ASTE 470

Rocket and Spacecraft Propulsion

Section 00, Part 1

Fall 2017

Mike Gruntman

Department of Astronautical Engineering
Viterbi School of Engineering
University of Southern California
Los Angeles

Rocket and Spacecraft Propulsion, 2017
(set of notes on spacecraft design)
Mike Gruntman, 2017

ASTE 470 *Spacecraft Propulsion*

Required for degrees in *Astronautical Engineering*

Regardless of your engineering or science major (electrical, mechanical, aerospace, systems, computer, etc. or physics, astronomy, chemistry, math, etc.) and regardless of your job function (research, development, design, test, management, etc.) ... If you work or plan to work in the space/defense industry or in government space R&D centers or in space operations, then **this course is for you.**

ASTE470 focuses on fundamentals of rocketry and spacecraft propulsion.

In academic year 2017–2018, ASTE470 *Spacecraft Propulsion* is offered in the Fall 2017 semester only (not offered in Spring 2018).

Fall 2017 Friday, 5:10 – 7:50 pm; OHE 136

Class enrollment is unlimited.

For students enrolled in the class:

Course materials for *ASTE 470 Spacecraft Propulsion* will be posted on the class web site at DEN in mid August.

Help with access DEN site: http://gapp.usc.edu/graduate-programs/den/students

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ASTE470 public web site (http://astronauticsnow.com/aste470/) provides some information on syllabus, textbooks, instructor, and much, much more.

Rocket and Spacecraft Propulsion
ASTE 470

Friday, 5:10–7:50 p.m., OHE-136 Fall 2017

CLASS	DATE	Topic	NS	H&P Text* Chapter	HW Due
1	Aug 25	Organization of the class. History of rocketry.	0 1		
2	Sep 01	Introduction. Solar system and environment. Elements of orbital mechanics	2 3 4	10.6	1, 2
3	Sep 08	Elements of orbital mechanics Basics of rocket dynamics.	4 5	10.6 10.1-10.4	3,4
4	Sep 15	Thermodynamics and combustion.	6	2	5, 6
5	Sep 22	Nozzle flow	7	3	7, 8
6	Sep 29	Non-ideal flow.	8	3.4-3.6, 4	9, 10
7	Oct 06	Ideal rocket and real nozzles	9	11.1-11.3	11, 12
8	**Oct 13**	**Mid-Term Exam**	**5:30–7:30 p.m., on campus rm TBD**		
9	Oct 20	Rocket heat transfer	10	11.4	13,14
10	Oct 27	Liquid rocket systems	11	12.1-12.5, 12.8	15, 16
11	Nov 03	Solid rockets	12	12.6-12.8	17,18
12	Nov 10	Launch Systems I Launch Systems II	13a 13b		19,20
13	Nov 17	Advanced (non-chemical) propulsion	14	14	21, 22
14	Dec 01	Interstellar Flight. Review	15		23, 24
15	**Dec 08**	**Final Exam**	**5:00–6:30 p.m., on campus rm TBD**		

* P. Hill and C. Peterson, *Mechanics and Thermodynamics of Propulsion*, Addison-Wesley.

Rocket and Spacecraft Propulsion

Contents

Section 0, Part 1 and Part 2
Organization of the Class

⇒ course contents
⇒ organization of the class
⇒ homework, exams, grading
⇒ books, other resources
⇒ survey

Section HW
Home Work problems

Section 01
Brief History of Rocketry

Section 02
Introduction

⇒ propulsion tasks
⇒ rocket concept
⇒ classification of rockets
⇒ space launchers
⇒ in-space propulsion

Section 02
Solar system and space environment

⇒ Universe and Galaxy
⇒ solar system, planets
⇒ coordinate systems
⇒ variable sun
⇒ solar energy output
⇒ solar wind
⇒ atmosphere and ionosphere
⇒ magnetosphere
⇒ effect of energetic particles
⇒ radiation belts
⇒ South Atlantic Anomaly
⇒ space debris

Section 04
Elements of orbital mechanics

⇒ gravitational field
⇒ elliptical orbits
⇒ circular and escape velocities
⇒ Earth oblateness
⇒ classical orbital elements
⇒ Hohmann transfer
⇒ launch sites
⇒ launch geostationary orbit
⇒ gravity-assist maneuvers
⇒ orbit perturbations
⇒ atmospheric drag
⇒ sun-synchronous orbit
⇒ Molniya orbit
⇒ geosynchronous orbit
⇒ typical delta-V's

