. # Graduate Spacecraft Education in the AFIT Department of Aeronautics and Astronautics

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## Abstract

Admission requirements, degree requirements, and the graduate programs at the Air Force Institute of Technology (AFIT) in the Department of Aeronautics and Astronautics related to space science and engineering are described. The Department of Aeronautics and Astronautics has three graduate programs related to space: Astronautical Engineering, Space Operations, and Aerospace and Information Operations. The three programs are related but each one has unique elements to accommodate different Air Force needs. The purpose of each program, program length, credit hours, common core courses, specialty sequence courses, and electives are described in some detail. The space-related research conducted in the Department of Aeronautics and Astronautics is discussed.

## Introduction

The United States Air Force is a mission-focused, combat-proven, decisive fighting force and its mission is "to defend the United States and protect its interests through aerospace power."[1] The foundation of the force is people, and the Air Force is committed to providing education, equipment, and training for its people to "achieve personal and professional excellence."[1] The Air Force vision for scientists and engineers is "Air Force Scientists and Engineers…guiding, producing and sustaining concepts, technologies and systems that are key to aerospace operations."[2] The Air Force Institute of Technology (AFIT) provides responsive graduate and professional continuing education, research, and consulting to keep the Air Force and the Department of Defense (DoD) on the leading edge of technology and management. Through frequent consultation with the major commanders of the Air Force, the AFIT faculty establishes and maintains educational programs meeting Air Force needs.

The Air Force Institute of Technology (AFIT), located at Wright-Patterson AFB, Ohio, is a component of Air University, (AU), which, in turn, is a part of the Air Education and Training Command (AETC). The Institute accomplishes its graduate resident program mission through the Graduate School of Engineering and Management. The Graduate School offers Doctor of Philosophy and Master of Science degrees in aeronautical engineering, applied mathematics, astronautical engineering, computer engineering, electrical engineering, electro-optics, applied physics, materials science, nuclear engineering and operations research. The Graduate School

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also offers master's degrees in a number of other programs, including, engineering and environmental management, environmental science and engineering, meteorology, aerospace and information operations, space operations, and systems engineering. In 1954, the 83rd Congress authorized the Commander, Air University to confer degrees upon accreditation by a nationally recognized association or authority. This accreditation was achieved in 1955. The first M.S. degrees were granted in 1956.[3] Today, the Institute is accredited by The Higher Learning Commission and is a member of the North Central Association. In addition, the Accreditation Board for Engineering and Technology (ABET) accredits selected engineering programs within the Graduate School of Engineering and Management, including Astronautical Engineering.[4]

The programs of the Department of Aeronautics and Astronautics are a major factor in graduate education in aeronautical and astronautical engineering in the United States based on the number of graduate degrees awarded over several years in the late 1970s and the 1980s.[3] This paper will focus on the space-related programs and their special nature. The paper will describe admission requirements, degree requirements, and the graduate programs in the Department of Aeronautics and Astronautics related to space and spacecraft education. Specific details about various courses, sequences, and other requirements will be given. The space-related research conducted in the Department of Aeronautics and Astronautics will be discussed, including some details on recent theses and dissertations. The educational expectations for our graduates are very high. Programs that enhance their technical capabilities, professional qualities, and research experiences and provide for future space-related assignments will be discussed.

## Admission Requirements

A cumulative GPA of 3.0 on a 4.0 grade-point system is required for admission to master's degee programs, but waivers in certain cases are granted where a B average has been maintained in upper-level engineering and science courses as well as a B average in calculus and all mathematics courses attempted beyond calculus. Minimum scores on the GRE of 500 (verbal) and 600 (quantitative) are required. Admission to a doctoral program requires a master's degree with a GPA of 3.5 and GRE scores of 550 (verbal) and 650 (quantitative). Additional admission requirements are given for each space-related program later in this paper, and more details on admission requirements are given in AFIT publications.[4,5] While most of the students at AFIT are full-time students, AFIT does allow part-time students to enroll for coursework and to work towards a degree after successful completion of 12 graduate credit hours.

