SPACE ENGINEERING

The Space Engineering program is intended for existing or aspiring space engineering professionals and will greatly expand their knowledge, capabilities, and opportunities, preparing students for rewarding careers in the space industry. Students are exposed to all the technical disciplines encountered throughout the space systems development life cycle including mission formulation, concept development, design, integration, test, and mission operations. Students are introduced to the formal systems engineering method, first as applied to entire space missions, and then with ever-increasing technical rigor, as applied to flight and ground systems and subsystems. A diverse array of technical electives permits students to tailor their curriculum to suit their individual professional interests. Students then have the opportunity to immerse themselves into case studies of current topics drawn from relevant real-world programs. Additionally, a hands-on small-spacecraft integration and test course allows students to work on a table-top spacecraft using modern test equipment and spacecraft control software in a laboratory environment. Program faculty are top subject matter experts and practitioners from across the space community, including the Johns Hopkins University Applied Physics Laboratory.

All core courses in the Space Engineering program may be completed remotely, except for the program capstone EN.675.710 Small Satellite Development and Experimentation, which includes a requirement that students attend a specified residency weekend in the Baltimore area to complete the laboratory component. Electives are offered online in either asynchronous or synchronous (virtual live) format. Some electives offer an in-person option at the Johns Hopkins Applied Physics Lab (Laurel, MD) or Bloomberg Center (Washington, D.C.). Several electives may be offered as in-person only; consult the website each semester for specifics.

Programs

- Space Engineering, Master of Science (https://e-catalogue.jhu.edu/engineering/engineering-professionals/space-engineering/space-engineering-master-science/)
- Space Engineering, Post-Master's Certificate (https://e-catalogue.jhu.edu/engineering/engineering-professionals/space-engineering/space-engineering-post-masters-certificate/)

Courses

EN.675.600. Systems Engineering for Space. 3 Credits.
This course introduces students to the fundamental principles of systems engineering and their particular application to the development of space systems. It describes how the systems engineering viewpoint differs from that of the engineering specialist, as well as the essential role that systems engineering plays across the mission design life cycle. Topics include requirements analysis, trade studies, concept definition, interface definition, system synthesis, and engineering design. Techniques and analysis methods for making supportable quantitative decisions will also be explored, along with risk assessment and mitigation planning. The importance of thorough systems engineering from the initiation of the project through launch and flight operations will be emphasized. This is intended as the first course in the Space Systems Engineering program curriculum so that the student establishes a firm grasp of the fundamentals of systems engineering as applied to space programs. Examples will be presented from real space missions and programs, with assignments, special topics, and a team project focused on typical space systems engineering problems and applied methods of technical problem resolution.
Prerequisite(s): Cannot have already completed EN.645.662 Intro to Systems Engineering

EN.675.601. Fundamentals of Engineering Space Systems I. 3 Credits.
The effective development of space systems is predicated on a firm understanding of the foundational technical and systems engineering components necessary to both comprehend the design task and formulate an appropriate solution. For engineers and technical managers seeking to develop this working knowledge and associated skills, this course will provide an overview of the key elements comprising space systems and an analytic methodology for their investigation. With a strong systems engineering context, topics will include fundamentals on astrodynamics, power systems, communications, command and data handling, thermal management, attitude control, mechanical configuration, and structures, as well as techniques and analysis methods for remote sensing applications. In addition, a number of supplemental topics will be included to provide further breadth and exposure. This is the first course of a two-semester sequence that features a combination of instruction from practitioner subject matter experts, and a team design project.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space, or with approval of the instructor.

EN.675.602. Fundamentals of Engineering Space Systems II. 3 Credits.
This course will build on the foundational elements introduced in 675.601 Fundamentals of Engineering Space Systems I, expanding on the breadth and depth of prior subject matter treatment, as well as their integrated application. Classes will again feature a combination of instruction from subject matter experts and a team design project.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space and EN.675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

