Structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Advanced Astrodynamics</td>
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<tr>
<td></td>
<td></td>
<td>Vibration Damping and Control</td>
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<tr>
<td></td>
<td></td>
<td>Control &amp; Optimization Theory</td>
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<tr>
<td></td>
<td></td>
<td>Aerospace Navigation</td>
</tr>
<tr>
<td>4EDY</td>
<td>Astronautical Engineering – Instrumentation</td>
<td>Aerospace Navigation</td>
</tr>
<tr>
<td>4EEY</td>
<td>Astronautical Engineering - Rocket Propulsion</td>
<td>Rocket Propulsion</td>
</tr>
<tr>
<td>4EFY</td>
<td>Astronautical Engineering - Space Facilities</td>
<td>Space Facilities</td>
</tr>
<tr>
<td>4EGY</td>
<td>Astronautical Engineering – Structures</td>
<td>Structural Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Structural Materials</td>
</tr>
<tr>
<td></td>
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<td>Vibration Damping and Control</td>
</tr>
<tr>
<td>4EYY</td>
<td>Astronautical Engineering - General</td>
<td>Any</td>
</tr>
</tbody>
</table>

Other Recommended Sequences for Graduate Astronautical Engineering Students

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Astrodynamic Re-entry</td>
<td>Space Navigation</td>
</tr>
<tr>
<td>Space Vehicle Design</td>
<td>Space Control</td>
</tr>
</tbody>
</table>

The second sequence is not required to match the education code, and students may select the second sequence from those listed with other programs/departments, subject to the approval of their academic advisor. Chapter 6 is a list of all specialty sequences offered annually by the Department of Aeronautics and Astronautics.

(4) Thesis

The fourth element of the GA program, the thesis, is an independent investigation of a problem of current DoD interest, conducted and documented by the student, with supervision by the faculty. Theses by previous GA students have been theoretical, experimental, and/or numerical. Topics for these theses are sometimes suggested by Air Force organizations.

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4.2.5 Sample Program—18 Month GA Thesis Student

Master of Science in Astronautical Engineering  
September - March (18 Months)

<table>
<thead>
<tr>
<th>Short Term Review (4 weeks)</th>
<th>September</th>
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<tbody>
<tr>
<td>Mathematics</td>
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<tr>
<td>Statics and Dynamics</td>
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<td>MATLAB</td>
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<td>Astronautics</td>
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### 1st Quarter

**Fall**

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<td>ASYS 525¹</td>
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<tr>
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### 2nd Quarter

**Winter**

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<tr>
<th>Course</th>
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<tbody>
<tr>
<td>ASYS 565¹</td>
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</tr>
<tr>
<td>MECH 532¹</td>
<td>4</td>
</tr>
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<td>4</td>
</tr>
<tr>
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### 3rd Quarter

**Spring**

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</table>

### 4th Quarter

**Summer**

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<td>2-4</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>4</td>
</tr>
<tr>
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<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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### 5th Quarter

**Fall**

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<thead>
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<td>4-8</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>0-4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4-12</strong></td>
</tr>
</tbody>
</table>
### 6th Quarter
#### Winter

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>TENY 799</td>
<td>Thesis Completion</td>
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</tr>
<tr>
<td>PHYS 521¹</td>
<td>Space Surveillance</td>
<td>4</td>
</tr>
<tr>
<td>EENG 571¹</td>
<td>Satellite Communications</td>
<td>4</td>
</tr>
<tr>
<td>AERO 799</td>
<td>Independent Study (Thesis)</td>
<td>2-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22-24</td>
</tr>
</tbody>
</table>

**TOTALS** 72-96

1. See Section 4.2.4 (1)

2. See Section 4.2.4 (2)

This sample program is for a full-time AF quota student in an 18-month program.  
NOTE: While it is possible to build a program with an approximately even load of 12 credits per quarter, students are encouraged to “front load” coursework in the first three quarters of their program (16-17 credits) to free up time for thesis work in the second half of their program.
4.3 Graduate Space Systems (GSS)

4.3.1 Introduction

The Graduate Space Systems (GSS) program is designed to provide officers with a broad knowledge of space systems engineering, space science, and space operations. Education in the fundamentals of these areas will increase military officers’ effectiveness in planning, executing, and evaluating space systems and operations. Each student completes a research thesis on some aspect of space systems (engineering, science, or operations).

The Space Systems graduate is ready to participate actively in organizations responsible for the selection, planning, management, operation, and evaluation of space systems for the DoD. Full-time quota students enter as a class in September and are scheduled to graduate in March, approximately 18 months later. Most graduates will receive a Master of Science (Space Systems); however students with adequate background may pursue an alternate degree as long as the GSS requirements detailed below are satisfied.

There are four different Academic Specialty Codes (ASCs) associated with this program: 4TSY and 4ISY Space Systems Engineering; OYRY Space Operations, General; OYRI Space Operations, Information Operations. The OYRI designation is the code used for Vigilant Scholar students (selected by AFSPC for the Vigilant Scholar program). All students must complete the GSS core, while the specialty sequence(s) is tailored to meet ASC requirements as discussed in Section 4.3.4.

4.3.2 Program Educational Objectives

This program provides the student with a broad education in the scientific and engineering disciplines associated with space systems engineering, space science and space operations. Our PEOs are to provide graduates who:

1. Make direct contributions to the area of space systems engineering and space science as a practicing engineer.

2. Successfully evaluate, monitor, and administer space systems research and development projects.

3. Use their AFIT education to approach and solve new technological challenges to meet the needs of the Department of Defense.

4.3.3 Program Outcomes

1. Space Programs: Be knowledgeable about current and past US and international space programs. Understand the objectives of these programs and how they fit into military operations. Understand the basic technical means through which these objectives are achieved.
Required courses are ASYS 530 Introduction to Space Programs and Operations or ASYS 535 Military Space Systems and Applications (note: ASYS535 is restricted to US only with a TS/SCI clearance, all others should enroll in ASYS530).

2. Spaceflight Dynamics: Understand the physics of orbital mechanics and what impact it has on orbital mission operations. Be able to calculate orbital maneuvers and understand the basics of orbit control in the presence of perturbations. Understand the basics of torque-free spacecraft attitude dynamics. Required course is MECH 532 Introduction to Space Flight Dynamics.

3. Satellite Communications: Understand modern communication principles with particular emphasis on applications to satellite and space communication systems including modulation, signals, multiplexing, demodulation, multiple access, coding, look angles, satellite hardware, earth station hardware, and link analysis. Required course is EENG 571 Satellite Communications.

4. Space Environment: Understand the physics of radiation, particles, and general conditions encountered in space. Understand spacecraft thermal equilibrium, orbit decay, spacecraft charging, space-to-ground communications, atmospheric chemistry, Van Allen belts, and solar phenomena. Required course is PHYS 519 Space Environment.

5. Remote Sensing: Understand the remote sensing process with an emphasis on visible light and infrared systems. Understand the physics of interaction of light with matter, atmospheric absorption and scattering, radiometry, optical systems, spectral and spatial resolution and imaging, and electro-optical detectors. Required course is PHYS 521 Space Surveillance.

6. Spacecraft Engineering: Be knowledgeable of the design issues related to complex space systems. Understand the key elements and subsystems of important classes of space systems. Gain experience with the systematic approach necessary to effectively design space systems through a group design project. Required course is ASYS 631 Spacecraft Systems Engineering.

4.3.4 Program Elements

The GSS curriculum is comprised of the following elements, which are discussed in greater depth below.

(1) Mathematics
(2) Core Courses
(3) Specialty Sequence
(4) Elective Courses
(5) Thesis

(1) Mathematics

The mathematics courses provide the student with the tools to perform the quantitative analysis of the engineering, physics and operations courses. At least one math course is required for the
degree. The recommended course is MATH 509 Mathematical Methods in the Physical Sciences. Note: Additional math courses may be needed as prerequisites or in preparation for other graduate-level classes.

(2) Core Courses

The core program assures that students have a broad background in the engineering and science of space systems and operations. The core program includes courses in orbit and attitude dynamics, sensor systems, telecommunications, space environment, spacecraft engineering, and space programs as follows:

a. MECH 532 - Introductory Space Flight Dynamics  
b. EENG 571 - Satellite Communications  
c. PHYS 521 - Space Surveillance  
d. PHYS 519 - Space Environment  
e. ASYS 631 - Spacecraft Systems Engineering  
f. ASYS 535 - Military Space Systems and Applications (US TS/SCI only)  
   or ASYS 530 - Introduction to Space Programs and Operations

(3) Specialty Sequence

The third element of the GSS curriculum is a three-course specialty sequence. This sequence is intended to provide depth in order to support the thesis effort and/or follow-on assignment requirements. As such, the sequences required for each ASC are different, and depend on which of the three ASCs you are assigned, as shown below. The courses comprising the sequences are available from each of the departments responsible for the sequence. The ENY sequences are listed in Chapter 6. Course offerings should always be verified with those posted by the department offering the course.

4TSY and 4ISY (Space Systems Engineering): These students are expected to complete the Space Vehicle Design sequence, plus at least one technical depth specialty sequence in areas of space engineering or science. To complete the Space Vehicle Design sequence, the students must take:

   ASYS 531 – Space Mission Analysis and System Design  
   ASYS 631 – Spacecraft Systems Engineering*  
   ASYS 632 – Satellite Design and Test  
   (*note: the 2nd course in the sequence, ASYS 631, is already part of the GSS core)

Some suitable sequences for space systems engineering students are listed below along with the department offering the sequence. The sequences must be approved by the curriculum advisor. Also note that many sequences require prerequisites.

   Sequence  
   Astrodynamics (ENY)  
   Astrodynamic Re-Entry (ENY)  
   Advanced Astrodynamics (ENY)
Control and Optimization Theory (ENY)
Mechanics and Control of Space Structures (ENY)
Rocket Propulsion (ENY)
Space Navigation (ENY)
Space Control (ENY)
Structural Analysis (ENY)
Structural Materials (ENY)
Communication Systems (ENG)
Navigation Systems (ENG)
Radar Systems (ENG)
Laser and Electro-Optic Systems (ENG)
Stochastic Estimation and Control (ENG)
Target Recognition (ENG)
Signal Processing (ENG)
Space Environment (ENP)

OYRY (Space Operations): These students are permitted to take a sequence outside of the engineering and science fields, such as those having a stronger management or operational emphasis, as consistent with customer needs. To satisfy the OYRY code, students must take the following courses in addition to a sequence:

CSCE 525 - Introduction to Information Warfare
Plus one of the following:
OPER 501 - Quantitative Decision Making
OPER 510 - Deterministic Operations Research
OPER 543 - Decision Analysis

Some suitable sequences (in addition to 4TSY suggestions above and OYRI suggestions below) are:

Sequence
Applied Statistics (ENS)
Deterministic Operations Research (ENS)
Probabilistic Operations Research (ENS)
Operational Modeling (ENS)
Simulation (ENS)
Applied Decision Analysis (ENS)
Computer Networks (ENG)
Database Systems (ENG)
Research and Development Management (ENV)
Information and Knowledge Integration (ENV)

OYRI (Vigilant Scholar): These students are required to develop an expertise in the collection, management, dissemination, and control of information. One of the following sequences must be completed. Refer to the department offering the sequence to get an up to date list of courses which satisfy each sequence.

Sequence
Information Assurance Sequence (ENG)
Information Operations (ENS)
Information Systems (ENV)

(4) Elective Courses (full-time students)

For full-time quota students, the minimum credit hours permitted in the six-quarter program are 72. These additional classes will be used to satisfy prerequisites for the specialty sequence, support thesis research, support follow-on assignments, or support the student’s career goals and interests.

Schedule permitting, a course in systems engineering is highly recommended for all GSS students. This will provide a coherent framework for engineering design of complex systems and the development of DoD tools that are important to the successful design of space systems. The recommended course is ASYS 531 Space Mission Analysis and System Design.

Schedule permitting, a course in space vehicle design and test is highly recommended for all GSS students. This will provide a hands-on experience in the design and test of spacecraft and selected space subsystems. The recommended course is ASYS632.

Schedule permitting, a course in GPS is highly recommended for all GSS students. This will provide a theoretical and practical understanding of the operations and utility of the Global Positioning System (GPS). The recommended course is EENG 533 Navigation Using the Global Positioning System.

(5) Thesis

The final element of the GSS program, the thesis, is an independent investigation of a space-related problem of current DoD interest, conducted and documented by the student, under supervision of the faculty advisor. Thesis requirements will be determined by the department of the faculty serving as the thesis advisor. For those students with thesis advisors in the Department of Aeronautics and Astronautics, Chapter 7 explains the thesis policies, procedures, and requirements. Students with a primary thesis advisor outside of ENY should follow the guidelines within the primary advisor’s department. (Also see additional thesis committee requirements in Sec 4.3.5)

4.3.5 Degree Options

If the student has the appropriate background (e.g. an ABET accredited undergraduate degree), he or she may pursue a degree other than the Master of Science (Space Systems). These alternatives are listed in the table below. These options are available to provide flexibility for full-time quota students who must satisfy the Space Systems Ed Code requirements (4TSY, OYRY, OYRI) but has professional goals to obtain one of these other engineering degrees. To qualify for one of these degrees, the student must satisfy the requirements of the degree in addition to the requirements of their ASC for the GSS program. Students that opt for degrees offered outside of the Department of Aeronautics and Astronautics will be co-advised by the GSS advisor and the advisor of the degree-granting program. The advisor of the degree-granting program will be responsible for ensuring all graduation requirements are met (including
WebAdvisor entries). The GSS advisor will provide oversight to ensure that the requirements of the GSS program are met. Note that pursuing many of the degrees requires course loads beyond the 72-hour minimum for quota students. See the GSS advisor for additional details.

<table>
<thead>
<tr>
<th>M.S. Degree Granted</th>
<th>Coordinating Dept.</th>
<th>Additional Entry Requirements</th>
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</thead>
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<tr>
<td>Mathematics</td>
<td>ENC</td>
<td>BS Mathematics</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>ENG</td>
<td>BS Electrical Eng</td>
</tr>
<tr>
<td>Comp Science or Comp Systems</td>
<td>ENG</td>
<td>BS Comp Sci or Equiv</td>
</tr>
<tr>
<td>Computer Engineering</td>
<td>ENG</td>
<td>BS Comp Eng or BS Elec Eng</td>
</tr>
<tr>
<td>Engineering Physics</td>
<td>ENP</td>
<td>BS Physics</td>
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<tr>
<td>Operations Research</td>
<td>ENS</td>
<td>--</td>
</tr>
<tr>
<td>Logistics</td>
<td>ENS</td>
<td>--</td>
</tr>
<tr>
<td>Research &amp; Development</td>
<td>ENV</td>
<td>--</td>
</tr>
<tr>
<td>Management</td>
<td></td>
<td></td>
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<tr>
<td>Aeronautical Engineering</td>
<td>ENY</td>
<td>BS Astro, Aero or Mech Eng.</td>
</tr>
<tr>
<td>Astronautical Engineering</td>
<td>ENY</td>
<td>BS Astro, Aero or Mech Eng.</td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>ENV</td>
<td>Any ABET accredited BS</td>
</tr>
</tbody>
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### 4.3.6 Sample Program—18 Month GSS Thesis Student

**Master of Science (Space Systems)**  
September - March (18 Months)

**Short Term Review (4 weeks)***  
- Mathematics  
- Statics & Dynamics  
- Computers (MATLAB)  
- Astronautics  
- AERO 698 (faculty research topics overview)  
*refer to ENY department handout for times/locations

<table>
<thead>
<tr>
<th>1st Quarter</th>
<th>Credit Hours</th>
</tr>
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<tbody>
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<tr>
<td>ASYS 535</td>
<td>Military Space Systems and Applications^2 1</td>
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<tr>
<td>MATH 509</td>
<td>Mathematical Methods in the Physical Sciences 4</td>
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<tr>
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<td>Space Environment 4</td>
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<tr>
<td>MECH 532</td>
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<td>EENG 571</td>
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<tr>
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<td>Military Space Systems and Applications^2 1</td>
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<tr>
<td>ASYS 631</td>
<td>Spacecraft Systems Engineering 4</td>
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<td>5-13</td>
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<td>AERO 799</td>
<td>Independent Study (Thesis) 2-4</td>
</tr>
<tr>
<td>ASYS 632</td>
<td>Satellite Design and Test 4</td>
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<td>XXXX XXX</td>
<td>Specialty Sequence/Elective 3-4</td>
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<tr>
<td>COMM 680</td>
<td>Technical Reports &amp; Thesis (or elective) 0-4</td>
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### 5th Quarter

**Fall**

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<td>Independent Study (Thesis)</td>
<td>2-6</td>
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<td>XXXX XXX</td>
<td>Specialty Sequence/Elective</td>
<td>3-4</td>
</tr>
<tr>
<td>XXXX XXX</td>
<td>Specialty Sequence/Elective</td>
<td>0-4</td>
</tr>
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### 6th Quarter

**Winter**

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<td>Independent Study (Thesis)</td>
<td>2-6</td>
</tr>
<tr>
<td>TENY 799</td>
<td>Thesis Completion</td>
<td>12</td>
</tr>
<tr>
<td>PHYS 521</td>
<td>Space Surveillance(^1)</td>
<td>4</td>
</tr>
<tr>
<td>XXXX XXX</td>
<td>Specialty Sequence/Elective</td>
<td>0-4</td>
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<tr>
<td></td>
<td></td>
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</tbody>
</table>

**TOTALS** **68-102**

1. It is recommended that some members of the GSS class switch this class with EENG 571/PHYS 521 (both are required courses) so that there is a mix of expertise for the design project in ASYS 631.

2. US only, TS/SCI required. This is a single 3-credit course divided over three quarters (all three quarters must be taken unless given special permission by instructor).
4.4 Graduate Certificate Program in Space Systems

4.4.1 Introduction
For those students not enrolled in the Space Systems (GSS) or Astronautical Engineering (GA) degree programs, AFIT offers a Graduate Space Systems Certificate Program (GSSC). This program consists of four courses—three core and one elective. The core courses cover the areas of spacecraft dynamics, space environment, and spacecraft design. The elective course may be in the area of space communications, remote sensing, or propulsion fundamentals.

The courses required to earn the Graduate Certificate are:

1. MECH 532—Introductory Space Flight Dynamics
2. PHYS 519—The Space Environment
3. ASYS 631—Spacecraft Systems Engineering
4. An applications course (choose ONE of the following):
   a. EENG 571—Satellite Communications
   b. OENG 530—Fundamentals of IR and MASINT Technology
   c. PHYS 521—Space Surveillance
   d. MENG 530—Chemical Rocket Propulsion
   e. MENG 531—Space Propulsion and Power Systems

These courses provide a common breadth of knowledge and the basic building blocks for all Air Force and DoD Space Systems Engineers.

4.4.2 Program Educational Objectives
The Graduate Space Systems Certificate Program is designed for students with traditional engineering backgrounds (mechanical, electrical, aerospace, etc.) and produces graduates who can effectively approach and analyze complex space-related problems, design feasible solutions, and select an appropriate solution. Specific objectives are as follows:

1. A graduate will have a general understanding of the purpose and requirements for all spacecraft subsystems and how these subsystems relate to the spacecraft payload and mission.

2. A graduate will have a thorough understanding of orbital mechanics and the space environment and how these can affect the spacecraft mission.

3. A graduate will have the skills to effectively participate in the evaluation of both competing designs as well as proposed processes from competing contractors.
4.5 **Graduate Materials Science (GMS)**

4.5.1 **Introduction**

The Graduate Materials Science (GMS) program leads to the degree of Master of Science (Materials Science). Students normally enter as a class in September and are scheduled to graduate in March after 18 months. The program is under the joint supervision of the Department of Aeronautics and Astronautics (Structural Materials) and the Department of Engineering Physics (Non-structural Materials) and is carried out in cooperation with the Materials and Manufacturing Directorate of the Air Force Research Laboratory.

4.5.2 **Program Educational Objectives**

The goal of the GMS program is to provide a student who has a background in engineering or physical science with the knowledge of materials science and engineering necessary for work in the fields of structural and non-structural materials for aerospace systems. Such positions may range from those requiring very detailed and advanced level work in a specific discipline to those involving broad responsibilities and requiring interaction among many disciplines.

The GMS program prepares students for a range of Air Force positions. It demands that the students develop a detailed understanding in specialty areas while ensuring that they are also well educated across all areas of materials science and engineering.

The specific goals of the GMS program are to produce graduates with:

1. A solid background in the fundamental areas of materials science and engineering (structural and non-structural materials, thermodynamics and kinetics, materials characterization, and materials selection and processing).

2. An in-depth knowledge in one specialty area.


4.5.3 **Program Outcomes**

1. Graduates of the GMS program will be able to apply engineering principles to solve Air Force and DoD problems.

2. Graduates of the GMS program will be able to communicate technical information, via oral presentations and written documents, to a wide range of audiences including engineering professionals and senior military officers.

3. Graduates of the GMS program will have the knowledge of significant aspects of both structural and non-structural materials used in the current and future aerospace and defense systems.
4.5.4 Program Elements

The GMS program is normally 6 quarters in length. The equivalent of 5 quarters of study is devoted to coursework and 1 quarter of study to thesis research. The program provides preparation in thermodynamics and kinetics of materials, mechanical, electronic and optical properties of materials, material characterization, material selection and processing, and mathematics. Also, each student is required to take an in-depth study and perform research either in structural materials (metallic, composite, polymer, ceramics, etc.) or non-structural materials (electronics, optical, magnetic, dielectric, coating, etc.) Emphasis is placed on the application of fundamental knowledge to the design, development, test and evaluation of materials for Air Force systems.