## Degree Requirements

The space-related M. S. degree programs are six quarters in length (approximately 18 months) and the Ph.D. program is three years long. A GPA of at least 3.00 on all courses in an approved program is required. Full-time students are expected to carry a load of 12 credit hours each quarter. This normally leads to 72 credit hours for six quarters of which 48 credit hours in an approved program must be submitted for the degree. All students in the space-related programs must complete a thesis or dissertation. The thesis accounts for 12 credit hours and is graded. Ph.D. requirements include approved coursework, qualifying examinations, dissertation prospectus examination, admission to candidacy, dissertation defense, and time limitation.

## Students and Faculty

The students in the graduate space programs of the Department of Aeronautics and Astronautics are primarily U. S. Air Force officers. Approximately 10 percent of the students are military officers from other services or allied countries, or are DoD civilians. The faculty is comprised of approximately 50 percent military and 50 percent civilians. Most of the civilians are permanent members of the faculty while the military faculty members generally have 4-year assignments.

## Department Space Programs

Space education at AFIT began over 40 years ago. The Astronautics Program began in 1958 as a two-year program. A Space Facilities Program was started in 1962 to provide engineering competence to design, develop, test, operate, and maintain fixed facilities and supporting systems in free space and on the lunar surface.[3] Today, the Astronautics Program is called the Graduate Astronautical Engineering Program. It is 18 months long, and its curriculum, which will be described later, has changed considerably from its early beginning. The Space Facilities Program no longer exists, but "a special program in space facilities is offered for officers in the Civil Engineering career field to prepare them for roles in the development and operation of launch facilities and large permanent space facilities."[4]

The Department of Aeronautics and Astronautics currently has three graduate programs related to space: Astronautical Engineering, Space Operations, and Aerospace and Information Operations. Broadly speaking, the goal of the space programs offered at AFIT is to provide students with the technical knowledge necessary to conduct, develop and manage space programs that increase the United States Air Force's effectiveness in waging war. After graduation, the assignments of AFIT graduates and the projects and programs they manage might typically include research on new concepts, development of program requirements, acquisition of space systems, and operation of existing space systems. AFIT's graduate education prepares students to make intelligent decisions on what technologies are feasible and would have the most impact on space operations. As graduates progress in their Air Force careers, many will lead teams of contractors and government personnel. In order to manage the people doing technical work, it is important that Air Force officers have had experience with the technical issues confronting their people. As knowledgeable researchers, managers, or acquisition personnel, their relationships are enhanced with their technical graduate education.

The character of each of the programs in the Department of Aeronautics and Astronautics is slightly different due to the needs of the Air Force organizations. The curriculum for each of the three master's programs is given in Table 1. The programs are comprised of math courses, core courses, specialty sequences and a thesis. Every student must complete an independent thesis. The math courses provide the students the necessary tools to complete the rigorous science and engineering coursework. The core courses provide foundational knowledge in each of the particular programs. There is significant overlap among the space programs in the core courses. Common core courses include space intelligence, space surveillance, satellite communications, space environment, and space flight mechanics. A brief description of the core courses is given in Table 2.

Specialty sequences provide in-depth knowledge in a given area; for example, there are sequences in rocket propulsion, advanced astrodynamics, mechanics and control of space structures, and aerospace navigation. The specialty sequences offered for each program are given in Table 3. Normally a sequence will include three graduate-level courses. A sequence may be three related courses of somewhat similar level or may be three courses in a given area of increasing level. Often, the courses must be taken in a specific order. For example, the sequence in advanced astrodynamics begins with a prerequisite in analytical mechanics, then a course in advanced astrodynamics and ends with a course in modern methods of orbit determination. Courses and course descriptions are given in the AFIT Catalog.[4] Each space program will be described separately along with the attributes that make each one distinct from the others.