EN.675.613. Bold Science Enabled by Engineering. 3 Credits.
This course will introduce students to the connection between innovative space engineering and the most significant scientific breakthroughs that have resulted from it. This course will first explore the early generation of engineering tools that were turned to the night sky due to curiosity, and the discoveries that were made. These tools fundamentally changed our understanding of what our place in the Universe was, and the exploration led to a new framework for how engineers and scientists partner together to advance space exploration. A long line of observatories, both on the ground and in space, followed and have brought the wonders of the cosmos to humanity. The latest marvel of engineering in this line of engineering tools, a tennis-court sized “eye” in space called the Webb Telescope, was just launched and has revealed the Universe to us in unimaginable ways. It took 20,000 engineers and scientists working over 20 years to enable this mission. The course will explore how these engineering marvels were motivated and built, how they are used, the challenges that were encountered along the way, and how we plan to move forward to chase down even bolder pursuits (e.g., a new generation of robotic engineering experiments to detect life on alien moons in the Solar System).This course is also being given during an era in which space exploration is one of the most exciting, fast-paced, and rapidly growing industries. The increased competition from hundreds of private companies that are entering space is resulting in incredible reductions in the cost to access to space, and has led to an explosion in the number of launches and space-based assets. Lessons in the course will challenge students to explore the modern capabilities of the space industry and how these innovations will power future scientific pursuits.

EN.675.617. Space Policy and Engineering. 3 Credits.
This course straddles the boundary between engineering and public policy related to space. It presents space policy and the effects that policy has on engineering decisions. It presents the underlying space systems engineering principles that necessitate space policy. Space is a highly technical and nonintuitive domain. Professionals working in any space-related field should have a basic understanding of the relationship between engineering and international public policy. EP students have the opportunity to enroll in this one-of-a-kind course which was developed in partnership with the JH School of Advanced International Studies (SAIS). This course focuses on the intersection of space systems engineering and policy, and will be offered for credit as an elective in both the EP SSE Program and SAIS. During fall semesters, the course is offered with in-person attendance required at the Bloomberg Center in Washington D.C. An asynchronous version is currently under development for offering during spring semesters.

EN.675.621. Space Environment and Effects. 3 Credits.
This course will introduce and explore analysis, design, and verification methods for the space environment in general and radiation and plasma environments in particular. Intended as a practical complement to 675.751, Space Weather and Space Systems, this course will focus on mission requirements definition, design features, analyses and ground testing, state-of-the-art engineering models / tools, and national / international standards associated with the design and operation of modern high reliability space systems. Design and operational impacts will consider Total Ionizing Dose (TID), Total Non-Ionizing Dose (TNID), Single Event Effects (SEE), spacecraft charging, material outgassing, atomic oxygen, and Micrometeoroids / Orbital Debris (MMOD). All phases of a program lifecycle will be discussed – from environment definition through operational anomalies and anomaly attribution. Lectures, journal reading, and homework assignments will prepare engineers to quantify and assess risk as well as mitigate space environmental effects. A final project will consider a more detailed analysis of a system of interest to the student.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space or with approval of the instructor.

EN.675.622. Spacecraft Hardware Design Considerations. 3 Credits.
This course will focus on the engineering of hardware systems that will reliably perform in the harsh environment of space. This course will cover design considerations, terrestrial based manufacturing, storage, launch, and on-orbit performance of successful hardware systems, as well as failure modes and mitigations for the design engineer, systems engineer or aerospace program manager. Design and manufacturing concerns covering electrical, electronic, and electromechanical components including part selection, materials considerations, radiation ratings and test, packaging, and manufacturing will be covered. The course will also cover the unique environments from terrestrial based to exo-atmospheric driving design and handling considerations relative to spacecraft hardware.

EN.675.641. Space Cybersecurity. 3 Credits.
Our space systems are under attack. Cyberattacks are among the most prevalent threats to space assets. They are often stealthy, inexpensive and highly effective at achieving an adversary’s goal – be it data corruption, IP theft or physical destruction of the satellite. Given space systems are complex, composing ground stations, communications and satellites the surface area of attack is vast and considering the constrained computing capacity of space systems, many traditional security mechanisms are not applicable. This course provides an introduction to how an adversary would approach attacking a satellite, opportunities for systems engineers to develop cyber-resilient assets and relevant policies and best practices to support space system cybersecurity.

EN.675.650. Mathematics for Space Systems. 3 Credits.
This course is designed to teach Mathematical Methods commonly employed for engineering Space Systems. The course will provide a solid technical foundation in mathematics so the students can apply this knowledge to this broad field. Topics will include select, applicable methods from vector calculus, linear algebra, differential equations, transform methods, complex variables, probability, statistics, and optimization. Various applications to real problems related to space systems and technical sub-disciplines will be used during the semester. No prior knowledge of advanced mathematics is assumed and important theorems and results from pure and applied mathematics are taught as needed during the course. Examples and relevant applications will be utilized throughout the course to further clarify the mathematical theory. Prerequisite(s): The course requires working knowledge of college calculus and algebra, or approval of the instructor.

