

**TO:** The Faculty of the College of Engineering  
**FROM:** School of Aeronautics and Astronautics of the College of Engineering  
**RE:** New Graduate Course, AAE 53400 Spacecraft Electric Propulsion

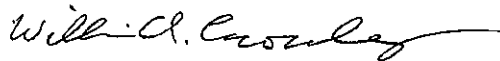
The faculty of the School of Aeronautics and Astronautics have approved the following new course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

**Course no.** AAE 53400 Spacecraft Electric Propulsion  
Fall, Lecture, Cr. 3  
Pre-req – AAE 33400 or equivalent, PHYS 24100 or equivalent, or permission of instructor

**Description:** Spacecraft electric propulsion systems are intended to provide thrust for propelling spacecrafts in interplanetary missions, orbital maneuvers, and attitude control. The course will start with reviewing material on the mechanics and thermodynamics of propulsion, and identifying the niche occupied by the electric propulsion systems. The course will cover elements of plasma physics and electromagnetic theory essential for studying the electric propulsion systems. The core of the course will focus on studying various electric propulsion concepts which utilize electric power produced on-board to generate thrust. Mechanisms of the utilization of the electric power to accelerate gas or plasma and produce thrust will be considered, including electrothermal, electrostatic, electromagnetic, and gasdynamic acceleration mechanisms.

**Reason:** Spacecraft electric propulsion technology is increasingly developed by NASA and the aerospace industry as the central technology for propelling spacecrafts in deep space missions and for maneuvering the miniature satellites in Earth orbits. As a result, electric propulsion-related research and careers are increasingly being pursued by our faculty and students. This course was created to teach fundamental underlying principles and practical applications of electric propulsion to prepare students for research and careers in the field of electric propulsion.

Enrollment history: F15 (16), F16 (25), F17 (24), F18 (18), F19 (26)



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William A. Crossley, J. William Uhrig and Anastasia Vournas Head of the School of Aeronautics and Astronautics, and Professor of Aeronautics and Astronautics  
School of Aeronautics and Astronautics

# AAE 534 Spacecraft Electric Propulsion

Fall 2019

Tue./Thu. 4:30-5:45 PM, ARMS 1103

**Instructor:** Alex Shashurin  
[ashashur@purdue.edu](mailto:ashashur@purdue.edu)  
Office: ARMS 3331  
Office hours: Thu. – 10:00am-12noon or by e-mail appointment

**Texts:** R.G. Jahn, *Physics of Electric Propulsion* New York: McGraw-Hill, 1968.

Y. P. Raizer, *Gas Discharge Physics* Springer, Berlin, 1991.

**Prerequisites:** AAE334 or equivalent; PHYS 241 or equivalent; permission of instruction

Passing an undergraduate level electricity and magnetism course is a requirement, although fundamentals of the electromagnetic theory will be reviewed during the course.

## Course description:

Spacecraft electric propulsion systems are intended to provide thrust for propelling spacecrafts in interplanetary missions, orbital maneuvers and attitude control. The course will start with reviewing material on mechanics and thermodynamics of propulsion, and identifying the niche occupied by the electric propulsion systems. The course will cover elements of plasma physics and electromagnetic theory essential for studying the electric propulsion systems. The core of the course will focus on studying various electric propulsion concepts which utilize electric power produced on-board to generate thrust. Mechanisms of the utilization of the electric power to accelerate gas or plasma and produce thrust will be considered, including electrothermal, electrostatic, electromagnetic, and gasdynamic acceleration mechanisms.

## By the end of the semester, successful students will be able:

1. To demonstrate fundamental understanding of concepts and acceleration mechanisms utilized in electric propulsion systems (electrothermal, electrostatic, electromagnetic).
2. To perform analysis of electrothermal accelerator at given frozen flow fraction
3. To perform analysis of ion acceleration in space-charge limited electrostatic accelerators
4. To perform basic analysis of plasma acceleration in crossed-field electromagnetic thruster
5. To identify optimal electric propulsion system based on specific mission requirements

**Course Website:**

All course materials including course announcements, blank and filled lecture notes, homework assignments, etc. will be posted on the course Blackboard site. Hard copies of the notes will not be provided unless specifically requested in advance.

**Lectures:**

The class will meet Tuesday/Thursday, 4:30-5:45 PM in ARMS 1103.

**Homework:**

Homework will be assigned approximately once every two weeks and, unless otherwise noted, will be due one week later at the beginning of class (see the class calendar on Blackboard). Any homework assignments turned in after 3:30pm on the due date will not be accepted. If you know you will be missing class, make arrangements to turn in the homework early.