**Table 1. Space Programs Curricula**

| Astronautical Engineering | Space Operations | Aerospace and Information Operations |
|---|---|---|
| Math Courses | Math Courses | Math Courses |
| Core Courses<br>Satellite Communications<br>Introductory Space Flight Mechanics<br>Space Surveillance<br>Space Environment<br>Space Intelligence Seminar<br>Linear Systems Analysis<br>Control and State Space Concepts<br>Intermediate Dynamics<br>Intermediate Space Flight Mechanics | Core Courses<br>Satellite Communications<br>Introductory Space Flight Mechanics<br>Space Surveillance<br>Space Environment<br>Space Intelligence Seminar<br>Introduction to Space Programs and Operations<br>Spacecraft Systems Engineering<br>Introduction to Information Warfare<br>Quantitative Decision Making | Core Courses<br>Satellite Communications<br>Introductory Space Flight Mechanics<br>Space Surveillance<br>Space Environment<br>Space Intelligence Seminar<br>Introduction to Space Programs and Operations<br>Spacecraft Systems Engineering<br>Acquisition Management |
| Major Elective Sequence | Major Elective Sequence | Information Operations Sequence |
| Minor Elective Sequence | Elective Courses | Minor Elective Sequence |
| Thesis | Thesis | Thesis |

## Graduate Astronautical Engineering Program

The Graduate Astronautics Program is designed to provide astronautical engineering specialists for the Air Force.[5] It focuses on providing students with a deep understanding of the engineering principles governing complex aerospace systems. Students entering the Astronautical Engineering program should have an ABET-accredited baccalaureate degree in, for example, astronautical engineering, aerospace engineering, mechanical engineering, aeronautical engineering, engineering mechanics, or electrical engineering. "For those students who are deficient in the requirements for an ABET-accredited degree or lack the necessary undergraduate preparation, the department offers several electives to remedy the deficiency."[4]

## Table 2. Course Descriptions

| Space Programs Core Courses | |
|---|---|
| Satellite Communication | Gives an overview of principles relating to satellite communications, including satellite coverage, link analysis, signal modulation, antenna fundamentals, transponders and interference. |
| Introductory Space Flight Mechanics | Give the fundamental principles of orbital and attitude dynamics, including conic sections, Kepler's equation, orbit maneuvers, relative motion, orbit perturbations and torque-free rigid body motion. |
| Space Surveillance | Investigates the physics of remote sensing with an emphasis on visible light and infrared systems. Topics include light-matter interaction, atmospheric absorption and scattering, radiometry, optical systems, spectral and spatial resolution imaging, and electro-optical detectors. |
| Space Environment | Investigates the physics of the environment from the sun to the upper atmosphere of the Earth, including solar physics, solar wind, geomagnetism, the magnetosphere and ionosphere, radiowave propagation, and spacecraft operations. |
| Space Intelligence Seminar | Provides an overview of worldwide space activities and systems, with an emphasis on foreign space systems and operations. Includes classified briefings by intelligence analysts. |
| **Astronautical Engineering Only** | |
| Linear Systems Analysis | Covers the fundamental theory of linear dynamic systems, both time invariant and time varying. Includes system modeling, classical analysis in time and frequency domain, and modern state space analysis. |
| Control and State Space Concepts | Covers concepts in classical and modern control. Topics include feedback system analysis, root locus, Bode and Nyquist plots, state feedback control and observers, and control system compensation design. |
| Intermediate Dynamics | Covers three-dimensional vector kinematics and dynamics of particles, systems of particles and rigid bodies. Topics also include impulse-momentum, collisions, and Lagrange's equations. |
| Intermediate Space Flight Mechanics | Treats advanced principles of orbital and attitude dynamics, including gravity gradient torques, equilibria and stability of synchronous and spinning satellites in orbit, attitude determination and control, patched conic trajectory design, and the restricted three-body problem. |
| **Space Operations and Aerospace and Information Operations Only** | |
| Introduction to Space Programs and Operations | Gives an overview of historical and current military space programs and operations, including a treatment of space law and policy, U.S. military space organizations, and foreign space programs. |
| Spacecraft Systems Engineering | Provides a detailed treatment of the design of complex space systems, culminating in a substantial design project. Key elements and subsystems of important classes of spacecraft are presented. |
| Introduction to Information Warfare | Gives a foundational understanding of information warfare and its ramifications for information security and assurance. |
| **Space Operations Only** | |
| Quantitative Decision Making | Provides the basics of optimization theory, including linear programming, integer programming, nonlinear programming, and dynamic programming. |
| **Aerospace and Information Operations Only** | |
| Information Operations Research | Covers the tools, techniques, and models currently in use to conduct analysis into information operations. |
| Discrete Simulation | Covers the basic techniques of using computer simulation modeling to analyze complex military systems. Emphasis is on analysis of simulation model input and output, including random variables, model verification, and output. |
| Acquisition Management | Covers the issues associated with managing the acquisition of DoD systems. Topics discussed include requirements generation, contracting, the acquisition life cycle, test and evaluation and configuration management. |