EN.675.691. Electro-Optical Space Systems. 3 Credits.
The goal of this course is to engage the student with multiple design studies of subsystems of space-based electro-optic systems. The technical and scientific elements necessary to be successful with these studies will be presented during the lectures. The concepts and technologies behind elements such as photon detectors, imaging elements over many spectral bands, optical elements and systems typically used in space sensors, and active optical sources will be described. These concepts and technologies will be the fundamental elements used to describe the various sensor types and modalities used in space electro-optical systems. Prerequisite(s): An undergraduate or graduate degree in a quantitative discipline (e.g., engineering, computer science, mathematics, physics, or equivalent), or with approval of the instructor.

EN.675.701. Applications of Space Systems Engineering. 3 Credits.
The ability to effectively apply knowledge and skills to new problems and situations is critical in the development of space systems. Building upon the foundational systems engineering and technical skills developed through prior coursework, this course will introduce further topics related to areas of active exploration and investigation, as well as practical details pertaining to mission formulation and assessment. Classes will be structured to include both information exchange led by subject matter experts from across the community and active group discourse. In addition, a number of topical case studies will be worked by students in both individual and group formats. Students will be asked to explore, in depth, various advanced areas of space systems engineering challenges and share information with each other in online discussions.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space, EN.675.601 Fundamentals of Engineering Space Systems I, and EN.675.602 Fundamentals of Engineering Space Systems II, or with approval of the instructor.

EN.675.702. Spacecraft Materials. 3 Credits.
Through online lectures and mini cohorts, this course illustrates the fundamental applications of materials to spacecraft design for a systems engineering perspective. Topics include the environments of dynamics, vacuum, thermal, reactive chemicals, radiation, and electrostatics relating to material selection; applications in the material classes of metals, ceramics, polymers, and composites to spacecraft design; design considerations from preliminary design through product verification, launch, and mission operations; and considerations for environment impacts, commons issues encountered, and lessons learned. The course is not intended to cover materials analysis that is taught specific to individual engineering domains, rather it instructs the application of the materials to the space environment with specific industry examples.

EN.675.710. Small Satellite Development and Experimentation. 3 Credits.
The capstone course in the Space Systems Engineering Program will introduce practical methods and tools used for evaluating the design and implementation of space systems—with a particular focus on small satellites and CubeSats. This will be principally achieved through a significant experimentation laboratory component intended to reinforce analytical experience with empirical exposure and insight. The laboratory will build on prior foundational understanding of spacecraft subsystem design and performance, through a structured series of experiments and investigations to be conducted both individually and in small student teams. It will utilize tabletop satellite simulator kits that are especially designed for hands-on educational purposes, while drawing heavily on the analysis methods and tools developed in the Fundamentals of Engineering Space Systems I/II sequence. All work is aimed at preparing for and executing a single long-residency-weekend exercise, nominally held during the final quarter, typically within the last three weekends of the semester in the Baltimore area. The lab component will have a mandatory set of core hours. The residency-lab will meet the Friday (4p-8p) and Saturday (9a-8p). Students are responsible for their own travel and accommodations, as required. Following residency weekend, only final laboratory deliverables and any remaining assignments are due per provided instructions.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space, EN.675.601 Fundamentals of Engineering Space Systems I, and EN.675.602 Fundamentals of Engineering Space Systems II, or with approval of the instructor.

