ASTE 572

ADVANCED SPACECRAFT PROPULSION

Spring 2017

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University of Southern California
Los Angeles, California

ASTE 572 Advanced Spacecraft Propulsion
Spring 2017 Schedule

Friday 5:10 – 7:50 P.M. DEN Remote Broadcast and OHE TBD classroom 3 Units

Date	Subject	Book	Notes	HW due
1/13	Organization of the class. Definitions. Intro. to advanced propulsion.	HP2 Chap. 10, Jahn chap. 1	1	
1/20	Mission ΔV and orbital mechanics. Review of rockets. System sizing.	HP2 Chap. 10, Jahn chap. 1	2	*
1/27	Review of thermodynamics and compressible gas dynamics.	HP2 Chap. 3	3,4,5	1
2/3	Review of thermal rockets. Heat transfer.	HP2 Chap. 11	6, 7	2
2/10	Heat transfer, Power systems. Nuclear reactions. Nuclear thermal rockets.	HP1 chap. 15	8	3
2/17	Nuclear reactions. Nuclear thermal rockets. Solar & Nuclear electric propulsion systems.	JPL notes, NASA NTR notes	8	4
2/24	Electromagnetic theory: electric charges and fields, currents, and magnetic fields, and applications to ionized gases.	HP1 chap. 5 Jahn chap. 2	TBD	5
3/3	Ionization. Introduction to rarified gases. Charged particle motion. Introduction to plasma physics. Electrode phenomena.	Jahn chaps. 4 and 5, V&K, HP1 chap. 5	TBD	6
3/10	Introduction to arc discharges.			7
3/17	Spring Break			
3/24	MIDTERM EXAM, in class, 1.5 hours	Jahn chap. 6	TBD	paper approvals due
3/31	Electrothermal acceleration: 1-D model and frozen flow losses. Resistojet thrusters. Arcjet thrusters.	Jahn chap. 6, JPL notes	9	8
4/7	Electrostatic acceleration: 1-D space charge model, ion thrusters, ion production, beam optics, beam neutralization. Other thrusters.	Jahn chap. 7 HP1 chap. 16 JPL notes	9	9
4/14	Electromagnetic acceleration: MHD channel flow; Magnetoplasmadynamic (MPD) thrusters, description and thrust derivation, operating limits, and performance calculation.	Jahn chap. 8 HP1 chap. 16 JPL notes	9	10
4/21	Hall Current Thrusters (HCT): physics and technology. Unsteady electromagnetic acceleration: pulsed plasma thruster (PPT). (HCT special guest lecture by Justin Pucci)	Jahn chap. 9 JPL notes	9	11 and paper reviews due
4/28	Overview of advanced concepts. Sails, beamed energy, fusion propulsion, antimatter propulsion. Interstellar missions Special topics: micro-propulsion, tethers, piloted Mars mission, other class-selected topics.	JPL APC Notes		12 (reistojet design project)

May 5 Final Exam 4:30 – 6:30 in class

HP1 = Hill and Peterson 1st ed. (copies on class DEN web site)
HP2 = Hill and Peterson 2nd ed.
V&K = *Intro to Physical Gas Dynamics*, Vincenti and Kruger

* Class survey, email addresses, and obtain additional needed materials for unfamiliar topics.

The first half of the course focusses on fundamentals and some systems level concepts (nuclear and power). We quickly review rocket basics, orbital mechanics, thermodynamics and compressible gas dynamics topics that are covered in ASTE 470. Additional introductory material on nuclear physics, rarefied gases, and plasma physics is covered. The second half of the class focuses on electric thruster characteristics (electrostatic, electrothermal and electromagnetic acceleration).

Instructor:

Dr. Keith Goodfellow
email: preferred keith.goodfellow@usc.edu

Communication by email is welcome and encouraged. It is reliable as well as providing a saved transcript.

