# AEROSPACE ENGINEERING

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## Academic Programs

| Program name | Program type |
|---|---|
| Aerospace Engineering | BS, MS |
| Multidisciplinary Design | Minor |

The mission of the Aerospace Engineering Department is to collaborate with the Aerospace Industry to build partnerships which promote excellence and innovation to serve diverse communities. We work as a team to provide an excellent Learn-by-Doing, systems and design focused engineering education; graduating Day One-ready professionals.

We accomplish our mission using a laboratory-based, hands-on approach to education students. This approach, coupled with a systems view of engineering, is encouraged through coursework and a group-based capstone design experience. This educational philosophy yields engineers capable of working in positions of technical responsibility and leadership in a modern multidisciplinary, systems-based industry.

The Bachelor of Science degree in Aerospace prepares students for engineering work in the exciting aerospace industry. The problems faced by the aerospace industry offer an unusual engineering challenge. Much of the analysis and testing must be accomplished at the very frontiers of technology and performance. Nevertheless, complex aerospace systems must be designed and manufactured; thus, an exceptionally wide range of engineering and problem solving abilities is required. Aerospace Engineering graduates obtain employment in all areas of the aerospace industry with a strong focus on aircraft and spacecraft design.

Aerospace Engineering students can choose between an Aeronautics or Astronautics concentration. Within Aeronautics, students learn the fundamentals of aerodynamics, flight mechanics, materials, structures, propulsion, and stability and control. Within Astronautics, students learn the fundamentals of orbital mechanics, space environment, space structures, telecommunications, attitude dynamics and control, and rocket propulsion. Both concentrations culminate with a Senior Design capstone course where students put theory into practice using a disciplined systems engineering approach to either aircraft or spacecraft design.

The BS degree program in Aerospace Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org/. It places emphasis on both analysis and design, with supplementary basic work in laboratory projects. Throughout the entire program there is constant interplay between theory and application. Opportunities are available for advanced elective work in the student's field of special interest.

The program maintains laboratory facilities for fabrication, air breathing and space propulsion, structures and composites, aerodynamics, dynamics and control, flight simulation and flight test, aerothermodynamics, advanced computation, and design.

Aerospace students may participate in two student chapters of national professional societies–the American Institute of Aeronautics and Astronautics and the Society for the Advancement of Material and Process Engineering. There is also a student chapter of the national aerospace engineering honor society, Sigma Gamma Tau. In addition, students have the opportunity to work on CubeSats and Autonomous Flight Systems, through other club activities or faculty research.

## Undergraduate Programs
## BS Aerospace Engineering

The Bachelor of Science degree in Aerospace Engineering prepares students for engineering work in the exciting aerospace industry. The aerospace industry is known for designing and building complex systems which push the limits of technology. Therefore a strong emphasis is placed on turning theory into practice and problem solving using a disciplined systems engineering approach. The program's faculty have developed a number of educational objectives to support this mission. These objectives are:

- Be life-long learners who continue to pursue professional development;
- Participate and thrive in a multi-disciplinary , systems-oriented work environment;
- Contribute to the solution of complex technical problems that exist in the aerospace industry; and
- Understand their ethical role as a professional engineer and strive to promote a practice of integrity, tolerance, and respect in the workplace.

### Concentrations

**Aeronautics**
**Astronautics**

## Multidisciplinary Design Minor

The minor enhances students' ability to work in multidisciplinary engineering teams. The students develop an understanding of the design process and the role of systems engineering in product design and development including costs analysis. They also learn the systems integration process and how different subsystems are interfaced to develop a successful product.

## Graduate Programs
## MS Aerospace Engineering

### General Characteristics

The Master of Science program in Aerospace Engineering prepares the student for entry into a well-established field of aerospace engineering. The MS program emphasizes engineering science and research activity. Graduates have an increased capability for complex research, development, and innovative design, and are prepared for further study in engineering, leading to a Ph.D. or advanced positions within industry.

### Prerequisites

For admission as a classified graduate student, an applicant must hold a bachelor's degree in engineering or a closely related physical science with a minimum grade point average of 3.0 in the last 90 quarter

units (60 semester units) attempted. Applicants are required to submit satisfactory scores for the General (Aptitude) Test of the Graduate Record Examination.

An applicant who meets these standards but lacks prerequisite coursework may be admitted as a conditionally classified student and must make up any deficiencies before advancement to classified graduate standing. Information pertaining to specific requirements for admission to graduate standing (classified or conditionally classified) may be obtained from the Graduate Coordinator, Department of Aerospace Engineering.

### Program of Study

A thesis is required as a culminating experience. Students work with their advisor and the Department Graduate Coordinator to develop a program of study which supports their thesis topic. A thesis topic would typically be in an area of faculty research interest.

For the most recent, comprehensive list of courses offered by the department, please contact the Department Graduate Coordinator or see the listing at https://aero.calpoly.edu.

### Program Learning Objectives

1. Competency in advanced mathematics, science, and aerospace engineering knowledge.
2. Ability to apply advanced mathematics, science, and aerospace engineering knowledge to a project that is conducted independently.
3. Make a specific contribution to a field that is relevant to aerospace professionals.
4. Ability to convey effectively engineering ideas and results both orally and in writing.
5. Awareness of professional and ethical responsibility.
6. Awareness of global, contemporary issues related to aerospace engineering and the society at large.
7. Awareness of rapid advancement of modern technology and ability for life-long learning.

## MS Aerospace Engineering, Specialization in Research

### Characteristics

Emphasizes engineering science and research activity. Graduates have an increased capability for complex research, development, and innovative design, and are prepared for further study in engineering, leading to the Doctor of Engineering or Ph.D. or advanced positions within industry.