**Table 3. Specialty Sequences**

| All Space Programs | Space Operations and Aerospace and Information Operations Only |
|---|---|
| Advanced Astrodynamics | Applied Statistics |
| Aerospace Navigation | Artificial Intelligence |
| Aerospace Robotics | Astrodyanmics |
| Control and Optimization Theory | Information Operations |
| Estimation | Operations Research |
| Mechanics and Control of Space Structures | Operational Modeling |
| Reliability | Project Management |
| Rocket Propulsion | Signal Processing |
| Space Facilities | Simulation |
| Structural Analysis | Space Environment |
| Structural Materials | Space Systems |
| Vibration Damping and Control | Systems Analysis and Design |

A primary follow-on assignment for graduates from the Astronuatical Engineering program is the Air Force Research Laboratory (AFRL). The mission of this organization "is to discover, develop, integrate, and deliver affordable technologies for improving warfighting capabilities."[6] Due to this focus on cutting-edge technology, AFRL requires personnel with the rigor of an engineering background. As part of AFRL, the Space Vehicle Directorate is especially concerned with space technologies, and the Astronautical Engineering program is particularly suited for support of the Space Vehicles Directorate. As shown in Tables 1 and 2, the Astronautical Engineering curriculum includes the common core and also engineering fundamentals of linear systems analysis, control and state space concepts, and intermediate dynamics. The program also includes the more advanced space engineering concepts of intermediate space flight mechanics and two of the sequences shown in Table 3. These graduates are well equipped to perform analysis and design of complex aerospace systems. They also have the background necessary to lead and manage research programs for new space systems.

## Graduate Space Operations

"The Graduate Space Operations program is designed to provide officers with a broad knowledge of space engineering, space physics, and information operations."[5] It "prepares the student for management and analysis roles in planning, executing, and evaluating space operations."[4] The flavor of the Space Operations program is to focus somewhat less on engineering issues and provide a broad understanding of all aspects of space programs and operations. Incoming students must have had undergraduate physics and calculus, but they are not required to have an engineering degree.

The main organization that draws from AFIT's Space Operations graduates is the Air Force Space Command (AFSPC). AFSPC's mission is concerned with a broad range of activities in space, from the acquisition and development of new systems to the operations of space assets to support the warfighter. The Space Operations graduates must be familiar with all aspects of space science and engineering. Instead of linear systems, controls and dynamics, the curriculum of the Space Operations program contains the following courses: Introduction to Space Programs and Operations, Spacecraft Systems Engineering, Introduction to Information Warfare and an operations research course in quantitative decision making. These courses are broad in nature, giving an overview of topics like current and past space programs and systems, space policy, spacecraft subsystems, how information can be attacked and safeguarded, and quantitative methods of decision making. In place of the minor sequence, Space Operations students may take any electives that they choose, again reflecting the broad character of the program (Table 1). This curriculum most effectively prepares the Space Operations graduate to work with space systems from the acquisition stage to the operation of space assets and ultimately to the integration of space assets and information with warfighting organizations.

**Aerospace and Information Operations**

"This master's degree program prepares the student for management and analysis roles in planning, executing, and evaluating space operations, particularly as they relate to the flow of information."[4] The Aerospace and Information Operations program is very closely related to the Space Operations program.