The GMS curriculum is built around five principal elements:

1. Basic Materials Core
2. Mathematics
3. Specialty Sequence
4. Thesis
5. Elective Courses

(1) Basic Materials Core

Each student who graduates with a Master of Science (Materials Science) must have a foundation in the theoretical and applied aspects of the fundamental areas of materials. This foundation is laid through a core of courses taken by all materials science and engineering students. The courses making up the core are:

- MATL 545 Mechanical Properties of Materials
- MATL 525 Thermodynamics and Kinetics of Materials
- MATL 560 Electronic, Magnetic, and Optical Properties of Materials
- MATL 680 Materials Characterization
- MATL 685 Materials Selection and Processing

All students are required to take this set of five core courses; however, if a student can demonstrate successful completion of a similar course a waiver may be granted. Students who find that most or all of the core requirements can be waived should consider an accelerated program and early graduation. Students with undergraduate degrees in areas other than materials science frequently lack this background.

(2) Mathematics

The second element of the GMS curriculum is mathematics. Each student must complete at least one graduate level (500 level or above) mathematics (MATH) course or one graduate level statistics (STAT) course. A second course is highly desirable. The particular courses each student takes are based upon background and area of specialization.

Nearly all students take mathematics courses that cover the following topics; advanced calculus, complex variables, Fourier series and boundary value problems, linear algebra, numerical
methods, and probability/statistics. MATH and STAT courses popular among students in the Graduate Materials Science program include (but are not limited to) MATH 508, MATH 509, MATH 511, MATH 513, MATH 521, STAT 527, STAT 537, and STAT 583.

(3) Specialty Sequence

The third element of the GMS curriculum consists of the specialty sequence. Each student is required to take one such sequence with the option of adding a second. These sequences, each composed of at least three courses, together form a coherent body of knowledge in a particular area and provide the student with a strong theoretical background for eventual applications in thesis work and post-graduation assignments. This sequence is normally dedicated to meeting Air Force requirements for specialized education.

Each full-time Air Force military student entering AFIT is assigned an advanced-level education specialty code (Ed Code). This code reflects the current requirements and availability of officers in each specialty. The system of Ed Codes is used by the Air Force to determine both the number of students and the type of advanced-level education for each student. Students will enter the GMS program with the following Ed Codes:

<table>
<thead>
<tr>
<th>Ed Code</th>
<th>Specialty</th>
</tr>
</thead>
<tbody>
<tr>
<td>4FAY</td>
<td>Materials Science and Engineering-Structural Materials</td>
</tr>
<tr>
<td>4FBY</td>
<td>Materials Science and Engineering-Electronic and Optical Materials</td>
</tr>
<tr>
<td>4FYY</td>
<td>Materials Science and Engineering-General</td>
</tr>
</tbody>
</table>

For Ed Codes 4FAY and 4FBY, students must take one sequence in the specialty identified above. Components of the sequences are given in Chapter 6: “Specialty Sequence Descriptions”. Students with the educational code 4FYY (Materials Science and Engineering-General) are free to choose either the Structural Materials sequence or the Electronic and Optical Materials sequence.

(4) Thesis

The fourth element of the GMS program, the thesis, is an independent investigation of a problem of current Air Force interest, conducted and documented by the student, with supervision of the faculty. This independent study may be done under the direction of either the Department of Aeronautics and Astronautics (for structural materials) or the Department of Engineering Physics (for non-structural materials) and can be carried out either at AFIT or at a directorate of the Air Force Research Laboratory. Theses by GMS students can be theoretical, experimental, or numerical. Topics will be proposed by Air Force research and development organizations, particularly the Materials and Manufacturing Directorate of the Air Force Research Laboratory. Flexibility in the program is maintained in order to take full advantage of the varied backgrounds and abilities of individual students.

(5) Elective Courses

Opportunities to take supporting courses and elective courses are provided. Included also are seminars covering current technical developments and Air Force projects. Elective courses are used to make up for undergraduate deficiencies and failed courses, prepare for future
assignments, increase depth in a specialty, develop an additional specialty, or pursue individual
interests in taking courses not normally found in a materials science and engineering program.

4.5.5 Administrative

This program is of a multidisciplinary nature and will be updated, changed and/or modified in
consultation with Materials and Manufacturing Directorate, Air Force Research Laboratory. The
curriculum committee will consist of at least one member from the Department of Aeronautics
and Astronautics, one from the Department of Engineering Physics, and the one from the
Materials and Manufacturing Directorate of the Air Force Research Laboratory. Students with
Ed Codes of 4FAY and 4FBY will be the responsibility of ENY and ENP, respectively, and will
accordingly follow the rules and regulations of these departments. Students with the Ed Code
4FYY will initially report to the chair of the GMS Curriculum Committee, who will assign these
students to either ENY or ENP depending upon whether their interest and background is in the
area of Structural (ENY) or Non-Structural (ENP) materials. For all GMS students, a form
69 will be signed by the Head of both the Department of Aeronautics and Astronautics and the
Department of Engineering Physics.
### 4.5.6 Sample Program - 18 Month GMS Thesis Student

Master of Science in Materials Science  
September - March (18 Months)

**Short Term Review (4 weeks)**  
Mathematics  
Physics  
Computers

#### 1st Quarter

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXXX xxx</td>
<td>MATH I</td>
</tr>
<tr>
<td>MATL 560</td>
<td>Electronic, Magnetic and Optical Materials</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective/Prerequisite</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective/Prerequisite</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16</strong></td>
</tr>
</tbody>
</table>

#### 2nd Quarter

<table>
<thead>
<tr>
<th>Winter</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXXX xxx</td>
<td>MATH II</td>
</tr>
<tr>
<td>MATL 680</td>
<td>Materials Characterization</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16</strong></td>
</tr>
</tbody>
</table>

#### 3rd Quarter

<table>
<thead>
<tr>
<th>Spring</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATL 525</td>
<td>Thermodynamics and Kinetics of Materials</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Elective</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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</tr>
</tbody>
</table>

#### 4th Quarter

<table>
<thead>
<tr>
<th>Summer</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATL 799</td>
<td>Thesis Research</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14-16</strong></td>
</tr>
</tbody>
</table>

#### 5th Quarter

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATL 799</td>
<td>Thesis Research</td>
</tr>
<tr>
<td>MATL 545</td>
<td>Mechanical Properties of Materials</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12-15</strong></td>
</tr>
</tbody>
</table>
6th Quarter

Winter

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>TENY 799</td>
<td>Thesis Completion</td>
<td>12</td>
</tr>
<tr>
<td>MATL 799</td>
<td>Thesis Research</td>
<td>4-6</td>
</tr>
<tr>
<td>MATL 685</td>
<td>Materials Selection and Processing</td>
<td>4</td>
</tr>
<tr>
<td>XXXX xxx</td>
<td>Sequence/Elective</td>
<td>4</td>
</tr>
</tbody>
</table>

**TOTAL**                                                                 24-26

98-107

Note: This program is intended to be typical for a full-time Air Force quota student.

**Program Notes**

1. The purpose of this curriculum guide is to assist the student and advisor in defining the best possible curriculum for each student. The above-listed curriculum guide represents a typical course load expected of full-time, 18-month, Air Force quota students. Some of these curriculum requirements are alterable if adequate justification exists.

2. The specific program requirements for Materials Science are:
   a. Core courses in Materials Science: MATL 545, MATL 525, MATL 560, MATL 680, and MATL 685
   b. At least one graduate mathematics course or one graduate statistics course (500 level or above)
   c. One sequence, which may be determined by student's Ed Code
   d. Twelve credit hours of thesis
   e. In addition to curriculum requirements specified for the degree, a minimum course load of 12-credit hours per quarter (on average) is required for full-time Air Force quota students. For purposes of reducing latter quarter course loads, programs containing an overload (more than four courses) in the first 3 quarters may be approved in certain cases.
CHAPTER 5: RESIDENT PHD PROGRAM

5.1 Introduction

Students are admitted to study leading toward programs in Aeronautical Engineering, Astronautical Engineering, Materials Science, or Space Systems, with concentration in one of the three major divisions of the Department of Aeronautics and Astronautics. A pro-tem advisor will be appointed by the Department to assist each full-time student in program planning. Additionally, each fully-funded officer student has an educational code, the requirements of which are to be met within the appropriate division. Typical selections are shown below:

<table>
<thead>
<tr>
<th>Fluid Mechanics</th>
<th>Solid Mechanics</th>
<th>Dynamics Systems &amp; Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>4AAY</td>
<td>4AGY</td>
<td>4AFY</td>
</tr>
<tr>
<td>4AEY</td>
<td>4EGY</td>
<td>4EGY</td>
</tr>
<tr>
<td>4EEY</td>
<td>4EYY</td>
<td>4ECY</td>
</tr>
<tr>
<td>4EYY</td>
<td>4AYY</td>
<td>4EDY</td>
</tr>
<tr>
<td>4AYY</td>
<td>4MYY</td>
<td>4EYY</td>
</tr>
<tr>
<td>4MYY</td>
<td>4MFY</td>
<td>4AYY</td>
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<td>4SY</td>
<td>4FAY</td>
<td>4MYY</td>
</tr>
<tr>
<td></td>
<td>4FYY</td>
<td>4TSY</td>
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<td></td>
<td></td>
<td>OYRY</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OYRI</td>
</tr>
</tbody>
</table>

Typically, a PhD degree program in the Department consists of two phases: phase one is coursework and an examination period of six academic quarters, and phase two is dedicated to research. During phase one, all requirements for admission to candidacy (course work, examinations, and approval of research prospectus) are met. During phase two, usually lasting 18-24 months, the students devote their full attention to a research problem investigated under the direction of an approved member of the faculty of the Graduate School of Engineering and Management.

A doctoral specialty may be pursued in any of the areas of concentration within the Department. Specialty coursework generally consists of one or more graduate sequences, augmented by the more advanced courses, which are offered for doctoral students. Students interested in a doctoral program should discuss those interests with a member of the department who is actively engaged in research in an area of interest to the student.
5.2 Admission Criteria

Admission to the PhD program is made by the Department following policies set down by the AFIT Doctoral Council. There is no set formula for admission, but the following are target minimum criteria:

- a quality BS program with grades averaging at least 3.00;
- a quality MS program with grades averaging at least 3.50;
- the successful completion of an MS thesis (desirable);
- endorsement by the student's MS faculty, especially by the MS thesis advisor; and
- GRE scores on the verbal and quantitative that sum to 128 percentile or greater, which is typically 156 verbal and 151 quantitative. The previous standard under the old scoring was 1200 total, with a desired minimum of 550 verbal and 650 quantitative.

5.3 Types of Programs

5.3.1 Regular Programs (Fully-Funded)

Each year, assignments directly into the PhD programs are sought for a few of the most outstanding AFIT graduates of the resident MS programs. Volunteers who have qualified for admission by applying annually through Admissions (AFIT/ENER) fill the remainder of the annual quota.

5.3.2 Civilian Long-Term, Full-Time Training

Civilian employees sponsored by their organization may use AFIT for full-time, long-term training programs. Candidates are encouraged to precede their full-time assignment with a period of part-time study and to consider developing an arrangement whereby the research for the dissertation may be conducted "on the job" after returning to their own organization.

5.3.3 Civilian Employees of AFMC

A special program for civilian employees of Air Force Research Laboratories has been developed. The AFIT/AFMC PhD program consists of three phases: part-time course work, full-time course work for one year, and dissertation research at or for the sponsoring laboratory. The entry requirement includes a Master's degree in engineering or science either from AFIT or elsewhere. During the part-time phase the student will take one or two courses per academic term. These courses should be selected in consultation with the part-time advisor as part of an overall plan. Procedures for enrolling and registering as a part-time student are given elsewhere in this document.
The student may progress to the full-time phase when the following three conditions are met:

a. First, the student can complete the remaining courses and examinations (including the defense of prospectus) in one year (12 months) of full-time schooling. To increase the probability of meeting this requirement, the Department of Aeronautics and Astronautics normally requires candidates for admission to the full-time phase to have completely satisfied one of two segments (mathematics, specialty core).

b. Second, the student has identified, been accepted by, and received departmental approval of a prospective research advisor.

c. Finally, the sponsoring AFMC organization agrees to release the student for full-time study.

At the end of one year of full-time study, the student is expected to have formed a research committee and successfully proposed and defended a research prospectus to that committee. The chair of the research committee will be a full-time member of the AFIT faculty. The prospectus will have the approval of the chief scientist of the student's laboratory as well as of the committee. At that time the student may be formally admitted to candidacy for the PhD degree. The student will return to the laboratory to complete the research. It is expected that the research will require two years of full-time effort. It is important that AFIT/AFMC PhD students not be assigned other duties during the research phase.

**NOTE:** This program may be extended to employees of other scientific and engineering organizations at Wright-Patterson AFB.

### 5.4 Requirements

#### 5.4.1 Coursework and Examinations

The PhD academic course work requirements are at least 36 quarter credit hours to include: (a) a minimum of 24 hours in the major area, and (b) 12 hours in mathematics. Additionally, the students must successfully complete: (a) a specialty examination in the major area, and (b) a defense of the prospectus, which may include further examination over the major.

#### 5.4.2 Residence

The residence requirement of three quarters of full-time study is to be met within a four-quarter period.

#### 5.4.3 Research and Dissertation

At least 48 hours of research must be completed under the supervision of an approved research advisor (also the chair of the research committee), who must be a full-time faculty member in the Graduate School of Engineering and Management. A prominent laboratory scientist or other scientist or engineer may be a member of the committee, but members of the full-time AFIT or
DAGSI faculty must constitute a majority of the committee. Finally, a suitable dissertation must be completed, defended and accepted. In selecting a research topic, students who are fully-funded officers must ensure that the research subject is appropriate to the assigned educational code. Admission to candidacy must be approved no later than four years from the beginning of the first course in the approved program, and graduation must occur no later than four years after admission to candidacy.

5.4.4 Policies and Procedures

A complete list of policies and procedures can be found in (a) the Doctoral Council Policy Letters located at the AFIT Homepage, and (b) the ENY Department Supplement, “Doctoral Committee Policies,” available in the ENY Department main office.
CHAPTER 6: SPECIALTY SEQUENCE DESCRIPTIONS

Most graduate programs require the completion of at least two approved specialty sequences. A wide variety is available to meet certain Air Force education requirements and to permit the development of programs tailored to meet special requirements. Certain sequences are approved for the various curricula. Others may be approved by the department to meet a special educational requirement. Those sequences, which are offered annually, are described on the following pages. In several cases, more advanced courses (primarily intended for doctoral students) are available as electives to students who have completed sequence requirements. The academic advisor may allow or disallow certain sequences for certain majors/backgrounds.

Specialty sequences currently available in ENY as well as those identified as part of a program for ENY students in Chapter 4 are:

Advanced Astrodynamics
Aerodynamics
Aeroelasticity
Aerospace Navigation
Air Breathing Propulsion
Air Weapons
Aircraft Stability and Control
Alternative Energy Systems
Astrodynamics
Astrodynamics Re-Entry
Computational Fluid Dynamics
Control and Optimization Theory
Electronic and Optical Materials
Finite Element Analysis
Heat Transfer

Hypersonics
Mechanics and Control of Space Structures
Optimization
Reliability
Rocket Propulsion
Space Control
Space Facilities
Space Navigation
Space Systems
Space Vehicle Design
Structural Analysis
Structural Materials
Systems Engineering
Unmanned Systems
Vibration Damping and Control
**Advanced Astrodynamics**

Courses in this sequence prepares students to do orbital mission analysis, re-entry, and orbit determination by using techniques of orbital analysis developed through special and general perturbations, and considers nonlinear resonance and the effects of the geopotential, air drag, and lunisolar perturbations. Courses in basic orbital mechanics are prerequisites to this sequence. Choose three from the following:

- **MECH 720** - Analytical Mechanics  
  - **WI**
- **MECH 732** - Advanced Astrodynamics  
  - **SP**
- **MECH 731** - Modern Methods of Orbit Determination  
  - **SU**
- **MECH 733A** - Numerical Methods for Orbit Design  
  - **SU**

**Aerodynamics**

Prepares students to perform the computations needed to determine aircraft performance characteristics, e.g., lift, drag and aerodynamic coefficients. Emphasis is given to the mathematical modeling and solution of flow problems peculiar to external aerodynamics. Knowledge of perfect fluid theory and compressible aerodynamics is presumed. Choose two courses to take with AERO 634 to complete the three-course sequence.

- **AERO 634** - Viscous Flow Theory (Required)  
  - **WI**
- **AERO 537** - Advanced Aerodynamics  
  - **WI**
- **AERO 729** - Theory of Gases for Aerodynamics and Propulsion  
  - **SP**
- **AERO 622** - Introductory Hypersonics  
  - **WI**
- **AERO 627** - Turbulence  
  - **SU**

**Aeroelasticity**

This sequence of courses is intended to provide students with a background in the analysis of systems that are simultaneously subjected to dynamic, structural, and aerodynamic loads. It is particularly relevant for those students wishing to pursue careers in aircraft model and flight test. Students are expected to have taken courses in aerodynamics, dynamics, and structures at least at the undergraduate level.

- **MECH 500** - Fundamentals of Solid Mechanics  
  - **FA**
  or **MECH 545** - Aerospace Structural Analysis  
  - **WI**
- **MECH 515** - Theory of Vibrations  
  - **FA**
- **MECH 662** - Introduction to Aeroelasticity  
  - **SP**
  or **AERO 610** - Rotorcraft Aeromechanics  
  - **WI**
Aerospace Navigation

The purpose of the Navigation Systems sequence is to provide the student with the necessary background to enable an individual to design, analyze, test, and evaluate modern navigation components and systems to meet current Air Force requirements. Throughout the sequence, the emphasis is placed on advanced components and systems, implementation methods accounting for sensor limitations, computer limitations, and on algorithms. Primary emphasis is on inertial navigation systems, the Global Positioning System (GPS), and integrated navigation systems combining the two.

EENG 533 - Navigation using the Global Positioning System WI
EENG 534 - Fundamentals of Aerospace Components & Systems FA
EENG 635 - Inertial Guidance & Control of Aerospace Vehicles WI
EENG 735 - Navigation Systems Analysis & Integration (Recommended) SP
EENG 633 - Advanced GPS Theory and Applications (Recommended) SP

Air Breathing Propulsion

This sequence of courses equips the student for preliminary analysis and design of ramjet and gas turbine type propulsion devices. It is intended for those who will be assigned in the areas of engine development, procurement, and/or evaluation, as well as those responsible for the propulsion system aspects of flight vehicle development, application, and maintenance. The student should have a background in thermodynamics and gas dynamics.

MENG 633 - Fundamentals of Combustion FA
MENG 732 - Advanced Turbomachinery SP
MENG 585 - Air Breathing Engine Design SU

If one of the above courses (or an equivalent course) has already been taken or is being used to meet another sequence’s requirements, the course below may be used as a substitution, pending approval of this sequence’s faculty POC.

AERO 729 - Theory of Gases for Aerodynamics and Propulsion FA
**Air Weapons**

This sequence prepares students for research and development activities in the field of weapons systems engineering. A background including such undergraduate core subjects as dynamics, mechanics of materials and fluid mechanics is presumed.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASYS 630</td>
<td>Analysis and Design for Weapons Delivery (Required)</td>
<td>FA</td>
</tr>
<tr>
<td>ASYS 640</td>
<td>Survivability Analysis and Design (Required)</td>
<td>SP</td>
</tr>
<tr>
<td>ASYS 635</td>
<td>Conventional Explosives &amp; Effects</td>
<td>WI</td>
</tr>
<tr>
<td>or</td>
<td>EENG 533 - Navigation Using the Global Positioning System</td>
<td>WI</td>
</tr>
<tr>
<td>or</td>
<td>CSCE 525 - Introduction to Cyber Warfare and Security</td>
<td>SU/FA</td>
</tr>
</tbody>
</table>

**Aircraft Stability and Control** (Recommended for TPS Students)

This sequence enables the student to model the dynamics and aerodynamics of flight vehicles, to determine flight vehicle response to initial conditions, random and control inputs and to design flight control systems using both classical and modern control theory. Basic courses in aircraft stability and linear systems are required as prerequisites to the sequence.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASYS 565</td>
<td>Control and State Space Concepts</td>
<td>WI</td>
</tr>
<tr>
<td>MECH 628</td>
<td>Aircraft Control</td>
<td>SP</td>
</tr>
<tr>
<td>MECH 629</td>
<td>Aircraft Handling Qualities</td>
<td>SU</td>
</tr>
</tbody>
</table>
**Alternative Energy Systems**

This sequence is intended to provide a coherent course of study for graduate engineering students interested in pursuing thesis topics in the area of alternative energy and advanced propulsion systems for micro air vehicles (MAVs), small unmanned aircraft systems (UASs), and high-altitude long-endurance (HALE) aircraft. The sequence is three courses. At least one of the courses must be an AFIT course selected from the following list. An independent study course could also be substituted for one of the AFIT courses listed below.

- AERO 729 - Theory of Gases for Aerodynamics and Propulsion  SP
- AERO 585 - Aerospace System Design  SU
- MECH 620 - Systems Optimization  WI
- MENG 501 - Aerospace Propulsion  FA
- MENG 633 - Fundamentals of Combustion  FA
- MENG 732 - Advanced Turbomachinery  SP
- MENG 585 - Air Breathing Engine Design  SU

Up to two courses may be chosen from the following list:

- Wright State University:
  - ME623-Energy Conversion
  - ME624-Solar Engineering
  - ME644-Internal Combustion Engines
  - ME890-Hydrogen Energy
  - ME890-Photovoltaics

- University of Dayton:
  - MEE524-Fuel Cell Fundamentals and Technology
  - MEE526-Aerospace Fuels
  - MEE568-Advanced Transportation Power
  - MEE571-Design of Thermal Systems
  - MEE573-Renewable Energy Systems
  - MEE590-Energy Harvesting

**Astrodynamic Re-Entry**

This sequence provides the student with an understanding of the dynamics of vehicles/objects entering a planetary atmosphere. Students also gain insight into the related areas of heat transfer, high-speed aero, and/or trajectory optimization.