### Program of Study

A thesis is required as a culminating experience. Students work with their advisor and the Department Graduate Coordinator to develop a program of study which supports their thesis topic. A thesis topic would typically be in an area such as: dynamics and control, fluid dynamics and aerodynamics, multidisciplinary design and optimization, aerospace propulsion, aerospace structures, and systems engineering.

For the most recent, comprehensive list of courses offered by the department, please contact the Department Graduate Coordinator or see the listing at https://aero.calpoly.edu.

## Blended BS + MS Aerospace Engineering

The blended program provides motivated students with an accelerated route to the MS Aerospace Engineering, with simultaneous conferring of both bachelor's and master's degrees. Students in the blended program are provided with a seamless process whereby they can progress from undergraduate to graduate status.

### Eligibility

Students majoring in BS Aerospace Engineering may be eligible to pursue the blended program toward the MS Aerospace Engineering. Participation in the program is based on prior academic performance and other measures of professional promise, with a minimum GPA of 3.0 required. Students are selected by a faculty committee. Please see Graduate Programs (http://catalog.calpoly.edu/graduateeducation/#graduateandpostbaccalaureateadmissionrequirements) for eligibility criteria.

### Program of Study

The program allows students to complete a more meaningful capstone experience that integrates the senior design course with the graduate thesis. This arrangement also increases opportunities for industry interaction.

The blended program allows students to double count up to four units of coursework to fulfill the requirements for the BS and MS degrees.

### AERO Courses

**AERO 121. Aerospace Fundamentals. 2 units**
Term Typically Offered: F
Introduction to the engineering profession including the aeronautical and aerospace fields. Engineering approach to problem-solving and analysis of data obtained from experiments. Basic nomenclature and design criteria used in the aerospace industry. Applications to basic problems in the field. 1 lecture, 1 laboratory.

**AERO 200. Special Problems for Undergraduates. 1-4 units**
Term Typically Offered: F, W, SP
Prerequisite: Consent of department head.

Individual investigation, research, studies, or surveys of selected problems. Total credit limited to 4 units.

**AERO 215. Introduction to Aerospace Design. 2 units**
Term Typically Offered: F, W
Prerequisite: AERO 121, MATH 143, and IME 144. Recommended: CSC 111.

Introduction to problem solving techniques and team-centered design projects in aerospace engineering. Primary emphasis on the solutions of design problems in aerospace engineering using computers. 2 laboratories.

**AERO 220. Aerospace Systems Engineering and Integration. 1 unit**
Term Typically Offered: F, W, SP
Prerequisite: AERO 121.

Project-based study of fundamental systems engineering concepts including sub-system interface requirements, verification and validation, modeling/analysis/design, and implementation of complex aerospace systems. 1 laboratory.

**AERO 270. Selected Topics. 1-4 units**
Term Typically Offered: TBD
Prerequisite: Open to undergraduate students and consent of instructor.

Directed group study of selected topics. The Schedule of Classes will list title selected. Total credit limited to 8 units. 1 to 4 lectures.

**AERO 299. Aerospace Thermodynamics. 4 units**
Term Typically Offered: SP
Prerequisite: ME 212. Corequisite: AERO 300. Recommended: AERO 215.

Basics of thermodynamics, energy, systems and control volume analysis. First law, second law, phase change and energy analysis for aerospace-relevant applications. Entropy and exergy, cycle analysis (Rankine, Brayton, turbojets and turbofans). Not open to students with credit in AERO 301. 3 lectures, 1 laboratory.

**AERO 300. Aerospace Engineering Analysis. 5 units**
Term Typically Offered: SP
Prerequisite: AERO 215, MATH 244, ME 211, and PHYS 133.

Analytical methods for aerospace engineering problems. Topics include vector calculus, linear algebra, differential equations, Laplace transforms and Fourier series. Computer tools and numerical methods as applied to problems in aerodynamics, structures, stability and control and astronautics. 4 lectures, 1 laboratory.

**AERO 302. Aerospace Fluid Mechanics. 4 units**
Term Typically Offered: F
Prerequisite: ME 212. Corequisite: AERO 300. Recommended: AERO 215; and AERO 299 or AERO 301.

Properties of fluids, statics, mass/energy/momentum for aeronautical applications, external aerodynamics (lift and drag), dimensional analysis for scale testing, introduction to differential analysis and Navier-Stokes equations, basics of laminar and turbulent boundary layers. 3 lectures, 1 laboratory.

**AERO 303. Aerospace Gas Dynamics and Heat Transfer. 4 units**
Term Typically Offered: W
Prerequisite: AERO 299 or AERO 301; and AERO 302.

Basics of heat transfer and approaches to problem solving, steady heat conduction, convection (forced and natural), heat exchanger design, shock waves and compressible flow in nozzles and diffusers (normal, oblique, expansion waves), thermal radiation and applications. 3 lectures, 1 laboratory.

**AERO 304. Experimental Aerothermodynamics. 2 units**
Term Typically Offered: W
Prerequisite: AERO 299 or AERO 301; ENGL 149.

Laboratory experiments verify the momentum and energy equations. Mass flow rate, fan performance, boundary layer measurements, diffuser performance, and induction pump performance experiments are evaluated. Introduction to electronic sensors, signals and data acquisition. 1 lecture, 1 laboratory.

**AERO 306. Aerodynamics and Flight Performance. 4 units**
Term Typically Offered: F
Prerequisite: AERO 215; AERO 299 or AERO 301. Concurrent: AERO 302.

