



NAVAL  
POSTGRADUATE  
SCHOOL

# STUDENT GUIDE

## Curriculum 591

Space Systems Engineering/  
Astronautical Engineering Degree Programs

Department of Mechanical and Aerospace  
Engineering

UPDATED JULY 2015

<http://www.nps.edu/Academics/GSEAS/MAE>

## Table of Contents

1. Introduction .....	3
2. Welcome Aboard.....	4
2.1. MESSAGE FROM THE CHAIR.....	4
2.2. MESSAGE FROM THE PROGRAM OFFICER.....	5
3. Program Educational Objectives and Student Outcomes .....	6
3.1. PROGRAM EDUCATIONAL OBJECTIVES .....	6
3.2. STUDENT OUTCOMES .....	6
4. Degree Requirements .....	7
4.1. MASTER OF SCIENCE IN ASTRONAUTICAL ENGINEERING - MSAE.....	8
4.2. MASTER OF SCIENCE IN ENGINEERING SCIENCE (ASTRONAUTICAL ENGINEERING) - MSES (AE) .....	9
4.3. ASTRONAUTICAL ENGINEER.....	9
4.4. SUMMARY OF DEGREE REQUIREMENTS FOR MASTER OF SCIENCE AND ASTRONAUTICAL ENGINEER DEGREE.....	10
5. Your Thesis .....	10
5.1. OVERVIEW .....	10
5.2. CHOOSING 4000-LEVEL COURSES AND THESIS SPECIALIZATION AREAS.....	13
6. Timeline for a Nine-Quarter Program .....	14
7. If an MS degree requires only 32 course credit-hours, why are there so many courses in my matrix? 15	
7.1. ABET REQUIREMENTS.....	16
7.2. BSAE EQUIVALENCY.....	16
8. Your Course Matrix.....	17
8.1. VALIDATING 2000-LEVEL COURSES .....	19
8.2. DROPPING 3000- AND 4000-LEVEL COURSES.....	20
8.3. GENERIC 9 QUARTER ASTRONAUTICAL ENGINEERING MATRIX (WITH REFRESHER QUARTER) .....	21
8.4. GENERIC 9 QUARTER ASTRONAUTICAL ENGINEERING MATRIX (WITHOUT REFRESHER QUARTER).....	22
8.5. REVIEW YOUR MATRIX.....	23
9. Filling Out the BSAE Equivalency Form and the MSAE Checklist .....	24
9.1. WHEN TO FILL OUT THESE FORMS .....	24
9.2. HOW TO FILL OUT THESE FORMS.....	25
9.3. MAE THESIS ADVISING POLICIES .....	25
10. Graduating Student Exit Survey .....	26
11. APPENDICES.....	26
APPENDIX 4 - EDUCATIONAL SKILL REQUIREMENTS (ESRs) AND THE SUBSPECIALTY CODES (P-CODES).....	26

# 1. Introduction

This document provides a guide to the resident Astronautical Engineering Degree Programs in the Department of Mechanical and Aerospace Engineering (MAE). Separate guides are available for distance learning programs, the Mechanical Engineering Program, and Doctoral Programs. Much of the information contained within is based on a standard 9-quarter 591 curriculum leading to a Master of Science in Astronautical Engineering (MSAE) and the 5500 subspecialty code. There are, however, students with programs of different lengths and this guide serves these students as well, with the necessary adjustment of the information provided. Regardless of duration, your academic program is tailored to you, and you should consult with the Program Officer and Academic Associate to ensure that your program meets your educational needs, the requirements of your sponsor and degree requirements. This guide provides information on educational objectives, degree requirements, thesis requirements, required paperwork, subspecialty code requirements (for Navy Officers), and planning your educational program. The MAE Department faculty and staff are here to help you succeed.

For questions please see the following people:

- CDR Christine McManus .....  
Program Officer (x-7517)
- Prof. Isaac Ross.....  
Academic Associate (x-2074)
- Prof. Garth Hobson .....  
MAE Dept Chair (x-2888)
- Prof. Claudia Luhrs .....  
MAE Dept Associate Chair (x-2568)

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## Acronyms:

- ABET ..... Accreditation Board for Engineering and Technology
- BS ..... Bachelor of Science
- BSAE ..... Bachelor of Science in Astronautical Engineering
- AE ..... Astronautical Engineering
- MS ..... Master of Science
- MSES ..... Master of Science in Engineering Science
- MSAE..... Master of Science in Astronautical Engineering

## 2. Welcome Aboard

### *2.1. Message from the Chair*

Welcome to the Department of Mechanical and Aerospace Engineering. This guide will help you with planning your academic program at NPS. While the guide is rather complete it is not totally proscriptive, and there can be room in some areas for variations that may better suit your personal educational objectives. So please take the guide in the spirit it was intended - as a guide - and not a complete, regimented set of absolute requirements. If you have questions, come ask us, we are here to support you!

I recommend that you read this document in its entirety so you better understand the complete program, including the requirements and necessary paperwork. This will provide you the opportunity to start exploring your options early, whether it is validating courses you have already taken as an undergraduate, adding special courses you want to take, or starting your thesis research in a given area early.

For most of you this will be your only opportunity at fully funded graduate education, so take full advantage of it. The MAE Department has excellent faculty and experimental and computational research facilities awaiting you. There are student professional organizations, such as ASME, ASNE, and AIAA that can enhance your educational experience and help in your future career. There is the opportunity to obtain a Professional Engineers License while you are here, and there is no better time.

Finally, I welcome you and your family to Monterey. I wish you a memorable and enjoyable experience at NPS. Wherever you go from here, please keep in contact with us so that we may hear from you and share in your successes. Bon Voyage in your academic journey!

**Garth V. Hobson, Ph.D.**  
**Chair, Department of Mechanical and Aerospace Engineering**

## ***2.2. Message from the Program Officer***

Welcome to the Naval Postgraduate School. On behalf of the Graduate School of Engineering and Applied Sciences (GSEAS) and the Space Systems Academic Group (SSAG), I would like to take this opportunity to congratulate each and every one of you on your acceptance and arrival at NPS. I believe that you will find this tour to be intellectually challenging and you will look back on it later in life as one of the most enjoyable tours of your career. I encourage you to seek out a balance of everything that NPS and Monterey have to offer. Maintain focus on your goal of obtaining an advanced degree from one of the finest institutions in the country, but also remember to give your mind a break and work the rest of your body from time to time. Take advantage of the many recreational activities, from kayaking in Monterey Bay to skiing at Lake Tahoe.

We have put together this Student Guide with your academic needs in mind. Inside you will find timelines and forms designed to ensure that you are successful in meeting the various academic and administrative requirements for earning a degree. Feel free to consult with the Academic Associate and me for additional guidance as you prepare these forms for submission. *Timely submission of these forms is imperative for successfully identifying any additional requirements that you may need to complete your Master's Degree.* In addition to required coursework, thesis research and presentation of your work to the faculty and your peers is a key graduation requirement. You choose the area for thesis research. Do not take this decision lightly. Start your search early by learning about current research that is being conducted in the department by the faculty and other students. You may be able to continue existing research. Perhaps you have knowledge of a fleet problem or a personal interest that you want to explore! With perseverance, it could be developed into an acceptable thesis proposal.