- MECH 637 - Astrodynamic Re-Entry  FA
- MENG 571 - Fundamentals of Heat Transfer  WI

Choose one of the following:

- MECH 622 - Functional Optimization and Optimal Control  SP
- AERO 537 - Advanced Aerodynamics  WI
- AERO 622 - Introductory Hypersonics  WI
**Astrodynamics**

This sequence provides the student with an understanding of the dynamics of space vehicles. Students also gain insight into the issues of orbit design and orbit determination. Choose 3 of the following (must include MECH 637 and/or MECH 731 and/or MECH 733A):

- **MECH 521** - Intermediate Dynamics  
  FA
- **MECH 532** - Introductory Space Flight Dynamics  
  FA/WI
- **MECH 632** - Intermediate Space Flight Dynamics  
  SP
- **MECH 637** - Astrodynamical Re-Entry  
  FA
- **MECH 731** - Modern Methods of Orbit Determination  
  SU
- **MECH 733A** - Numerical Methods for Orbit Design  
  SU

**Computational Fluid Dynamics**

Computational methods for solving equations of motion for fluid mechanics and their various special cases are addressed. For this sequence, the student should have some knowledge of linear algebra and a good background in Fortran (or other programming language) and fluid dynamics (compressible, viscous and turbulent flows).

- **AERO 543** - Adv Computational Modeling for Aerodynamics  
  (Optional)  
  SP
- **AERO 551** - Numerical Methods for Computational Fluid Dynamics  
  FA
- **AERO 640** - Hypersonic Computational Fluid Dynamics  
  (Optional)  
  SP
- **AERO 652** - Computational Fluid Dynamics  
  WI
- **AERO 753** - Adv Computational Fluid Dynamics  
  SP
**Control and Optimization Theory**

This sequence enables the student to formulate and solve a broad class of optimization problems related to the design and control of aerospace systems. Variational calculus and Pontryagin's Maximum Principle have direct application in optimization for aircraft flight performance and in spacecraft and robot trajectory planning. Modern optimal control based on these principles finds use in the multivariable control requirements of aerospace systems. Robust control techniques make it possible to ensure stability and some measure of performance in the face of uncertainty, and non-linear control methods offer alternatives to the traditional method of linearization and gain scheduling. Prerequisite for the sequence is a basic course in linear systems analysis. MATH 521 (Linear Algebra) is a recommended elective that complements this sequence. Only one optimization course can be used to satisfy the requirements of this sequence. Choose two courses to take with ASYS 565 to complete this sequence.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASYS 565</td>
<td>Control and State Space Concepts (Required)</td>
<td>WI</td>
</tr>
<tr>
<td>ASYS 765</td>
<td>Robust Control</td>
<td>SP</td>
</tr>
<tr>
<td>EENG 765</td>
<td>Stochastic Estimation and Control</td>
<td>WI</td>
</tr>
<tr>
<td>ASYS 625</td>
<td>Non-Linear Systems Analysis and Control</td>
<td>SU</td>
</tr>
<tr>
<td>MECH 620</td>
<td>Systems Optimization</td>
<td>WI</td>
</tr>
<tr>
<td>MECH 622</td>
<td>Functional Optimization and Optimal Control</td>
<td>SP</td>
</tr>
</tbody>
</table>

**Electronic and Optical Materials**

This sequence provides a foundation in chemical and physical properties of materials that are important to electronics and optics applications. The sequence is most beneficial to those who will be modeling, analyzing or conducting experiments related to electrical or optical aerospace systems.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATL 620</td>
<td>Chemistry of Materials</td>
<td>FA</td>
</tr>
<tr>
<td>PHYS 670</td>
<td>Introduction to Solid State Physics</td>
<td>SP</td>
</tr>
<tr>
<td>MATL 672</td>
<td>Optical Properties of Materials</td>
<td>SU</td>
</tr>
</tbody>
</table>
Finite Element Analysis

This sequence is designed to give the student a background in the use and practical application of finite element analysis as it applies to structural materials. The sequence is most beneficial to those who will be assigned to analysis groups, which use finite element methods to model structures for either static or dynamic applications. Students will be capable of developing finite element computer codes or modifying and supplementing existing codes to solve current problems. The prerequisites for the sequence are a good background in matrix algebra, analysis of simple structural members, and computer programming.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>MECH 500</td>
<td>Fundamentals of Solid Mechanics</td>
<td>FA</td>
</tr>
<tr>
<td>MECH 542</td>
<td>Intro to Fin Elem Analysis &amp; Computer-Aided Design</td>
<td>WI</td>
</tr>
<tr>
<td>MECH 642</td>
<td>Finite Element Methods for Structural Analysis I</td>
<td>SP</td>
</tr>
<tr>
<td>MECH 644</td>
<td>Finite Element Methods II</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(not currently scheduled but please see advisor if course is desired)</td>
<td></td>
</tr>
</tbody>
</table>

Heat Transfer

This sequence is designed to provide the fundamentals regarding viscous and thermal energy processes. These courses provide a coherent course of study for aeronautical engineering students interested in pursuing thesis topics in the area of turbine heat transfer, combustor heat transfer, thermal management, pulse detonation engines, internal combustion engines, and others.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>MENG 571</td>
<td>Fundamentals of Heat Transfer (Required)</td>
<td>WI</td>
</tr>
<tr>
<td>MENG 633</td>
<td>Fundamentals of Combustion</td>
<td>FA</td>
</tr>
<tr>
<td>AERO 634</td>
<td>Viscous Flow</td>
<td>WI</td>
</tr>
<tr>
<td>MENG 674</td>
<td>Convection Heat Transfer</td>
<td>SP</td>
</tr>
<tr>
<td>MENG 673</td>
<td>Radiation Heat Transfer</td>
<td>SP</td>
</tr>
</tbody>
</table>
Hypersonics

This course sequence prepares students for research and study into the highly complex aerodynamics, physics, and chemistry of flight at speeds in excess of Mach 5. Participation in either the Aerodynamics course sequence or the Computational Fluid Dynamics sequence is recommended as an adjunct to this course sequence. In addition, US Citizenship is required for the AERO 640 class. An Aerospace Engineering background is further assumed. Students must take three of the following courses.

AERO 622 – Introduction to Hypersonics  WI
AERO 729 – Theory of Gases for Aerodynamics and Propulsion  SP
AERO 640 – Hypersonic Computational Fluid Dynamics  SP
AERO 740 – Nonequilibrium Hypersonic Flows  FA

Mechanics and Control of Space Structures

Prepares students to analyze the dynamics and control of both rigid and flexible spacecraft.

MECH 515 - Theory of Vibrations  FA
ASYS 765 - Robust Control  SP
MECH 719 - Vibration Damping and Control  FA

Optimization

Optimization provides the tools and techniques necessary to develop balanced designs, which are subject to one or more constraints. Take MECH 620 and two more classes from the following list:

OPER 510 - Introduction to Mathematical Programming  FA/WI
OPER 610 - Linear Programming  WI/SP
OPER 612 - Nonlinear Programming  FA/SU
MECH 620 - Systems Optimization  WI
OPER 613 - Integer Programming  SU
OPER 615 - Large-scale System Optimization  WI
MECH 622 - Functional Optimization and Optimal Control  SP
MECH 646 - Structural Optimization  SU
Reliability

This sequence enables the student to identify and model mathematically the reliability of functional types of operational systems. These statistically based courses explore applications to components and systems, which demonstrate various operations failure, and restoration distributions. Courses in probability and statistics are prerequisites for the sequence.

SENG 585 - Reliability in Systems Design  FA/WI/SP
SENG 685 - Reliability Engineering  SP
SENG 687 - Advanced Topics in Reliability  SU
or
STAT 687 - Mathematics of Reliability Theory I  FA SU
or
OPER 746 - Advanced Topics in Reliability  FA/WI

Rocket Propulsion

This sequence of courses is intended to provide students with a background in propulsion and energy systems as required for R&D assignments in rocket and missile systems. A course including high-speed internal flows is required as a prerequisite or may be waived by permission of the instructor.

MENG 633 - Fundamentals of Combustion  FA
MENG 530 - Chemical Rocket Propulsion  WI
MENG 531 - Space Propulsion and Power Systems  SU

Space Control

This sequence of courses provides students with an understanding of emerging space control concepts, including the analysis of spacecraft failures and reliability, an examination of spacecraft survivability, the exploration of rendezvous and proximity operations, and the robust modeling and simulation techniques relevant to the space domain.

ASYS 633A - Spacecraft Safety & Survivability  SP
MECH 633A - Spacecraft Maneuver & Rendezvous  SU

And one of the following:

ASYS 733A - Space Domain Combat Modeling  SP
MECH 733A - Modern Methods for Orbit Design  SU
SENG 621 - Space Mission Modeling and Simulation  WI
Space Facilities

This sequence of courses provides graduate astronautical students, in the space facilities specialty, the necessary background for their roles in the development of large permanent space facilities. This sequence is approved for students with a 4EFY Ed Code only.

MENG 530 - Chemical Rocket Propulsion WI
MECH 515 - Theory of Vibrations FA
MENG 531 - Space Propulsion and Power Systems SU

Space Navigation

This sequence provides understanding of current methods of determining the location of aerospace vehicles. Knowledge of orbit mechanics is a necessary prerequisite.

EENG 533 - Navigation using the Global Positioning System WI
MECH 731 - Modern Methods of Orbit Determination SU

And one of the following:
EENG 534 - Fundamentals of Aerospace Instruments and Navigation Systems FA
EENG 633 - Global Navigation Satellite System Receiver Design SP
EENG 765 - Stochastic Estimation & Control I WI
ASYS 765 - Robust Control SP
Space Systems Design

This sequence is designed to give students broad knowledge of past and current space systems. It will also provide an in-depth understanding of how typical spacecraft subsystems are designed and integrated into an operational vehicle. This sequence is only for non-GSS and non-GA students:

ASYS 631 - Spacecraft Systems Eng  SP

and two of the following:

ASYS 531 - Space Mission Analysis & Sys Design  WI

ASYS 530 - Introduction to Space Programs and Operations  FA/WI/SP

--or--

ASYS 535 - Military Space Systems and Applications  FA/WI/SP

MECH 532 - Introductory Space Flight Dynamics  FA/WI

MECH 632 - Intermediate Space Flight Dynamics  SP

PHYS 519 - The Space Environment  FA/SU

PHYS 521 - Space Surveillance  FA/WI/SP

EENG 571 - Satellite Communications  WI

EENG 533 - Navigation Using the Global Positioning System  WI

MENG 673 - Radiation Heat Transfer  SP

Space Vehicle Design

This sequence is designed to give students in-depth knowledge of all aspect of spacecraft design and test. The sequence combines analytical design with laboratory tests of spacecraft systems.

ASYS 531 - Space Mission Analysis & Sys Design  WI

ASYS 631 - Spacecraft Systems Eng  SP

ASYS 632 - Satellite Design & Test  SU
**Structural Analysis**

This sequence prepares students to perform detailed analysis of complex aerospace structures. Any course used as part of one sequence may not be counted in another sequence.

- **MECH 500** - Fundamentals of Solid Mechanics  FA
- **MECH 600** - Elasticity  WI
- **MECH 601** - Introduction to Time-Dependent Material Behavior  SU
- **ASYS 632** - Satellite Design & Test  SU

**Structural Design and Test**

This sequence prepares students to design structures and then analyze their structural performance.

- **MECH 542** - Intro to Finite Element Analysis  WI
- **MECH 642** - Finite Element Methods for Structural Analysis  SP
- **MECH 515** - Theory of Vibrations  FA
- **MECH 719** - Vibration Damping and Control  FA

**Structural Materials**

This sequence of courses provides a treatment of advanced topics in modern aerospace materials and material-related design problems. The approach taken is that of mechanics rather than metallurgy.

- **MECH 500** - Fundamentals of Solid Mechanics  FA
  or  **MECH 545** - Mechanical Properties of Materials  SU
- **MECH 541** - Mechanics of Composite Materials  WI
- **MECH 601** - Introduction to Time-Dependent Material Behavior  SU
  and/or
- **MECH 605** - Fracture Mechanics  SP
- **MATL 545** - Mechanical Properties of Materials (Optional)  FA
Systems Engineering Sequence and Certificate

The Department of Systems Engineering and Management (AFIT/ENV) offers a Systems Engineering Certificate (SEC). The Certificate can be earned as a minor concentration sequence within our ENY programs. As most engineers across the Air Force perform many systems engineering activities, these courses provide techniques to specific, design, analyze, and develop complex military systems. Such knowledge and skills include: modern model-based systems engineering (MBSE), agile software development, System Modeling Language (SysML), architecture frameworks, and project management. Student can any take 3 courses for an ENY sequence, or take all 4 to earn the SE Certificate. All courses are offered in both resident and online/ distance learning (DL) modalities.

SENG 520 - Systems Engineering Design FA (IR/DL)
SENG 593 - Agile Software System Engineering FA (IR) / WI (DL)
SENG 640 - System Architecture WI (IR) / SP (DL)
Prerequisite: SENG 520
SENG 610 - Project Management SP (IR) / SU (DL)

Unmanned Airborne Systems Sequence

The Department of Systems Engineering and Management (AFIT/ENV) also offers a 3 course sequence in the design, development and flight test of small unmanned airborne systems (UAS). This sequence attracts students from several programs and Departments. The sequence is similar to the Space Systems sequence of ASYS 531, ASYS 631 and ASYS 632, but for airborne autonomous systems. The sequence will take students through the system lifecycle, including mission area analysis, definition of operational need, concept formulation, analysis of alternatives, system requirements refinement, architecture, preliminary design, detailed design, build, test and fly. This is an intensive hands-on engineering activity. A sponsored project will guide the sequence that provides a relevant educational experience on fixed and rotatory unmanned systems, while providing a prototype solution and mission analysis to the sponsor. Note: as multidisciplinary groups are formed early and maintained across the three courses; students must take all 3 courses. This track is essential for any student that plans on conducting small unmanned flight testing as part of their thesis.

SENG 550 - SUAS: Concept Definition & Prelim Design WI
Prerequisite: ASYS525 or equivalent Linear Systems course
SENG 650 - SUAS: Design SP
SENG 651 - SUAS: Build and Test SU

The addition of a 4th course from the Department of Electrical and Computer Engineering, EENG 550 Introduction to Autonomy, will allow the student to earn a Graduate Certificate in Autonomy.

EENG 550 Introduction to Autonomy FA
**Vibration Damping and Control**

This sequence prepares students to analyze structural vibrations and design effective and efficient vibration suppression schemes using either passive or active means, preparing students for R&D assignments in either air or space technology. Courses in basic dynamics and linear systems are prerequisites for this sequence.

- **ASYS 565** - Control and State Space Concepts  
  WI
- **MECH 515** - Theory of Vibrations  
  WI
- **MECH 719** - Vibrations Damping and Control  
  FA

**NOTE:** GAE students are required to take ASYS 565. GA students are required to take MECH 500. GMS, GSE, and GSS students are required to take ASYS 565.
CHAPTER 7: THESIS

7.1 Thesis Topic and Faculty Advisor Selection

Thesis topic selection is an important choice in your AFIT program. Full-time thesis students will attend the short course review before the start quarter to help you become familiar with the department faculty and the research topics available. Due to a shortage of students needed to perform funded research, you may be required to select a funded topic. The time to make your selection of a thesis advisor is during the first quarter. You must submit a topic selection statement signed by your advisor and yourself by the end of the fourth week of the second quarter. This statement is a one-line identification of your general topic and the faculty advisor. A template of the statement is located in the L:\Research\ENY THESISTOPICLTR&Prospectus folder. A printed copy signed by the student, thesis advisor, and Department Head will be turned into the Department Education Technician.

7.2 Preparation of the Prospectus

Once you have chosen a topic and a faculty member has agreed to be your thesis advisor, your next task is to prepare a prospectus. Generally, this is done by the end of the 10th week of the second quarter but must be completed before the beginning of the 1st quarter for which the student Ed Plan has AERO 799 credit. Out-of-department theses need to be enrolled for that department’s AERO 799 equivalent. The prospectus is used for several purposes: assignment of advisory committee, allocation of laboratory resources, and the safety review of experimental theses. A template is located in the L:\Research\ENY THESISTOPICLTR&Prospectus folder. Completion of the prospectus is electronically sent to the thesis advisor and, if accepted, the advisor will forward it to a Department Education Technician. The memorandum should include the following information:

a. Your name
b. Tentative title
c. Name of thesis advisor
d. A short description, to include what you propose to do, how you propose to do it, and the nature and utility of the anticipated results
e. Required support, i.e., laboratory facilities and/or computers
f. Suggested committee members
g. Sponsor name and organization (if any)
h. Sequences / Options
7.3 Thesis Advisory Committee

There are two or more committee members besides your advisor on your thesis committee. All three vote on your thesis grade. Sponsors and other people related with the thesis research may be non-voting readers. Committee members may be from other departments, but, if so, the members should be asked to initial the prospectus to indicate their willingness to serve on your committee.

7.4 Progress Reporting

You will be required to report your progress to your thesis committee on a regular basis. Your advisor will delineate this requirement.

7.5 General Thesis Information

7.5.1 Style and Format

"A Style Guide for Theses and Dissertations," is published by AFIT and available for students on the AFIT website or a paper copy available in the Research Department. The style guide explains in detail all mandatory requirements to be met. Your thesis advisor may impose additional stylistic requirements.

In particular, you will need to pay as much attention to the clarity and margins of your figures and computer listings as you do to the thesis text. All must pass the standards of the Defense Technical Information Center, and if not sufficiently legible, the thesis will not be accepted for distribution.

7.5.2 Classified Theses

If you use any information that will cause your thesis to have other than unlimited distribution, coordinate carefully with your thesis advisor (and sponsor if you have one). Classified MS theses are permitted.

7.5.3 Thesis Designator

The Thesis Processing Center will assign a thesis designator for each thesis. The typical thesis designator is of the form AFIT-ENY-MS-YY-M-XXX, where YY-M-XXX denotes graduation year and month, and sequence number of your thesis (e.g., 18-M-001.) The ENY denotes that your thesis advisor is a faculty member of the Department of Aeronautics and Astronautics (AFIT/ENY) and that you have registered for the course AERO 799. This will be different for out-of-department theses.
### 7.5.4 Thesis Due Dates

<table>
<thead>
<tr>
<th>ITEM</th>
<th>PROGRAM WEEK</th>
<th>POINT OF CONTACT</th>
<th>2020M DATE(S) (Estimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education Plan Completed and signed by All</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; qtr – week 1</td>
<td>Dept Office Support / Advisor</td>
<td>6 Oct 2018</td>
</tr>
<tr>
<td>Thesis topic and Advisor selected - turn in memo with signatures</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; qtr – week 4</td>
<td>Dept Office Support</td>
<td>25 Jan 2019</td>
</tr>
<tr>
<td>Prospectus submitted to Thesis Advisor electronically</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; qtr – week 10</td>
<td>Dept Office Support</td>
<td>10 Mar 2019</td>
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<tr>
<td>Thesis designator number assigned</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 1</td>
<td>Thesis Processing Center</td>
<td>3 Jan 2020</td>
</tr>
<tr>
<td>Draft of Thesis to Advisor</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 6</td>
<td>Advisor</td>
<td>7 Feb 2020</td>
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<tr>
<td>Draft of Thesis to readers</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 6</td>
<td>Readers</td>
<td>3-6 Feb 2020</td>
</tr>
<tr>
<td>Thesis Presentation Day</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 8</td>
<td>Dept Office Support</td>
<td>17-20 Feb 2020</td>
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<tr>
<td>Original Thesis, all copies &amp; forms submitted</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 10</td>
<td>Thesis Processing Center</td>
<td>6 Mar 2020</td>
</tr>
<tr>
<td>End of program review</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 12</td>
<td>Dept Office Support</td>
<td>17 Mar 2020</td>
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<td>GRADUATION</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 12</td>
<td>Student Services/ Dept Office Support</td>
<td>19 Mar 2020</td>
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<table>
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<tr>
<th>ITEM</th>
<th>PROGRAM WEEK</th>
<th>POINT OF CONTACT</th>
<th>2020M DATE(S) (Estimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education Plan Completed and signed by All</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; qtr – week 1</td>
<td>Dept Office Support / Advisor</td>
<td>4 Oct 2019</td>
</tr>
<tr>
<td>Thesis topic and Advisor selected - turn in memo with signatures</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; qtr – week 4</td>
<td>Dept Office Support</td>
<td>31 Jan 2020</td>
</tr>
<tr>
<td>Prospectus submitted to Thesis Advisor electronically</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; qtr – week 10</td>
<td>Dept Office Support</td>
<td>13 Mar 2020</td>
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<tr>
<td>Thesis designator number assigned</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 1</td>
<td>Thesis Processing Center</td>
<td>8 Jan 2021</td>
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<td>Draft of Thesis to Advisor</td>
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<td>12 Feb 2021</td>
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<td>Draft of Thesis to readers</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 6</td>
<td>Readers</td>
<td>8-12 Feb 2021</td>
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<tr>
<td>Thesis Presentation Day</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 8</td>
<td>Dept Office Support</td>
<td>22-25 Feb 2021</td>
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<tr>
<td>Original Thesis, all copies &amp; forms submitted</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 10</td>
<td>Thesis Processing Center</td>
<td>12 Mar 2021</td>
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<tr>
<td>End of program review</td>
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<td>Dept Office Support</td>
<td>23 Mar 2021</td>
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<td>GRADUATION</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; qtr – week 12</td>
<td>Student Services/ Dept Office Support</td>
<td>25 Mar 2021</td>
</tr>
</tbody>
</table>
7.5.5 Grade Determination/Incomplete

The grade on the thesis is a collective decision reached by the entire committee. Your faculty advisor will give you your thesis grade. If you do not complete your thesis in time, you will receive the grade of "Incomplete" and will not graduate with your section. Further, before leaving AFIT you will be required to develop a schedule, approved by the thesis advisor and department head, for completion with new dates. Failure to develop such a schedule will lead to the grade of "F" being assigned at the end of the 6th week of the following quarter.
### 7.5.6 Thesis Grading Guidelines