Introduction to theoretical aerodynamics. Primary emphasis in the subsonic region, including compressibility effects. Basic aerodynamic theory: Airfoil theory, wing theory, lift and drag. Team-centered aerodynamic design. Flight performance. 4 lectures.

**AERO 307. Experimental Aerodynamics. 2 units**
Term Typically Offered: SP
Prerequisite: AERO 302, AERO 306, ENGL 149.

Wind tunnel testing of basic aerodynamic properties of airfoils, finite wings, aircraft or spacecraft models, and vehicle flight performance. Emphasis on both static and dynamic responses of aircraft. Various measurement techniques, data reduction schemes, and analysis methods. 2 laboratories.

**AERO 310. Air and Space. 4 units**
GE Area F
Term Typically Offered: F,W,SP,SU
Prerequisite: Junior standing and Completion of GE Area B.

Technological innovations that have led to modern aircraft and spacecraft as viewed from an historical perspective. Development of aerodynamics, propulsion systems, light-weight structures, and control systems. How aviation has affected, and been affected by, history. Impact of aviation on society, including civil and military aircraft/spacecraft. Federal regulation of aviation, including air traffic control and airlines. Future developments in air and space technology. 4 lectures. Crosslisted as AERO/HNRS 310. Fulfills GE Area F.

**AERO 311. Aircraft Development History. 4 units**
Term Typically Offered: F
Prerequisite: AERO 215. Recommended: Sophomore standing.

Traces the engineering evolution of commercial and military aircraft from the Wright Flyer to modern designs. Studies include how aircraft design is driven by the combination of requirements, deterrents and advancing technologies resulting in the continuous innovation of configurations. 4 lectures.

**AERO 320. Fundamentals of Dynamics and Control. 4 units**
Term Typically Offered: F
Prerequisite: AERO 300 and ME 212. Corequisite: AERO 321.

Introduction to six degree of freedom rigid body dynamic and kinematic equations of motion, including coordinate transformations, Euler angles and quaternions for aerospace vehicles. Linearization and dynamic system theory and stability. Introduction to linear control theory, controller design and analysis. 4 lectures.

**AERO 321. Experimental Sensors, Actuators and Control. 1 unit**
Term Typically Offered: F
Corequisite: AERO 320.

Experiments in translational and rotational dynamics, structural, thermal, and flow control. Comparison of modeling/simulation results to experimental data. Role of actuators, sensors, noise, feedback, and supporting instrumentation hardware and software. Introduction to technical communication. 1 laboratory.

**AERO 331. Aerospace Structural Analysis I. 4 units**
Term Typically Offered: W
Prerequisite: AERO 300, CE 207, and ME 212.

Deflection analysis. Principles of fictitious displacement, virtual work, and unit load method. Energy methods: Castigliano's theorem, Maxwell-Betti reciprocal theorem, minimum principles, Rayleigh-Ritz's method and Galerkin's method. Stress analysis of aircraft and spacecraft components. 4 lectures.

**AERO 351. Introduction to Orbital Mechanics. 4 units**
Term Typically Offered: F
Prerequisite: AERO 300 and ME 212.

Motion of a body in a central field. Keplerian Orbits. Orbital maneuvers. Interplanetary trajectories. 4 lectures.

**AERO 353. Spacecraft Environment. 4 units**
Term Typically Offered: W
Prerequisite: AERO 299 or AERO 301; AERO 300.

Effects of the space environment on a spacecraft and design considerations. Topics include the launch, vacuum, particulate, plasma, and radiation environments 4 lectures.

**AERO 354. Space Environment Laboratory. 2 units**
Term Typically Offered: SP
Prerequisite: ENGL 149 and AERO 353.

Laboratory examples of the effects of the space environment on a spacecraft and design considerations. Topics include the launch, vacuum, particulate, plasma, and radiation environments. All topics are applied to how the environment affects spacecraft design considerations. 2 laboratories.

**AERO 360. Creative Problem Solving in Engineering Design. 2 units**
Term Typically Offered: W
Prerequisite: PSY 350.

The creative problem solving process for an engineering design team. How to explore context and causes as part of defining a design problem; the principles of brainstorming, synthesis, and judgment. Role of iteration, implementation, and communication. Importance of a diverse view, including: customers, products, processes, systems, ethics, and professional responsibility. Team-based applications to case studies and real-world engineering design problems. 2 laboratories.

**AERO 400. Special Problems for Advanced Undergraduates. 1-4 units**
Term Typically Offered: F,W,SP,SU
Prerequisite: Consent of instructor.

Individual investigation, research, studies, or surveys of selected problems. Total credit limited to 8 units.

**AERO 401. Propulsion Systems. 5 units**
Term Typically Offered: F
Prerequisite: AERO 303, CHEM 124.

Power plant types, components, characteristics, and requirements. Principles of thrust and energy utilization. Thermodynamic processes and performance of turboprop, turboshaft, turbofan, turbojet, ramjet, and rocket engines. 4 lectures, 1 laboratory.

**AERO 402. Spacecraft Propulsion Systems. 5 units**
Term Typically Offered: F
Prerequisite: AERO 303, AERO 353 and CHEM 124.

Effects of the propulsion subsystem on spacecraft design. Introduction to air breathing propulsion systems. Topics include basic rocket performance, monopropellant thrusters, bipropellant thrusters, electric thrusters, thruster placement, plumbing, tank sizing and design, system layout, component design, and systems integration. 4 lectures, 1 laboratory.