EN.675.711. Ground System Engineering and Mission Operations. 3 Credits.
This course will focus on the critical functions performed by ground systems and mission operations throughout the space systems life-cycle and their integrated application. Course topics will include planning and sequencing, uplink and control, testing, real-time operations, communications, data management, data analysis, and assessment. Students will learn about end-to-end best practices that pertain to most missions and how ground systems and mission operations concepts are tailored across a diversity of missions. Examples will be presented from real space missions and programs, with assignments, special topics, and a team project focused on typical ground system engineering problems, mission operations challenges, and applied methods of technical problem resolution.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space and EN.675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

EN.675.712. Space Mission Formulation. 3 Credits.
This course covers the creative and generative side of space mission engineering. Highly successful space science and exploration missions are the result of close collaboration between scientists who define the highest-level goals and the engineers who provide the means to make the measurements necessary to achieve those goals. In addition, mission formulation teams must understand the external strategic environment that supports a mission, specifically the government sponsors, their funding capabilities, how their priorities get set, and the cycles they go through. This course will help the student develop an understanding of that external environment, the process of collaboration between the scientists and the engineers and their sponsors, and how to frame mission goals and requirements in terms that lead to mission success. The instructors will provide insight into the formulation of scientific investigations, the process of crafting a compelling and accurate narrative for a mission proposal. Topics also include: derivation of mission requirements, launch vehicle capabilities and selection; mission architecture elements; and project flow from pre-proposal through mission confirmation.
Prerequisite(s): Completion of 675.600 Systems Engineering for Space and 675.601 Fundamentals of Engineering Space System, or with approval of the instructor.

EN.675.713. Fault Management & Autonomy. 3 Credits.
This course introduces students to the fundamental principles of fault management engineering as it pertains to space systems. It describes how the fault management engineering viewpoint differs from that of systems engineers and engineering specialists, as well as the role that fault management plays throughout the mission design life cycle. Fault management is a systems engineering function that defines the functional requirements distributed throughout the spacecraft (hardware, software, and autonomy) and ground/mission operations that enable the detection, isolation, and recovery from events that upset nominal operations. Students will learn about the principles of fault management architecture (i.e., driving requirements, redundancy concept, safing and modes concept, ground intervention concept, and critical sequences) and how those principles inform the fault management design, the analytical techniques used for fault analysis, trade studies, and requirements allocation, and the role of the fault management engineer from the initiation of the project through design, integration and test, launch, and flight operation. Examples will be presented from real space missions and programs to emphasize the different implementations of fault management systems given the technical, cost, and schedule constraints.
Prerequisite(s): EN.675.600 Systems Engineering for Space AND EN.675.601 Fundamentals of Engineering Space Systems I or with approval of the instructor.

EN.675.722. Space Mechanical Design and Analysis. 3 Credits.
The mechanical system is a critical element of any space vehicle. This course addresses the requirements, functions, analysis, physical design, verification and characterization of the structure and associated mechanisms. The structural analysis includes assessment of the launch vehicle interfaces and coupled-loads analysis of dynamic responses, requirements for payloads and instruments, and accommodations for all vehicle subsystems. Engineering design approaches are described. Interactions and requirements driven from other subsystems on the mechanical design will be illuminated. Students will configure space vehicles based on a variety of system requirements, perform analysis of various elements of real-world structural elements and will carry out associated design tasks.

EN.675.724. Space Internetworking. 3 Credits.
This course addresses the requirements, architectures, and protocols used to build and operate space-terrestrial internetworks. These internetworks federate both space-to-space and space-to-ground links into secure, resilient, end-to-end telecommunications. The course covers terrestrial networking technologies, special constraints of space-based systems, and emerging space networking protocols. Topics will include resilient data transport, naming and addressing, network security, time-variant routing, and autonomous network management. Unique requirements and applications to cislunar and deep-space networks will be addressed. Students will implement networking concepts in the C programming language.
Prerequisite(s): EN.675.600, EN.675.601, and knowledge of Linux systems and software engineering with an emphasis on the C language.

EN.675.731. Spacecraft Propulsion. 3 Credits.
The intent of this class is to teach the basics of propulsion such that you will be able to make informed decisions about which sort of system would be best for a particular application. To do this, the class starts with a basic primer on the physics of propulsion and then covers key elements of the various types of propulsion systems that are typically used on spacecraft, including chemical and electric systems, and also some types of system not typically used now, but that might be available in the future (e.g., nuclear propulsion, matter/antimatter propulsion). In the class, you are introduced to how a propulsion subsystem is used and how it interacts with the rest of the spacecraft, so it can be seen from a system perspective and not just from the subsystem view. Key pros and cons of each type of system presented are discussed, as well as key constraints and failure modes. Subsystem components and performance characteristics are introduced and then used in examples from actual spacecraft to explain why these systems were selected for flight. Then, you are shown how to specify a propulsion subsystem and trade various subsystem types against each other, how to size them, how to integrate and test them, and ultimately how to fly them.
Prerequisite(s): EN.675.600 Systems Engineering for Space and EN.675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