**Attendance**

Students are expected to attend for every meetings of the class. Students bear the responsibility of informing the instructor on the absences in a timely fashion, when possible. There will be unannounced quizzes and in-class exercises throughout the semester to check the attendance. These activities account for 5% of your grade and will be conducted using iClickers. If you must miss a class, arrive late, or leave early, please send me an email with some sort of documentation, if possible. It generally makes a better impression to let me know before you miss a class.

<b>Course grading:</b>	Homework	= 30%
	Mid-term exam	= 30%
	Final exam	= 35%
	Quizzes	= 5%
	TOTAL	= 100%

**Grading schema:** A+ ( $\geq 97$ ), A ( $\geq 93$ ), A- ( $\geq 90$ ), B+ ( $\geq 87$ ), B ( $\geq 83$ ), B- ( $\geq 80$ ), C+ ( $\geq 77$ ), C ( $\geq 73$ ), C- ( $\geq 65$ ), D ( $\geq 60$ ), F ( $< 60$ )

**Collaboration Policy:**

Students are permitted to discuss homework assignments with each other and may collaborate by discussing the theory and possible solution methods. However, each student is expected to turn in work that is entirely their own; if a student is found to have simply copied another student's work, there will be severe penalties.

## Course Schedule and Reading Assignments

#	Topics covered	Reading in addition to the lecture notes
1	Review of space propulsion and mission requirements. Electric propulsion.	1 week; Jahn Ch. 1
2	Fundamentals of electrodynamics. Maxwell equations in vacuum and matter.	1.5 week, Jahn Ch. 2
3	Elementary processes in plasmas. Thermal and non-thermal plasmas. Saha equation. Types of discharges: glow, arc, corona. Isotropic and magnetoactive plasmas. Particle motion in magnetic field. Ohm's law	2 weeks; Raizer Ch. 2-4, 8, 10, 12 & Jahn Ch. 3-5
4	Electrothermal acceleration: 1-D model and frozen flow losses. Resistojet thrusters. Arcjet thrusters.	2 weeks; Jahn Ch. 6
5	Electrostatic acceleration: Ion thruster. Electron neutralization. Electrospray thrusters.	2 weeks; Jahn Ch. 7
6	Electromagnetic acceleration: 1D cross-field accelerator. Hall thruster. Magnetoplasmadynamic (MPD) thruster. Pulsed Plasma Thruster (PPT).	4 weeks; Jahn Ch. 8,9
7	Gasdynamic acceleration: Vacuum arc fundamentals. Vacuum arc thruster.	1 week; Raizer Ch. 10
8	Electric power generation and storage for propulsion systems. Review of the advanced electric propulsion concepts.	1 week; Jahn Ch. 9 & Appendix

### Additional Reading:

1. P. Hill and C. Peterson *Mechanics and Thermodynamics of Propulsion /2<sup>nd</sup> ed.*, Addison-Wesley Publishing Company, 1992.
2. G. P. Sutton and O. Biblarz, *Rocket Propulsion Elements/ 7<sup>th</sup> ed.*, John Wiley & Sons, 2001.
3. R. W. Humble, G. N. Henry and W. J. Larson, *Space Propulsion Analysis and Design*, McGraw-Hill Inc, 1995.
4. R.G. Jahn, E.Y. Choueiri "Electric Propulsion," *Encyclopedia of Physical Science and Technology*, third edition, vol. 5, New York: Academic Press, 2002.
5. F. F. Chen, *Introduction to Plasma Physics and Controlled Fusion 2nd ed.*, Plenum Press, 1985.
6. J. D. Jackson *Classical Electrodynamics/ 3<sup>rd</sup> ed.*, John Wiley & Sons, 1999.
7. A special issue of the *Journal of Propulsion and Power* Vol. 14, No. 5, 1998.

**This syllabus is subject to change**



## University Policies

### Purdue Honors Pledge

*"As a boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together - we are Purdue."*

<https://www.purdue.edu/provost/teachinglearning/honor-pledge.html>

### Policy for Academic Dishonesty:

*Purdue prohibits "dishonesty in connection with any University activity. Cheating, plagiarism, or knowingly furnishing false information to the University are examples of dishonesty." [Part 5, Section III-B-2-a, University Regulations] Furthermore, the University Senate has stipulated that "the commitment of acts of cheating, lying, and deceit in any of their diverse forms (such as the use of substitutes for taking examinations, the use of illegal cribs, plagiarism, and copying during examinations) is dishonest and must not be tolerated. Moreover, knowingly to aid and abet, directly or indirectly, other parties in committing dishonest acts is in itself dishonest." [University Senate Document 72-18, December 15, 1972]*