**AERO 405. Supersonic and Hypersonic Aerodynamics. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 303; and AERO 306 or AERO 353.

Review of gas dynamics, shock-wave and boundary-layer interaction, aerodynamic design. 2-dimensional supersonic flows around thin airfoil; finite wing in supersonic flow. Local surface inclination methods for high-speed flight, boundary-layer and aerodynamic heating, viscous interactions. 4 lectures.

**AERO 406. Applied Computational Fluid Dynamics. 4 units**
Term Typically Offered: F
Prerequisite: AERO 302 and AERO 306.

Application of Computational Fluid Dynamics to study a range of problems relating to applications in aerospace and automotive engineering. Grid generation, sources of errors in CFD studies, boundary conditions, 2D and 3D external flows, and turbulence modeling. 2 lectures, 2 laboratories.

**AERO 407. Reentry Aerodynamics. 4 units**
Term Typically Offered: W
Prerequisite: AERO 303.

Near planet environments. Transition from orbital to aero-dynamic motion. Aerodynamic heating and effects on design. 4 lectures.

**AERO 409. Flight Test. 4 units**
Term Typically Offered: W
Prerequisite: AERO 306. Concurrent: AERO 320.

Overview of flight tests, test equations, and supporting facilities. Principles of team-centered flight testing with applications to performance, stability and control, and avionics systems testing. Test planning, instrumentation, data analysis and reports. 2 lectures, 2 laboratories.

**AERO 420. Aircraft Dynamics and Control. 4 units**
Term Typically Offered: W
Prerequisite: AERO 306 and AERO 320.

Newton's 6-degree-of-freedom equations of motion applied to aerospace vehicles. Stability and control derivatives, reference frames, steady-state and perturbed dynamic analyses applied to aerospace vehicles. Stability and control design principles applied to transfer functions, state-space, and modal system dynamics. 4 lectures.

**AERO 421. Spacecraft Attitude Dynamics and Control. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 320 and AERO 351.

Introduction to spacecraft attitude dynamics and control. Momentum exchange devices and bang-bang thruster control. Orbit determination (GPS), maneuvers and station keeping. Fundamentals of guidance and navigation systems. Analysis and design of control systems for aerospace vehicles. 4 lectures.

**AERO 425. Aircraft Performance. 4 units**
Term Typically Offered: F
Prerequisite: ME 212, AERO 306, AERO 300.

Fundamentals of propeller and jet aircraft performance. Steady and accelerated flight. Equations of motion. Level flight, gliding, climbing, driftdown. Takeoff and landing. Federal Aviation Regulations (FARs). Range and endurance. Payload-range diagram. Maneuvering. V-n diagram. Turning and pull-ups. Stall and spin behavior. Energy methods. 4 lectures.

**AERO 431. Aerospace Structural Analysis II. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 331.

Basic equations of elasticity with applications to typical aerospace structures. Concepts studied include analysis of aircraft and aerospace structures; airworthiness and airframe loads; structural constraints; elementary aeroelasticity; structural instability; introduction to modern fatigue; fracture mechanics; and composite structures analysis. 4 lectures.

**AERO 432. Advanced Composite Structures Analysis. 4 units**
Term Typically Offered: F
Prerequisite: AERO 331.

Review of isotropic material behavior. Behavior of unidirectional fiber composites. Properties of short-fiber composites and orthotropic lamina. Analysis of laminated composites. Stresses and strains of composites. Strength and hygrothermal behavior of composite materials. 3 lectures, 1 laboratory.

**AERO 433. Experimental Stress Analysis. 1 unit**
Term Typically Offered: F, W, SP
Prerequisite: AERO 331, AERO 431.

Employing the knowledge of stress analysis and aerospace structural analysis in an individual and group design project dealing with aerospace structures. 1 laboratory.

**AERO 434. Aerospace Structural Analysis III. 4 units**
Term Typically Offered: F
Prerequisite: AERO 431.

Analysis and design applications for aircraft and spacecraft structures. Stress concentrations, fatigue, and fracture mechanics. Structural dynamics. Framed structures, plates and shells. Composite applications. 4 lectures.

**AERO 435. Aerospace Numerical Analysis. 4 units**
Term Typically Offered: F
Prerequisite: AERO 300, AERO 331.

Taylor series. Finite difference calculus. Interpolation and extrapolation. Finite difference method. Basic equations of elasticity. Global stiffness matrix. Rayleigh-Ritz method. Galerkin method. Bernoulli-Euler beam element. Finite element formulation. Dynamic analysis. 3 lectures, 1 laboratory.

**AERO 443. Aircraft Design I. 4 units**
Term Typically Offered: F
Prerequisite: Senior standing, IME 144, AERO 215, AERO 303, AERO 306, AERO 331, AERO 405, AERO 420, AERO 431. Concurrent: AERO 401.

Preliminary layout of a typical aircraft vehicle using design and calculation techniques developed in previous aerospace engineering courses. Design of a flight vehicle, including its structures and systems. Preparation of necessary drawings and a report. 2 lectures, 2 laboratories. Open to students enrolled in the multidisciplinary design minor.

**AERO 444. Aircraft Design II. 3 units**
Term Typically Offered: W
Prerequisite: AERO 443 and senior standing.

Preliminary layout of a typical aircraft vehicle using design and calculation techniques developed in previous aerospace engineering courses. Design of a flight vehicle, including its structures and systems. Preparation of necessary drawings and a report. 3 laboratories.