Please consider the faculty and staff as the most valuable resource in your academic endeavors. We are here to help you succeed. Without you, there is no Naval Postgraduate School and the service that it provides. We will do our part to make your tour successful through a blend of quality education, career guidance and esprit de corps. I look forward to continued interaction with each and every one of you! My door is always open and again, Welcome Aboard!

**Christine McManus**  
**CDR, USN**  
**Program Officer, Space Systems Engineering**

### **3. Program Educational Objectives and Student Outcomes**

#### ***3.1. Program Educational Objectives***

*The overall Program Educational Objective of the NPS Astronautical Engineering Program is to support the NPS Mission by producing graduates who have knowledge and technical competence in astronautical engineering at the advanced level and who can apply that knowledge and competence to fill technical leadership roles in support of national security.*

In order to achieve this goal, the specific objectives are to produce graduates who achieve the following within a few years of graduation:

1. Are established as a valued source of technical expertise in research, design, development, acquisition, integration and testing of national security space (NSS) systems including formulation of operational requirements, plans, policies, architectures, and operational concepts for the development of space systems.
2. Have assumed positions of leadership involving program management, systems engineering, and/or operational employment of space systems within the national security space (NSS) enterprise.
3. Have effectively managed the operation, tasking, and employment of national security space (NSS) systems to increase the combat effectiveness of the Naval Services, other Armed Forces of the U.S. and our partners, to enhance national security.

#### ***3.2. Student Outcomes***

Student Outcomes for the NPS Astronautical Engineering program are:

1. Graduating students will meet the ABET (a) through (k) outcomes either by previous attainment of an ABET BSAE Degree, or by having the knowledge and skills equivalent to an ABET-accredited BSAE.
2. Graduating students will have a minimum of one (1) year of advanced study beyond the bachelor's level and have advanced level knowledge in Astronautical Engineering as demonstrated by the ability to apply master's level knowledge in one of the available specialized disciplines of Astronautical Engineering.
3. Graduating students will have the ability to apply technical knowledge in a leadership role related to national security.

The ABET (a) though (k) outcomes are:

- (a) an ability to apply knowledge of mathematics, science, and engineering
- (b) an ability to design and conduct experiments, as well as to analyze and interpret data

- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- (d) an ability to function on multidisciplinary teams
- (e) an ability to identify, formulate, and solve engineering problems
- (f) an understanding of professional and ethical responsibility
- (g) an ability to communicate effectively
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- (i) a recognition of the need for, and an ability to engage in life-long learning
- (j) a knowledge of contemporary issues
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

In addition, to fulfill their future responsibilities and meet the intent of Student Outcome 3, the program sponsor has specified that Navy officer graduates have technical knowledge and competence in the following specific areas:

1. Orbital Mechanics and Space Environment
2. National Security Space Systems
3. Project Management and System Acquisition
4. Spacecraft Communications and Signal Processing
5. Computers: Hardware and Software
6. Spacecraft Guidance and Control
7. Spacecraft Structures, Materials and Dynamics
8. Propulsion Systems
9. Spacecraft Thermal Control
10. Spacecraft Power
11. Remote Sensing and Payload Design
12. Spacecraft Design, Integration and Systems Engineering
13. Ground Systems and Systems Engineering

The specific areas of technical knowledge and competence listed above are derived from the Educational Skill Requirements (ESRs) for the Space Systems Engineering (591) curriculum. The ESRs (listed in Chapter 7) are established by program sponsors with input from the Space Systems and Astronautical Engineering faculty, the Dean of the Graduate School of Engineering and Applied Sciences (GSEAS) and the Provost.

## 4. Degree Requirements

Each course in the MAE Department falls into one of the following levels:

- ME1xxx/AE1xxx** – Introductory undergraduate-level class
- ME2xxx /AE2xxx** – Undergraduate-level class
- ME3xxx /AE3xxx** – Advanced undergraduate or introductory graduate-level class
- ME4xxx /AE4xxx** – Graduate-level class

The course catalog (either the print /on-line version or in Python) lists the quarter credit-hours provided by all courses. For example, consider the course, AE2820 Introduction to Spacecraft Structures. This class is assigned a value of (3-2), which means that every week there are 3 hours of lecture, and 2 hours of laboratory. To calculate the quarter credit-hour (QCH) value of a class, apply the following formula:

$$\text{QCH} = \text{Lecture Hours} + \frac{1}{2} * \text{Laboratory Hours}$$

For successful completion of AE2820, you will earn  $3 + \frac{1}{2} * 2 = 4$  QCH. Note that your matrix has four AE0810 classes, which are thesis “slots”. These are slots in your matrix which are included as a means of assigning QCH to the thesis (there is no actual lecture or lab meeting). These classes have a value of (0-8) and therefore each AE0810 earns you 4 QCH and hence your thesis earns a total of 16 QCH towards the Master of Science degree.

The following degree requirements are taken from the NPS Academic Catalog.

#### ***4.1. Master of Science in Astronautical Engineering - MSAE***

- You must have completed work equivalent to the department's requirements for a Bachelor of Science (BS) degree. If you do not have a BS in Astronautical Engineering from an ABET-accredited undergraduate program, you may be able to establish *BSAE equivalency*, and hence become eligible to earn the MSAE degree. Please refer to **Section 7.2** for discussion of this issue.
- You must earn a minimum of 32 quarter hours of credits in 3000 and 4000 level courses, of which at least 12 credits must be at the 4000 level. Please see **Section 5.2** for information about further requirements for 4000 level courses.
- Of the 32 quarter hours, at least 24 quarter hours must be in courses offered by the Dept. of Mechanical and Aerospace Engineering.
- Of the 32 quarter hours, 8 quarter hours must be taken in technical topics from outside the department, at the 3000 or 4000 level.
- Of the 12 credits at the 4000 level, at least eight quarter-hours must be taken in courses from the MAE Department in the thesis area
- An acceptable thesis for a minimum of 16 credits.
- The total quarter credit-hours required is therefore 48 (coursework + thesis).



#### ***4.2. Master of Science in Engineering Science (Aeronautical Engineering) - MSES (AE)***

- You must have an acceptable academic background.
- You must earn a minimum of 32 quarter hours of credits in 3000 and 4000 level courses, of which at least 12 credits must be at the 4000 level. Please see **Section 5.2** for information about further requirements for 4000 level courses.
- Of the 32 quarter hours, at least 24 quarter hours must be in courses offered by the Dept. of Mechanical and Aerospace Engineering.
- Of the 32 quarter hours, 8 quarter hours must be taken in technical topics from outside the department, at the 3000 or 4000 level.
- Of the 12 credits at the 4000 level, at least eight quarter-hours must be taken in courses from the MAE Department in the thesis area
- An acceptable thesis for a minimum of 16 credits.
- The total quarter credit-hours required is therefore 48 (coursework + thesis).

#### ***4.3. Aeronautical Engineer***

- You must have a superior academic record, including a graduate QPR (3000 and 4000 level classes) of 3.70 or better.
- You may apply to this program after the completion of approximately one year of graduate level study.
- You must have:
  - At least 32 quarter-hours of credit at the 4000-level in MAE courses.
  - At least 20 quarter-hours of credit at the 3000 or 4000-level in MAE courses.
  - At least 12 quarter-hours of credit at the 3000 or 4000-level in courses outside of MAE courses. Of these 12 quarter-hours, at least at least one of them must be in mathematics.
- You must have an acceptable thesis of 28 credits.
- The total minimum quarter credit-hours required is therefore 92 (coursework + thesis).