Section 05
Basic of Rocket Dynamics

⇒ thrust equation
⇒ total and specific impulse
⇒ rocket equation
⇒ sounding rocket problem
⇒ multistaging
⇒ energy efficiency
⇒ launch to orbit

Section 06
Elements of thermodynamics and combustion

- ⇒ continuity and momentum equations
- ⇒ energy equation
- ⇒ second law of thermodynamics
- ⇒ equation of state
- ⇒ specific heat
- ⇒ isentropic and nonisentropic processes
- ⇒ mixture of gases
- ⇒ combustion and chemical reactions
- ⇒ heat of formation
- ⇒ adiabatic flame temperature
- ⇒ composition of reaction products
- ⇒ equilibrium constants

Section 07
Nozzle flow

- ⇒ one-dimensional flow
- ⇒ stagnation
- ⇒ isentropic flow
- ⇒ speed of sound
- ⇒ nozzle flow
- ⇒ normal shocks
- ⇒ entropy at shocks
- ⇒ oblique shocks
- ⇒ overexanded and underexpanded flows

Section 08
Nonideal flow

- ⇒ nonisentropic flow
- ⇒ frictionless flow
- ⇒ flow with friction
- ⇒ boundary layer
- ⇒ mass flux and momentum flux defects
- ⇒ skin friction coefficient
- ⇒ boundary layer heat transfer

Section 09
Ideal rocket and real nozzles

- ⇒ idea rocket
- ⇒ exhaust velocity
- ⇒ characteristic velocity and thrust coefficient
- ⇒ thrust
- ⇒ conical nozzle
- ⇒ contoured nozzle
- ⇒ plug nozzle and aerospike
- ⇒ scarfed nozzles
- ⇒ losses in nozzles
- ⇒ rocket performance evaluation

Section 10
Rocket heat transfer

- ⇒ cooling methods
- ⇒ regenerative cooling
- ⇒ convective heat transfer
- ⇒ adiabatic wall temperature
- ⇒ radiative heat transfer
- ⇒ cooling jacket
- ⇒ film cooling
- ⇒ heat sink
- ⇒ ablative cooling

Section 11
Liquid rocket systems

- ⇒ power plant
- ⇒ gas-pressure and turbopump propellant feed systems
- ⇒ propellant tanks
- ⇒ sloshing
- ⇒ gravity-free environment

- ⇒ ignition
- ⇒ injectors
- ⇒ combustion chamber
- ⇒ combustion losses
- ⇒ liquid propellants
- ⇒ cryogenic propellants
- ⇒ oxidizers
- ⇒ fuels
- ⇒ monopropellant thrusters
- ⇒ gelled propellants

Section 12
Solid rockets

- ⇒ solid propellant combustion
- ⇒ burning rate
- ⇒ combustion pressure
- ⇒ propellant grain
- ⇒ burning stability
- ⇒ erosive burning
- ⇒ Star family of motors
- ⇒ solid propellants
- ⇒ deflagration and detonation
- ⇒ hybrid rockets
- ⇒ thrust vector control

Section 13a
Launch systems I

- ⇒ selection process
- ⇒ launch sites
- ⇒ Delta
- ⇒ Atlas
- ⇒ SpaceX
- ⇒ Orbital Sciences
- ⇒ payload
- ⇒ stowed spacecraft
- ⇒ dual launch
- ⇒ structural loads
- ⇒ mechnical launch environment
- ⇒ acoustic environment

Section 13b
Launch systems II

- ⇒ flame duct
- ⇒ Atlas V at launch site
- ⇒ SRB assembly
- ⇒ Delta II at launch site
- ⇒ Delta launch

Section 14
Advanced (non-chemical) propulsion

- ⇒ sources of power
- ⇒ electric power systems
- ⇒ nuclear energy
- ⇒ RTG
- ⇒ Nuclear propulsion
- ⇒ electrostatic thrusters
- ⇒ power losses and efficiency
- ⇒ ion thrusters
- ⇒ field emission electric propulsion
- ⇒ resistojet
- ⇒ arcjet
- ⇒ pulsed plasma thrusters
- ⇒ magnetoplasmadynamic thrusters
- ⇒ solar sails