**AERO 445. Aircraft Design III. 3 units**
Term Typically Offered: SP
Prerequisite: AERO 444 and senior standing.

Preliminary layout of a typical aircraft vehicle using design and calculation techniques developed in previous aerospace engineering courses. Design of a flight vehicle, including its structures and systems. Preparation of necessary drawings and a report. 3 laboratories.

**AERO 446. Introduction to Space Systems. 4 units**
Term Typically Offered: SP
Prerequisite: ME 212; EE 201 and EE 251; and AERO 353.

Basic satellite types and their applications. Major subsystems of a satellite system including ground support and launch systems. Interactions between subsystems and their effects on the overall system design. Detailed analysis of key subsystems on a spacecraft with special emphasis on power and communications subsystems. 4 lectures.

**AERO 447. Spacecraft Design I. 4 units**
Term Typically Offered: F
Prerequisite: IME 144; AERO 215; AERO 303; AERO 331; AERO 351; AERO 420 or AERO 421; AERO 431; AERO 446; and senior standing. Concurrent: AERO 402. Recommended: AERO 353.

Preliminary layout of typical space vehicle using design and calculation techniques developed in previous aerospace engineering courses. Design of selected components and preparation of necessary drawings. 2 lectures, 2 laboratories. Open to students enrolled in the multidisciplinary design minor.

**AERO 448. Spacecraft Design II. 3 units**
Term Typically Offered: W
Prerequisite: AERO 447.

Preliminary layout of typical space vehicle using design and calculation techniques developed in previous aerospace engineering courses. Design of selected components and preparation of necessary drawings. 3 laboratories. Open to students enrolled in the multidisciplinary design minor.

**AERO 449. Spacecraft Design III. 3 units**
Term Typically Offered: SP
Prerequisite: AERO 448.

Preliminary layout of typical space vehicle using design and calculation techniques developed in previous aerospace engineering courses. Design of selected components and preparation of necessary drawings. 3 laboratories. Open to students enrolled in the multidisciplinary design minor.

**AERO 450. Introduction to Aerospace Systems Engineering. 4 units**
Term Typically Offered: W
Prerequisite: Senior standing or graduate standing.

Aerospace systems and subsystems. Systems integration. Development of system requirements. Analysis, modeling and simulation of complex systems. Project management. Cost analysis. Optimization and trade studies. 4 lectures.

**AERO 452. Spaceflight Dynamics II. 4 units**
Term Typically Offered: F
Prerequisite: AERO 351.

Relative orbital motion and rendezvous, linearization of the equations of motion. Clohessy-Wiltshire equations. Two-impulse rendezvous. Aspherocity of the earth, aerodynamic drag, solar radiation pressure, and n-body perturbations on an orbit. Encke, Cowell, and Variation of Parameters solution techniques. Speciality orbit due to perturbations such as low thrust trajectories, sun-synchronous, and molynia orbits. 4 lectures.

**AERO 460. Aerospace Engineering Professional Preparation. 1 unit**
Term Typically Offered: F
Prerequisite: Senior standing.

Topics on professional development for student success including resume building and career prospecting, current events in the aerospace industry, graduate studies, engineering ethics, intellectual property, non-disclosure agreements, teamwork, and innovation and entrepreneurship. 1 activity.

**AERO 463. Senior Project Laboratory I. 2 units**
Term Typically Offered: TBD
Prerequisite: Senior standing.

Selection and completion of a project by individuals or team which is typical of problems which graduates must solve in their fields of employment. Project involves, but is not limited to, physical modeling and testing of integrated design and may include students from other disciplines. Formulation of outline, literature review, and project schedule. 2 laboratories. Note: although AERO 463, 464 substitute for AERO 461, 462, students may not use repeat credit for the purpose of increasing GPA.

**AERO 464. Senior Project Laboratory II. 3 units**
Term Typically Offered: TBD
Prerequisite: Senior standing.

Selection and completion of a project by individuals or team which is typical of problems which graduates must solve in their fields of employment. Project involves, but is not limited to, physical modeling and testing of integrated design and may include students from other disciplines. Formulation of outline, literature review, and project schedule. 3 laboratories. Note: although AERO 463, 464 substitute for AERO 461, 462, students may not use repeat credit for the purpose of increasing GPA.

**AERO 465. Aerospace Systems Senior Laboratory. 1 unit**
Term Typically Offered: F, W, SP
Prerequisite: AERO 303, AERO 320, AERO 431 and senior standing.

Culminating laboratory based experience. Experiments require the integration of the many disciplines in Aerospace Engineering. The successful completion of each experiment requires synthesis and integration of the fundamental concepts of the engineering sciences. Experimentation in the areas of aeroelasticity, active vibration control, inertial navigation, thermal control, hardware-in-the-loop simulation, and momentum exchange. 1 laboratory.

**AERO 470. Selected Advanced Topics. 1-4 units**
Term Typically Offered: TBD
Prerequisite: Consent of instructor.

Directed group study of selected topics for advanced students. Open to undergraduate and graduate students. Class Schedule will list topic selected. Total credit limited to 8 units. 1 to 4 lectures.

**AERO 471. Selected Advanced Laboratory. 1-4 units**
Term Typically Offered: TBD
Prerequisite: Consent of instructor.

Directed group laboratory study of selected topics for advanced students. Open to undergraduate and graduate students. Class Schedule will list topic selected. Total credit limited to 8 units. 1 to 4 laboratories.

**AERO 493. Cooperative Education Experience. 2 units**
CR/NC
Term Typically Offered: F,W,SP,SU
Prerequisite: Sophomore standing and consent of instructor.