#### 4.4. Summary of Degree Requirements for Master of Science and Astronautical Engineer Degree

	MSAE/MSES		AE Engineer
Content	Level	Qtr-Hours (min req'd)	
MAE	4000	12	32
	3000-4000	12	20
Non-MAE	3000-4000	8	12
Thesis		16	28
Total QTR Hours		48	92

## 5. Your Thesis

### 5.1. Overview

This overview will describe the thesis, why it is very important to your graduate study, what are the steps that you will need to perform and when they should or must be done, how to find an advisor, and the resources that are available to help you along the way. In the following section, questions and answers are provided for some common questions.

A thesis is a “position or proposition that a person (as a candidate for scholastic honors) advances and offers to maintain by argument” and a document containing results of original research and especially supporting a specific view.

The thesis is the most important part of your graduate education. While the coursework lays the foundation by providing analytical methods and tools, it is the thesis that provides you with the opportunity to use this knowledge in a new, original and creative manner. During your thesis research you will be able to consolidate what you have already learned, and possibly extend this by further self-

study, and to use this body of knowledge to address a new problem. The thesis will hopefully be the crowning achievement of your graduate study, and will be your introduction to the community of scholars.

The first step in the thesis process is choosing an advisor and a topic. While your formal thesis slots may be in the last 2 or 3 quarters at NPS, it is very important that you have a thesis advisor and topic chosen well before this, preferably a year or so before you plan to graduate. During the time between choosing an advisor/topic and the start of your thesis slots, you should meet regularly with your advisor and spend a few hours a week reading background material and thinking about the problem. Your research can and should in fact begin as soon as possible.

The method for choosing your topic and advisor is completely up to you. However, you are strongly advised to talk to every faculty member in all the areas that you have any interest before making decisions. There are several questions you might want to ask yourself, before talking to the faculty. What type of work do you most enjoy? Generally, thesis research may be categorized as analytical (e.g. using a pencil and paper for mathematical modeling and derivation of solutions), computational (e.g. using finite element technique or computational fluid mechanics to find solutions, or perhaps writing computer programs yourself), experimental (e.g. designing, building, or modifying an existing set-up to obtain new data) or some combination of the three. It is generally advisable that you take a course from a professor before you make a commitment to work for him or her. The MAE and SSAG faculty periodically schedule thesis opportunity presentations, where they will discuss their current research interests and the available topics. In addition, there are MAE and SSAG websites which contain short written descriptions for current thesis topics of MAE/SSAG faculty. You may talk to fellow students, who are close to graduating to discuss what they have done and how they enjoyed their experience. However, the faculty member is the best source of information regarding available thesis topics. Finally, you may wish to review previous theses, as well as conference and journal publications from the various faculty members.

Note that your thesis advisor must be a faculty member from the MAE Dept. Also, in addition to choosing a thesis advisor, you must also identify another faculty member who will serve as a thesis co-advisor, or alternatively, as *second reader*. A thesis co-advisor is typically someone who is

technically involved with the thesis research and who will also help guide you in your research. A second reader is someone who is not directly involved with your research, but has agreed to read, critique, and edit your thesis.

After you find an advisor and agree on the topic, you are required to fill out a thesis approval form, which must be signed by the thesis advisor, the (591) Academic Associate and the Chair of the MAE Department no later than the beginning of the quarter in which first thesis slot is scheduled.

While your advisor will help you along the way and provide broad guidance and feedback, it is the responsibility of the student to be self-motivated and to initiate all of the steps. Do not expect your advisor to provide a detailed, step-by-step, road map for you. You should develop independence, and think through problems first, before asking your advisor. However, that does not in any way mean you should avoid meeting with your advisor. You should meet regularly with your advisor to discuss what you have done, what issues have arisen, how you plan to solve them, and what your next steps should be.

One common problem faced by researchers is the failure to sufficiently limit the scope of their work. Being overly broad can lead to a lack of focus and prevent any contribution from being made. It may seem to you that your advisor has asked you to solve a problem that you consider trivial and you may be inclined to broaden the scope. Stay focused on the immediate problem. If you solve the problem then by all means go on to a larger problem. But initially, keep your focus on a narrow and well-defined problem.

One way that you can help yourself is to write a short Thesis Proposal. It can be useful in helping to consolidate your understanding and focusing your future work. This may be written after you have been working on the problem for several months, have read dozens of articles and it may contain the following elements:

1. Introduction to the problem. This describes the problem and why it is important.
2. State of the art literature review and what is not known.
3. Objectives. Your goals for the work. What would be the desired outcome(s)? Be specific. Do not say to better understand something.

4. Proposed work. Very limited and specific.

For you to make an original contribution, it generally requires that you have an understanding of what is already known, by experts in your field. Therefore, one of the primary resources on which you will depend is the NPS library and the reference staff. The library offers a wide variety of seminars on conducting research and completing a thesis. While the world-wide-web is becoming an increasing source of information, and you should make use of it, there are many primary sources, such as books and journals, which are not available on the web. Most of the information on the web is not archival in nature – that is, it might not exist if a certain site is closed. Generally, journal articles are peer-reviewed, and hence provide one of the most reliable and authoritative sources of information. On the other extreme, for example, is Wikipedia, which is not reviewed and may include unreliable information. One of the most valuable skills you should learn during your thesis is how to obtain and process information and how to synthesize new results from that original information.

After your research is complete you will be required to write and submit a thesis document. For many of you it will be the longest document that you have written. There are several sources available to help you in writing the document, including “How to Write a Thesis” by the MAE Department and several guidelines and templates available on the NPS web site.

Finally you are required to make an oral presentation of your thesis research to the faculty and students of the MAE Department and SSAG. The presentation is approximately fifteen minutes with about a 5-minute question and answer period. A document on how to prepare and deliver this presentation is available from the Department.

In addition to the forms and the guidelines contained in this document, NPS has extra requirements with regards to thesis processing and other forms to fill out. You will find all of this information in <http://www.nps.edu/Research/research1.html>.

## ***5.2. Choosing 4000-Level Courses and Thesis Specialization Areas***

The requirements for the MS degree include at least twelve quarter hours of 4000-level classes. In addition, at least eight quarter hours of the 4000 level credits will be fulfilled by courses in the MAE

department in the thesis specialization area. Once you have identified a thesis advisor and topic, you and your advisor should identify your 4000 level course requirements. These will be chosen to provide you with the advanced knowledge you will need in order to conduct research in your chosen area. Generally, thesis topics will fall into one of the following primary disciplines:

- Orbital mechanics
- Attitude determination and control
- Spacecraft materials, structures and dynamics
- Spacecraft guidance, navigation and control
- Spacecraft/rocket propulsion
- Spacecraft thermal control
- Spacecraft design, testing and systems engineering
- Ground systems and systems engineering

The requirement for eight credit hours of 4000-level credits to support your thesis specialization area serves to ensure that you will have some depth in a single technical area (typically two 4xxx courses) while obtaining some breadth by virtue of your additional 4xxx credits in a different technical area.