The main customer of the Space Operations program, Air Force Space Command, has recently been tasked with the responsibility of conducting information operations for the Air Force, which includes a broad spectrum of activities from protecting computing assets from hacker attacks to denying enemy information by destroying an enemy satellite ground station. AFSPC is working toward developing more expertise in this area so they requested the development of a new program. To accommodate this new need, two courses were added to the Space Operations curriculum: Discrete Event Simulation and Information Operations Research. Along with the Introduction to Information Warfare, these courses constitute a major sequence in Information Operations. These courses provide the students insight into the ways in which information is obtained, denied, protected, and ultimately used by the warfighter. Due to the Space and Missile Systems Center (an acquisition center for space systems) recently coming under the command of AFSPC, a course in acquisition management was also added to the curriculum in place of quantitative decision making. These changes in the program better prepare graduates to continually improve AFSPC's ability to provide space support for the armed forces. The development of this program also illustrates the fast response capability in meeting Air Force needs.

**Space-Related Research**

Regarding the thesis or dissertation, AFIT is closely affiliated with Air Force and DoD research organizations and operational agencies. This allows a wide range of opportunities for research and makes AFIT unique compared with civilian institutions. AFIT's contribution to research and technological advancements is identified in a number of ways such as through financial support of its research projects, its technical and management publications accepted by the editors of journals, the number of presentations accepted for regional, national, and international conferences, and the number of consultations for Air Force and DoD customers.[7]

Statistics and contributions of the Graduate School of Engineering and Management are available for fiscal year 2000 in the yearly research report.[7]

**M. S. Thesis Examples**

Three theses by students in the Space Operations program explored the use of lean practices related to space launch operations to reduce wasteful practices and provide better, faster, and cheaper services. A separate paper based on each thesis has been published.[8-10] Capt Endicott's research considered lean practices in space launch operations with emphasis on systems that are developed, processed, and launched through the most reliable, responsive, and cost effective means.[8] Capt Matuszak examined how lean principles associated with elimination of wasteful practices can be applied toward improving scheduling activities at the U. S. space launch ranges at Cape Canaveral and Vandenberg AFB.[9] Capt Galbreath's study concerned the use and application of lean practices, Six Sigma, and system engineering for the development of reusable launch vehicles.[10] Following completion of their graduate studies all three were assigned to space-related duties within Air Force Space Command.

Students in other programs at AFIT may also conduct research in space-related areas. For example, Capt Bergren, a student in the Graduate Aeronautical Engineering program, conducted a study on cold flow through a configuration of ten nozzles and a diffuser that is related to the operation of a space-based laser. A paper has been prepared on this research.[11]

Capt Ralph Bordner, received a Master of Science in Astronautical Engineering in 2001 with his thesis entitiled "Estimation of Relative Satellite Formation Element Positions in Near Circular Orbits." A paper based on his thesis was recently presented.[12] This research supported an Air Force program called TechSat 21 that is being developed by the Air Force Research Laboratory. This program, illustrated in Figure 1, is an effort to study and understand the technologies necessary to use a formation of small satellites in orbit in order to perform missions such as surveillance, passive radiometry, terrain mapping, navigation, and communications.[13] For certain applications, the relative position of these satellites must be known very accurately. Capt Bordner's thesis addresses this issue of determining the relative positions of the satellites. He developed new computer software to increase the accuracies obtainable using measurements that could be obtained from GPS satellites.

Flt Lt Anthony Rogers, a 2001 graduate of the Space Operations program, completed his thesis entitled "Concept Exploration of an Australian Indigenous Space Launch Capability." In this work, he studied various options for developing an Australian launch vehicle and launch complex. He considered various vehicle architectures, from completely reusable to completely expendable, and various potential launch sites around the continent (Figure 2). Flt Lt Rogers evaluated the value of the various designs based upon political attractiveness, potential commercial markets, national security issues, and the effect on increasing technical aerospace jobs in Australia. The study employed a combination of technical engineering theory (e.g. orbital mechanics) and value system design.[14]