EN.675.732. Advanced Topics in Aerospace Hardware. 3 Credits.
This course focuses on spacecraft hardware topics to include current and emerging technologies including hardware in system configurations such as constellations and for sensing and communication applications. The course is grounded in a hardware and software design understanding of materials and operations in the space environment (design rules, material and component considerations, safe life versus fail safe designs, environmental considerations, among other hardware guidelines). Specific topics in hardware addressed in these studies include Instruments and Detectors (Optical, Radio Frequency, Imagers…), Low Earth Orbit Commercial Constellations and Swarms, Geostationary (GEO) and GEO Transfer Comm and Remote Sensing, Flagship Missions, Cislunar, In Situ Resource Utilization, Landers and Samplers, Subsystem specifics, Hardware, Firmware and Software Interfaces and Launch vehicles.
Prerequisite(s): Completion of?EN.675.600?Systems Engineering for Space and?EN.675.601?Fundamentals of Engineering Space Systems I, EN.675.622 Spacecraft Hardware Design Considerations or with approval of the instructor.

EN.675.733. Spacecraft Rendezvous and Proximity Operations. 3 Credits.

The objectives of this course are to develop the general principles governing spacecraft proximity operations, rendezvous, and docking, and analyze the challenges associated with their operational implementation. Students will be introduced to topics such as near and far range rendezvous, natural motion circumnavigation (NMC), autonomous rendezvous guidance, and relative navigation using GPS and relative motion sensors. Practical mission constraints, including passive safety, collision avoidance, and sun illumination will be discussed. Applications from emerging areas including on-orbit servicing, in-space manufacturing/assembly/refueling, formation flying, active debris removal, close inspection, and logistics resupply to a cislunar human habitat will also be studied. Students are expected to be comfortable in programming with Matlab, Python or similar simulation platforms, and must have been exposed to the mathematical topics of Linear Algebra, Differential Equations, Calculus, and elementary Probability through prior coursework.

Prerequisite(s): EN.675.600 Systems Engineering for Space; EN.675.601 Fundamentals of Engineering Space Systems I and EN.675.602 Fundamentals of Engineering Space Systems II/ approval of the instructor.

EN.675.734. Fundamentals of Celestial and Orbital Mechanics. 3 Credits.

This course will focus on the study of orbital and celestial mechanics, using many of the methods that are covered in a traditional advanced mechanics course. This is foundational and necessary information for the study of advanced astrodynamics. We will look primarily at closed form and approximation methods (as opposed to numerical solutions) in a wide variety of problems in orbital and celestial mechanics. Students who take this class will be well-versed in fundamentals that can then be leveraged in more advanced future space applications such as spaceflight mechanics, navigation and control, geodesy, maneuver design, orbit determination rendezvous and proximity operations, and others. Topics will include Newtonian Mechanics, Newtonian Gravitation, Central Force Orbits (with a focus on Keplerian Orbits), Orbital & Interplanetary Maneuvers, Non-inertial Reference Frames, the Lagrangian Formalism, Rigid Body Rotation, the Three Body Problem, Approximation Methods for Orbits, Spherical Harmonic Representation of the Earth’s geoid, and Lunar Motion. Discussions will include the historical figures who contributed significantly to the topics discussed.

EN.675.740. Assuring Success of Aerospace Programs. 3 Credits.

Technical managers, systems engineers, lead engineers, and mission assurance professionals will benefit from this course, which focuses on the leadership of system safety and mission assurance activities throughout the life cycle of a project to achieve mission success. This advanced course provides crucial lessons learned and proven best practices that technical managers need to know to be successful. The integrated application of mission assurance and systems engineering principles and techniques is presented in the context of aerospace programs and is also applicable to other advanced technology research and development programs. Students discuss critical risk-based decision making required from system concept definition and degree auditing through design, procurement, manufacturing, integration and test, launch, and mission operations. Experiences shared by senior aerospace leaders and extensive case studies of actual mishaps explore quality management topics relevant to aircraft, missiles, launch vehicles, satellites, and space vehicles. The course addresses contemporary leadership themes, government policies, and aerospace industry trends in mission assurance requirements, organizational structure, knowledge sharing and communication, independent review, audit, and assessment. Mission assurance disciplines covered include risk management, system safety, reliability engineering, software assurance, supply chain management, parts and materials, configuration management, requirements verification and validation, non-conformance, and anomaly tracking and trending.