Section 15
Interstellar Flight

- ⇒ nearby stars
- ⇒ Doppler shift
- ⇒ aberration
- ⇒ relativistic rocket equation
- ⇒ antimatter propulsion
- ⇒ alternative approaches
- ⇒ Interstellar Probe mission

ASTE-470 Spacecraft Propulsion Fall 2017

Homework Schedule

Problem	due date
1	09/01/2017
2	09/01/2017
3	09/08/2017
4	09/08/2017
5	09/15/2017
6	09/15/2017
7	09/22/2017
8	09/22/2017
9	09/29/2017
10	09/29/2017
11	10/06/2017
12	10/06/2017
	10/13/2017
13	10/20/2017
14	10/20/2017
15	10/27/2017
16	10/27/2017
17	11/03/2017
18	11/03/2017
19	11/10/2017
20	11/10/2017
21	11/17/2017
22	11/17/2017
23	12/01/2017
24	12/01/2017

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Mike Gruntman was graduated (M.Sc.) from the Department of Aerophysics and Space Research of the Moscow Physical-Technical Institute in 1977 and received his Ph.D. in physics from the Space Research Institute (IKI) of the USSR Academy of Sciences in 1984. He received specialized training in servicing liquid rocket engines.

Dr. Gruntman actively worked on the development of space technology, in particular novel instrumentation for laboratory and space applications, and conducted research in experimental and space physics. He has been especially active in the development of imaging photon-counting detectors for ground and space telescopes. Gruntman excelled in the study of the neutral components of space plasmas and developed new instrumentation for detection of energetic neutral atoms (ENAs). He was a visiting scientist at the FOM-Institute for Atomic and Molecular Physics in Amsterdam.

In March 1990, Gruntman joined the University of Southern California (USC), where he initially worked on reduction and evaluation of the data from Pioneer 10/11 spacecraft and actively participated in sounding rocket and space instrument development programs. He worked on the sounding rocket payload integration and testing at White Sands Missile Range.

Dr. Gruntman is Professor of Astronautics at USC since 1993. (He is also Professor of Aerospace Engineering and Professor of System Architecture Engineering.) He was/is Principal Investigator and/or Co-Investigator in theoretical and experimental programs funded by NASA and Air Force; he is Co-Investigator on current NASA missions TWINS and IBEX. His interests include astronautics, space mission and spacecraft design, satellite technologies, rocket and spacecraft propulsion, space sensors and instrumentation, local interstellar medium, heliospheric and magnetospheric physics, orbital debris and interplanetary dust, space plasmas and environment, particle and photon analyzers and detector systems, ion and neutral particle beams, atomic collisions, and particle interactions with surfaces.

Gruntman authored and co-authored nearly 300 scholarly publications, including four books, in various fields of astronautics, space technology, space physics, space and laboratory sensors and instrumentation, spacecraft propulsion, history of rocketry, spacecraft, and missile defense, and space education. He presented results of his research at numerous international and national scientific and technological conferences and symposia and at scientific seminars at leading American and foreign research institutions and universities.

Prof. Gruntman taught/teaches courses in astronautics, spacecraft design, spacecraft propulsion, and space sciences. Dr. Gruntman also teaches short courses on space technology for government and industry.

Prof. Gruntman is the founder of the USC Astronautics Program that today offers BS, BS Minor, MS, Engineer, and PhD degrees and Graduate Certificate in Astronautical Engineering. In August 2004, Dr. Mike Gruntman was appointed the first (founding) Chairman (2004–2007) of the new space-focused (unique for American universities) academic unit in the USC Viterbi School of Engineering, known today as the Department of Astronautical Engineering. He again serves as the ASTE chairman in 2016-2019.

Gruntman is Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA) and he served as Vice Chair (elected) for Education of the Los Angeles Section of AIAA from 1996–1998. Dr. Gruntman is a member of the American Physical Society (APS) and American Geophysical Union (AGU). He is Member (Academician) of the International Academy of Astronautics (IAA)

Gruntman is a recipient of NASA's Group Achievement Awards (2000,2001,2011) and the USC School of Engineering Exceptional Service Award (1999). He served/serves (elected) on the USC Engineering Faculty Council in 1996-1998,1998-2000,2008-2010, 2011-2012,2014-2016. In 2006, his AIAA-published book on history of rocketry and spacecraft received an award from the International Academy of Astronautics.

