

EN.675 (SPACE SYSTEMS ENGINEERING)

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): Admission into the SSE program, or with approval of the instructor.

Prerequisite(s): Cannot have already completed EN.645.462 OR 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.675.621. Space Environment and Effects. 3 Credits.

This course will introduce and explore 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 and EN.675.601 Fundamentals of Engineering for Space Systems I, 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.675.640. Satellite Communications Systems. 3 Credits.

This course presents the fundamentals of satellite communications link design and an in-depth treatment of practical considerations. Existing commercial, civil, and military systems are described and analyzed, including direct broadcast satellites, high throughput satellites, VSAT links, and Earth-orbiting and deep space spacecraft. Topics include satellite orbits, link analysis, antenna and payload design, interference and propagation effects, modulation techniques, coding, multiple access, and Earth station design. The impact of new technology on future systems in this dynamic field is discussed. Prerequisite(s): EN.525.616 Communication Systems Engineering or equivalent, or with approval of the instructor. Course Note(s): This course is cross-listed with EN.525.640 Satellite Communications Systems.

Prerequisite(s): EN.525.616 Communication Systems Engineering or equivalent, or with approval of the instructor.

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 prior 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.675.710. 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 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 the 10th week of the semester at the Johns Hopkins University Applied Physics Laboratory. In lieu of meeting during normal class time during the 10th week, the lab will meet the Friday, Saturday, and Sunday immediately following the normal class date. The lab component will have a mandatory set of core hours during a time period running from Friday at 5 p.m. through Sunday at 12 p.m.; students are responsible for their own travel and accommodations, as required. An optional tour of APL space facilities is planned for 4 p.m. on Friday. There will be no further classes following the residency weekend, with only final laboratory deliverables 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.

EN.675.713. Fault Management and Autonomy: Improving Spacecraft Survivability. 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

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.675.740. 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. Course Note(s): This course is cross-listed with EN.595.740

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.675.741. Passive Emitter Geo-Location. 3 Credits.

This course covers the algorithms used to locate a stationary RF signal source, such as a radar, radio, or cell phone. The topics covered include a review of vectors, matrices, and probability; linear estimation and Kalman filters; nonlinear estimation and extended Kalman filters; robust estimation; data association; measurement models for direction of arrival, time difference of arrival, and frequency difference of arrival; geo-location algorithms; and performance analysis. Most of the course material is developed in planar Cartesian coordinates for simplicity; however, the extension to WGS84 coordinates is provided to equip the students for practical applications. Homework consists of both analytical problems and problems that require computer simulation using software such as MATLAB.

Prerequisite(s): EN.525.614 Probability and Stochastic Processes for Engineers, EN.675.600 Systems Engineering for Space AND EN.675.601 Fundamentals of Engineering Space Systems I. An undergraduate course in linear algebra/matrix theory, and familiarity with MATLAB are required. 675.600 Systems Engineering for Space 675.601 Fundamentals of Engineering Space Systems I An undergraduate course in linear algebra/matrix theory, and familiarity with MATLAB are required.

EN.675.751. Space Weather and Space Systems. 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 of Space Systems. 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 and EN.675.650 Mathematics for Space or with approval of the instructor.

EN.675.753. Spacecraft Avionics and Power Systems. 3 Credits.

This course will focus on the engineering development and operations of the spacecraft Avionics and Power systems. Course topics for Avionics will include spacecraft avionics systems overview, requirements, key parts identification for processors, volatile and non-volatile memories, and field-programmable gate arrays (FPGA). Onboard spacecraft command and telemetry data flow architectural trade-offs will be evaluated against reference design scenarios. Avionics topics such as hardware development, integration and test and inflight support will be used to illustrate the concepts. (power systems portion to be added by co-instructor to be appointed)

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 for Space Systems. 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. Antenna Design for Space Systems. 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.

EN.675.757. Space-Based Radar Systems. 3 Credits.

Radar systems launched in and used in space are utilized in a number of applications including navigation, intelligence, maritime domain awareness, ocean ice monitoring, meteorology, disaster recovery, and lunar and planetary science. This course will begin with radar fundamentals before covering the scientific requirements that drive the engineering decisions that go into designing a space-based radar system, the data processing that must occur, and how that data is then exploited. Emphasis will be on Synthetic Aperture Radar, but other techniques and technologies will also be included. Case studies of historic, existing, and future systems will be done. Students will select a particular mission of interest and create a conceptual design for a space radar system that would be capable of executing the chosen mission.

Prerequisite(s): Completion of EN.675.600 Systems Engineering for Space; EN.675.601 Fundamentals of Engineering Space Systems I and EN.675.650 Mathematics for Space or with approval of the instructor.

EN.675.761. Reliability Engineering and Analysis for Space Missions. 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 and EN.675.650 Mathematics for Space or with approval of the instructor.

EN.675.772. Verification and Validation of Space Systems. 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 and EN.675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor

EN.675.800. Directed Studies in Space Systems 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.