<table>
<thead>
<tr>
<th>Factor</th>
<th>A</th>
<th>A-</th>
<th>B+</th>
<th>B</th>
<th>≤ B-</th>
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</thead>
<tbody>
<tr>
<td>Technical Accuracy</td>
<td>Extremely rigorous and accurate</td>
<td>Accurate work</td>
<td>Questionable accuracy</td>
<td>Minor inaccuracies</td>
<td>Significant inaccuracies</td>
</tr>
<tr>
<td>Contribution to Field</td>
<td>Innovative and important</td>
<td>Significant</td>
<td>Some relevance</td>
<td>Little relevance</td>
<td>No relevance</td>
</tr>
<tr>
<td>Initiative/Independence</td>
<td>Go-getter</td>
<td>Significant self-directed progress and ideas</td>
<td>Works well under supervision</td>
<td>Required close supervision</td>
<td>Extremely close supervision</td>
</tr>
<tr>
<td>Level of Effort</td>
<td>Dedicated and very hard working</td>
<td>Hard Working</td>
<td>Significant Effort</td>
<td>Some effort</td>
<td>Little effort</td>
</tr>
<tr>
<td>Problem Difficulty/Scope</td>
<td>Difficult problem and/or many issues addressed</td>
<td>Significant problem</td>
<td>Straightforward problem with little risk</td>
<td>Easy problem</td>
<td>Comparable to a class project</td>
</tr>
<tr>
<td>Publishable</td>
<td>Journal</td>
<td>Conference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thesis Document/Defense</td>
<td>-Very clear, concise, complete, organized -Exceptionally strong understanding</td>
<td>-Clear, concise, complete, organized -Demonstrates good understanding</td>
<td>-Sometimes unclear &amp; difficult to follow -Understanding appears tenuous</td>
<td>-Poorly expressed ideas, incomplete -Some lack of understanding</td>
<td>-Muddled and disorganized -Major lack of understanding</td>
</tr>
<tr>
<td>Editing (First Draft)</td>
<td>Minor Modification</td>
<td>Some Reworking</td>
<td>Significant Reworking</td>
<td>Extensive Reworking</td>
<td>Deficient</td>
</tr>
</tbody>
</table>
CHAPTER 8: FACULTY

8.1 Faculty Summary

Fluid Mechanics and Energy Transmission
- Bohan
- Greendyke
- Komives
- Lingenfelter
- Polanka
- Reeder
- Rutledge
- Schauer
- Thomas
- Walker

Dynamics, Systems, and Controls
- Ayres
- Bettinger
- Cobb
- Grandhi
- Hess
- Hartsfield
- Johnson
- Keys
- Kunz
- Liebst
- Wiesel
- Zagaris

Solid Mechanics and Structures
- Grandhi
- Kemnitz
- Palazotto
- Ruggles-Wrenn
8.2 Adjunct Faculty

Dr. Bradley J. Ayres
BS, MS, PhD
Adjunct Assistant Professor
AFIT/ENY

Dr. Jonathan T. Black
BS, MS, PhD
Adjunct Associate Professor
Virginia Tech

Capt Matthew P. Clarey
BS, MS, PhD
Adjunct Assistant Professor (till Apr 2022)
AFRL/RXSS

Lt Col Darrell S. Crowe
BS, MS, PhD
Adjunct Assistant Professor
AFRL/RQQ

Dr. Tabitha E. Dodson
BS, MS, PhD
Adjunct Assistant Professor (till July 2020)

Maj David Liu
BS, MS, PhD
Adjunct Assistant Professor
AFLCMC/EB

Dr. Christopher L. Martin, Jr
BS, MS, PhD
Adjunct Assistant Professor
Lockheed Martin Missile and Fire Control

Mr. David W. Meyer
BS, MS
Adjunct Instructor (till July 2021)
AFIT/ENY
8.3 Faculty Biographies

Ayres, Bradley J.
Visiting Assistant Professor of Systems Engineering, 255-3355 x3422

BS, Chemical Engineering, University of Missouri, Columbia, 1982; M.A., Procurement and Acquisition Management, Webster University, St. Louis, 1991; M.S., Software Systems Management, Air Force Institute of Technology, 1992; Ph.D., Business Administration specializing in MIS, Florida State University, 2003. Dr. Ayres' research interests include management of complex systems, model-based systems engineering, and space systems engineering. He is a member of the Project Management Institute, the International Council on Systems Engineering, and AIAA.
E-mail: Bradley.Ayres.ctr@afit.edu

Bettinger, Robert A., Maj, USAF
Assistant Professor of Aerospace Engineering, 255-3636 x4578

BS, Astronautical Engineering, United States Air Force Academy, 2007; MA, History, American Public University, 2010; MS, Astronautical Engineering, Air Force Institute of Technology, 2011; PhD, Astronautical Engineering, Air Force Institute of Technology, 2014. Maj Bettinger's research interests include re-entry dynamics, spacecraft design, and optimization and control for aerospace applications. Recent research includes spacecraft survivability and space law concepts, uncontrolled atmospheric re-entry prediction, and the development of optimal skip re-entry maneuvers for altering spacecraft orbital elements. Maj Bettinger is a member of Tau Beta Pi and Sigma Gamma Tau.
Email: Robert.Bettinger@afit.edu

Bohan, Brian T., Maj, USAF
Assistant Professor of Aerospace Engineering, 255-3636 x4773

BS, Aeronautical Engineering, Clarkson University - Potsdam, NY 2005; MS, Aeronautical Engineering, Air Force Institute of Technology, 2011; PhD, Aeronautical Engineering, Air Force Institute of Technology, 2018. Major Bohan's research interests include turbomachinery, combustion, heat transfer, applied fluid dynamics, and computational fluid dynamics. Major Bohan teaches courses on turbomachinery, computational fluid dynamics, and aircraft design. He has experience in Air Force test and evaluation, propulsion integration, aerodynamic configuration, and as a propulsion subject matter expert for weapon system development. He is a member of Tau Beta Pi, Sigma Gamma Tau, AIAA, and ASME.
Email: Brian.Bohan@afit.edu

81
Cobb, Richard G.
Professor of Aerospace Engineering, 255-3636 x4559

BS, Aerospace Engineering, the Pennsylvania State University, 1988; MS, Astronautical Engineering, Air Force Institute of Technology, 1992; PhD, Astronautical Engineering, Air Force Institute of Technology, 1996. Dr. Cobb teaches courses on control theory, optimization, system identification and satellite design. His research focuses on dynamics and control of space structures for space-based remote sensing, and optimization and control for aerospace applications. Recent research includes developing optimal trajectory plans for Global Strike missions, autonomous aircraft collision avoidance trajectories, maneuver planning for satellite proximity operations, and dynamics and control techniques for lightweight space optics and sensor systems for Space Situational Awareness. He is a member of Tau Beta Pi, Sigma Gamma Tau and an Associate Fellow of AIAA.
E-mail: Richard.Cobb@afit.edu

Grandhi, Ramana
Professor of Aerospace Engineering, 255-3636 x4723

BSME at National Institute of Technology, India, 1978; MSME at Indian Institute of Technology, Kanpur, India, 1980; PhD, Engineering Mechanics, Virginia Tech, 1984. Previously he was a Distinguished Professor at Wright State University, Dayton, OH, and also served as the Director of Engineering Ph.D. program for 15 years and Executive Director of International Collaborations and Graduate Programs for 4 years. His research interests are in multidisciplinary analysis and optimization, aircraft structures, risk-based design, and advanced manufacturing processes. He is the author of more than 180 journal papers, 230 conference articles, and one textbook. In his 30-year academic career at Wright State Dr. Grandhi has supervised 28 Ph.D. dissertations, 50 M.S. theses, and 30 post-doctoral fellows. His extensive research has included partnerships with the U.S. Air Force, U.S. Navy, NASA, NSF, DARPA, GE, Boeing, Lockheed, Pratt & Whitney, Caterpillar, Ford, GM, and small businesses. In recognition of his sustained contributions in teaching and research, Dr. Grandhi has been honored with numerous awards: ASME Fellow, AIAA Fellow, the AIAA MDO Award, the Solberg Award from the American Society of Naval Engineers, the TANA Award for Excellence in Engineering, Mahatma Gandhi Pravasi Samman Award, the Outstanding Engineers and Scientists Award from the Engineering and Science Foundation of Dayton, the University Professor Title, the Brage Golding Distinguished Professor Award, the UP & COMERS Award from Price Waterhouse, the Caterpillar Quality Improvement Award, the DOW Outstanding Faculty Award from ASEE, and the RALPH R. TEETOR Educational Award from SAE.
E-mail: Ramana.Grandhi@afit.edu
Greendyke, Robert B.
Associate Professor of Aerospace Engineering, 255-3636 x4567

B.B.A., Baylor University, 1979; B.S., Texas A&M University, 1986; M.S., Texas A&M University, 1988; Ph.D., Texas A&M University, 1998. Dr. Greendyke’s research interests are in the field of Computational Fluid Dynamics with specialties in hypersonics re-entry flows, rarefied gas dynamics, plasma flows, and molecular computational methods. He has published over 30 conference papers, journal articles, technical reports, and book chapters. Previous to employment at AFIT, Dr. Greendyke was first a contract Research Scientist at NASA Langley Research Center’s Aerothermodynamics Branch. After NASA, he taught for seven years at the University of Texas at Tyler where he was twice voted “Professor of the Year” in the College of Engineering and Computer Sciences, and also named an Associate Fellow of the AIAA.
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CHAPTER 9: RESEARCH FACILITIES

9.1 Introduction

The research laboratories of the Department of Aeronautics and Astronautics are equipped for the study of fluid mechanics, solid mechanics, ballistics, and system dynamics and control. Laboratory facilities specifically support lecture courses, laboratory courses, faculty research, and student thesis research at Master, PhD, and postdoctoral levels.

The laboratory facilities are comprised of general instrumentation and equipment, which are shared by a variety of facilities. These research facilities are dedicated to specific research topics and have unique equipment and instrumentation requirements. The facilities are housed in two different buildings. Building 640 has 13,000 square feet of general laboratory facilities, including the computational dynamics and design laboratory which is equipped with high-performance Linux workstations and access to local Linux-based computer clusters. Building 644 has 5,246 square feet of laboratory space housing a 44” x 31” wind tunnel, 5.0 kip shaker with digital controller, Simulated Satellite (SIMSAT II), vibration lab, an instrumentation lab, high pressure shock tube facility, 9.0 inch low velocity wind tunnel, and turbine cascade facility, among other facilities. A new Additive Manufacturing Laboratory was added in early 2017 in Building 644. Additionally, partnerships with base organizations have permitted shared use of space for ballistics research and weapons testing.

Support instrumentation and sensors include: digital data acquisition systems, Schlieren, Moire, shadowgraph, high speed video recording equipment, one and three component laser velocimeter, hot wire anemometers with linearizers and signal conditioners, optical equipment, modal analyzers, frequency spectrum analyzers, multi-port pressure measuring systems, material test and characterizations facility, material preparation facility, and a full range of transducers (temperature, force, pressure, acceleration, displacement).

The fixed facilities include air and electrical supplies. A dry oil-free 100 psi (1000 ft³) air supply is available in Rooms 273, and 275, also 250 psi (800 ft³) and 2500 psi (44 ft³) are located in Room 275 of Building 640. Rooms 273 275, and 271 have two overhead electrical buss bar systems. The two systems include 440-volt three-phase, 220-volt three-phase.
### 9.2 Facilities Overview

#### GENERAL

<table>
<thead>
<tr>
<th>Facility</th>
<th>Key Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational Dynamics and Design Laboratory (“Linux Lab”) Bldg 640 Rm 242</td>
<td>Workstations and peripherals</td>
</tr>
<tr>
<td>Laboratory Lecture and Meeting Room Bldg 644 Rm 104</td>
<td>Space for lectures or meetings</td>
</tr>
<tr>
<td>Technician Work Area Bldg 640 Rm 270</td>
<td>Technician office and work area</td>
</tr>
<tr>
<td>Small Scale Ballistics Laboratory (Range A) Bldg 22B</td>
<td>Compressed Gas Projectile Acceleration Device, Kinetic Energy Diffusion Containers</td>
</tr>
</tbody>
</table>

#### FLUID MECHANICS AND ENERGY TRANSMISSION

<table>
<thead>
<tr>
<th>Facility</th>
<th>Key Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational Dynamics and Design Laboratory (“Linux Lab”) Bldg 640 Rm 242</td>
<td>High performance computers for computational fluid dynamics</td>
</tr>
<tr>
<td>Fluid Flow Laboratory Bldg 24C</td>
<td>12-in Low Speed Wind Tunnel</td>
</tr>
<tr>
<td>Combustion Lab Bldg 640 Rm 275</td>
<td>Ultra Compact Combustor Rig Advanced Laser Combustion Diagnostics Atmospheric Pressure Burner Rig</td>
</tr>
<tr>
<td>Water Tunnel Facility Bldg 644 L120</td>
<td>Rolling Hills Educational Water Tunnel 7” by 10” Test section</td>
</tr>
<tr>
<td>Low Speed Wind Tunnel Bldg 644 L120</td>
<td>31” x 44” Test section High Pressure Shock Tube</td>
</tr>
<tr>
<td>Advanced Space Propulsion Research Bldg 644 Rm L120</td>
<td>Space Environment Chamber Advanced Satellite Propulsion Diagnostics</td>
</tr>
<tr>
<td>Turbine Engine Demonstrator</td>
<td>Engine and instrumentation</td>
</tr>
</tbody>
</table>
### DYNAMICS, SYSTEMS, AND CONTROLS

<table>
<thead>
<tr>
<th>Facility</th>
<th>Key Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials Analysis Laboratory Bldg 640 Rm 271</td>
<td>17 MTS Systems load frames, ranging from 1 kip to 110 kip, used for material failure analysis</td>
</tr>
<tr>
<td>Computational Dynamics and Design Laboratory (“Linux Lab”) Bldg 640 Rm 242</td>
<td>High Performance Computers for guidance, navigation and control system design and simulation</td>
</tr>
<tr>
<td>Systems Engineering Project Room Bldg 641 Rm 324</td>
<td>Space, terminals for Systems Engineering students</td>
</tr>
<tr>
<td>Spacecraft Dynamics Bldg 644 L123A</td>
<td>AFIT Simulation Satellite (SimSat II) D-space Controller Wireless LAN</td>
</tr>
<tr>
<td>Spacecraft Tracking Bldg 644 L127B</td>
<td>WAVE Scope 4x8 optical table (floating) 4x10 optical table (floating)</td>
</tr>
<tr>
<td>Vibration Lab Bldg 644 L125AB</td>
<td>PSV 400 3D Scanning Vibrometer MB Dynamics 5kip shaker 36” x 30” x 30” Vacuum Chamber</td>
</tr>
<tr>
<td>Vibration Laboratory Annex Bldg 640 Rm 279</td>
<td>HP Modal Analysis System</td>
</tr>
<tr>
<td>Autonomous Guidance, Navigation and Control (GNC) Laboratory, Bldg 640 Rm 279</td>
<td>High-fidelity vehicle simulations with control system hardware-in-the-loop for autonomous GNC design, simulation, and pre-test checkout. Ground and air vehicles for autonomous GNC demonstrations</td>
</tr>
<tr>
<td>Pilot-in-the-loop Simulation Laboratory Bldg 640 Rm 279</td>
<td>High-fidelity aircraft simulations with pilot-in-the-loop control interface and synthetic vision display</td>
</tr>
</tbody>
</table>

### SOLID MECHANICS AND STRUCTURES

<table>
<thead>
<tr>
<th>Facility</th>
<th>Key Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials Analysis Laboratory Bldg 640 L127A</td>
<td>Ultra-high Resolution Scanning Electron Microscope Equipped with Electron Backscatter Diffraction and Energy Dispersive Spectroscopy Detectors; Scanning Electron Microscope with EBSD and EDS Detectors; CT Scanner</td>
</tr>
<tr>
<td>Material Preparation Facility Bldg 644 L123B</td>
<td>Mounting press, sectioning saw, grinder-polisher, vibratory polisher</td>
</tr>
<tr>
<td>Structures and Materials Testing Laboratory Bldg 640 Rm 271</td>
<td>State-of-the-art Materials Testing Facilities, High Temperature Ovens Smart Structures High Frequency Test Stand</td>
</tr>
<tr>
<td>Optical Microscopy Laboratory Bldg 640 Rm 266</td>
<td>Two Optical Microscopes; Inverted Optical Microscope; Laser Scanning Microscope</td>
</tr>
<tr>
<td>Plastic Additive Manufacturing Laboratory Bldg 640 Rm 268</td>
<td>Four fused-deposition printers; Three high-resolution printers; Design software</td>
</tr>
<tr>
<td>Additive Manufacturing Laboratory Bldg 644, Rm L129</td>
<td>Two state-of-the-art laser powder based fusion metal printer</td>
</tr>
</tbody>
</table>
9.3 Facility Descriptions

9.3.1 General

Building No. 644  
Room No. L104

Function: Laboratory Lecture and Meeting Room

Area: 672 Square Feet

This room is primarily used for briefings during scheduled laboratory course periods. When not required for scheduled classes, the briefing area is made available for departmental, meetings, thesis projects progress reports, and design course projects.

Building No. 640  
Room No. 274

Function: Instrumentation Laboratory

Area: Instrumentation Lab: 806 Square Feet
Preparation and Storage Room: 352 Square Feet

This room is generally used for laboratory course work involving experimental fluid and solid mechanics. The fixed facilities include laboratory benches with multiple electrical outlets. These benches are used for preliminary instrumentation setup and calibration and also have four designated experimental mechanics workstations established. These four workstations consist of the following equipment.

a. Electrodynamic Shakers: Small electrodynamic shakers ranging from 10 to 50 pounds of force capacity with power amplifiers and can be driven by the function generator.

b. Free vibration demonstration rigs, used in experimental mechanics and instrumentation courses.

c. Modal Analyzers: Two modal analyzers are available for sharing between the four workstations. These modal analyzers are capable of providing auto- and cross-correlation and coherence functions as well as the system frequency response functions with the associated animated mode shapes as products of a modal analysis of a structural system.

d. Agilent LabPack Workstations: The Agilent LabPack Workstation is a single package unit that includes an oscilloscope, digital-multimeter, function generator, frequency counter and a DC power supply module.

e. Dell PC Computers: The Dell PC computers are LabPack models with analog-to-digital and digital-to-analog circuit boards included for digital data acquisition and control experiments.
f. Calibration Workstation: Several standards are available for instrument calibration they include; thermocouples, AC/DC and resistance standards, SPL calibrator, accelerometer standard and dead weight tester for pressure calibration.

g. PSV-400 very quickly gathers complete, calibrated vibration data from an entire structural area. Animations of structural resonance’s can be viewed immediately after a scan is completed. These "operating deflected shapes" (ODS) are usually enough to identify which parts of a structure require reinforcement or damping, or which parts of the structure are generating noise. ODS is also a very accurate approximation of the actual mode shape, if the mode is not closely coupled to adjacent modes.

Building No. 22B

Function: Small Scale Ballistics Laboratory

Area: 864 Square Feet

This small scale ballistics laboratory enables exploratory diagnostic methods for ballistics research. Projectiles are limited to below supersonic velocities. Two types of kinetic energy depletion devices are certifies for use. A 12W continuous wave laser is available for experimental setups. This laboratory allows AFIT/ENY to expand its research capabilities and partnerships with joint organizations and research ballistic properties of materials and fluid interactions.

9.3.2 Fluid Mechanics and Energy Transmission

Building No. 640
Room No. 242

Function: Computational Fluid Dynamics (CFD) Laboratory

Area: Approximately a 400 Square feet section Room 242

This laboratory is the site of computational hardware and software focused on the development testing and applications of CFD algorithms.

Building No. 640
Room No. 275

Function: Combustion Laboratory

Area: 1099 Square Feet

a. Combustion Optimization And Laser (COAL) Laboratory: An atmospheric pressure combustion test facility is suitable for demonstrations, evaluations and experiments on combustors and combustion systems. The facility has two legs of independently controllable
(0.07 kg/s & 0.2 kg/s), heated (500F) air. A third leg of unheated air can provide flow up to 1 kg/s. Two research rigs are currently in place. First, an annular Ultra Compact Combustor facility for understanding how to combine the compressor, combustor, and turbine into an integrated system. The UCC utilizes liquid and gaseous fuels which may be used with overall equivalence ratios up to one and cavity equivalence ratios as high as $\phi_{\text{cav}} = 4$. The second facility features a well stirred reactor which enables precise control of combustion species and high temperatures for use on various research topics such as fuel characterization. Currently the facility is configured for the evaluation of secondary burning at film cooling holes for turbines. Both facilities are fully instrumented for temperature, pressure and mass flows.

b. Laser Diagnostics: Characterization of specified flow fields can be achieved by employing non-intrusive measuring techniques to include instantaneous Particle Image Velocimetry (PIV), and Planar Laser-Induced Fluorescence (PLIF). Lasers and optics are also available to obtain Laser Absorption Spectroscopy (LAS) and picosecond Coherent Anti-Stokes Raman Scattering (CARS) measurements of combustion flows.

c. Data Acquisition Systems: Multi-channel data acquisition systems for logging and control of both facility and test rig are available for experiments done in the COAL laboratory. A FLIR infrared camera is available for thermal imaging of surfaces. A Malvern Spraytec particle size analyzer is capable of measuring particles and droplets in sizes ranging from 1.0 to 400 microns at a data rate of 2500 Hz. A full California Analytics emissions test rack is capable of measuring HC, CO, CO2, O2, and NOx in accordance with SAE Aerospace Recommended Practices.

d. Atmospheric Pressure Burner Rig and High Velocity Oxygen Facility: High temperature testing of ceramic matrix composites (CMCs) as well as other advanced materials under temperature load simulating more realistic turbine engine conditions.