Gruntman served (2001–2003) on the editorial board of the world leading journal on experimental techniques and scientific instrumentation, the *Review of Scientific Instruments*. He reviews manuscripts for scientific journals, for book publishers, and for NASA. He organized (convened) sessions at major scientific conferences (AGU, COSPAR). Gruntman served/serves on advisory panels on science and technology programs at NASA Headquarters, NASA centers, and in other government agencies.

USC Astronautics program history, focus, rationale, and organization

Article in

Acta Astronautica
v. 103, 92–105, 2014

Acta Astronautica 103 (2014) 92–105

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Advanced degrees in astronautical engineering for the space industry

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ARTICLE INFO

Article history:
Received 2 January 2014
Received in revised form
7 May 2014
Accepted 11 June 2014
Available online 19 June 2014

Keywords:
Space education
Astronautical engineering
Space engineering
Workforce development
Distance learning
Space systems

ABSTRACT

Ten years ago in the summer of 2004, the University of Southern California established a new unique academic unit focused on space engineering. Initially known as the Astronautics and Space Technology Division, the unit operated from day one as an independent academic department, successfully introduced the full set of degrees in Astronautical Engineering, and was formally renamed the Department of Astronautical Engineering in 2010. The largest component of Department's educational programs has been and continues to be its flagship Master of Science program, specifically focused on meeting engineering workforce development needs of the space industry and government space research and development centers. The program successfully grew from a specialization in astronautics developed in mid-1990s and expanded into a large nationally-visible program. In addition to on-campus full-time students, it reaches many working students on-line through distance education. This article reviews the origins of the Master's degree program and its current status and accomplishments; outlines the program structure, academic focus, student composition, and enrollment dynamics; and discusses lessons learned and future challenges.

1. Introduction

Ten years ago in June 2004, the University of Southern California (USC) announced establishment of a new unique academic unit focused on space engineering [1]. Initially known as the Astronautics and Space Technology Division (ASTD), the unit operated from day one as an independent academic department and successfully introduced the full set of degrees (Bachelor, Bachelor Minor, Master, Engineer, Ph.D., and Graduate Certificate) in Astronautical Engineering. (This article author had the privilege to serve the founding chairman of ASTD from 2004–2007.) The Division was formally renamed the Department of Astronautical Engineering in the USC's Viterbi School of Engineering (VSOE) in 2010.

In the United States, space engineering education was traditionally part of a significantly broader aerospace curriculum, historically anchored in aeronautics and dominated by fluids-focused engineering and sciences. Aerospace degrees are usually offered by departments of aerospace engineering or by departments combining aerospace with other engineering disciplines, particularly with mechanical engineering.

In contrast, USC established a unique separate pure-space-focused academic department to address specific challenges in space engineering education. The largest component of the Department of Astronautical Engineering has been and continues to be its flagship Master of Science in Astronautical Engineering (M.S. ASTE) program, specifically focused on meeting needs of the American space industry and government space research and development

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http://dx.doi.org/10.1016/j.actaastro.2014.06.016
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Abstract

Twelve years ago in the summer of 2004, the University of Southern California established a new unique academic unit focused on space engineering. Initially known as the Astronautics and Space Technology Division, the unit operated from day one as an independent academic department, successfully introduced the full set of degrees in Astronautical Engineering, and was formally renamed the Department of Astronautical Engineering in 2010. The largest component of Department's educational programs has been and continues to be its flagship Master of Science program, specifically focused on meeting engineering workforce development needs of the space industry and government space research and development centers. The program successfully grew from a specialization in astronautics developed in mid-1990s and expanded into a large nationally-visible program. In addition to on-campus full-time students, it reaches many working students on-line through distance education. This article reviews the origins of the Master's degree program and its current status and accomplishments; outlines the program structure, academic focus, student composition, and enrollment dynamics; and discusses lessons learned and future challenges.

Article download

http:// http://astronauticsnow.com/2014aste.pdf

or from http://astronauticsnow.com/SpaceEducation/

Integrity

Academic integrity of all students participating in this course is of the fundamental importance for this instructor and is one of the most important components of the University rules and regulations. Students who violate University standards of academic integrity are subject to disciplinary sanctions, including failure in the course and suspension from the University. Since dishonesty in any form harms the individual, other students and the University, policies on academic integrity will be strictly enforced. I expect you will familiarize yourself with Section 11, *Behavior Violating University Standards* in *Scampus*.