## 6. Timeline for a Nine-Quarter Program

A standard program leading to the MS-AE degree is nine quarters. The following timeline will indicate the approximate times during your program when important actions need to be taken by you. With the exception of the first quarter all other items should be completed by the end of the indicated quarter. If your program is of shorter duration, most if not all of the indicated actions must be taken by you, but at earlier times. We will explain the various actions following the timeline.

Quarter	To Do
<b>1</b>	<p>Review the course matrix assigned to you. Compare with the standard matrix (for the appropriate number of quarters to match your program) found in Sections 8.3 and 8.4.</p> <p>You may be able to <b>validate</b> 2000-level classes and/or <b>drop</b> 3000-level classes if you have taken equivalent classes elsewhere (e.g. undergraduate program). Please see Section 8.1 for further information.</p> <p>Fill out your <b>first draft</b> of the <b>BSAE Equivalency</b> form (Appendix 2) and the <b>MSAE Checklist</b> (Appendix 1). Bring to Academic Associate for review.</p>
<b>2</b>	<p>Start interviewing faculty members in order to identify potential thesis topics. Make sure you read Section 5, “Your Thesis,” before you do that.</p>

<b>4</b>	<b>Pick your Thesis Advisor/Topic.</b> This determines your area of specialization. Select and <b>schedule your electives</b> (See Section 5.2).
<b>5</b>	If you haven't picked a Thesis Advisor already, delay no longer! Fill out (with your Thesis Advisor) and submit (to the Academic Associate) the <b>Thesis Approval Form</b> (Appendix 3). Start working on your thesis.
<b>6</b>	Start your thesis slots (maybe earlier). UPDATE the BSAE Equivalency Form (Appendix 2) and MSAE Checklist (Appendix 1) AND REVIEW WITH ACADEMIC ASSOCIATE.
<b>7</b>	<b>Submit</b> Final revisions (if needed) of the BSAE Equivalency and MSAE Checklist forms. Fill out the Graduating Student Exit Survey (on-line).
<b>After you graduate</b>	Please keep in touch. Let us know when you reach important milestones in your career, change career paths, etc.

## 7. If an MS degree requires only 32 course credit-hours, why are there so many courses in my matrix?

The requirements for an MS degree are listed above in Section 4 (and can be found in the NPS Academic Catalog). As you can see, these requirements include approximately eight courses, comprised of approximately three ME/AE3xxx courses, three ME/AE4xxx courses, and two technical 3xxx/4xxx courses taken outside the department. However, your course matrix, extending over a period of two years, consists of many more courses. Understanding the reasons for the additional courses will help you understand better the impact of changes to your matrix. Keep in mind that your specific educational background and goals will likely require modifications to your assigned matrix, and may in fact require fewer courses (while still meeting the above-stated requirements for the MS degree). Please discuss this with the Program Officer and Academic Associate.

The various courses that you will take serve several purposes. Chief among them are the following:

1. Meet credit-hour requirements for the Master of Science degree (see Section 4)
2. Meet Subspecialty Code 5500P Engineering Skill Requirements (See Section 7.1)

3. Meet prerequisite requirements for graduate (4000-level) classes also taken as part of your program. See Section 5.2.
4. Provide necessary technical background to support your thesis research.
5. Meet ABET requirements (See Section 7.2)

We have described the credit-hour requirements of the MS degree previously. We will now describe the the ABET requirements.

### ***7.1. ABET Requirements***

ABET is the Accreditation Board for Engineering and Technology. What is accreditation? From the ABET website:

"In the United States, accreditation is a non-governmental, peer-review process that assures the quality of the postsecondary education students receive. Educational institutions or programs volunteer to undergo this review periodically to determine if certain criteria are being met."

What is ABET accreditation? Again, from the ABET website:

"ABET accreditation is assurance that a college or university program meets the quality standards established by the profession for which it prepares its students. For example, an accredited engineering program must meet the quality standards set by the engineering profession. An accredited computer science program must meet the quality standards set by the computing profession."

The NPS Astronautical Engineering program is ABET-accredited at the Master's level, and the MSAE degree (See Section 4.1) awarded reflects this accreditation. The MSES degree (Section 4.2) is not ABET-accredited, but is equivalent in all other respects.

In order to be awarded an ABET-accredited MSAE degree, you must have an earned a BSAE degree from an ABET-accredited undergraduate program, or demonstrate that you have accumulated the equivalent education. This is explained in the following section.

### ***7.2. BSAE Equivalency***

In order for you to be eligible to earn the MSAE degree, you must:



1. Have a BSAE degree from an ABET-accredited undergraduate program, *or*,
2. Demonstrate BSAE equivalency by filling out the BSAE Equivalency Checklist (included in the Appendices).

The BSAE Equivalency Checklist is an accounting of all undergraduate-level courses you have taken that are equivalent to courses you would have taken in an accredited BSAE program. You will fill out this list with all eligible courses from your prior schooling, and from NPS. You will then establish whether your various credit-hour totals meet or exceed the requirements, as indicated on the Checklist. If all of the requirements are met, this checklist then serves to document that you have had the equivalent undergraduate education to that of an ABET accredited BSAE program, and you are then eligible to earn the MSAE. If you cannot satisfy all of the requirements on the Checklist, you are therefore not eligible to earn the MSAE, and can earn the MSES.

The course accounting required by the Checklist includes courses in mathematics, up through linear algebra and differential equations, courses in science including college-level chemistry and calculus-based physics, humanities and liberal arts courses, as well as aeronautical engineering and other (non-aeronautical) engineering courses. You may populate this list with courses you have taken at other colleges and universities as well as with courses you have taken here at NPS. Since your NPS Master's degree requires only 32 credit-hours, you will find that many of the courses in your matrix can be used to populate the list and contribute to the establishment of BSAE equivalency. In other words, once you have set aside the required 3000-level and 4000-level classes in your matrix to count toward MS credit-hour requirements, some of the remaining courses in your matrix can be used to populate the BSAE Checklist. It is important to keep in mind that if a course is used to establish BSAE equivalency (i.e. is included on the checklist) it cannot be counted towards credit-hour requirements for the MS degree.

## **8. Your Course Matrix**

You are assigned a course matrix when you arrive at NPS. This matrix is generic, and is intended to be modified by you with the advice and consent of the Academic Associate and Program Officer. In order to ensure proper scheduling, it is highly recommended having your matrix in Python updated for each quarter by the end of the second week of the preceding quarter. Even though the matrix has been

generated in Python, it is the student's responsibility to ensure that it meets the requirements for graduation and ESRs. Also, ensure courses selected are in the correct quarter by verifying course offerings with the NPS Academic Catalog. Generic 9-quarter course matrices with and without refresher quarters are shown in Sections 8.3 and 8.4 respectively.

Looking at your matrix, you will notice that each quarter will have at least four courses, and several quarters may have more than four. You are required to carry a minimum of four courses per quarter (a "full load"). You will also see that there are "courses" that reappear every quarter, such as SS4000 Space Systems Seminar. This course is used for the Space Systems Academic Group (SSAG) or MAE Department to bring in speakers from the military, industry, and academia to provide information on topics of current interest. Attendance by all students is mandatory, unless specially excused. Therefore, SS4000 must appear in your matrix every quarter.