**Building No. 640**
**Room No. 273**

Function: High Speed Aerodynamics and Space Environment Chamber

Area: 1527 Square Feet

The AFIT High-Speed Aerodynamics Laboratory located in building 640, room 273, houses three wind tunnel facilities (Mach numbers ranging from 1.5 to 5.0), two high pressure air supply systems, and advanced laser velocimetry, hot-wire anemometry, and optical diagnostic equipment. These facilities and equipment are used to perform state of the art research in the areas of high-speed aerodynamics and propulsion.

a. Variable Mach Blow Down facility was designed and constructed by Aerolab, Incorporated. This facility has a 15.24 x 15.24 cm test section cross-section. The free stream Mach number is continuously variable over a range of 1.5 to 4.0. The run time varies from 10 to 35 seconds depending on the free stream Mach number. The stagnation pressure in this high Reynolds number facility peaks at 8.85 atm for the Mach 4.0 condition. Two Ingersoll-Rand compressors (housed in
room 275) are used to fill the 22.7 m³ supply tank with aerodynamically clean and dry air (-75 °C) to a pressure of 13.6 atm. The tank recharge time is approximately 30 minutes.

b. Pressure-Vacuum Supersonic Wind Tunnel was designed and constructed in-house to perform basic research. This facility has a 6.35 x 6.35 cm test section cross-section. Currently two nozzle (M = 1.7 and 3.0) blocks are available. The facility was designed to provide a long (60.0 cm) constant pressure test section. A variable geometry wall was incorporated to control the streamwise pressure. The high pressure for this moderate Reynolds number facility is supplied by the Ingersoll-Rand system discussed above. A 12.0 m³ vacuum system is also used. At Mach 3.0, the system provides a 25-second run time. The recharge time for this system is about 5-7 minutes.

c. Hypersonic Blow Down Wind Tunnel was also designed and constructed in house. This facility has a 7.62 x 7.62 test section cross-section. The Mach number is 5.0. A 1.25 m³ air supply tank is charged to 170 atm with aerodynamically clean and dry air by a compressor/dryer/filter system housed in room 275. An in house designed and constructed pebble bed heater is used to heat the test air in order to prevent liquefaction of the oxygen during expansion to Mach 5.0. The stagnation temperature is maintained at 100° C by the heaters. The stagnation pressure held constant at a user-selected value in the range of 20.0 to 30.0 atm. The run times for this facility are limited by the heater system. Each of the three heaters provides about 20 to 30 seconds of constant temperature. The reheat time for the pebble beds is 1.0 to 2.0 hours.

d. Data Acquisition Systems: Multi-channel data acquisition systems for simultaneous recording of up to 20 channels are available for acquiring and processing data for experiments done in the blow down tunnel facilities. A high-speed Schlieren visualization system is capable of digitally recording events at speeds of up to 16,000 frames per second. Full-model pressure and temperatures may be measured using a system, which incorporates a light source, high spatial resolution cooled CCD camera, and commercially available pressure and temperature sensitive paint. A Malvern Spraytec particle size analyzer is capable of measuring particles sizes ranging from 1.0 to 400 microns at a data rate of 2500 Hz.

e. Space Environment Cells: AFIT has two space environment cells specifically designed to test micro satellite propulsion systems such as the pulsed plasma thruster. These systems are stand alone test cells complete with multi channel data acquisition and control systems. Instrumentation includes various standard pressure and temperature sensors as well as a torsional thrust balance capable of measuring micro Newtons (10⁻⁶).

Building No. 644
Room No. L120
Function: Aerodynamic Test Facility and Space Environment Chamber
Area: 1980 Square Feet

The wind tunnel is an Open Circuit Wind Tunnel. It will attain a maximum airspeed of at least 230 feet/sec through a 31 "x 44" test section. The transverse velocity distribution across the test
section and within the boundary layers is within 1.0% of the mean. The turbulence measured at the test section centerline is less than 0.1% at full speed. The contraction Area Ratio is a minimum of 9.5:1. The ceiling and floor of the test section is fabricated from aluminum plate. Side doors are made of Plexiglas. These doors have gas-actuated hinges to provide easy access to the test section. A removable Plexiglas window is installed in the ceiling. A removable turntable is provided in the floor.

Water Tunnel Facility: The Model 0710 tunnel from Rolling Hills Research is equipped with a settling basin, flow straighteners and contoured walls on either side of the test section. Circulation is provided by a pump controlled by a variable frequency A/C motor, with mean test section velocities ranging from 0 to 5 inches per second. A tunnel wall support and dye wand are also available with the system.

Instrumentation: Instrumentation support for the wind tunnel facility includes: digital data acquisition system, several six component strain gage balance systems ranging in scale from nominally 8 lbf to 100 lbf, conventional pressure and temperature sensors, a two-channel hot-wire anemometer system, and a house air supply system for blowing studies. Models may be built using the Stratasys 3300 modeler or, alternatively, with a second Stratasys rapid modeling system. A Dantec stereo particle imaging velocimetry (SPIV) system incorporates two high resolution cameras and a dual-chamber Nd:YAG laser to interrogate flow fields for three component velocity measurements. In addition, a 3-component Dantec laser Doppler velocimetry system with a single-lens optical head can be used to measure velocity and turbulence statistics in the wind tunnel.

Space Environment Chamber: Stand alone testing and data acquisition system for advanced space propulsion testing and evaluation. The laboratory has several flight ready 200W & 600W Hall Thrusters, 10 to 100W Ion Engines and all associated control and monitoring systems. The diagnostic systems include a microwave interferometer system for electron density measurements, high speed (1Mfps) video cameras, high rate emissive probes, high rate Hall current magnetic sensors, moderate rate Faraday and ExB probes and in the near future additional laser-based diagnostics for full velocity field measurements in both neutral and ionized Xenon. The microwave interferometer system covers both Ku and Ka band of the electromagnetic spectrum. The interferometer system is on a rigid arm so it can travel in the XY directions with minimal vibrations in order to make measurements in two planes of plasma thrusters. Added to the microwave system are the infrared imaging capability and direct thrust measurements.

9.3.3 Dynamics, Systems, and Controls

Building No. 644  
Room No. L123A

Function: Spacecraft Dynamics

Area: 270 Square Feet

The SIMSAT system supports satellite experimentation in areas of attitude control, precision
pointing, and vibration suppression. The SIMSAT system consists of: (1) Space Electronics, Inc. Tri-Axis Spherical Air Bearing (spherical rotor, hollow shaft, mounting flanges, pedestal, and air compressor) which allows nearly frictionless three rotational degrees-of-freedom for a small scale satellite assembly, and (2) Small scale satellite assembly which consists of a Humphrey CF 75 3-axis gyroscope, 3-momentum wheels with motors and power amps, a dSPACE 32-input/32-output command and control processor, three 12-volt Power Sonic PS-12180 sealed lead-acid batteries, and a Radio LAN wireless LAN for real-time command/data transmission to/from a ground station PC running the dSPACE cockpit software. In addition to the three experiments, the lab contains two SUN Spare II workstations for numerical control/structure interaction analysis.

**Building No. 644**  
**Room No. L125**  
Function: Spacecraft Hardware Qualification Lab

Area: 576 Square Feet

The Spacecraft Hardware Qualification Laboratory supports prototype and flight hardware qualification testing of small satellites and satellite subcomponents. The facility is equipped for both random vibration testing and thermal/vacuum testing of flight hardware.

For vibration testing, the C40HP Electrodynamics (E-D) Shakers from MB reflects the latest in enhanced design and increased performance. The C-Series HP shakers have 2" of stroke, automatic payload re-centering, and force ratings ranging from 5,000 lbf. Classical waveforms include: half sine, saw tooth, triangle, and rectangle, user-supplied time history, i.e., the ability to perform tests from digitized time domain data, frequency Range: 1 - 4 kHz.

For Thermal/Vacuum testing, a custom built chamber by PHPK Industries can provides space environmental testing. The chamber accommodates testing of payloads of up to 200 lbs, with dimensions up to 30” x 30” x 36”. The chamber provides a vacuum environment down to 1x10^{-7} Torr, and computer controlled temperature ranging from -60 to +100 deg C. The chamber is amply instrumented with thermal couples to support component testing.

As currently configured, the Spacecraft Hardware Qualification Lab is supporting hardware qualification testing of AFIT’s Rigidizable Inflatable Get-Away-Special Experiment (RIGEX) that launched on the Space Shuttle in 2008.

The Vibrations laboratory supports passive and active vibration suppression research. The facility includes an 8’x4’ isolated granite backed optical table for mounting experimental fixtures in an isolated room to minimize disturbances. Standard modal test excitation/instrumentation is available. Data acquisition is provided by an HP VXI based 16 channel system or a dSpace 32-in, 32-out real-time control system. Current projects include vibration suppression of a bladed disk assembly and a space antenna model.
Building No. 644  
Room No. L127B  

Function: Spacecraft Tracking  
Area:  576 Square Feet  

The WaveScope two-dimensional lens array divides the incoming wave front into an array of spatial samples called sub-apertures. Light from these sub-apertures is brought to a focus behind the array on a CCD camera. The lateral position of the focus spots depends on the local tilt of the wave front. A change in the gradient of the wave front across a sub-aperture will produce a shift in the position of the spots. By measuring the shift of the spots, the gradient of the incoming wave front can be calculated.

In a conventional Shack-Hartmann sensor, when the local tilt is large enough to move the focus spot into the field of the next sub-aperture, an ambiguity arises as to the origin of the spot. This severely limits the dynamic range of the measurement. WaveScope resolves this ambiguity by moving the camera to trace the path of the spots during calibration. This is how WaveScope measures aberrations of many hundreds of waves with fractional wave accuracy. Additionally, the ability to move the camera allows imaging of the entrance pupil at the lenslet array, providing an invaluable aid in alignment.

Building No. 640  
Room No. 281  

Function: Autonomous Guidance, Navigation, and Control (GNC)  

The Autonomous GNC Laboratory, which is a part of AFIT’s Advanced Navigation Technology (ANT) Center, provides the space, computers, equipment, and vehicles required to conduct and demonstrate research in the area of autonomous guidance, navigation, and control for both ground and air vehicles. The lab includes digital control systems, hardware-in-the-loop simulations, multiple ground vehicles, and multiple air vehicles.

Building No. 640  
Room No. 281  

Function: Flight Control Design and Evaluation, and Development of Synthetic Vision Systems  

The Pilot-in-the-loop Simulation Laboratory, which is a part of AFIT’s Advanced Navigation Technology (ANT) Center, provides the space, computers, and equipment required to conduct and demonstrate research in the areas of advanced flight control, pilot-in-the-loop handling quality evaluations, and synthetic vision systems.
9.3.4 Solid Mechanics and Structures

Building No. 644
Room No. 127A

Function: Materials Analysis Laboratory

Area: 275 Square Feet

This space houses equipment that enables topographical and microstructural analysis of materials. The room contains two scanning electron microscopes (SEM) and a CT scanner. The Tescan MAIA3 SEM is capable of acquiring micrographs of materials on the sub-nanometer level, while the Thermo Scientific™ Quanta™ 450 is suitable for detecting micrometer-sized features. Both systems are equipped with electron backscatter diffraction (EBSD) detectors and energy dispersive spectroscopy (EDS) detectors. EBSD is used to analyze a material’s grain structure, while EDS is used to analyze a material’s chemical composition. The CT scanner is used to non-destructively analyze the interior of materials or enclosed materials. This is a valuable tool for failure analysis.

Building No. 644
Room No. L123B

Function: Specimen Preparation and Polishing

Area: 270 Square Feet

This space houses multiple pieces of equipment that are used to prepare samples for further analysis of their material properties. The equipment includes a Buehler Isomet 2000 sectioning saw, a MetLab Metpress A mounting press, a Buehler EcoMet 300 Grinder Polisher, and an ATM Saphir Vibro vibratory polisher. This facility is an extension of the material testing facility located in Rm 271.

Building No. 640
Room No. 271

Function: Structures and Materials Testing Laboratory

Area: 2961 Square Feet

This state-of-the-art laboratory houses numerous facilities for mechanical testing of materials and structural elements. Fourteen servo-hydraulic MTS mechanical testing machines with capacities ranging from 1.0 to 110 kip permit static and fatigue testing. A servo-hydraulic MTS tension-torsion machine is available for testing under multiaxial, combined tension-torsion loading conditions. All testing machines are equipped with MTS Test Star II digital controllers for computerized input signal generation and data acquisition. Heating chambers and
temperature controllers are employed for testing at ultra-high temperatures (above 1000ºC). Environmental and vacuum chambers are available for testing in controlled environment. Several MTS uniaxial and biaxial high-temperature extensometers permit accurate strain measurement. Two MTS high-frequency facilities permit testing at frequencies of up to 1000 Hz. The MTS Nano- and MTS Microforce- Testing Systems are available for testing of individual fibers and nano-composite specimens. Nano-indenter, Atomic Force Microscope and a Scanning Electron Microscope are available for micro- and nano-scale research. In addition, the laboratory includes unique facilities for automated thermo-mechanical fatigue testing, as well as a capability for crack growth measurement using the electric potential method at room and elevated temperatures. Three laser interferometric systems permit non-contact displacement measurement at room and elevated temperatures by using a laser and optical interferometry with different gage lengths. An acoustic emission test system is available for monitoring the damage growth in composite materials. Three servo-hydraulic testing machines are equipped with specially designed fretting fixtures for investigating the fretting fatigue phenomenon in jet turbine engine components.

MTS Planar Biaxial Testing Systems combine modular load frame technology, innovative control methods, advanced alignment techniques and integrated environmental chambers to effectively simulate the mixed mode loading environments of aircraft materials and components. The increasing sophistication of aircraft designs has necessitated the development of more descriptive and complex material and component models. Validating these models, however, requires very realistic simulations of airframe and turbine operating environments. Employing uniaxial testing technology for this yields less than accurate results, while full-scale tests with spinning components are expensive when evaluating design iterations. Achieving truly accurate and affordable simulation of these environments requires the use of multiaxial loading technology. The MTS Planar Biaxial Testing System employs multiaxial loading technology to apply and measure in-plane stresses in both the X and Y axes.

Building No. 640
Room No. 266

Function: Optical Microscopy Laboratory

Area: 250 Square Feet

This room houses equipment that is used for macroscopic topographical analysis. The room contains two Zeiss optical microscopes, a Zeiss inverted microscope, and a Zeiss laser scanning microscope. The optical microscopes are used to analyze macroscopic features of non-conductive materials such as polymers and ceramics, while the inverted microscope is the preferential way to analyze flat or mounted specimens or large area maps. The laser scanning microscope is able to create 3D topographical maps of a specimen’s surface that are used to measure a sample’s roughness. In addition to these microscopes, this room also houses a Tytron 250 tensile tester and a Faro 3D arm. The Tytron 250 is used to perform mechanical tests on non-metallic specimens, while the Faro 3D scanner is used to scan and model samples.
Building No. 640  
Room No. 268

Function: Plastic Additive Manufacturing

Area: 250 Square Feet

This room is designed to provide an area that enables rapid prototyping of components using a variety of plastics. Some of the plastics that have been researched include PLA, carbon fiber, and Ultem. Researchers can choose between seven different printers to generate parts that meet their required time and dimensional constraints.

Building No. 644  
Room No. L129

Function: Additive Manufacturing Laboratory

Area: 432 Square Feet

This metal additive manufacturing laboratory houses AFIT’s laser powder based fusion metal printer that can directly fabricate digital designs in advanced aerospace metals. Research plans focus on advancing the employment of three primary aerospace metals: Inconel (IN718) - a nickel super alloy, titanium (Ti6Al4V), and aluminum (AlSiMg10). This system can produce metal parts up to 250 mm x 250 mm x 280 mm in size. Additional capabilities, include the incorporation of numerous in-situ monitoring capabilities (melt pool area, melt pool intensity, and thermal signatures) for quality assessment. This printer allows for AFIT/ENY to continue its prominence as an expert in the application of metal additive processes so it can make recommendations to the Air Force on the practical implementation of metal additive components for flight-critical air and space applications.
CHAPTER 10: COMPUTER RESOURCES

10.1 Computing at AFIT

10.1.1 Microsoft Windows Environment

10.1.1.1 General-Use Computing Labs
AFIT/SC maintains computer labs for general student use in Bldg 640 Rooms 220, 222, 232, and 234. These labs are equipped with single-processor Windows 7 computers, printers, and scanners.

A wide range of software is available in the general-use computer labs. Software of particular interest to ENY students includes:

- **Adobe Acrobat**: Create, edit and annotate PDF files.
- **Chemkin**: Numerical chemistry software.
- **LaTeX (MikTeX + WinEDT / TeXnicCenter / Scientific Workplace)**: Scientific typesetting software.
- **Mathematica**: Symbolic mathematics and plotting software.
- **MATLAB**: Linear algebra software with a large number of special purpose toolboxes for dynamics and control, signal processing, and other engineering tasks.
- **Mathtype**: Mathematical equation typesetting (integrates with Microsoft Office).
- **Microsoft Office**: Word, Excel, PowerPoint, etc.
- **Tecplot 360**: General purpose data plotting software.
- **Intel Visual FORTRAN**: FORTRAN 90/95 in the Microsoft Visual Studio environment.
- **Visual Studio (C, C++, Java, Basic)**: Microsoft visual software development environment.

10.1.1.2 Computer Lab Software
Most of the software available in the general-use computer labs is also available on the Windows workstations in the Computational Dynamics and Design Laboratory in Bldg 640 Room 242. Additional software packages unique to the ENY research subjects are available on some or all of these workstations (check with your instructor for specifics). Examples include:
**ABAQUS**: Finite element program for non-linear structural analysis.

**AutoCAD LT**: Two-dimensional design and drafting software product.

**MD NASTRAN**: General-purpose finite-element structural analysis program for linear and nonlinear statics, buckling, frequency and transient dynamic response, heat transfer, and aeroelastic response.

**FEMAP**: General-purpose finite-element structural analysis program for linear and frequency and transient dynamic response, and heat transfer response.

**GPOPS-II**: GPOPS-II is a new MATLAB software intended to solve general nonlinear optimal control problems. GPOPS-II implements a class of variable-order Gaussian quadrature methods where the continuous-time optimal control problem is approximated as a sparse nonlinear programming problem (NLP). This NLP is then solved using either the NLP solver IPOPT or the NLP solver SNOPT.

**PATRAN**: Pre- and post-processor for finite element applications such as NASTRAN and ABAQUS.

**STK**: Module allows the user to analyze and visualize communications links among spacecraft, and between spacecraft and Earth stations.

**Solid Works**: Mechanical design automation application that takes advantage of graphical user interface, and allows designers to quickly sketch out ideas, and experiment with features and dimensions.

The primary purposes of these workstations are thesis research and special-purpose classroom activities. Normal class work and administrative tasks such as email should be carried out in the general-use computing labs.

### 10.1.1.3 Windows Terminal Servers

Most of the software available in the general-use computer labs, as well as some of the more specialized software applications noted above, are available on the Windows Terminal Servers, accessible via a Remote Desktop Connection (built-in to Windows). The two main servers are `vl1.afit.edu` and `vl2.afit.edu`. The terminal servers are available from within AFIT as well as from outside AFIT (e.g. from home).

### 10.1.2 Linux Environment

AFIT/SC maintains Linux engineering workstations in the Computational Dynamics and Design Laboratory (Bldg 640 room 242). At the time of publication, there were fifteen Opteron CentOS 6 Linux workstations, with 20-48 cores with 8-192 GB of RAM. All Linux workstation accounts mount a common home directory, so user files are available from any workstation. Accounts on these machines are not automatically generated—they must be requested by faculty through AFIT UNIX Help.

The Linux workstations are loaded with a wide array of software tools included in the CentOS 6 Linux distributions. In additions, the following commercial software applications are available on the Linux workstations and the compute clusters as well as numerous government-developed
software applications:

**Abaqus**: Finite element program for non-linear structural analysis.

**Compilers**: Commercial (Intel) and open source compilers and debuggers for C, C++, FORTRAN 77, FORTRAN 90, ADA, JAVA, as well as interpreters for Python, Perl, and TCL/Tk.

**CREATE-AV Kestrel**: Government off-the-shelf computational fluid dynamics and computational design software.

**Fieldview**: Visualization software for 3-D field data, such as that generated by computational fluid dynamics.

**Ansys Fluent**: Computational fluid dynamics software for fluid flow modeling.

**Pointwise**: Numerical grid-generation tool suitable for two- and three-dimensional structured and unstructured grids.

**LINK3D**: Block-structured grid generation tool with capability to smooth large grids via parallel computation

**Mathematica**: Symbolic mathematics and plotting software.

**MATLAB**: Linear algebra software with a large number of special purpose toolboxes for dynamics and control, signal processing, and other engineering tasks.

**MPICH and OpenMPI**: Implementations of the Message Passing Interface (MPI) parallel programming tools.

**NASTRAN**: General-purpose finite-element structural analysis program for linear and nonlinear statics, buckling, frequency and transient dynamic response, heat transfer, and aeroelastic response.

**PATRAN**: Pre- and post-processor for finite element applications such as NASTRAN and ABAQUS.

**Tecplot 360**: General-purpose data plotting software.

**US3D**: Compressible-reacting computational fluid dynamics solver specialized in hypersonic flows.

The Windows terminal servers are accessible from the Linux workstations via the rdesktop utility.

**10.1.3 Parallel / High-Performance Computing**

To meet parallel / high-performance computing requirements, AFIT/SC maintains several Linux-based compute clusters. At the time of publication, these include those shown in Table 10.1:
Table 10.1: Linux-based clusters maintained by AFIT

<table>
<thead>
<tr>
<th>Cluster</th>
<th>PBS Queue</th>
<th>Nodes</th>
<th>Processors per Node</th>
<th>Processor Type</th>
<th>RAM per Node (GB)</th>
<th>Interconnection</th>
</tr>
</thead>
<tbody>
<tr>
<td>pbs-afit-l01</td>
<td></td>
<td>8</td>
<td>16</td>
<td>2.4 GHz Opteron</td>
<td>64</td>
<td>10-Gigabit</td>
</tr>
<tr>
<td>pbs-afit-l01</td>
<td></td>
<td>2</td>
<td>32</td>
<td>2.4 GHz Opteron</td>
<td>256</td>
<td>10-Gigabit</td>
</tr>
<tr>
<td>pbs-afit-l01</td>
<td></td>
<td>2</td>
<td>16</td>
<td>2.4 GHz Opteron</td>
<td>132</td>
<td>10-Gigabit</td>
</tr>
</tbody>
</table>

All clusters share the same accounts, home directory, and software applications as the Linux workstations described above. Though not specifically defined, the general functional breakout of the clusters is as follows:

Nordic/pbs-afit-l01 - Larger numerically-intensive parallel computations and/or parallel computations requiring large amounts of memory.