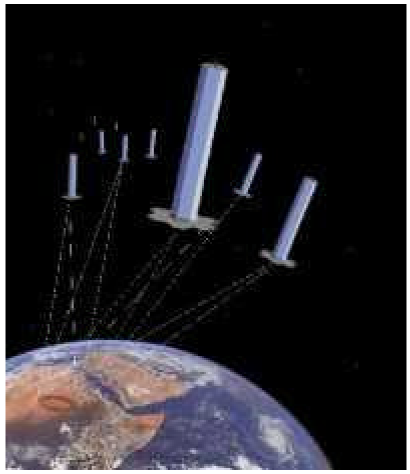

**Figure 1. TechSat 21 Satellite Formations**

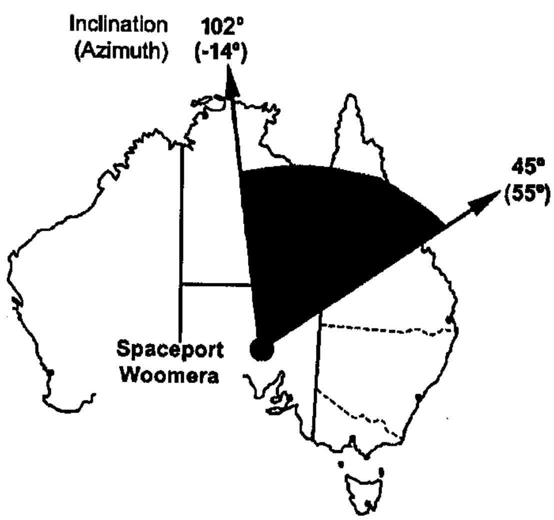


**Figure 2. Accessible Orbit Inclinations from a Possible Australian Launch Facility**

Currently, 2nd Lt Hakan San is completing his research effort on orbital maneuvering with electrodynamic tethers.[15] He is making use of the physical forces that arise between the magnetic field of the Earth and the current that can be generated in a conducting tether (Figure 3). This force is manipulated to change the orbit of the tethered spacecraft. Using electrical energy instead of chemical propellant has the tremendous potential of allowing continuous maneuvering over the spacecraft's lifetime (which would quickly deplete the fuel of a traditional system). Lt San's work will help to realize applications such as satellite servicing, whereby one satellite is able to repair or refuel other expensive space assets in order to extend their lifetime.

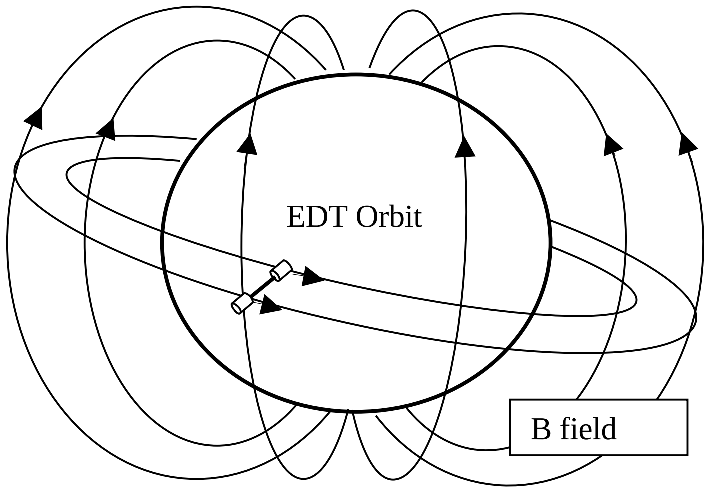


**Figure 3. Spacecraft Maneuvering with Electrodynamic Tethers**

## Doctoral Dissertation Examples

There have been several space-related Ph.D. dissertations completed recently in the Department of Aeronautics and Astronautics. For example, dissertation topics included modeling of piezoelectric membranes for space optics, rigid satellite equilibria in a central gravity field, attitude control of a space robot for orbit capture, and structural damage identification from frequency response data. Particular details are given in the dissertations.[16-19]

## Space Education in Other AFIT Departments

While this paper is directly concerned with the space-related programs in the Department of Aeronautics and Astronautics, there are also space-related interests, courses, and research in other departments at AFIT, such as Electrical Engineering, Physics, and Operations Research. Most of those activities have not been described in this paper. Only those courses and sequences offered by other departments that are part of the three space-related programs in the Department of Aeronautics and Astronautics have been identified by name, but not by department.