Part-time work experience in business, industry, government, and other areas of student career interest. Positions are paid and usually require relocation and registration in course for two consecutive quarters. Formal report and evaluation by work supervisor required. Credit/No Credit grading only. No major credit allowed; total credit limited to 6 units.

**AERO 494. Cooperative Education Experience. 6 units**
CR/NC
Term Typically Offered: F,W,SP,SU
Prerequisite: Sophomore standing and consent of instructor.

Full-time work experience in business, industry, government, and other areas of student career interest. Positions are paid and usually require relocation and registration in course for two consecutive quarters. Formal report and evaluation by work supervisor required. Credit/No Credit grading only. No major credit allowed; total credit limited to 18 units.

**AERO 495. Cooperative Education Experience. 12 units**
CR/NC
Term Typically Offered: F,W,SP,SU
Prerequisite: Sophomore standing and consent of instructor.

Full-time work experience in business, industry, government, and other areas of student career interest. Positions are paid and usually require relocation and registration in course for two consecutive quarters. A more fully developed formal report and evaluation by work supervisor required. Credit/No Credit grading only. No major credit allowed; total credit limited to 24 units.

**AERO 500. Individual Study. 1-4 units**
Term Typically Offered: F,W,SP,SU
Prerequisite: Consent of department head, graduate advisor and supervising faculty member.

Advanced study planned and completed under the direction of a member of the department faculty. Open only to graduate students who have demonstrated ability to do independent work. Enrollment by petition. Total credit limited to 12 units.

**AERO 510. Systems Engineering I. 4 units**
Term Typically Offered: W
Prerequisite: Graduate standing or consent of instructor.

Project management. Scheduling and budgeting. Queuing theory. Process control and life-cycle cost analysis. Contracts and negotiation. 4 lectures. Crosslisted as AERO/IME 510.

**AERO 511. Systems Engineering II. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 510 or IME 510, graduate standing or consent of instructor.

Risk management. Design strategies to meet system/mission requirements. Design for supportability, manufacturability, reliability, etc. Quality function development and quality control concepts. 4 lectures. Crosslisted as AERO/IME 511.

**AERO 512. Aerospace Vehicle Software Application. 4 units**
Term Typically Offered: W
Prerequisite: AERO 510, AERO 546 and graduate standing.

Computer system requirements for aerospace vehicles. Typical aerospace vehicle computer architectures. Software testing, verification and validation. Vehicle automatic systems. Risks and benefits of vehicle autonomous operations. Integration of software with vehicle subsystems. Software development cost/schedule estimation. 4 lectures.

**AERO 513. Applications of Unmanned Aircraft Systems. 4 units**
Term Typically Offered: F
Prerequisite: Graduate standing or consent of instructor.

Engineering development and analysis of unmanned aircraft systems (UAS) as airborne tools for societal benefit. Use of UAS for military, public service, and commercial purposes. Characterization of missions and applications. Development of system requirements and concepts of operation. Evaluation of relative merits and limitations of UAS. 4 lectures.

**AERO 515. Continuum Mechanics. 4 units**
Term Typically Offered: SP
Prerequisite: Graduate standing or consent of instructor.

Vectors and tensors stress analysis. Analysis of deformation. Velocity fields and compatibility conditions. Constitutive equations. Isotropy. Mechanical properties of real fluids and solids. Field equations and boundary conditions in fluid mechanics problems and applications in elasticity. Active remodeling of structures. 4 seminars.

**AERO 517. Multidisciplinary Design and Optimization. 4 units**
Term Typically Offered: W
Prerequisite: Familiarity with programming in Matlab and graduate standing or consent of instructor.

Numerical optimization applied to the design of complex systems. Multi-criteria decision making, unconstrained and constrained optimization methods, system sensitivity analysis, system decomposition techniques, and multidisciplinary design optimization. 4 lectures.

**AERO 519. Fundamentals of Vehicle Dynamics and Control. 4 units**
Term Typically Offered: SP
Prerequisite: Graduate standing or consent of instructor.

Fundamentals of particle and rigid body dynamics as they apply to aerospace vehicles. Kinematic variables and coordinate transformations. Attitude dynamics. Fundamentals of feedback control and its application to aerospace systems. Stability analysis. Numerical simulation. Not open to students with credit in AERO 451 and AERO 452. 4 lectures.

**AERO 522. Boundary-Layer Theory. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 302, graduate standing or consent of instructor.

Concept of boundary-layer. Boundary-layer equations, similarity transformation, integral and differential methods for steady, two-dimensional laminar and turbulent boundary layers. 4 lectures.

**AERO 523. Turbulence. 4 units**
Term Typically Offered: W
Prerequisite: AERO 302, graduate standing or consent of instructor.

Flow physics of turbulence. Turbulence scales and structures. Reynolds equations. Vorticity dynamics. Energy production, convection, and dissipation. Similarity rules and turbulence modeling for jets, wakes, mixing and boundary layers. Effect of turbulence on noise, combustion, heat transfer, and flow control. Not open to students with credit in AERO 529. 4 lectures.

**AERO 525. Computational Fluid Dynamics. 4 units**
Term Typically Offered: W
Prerequisite: AERO 303, graduate standing or consent of instructor.

Classification of partial differential equations. Numerical methods applicable to the solution of elliptic, parabolic, and hyperbolic partial differential equations. Consideration of accuracy and stability of numerical methods. Application to the fundamental equations of fluid dynamics, grid generation, turbulence modeling. 4 lectures.

**AERO 526. Spacecraft Thermal/Fluid Control. 4 units**
Term Typically Offered: W
Prerequisite: AERO 299 or AERO 301; AERO 302; AERO 303; or graduate standing.