HomeWork, Exams, etc. are **individual efforts**

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Section 11, *Behavior Violating University Standards* https://scampus.usc.edu/1100-behavior-violating-university-standards-and-appropriate-sanctions. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Discrimination, sexual assault, and harassment are not tolerated by the university. You are encouraged to report any incidents to the *Office of Equity and Diversity* http://equity.usc.edu or to the *Department of Public Safety* http://adminopsnet.usc.edu/department/department-public-safety. This is important for the safety of the whole USC community. Another member of the university community – such as a friend, classmate, advisor, or faculty member – can help initiate the report, or can initiate the report on behalf of another person. *The Center for Women and Men* http://www.usc.edu/student-affairs/cwm/ provides 24/7 confidential support, and the sexual assault resource center webpage http://sarc.usc.edu describes reporting options and other resources.

Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://dornsife.usc.edu/ali, which sponsors courses and workshops specifically for international graduate students.

The *Office of Disability Services and Programs* http://sait.usc.edu/academicsupport/centerprograms/dsp/home_index.html provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information* http://emergency.usc.edu will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.

Some Useful Math

Taylor's theorem

Let f(x) be analytic at *a*. Then

$$f(x)=f(a)+f'(a)\frac{(x-a)}{1!}+f''(a)\frac{(x-a)^2}{2!}+f'''(a)\frac{(x-a)^3}{3!}....+f^{(n-1)}(a)\frac{(x-a)^{n-1}}{(n-1)!}+....$$

An alternative form is

$$f(a+x)=f(a)+f'(a)\frac{x}{1!}+f''(a)\frac{x^2}{2!}+f'''(a)\frac{x^3}{3!}....+f^{(n-1)}(a)\frac{x^{n-1}}{(n-1)!}+....$$

The special case when a=0 is called Maclaurin's series

$$f(x)=f(0)+f'(0)\frac{x}{1!}+f''(0)\frac{x^2}{2!}+f'''(0)\frac{x^3}{3!}....+f^{(n-1)}(0)\frac{x^{n-1}}{(n-1)!}+....$$

Examples (elementary functions):

$$(1+x)^n=1+nx+\frac{n(n-1)}{2!}x^2+\frac{n(n-1)(n-2)}{3!}x^3+....$$

$$e^x=1+x+\frac{x^2}{2!}+\frac{x^3}{3!}+...$$

$$\ln(1+x)=x-\frac{x^2}{2}+\frac{x^3}{3}-\frac{x^4}{4}+....$$

$$\sin x=x-\frac{x^3}{3!}+\frac{x^5}{5!}-\frac{x^7}{7!}+...$$

$$\cos x=1-\frac{x^2}{2!}+\frac{x^4}{4!}-\frac{x^6}{6!}+....$$

$$\tan x=x+\frac{x^3}{3}+\frac{2x^5}{15}+\frac{17x^7}{315}+...$$

Indefinite integral of functions $\int dF(x)=F(x)+C$

Integration by parts $\int u\,dv=uv-\int v\,du$

ASTE 470 Rocket and Spacecraft Propulsion

Fall 2017

Mike Gruntman

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Viterbi School of Engineering
University of Southern California
Los Angeles

Section 00, Part 2

Organization of the Class

ASTE 470 Spacecraft Propulsion

Rocket and Spacecraft Propulsion, 2017
Section 00, Part 2, ***Rocket and Spacecraft Propulsion***
(set of notes on rocket and spacecraft propulsion)
Mike Gruntman, 2017

Rocket and Spacecraft Propulsion

- Organization of the class
- Course Content
- Schedule
- Course notes
- Other supporting material
- Homework
- Exams
- Distance Education Network DEN

Organization of the Class – First Lecture

- Course Notes are essential and mandatory for ASTE 470
- On-campus and remote students: download Course Notes from the class web site at DEN (http://courses.uscden.net).

  password required (see Slides 26–27)
- Teaching will be done directly from the notes – bring the required materials to the class
- Files for the first class meeting on **August 25, 2017**:

  2017-Fall_MG_RSCP_00_part_1_no_pswd.pdf

  2017-Fall_MG_RSCP_00_part_2_no_pswd.pdf (this file)

  2017-Fall_MG_RSCP_01.pdf

  2017-Fall_MG_RSCP_02.pdf

Attention: read this section of Class Notes for rules

ASTE 470 – Contents

- **Section 00, Part 1 and Part 2**
  Organization of the Class
- **Section HW**
  Homework Problems
- **Section 01**
  Rocket History
- **Section 02**
  Introduction
- **Section 03**
  Solar System and Space Environment
- **Section 04**
  Elements of Orbital Mechanics
- **Section 05**
  Basics of Rocket Dynamics
- **Section 06**
  Elements of Thermodynamics and Combustion
- **Section 07**
  Nozzle Flow
- **Section 08**
  Non-Ideal Flow
- **Section 09**
  Ideal Rocket and Real Nozzles
- **Section 10**
  Rocket Heat Transfer
- **Section 11**
  Liquid Rocket Systems
- **Section 12**
  Solid Rockets
- **Section 13a**
  Space Launch Systems I
- **Section 13b**
  Space Launch Systems II
- **Section 14**
  Advanced (Non-Chemical) Propulsion
- **Section 15**
  Interstellar Flight

ASTE470 – Course Objectives

- This course focuses on fundamentals of rocket and spacecraft propulsion systems.
- The class notes and textbook(s) provide most of the details, and the homework helps to develop a first-level understanding.
- We will also learn the basic nomenclature and vocabulary, so that you can converse with understanding with specialists.
- Students are expected to remember (some) undergraduate Physics and Mathematics

Instructor

Mike Gruntman

Professor of Astronautics, Chairman (founding) 2004-2007, 2016-2019

Department of Astronautical Engineering

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mikeg@usc.edu

- detailed biographical sketch in *Section 00, Part 1*
- communications on the first-name basis most welcome

Specialist in astronautics, space physics, space sensors and instrumentation, space missions, rocketry, spacecraft technologies, space education, and space and rocket history; Co-Investigator (Co-I) and participant in several NASA missions

~300 scholarly pubs, incl. 4 books (incl. IAA award)

- E-mail mikeg@usc.edu
- URL http://astronauticsnow.com

ASTE470 – Is This Course for You?

- **Required for *BS, MS, PhD in Astronautical Engineering***
- Regardless of your major, if you work or plan (want) to work in the rocket, space, missile, or defense industry or in government rocket or space research and development centers (NASA, Air Force, IC, DOE, NOAA, …) or space mission operations and control centers, then

  this course – ASTE 470 – IS FOR YOU

- In addition to classroom, ASTE 470 *Spacecraft Propulsion* is simultaneously webcast by the USC Viterbi SOE's Distance Education Network (DEN). It can be taken by students anywhere in the United States. Students can view webcasts of course lectures as needed during the semester.

Astronautics at USC

- USC established the *Astronautics and Space Technology Division* (ASTD) in August 2004 "to position the USC Viterbi School of Engineering to take full advantage of rapidly growing opportunities in space"
  - independent academic unit within the USC Viterbi School of Engineering operating as an academic department from day one (based on Astronautics specialization from mid-1990s)
  - renamed (July 1, 2010) *Department of Astronautical Engineering* (ASTE)

  a unique pure-space-engineering Department in the United States
- offers BS, BS Minor, MS, Engineer, and PhD degrees and Graduate Certificate in *astronautical engineering* (postcode ASTE)
- ASTE is responsible for programs in astronautics and space technology at USC, concentrating on meeting the educational and research needs of the space and defense industries, government R&D centers, and academia

USC Astronautics program history, focus, rationale, and organization

Acta Astronautica, v. 103, 92-105, 2014; download **http://astronauticsnow.com/2014aste.pdf**

or from http://astronauticsnow.com/SpaceEducation/

Department of Astronautical Engineering (ASTE)