## Conclusions

The United States Air Force scientists and engineers have "produced, sustained, and operated leading-edge technologies to provide such capabilities for the warfighter."[2] Graduate education is one way of continuing this technological prowess. The Air Force Institute of Technology is committed to provide graduate spacecraft education that is responsive to the needs of the Air Force. This paper has emphasized the importance of space-related education for our graduates for use in follow-on assignments. Furthermore, the graduate programs and related research at AFIT support the needs of the Air Force in a way that is unique among institutions of higher education.

## References


1. America's Air Force Vision 2020, http://www.af.mil/vision/vision.pdf

2. Office of the Secretary of Defense, SAF/AQR, "Concept of Operations for Scientists and Engineers," September 2001.

3. Torvik, Peter J., "The Evolution of Air Force Aerospace Education at the Air Force Institute of Technology," Paper No. AIAA 2002-0563, 40th AIAA Aerospace Sciences Meeting & Exhibit, Reno, NV, 14-17 January 2002.

4. Academic Catalog 2001-2002, Graduate School of Engineering & Management, Air Force Institute of Technology, Wright-Patterson AFB, OH 45433-7765.

5. Department Brochure 2001, 1st Edition, Department of Aeronautics and Astronautics, Air Force Institute of Technology, Wright-Patterson AFB, OH, July 2001.

6. Space Vehicles Directorate, http://www.vs.afrl.af.mil/Directorate/

7. Research Report 2000, Graduate School of Engineering and Management, AFIT/EN-TR-01-01, Air Force Institute of Technology, Wright-Patterson AFB, OH 45433-7765, March 2001.

8. Endicott, Troy L. and Franke, M. E., "Lean Space Launch Operations," Paper No. AIAA 99-4614, AIAA Space Technology Conference & Exposition, Albuquerque, NM, 28-30 September 1999.

9. Matuszak, Alan M. and Franke, M. E., "Lean Space Range Scheduling Operations," Paper No. AIAA 2000-5182, AIAA Space 2000 Conference & Exposition, Long Beach, CA, 19-21 September 2000.

10. Galbreath, Charles S. and Franke, M. E., "Quality Initiatives in the Air Force Development of Reusable Launch Vehicles," Paper No. AIAA 2001-4621, AIAA Space 2001 Conference and Exposition, Albuquerque, NM, 28-30 August 2001.

11. Bergren, Scott and Franke, M. E., "Fabrication and Test of a Cold-Flow Model of Nozzle Rings and Exhaust Manifold," Paper No. AIAA-2002-2129, accepted for presentation at the 33rd AIAA Plasmadynamics and Lasers Conference, Maui, Hawaii, 20-23 May 2002.

12. Bordner, Ralph E. and Wiesel, William E., "Trajectory Estimation for Satellite Clusters," AIAA/AAS Astrodynamics Conference, Paper No. 01-342, Quebec City, Quebec, August 2001.

13. TechSat 21, Space Missions Using Satellite Clusters, http://www.vs.afrl.af.mil/Factsheets/techsat21.html/

14. Rogers, A., Tragesser, S. and Smith, E., "Concept Exploration into an Australian Indigenous Space Launch Capability," *Proceedings of the International Council on Systems Engineering*, July 2001.

15. Tragesser, S.G. and San, H. "Orbital Maneuvering with Electrodynamic Tethers," AAS Astrodynamics Conference, Paper No. 02-201, San Antonio, TX, January 2002.

16. Rogers, James, "Modeling Axisymmetric Piezoelectric Membranes for Space Optics," Ph.D. Dissertation, Air Force Institute of Technology, Wright-Patterson AFB, OH, 2001.

17. Beck, Jeffery, "Relative Equilibria of a Rigid Satellite in a Central Gravity Field," Ph.D. Dissertation, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1997.

18. Titus, Nathan, “Singularity Avoidance Strategies for Satellite Mounted Manipulators Using Attitude Control,” Ph.D. Dissertation, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1998.

19. Cobb, Richard, “Structural Damage Identification from Limited Measurement Data,” Ph.D. Dissertation, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1996.

## Biography

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