Jobs are submitted to a cluster by means of the Portable Batch System (PBS). PBS keeps track of which nodes are in use and which are free. When jobs are submitted, the job is run on the requested cluster with the requested number of nodes, if available. If the nodes are not available, the job is held in a queue and will automatically start when the nodes become available. AFIT utilizes the TORQUE implementation of the OpenPBS scheduler.

**NOTE:** PBS has no way of tracking jobs started by logging directly into the cluster and running interactively. Because of this, PBS may start additional jobs on the same node, significantly degrading performance. As a result, direct login to the cluster computers is highly discouraged. The AFIT parallel computing resources are intended for problems requiring less than 32 processors. Very large problems requiring more processors should be run at the AFRL DoD Shared Resource Center (DSRC). An account and allocation at the DSRC must be requested by your research advisor.

### 10.2 Computing At Home

#### 10.2.1 Software Available for Checkout

Select commercial software applications (such as MATLAB) can be checked out for installation on your home computer. For more information, see the AFIT Intranet.

#### 10.2.2 Computing at AFIT from Home

Remote logins to the AFIT Windows network are routed through a Virtual Private Network (VPN) that sends all communications through the WPAFB firewalls. You first must connect to the internet through your own ISP. Instructions for connecting to AFIT through the VPN are available on the AFIT Intranet. Once users are connected through the VPN, users may launch remote desktop sessions on the Windows Terminal Servers.

Remote logins and file transfers to the AFIT Linux network are accomplished via secure shell (ssh). All remote ssh connections must be made through alpine.afit.edu or telemark.afit.edu, which are Linux Workstations. Once logged in to one of these workstations, the Linux
workstations can be reached by a second ssh to the desired machine. A Windows version of ssh can be freely downloaded from the Internet.

If your home computer is running either Linux or an X-server (e.g. cygwin Xorg) under MS Windows, and you have a high-speed internet connection, then it is possible to run graphical applications on AFIT workstations while displaying the output on your home computer.
APPENDIX A: SELECTED FORMS

A.1 Education Plan

This form, commonly known as an "ed plan," (WebAdvisor – Student Plan Inquiry) is used to record student's projected and actual academic programs. Each new student is required to submit an initial education plan, (ENOI 36-120) which lists all courses to be included in the academic program before the end of the first quarter of study. The plan is prepared in conjunction with the student's academic advisor and entered by the student. The proposed program must satisfy the general requirements for the MS degree and the specific requirements of the student's curriculum area and primary and secondary sequence options. The student should make sure that all prerequisites and co-requisites for all courses in the education plan are satisfied and that courses are scheduled to be offered in the desired quarter.

The education plan is subject to the approval of the student's advisor, the curriculum chair, and the department head. Any subsequent changes to this plan must be coordinated with the student's academic advisor. A major restructuring of a program may require a complete revision of the plan and formal re-coordination.

Immediately prior to graduation a final grade summary listing the grades received in all courses and the thesis title will be prepared for final approval by the department head and reviewed by the Graduate School of Engineering and Management Academic Standards Committee.

A.2 Drop/Add - Special Study Request and DAGSI Forms

Registration changes will be accomplished by the student through the on-line process or filling out the Drop/Add Form. The form is available on the Intranet. Students should fill out the form electronically and obtain his/her academic advisor’s signature, instructor’s signature, and Department Head signature and email it to the Registrar’s office.

DAGSI Scholarship students wishing to cross-register must complete the DAGSI forms.

When any student registers for a Special Study (AERO 699 and AERO 899), a Drop/Add Form is required. This form is used to provide the name of the special study, the course instructor, and the number of credit hours. A syllabus for the course must accompany the form.
APPENDIX B: SELECTED COURSE DESCRIPTIONS

Not all of the following courses are offered each year. See Appendix G for forecast of course offerings.

AERO 500 – Introduction to Aeronautical Engineering

Introduction to fluid mechanics, airfoil and wing aerodynamics, steady and accelerated aircraft performance, and stability and control. Permission of Instructor. Not open to graduates of an Aeronautical Engineering Program.

Prerequisites: None

AERO 517 – Fluid Measurements Lab

Introduction to instrumentation and procedures used in the calibration of measurement systems and measurement of the static and dynamic response of fluid and thermal systems. Notes: Instrumentation includes oscilloscopes, anemometers (laser and hot-film/wire), pressure transducers, heat and temperature sensors, Schlieren flow visualization, and other measurement systems at the discretion of the instructor.

Prerequisites: AERO 534 or Permission of Instructor

AERO 533 – Incompressible Aerodynamics

Dynamics of incompressible, inviscid and viscous flow fields. Topics include kinematics and dynamics of flow fields, potential flow theory, circulation theory of lift, characteristics of airfoils, fixed wings and rotary wings, introduction to laminar and turbulent boundary layers.

Prerequisites: Permission of Instructor

AERO 534: Aerodynamic Fundamentals

Introduction to the fundamental dynamics of both incompressible and compressible flows, with specific applications for external aerodynamics problems such as lift generation by 2-D airfoils and 3-D wings. Topics fundamental to incompressible flow include potential flow, thin airfoil theory, lifting line theory, and an overview of boundary layers. Topics fundamental to compressible aerodynamics include 1-D compressible flow within a pipe, wave motion, normal and oblique shocks, and Prandtl-Meyer expansions.

Prerequisites: None
**AERO 536 – High Speed Aerodynamics**

Theory of compressible aerodynamics including classical gas dynamics, wave motion, normal and oblique shocks, Prandtl-Meyer expansions, linear airfoil theory, similarity rules and the method of characteristics.

Prerequisites: Undergraduate Thermodynamics

**AERO 537 - Advanced Aerodynamics**

Using potential flow theory and linearized potential flow theory to quantify ground effect and trends in subsonic, transonic, and supersonic flows. Using the method of characteristics for the design of supersonic nozzles and to assess flow in a shock tube. Taylor-Maccoll solution for supersonic flow past a cone. Additional topics include Crocco’s theorem, aspects of compressible boundary layers, and discussion of aerodynamic heating.

Prerequisites: AERO 534 or equivalent

**AERO 543 – Advanced Computational Modeling for Aerodynamics**

Use of commercial and government software packages for detailed modeling and analysis of internal and external aerodynamic flow fields to include incompressible and compressible viscous solutions with various turbulence models will be discussed. Topics will include techniques for mesh generation and adaptation, boundary condition definitions, flow solver options to include serial versus parallel processing, and scientific visualization of numerical results.

Prerequisites: None

**AERO 543 Lab**

Lab associated with AERO-543.

Prerequisites: None; Corequisites: AERO 543

**AERO 551 – Numerical Methods for Computational Fluid Dynamics**

Application of numerical finite-difference methods to selected model equations from fluid mechanics and heat transfer: Classification of partial differential equations (PDEs); Development and analysis of finite difference representations of partial derivatives; Analysis of consistency, stability, and accuracy of explicit and implicit finite difference solution schemes; Implementation of selected finite difference schemes in FORTRAN or MATLAB.

Prerequisites: Undergraduate CS/Programming, Undergraduate Linear Algebra & Diff Eq
AERO 580 – Technical Communications for Aerospace Engineers
This course is designed to provide an understanding of research in an applied sense. Work will be accomplished leading towards development of a master’s quality thesis. Students will learn critical thinking, and communication skills. This will focus on how to review other people’s work from literature and peers as well as writing effectively. The Assertion-Evidence technique will be taught to improve technical presentation of the work. The quarter will consist of a full literature review along with a conference type presentation of the work.

Prerequisites: None

AERO 580 Lab – Technical Communications for Aerospace Engineers Lab
This lab supplements the AERO 580 course which is designed to provide an understanding of research in an applied sense. Work will be accomplished leading towards development of a master’s quality thesis. Students will learn critical thinking, and communication skills. This will focus on how to review other people’s work from literature and peers as well as writing effectively. The Assertion-Evidence technique will be taught to improve technical presentation of the work. The quarter will consist of a full literature review along with a conference type presentation of the work. The lab will focus on the execution of the technical writing and presentations.

Prerequisites: None; Corequisites: AERO 580

AERO 585 – Aerospace System Design
Team design project of an aircraft in response to a Request-For Proposal. Design methodology focuses on a military need and incorporates performance, cost supportability, deployment, manufacturing, product quality and environmental considerations. The project draws on all of the aeronautical core disciplines and provides students experience in applications of such disciplines to military aircraft design.

Prerequisites: Core Aeronautical Engineering

AERO 610 – Rotorcraft Aeromechanics
This course provides the student with an understanding of the basics of rotorcraft aeromechanics. Primary areas of study include rotorcraft aerodynamics, dynamics of rotor blades, and rotorcraft aeroelasticity. Topics in aerodynamics include momentum theory, blade element theory, and rotorcraft performance. Dynamics of rotor blades includes topics in both rigid and elastic blade motion. Topics in aeroelasticity include vibration and stability of rotors and rotor-fuselage systems. While the primary emphasis in this course is on basic analytical techniques, the students are also introduced to more sophisticated methods commonly used in government and industry.

Prerequisites: AERO 534 or equivalent (MECH 515 recommended)
**AERO 620 – Helicopter Mission Performance and Handling Qualities**

Influence of mission performance and flying qualities on helicopter design. Performance topics covered will include hover, forward flight, and mission performance; main rotor, fuselage, empennage, and tail rotor design; flight dynamics; ADS-33; and objective and subjective assessment of flying qualities. Students will complete two mini-design projects: one focused on mission performance, and the other focused on flying qualities.

Prerequisites: MECH 529 or equivalent, AERO 610

**AERO 622 – Introductory Hypersonics**

Character of hypersonic flow and assumptions underlying inviscid hypersonic flow theories. Similarity, small disturbance and surface inclination methods are covered. The equivalence principle, low density aerodynamics, high temperature aerodynamics, gas-surface interactions, SCRAMJET propulsion and re-entry trajectories are also discussed.

Prerequisites: AERO 534 or equivalent

**AERO 627 – Turbulence**

The course approaches turbulence predominantly from an experimental point of view. A statistical description of turbulence is presented in order to quantify the variations in the flow caused by turbulence. This leads to order of magnitude estimates for diffusion, transport, and dissipation of turbulence. These quantities are understood relative to the fundamental length scales that they occur at. The second part of the course looks closely at the fundamental equations when subjected to fluctuations around the mean levels. Reynolds time averaging of the Navier Stokes equations is presented along with discussion of the closure problem. Several methodologies are presented to solve the N-S equations including turbulent energy and vorticity balances. Turbulence modeling methods are presented and some application to Computational Fluid Dynamics is developed. The turbulence equations are then applied to Boundary-free shear flows and wall-bounded shear flows for internal and external flows.

Prerequisites: AERO 634

**AERO 634 – Viscous Flow Theory**

Derivation of the Navier-Stokes equations. Exact solutions of the N-S equations, similarity variables. Boundary layer equation, Falkner-Skan solutions, momentum-integral methods. Factors affecting transition; turbulent boundary layers.

Prerequisites: AERO 534 or equivalent
AERO 640 – Hypersonic Computational Fluid Dynamics

The use of commercial and government ITAR software for the simulation of hypersonic flows. Topics covered include mesh generation, simulation of chemically reacting and thermally nonequilibrium flowfields that occur at hypersonic velocities and post-processing flow visualization and data reduction techniques. In addition, high performance computing and parallel programming will be studied.

Prerequisites: AERO 622, US Citizenship

AERO 640 Lab

Lab associated with AERO-640.

Corequisites: AERO 640
Prerequisites: AERO 622, US Citizenship

AERO 652 – Computational Fluid Dynamics

Explicit and implicit algorithms for the solution of the compressible Euler equations in one and two dimensions: Development of finite difference and finite volume formulations of the governing equations; Transformation of PDEs to generalized curvilinear coordinates and the geometric conservation law; Flux and flux-difference splitting schemes; Total variation diminishing (TVD) schemes; Characteristic Variable Boundary Conditions; Implementation of selected 2-D solution schemes in FORTRAN.

Prerequisites: AERO 551 and AERO 534 or permission of instructor

AERO 698 – Graduate Seminar in Aeronautics and Astronautics

Current problems and solutions in the design of Air Force aeronautical and astronautical systems are presented by representatives of USAF agencies and the aerospace industry.

Prerequisites: None

AERO 699 – Master’s Level Special Study

Directed study at an intermediate graduate level on a special topic which is not normally covered in a regularly scheduled course or as part of thesis research. Topic, format, and course requirements are determined by the faculty member directing the study. Requires submission of Special Studies Form and syllabus to the department for registration.
AERO 729 – Theory of Gases for Aerodynamics and Propulsion

Introduction to the behavior of gases. Gases are treated as interacting particles and the collective behavior is studied as an ensemble of semi-random events. The evolution of gas properties from the molecular viewpoint to the continuum viewpoint will be examined. Applications of interest include chemical reactions important to hypersonic aircraft and scramjet engines as well as current and future high pressure ratio gas turbine engines.

Prerequisites: Undergraduate Thermodynamics

AERO 740 – Nonequilibrium Hypersonic Flows

Analysis and study of the strong regions of thermodynamic, chemical, and mechanical nonequilibrium resulting from travel at hypersonic velocities. The resulting physical phenomena from the nonequilibrium – such as very high temperatures, high heat convection, chemical surface reactions, flowfield thermal radiation, and population inversions will discussed.

Prerequisites: AERO 622 and AERO 729

AERO 753 – Advanced Computational Fluid Dynamics

Advanced Computational Fluid Dynamics Explicit and implicit algorithms for the solution of the incompressible and compressible Navier-Stokes equations in two and three dimensions: Turbulence Modeling; Numerical grid generation; Introduction to unstructured solution techniques; Selected topics of current interest in CFD such as Preconditioning for low-speed flows, High-Order Methods, Convergence acceleration techniques, Parallelization; Implementation of selected viscous solution schemes in FORTRAN.

Prerequisites: AERO 652 or Permission of Instructor

AERO 799 – Independent Study

The topic for an independent study is selected from a wide variety of problems of current interest to the Air Force. The results of the study are reported in a thesis written under the supervision of a departmental faculty member and are presented in a formal oral report. Ordinarily this study extends over four quarters and no credit is given until the end of the last quarter.

AERO 899 – Doctoral Independent Study

Directed study for doctoral students on a special topic which is not normally covered in a regularly scheduled course or as part of dissertation research. Topic, format, and requirements of the course are determined by the faculty member directing the study. Requires submission of Special Studies Form and syllabus to the department for registration.

Prerequisites: Permission of Instructor
AERO 999 – Dissertation Research

The topic for dissertation research is selected from a wide variety of problems of current interest to the Air Force. The results of the study are reported in a dissertation written under the supervision of a member of the department faculty and are defended in a formal oral defense. As a full-time effort, this study ordinarily extends over at least six quarters.

Prerequisites: Approval of Research Advisor

ASYS 521A – Space Remote Sensing

This is a new course developed to match the material covered in PHYS 521 with a focus on space application and utilization.

Prerequisites: None

ASYS 525 – Linear Systems Analysis

This course covers the underlying theory of linear time invariant and time varying dynamic systems. The modeling of engineering systems with an emphasis on mechanical systems is covered. Analysis techniques include classical analysis in the continuous time domain and frequency domain as well as modern state space analysis techniques for linear systems.

Prerequisites: None

ASYS 530 – Introduction to Space Programs and Operations

This course examines the history and current status of military space operations. Topics include the history of space flight, the relationships between military and civil space programs, space law, US space policy, military space missions, US military space organizations, and non-US space programs. Introduction to standard space mission analysis software.

Prerequisites: Permission of Instructor. This is a single three-credit course divided over three quarters (students must enroll in all three quarters).
ASYS 531 – Space Mission Analysis and Systems Design

This course provides a detailed introduction to the application of space systems engineering processes throughout the life cycle with an emphasis on space mission analysis, systems design, and systems engineering management. Topics include space mission concept definition & analysis, concept of operations, engineering system requirements, system functional & physical partitioning, system integration, verification & validation, decision making, technical reviews, configuration & interface management, cost analysis, and risk management.

Course Prerequisites: None
Other Prerequisites: US Citizenship Required

ASYS 535 – Military Space Systems and Applications

This course is designed to provide the student with a picture of worldwide space activities, with an emphasis on military space operations. Seminars will include classified presentations by intelligence analysts. Subjects covered will include operational and technical aspects of US and foreign space systems and related topics of DoD interest.

Prerequisites: Permission of Instructor (US only, TS//SCI required). This is a single three-credit course divided over three quarters (students must enroll in all three quarters).

ASYS 545 – Linear Systems Analysis for Control

This course covers the fundamentals of Linear System Analysis which is used as a basis for Control Theory Design. Topics include transfer function development, response analysis and controllability & observability concepts. The interrelation between conventional and modern control approaches is emphasized. Control specific topics include classical feedback systems analysis, root locus, Bode and Nyquist analysis, and state-space feedback systems analysis.

Prerequisites: Permission of Instructor

ASYS 563 – Terminal Effects and Delivery of Conventional Weapons

This course provides the analytical basis for computing delivery trajectories and terminal effects of conventional weapons. It covers such topics as vacuum trajectories and atmospheric trajectories, powered trajectories, and projectile stability. Terminal effects are quantified and related to potential targets and their damage criteria. The following terminal effects topics are studied in some detail: chemical explosives and blast waves, guns and projectiles, fragmentation warheads, projectile impact, target hardness, armor penetration, and shaped charge weapons.

Required: U.S. Citizenship and Secret Clearance
Prerequisites: AERO 534, Permission of Instructor, US Citizens only
ASYS 565 – Control and State Space Concepts

This course covers topics in conventional and modern control theory. The interrelation between conventional and modern approaches is emphasized. Topics include: feedback systems analysis, root locus, Bode, and Nyquist analysis, state space feedback systems analysis, and control system compensation design.

Prerequisites: Linear Systems Analysis - ASYS 525 or equivalent.

ASYS 590 – Aircraft Survivability

This course provides the student with an understanding of the essential elements in the study of survivability and system safety engineering of aerospace vehicles. Presented are technologies for increasing survivability and methodologies for assessing the probability of survival in hostile (non-nuclear) environments. Air defense threat technology, identification of mission threat characteristics and threat operations are presented. Primary areas of study include identification, assessment and reduction of susceptibility and vulnerability and survivability enhancement of aerospace vehicles.

Required: U.S. Citizenship and Secret Clearance
Prerequisites: Undergraduate degree in engineering or science

ASYS 625 – Non-linear Systems Analysis and Control

This course serves as an introduction to the fundamental results of modern nonlinear control. The first half of the course will concentrate on the analytical tools that can be used to study a non-linear system. Specific topics in this area are phase-plane analysis, stability, and Lyapunov theory, perturbation methods and describing functions. The second half of the course will cover several nonlinear control synthesis techniques such as feedback linearization, sliding mode, and model reference adaptive control.

Prerequisites: Linear systems and state space control (ASYS 525, 565 or equivalent).

ASYS 630 – Analysis and Design for Weapons Delivery

This course provides the analytical basis for computing delivery trajectories and terminal effects of conventional weapons. It covers such topics as vacuum trajectories and atmospheric trajectories, powered trajectories and projectile stability. Terminal effects are quantified and related to potential targets and their damage criteria.

Prerequisites: None
ASYS 631 – Spacecraft Systems Engineering

This course provides a detailed introduction to the design of complex space systems. The key elements and subsystems of several important classes of space systems are presented. The systematic approach necessary to effectively design space systems is illustrated through case studies. Individual or group design projects are conducted and presented. Note: This course is planned to be offered via Distance Learning, in the same quarter as the in residence offering.

Prerequisites: MECH 532 or Permission of Instructor

ASYS 632 – Satellite Design & Test

This course provides a comprehensive overview of the design, manufacture, and testing of complex space systems. The key elements and subsystems components of several important classes of space systems are presented. The systematic approach necessary to effectively design, build, test, and qualify space systems is illustrated through hands-on labs using satellite hardware and space testing facilities. Individual or group projects are conducted and presented.

Required: U.S. Citizenship
Prerequisites: ASYS 631 or Permission of Instructor

ASYS 633A – Spacecraft Safety & Survivability

Introduction to safety and survivability of spacecraft and space operations. Preliminary topics will include the analysis of spacecraft failure modes and the development of probabilistic risk assessments. Next, statistical reliability analysis will be investigated using both non-parametric and parametric techniques, as well as safety design principles for launch, on-orbit, and reentry operations. Finally, a framework for spacecraft survivability will be discussed with related topics on resiliency and robustness.

Prerequisites: MECH 532 or Permission of Instructor; Corequisites: ASYS 631 or Permission of Instructor

ASYS 635 – Conventional Explosives & Effects

Introduction to conventional explosives engineering and the blast effects of conventional explosives. Chemical and thermodynamic theory of explosive compounds. Nonreactive and reactive shock waves. Shock wave effects in air and solids.

Prerequisites: Undergraduate thermodynamics and fluid dynamics

ASYS 640 – Aircraft Combat Survivability
Introduction into aircraft combat survivability engineering and effects of conventional weapons on aircraft systems. Probability theory, radar fundamentals, infrared fundamentals, countermeasures, weapons effects.

Prerequisites: None

**ASYS 650 – Advanced Explosives and Warhead Design**

An examination of basic warhead physics and advanced explosive phenomenon such as initiation and detonation. The course will also study the design of multiple warhead types such as fragmentation, blast, direct energy, and kinetic energy rod warheads.