This class is being taught off campus through the DEN system using WebEx. Tuning in to the live lectures is strongly encouraged, since it enables students to ask questions and bring up topics for discussion. A classroom/studio will be available on campus so students attend the lectures together.

TA: To be announced

Prerequisite: ASTE 470 (formerly AME 473) Spacecraft Propulsion or equivalent. You should be familiar with rocket performance, simple orbital mechanics (such as Hohmann transfer), compressible gas dynamics and nozzles, and basic heat transfer. We will quickly review these areas.

Required Text:

Physics of Electric Propulsion, Robert Jahn, McGraw-Hill, 1968.
Reprint in paperback from Dover Publications (2006), ISBN 0- 486-45040-6, about $15 - $25 from several online book stores. (about $22 at Amazon.com)

Recommended Text:

Mechanics and Thermodynamics of Propulsion 2nd ed., P. Hill and C. Peterson, Addison-Wesley Publishing Company, 1992 ISBN 0-201-14659-2. (same text as ASTE 470) An excellent book covering the fundamentals of propulsion. It covers both rockets and air-breathing. Not as much details on rockets as the following 3 textbooks, but it is a better textbook for fundamentals. This was the required text for this class for ASTE 470 for 18+ years.

Additional References:

1. *Rocket Propulsion Elements 8th ed.*, G. P. Sutton and O. Biblarz, John Wiley & Sons, 2001. An excellent book for the fundamentals of variety of chemical rocket elements (propellants, feed system layouts, thrust vectoring, etc.). The 7th and 8th editions are much better than the previous editions.

2. Space Propulsion Analysis and Design, R. W. Humble, G. N. Henry and W. J. Larson, McGraw-Hill Inc, 1995.
This book focuses more on the design methodologies of spacecraft propulsion systems and missions rather than on the fundamentals. It covers chemical, electric and nuclear systems.

3. *Introduction to Physical Gas Dynamics*, W. G. Vincenti and C. H. Kruger, Krieger Publishing, 1986.
Good book for molecular gas dynamics, statistical thermodynamics and real gas properties. Was out of print but has been recently reprinted.

4. *Partially Ionized Plasmas*, M. Mitchner and C. H. Kruger, John Wiley and Sons, 1974.
Excellent book for plasmas, lots of details. Out of print but copies are available on web.

5. *Introduction to Plasma Physics and Controlled Fusion 2nd ed*., F. F. Chen, Plenum Press, 1985.
Excellent introductory book for plasmas.

6. *Fundamentals of Plasma Physics 3rd ed*., J.A. Bittencourt, Springer Publishing , 2004. Excellent introductory book for plasmas.

7. *Any Sufficiently Advanced Technology is Indistinguishable from Magic*, R. L. Forward, Baen Publishing 1995.
An excellent combination of science fact and science fiction on advanced propulsion. Paperback (about $6).

History Books of Interest:
1. M. Gruntman, *Blazing the Trail, The early History of Spacecraft and Rocketry*, AIAA, 2004, ISBN 1-56347-705-X.
An excellent book on the history of the field. Unique in its coverage of both the US and Soviet programs

2. J. Dewar, *To the End of the Solar System, The Story of the Nuclear Rocket*, The University Press of Kentucky, 2004, ISBN 0-8131-2267-8.
An excellent book covering the history of the nuclear thermal rocket program. Both the technology and the politics.

Book to Avoid:
Martin Tajmar, *Advanced Space Propulsion Systems*, Springer /Wien, New York. 2003. A 130 page paperback book that has less material in it than the JPL notes that will handed out in class. It sells for about $60 (it did sell for $80) but should sell for $10.

Hand-Outs. Will consist of homework assignments and notes that are essential and mandatory to the course. Course notes, homework assignments and homework solutions will be posted on the DEN ASTE 572 Web site. The DEN home page is: https://courses.uscden.net/d2l/login Our class site will contain the notes for each lecture, the homework assignments, the homework and exam solutions, and the annotated lecture notes from each class. The notes we will be using for each lecture will be posted prior to class. Please bring a copy to class. We will be annotating those notes plus including additional material in each lecture. At the end of each lecture I will post the annotated lecture notes. You can download these notes if you miss anything during the lecture.