All changes to your program are subject to approval or disapproval by the Academic Associate, Program Officer and Department Chair. There are various modifications you might make to your matrix and also various reasons why you might do so. Modifications can include moving a class to a different quarter, adding a course, or dropping or validating a course. As we discussed in Section 7, the various courses which appear in your matrix in general serve a variety of purposes. So it is important that you discuss any proposed change with the Academic Associate and Program Officer.

A good thing to keep in mind is that you are attending a graduate school, with the opportunity to gain advanced knowledge in engineering. This advanced knowledge is primarily contained in the 4000-level classes. You are required to take twelve credit hours of 4000-level classes in order to earn a MS degree. However, if possible, it is to your advantage to evaluate your matrix to see if you can take more than that. This will benefit you greatly, not only in doing your thesis research, but in the additional advanced knowledge you will gain.

One possible opportunity gained from validating and dropping courses is to make room in your matrix to earn the Astronautical Engineer's (AE) Degree. This degree involves substantially more coursework than the MS degree, and a more substantial thesis. The MS thesis requires 16 credits, while the AE degree requires 28 credits. This degree can be seen as being a great opportunity to take more advanced courses, do more research, and perhaps earn credit hours towards a Ph.D.

We will now discuss how you might remove courses you have already taken, at another college or university, from your matrix.

### ***8.1. Validating 2000-Level Courses***

You will see that there are a variety of 2000-level classes in your matrix. Validating a class is a means of documenting that you have already successfully taken this class elsewhere, and have also received permission to drop the class. You may have had one of more of these classes previously, such as in an undergraduate engineering program. For example, you might have taken a course in communications and signal processing at a previous college or university if you were an Astronautical Engineering student, or an Electrical Engineering student. If you received a grade of C or better, you should consider validating this class. By validating a class, and hence dropping it from your matrix, you make room to move another class “up” (i.e. take it earlier in your matrix) and hence make room for additional 4000-level classes. Keep in mind that while you may have had a course previously, if it has been a long time since you took the course, you may benefit from taking it again at NPS. This is a judgment you must make; please consult with the Academic Associate and Program Officer for guidance.

The only classes that require validation in order to drop them are 2000-level classes. 3000-level classes and above can be dropped by making a drop request in Python. The drop requires the approval of both the Academic Associate and Program Officer. See Section 8.2.

The steps you must take to **validate a course** are:

1. Make an appointment with the Course Coordinator for the course to discuss validation. Bring your transcript from the school where you took the course previously, the syllabus, and the text book (if you have it).
2. The Course Coordinator will ask you questions about the course material, and may ask you to take a test to evaluate your knowledge.
3. If the Course Coordinator concurs with the validation, the student enters the validation request into Python.

4. Once the Course Coordinator approves the validation request in Python, it will be automatically routed to the Academic Associate and Program Officer for their approval. Once approved, the course will turn pale yellow and appear on the NPS transcript with a grade of “V”.

## ***8.2. Dropping 3000- and 4000-Level Courses***

You may find that you have a 3000-level course in your matrix which you may have taken already at a previous school, or you may have limited time at NPS and you need to take another course and can't fit both courses in. You may request, through Python, to drop this course. The Academic Associate and Program Officer may approve this drop; however you must provide a justification for dropping this course. Keep in mind the potential impact of dropping a course on meeting the requirements for:

- Earning the MS degree (credit-hours) (See Section 4)
- Fulfilling your ESRs (Section 2)
- Meeting ABET requirements (Section 7.2)
- Prerequisites for follow-on courses (e.g. 4000-level classes)
- Maintaining a full course load each quarter

### 8.3. Generic 9 Quarter Astronautical Engineering Matrix<sup>1</sup> (with Refresher Quarter)

<b>(591) Space Systems Engineering Matrix - MS-AE Track URL Matrix w/ Integrated JPME and Refresher (updated July 2015)</b>						
Qtr	Course	Course	Course	Course	Seminar	Course
0 Su	<b>MA2043</b> (4-0) Matrix Algebra	<b>MA1115</b> (4-0) <b>MA1116</b> (4-0) Multi-variable Calculus	<b>PH1121</b> (4-2) Mechanics	<b>JPME - NW3230</b> (4-0) Strategy & War	<b>SS4000</b> (0-1) Seminar	
1 F	<b>MA2121</b> (4-0) Differential Equations	<b>AE2820</b> (3-2) Introduction to Spacecraft Structures	<b>EC2820</b> (3-2) Digital Logic Circuits	<b>PH1322</b> (4-2) Electromagnetism	<b>SS4000</b> (0-1) Seminar	
2 W	<b>SS3500</b> (4-2) Orbital Mechanics & Launch Systems	<b>PH2514</b> (4-0) Space Environment	<b>MA3046</b> (4-1) Matrix Analysis	<b>EC2300</b> (3-2) Control Systems	<b>SS4000</b> (0-1) Seminar	
3 Sp	<b>AE3815</b> (3-2) Spacecraft Rotational Mechanics	<b>EO2525</b> (4-1) Analysis of Signals & Comm Systems	<b>PH3052</b> (4-0) Remote Sensing	<b>AE3811</b> (2-2) Space Systems Laboratory	<b>SS4000</b> (0-1) Seminar	
4 Su	<b>AE3851</b> (3-2) Spacecraft Propulsion	<b>EO3525</b> (4-1) Communications Engineering	<b>PH3360</b> (4-1) EM Wave Propagation (or PH2351 & 3352)	<b>ME3521</b> (3-2) Mechanical Vibrations	<b>SS4000</b> (0-1) Seminar	
5 F	<b>AE3804</b> (3-0) Thermal Control of Spacecraft	<b>EC3230</b> (3-1) Space Power	<b>AE3818</b> (3-2) Spacecraft Attitude Determination & Control	<b>AE4820</b> (3-2) Robotic Multibody Systems	<b>SS4000</b> (0-1) Seminar	<b>AE4850</b> (3-2) Astrodynamics Optimization
6 W	<b>AE3870</b> (2-2) Spacecraft Design Tools	<b>SS3051</b> (4-0) Space Systems & Operations II <b>TS/SCI</b>	<b>SS3001</b> (3-2) Military Applications of Space <b>TS/SCI</b>	<b>AE4818</b> (3-2) Acquisition, Tracking and Pointing of Military Spacecraft	<b>SS4000</b> (0-1) Seminar	
7 Sp	<b>AE4870</b> (4-0) Spacecraft Design & Integration I	<b>AE0810</b> (0-8) Thesis Research	<b>SS3035</b> (3-2) Microprocessors for Space Applications (or EC2840 & 3800)	<b>AE3830</b> (3-2) Spacecraft Guidance & Control	<b>SS4000</b> (0-1) Seminar	
8 Su	<b>AE4871</b> (2-4) Spacecraft Design & Integration II	<b>AE0810</b> (0-8) Thesis Research	<b>MN3331</b> (5-1) Principles of Acquisition & Pgm Management	<b>JPME - NW3275</b> (4-0) Joint Maritime Operations - Part 1	<b>SS4000</b> (0-1) Seminar	
9 F	<b>JPME - NW3285</b> (4-0) Theater Security Decision Making	<b>AE0810</b> (0-8) Thesis Research	<b>AE0810</b> (0-8) Thesis Research	<b>JPME - NW3276</b> (2-2) Joint Maritime Operations - Part 2	<b>SS4000</b> (0-1) Seminar	Legend Preparatory Courses 591 Core Degree Specialization JPME

<sup>1</sup> Consult with your (591) AE for changes to the 591 Core (grey) and with your thesis advisor and AE for changes to the degree specialization (yellow).