Prerequisites: ASYS 635 – Conventional Explosives & Effects

**ASYS 699 – Master’s Level Special Study**

Directed study at an intermediate graduate level on a special topic which is not normally covered in a regularly scheduled course or as part of thesis research. Topic, format, and course requirements are determined by the faculty member directing the study. Requires submission of Special Studies Form and syllabus to the department for registration.

**ASYS 733A – Integrated Multi-Domain Combat Modeling**

This course provides a detailed introduction to campaign analysis and combat modeling with an emphasis on today’s integrated and multi-domain warfighting environment. Topics include campaign analysis, the classification of combat models, shooting with and without feedback, target defense, attrition models and game theory and wargaming. Historical events will be analyzed, potential future force structures will be critiqued, and students will use the tools learned to conduct integrated multi-domain combat modeling for the 21st century.

Required: US Citizenship
Prerequisites: SENG 621 Advanced Modeling and Simulation

**ASYS 765 – Robust Control**

This course covers the fundamentals of linear multivariate control systems, with an emphasis on the design of robust and optimal controllers. Extensions to basic linear system theory are covered emphasizing multivariate analysis. Performance specification and limitations are discussed along with the selection of weighting functions to achieve desired levels of performance and stability robustness. Linear quadratic controller designs are presented.

Prerequisites: ASYS 565
ASYS 771A – Pseudospectral Methods

This course covers the foundations for solving multi-phase optimal control problems (to high accuracy) both on regular and highly irregular domains, in any number of dimensions. We will explain how, when, and why the pseudospectral (PS) or direct orthogonal collocation approach works. The course is centered around the mathematical fundamentals behind many of the current software packages that use direct methods to solve dynamic optimal control problems.

Prerequisites: MECH 622 and ASYS 765

ASYS 899 – Doctoral Level Special Study

Directed study for doctoral students on a special topic which is not normally covered in a regularly scheduled course or as part of dissertation research. Topic, format, and requirements of the course are determined by the faculty member directing the study. Requires submission of Special Studies Form and syllabus to the department for registration.

MATL 498 – Materials Selection Seminar

Definition of material properties as they relate to load bearing structural materials. General discussion of constitutive equations and how material properties are necessary both for stress strain relationships and for limit load analyses. Presentations on the material characteristics, strengths, weaknesses, applications, problems, and current research objectives for airframe metals, high temperature metals, organic composites, metal matrix composites, carbon-carbon, viscoelastic materials.

Prerequisites: Strength of Material Course

MATL 525 – Thermodynamics and Kinetics of Materials

Applications of thermodynamics and kinetics relevant to materials science and engineering are presented. Concepts treated include free energy of phases, phase diagrams, metastability, and applications to problems in solids and thin films. Thermodynamics is applied to pure materials, solid solutions, phase equilibria, interfaces and defects. Kinetics topics include diffusion in solids, nucleation kinetics, composition-invariant solid/solid interface migration, and kinetics of surface deposition.

Prerequisites: Undergraduate Materials Science Course
MATL 545 – Mechanical Properties of Materials

Course is designed to provide a background for the understanding of the mechanical behavior of metals, ceramics, polymers, and composites in aerospace applications. Topics include behavior of materials under simple and combined stress systems, elastic and plastic behavior, strengthening mechanics, fatigue, creep, residual stress, fracture, and mechanical testing.

Prerequisites: Permission of Instructor

MATL 560 – Electronic, Magnetic and Optical Properties of Materials

Introduction to the theory and engineering applications of electronic, magnetic, and optical materials. Atomic bonding, crystal structure, crystal defects, lattice properties, diffusion, electrical properties of materials, metals, dielectrics, semiconductors, magnetic properties of materials, ferroelectrics, superconductors, polymers, ceramics and the growth and processing of materials are covered. Use of such materials in solid state devices, hard and soft magnets, superconductors, and optical devices are treated.

Prerequisites: Undergraduate Materials Science Course

MATL 598 – Materials and Processes Seminar

Current technologies, applications, and research issues in the materials and processes are presented by experts from the Air Force, industries and other universities.

Prerequisites: None

MATL 620 – Chemistry of Materials

A study of the electrochemistry, inorganic chemistry, organic chemistry, polymer chemistry and solid-state chemistry relevant to synthesis processing of materials. Computational methods of predicting and correlating materials structure with properties of alternative materials will be introduced. This course introduces the student to chemistry of materials and chemical processes which use or produce significant quantities of toxic chemicals. Emphasis will be placed on chemistry of materials and processes important in current and future aerospace manufacture and maintenance. This course provides background for understanding pollution prevention.

Prerequisites: CHEM 590

MATL 662 – Electronic Properties of Molecules and Solids

This course is an introduction to the electronic behavior of molecules and solid state materials with an emphasis on the symmetrization postulate, tight binding methods, band theory, Hartree Fock - self consistent field methods, configuration interaction methods, and density functional theory.

Prerequisites: MATL 620, PHYS 655
MATL 672 – Optical Properties of Materials

Study of the various optical phenomena in materials; topics will be selected from absorption, reflection and emission processes, luminescence, dispersion theory, optical materials, polymers, wave propagation in anisotropic media, and nonlinear properties of materials. Application will be made to the material requirements of optical devices such as lasers, detectors, etc.

Prerequisites: PHYS 670

MATL 680 – Materials Characterization

The objective of this course is to provide an integrated view of characterization as a process requiring application of many methods to extract information about a material. Two classes of methods are considered, those using particles and those using waves. Particles are grouped into photons (visible, infrared, ultraviolet, x-ray), electrons, and atoms/ions/neutrons. Frequency ranges of waves include acoustic and microwave. The challenge in characterization is to understand the probe-material-sensor interactions, because these are the drivers to characterizing the material. Only a few specific methods are covered as representatives of the several hundred methods now used.

Prerequisites: Undergraduate Materials Science Course

MATL 685 – Materials Selection and Processing

An introduction to methods for logical choice of materials processes for applications with emphasis on aerospace requirements. Includes methods for assessment of risk and cost with respect to requirements.

Prerequisites: Undergraduate Materials Science Course

MATL 699 – Master’s Level Independent Study

Course content determined by faculty member based on student need.
Prerequisites: Permission of Instructor

MATL 701 – Research Apprenticeship

Students will work on special problems related to an individual professor's or laboratory scientist’s materials research program. These special problems will range from pedagogical problems intended to bring the student up to the state of knowledge to problems which represent immediate goals of a research program. The problems may be computational, experimental or theoretical and will vary depending upon the needs of the student and the individual research interests of the professor or laboratory scientist.

Prerequisites: Permission of Instructor
MATL 799 – Independent Study

This course is an in-depth study of a research topic selected from a wide variety of problems of current interest to the Air Force, with the results presented in a formal thesis and defense. Ordinarily, this course extends over several quarters, and no credit is given until the end of the last quarter. An oral presentation and defense of the re-search are required.

MATL 899 – Doctoral Level Independent Study

Course content determined by faculty member based on student need. Prerequisites: Permission of Research Advisor

MECH 500 – Fundamentals of Solid Mechanics

Analysis of deformation, strain, and stress continuum. Introduction to elasticity, including definitions of stress, strain, compatibility, equilibrium, generalized Hooke's law, and boundary conditions. The Principle of Minimum Potential Energy is applied to beams in tension, shear, and bending. Torsion of bars with non-circular cross-sections is analyzed by applying St. Venant's Semi-Inverse Principle.

Prerequisites: Undergraduate Strength of Materials

MECH 505 – Introduction to Aircraft Structural Analysis and Mechanics

This course covers fundamental aspects of structural analysis useful for understanding the response characteristics of aircraft/ spacecraft components and materials. Topics include definitions and applications of stress, stiffness, strength, environmental aspects, failure analysis, impact response, fatigue and fracture, and relevant algorithms. Both metallic and nonmetallic materials and their composites are included. All these aspects are related to tools development for optimum design, residual life evaluation, hazard detection, information evaluation and risk management.

Prerequisites: None

MECH 515 – Theory of Vibrations

Free and forced vibrations of damped and undamped systems with a finite number of degrees of freedom. Characteristic frequencies and mode shapes. Generalized coordinates and normal modes. Free and forced vibrations of simple continuous systems; transverse oscillations of strings, longitudinal and torsional oscillations of rods, and bending vibrations of beams.

Prerequisites: Undergraduate dynamics and ordinary differential equations or Permission of Instructor
MECH 521 – Intermediate Dynamics

Three-dimensional kinematics using generalized vector notation, rotating and translating coordinate frames, particle and rigid body dynamics, equations of motion via direct and indirect methods, equations of motion via Lagrangian approach, aerospace vehicle applications.

Prerequisites: Undergraduate dynamics

MECH 529 – Dynamics and Control of Flight Vehicles


Prerequisites: MECH 521 or equivalent or Permission of Instructor

MECH 532 – Introductory Space Flight Dynamics

Formulation and solution of the two-body problem in three dimensions. Orbital elements, reference frames, coordinate transformations, and basic orbital maneuvers. Formulation and description of basic attitude dynamics and control concepts, including spin-, dual-spin, three-axis, and gravity gradient stabilization. Note: This course is planned to be offered via Distance Learning.

Prerequisites: Undergraduate dynamics or Permission of Instructor

MECH 541 – Mechanics of Composite Materials

Introduction to the analysis of composite materials. The nature and scope of composite materials are discussed as well as mechanical behavior. Micromechanics, macromechanics, and characterization of composite materials are presented. Emphasis is placed on gaining a basic understanding of composite materials behavior from both the applied mechanics and materials science aspects.

Prerequisites: MECH 500
MECH 542 – Introduction to Finite Element Analysis and Computer-Aided Design

Introduce finite element analysis and computer-aided design tools for analyzing, pre-, and post-processing finite element models. Review historical development of finite element analysis and related computational tools. Demonstrate finite element process for truss elements. Program simple finite element code for trusses. Learn graphics software in AFIT computer environment to model one-, two-, and three-dimensional structures. Use pre-processor to create geometric models and associated finite element meshes. Use post-processor to generate deformed geometry, x-y plots, and contour plots. Present modeling guidelines and adaptive meshing techniques.

Prerequisites: MECH 500

MECH 545 – Aerospace Structural Analysis

External loads on the aircraft, forces and load factors on space structures, spanwise airload distribution, shear and bending in symmetrical and unsymmetrical beams, analysis of typical semimonocoque structures, wing beam theory, deflections in aircraft structures, energy methods, introduction to structural stability and structure-aerodynamic interactions.

Prerequisites: Undergraduate strength of materials

MECH 600 – Elasticity


Prerequisites: MECH 500 or Permission of Instructor

MECH 601 – Introduction to Time-Dependent Material Behavior

The course provides a fundamental background in inelastic solid mechanics. Phenomenological aspects of inelastic material behavior and inelastic constitutive models are discussed. Topics include Kelvin-Voigt, Maxwell and Standard Linear Solid models for materials with internal variables, creep, stress relaxation, linear and nonlinear viscoelasticity. In addition, rate-independent plasticity, viscoplasticity, yield criteria, yield surfaces, and isotropic and kinematic hardening rules are discussed.

Prerequisites: MECH 500
MECH 605 – Fracture Mechanics

The course is designed to acquaint students with analytical and experimental techniques used to solve current fracture problems. Specific course objectives are to develop the linear elastic fracture mechanics principles which allow one to predict the critical crack size for a given component (i.e., predict fatigue crack growth, stress corrosion cracking, etc.). The role fracture mechanics can play in assuring fracture prevention is discussed, with emphasis on current USAF requirements.

Prerequisites: MECH 500 or MECH 545 or Permission of Instructor

MECH 620 – Systems Optimization

This course covers theory and procedures for optimizing multi-variable, nonlinear objective functions that measure system performance. Topics include: formulation of classical and Karush-Kuhn-Tucker (KKT) optimality conditions, numerical algorithms for solving different classes of problems, linear programming, gradient algorithms, search techniques for nonlinear problems, multi-objective optimization theory, and special topics illustrated with problems in aerospace design.

Prerequisites: MATLAB Programming

MECH 622 – Functional Optimization and Optimal Control

Variational techniques are applied to optimize linear and nonlinear dynamic systems with respect to prescribed constraints are considered. Optimization of functionals using the calculus of variations and Pontryagin's Maximum Principle, leading to the derivation and solution of the optimal control problem. Special topics include; "bang-bang" control, dynamic programming, terminal controllers and regulators, perturbation techniques and singular solutions.

Prerequisites: Knowledge of linear feedback control - ASYS 565 or equivalent

MECH 628 – Aircraft Control

Introduction to aircraft flight control systems. Response to control inputs. Use of classical control theory to analyze and design longitudinal and lateral autopilots. Digital computer techniques and response to random inputs.

Prerequisites: MECH 529 or equivalent; ASYS 565 or equivalent
MECH 629 – Aircraft Handling Qualities and Performance

This course presents an overview of aircraft performance and handling qualities. Topics covered in performance include climb, cruise, and turn performance. The flying qualities portion includes aircraft dynamics, classical aircraft handling qualities, parameters, pilot modeling, pilot ratings, and their prediction.

Prerequisites: MECH 529 or equivalent

MECH 632 – Intermediate Space Flight Dynamics

Rigorous development of equations of motion of a rigid body in a gravitational field. Decoupling the translational and rotational equations of motion. Ballistic missile and interplanetary trajectories. The three-body problem and perturbation methods. Analysis of important problems in attitude dynamics and control, including reorientation, despin, control moment gyros, and reaction wheel systems. Introduction to attitude determination methods.

Prerequisites: MECH 521 and MECH 532

MECH 633A – Spacecraft Maneuver and Rendezvous

This course serves as an introduction to the dynamic modeling and control of multiple spacecraft operating in close proximity. The first half of the course will focus on modeling relative satellite motion, including common state transition matrices and relative state realizations. The second-half of the course will focus on control strategies for formation maintenance as well as rendezvous and proximity operations (RPO). A number of advanced topics such as perturbation mitigation, coupled rotational/translational motion, uncertainty propagation, and relative navigation will also be presented.

MECH 637 – Astrodynamic Re-Entry

Introduction to astrodynamics with an examination of planetary atmospheres, aerodynamic forces, and endo-atmospheric re-entry trajectories. Preliminary topics will include the concept, theory, and performance of exo-atmospheric spaceflight and the associated equations of flight over a spherical planet. Next, the basic equations for planar entry trajectories will be developed, with subsequent analysis of first-order planetary entry solutions, Loh’s Second-Order theory, Yaroshchuk’s theory, and Chapman’s theory. Additional topics will include entry corridors, the unified theory of re-entry, and orbit contraction due to atmospheric drag.

Prerequisites: MECH 521 or Permission of Instructor
Corequisites: MECH 532 (if not previously taken) or Permission of Instructor
MECH 642 – Finite Element Methods for Structural Analysis I

Energy Principles are used throughout. Consideration is given to the formulation of Truss, Plane Stress and Strain, Beam, Plate and Shell elements. Isoparametric elements are considered. Vibration formulation of structures is presented. The use of MATLAB coding and Abaqus is made use of throughout the course.

Prerequisites/Corequisites: MECH 542 or Permission of Instructor

MECH 644 – Finite Element Methods for Structural Analysis II

Advanced topics in finite element techniques. Formulation and solution of the system equations. Application to free and forced response, stability, and nonlinear analysis.

Prerequisites: MECH 642

MECH 646 – Structural Optimization


Prerequisites: MECH 500

MECH 662 – Introduction to Aeroelasticity


Prerequisites: AERO 534 and MECH 515 (or equivalent)

MECH 699 – Master’s Level Independent Study

Course content determined by faculty member based on student need.

Prerequisites: Permission of Instructor
MECH 712 – Nonlinear Oscillations


Prerequisites: MECH 720 or Permission of Instructor

MECH 719 – Vibration Damping and Control

A survey course in vibration damping and control providing the necessary background to analyze structural vibrations and design effective and efficient vibration suppression using either passive or active means. Topics covered include modal analysis, viscoelastic damping treatments, vibration absorbers, vibration isolators, and active feedback control using both traditional and adaptive structures technology. Method of instruction will include both lecture and laboratory sessions.

Prerequisites: MECH 515 and ASYS 565 or Permission of Instructor

MECH 720 – Analytical Mechanics

Elements of the calculus of variations, virtual work, D'Alembert's principle, Lagrange's and Hamilton's equations of motion, applications to holonomic and nonholonomic systems, with emphasis on rigid body motion and gyroscopic instruments.

Prerequisites: MECH 521

MECH 728 – Advanced Flight Mechanics

Advanced topics in flight mechanics and control chosen from optimal control, discrete-data control systems, aeroelastic effects, human pilot models and nonlinear effects.

Prerequisites: MECH 628 and ASYS 525 or equivalent

MECH 731 – Modern Methods of Orbit Determination

Introduction to probability theory. Statistical mission assessment. Derivation of the methods of the least squares in linear and nonlinear problems. Sequential estimation methods, including numerical instabilities and time weighting. Applications to the problem of determining the updating of the orbital elements of satellites.

Prerequisites: MECH 532
MECH 732 – Advanced Astrodynamics

Introduction to canonical dynamics and applications to the two body problem. Classical and canonical variation of parameter equations of motion. Forces influencing earth satellite motion are surveyed. Applications to earth satellite motion. Additional topics from resonance, stability, periodic motion.

Prerequisites: MECH 521

MECH 733A – Numerical Methods for Orbit Design

Advanced topics in satellite trajectory analysis. Emphasis on tools enabling successful mission design in complex dynamical environments. Analysis of restricted and circular-restricted three-body problem, specifically the Earth-Moon-Satellite system. Development of satellite equations of motion using special perturbations and variational techniques. Introduction to satellite trajectory planning, with emphasis on computational guidance and control. Focus is on numerical trajectory planning and optimization algorithms that can be used on-board for autonomous guidance.

Prerequisites: MECH 732 or Permission of Instructor

MECH 899 – Doctoral Level Independent Study

Directed study for doctoral students on a special topic which is not normally covered in a regularly scheduled course or as part of dissertation research. Topic, format, and requirements of the course are determined by the faculty member directing the study. Requires submission of Special Studies Form and syllabus to the department for registration.

Prerequisites: Permission of Research Advisor

MENG 501 – Aerospace Propulsion

This course provides the student with an understanding of the essential elements of airbreathing and non-air breathing propulsion systems. Covered are basic principles of thermodynamics and fluid dynamics applied to the analysis of on-design and off-design performance of turbojet systems (turbojet, turbofan, turboprop), to performance parameters of ramjet and scramjet engines and to fundamentals of chemical and non-chemical rocket propulsion. Performance trade-offs are reviewed relative to military applications.

Prerequisites: Undergraduate thermodynamics
MENG 530 – Chemical Rocket Propulsion

Development of performance parameters, analyses of combustion, fluid mechanics, and heat transfer as they pertain to rocket engines and motors, comparison of propellants, and analysis of simple rocket flight and staging. Note: This course is planned to be offered via Distance Learning, in the same quarter it is offered in residence.

Prerequisites: Undergraduate Thermodynamics

MENG 531 – Space Propulsion and Power Systems

Concept, theory, and performance of chemical and nonchemical propulsion systems for use in space. Typical Systems will include electrical, nuclear, liquid propellant, and exotic space propulsion systems. Concept, theory and performance of power generation methods in space. Systems studied will include low and high power systems intended for short term or long term applications. Chemical, solar and nuclear devices and the energy conversion means for converting energy from these sources into useful electrical power will be studied. An overview of space mission requirements and how they impact propulsion and power system selection. Review of current and future trends in spacecraft propulsion and power generation.

Prerequisites: Undergraduate Thermodynamics

MENG 571 – Fundamentals of Heat Transfer

Course covers the fundamentals of conduction, convection, and radiation heat transfer. The derivation and solution of the general heat conduction equation for one-and two dimensional, steady and unsteady conduction problems will be covered. Both analytical and numerical solution techniques will be studied for forced convection in laminar and turbulent flows on internal and external surfaces. We will lastly have an introduction to general radiation terms and develop solutions to relevant situations including solar radiation.

Prerequisites: None

MENG 585 – Airbreathing Engine Design

The laws of mechanics and thermodynamics are applied to determine the design point requirements for and the design of an aircraft gas turbine engine. Emphasis is placed on determining the engine type heat suited to the requirements of a specified aircraft mission. Computer analysis is used extensively in mission analysis, on-design engine performance analysis, and in component design. Note: This course is not open to students who have taken AE 483 at USAFA.

Prerequisites: MENG 501 or Permission of Instructor
MENG 623A – Advanced Engineering Thermodynamics

This course provides a treatment of macroscopic thermodynamics and thermostatistics for engineers. The conditions of equilibrium, fundamental relations, Legendre transformations, Maxwell Relations, and cycle analyses are presented.

Prerequisites: Undergraduate Thermodynamics

MENG 633 – Fundamentals of Combustion

This course is designed to provide an understanding of the fundamentals of combustion and combustion aerodynamics. An overview of the variety of topics in combustion will be covered including: Chemical thermodynamics; Chemical kinetics; Gas dynamics of reacting flows; Deflagration and detonation of premixed gases; Laminar flames, and Turbulent flames. Details of flame temperatures, structures, flame speeds, and flame lengths will be visualized as well as calculated with analytical tools such as Chemical Equilibrium and Applications (CEA) and Chemkin. Real combustion systems such as the Well Stirred Reactor, the Ultra Compact Combustor, and the Rotating Detonation Engine will be discussed.

Prerequisites: Undergraduate Thermodynamics and Chemistry

MENG 673 – Radiation Heat Transfer

Study of methods for calculating heat transfer by thermal radiation. Integral equations are formulated for thermal radiation among surfaces with and without an intervening gas. Approximate engineering methods of solution are discussed and applied to components of satellite, propulsion, and solar energy systems. In addition, the radiative properties of gasses and particulate media will be discussed.

Prerequisites: MENG 571 or equivalent

MENG 674 – Convection Heat Transfer

This course provides a treatment of convection heat transfer. Laminar and turbulent flows, internal and external flows, forced and free convection and steady and unsteady heat transfer are considered. High speed and variable property effects are examined with emphasis on thermal management. Various boundary conditions are examined along with inverse experimental methods.