EN.675.742. Optical Communications and Laser Radar. 3 Credits.

This course will cover the fundamentals and applications of free space optical (FSO) communications systems as well as laser radar (LIDAR). FSO is rapidly becoming the communications method of choice for satellite cross links and for very high data rate downlinks. LIDAR has an extensive heritage in space applications for remote sensing as well as for applications such as precision range determination. This course will cover the multiple common enabling technologies shared by FSO and LIDAR, describe the concepts and theories behind these technologies, discuss the integration of these technologies into systems, and analyze current deployed as well as planned systems to help understand how FSO and LIDAR are implemented and used.This course will leverage Calculus as well as basic probability concepts to implement the physical models used to describe FSO and LIDAR systems and applications.

Prerequisite(s): EN.675.600 Systems Engineering for Space and EN.675.601 Fundamentals of Engineering Space Systems I

EN.675.743. Communication Systems for Space Missions. 3 Credits.
In this course, the principles of spacecraft communication systems will be examined with a specific emphasis on real-world implementation, application, and performance. Existing commercial, civil, and military systems are described and analyzed, including those for Earth-orbiting, cislunar, and deep space spacecraft. The various entities that spacecraft communication systems interact with are reviewed including the host spacecraft, the space environment, ground- and space-entry points, and sources of interference, both intentional and unintentional. Topics include: requirements analysis and definition, end-to-end functional analysis and definition, design options and implementations, performance predictions and analysis, system integration, system verification, and mission operations. The analysis required for system development and operations are introduced including navigation, link analysis, antenna performance, analog and digital modulation/demodulation systems in noise and interference, filtering, sampling, quantization, encoding, and detection techniques to improve signal-to-noise ratio (SNR) and bit error rate (BER) performance. Prerequisite
Prerequisite(s): EN.675.600, EN.675.601, EN.525.640 or equivalent, and a basic working knowledge of Fourier transforms, linear systems, and probability theory, and MATLAB, or with approval of the instructor.

EN.675.746. Digital Engineering for Space. 3 Credits.

EN.675.750. Numerical Methods for Space. 3 Credits.
This course explores the numerical algorithms at the core of many of the fundamental as well as advanced computational techniques used in Space Engineering. Engineers routinely use Commercial-Off-The-Shelf (COTS) software tools for creating mission orbits, computing trajectories, and analyze subsystems such as GNC, Communication, and Propulsion. The focus of this course is to develop the mathematical principles and numerical methods behind many of those commonly-used, often times as “black box”, COTS tools, as well as introduce state-of-the-art ones from the current research literature. Students will be exposed to topics such as Numerical Optimization, Differential Correction, Finite Difference and Complex-Step Derivative computation, Stochastic Differential Equations and more. Applications ranging from accurate Orbit Propagation, Launch Vehicle Trajectory Optimization, RF Link Design, Propulsion System sizing and others will be studied through in-class discussions and homework assignments. Students are expected to be comfortable in programming with MATLAB, Python or similar simulation platforms, and must have been exposed to the mathematical topics of Linear Algebra, Differential Equations, Calculus, and elementary Probability through prior coursework.

EN.675.751. Space Weather. 3 Credits.
This course will explore the space environment in the context of its impact on space system operations. Topics include the impacts of ionospheric variability on HF propagation, satellite communications, and GPS; impacts of energetic charged particles on spacecraft; impacts of auroral precipitation on radar and communication systems; and impacts of varying geomagnetic activity on power grids and space situational awareness. Lectures and homework assignments will prepare engineers to quantify and mitigate space weather impacts, and a final project will consist of a detailed analysis on a system of interest to the student. Prerequisite(s): An undergraduate or graduate degree in a quantitative discipline (e.g., engineering, computer science, mathematics, physics, or equivalent), or with approval of the instructor.