### 8.4. Generic 9 Quarter Astronautical Engineering Matrix<sup>2</sup> (without Refresher Quarter)

**(591) Space Systems Engineering Matrix - MS-AE Track URL Matrix w/ Integrated JPME and no Refresher (updated July 2015)**

Qtr	Course	Course	Course	Course	Seminar	Course
1 F	<b>MA2121</b> (4-0) Differential Equations	<b>AE2820</b> (3-2) Introduction to Spacecraft Structures	<b>EC2820</b> (3-2) Digital Logic Circuits	<b>JPME - NW3230</b> (4-0) Strategy & War	<b>SS4000</b> (0-1) Seminar	
2 W	<b>SS3500</b> (4-2) Orbital Mechanics & Launch Systems	<b>PH2514</b> (4-0) Space Environment	<b>MA3046</b> (4-1) Matrix Analysis	<b>EC2300</b> (3-2) Control Systems	<b>SS4000</b> (0-1) Seminar	
3 Sp	<b>AE3815</b> (3-2) Spacecraft Rotational Mechanics	<b>EO2525</b> (4-1) Analysis of Signals & Comm Systems	<b>PH3052</b> (4-0) Remote Sensing	<b>AE3811</b> (2-2) Space Systems Laboratory	<b>SS4000</b> (0-1) Seminar	
4 Su	<b>AE3851</b> (3-2) Spacecraft Propulsion	<b>EO3525</b> (4-1) Communications Engineering	<b>PH3360</b> (4-1) EM Wave Propagation (or PH2351 & 3352)	<b>ME3521</b> (3-2) Mechanical Vibrations	<b>SS4000</b> (0-1) Seminar	
5 F	<b>AE3804</b> (3-0) Thermal Control of Spacecraft	<b>EC3230</b> (3-1) Space Power	<b>AE3818</b> (3-2) Spacecraft Attitude Determination & Control	<b>AE4820</b> (3-2) Robotic Multibody Systems	<b>SS4000</b> (0-1) Seminar	<b>AE4850</b> (3-2) Astrodynamics Optimization
6 W	<b>AE3870</b> (2-2) Spacecraft Design Tools	<b>SS3051</b> (4-0) Space Systems & Operations II TS/SCI	<b>SS3001</b> (3-2) Military Applications of Space TS/SCI	<b>AE4818</b> (3-2) Acquisition, Tracking and Pointing of Military Spacecraft	<b>SS4000</b> (0-1) Seminar	
7 Sp	<b>AE4870</b> (4-0) Spacecraft Design & Integration I	<b>AE0810</b> (0-8) Thesis Research	<b>SS3035</b> (3-2) Microprocessors for Space Applications (or EC2840 & 3800)	<b>AE3830</b> (3-2) Spacecraft Guidance & Control	<b>SS4000</b> (0-1) Seminar	
8 Su	<b>AE4871</b> (2-4) Spacecraft Design & Integration II	<b>AE0810</b> (0-8) Thesis Research	<b>MN3331</b> (5-1) Principles of Acquisition & Pgm Management	<b>JPME - NW3275</b> (4-0) Joint Maritime Operations - Part 1	<b>SS4000</b> (0-1) Seminar	
						Legend
9 F	<b>JPME - NW3285</b> (4-0) Theater Security Decision Making	<b>AE0810</b> (0-8) Thesis Research	<b>AE0810</b> (0-8) Thesis Research	<b>JPME - NW3276</b> (2-2) Joint Maritime Operations - Part 2	<b>SS4000</b> (0-1) Seminar	Preparatory Courses
						591 Core
						Degree Specialization
						JPME

<sup>2</sup> Consult with your (591) AE for changes to the 591 Core (grey) and with your thesis advisor and AE for changes to the degree specialization (yellow).

## **8.5. Review Your Matrix**

When you arrive at NPS and are assigned a matrix, there are several important issues to carefully review. We will describe the various courses in your matrix, and the purposes they serve. Those courses that you might be able to validate or drop (in order to add additional 4000-level classes) will be identified.

**AE2xxx - Undergraduate-level Astronautical Engineering (AE):** These courses are provided for those students who do not have AE degrees, or who have been out of school for a long time and need a refresher. The credit earned by these courses cannot be used to satisfy MS degree requirements, but can be used to establish BSAE equivalency (See Section 7.3). These courses are typically prerequisites for the AE3xxx classes. These classes are also part of ESR requirements and hence contribute to earning the P-Code (see Section 7.1).

You should consider validating (see Section 8.1) as many of the 2000-level classes as possible. If you have taken these classes previously, you might be able to validate these classes, creating more room in your matrix for additional 4000-level classes or other coursework.

**MA1xxx-MA3xxx –Undergraduate through Graduate-level Math:** These classes provide you with necessary mathematics for the engineering classes. Several engineering classes explicitly require at least one of these math classes as a prerequisite. You may be able to validate some (or all) of the MA1xxx-2xxx classes, including MA2043, if you have taken them elsewhere. You can discuss validation with the Course Coordinator for each math classes. The names of the course coordinators for specific courses can be found in the course description in Python. Some of these math classes are ESR requirements, and hence contribute to earning the P-Code (see Section 7.1).

**AE3xxx - Advanced undergraduate or introductory graduate-level AE:** These classes constitute the core of the Astronautical Engineering program. They contribute to the credit-hour requirements for the AE degree, are ESR requirements (contribute to earning the P-Code, see Section 7.1), and individually, may be prerequisites for other classes, such as graduate-level (4xxx) Mechanical and Astronautical Engineering classes. If you have taken one or more of these classes elsewhere, you may be able to drop them, with approval of the Academic Associate and Program Officer. Discuss this with the Academic Associate and Program Officer.

**AE4xxx - Graduate-Level AE:** In addition to courses required for the AE degree, specific AE4xxx classes will be required by your Thesis Advisor, as they will provide you with the advanced knowledge required for you to perform the research. At least 12 credit hours of 4xxx classes are required for the MS degree. Please see Section 5.2 for specific requirements for graduate electives. Note that each student is required to obtain technical specialization by taking courses from within their thesis “specialization area” (See Section 5.2).

**AE0810 ME Thesis:** These four slots provide you with 16 credit-hours for your thesis. You may have no more than two thesis slots in a single quarter, and you are limited to four slots total for the MS degree.

**NW3xxx – Naval War College JPME:** If you are a Navy URL Officer, you will have the four Naval War College (NW) courses in your matrix. If you are a Navy Aerospace Engineering Duty Officer (AEDO) or Engineering Duty Officer (EDO) or an officer from another service, you will be required to take only NW3230. These courses are offered every quarter, so moving them to different quarters, if necessary, is possible.

## **9. Filling Out the BSAE Equivalency Form and the MSAE Checklist**

As discussed in section 7.3, every student must fill out the BSAE Equivalency form prior to graduation. Additionally, every student must also fill out the MSAE Checklist. The MSAE Checklist documents all of the classes you have taken which contribute to the credit-hours required for the MS degree. All students, regardless of the specific degree they are earning (MSAE or MSES) must fill out this form.