They are usually posted the day after our class. The class web site is available to both on-campus and off-campus students. Everyone should have an account.

Additional course material will also be provided in PDF format on the class Distance Education Network (DEN) web site. These will include review material from ASTE 470, copies of material from out of print texts, and material from the advanced propulsion systems notebooks prepared by the JPL Advanced Propulsion Technology group over the last two decades. The JPL notes were available online for several years but were removed around 2003. We will cover portions of these materials, but the entire contents are posted so you can use them for reference.

Class Procedure: Teaching will be done directly from the notes and additional in class notes. It is advisable to review the appropriate material before the lecture and bring the appropriate material to class.

Discussion Forum on DEN site. The DEN ASTE 572 web site has discussion forums in the areas of class lectures, homework and areas of interest. This is a good place to ask clarification questions on the lectures or homework that would be of interest to everyone. Please do not post solutions and keep it professional. Violators will be removed from the forum. Areas of Interest could be anything you think the rest of the class would be interested in or questions you may have.

Homework: As scheduled. One homework score (30 points) will be dropped for a total of 11 recorded scores. Problem set 12 (resistojet design) is worth 90 points. The homework is worth 30% of the total grade and the exam questions are often based on the homework. Therefore, if you fail to do the homework, it is unlikely you will receive a good grade for the course. Extra credit problems may be given at times. No other “special” problems, projects, or extra work will be given.

Homework is due at class time on the specified date. Homework is considered late if received after 9:00 AM on morning after class (Monday morning). Homework can be left in our class mailbox (outside Prof. Erwin’s office) before class or get it directly to the TA. It is your responsibility to get it to the TA. Do not leave late homework in one of the mailboxes since we won’t know when it was turned in. Late homework can be submitted up to one week after the due date and will be graded and reduced by a 50% factor. No homework will be accepted after the homework has been returned or the solutions have been posted. If you have grading questions please call of see the TA first and then contact the instructor if there is still a problem. The Resistojet project is due on the assigned date (last class) and will not be accepted after that date.

Students are encouraged to work together and share ideas but each student must turn in their own work. Plagiarism, either from another’s work or from previous homework solutions will not be allowed and will result in loss of credit for the assignment. Repeat offenders may be dropped from the course and expelled from the department.

If you are a distant student and would like to know if there are others in your region, let me know. I will provide a local contact list for anyone wanting it. Your contact information will not be shared to others without your written approval (email).

Paper Review: Each student will write a one-page review of a student selected technical publication. Papers may be on any topic related to the course. (electric propulsion, nuclear propulsion, advanced concepts, etc.) The paper must be a technical conference or journal

publications and be at least 5 pages long. A Powerpoint presentation will not be accepted as a technical paper. This will count as one homework assignment. Students are encouraged to pick a topic of personal or professional interest. Each student will submit a paper (or selection of papers) for approval on or before March 25 (midterm exam) for 5 points. Final paper reviews are due on April 22 (25 points).
Each review should address the following in one page:

What is the paper about?
Why is this topic important?
Is it good work or not? Why?
Your overall impression of the work and its relevance.