Satellite thermal/fluid control hardware. Governing equations for flow and heat transfer. Surface tension and liquid/vapor interface. Heat transfer by free convection, forced convection and radiation in low-gravity environment. Heat pipes. Capillary-pumped loops. Cryogenic systems. Fluid management in space. 4 lectures.

**AERO 528. Laminar Flow Aircraft Development. 4 units**
Term Typically Offered: F
Prerequisite: AERO 306 and AERO 307; or graduate standing.

Fundamentals of laminar boundary layers in the design of aircraft. History and development of laminar flow aircraft. Modern approaches to designing for laminar flow. Analysis and testing of laminar flow designs and determination of practical limits for laminar flow application. 4 lectures.

**AERO 529. Turbulence and Flow Control. 4 units**
Term Typically Offered: W
Prerequisite: AERO 307 and AERO 406 for students in a BMS program; or graduate standing. Recommended: AERO 522 and AERO 525.

Physics and analysis of turbulence. Vorticity, mixing, jets, wakes, boundary layer transition, scales and structures. Effects of turbulence on noise and aerodynamics. Experiments and simulations in boundary layer transition, separation phenomena, passive and active flow control. Not open to students with credit in AERO 523. 2 lectures, 2 laboratories.

**AERO 531. Airworthiness and Aeroelasticity. 4 units**
Term Typically Offered: F
Prerequisite: AERO 431 and Graduate standing.

Fundamentals of airworthiness and aeroelasticity of flight vehicles. Flight envelope and aircraft loads. Loads and normal acceleration for various maneuvers. Gust loads. Load distribution and diversions. Control effectiveness and reversal. Fatigue and structural vibration. Introduction to flutter. 3 lectures, 1 laboratory.

**AERO 532. Advanced Aerospace Composite Design. 4 units**
Term Typically Offered: W
Prerequisite: Graduate standing or consent of instructor.

Behavior of composite materials. Bending, buckling, and vibration of laminated plates. Fatigue and fracture mechanics analysis of composite structures. Optimum design of composite pressure vessels. 2 seminars, 2 laboratories.

**AERO 533. Finite Elements for Aerospace Structural Analysis. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 431.

Overview of theoretical and applied methods of finite element analysis for aerospace structures including composite and light weight structures. Topics include basic equations of elasticity, solutions of linear systems of equations transformation, global stiffness matrix, Bernoulli-Euler element, plane stress triangles, finite element formulation, isoparametric elements, alternative formulation, eigenvalue problems and dynamic analysis. 3 lectures, 1 laboratory.

**AERO 534. Aerospace Structural Dynamics Analysis. 4 units**
Term Typically Offered: F
Prerequisite: Graduate standing.

Structural dynamics and aeroelasticity of flight vehicles. Vibration and forced response of continuous structures. Introduction to unsteady aerodynamic analysis methods. Normal-Mode Method and Modal Analysis. Framed structures and rigid body structures. Airworthiness and aeroelasticity. Random Vibrations. 3 lectures, 1 laboratory.

**AERO 535. Advanced Aerospace Structural Analysis. 4 units**
Term Typically Offered: SP
Prerequisite: Graduate standing or consent of instructor.

Types of failure. Theories of failure. Stability of structures. Advanced flight vehicle and fracture mechanics analysis and design. Fundamentals and applications of modern fatigue analysis in the aerospace industry. 3 lectures, 1 laboratory.

**AERO 540. Elements of Rocket Propulsion. 4 units**
Term Typically Offered: W
Prerequisite: AERO 303, AERO 401, graduate standing or consent of instructor.

Thrust and impulse equations, propellant composition and mixture ratios, nozzle expansion ratios, solid and liquid propellant combustion, internal ballistics, thermo-chemical computations, chemical kinetics, and combustion instability, nozzle design and exhaust plumes. 4 seminars.

**AERO 541. Air Breathing Propulsion. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 401, graduate standing or consent of instructor.

Aerothermodynamics of propulsion systems, power plant selection and design, on-off design performance, component characterization, component design, component matching, optimization, and introduction to power plant and airframe integration systems for aircraft. 4 seminars.

**AERO 546. Spacecraft Systems Design. 4 units**
Term Typically Offered: F
Prerequisite: Graduate standing.

Spacecraft missions, vehicle types, and applications. Introduction and preliminary sizing of major subsystems of a space system. Introduction to and design drivers for space environments, propulsion system, power system, structural design, spacecraft dynamics and attitude control, orbit mechanics, thermal control, communications, and ground segments. 4 lectures.

**AERO 551. Global Positioning Satellite Navigation Systems. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 420, graduate standing or consent of instructor.

Principles of Global Positioning Satellite navigation systems. Kalman filter design and application to integrated navigation and guidance systems. Statistical evaluation and test methods in aerospace. Interactive computer simulations. 3 lectures, 1 laboratory.

**AERO 553. Advanced Control Theory. 4 units**
Term Typically Offered: W
Prerequisite: AERO 320 and graduate standing.

Advanced control theory techniques. Analytical and computational methods applied to dynamic systems. State space system representation, solutions to dynamic systems, non-linear and linear stability analysis, full-state and output feedback, controllability and observability and advanced control topics (LQR/LQG, Kalman Filters, Adaptive Control, etc.). 4 lectures.

**AERO 557. Advanced Orbital Mechanics. 4 units**
Term Typically Offered: W
Prerequisite: AERO 351 and graduate standing.

Initial orbit determination using angles only methods. Various Solutions to Lambert's Problem. Orbit and transfer optimization, libration points, halo orbits, and secondary orbit perturbations. 4 lectures.