### ***9.1. When to Fill Out These Forms***

These forms are reviewed and signed by the Academic Associate and Department Chair and completion is verified by the Program Officer prior to your graduation. Therefore, final versions of these forms must be in your folder (maintained by the Ed. Tech) prior to certification for graduation. As you progress through your program, your course matrix will undoubtedly change, such as when you select your specific 4000-level classes. You should keep these forms up to date as you progress



through the program, so that at graduation time, the forms are accurate and complete. Nobody wants to find themselves without sufficient credit-hours in their last quarter, thereby jeopardizing their degree eligibility. Note that if you have a BSAE degree from an ABET-accredited program, you can fill out and sign the BSAE Equivalency form in your first quarter. The form can then be reviewed and signed by the Academic Associate, Program Officer and Department Chair.

### ***9.2. How to Fill Out These Forms***

You should first fill out the MSAE Checklist. This form asks you to list all of the courses that will count towards the required credit-hours for the MS degree. In short, this form requires 12 credit hours of AE3xxx courses, 12 credit hours of ME/AE4xxx courses, and 8 credit hours of technical 3000 or 4000-level classes from outside the MAE department. Once a class is listed on your MSAE Checklist, you may not list it on your BSAE Equivalency form. Your remaining classes (classes not listed on the MSAE Checklist) are available to be included on your BSAE Equivalency form if you do not have a BSAE degree from an ABET-accredited program.

If you have a BSAE degree from an ABET-accredited program, filling out the BSAE form is still required, but involves only completing the first page. If not, you must completely and accurately fill out the entire form. You will most likely need your undergraduate transcript in order to do this. Please see the Academic Associate and Program Officer for guidance.

### ***9.3. MAE thesis advising policies***

The following policies apply for thesis advising for AE degrees:

1. The Primary Advisor is required to be an MAE faculty member.
2. A co-advisor or second reader is required.

## **10. Graduating Student Exit Survey**

The Ed. Tech will provide directions for filling out the graduating student exit survey at the beginning of your final quarter at NPS. Completion of this on-line survey is very important to ensure continuous improvement of MAE and Space Systems programs and to meet curriculum review and accreditation requirements.

## **11. APPENDICES**

**The first three appendices are posted separately on the MAE Department website at:**

**<http://www.nps.edu/Academics/GSEAS/MAE/Students.asp>**

**Appendix 1 - NPS Department of Mechanical and Aerospace Engineering Checklist for MS-AE/MS-ES(AE) and Astronautical Engineer Degrees**

**Appendix 2 - NPS Department of Mechanical and Aerospace Engineering Checklist for BS-AE Degree Equivalence**

**Appendix 3 - NPS MAE Dept. Thesis Approval Form (AE Degrees)**

**Appendix 4 - Educational Skill Requirements (ESRs) and the Subspecialty Codes (P-Codes)**

The Educational Skill Requirements (ESRs) are a set of technical disciplines which the program sponsor (NAVSEA) and Subject Matter Expert (Program Executive Officer for Space Systems) expect Navy military students to master at various levels of learning. Navy students meet the ESR in a particular area by successfully completing courses in that area. For Navy students in the Space Systems Engineering (591) program, many of the courses in your matrix serve to fulfill the ESRs and hence your eligibility for the 5500P subspecialty code. The ESRs for the 5500P subspecialty code are as follows:

### **1. JOINT STRATEGY AND POLICY:**

- a. Officers develop a graduate-level ability to think strategically, critically analyze past military campaigns, and apply historical lessons to future joint and combined operations, in order to discern the relationship between a nation's policies and goals and the ways military power may be used to achieve them. This is fulfilled by completion of the first of the Naval War College course series leading to Service Intermediate-level Professional Military Education (PME) and Phase I Joint PME credit.

- b. Officers gain an understanding of current Navy and USMC doctrine (e.g., Sea Power 21, Expeditionary Maneuver Warfare).

## 2. ORBITAL MECHANICS AND SPACE ENVIRONMENT:

- a. Graduates will examine the basic physics of orbital motion, and calculate and distinguish the parameters used in the description of orbits and their ground tracks.
- b. Graduates will examine the design of orbits and constellations, and analyze how they are achieved, maintained, and controlled; to include spacecraft maneuver and orbit transfer calculations.
- c. Graduates will examine the fundamentals of spacecraft tracking and command/control from a ground station.
- d. Graduates will examine the various orbital perturbations, including those due to non-spherical earth and due to atmospheric drag, and interpret their effects.
- e. Graduates will analyze the relationship between various orbital characteristics and the satisfaction of mission requirements, including the advantages and disadvantages of various orbits.
- f. Graduates will design and optimize mission orbits through the analysis of common performance measures such as access, coverage, and revisit; and will employ appropriate tools to conduct these analyses.
- g. Graduates will examine the physical behavior of the upper atmosphere, ionosphere and space environment under the influence of both natural and artificial phenomena such as solar activity, geomagnetic and magnetospheric effects, and man-made disturbances.
- h. Graduates will apply this understanding of how the space environment impacts spacecraft parts, materials, and operations to spacecraft and mission design.

## 3. NATIONAL SECURITY SPACE SYSTEMS:

- a. Graduates will examine the nature of space warfare (theory, history, doctrine, and policy); distinguish between the five JP 3-14 defined Space Mission Areas (Space Situational Awareness, Space Force Enhancement, Space Support, Space Control, Space Force Application); and interpret how current and planned space capabilities contribute to the satisfaction of these mission areas.
- b. Graduates will examine the roles, responsibilities, and relationships of National and DoD organizations in establishing policies, priorities, and requirements for National Security Space systems; and in the design, acquisition, operation, and exploitation of these systems.
- c. Graduates will examine the role of the Services / Agencies in establishing required space system capabilities, and will translate these capabilities into system performance requirements.
- d. Graduates will examine: current and planned Intelligence, Surveillance, and Reconnaissance (ISR) capabilities; how space systems contribute to these capabilities; the intelligence collection and analysis process; and how war-fighters access information from these sources.
- e. Graduates will develop and assess space tactics and/or CONOPS, including space protection concepts that integrate with and enhance or support military operations.
- f. Graduates will identify how proposed space-related capabilities / doctrine transition from concept to real-world implementation through experimentation.

- g. Graduates will examine the capabilities of unclassified DoD and commercial space systems, and how those systems relate to National Space Systems to include potential overlaps and leverage opportunities.

#### 4. PROJECT MANAGEMENT AND SYSTEM ACQUISITION:

- a. Graduates will examine project management and DoD system acquisition methods and procedures to include contract management, financial management and control, and the Planning, Programming, Budgeting and Execution (PPBE).
- b. Graduates will recognize the role of the Defense Acquisition University and the acquisition courses and qualifications available.
- c. Graduates will examine system acquisition organizational responsibilities and relationships (e.g., Congress, DoD, Services, Resource Sponsor, Systems Commands, Operating Forces) as they pertain to the acquisition of systems for DoD, Naval, and civilian agency users.
- d. Graduates will examine the unique nature of space acquisition programs and plan a notional space system acquisition program.