Good sources for papers are: American Institute of Aeronautics and Astronautics (AIAA) Journal of Propulsion and Power and the AIAA Journal of Spacecraft and Rockets. However, the best sources for papers are the annual AIAA Joint Propulsion Conference (held June or July each year) and the International Electric Propulsion Conference (IEPC) (held alternating years.) Prior to 1993 AIAA co-hosted the IEPC conferences and these papers have AIAA assigned paper numbers, and can be obtained through AIAA. After 1993 the papers have an IEPC number and can be obtained through the Electric Rocket Propulsion Society (ERPS). http://erps.spacegrant.org/index.php?page=iepc-download-88-07
Typically, there are 200+ papers presented at these conferences each year on the topics of electric and advanced propulsion while only a few papers will be in the journals. Other possible journals of interest are the IEEE Transactions in Plasma Science, and the Physics of Fluids. The paper must be a full paper (> 3 pages long) not a "technical note."
Paper format: 1 page, 10 or 12 point font, single spaced, 1 inch margins. Include title, authors, publisher (journal or conference) and date.

Resistojet Thruster Design Project: The last homework assignment (HW 12) will consist of a resistojet thruster design project. It is worth three times as many points a normal assignment (90 points). Each student will select an application (orbit transfer, station keeping, etc.) and design a thruster for that application. The design will include the heating mechanism, nozzle and thermal analysis. More details and the assignment will be given later (Usually after the heat transfer lectures).

Exams:	Midterm exam:	Friday, March 24, 5:10 – 7:50 PM. Class time, Location TBD
	Final exam:	Friday, May 5, 4:30 – 6:30 P.M. Location TBD

Exams are closed book and closed notes. One 8 ½ inch by 11 inch sheet of notes (both sides) is allowed for the Midterm exam and 2 sheets are allowed for the Final exam.

Make-up Exams: Make-exams will be given only for special circumstances. Make-up exams will be more difficult than the regular exams.

Grading:	Homework	= 30%
	Midterm	= 30%
	Final	= 40%

Attendance: Up to you. We will not be keeping track.

Religious Holy Days: Please arrange in advance to make up work missed on those days.

Questions: Discussion is always welcome and encouraged on all aspects of astronautics and space explorations as well as on the topic at hand. Given the wide variety of topics in this class, there are few areas of spacecraft propulsion or power (including your favorite sci-fi vehicles) that would be considered "off topic."

Biography:

Keith Goodfellow, Chief Engineer, Arcjet Thruster System, Aerojet Rocketdyne Space Systems, Redmond, WA

Keith Goodfellow got his B.S. in mechanical engineering with a minor in physics from the University of Utah in 1986 and his M.S. in mechanical engineering from Purdue University in 1988. At Purdue his pursued coarse-work in solid and liquid propellant rockets, hypersonic aerodynamics and performed research on electric propulsion thrusters and plasma physics. He received his Ph.D. in aerospace engineering from USC in 1996. His work was on the interactions of plasma-arc-discharges and electrodes in electric propulsion thrusters. He was a member of the Advanced Propulsion Technology Group at the Jet Propulsion Laboratory (JPL) from 1988 until 2004. At JPL he was involved with the performance and endurance testing of many different types of electric thrusters (arcjet thrusters, Hall thrusters, ion engines, MagnetoPlasmaDynamic (MPD) thrusters, and innovative thrusters), plasma diagnostics, facility and data acquisition system development, evaluation of advanced propulsion concepts, development and testing of solar and microwave driven sails, mission studies, spacecraft design, spacecraft thermal and vacuum testing, and flight operations support (Deep Space One). He was a member of the American Institute of Aeronautics and Astronautics (AIAA) Electric Propulsion Technical Committee for 5 years. At the Lockheed Martin Advanced Development Programs (Skunk Works) from 2004 to 2013 he was a member of the Revolutionary Technology Programs group and performed research and development work in propulsion systems, plasma devices, advanced materials, and vehicle conceptual design. He is currently the Chief Engineer of the Arcjet Thruster System (thruster and Power Conditioning Unit (power electronics box)) for Aerojet Rocketdyne in Redmond, WA. He has been developing and teaching courses at USC since January 2000. He codeveloped and taught ASTE 470 Spacecraft Propulsion and ASTE 280 Introduction to Astronautics and the Space Environment; and developed and teaches ASTE 572 Advanced Spacecraft Propulsion.