EN.675.752. Attitude Determination and Control. 3 Credits.
The Attitude Determination and Control Subsystem, or ADCS, is intimately connected with all the other spacecraft subsystems, and will be studied in the context of the systems engineering of the whole spacecraft and its mission. Students will examine the requirements imposed on the ADCS, and will explore how to meet those requirements. To this end, it starts with a student’s understanding of rigid-body dynamics as it relates to spacecraft dynamics and will introduce common and classical approaches to problems encountered in the design of this critical spacecraft subsystem. The course will also include a team design project involving an ADCS for a small spacecraft.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space, EN.675.601 Fundamentals of Engineering Space Systems I

EN.675.753. Avionics. 3 Credits.
This survey course will focus on the management, engineering development and operation of the spacecraft Avionics system consisting of hardware topics covering Spacecraft Processing; Command Data Handling and Command Execution; Telemetry Acquisition, Conditioning and Conversion and Telemetry Data Handling; Bulk data storage; Fault Management Support; and Timekeeping Support. The course is grounded in computer and data architecture fundamentals with focus on key electronics such as data interfaces, spacecraft processors, volatile and non-volatile memories, field-programmable gate arrays (FPGA), and analog sensors and circuits. Spacecraft Avionics systems topics will be applied through reference design scenarios to illustrate requirements/implementation trades bound by the constraints of the space environment and spacecraft data resource limitations. Topics such as hardware development, integration and test and inflight support will be used to illustrate the difficulties inherent to the spacecraft’s Avionics system.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space and EN.675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

EN.675.754. Flight Software. 3 Credits.
This survey course reviews the architectures, designs, and implementations of spacecraft flight software systems. The course provides an overview of typical command and data handling software functions and the open-source tools, frameworks, and applications that can implement them. A semester-long programming assignment is provided to build a working flight software system. Special topics include application to resource-constrained Internet-of-Things (IoT) devices, spacecraft security, and space-based networking. Flight software encompasses the complete set of computer instructions running on every processor on a spacecraft.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space and EN.675.601 Fundamentals of Engineering Space Systems I, experience programming in C, or with approval of the instructor.

EN.675.756. Spacecraft Antenna Design. 3 Credits.
This course presents an engineering approach to the design of antennas for space systems. Students will examine antennas for both large and small space based platforms in earth orbit and beyond. Antenna design is presented in the context of the space environment with particular attention to the flight design and testing cycle, thermal and mechanical considerations, space compatible materials, and high power operation. A primary focus of the course will be single, dual and shaped reflector designs including feed network topologies. Several horn antenna designs including corrugated and multimode horns will be covered as well as feed network components. A variety of other antennas including helices, patches, and arrays will be discussed for applications including: Global Navigation Satellite System (GNSS); Tracking, Telemetry and Command (TT&C); isoflux; smallsat and cubesat antennas. Prerequisite(s): An undergraduate- or graduate-level introductory antenna systems course, or with approval of the instructor. Course Note(s): This course is cross-listed with 525.656 Antenna Design for Space Systems. SSE students can only register for 675.756.

EN.675.761. Reliability Engineering and Analysis. 3 Credits.
This course covers the principal methods of reliability analysis as it pertains to space systems. These seek to help development teams to anticipate and find design and operational issues. Basic analytical techniques covered include fault tree and reliability block diagrams; Failure Mode and Effects Analysis (FMEA); event tree construction and evaluation; and reliability data collection and analysis. More advanced techniques of risk and reliability modeling of systems include Bayesian methods and applications, estimation of rare event frequencies, uncertainty analysis and propagation methods. These methods and techniques are integrated into quantitative assessments to address hardware, software, and human reliabilities, as well as their dependencies.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space and EN.675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

EN.675.768. Spacecraft Integration and Test. 3 Credits.
This course introduces students to the fundamental principles of developing Integration & Test (I&T) programs for space systems. Topics covered will provide a detailed understanding with practical applications of all phases of Spacecraft I&T starting with the design input/planning phase, staffing/budget phase, subsystem and instrument integration phase, environmental testing phase, and finally the launch campaign phase in the field. Classes will be structured to provide students information exchange sessions with subject matter experts and actual practitioners within the I&T community. Students will learn about all of the Electrical and Mechanical ground support equipment needed to build a spacecraft and the importance of the paperwork and processes used throughout all phases to manage spacecraft systems I&T.
Prerequisite(s): EN.675.600 Systems Engineering for Space and EN.675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