#### 5. COMMUNICATIONS:

- a. Graduates will examine the basic principles of communications systems engineering to include both the space and ground segments.
- b. Graduates will examine digital and analog communications architecture design, including such topics as frequency reuse, multiple access, link design, repeater architecture, source encoding, waveforms/modulations, and propagation media.
- c. Graduates will calculate and analyze link budgets to assess communication system suitability to support mission requirements, and to translate mission requirements into communications system design characteristics.
- d. Graduates will differentiate, compare, and contrast the characteristics and capabilities of current and future communications systems in use or planned by Naval operating and Joint forces afloat and ashore.
- e. Graduates will examine how current and planned space communications systems are used to meet Joint communications requirements.
- f. Graduates will differentiate signal processing techniques, both digital and analog, as applied to missions such as spacecraft communications, surveillance, and signals intelligence.
- g. Graduates will examine spacecraft vulnerabilities in an electronic warfare context.

#### 6. COMPUTERS: HARDWARE AND SOFTWARE

- a. Graduates will understand the fundamentals of digital logic and digital system design of simple digital computer subsystems.
- b. Graduates will examine the design of current and planned computer hardware and software architectures for space-based applications.
- c. Graduates will examine the use of computers in complex systems such as guidance, signal processing, communications, and control systems.
- d. Graduates will examine the fundamentals of electronic component design, fabrication, reliability, and testing (to include radiation hardening), with an emphasis on parts, materials, and processes.
- e. Graduates will examine modern Information Technology capabilities and their applications for space systems ground processing, data storage, information sharing, and network design.

## 7. SPACECRAFT GUIDANCE AND CONTROL

- a. Graduates will analyze the field of spacecraft guidance and control, to include topics such as linear control, rotational kinematics, rigid body dynamics, gravity gradient, spin and three-axis stabilization design, active nutation control, sources of and response to disturbance torques, and attitude determination and associated sensors and actuators.
- b. Graduates will apply these techniques to the analysis and design of spacecraft guidance and control systems.

## 8. SPACECRAFT STRUCTURES, MATERIALS AND DYNAMICS

- a. Graduates will examine the engineering of space structures and perform simplified sizing calculations and analytical modeling of advanced materials.
- b. Graduates will analyze the advanced dynamics and control of these structures.

## 9. PROPULSION SYSTEMS

- a. Graduates will examine the operating principles (fluid mechanics, thermodynamics, electricity and magnetism) and propulsion devices used in current and proposed space applications.
- b. Graduates will analyze and choose appropriate propulsion systems for spacecraft applications to include launch, orbit transfers, and spacecraft maneuvering.

## 10. SPACECRAFT THERMAL CONTROL

- a. Graduates will examine the principles of heat transfer and how surfaces and materials are manipulated in spacecraft thermal control.
- b. Graduates will examine the design, analysis, and applications of current active and passive thermal control devices (including heat pipes, louvers, and materials).
- c. Graduates will examine the sources of heat in space (solar, terrestrial, reflected solar, internal vehicle generation) and their variation as a function of vehicle orbit, and apply this knowledge to thermal subsystem analysis and design.

## 11. SPACECRAFT POWER

- a. Graduates will examine the principles and operating characteristics of major power generating systems for spacecraft, including the performance of photovoltaic sources in the natural and artificial radiation environment.
- b. Graduates will examine the principles and operating characteristics of energy storage devices in power systems design.

## 12. REMOTE SENSING AND PAYLOAD DESIGN

- a. Graduates will examine principles of active and passive sensors in current or planned use, to include analysis of electromagnetic wave propagation and design of optics, detectors, and antennae.
- b. Graduates will examine the effects of the space, atmospheric, and terrestrial environments (including countermeasures) on sensor performance.

- c. Graduates will assess and conduct tradeoffs among various sensors and platforms, evaluating how each satisfies mission requirements such as access area, resolution, timeliness, and capacity.
- d. Graduates will examine the design of current and planned space-based mission payloads (e.g., ISR, Communications, PNT, SIGINT).
- e. Graduates will analyze mission capabilities and conduct associated trades in order to develop associated payload design requirements.

### 13. SPACECRAFT DESIGN, INTEGRATION, AND SYSTEMS ENGINEERING

- a. Graduates will develop and assess an overall space system architecture to meet defined mission requirements through the use of systems engineering tools and processes.
- b. Graduates will derive system and subsystem performance criteria from stated mission capabilities and conduct trade-offs between payload and other spacecraft subsystems in addressing these capabilities.
- c. Graduates will examine a broad spectrum of mission assurance concerns such as reliability, risk management, configuration management, qualification and acceptance testing, and parts materials and processes.
- d. Graduates will examine various engineering and mathematical definitions of cost functions (revisit time, dwell time, local coverage, etc.) and apply emerging methods and tools to optimizing these utility measures in support of mission objectives.
- e. Graduates will examine the basic principles and operational issues of space access to include launch vehicle performance, launch windows, and their impact on military operations.
- f. Graduates will examine the capabilities of the various current and planned launch systems, and characterize the issues associated with integrating a spacecraft with a launch vehicle, to include the effects of launch environment.
- g. Graduates will perform a trade-off analysis in the selection of a launch vehicle based on mission requirements, performance and design constraints, and business issues involved (e.g., pricing, insurance, policy).
- h. Graduates will demonstrate proficiency in design, analysis, and modeling / simulation tools such as IDEAS, MATLAB / Simulink, and Satellite Tool Kit (STK).
- i. Graduates will examine the processes and methods of systems engineering including requirements analysis, functional analysis and allocation, system design, and verification.

### 14. GROUND SYSTEMS AND SYSTEMS ENGINEERING

- a. Graduates will understand the fundamentals of a space ground system architecture including the system-of-systems that comprise a space network across all mission areas.
- b. Graduates will examine Department of Defense Architecture Framework (DoDAF) views of real or notional space network architectures in order to understand necessary internal and external interfaces and domain interactions.
- c. Graduates will analyze enterprise and mission-specific frameworks from standard communications infrastructures (C&C, messaging, data, etc.), services, and tools to mission specific T&C, information products and data.
- d. Graduates will analyze network and non-network communications within an Information Technology Enterprise Domain context.

- e. Graduates will understand application program interface (API) challenges in relation to security requirements, risks and mitigation.
- f. Graduates will understand Risk Management Framework integration for cyber security system engineering efforts including information assurance and relevant documentation such as NIST SP800-30, DOD8500.1 and 8500.2.
- g. Graduates will analyze command and telemetry requirements and capabilities to support mission execution, vehicle operations and anomaly resolution.
- h. Graduates will analyze services for access, sharing, processing and external dissemination of information including data management and storage challenges such as "Big Data", open-source implementation and cloud technology applications for Ground Systems.

#### 15. CONDUCT AND REPORT INDEPENDENT RESEARCH

- a. Graduates will conduct independent research on a space systems problem, including resolution of the problem and presentation of the results and analysis in both written and oral form.

Some of the ESRs listed above may be satisfied by your undergraduate education, especially if your undergraduate degree is a BSAE. It is also possible to validate or drop classes that appear on this list if you have taken a similar class elsewhere. However, you should check with the Program Officer to make sure you understand the impact on the associated ESRs and the P-code. Please refer to Section 8 on Making Changes to Your Course Matrix.