**AERO 560. Advanced Spacecraft Dynamics and Control. 4 units**
Term Typically Offered: W
Prerequisite: AERO 421 and graduate standing.

Attitude determination and control of rigid spacecraft via reaction wheels, control moment gyros and thrusters. Modeling, analysis and control of flexible spacecraft. Non-linear stability theory as applied to spacecraft. 4 lectures.

**AERO 561. Vehicle Integration and Testing. 2 units**
Term Typically Offered: F
Prerequisite: AERO 446 and graduate standing or consent of instructor.
Recommended: AERO 450.

Space vehicle integration requirements and procedures. Clean room requirements and operations. Quality control and inspection. Qualification and acceptance testing requirements. Test equipment. Vibration and shock testing. Space environment and thermal-vac testing. Development of test procedures. 1 lecture, 1 laboratory.

**AERO 562. Space Operations. 2 units**
Term Typically Offered: F
Prerequisite: AERO 446 and graduate standing or consent of instructor.
Recommended: AERO 450.

Launch operations and vehicle integration with launch vehicle. In-orbit operations and maneuvers. Spacecraft tracking. Telemetry and command. Ground systems. Failure detection and identification. Emergency operations. 1 lecture, 1 laboratory.

**AERO 565. Advanced Topics in Aircraft Design. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 522 and graduate standing; or consent of instructor.

Application of advanced analytic engineering methods to aircraft design problems. Analysis and synthesis of advanced topics related to design of aircraft. 4 lectures.

**AERO 566. Advanced Topics in Spacecraft Design. 4 units**
Term Typically Offered: F
Prerequisite: AERO 510, AERO 546, and graduate standing.

Application of advanced engineering tools to the design of space vehicles. System architecture and mission design. Concept of operations. Requirements development and flow down. System and subsystems trade studies and preliminary design. 4 lectures.

**AERO 567. Launch Vehicle and Missile Design. 4 units**
Term Typically Offered: SP
Prerequisite: AERO 401, AERO 450, AERO 446, graduate standing or consent of instructor.

Basic launch vehicle/missile types. Launch vehicle subsystems and their interactions. Vehicle requirements development and flow down. Payload accommodations. System and subsystems trade studies and preliminary design. 4 lectures.

**AERO 568. Aerodynamic Research and Development I. 2 units**
Term Typically Offered: W
Prerequisite: AERO 307, AERO 406, and graduate standing.
Recommended: AERO 525.

Immersive team-based approach to an aerodynamic research and development cycle. Theoretical work, preliminary design based upon computational fluid dynamics, and design of experiments. Advanced techniques in using a multi-variable wind tunnel. Validation of numerical work using correlation techniques. 2 laboratories.

**AERO 569. Aerodynamic Research and Development II. 2 units**
Term Typically Offered: SP
Prerequisite: AERO 568. Recommended: AERO 529.

Continuation of AERO 568. Single and multi-variable design optimization cycles based upon computational fluid dynamics. Numerical and experimental flow visualization, high-fidelity verification wind tunnel testing of optimized designs, and archival-quality technical reporting of aerodynamic data. 2 laboratories.

**AERO 570. Selected Advanced Topics. 4 units**
Term Typically Offered: TBD
Prerequisite: Graduate standing or consent of instructor.

Directed group study of selected topics for graduate students. Open to undergraduate and graduate students. The Schedule of Classes will list topic selected. Total credit limited to 8 units. 4 lectures.

**AERO 571. Selected Advanced Topics Laboratory. 1-4 units**
Term Typically Offered: TBD
Prerequisite: Graduate standing or consent of instructor.

Directed group laboratory study of selected topics for advanced students. Open to undergraduate and graduate students. Class Schedule will list topic selected. Total credit limited to 8 units. 1-4 laboratories.

**AERO 593. Cooperative Education Experience. 2 units**
CR/NC
Term Typically Offered: TBD
Prerequisite: Graduate standing and consent of instructor.

Advanced study analysis and part-time work experience in student's career field; current innovations, practices, and problems in administration, supervision, and organization of business, industry, and government. Must have demonstrated ability to do independent work and research in career field. Credit/No Credit grading only.

**AERO 594. Cooperative Education Experience. 6 units**
CR/NC
Term Typically Offered: TBD
Prerequisite: Graduate standing and consent of instructor.

Advanced study analysis and full-time work experience in student's career field; current innovations, practices, and problems in administration, supervision, and organization of business, industry, and government. Must have demonstrated ability to do independent work and research in career field. Credit/No Credit grading only.

**AERO 595. Cooperative Education Experience. 12 units**
CR/NC
Term Typically Offered: F,W,SP,SU
Prerequisite: Graduate standing and consent of instructor.

Advanced study analysis and full-time work experience in student's career field; current innovations, practices, and problems in administration, supervision, and organization of business, industry, and government. Must have demonstrated ability to do independent work and research in career field. A fully-developed formal report and evaluation by work supervisor required. Credit/No Credit grading only.

**AERO 596. Culminating Experience in Space Systems Engineering. 5 units**
Term Typically Offered: F,W,SP,SU
Prerequisite: Graduate standing.

Performance of comprehensive systems analysis of a space system. Communication of the results and findings of such evaluations in written report and by oral presentation. Conducted under supervision of faculty.

**AERO 599. Thesis (Design Project). 1-9 units**
Term Typically Offered: F,W,SP,SU
Prerequisite: Graduate standing.

Each individual or group will be assigned a project for solution under faculty supervision as a requirement for the master's degree, culminating in a written report/thesis.