EN.675.771. Space Mission Design and Navigation. 3 Credits.
Critical to the development of space missions is the careful analysis and design of the desired path of the space vehicle (mission design) and the determination of the space vehicle's actual state vector (navigation). This course presents these two topics in an integrated manner, intended to provide space engineering professionals with a technical understanding of these complex subjects. Mission Design topics include kinematics, Kepler's Laws, Newton's Law of gravitation, modeling of several fidelity levels of spacecraft trajectory dynamics, and optimization of objective functions and satisfaction of constraints. Navigation topics include dynamics and measurement model formulations, standard estimation algorithms such as the Kalman filter and batch estimators, and performance analysis. This course will focus on the theory from a mathematical derivation perspective, example problems, and practical implementation considerations. This is an algorithm intensive course and students are expected to be comfortable with the following: MATLAB programming (or equivalent), Linear Algebra, Linear Systems, Differential Equations, basic Probability concepts, and Calculus.
Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space; EN.675.601 Fundamentals of Engineering Space Systems I

EN.675.772. Requirements, Verification and Validation. 3 Credits.
A survey course that reviews the specification, verification and validation of spacecraft flight system requirements. The course provides an overview of the requirements gathering process, subsystem allocation, verification methods, typical spacecraft system tests and test events. An overview of the construction of spacecraft comprehensive performance tests and mission scenarios will be part of this course, as well as the development of a requirements verification matrix.
Prerequisite(s): EN.675.600 Systems Engineering for Space, or with approval of the instructor

EN.675.781. Physics of Space Security. 3 Credits.
This comprehensive course touches the wave tops of the math and physics of offensive and defensive space control systems. The course is developed around the foundational physics of competitor nation systems under development and operational fielding as published in public U.S. government reports. We explore each of the systems and the basic principles that underlie the technological approach at the level of fundamental engineering, math, and physics. The list of techniques that we explore are ground- and space-based kinetic interceptors (and the affects and concerns around orbital debris), accuracy in targeting and orbit estimation, space-based attack robots (touching on rendezvous and proximity operations), fractional orbital bombardment systems, ground-based and space-based electronic jamming and attack as well as laser dazzling and damage. We explore future technologies such as the impacts of quantum encryption, artificial intelligence, cislunar basing, dynamic space operations, the possibility of nuclear weapons in space, and the practical use of space plane systems.
Prerequisite(s): EN.675.600 Systems Engineering for Space and EN.675.601 Fundamentals of Engineering Space Systems I andEN.675.602 Fundamentals of Engineering Space Systems II

EN.675.792. Scientific Instruments for Space. 3 Credits.
At the heart of every scientific discovery is a set of measurements enabled by precise and verifiable instrumentation. Through lectures, test case scenario, writing assignments, and design projects, this course draws on the history of scientific instrumentation and techniques for measurement using in-situ and remote sensing technologies to foster and inspire future instrumentation engineers to develop new and better space-based instruments facilitating future scientific discoveries. Topics include the physical basis for remote sensing, precise analog measurements, digital processing, spatial data analysis, verification of measurements, instrument life cycle, and science traceability matrices. The course is not intended to provide students with extensive training in a particular type of scientific instrument (e.g. particle, optical, magnetic). Working knowledge of computing package (e.g. coding in Python or Matlab) and completion of a design project are required. Although there are no specific prerequisites for this course, it will be helpful if students have completed courses 675.600 and 675.601 in this program prior to taking this class.

EN.675.793. Science and Payload Operations Centers. 3 Credits.
This course will focus on the design and development of science and payload operations centers, and their use to execute the science operations of space missions. Course topics will include science activity planning, interfaces with mission operations and ground systems, science data pipelines, archive delivery, data analysis and science decision making, and operation of the SOC during a mission. Students will learn about the needs of the science and instrument teams, as well as the broader science community, and how to design and operate a software system to satisfy their requirements. Examples will be presented from real missions, with assignments that illustrate the various topics building towards a final simulated science planning activity where the student will step into the shoes of an instrument operations lead and execute a plan using the tools and skills they have developed.Some programming experience in Python, Java, or similar strongly recommended.

EN.675.800. Directed Studies in Space Engineering. 3 Credits.
In this course, qualified students are permitted to investigate possible research fields or to pursue problems of interest through reading or non-laboratory study under the direction of faculty members. Prerequisite(s): The Independent Study/Project Form (ep.jhu. edu/student-forms) must be completed and approved prior to registration. Course Note(s): This course is open only to candidates in the Master of Science in the Space Systems Engineering program.