### Use of Copyrighted Materials

*Among the materials that may be protected by copyright law are the lectures, notes, and other material presented in class or as part of the course. Always assume the materials presented by an instructor are protected by copyright unless the instructor has stated otherwise. Students enrolled in, and authorized visitors to, Purdue University courses are permitted to take notes, which they may use for individual/group study or for other non-commercial purposes reasonably arising from enrollment in the course or the University generally.*

*Notes taken in class are, however, generally considered to be "derivative works" of the instructor's presentations and materials, and they are thus subject to the instructor's copyright in such presentations and materials. No individual is permitted to sell or otherwise barter notes, either to other students or to any commercial concern, for a course without the express written permission of the course instructor. To obtain permission to sell or barter notes, the individual wishing to sell or barter the notes must be registered in the course or must be an approved visitor to the class. Course instructors may choose to grant or not grant such permission at their own discretion, and may require a review of the notes prior to their being sold or bartered. If they do grant such permission, they may revoke it at any time, if they so choose.*

### Policy for Attendance

*Students are expected to be present for every meeting of the classes in which they are enrolled. Only the instructor can excuse a student from a course requirement or responsibility. When conflicts or absences can be anticipated, such as for many University sponsored activities and religious observations, the student should inform the instructor of the situation as far in advance as possible...For unanticipated or emergency absences when advance notification to an instructor is not possible, the student should contact the instructor as soon as possible by email, or by contacting the main office that offers the course. When the student is unable to make direct contact with the instructor and is unable to leave word with the instructor's department because of circumstances beyond the student's control, and in*

*cases of bereavement, the student or the student's representative should contact the Office of the Dean of Students,*

### **Grief Absence Policy for Students**

*Purdue University recognizes that a time of bereavement is very difficult for a student. The University therefore provides the following rights to students facing the loss of a family member through the Grief Absence Policy for Students (GAPS). GAPS Policy: Students will be excused for funeral leave and given the opportunity to earn equivalent credit and to demonstrate evidence of meeting the learning outcomes for misses assignments or assessments in the event of the death of a member of the student's family.*

### **Violent Behavior Policy**

*Purdue University is committed to providing a safe and secure campus environment for members of the university community. Purdue strives to create an educational environment for students and a work environment for employees that promote educational and career goals. Violent Behavior impedes such goals. Therefore, Violent Behavior is prohibited in or on any University Facility or while participating in any university activity.*

### **Students with Disabilities**

*The Disability Resource Center (DRC) is a resource for students and instructors. Students may present a "Letter of Accommodation" to you at any point in the semester. Should you have questions about accommodations, please contact the DRC at: 494-1247 or [drc@purdue.edu](mailto:drc@purdue.edu). In many cases the DRC can partner with you to develop inclusive teaching strategies that benefit all students in your class.*

*Accessibility and Accommodations Syllabus Statement: The DRC recommends the following statement be included in your syllabus. "Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, you are welcome to let me know so that we can discuss options. You are also encouraged to contact the Disability Resource Center at: [drc@purdue.edu](mailto:drc@purdue.edu) or by phone: 765-494-1247." <http://www.purdue.edu/drc/faculty/syllabus.html>*

### **Emergencies**

*In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances beyond the instructor's control. Relevant changes to this course will be posted onto the course website or can be obtained by contacting the instructors or TAs via email or phone. You are expected to read your @purdue.edu email on a frequent basis.*

### **Nondiscrimination**

*Purdue University is committed to maintaining a community which recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many*

*members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. Purdue's nondiscrimination policy can be found at: [http://www.purdue.edu/purdue/ea\\_eou\\_statement.html](http://www.purdue.edu/purdue/ea_eou_statement.html).*

*Purdue University prohibits discrimination against any member of the University community on the basis of race, religion, color, sex, age, national origin or ancestry, genetic information, marital status, parental status, sexual orientation, gender identity and expression, disability, or status as a veteran. The University will conduct its programs, services and activities consistent with applicable federal, state and local laws, regulations and orders and in conformance with the procedures and limitations as set forth in [Executive Memorandum No. D-1](#), which provides specific contractual rights and remedies. Any student who believes they have been discriminated against may visit [www.purdue.edu/report-hate](http://www.purdue.edu/report-hate) to submit a complaint to the Office of Institutional Equity. Information may be reported anonymously.*

### **CAPS Information**

*Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at (765)494-6995 and <http://www.purdue.edu/caps/> during and after hours, on weekends and holidays, or through its counselors physically located in the Purdue University Student Health Center (PUSH) during business hours.*