Prerequisites: AERO 634 or equivalent
**MENG 699 – Master’s Level Independent Study**

Course content determined by faculty member based on student need.

Prerequisites: Permission of Instructor

**MENG 732 – Advanced Turbomachinery**

The principles of fluid mechanics, thermodynamics, heat transfer, and combustion are applied to gas turbine engines. Cycles and component performance are covered with emphasis on application in high performance aircraft propulsion systems.

Prerequisites: MENG 501

**MENG 899 – Doctoral Level Independent Study**

Directed study for doctoral students on a special topic which is not normally covered in a regularly scheduled course or as part of dissertation research. Topic, format, and requirements of the course are determined by the faculty member directing the study. Requires submission of Special Studies Form and syllabus to the department for registration.

**TENY 799 – Thesis Completion**

Thesis Completion course for graduating students to be taken during the last quarter of study. Registration in TENY 799 for 12 non-billable credit hours is required for all master's students whose research advisors are in the Department of Aeronautics and Astronautics. The grade assigned to this course is the official thesis grade.
**Aero Core Requirements**

The following is a complete list of the courses that comprise each discipline contained in the Core Aero sequence (as referenced in Section 4.1.4):

<table>
<thead>
<tr>
<th>Aerodynamics</th>
<th>Structures &amp; Materials</th>
<th>Aircraft Stability &amp; Control</th>
<th>Propulsion</th>
<th>Air Weapons</th>
</tr>
</thead>
<tbody>
<tr>
<td>AERO-517</td>
<td>MATL-525</td>
<td>AERO-620</td>
<td>MENG-501</td>
<td>ASYS-563</td>
</tr>
<tr>
<td>AERO-534</td>
<td>MATL-545</td>
<td>ASYS-525</td>
<td>MENG-530</td>
<td>ASYS-590</td>
</tr>
<tr>
<td>AERO-537</td>
<td>MATL-560</td>
<td>ASYS-565</td>
<td>MENG-571</td>
<td>ASYS-630</td>
</tr>
<tr>
<td>AERO-543</td>
<td>MATL-620</td>
<td>ASYS-625</td>
<td>MENG-585</td>
<td>ASYS-635</td>
</tr>
<tr>
<td>AERO-551</td>
<td>MATL-662</td>
<td>ASYS-765</td>
<td>MENG-633</td>
<td>ASYS-640</td>
</tr>
<tr>
<td>AERO-585</td>
<td>MATL-672</td>
<td>MECH-521</td>
<td>MENG-673</td>
<td>ASYS-650</td>
</tr>
<tr>
<td>AERO-610</td>
<td>MATL-680</td>
<td>MECH-529</td>
<td>MENG-674</td>
<td>SENG-520</td>
</tr>
<tr>
<td>AERO-622</td>
<td>MATL-685</td>
<td>MECH-620</td>
<td>AERO-729</td>
<td>SENG-593</td>
</tr>
<tr>
<td>AERO-627</td>
<td>MECH-500</td>
<td>MECH-622</td>
<td>MENG-732</td>
<td>SENG-610</td>
</tr>
<tr>
<td>AERO-634</td>
<td>MECH-515</td>
<td>MECH-628</td>
<td></td>
<td>SENG-640</td>
</tr>
<tr>
<td>AERO-640</td>
<td>MECH-541</td>
<td>MECH-629</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AERO-652</td>
<td>MECH-542</td>
<td>MECH-719</td>
<td></td>
<td></td>
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<td>AERO-729</td>
<td>MECH-600</td>
<td>MECH-720</td>
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<tr>
<td>AERO-740</td>
<td>MECH-601</td>
<td>MECH-728</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AERO-753</td>
<td>MECH-605</td>
<td></td>
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<td>MECH-610</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>MECH-642</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>MECH-644</td>
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<tr>
<td></td>
<td>MECH-646</td>
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<td></td>
<td>MECH-662</td>
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<td></td>
<td>MECH-712</td>
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<td></td>
<td>MECH-719</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
AFIT operates on a quarter system. Each quarter consists of 10 weeks of classes plus a final exam week and a break week. There are also two four-week short terms that are used for preparatory courses for incoming students prior to their first regular quarter.

### 2019 Fall Orientation / Review Session
- Military Students Arrive: 22 Aug
- Student Orientation/In-Processing: 19-22 Aug
- AETC Family Day (no classes): 30 Aug
- Labor Day (no classes): 2 Sep
- Review Session: 3-27 Sep

*All ENY new students must have approved completed Ed Plan in Web Advisor NLT 4 Oct*

### 2019 Fall Quarter
- Classes begin: 1 Oct
- Columbus Day (no classes): 14 Oct
- Veteran’s Day (no classes): 11 Nov
- Thanksgiving (no classes): 28 Nov
- AETC Family Day (classes held): 29 Nov
- Classes End: 9 Dec
- Finals: 10-13 Dec

### 2020 Winter Quarter
- Classes begin: 6 Jan
- MLK Day (no classes): 20 Jan
- President’s Day (no classes): 17 Feb
- Classes end: 13 Mar
- Finals: 16-19 Mar
- Graduation: 26 Mar

### 2020 Spring Quarter
- Classes begin: 30 Mar
- AETC Family Day: 22 May
- Memorial Day (no classes): 25 May
- Classes end: 5 Jun
- Finals: 8-11 Jun
- Graduation (no ceremony): 18 Jun

### 2020 Summer Orientation / Review Session
- Military Students Arrive: 15 May
- Student Orientation/In-Processing: 18-22 May
- Review Session: 26 May-19 Jun
- AETC Family Day: 22 May
- Memorial Day (no classes): 25 May

### 2020 Summer Quarter
- Classes begin: 29 Jun
- Independence Day (no classes): 3 Jul
- AETC Family Day: 6 Jul
- Classes end: 3 Sep
- AETC Family Day: 4 Sep
- Labor Day (no classes): 7 Sep
- Finals: 8-11 Sep
- Graduation (no ceremony): 17 Sep

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138
# APPENDIX D: CURRICULUM COMMITTEES AND ADVISORS

**DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS**

**CURRICULUM COMMITTEES**

Effective June 2018

<table>
<thead>
<tr>
<th>GROUP</th>
<th>GRAD AERO (GAE)</th>
<th>GRAD ASTRO (GA)</th>
<th>GRAD MATERIAL SCI (GMS)</th>
<th>GRAD SPACE SYS (GSS)</th>
<th>DOCTORAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid Mechanics</td>
<td>Reeder</td>
<td>Hartsfield</td>
<td>Polanka</td>
<td>Greendyke</td>
<td>Reeder</td>
</tr>
<tr>
<td>Solid Mechanics</td>
<td>Palazotto</td>
<td>Ruggles-Wrenn*</td>
<td>Palazotto</td>
<td>Ruggles-Wrenn*</td>
<td></td>
</tr>
<tr>
<td>Dynamics Systems &amp; Controls</td>
<td>Kunz*</td>
<td>Bettinger*</td>
<td>Wiesel</td>
<td>Cobb*</td>
<td>Cobb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DAGSI/PTS</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polanka</td>
<td>Kunz</td>
</tr>
</tbody>
</table>

* Denotes Chair
APPENDIX E: AWARDS AVAILABLE TO GRADUATING ENY STUDENTS

Students earning a Master’s degree within the Department of Aeronautics and Astronautics are eligible for a variety of awards. Descriptions of these awards, along with the selection criteria, are provided below.

THE MERVIN E. GROSS AWARD

The Mervin E. Gross Award is given to the graduating student who has demonstrated the most exceptional academic achievement and high qualities of character, initiative, and leadership while pursuing a master's degree in the Graduate School of Engineering and Management. To be eligible for consideration, a graduating student must have a cumulative grade point average of at least 3.75.

ENY BEST THESIS AWARDS

The ENY Best Thesis Award is given in recognition of the most exceptional master's thesis by graduating students of the Department of Aeronautics and Astronautics in each of the following technical categories: (1) Dynamics and Control, (2) Fluids/Heat Transfer, (3) Materials and Structures, and (4) Research Outside of ENY.

AIR FORCE INSTITUTE OF TECHNOLOGY DEAN’S AWARD

The Dean’s Award is given in recognition of the most exceptional master’s thesis by a graduating student in each academic department of the Graduate School of Engineering and Management. In the Department of Aeronautics and Astronautics, the Dean’s Award is given to the best and most exceptional master’s thesis among the three ENY Best Thesis Award winners.

AIR FORCE INSTITUTE OF TECHNOLOGY CHANCELLOR’S AWARD

The Chancellor's Award is given in recognition of the most exceptional master's thesis by a graduating student of the Graduate School of Engineering and Management. The award is based on a master's thesis, which reflects exceptional defense research contributions to scientific, management, or engineering knowledge; in addition, consideration may be given to originality, resourcefulness, completeness, scope, clarity of presentation, and level of difficulty. The nature of the research (scientific versus engineering, or theoretical versus experimental) is not a consideration.
DISTINGUISHED GRADUATE RECOGNITION

The commandant of AFIT is authorized to designate as Distinguished Graduates (DG) those students who have performed in an outstanding manner in accomplishing the overall educational objectives of the Graduate School of Engineering and Management. The criteria for identifying DG achievement encompass academic scores (GPA of 3.75 or higher) and the "whole person" concept, based on professional qualities (e.g. character, integrity, leadership, fellowship, and team building), and recommendation of the department heads.

THE LOUIS F. POLK AWARD

The Louis F. Polk Award, sponsored by National Defense Industrial Association (NDIA), is given in recognition of the student who has made an advanced contribution in their professional field in direct furtherance of the objectives of NDIA. The honoree is expected to achieve the highest standards of academic and professional accomplishment during their participation in the Institute's graduate programs as demonstrated by (1) a high cumulative grade point average (GPA) in all graduate courses taken in resident AFIT programs and (2) ability to apply academic and professional theory to the solution of a significant problem of direct value to national defense through research and thesis accomplishment.

THE LT EDWIN E. ALDRIN, SR., AWARD

The Lt Edwin E. Aldrin, Sr., Award, sponsored by the Wright Memorial Chapter of the Air Force Association and authorized by AFITI 36-110, is given in recognition of the student who has displayed exceptional leadership characteristics, and demonstrated high quality academic accomplishments, military decorum and the ability to work with faculty and fellow students.

THE AIAA DAYTON-CINCINNATI GRADUATE STUDENT AWARD FOR SERVICE

The American Institute of Aeronautics and Astronautics (AIAA) Dayton-Cincinnati Graduate Student Award for Service is presented to an AFIT graduating AIAA member in a master's level engineering program who has demonstrated exceptional service to the aerospace engineering profession, the local community, and the Air Force whether via the student section of AIAA, the professional section of AIAA, or another means over the duration of the student's full-time residency. The recipient of the award will have their achievements acknowledged with a certificate given out at the March graduation awards ceremony and a plaque given at the local AIAA Awards Banquet in May.

THE IVAN B. THOMPSON AWARD

The Ivan B. Thompson Award is given to a member of the graduating class who has shown exceptional service to the class, the School, the Air Force, and/or the local community.
DARPA INTERN PROGRAM

This program is not an award, but is a competitive internship assignment that is served during the year following Graduation. The purpose of this program is to bring officers with operational backgrounds who have the potential to be senior leaders in their Service to DARPA to expose them to the mission and operation of DARPA, and to demystify perceptions about the agency. Selectees will typically spend 3-4 months at DARPA.

SIGMA GAMMA TAU AWARD

Sigma Gamma Tau is the honor society for Aerospace Engineering. The society seeks to identify and recognize achievement and excellence in the Aerospace field. Sigma Gamma Tau's collegiate chapters elect annually to membership those students, alumni, and professionals who, by conscientious attention to their studies or professional duties, uphold this high standard for the betterment of their profession. The objectives of Sigma Gamma Tau, as stated in the preamble of the Society's national constitution, are: "to recognize and honor those individuals in the field of Aeronautics and Astronautics who have, through scholarship, integrity, and outstanding achievement, been a credit to their profession. The society seeks to foster a high standard of ethics and professional practice and create a spirit of loyalty and fellowship, particularly among students of Aerospace Engineering." Distinguished scholarship or eminent professional attainment in Aerospace Engineering is the primary eligibility requirement for Sigma Gamma Tau. At graduation, the Sigma Gamma Tau Award may be presented to the graduating Sigma Gamma Tau student member who demonstrates leadership, character, and initiative within the Institute, the Air Force, and/or local community while simultaneously demonstrating outstanding scholarship. Eligibility for the award is restricted to AFIT resident students who are members of SGT and have a cumulative grade point average of at least 3.75 (4.00 scale).
APPENDIX F: SECTION COURSE REQUIREMENTS

The course requirements for qualification for the Master of Science degree are specified in the Program Guide (Chapter 4) and on the Section Course Requirements (SCR) Form, AFIT Form 69. The AFIT Form 69 for each program is provided in this appendix.
Academic Program Summary

Program Title:
Master of Science in Aeronautical Engineering

Purpose: Minor Revision

Academic Implementation Year: 2014-2016

Department:

Program Description:

This ABET-accredited program is designed to produce graduates who are technically well-prepared for their subsequent duties and responsibilities as aeronautical engineers in DoD organizations.

<table>
<thead>
<tr>
<th>Program Requirements</th>
<th>Min Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research AER0-799 and TENY-799</td>
<td>12</td>
</tr>
<tr>
<td>Core Completion of ABET core (see Program Guide)</td>
<td>0</td>
</tr>
<tr>
<td>Math or Stat, If Applicable Any MATH or STAT course 500 or above; plus department-approved math or substitute</td>
<td>8</td>
</tr>
<tr>
<td>AERO Core One ENY course (min) from 3 of the 5 aeronautics disciplines. May be concurrent with Math or Other.</td>
<td>9</td>
</tr>
<tr>
<td>Sequences Two 3-course sequences selected from a department-approved list</td>
<td>20</td>
</tr>
<tr>
<td>Other Other graduate courses as required to total 48 credit hours</td>
<td>0</td>
</tr>
</tbody>
</table>

Program Restrictions (e.g. U.S. Citizens Only): None

Accreditation/Review Expiration Date:

Attachments Memo Letter Program Guide
# Academic Program Summary

## Program Title:

Graduate Aeronautical Engineering (AERO.MS)

## Purpose:

Minor Off-cycle Revision

## Academic Implementation Year:

2014

## Department:

Aeronautical Engineering

## Degree Title:

Master of Science (Aeronautical Engineering)

## Program Description:

This program is designed to produce graduates who are technically well prepared for their subsequent duties and responsibilities as aeronautical engineers in DoD organizations.

## Program Requirements

<table>
<thead>
<tr>
<th>Program Requirements</th>
<th>Min Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thesis</td>
<td>12</td>
</tr>
<tr>
<td>Core</td>
<td>9</td>
</tr>
<tr>
<td>Math or STAT</td>
<td>8</td>
</tr>
<tr>
<td>Other</td>
<td>20</td>
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</table>

## Program Restrictions (e.g. U.S. Citizens Only):

None

## Accreditation/Review Expiration Date:

None

## Attachments

- Memo Letter
- Program Guide
### Academic Program Summary

**Program Title:**
The Graduate Astronautical Engineering (GA) program

**Purpose:**
- Minor Off-cycle Revision
- Moderate Revision
- Deactivation
- Major/Other

**Academic Implementation Year:**
2017-19

**Department:**
Astronautical Engineering

**Degree Title:**
Master of Science in Astronautical Engineering

**Program Description:**
The Graduate Astronautical Engineering (GA) program is designed to provide astronautical engineering specialists for the Air Force. Astronautical engineering is dedicated to the design, testing, and development of spacecraft, missiles, launch vehicles, and related systems. In the traditional program, students enter as a class in September and graduate in 18 months. This ABET accredited program leads to a Master of Science in Astronautical Engineering.

### Program Requirements

<table>
<thead>
<tr>
<th>Program Requirements</th>
<th>Min Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thesis</td>
<td>TENY799</td>
</tr>
<tr>
<td>Core</td>
<td></td>
</tr>
<tr>
<td>(MECH532 or MECH731 or MECH732) or (MECH632) (may be concurrent with Cat. 4 or 5)</td>
<td></td>
</tr>
<tr>
<td>(PHYS 521) or (ASYS 525) (waiverable by academic adv.)</td>
<td></td>
</tr>
<tr>
<td>(MECH 521) (waiverable by academic adv.)</td>
<td></td>
</tr>
<tr>
<td>Math or STAT if applicable</td>
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</tr>
<tr>
<td>(two graduate Math courses)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>Major Sequence (Minimum of 3 courses)</td>
<td></td>
</tr>
<tr>
<td>/ Minor Sequence (Minimum of 3 Courses)</td>
<td></td>
</tr>
<tr>
<td>Other graduate courses required to total at least 48 hours</td>
<td></td>
</tr>
<tr>
<td>ABET Core</td>
<td></td>
</tr>
<tr>
<td>Meet all ABET Requirements in Department Program Guide (Waiverable by academic adv.)</td>
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</tr>
<tr>
<td>Electives</td>
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</tr>
<tr>
<td>Other Graduate Courses required to total at least 48 hours</td>
<td></td>
</tr>
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</table>

**Program Restrictions (e.g. U.S. Citizens Only):**
## Academic Program Summary

**Program Title:**

1. Master Degree Program
2. Certificate Program

The Graduate Astronautical Engineering (GA) (ASTRO_NON_ABET.MS) Program

**Purpose:**

- Minor Off-cycle Revision
- Moderate Revision
- Deactivation
- Major/Other

**Academic Implementation Year:**

2014

**Department:**

**Major:**

Astronautical Engineering

**Degree Title:**

Master of Science (Astronautical Engineering)

**Program Description:**

The Graduate Astronautical Engineering (GA) program is designed to provide astronautical engineering specialists for the Air Force. Astronautical engineering is dedicated to the design, testing, and development of spacecraft, missiles, launch vehicles, and related systems.

<table>
<thead>
<tr>
<th>Program Requirements</th>
<th>Min Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thesis</td>
<td>12</td>
</tr>
<tr>
<td>AERO-799 and TENY 799</td>
<td></td>
</tr>
<tr>
<td>Core</td>
<td>8</td>
</tr>
<tr>
<td>(MECH 532 or MECH 731 or MECH 732), (MECH 632) (may be concurrent with Cat 4 or 5), (PHYS 521), (ASYS 525) (waiverable by academic adv.), and (MECH 521) (waiverable by academic adv.)</td>
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</tr>
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<td>Math or STAT</td>
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<td>If applicable (two graduate Math courses)</td>
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<tr>
<td>Other</td>
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<tr>
<td>Major Sequence (Minimum of 3 courses) / Minor Sequence (Minimum of 3 Courses); Other graduate courses required to total at least 48 hours</td>
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</table>

**Program Restrictions (e.g. U.S. Citizens Only):**


**Accreditation/Review Expiration Date:**


**Attachments**

- Memo Letter
- Program Guide
Section Course Requirements - Graduate Materials Science (GMS)

Academic Program Summary

Program Title: Graduate Materials Science (GMS) program

Purpose: Moderate Revision

Academic Implementation Year: 2014-2016

Department: Materials Science

Degree Title: Master of Science (Materials Science)

Program Description:

The goal of the GMS program is to provide a student who has a background in engineering or physical science with the knowledge of materials science and engineering necessary for work in the fields of structural and non-structural materials for aerospace systems. Such positions may range from those requiring very detailed and advanced level work in a specific discipline to those involving broad responsibilities and requiring interaction among many disciplines.

<table>
<thead>
<tr>
<th>Program Requirements</th>
<th>Min Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thesis</td>
<td>MATL 799</td>
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<td>Core</td>
<td>MATL 525, MATL 545, MATL 680, MATL 560 and MATL 685</td>
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<td>Math or STAT</td>
<td>one graduate Math course</td>
</tr>
<tr>
<td>Other</td>
<td>Specialty Sequence (minimum three courses)</td>
</tr>
</tbody>
</table>

Program Restrictions (e.g. U.S. Citizens Only):

Accreditation/Review Expiration Date: Mar 1, 2015

Attachments

Academic Program Summary

Program Title: Graduate Space Systems (GSS)

Purpose: O Minor Off-cycle Revision [S] Moderate Revision O Deactivation O Major/Other

Academic Implementation Year: 2014
Department: Major: Space systems

Degree Title: Master of Science (Space Systems)

Program Description:
The Graduate Space Systems (GSS) program is designed to provide officers with a broad knowledge of space systems engineering and space science. Education in the fundamentals of these areas will increase a student's effectiveness in planning, executing, and evaluating space systems and operations. Each student completes a research thesis on some aspect of space systems (engineering, science, or operations). The Space Systems graduate is ready to participate actively in organizations responsible for the selection, planning, management, operation, and evaluation of space systems for the DoD.

<table>
<thead>
<tr>
<th>Program Requirements</th>
<th>Min Credit Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thesis</td>
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<tr>
<td>Core</td>
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<tr>
<td>Math or STAT if applicable</td>
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<td>Other</td>
<td>10</td>
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</table>

Program Restrictions (e.g. U.S. Citizens Only):

Accreditation/Review Expiration Date: Mar 31, 2015

Attachments
| Memo Letter | Program Guide |
APPENDIX G: FORECAST OF COURSE
OFFERINGS FOR SUMMER 2019 - WINTER 2021

This information is provided for planning purposes and reflects the most accurate information available at the time of printing. Students should ensure the classes are being offered during the quarter they desire. Credit hour format: (hrs lecture - hrs lab) credit hrs.

<table>
<thead>
<tr>
<th>AERO</th>
<th>SU 19</th>
<th>FA 19</th>
<th>WI 20</th>
<th>SP 20</th>
<th>SU 20</th>
<th>FA 20</th>
<th>WI 21</th>
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<td>500</td>
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<td></td>
<td>Introduction to Aeronautics</td>
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<td></td>
<td></td>
<td></td>
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Note: DL indicates the course is planned to be offered via Distance Learning.
Availability for required courses outside of ENY is shown in the tables below:

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