- **USC Astronautics Program**

  Combines science and engineering fundamentals with highly specialized classes taught by astronautics adjunct faculty and part-time lecturers (top specialists in the trenches)
- MS ASTE web sites

  http://gapp.usc.edu/graduate-programs/masters/astronautical-engineering

  http://astronauticsnow.com/msaste/
- web site MS ASTE *Frequently Asked Questions FAQ*

  http://astronauticsnow.com/msaste/faq.html

  Master of Science in Astronautical Engineering: Overview

  video (53 min): http://astronauticsnow.com/msaste/overview.html
- long-term class schedule —

  http://astronauticsnow.com/msaste/astd_ms_class_schedule.pdf
- always check with ASTE Student Advisor for updated class schedule

ASTE 470 Spacecraft Propulsion

- **Prerequisite**
  Senior or graduate standing in engineering or science
- **Class Notes**
  Class Notes are essential and mandatory for the course. Download Notes from the class web site at DEN (http://courses.uscden.net).
- **Class Procedure**
  Teaching will be done directly from the notes. It is advisable to bring appropriate materials to class.

Homework

- First HW assignments (1,2) due on September 01, 2017.
- There are 24 homework assignments. Submission schedule is in Section 00, Part 1.
- Late homework may be submitted within two weeks after the due date but not later (≡ must be received by TAs) than November 17, 2017 (inclusive).
  Late homework will be graded; the grade will be reduced by 50%.
  No late homework submissions after November 17, 2017. ("No" means "No.")
- No "make up" (home)work is possible. No special "deals" on homework submission, regardless of the cause, are possible.
  "No" means "No." "Regardless" means "Regardless."
- Homework assignments and solutions are posted at the class web site at DEN (http://courses.uscden.net); solutions usually posted a few days after the due date).
- On-campus students submit homework in class. Online DEN students submit homework through http://courses.uscden.net .

Students must keep records of their HW assignment scores and check with TAs 2-3 times during the semester the accuracy of the scores in our records. Simply email TAs the scores and they will check the accuracy.

Exams and Grading

- Midterm Exam
  13 October (Friday), 2017
  5:30 – 7:30 p.m. (120 min)
  Instructor and TA will be present at 5:00 p.m.
  DEN will arrange proctoring for remote students

- Final Exam (entire semester content)
  8 December (Friday), 2017
  5:00 – 6:30 p.m. (90 min)
  Instructor and TA will be present at 4:30 p.m.
  DEN will arrange proctoring for remote students

- DEN rule: remote students from the Greater Los Angeles area must take exams on campus. Contact DEN directly if you have questions.

Grading

ASTE 470

Homework	**20%**
Midterm Exam	**40%**
Final Exam	**40%**

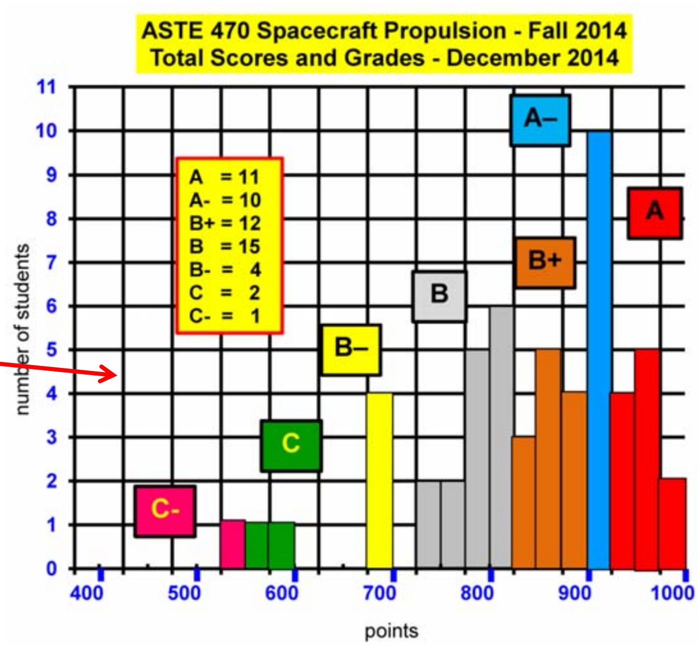
Exams are usually open-book, -notes, -….. No laptops.

Typical Grade Distribution

Important question by enrolled students:

What is a typical grade distribution in the class?

Example



ASTE 470
Spacecraft Propulsion
Fall 2014
Grade Distribution
(55 students)

Organization of the Class

- Syllabus and schedule – flexible guidelines
- Class begins at 5:10 p.m. We have one 10-minute break during class.
- Grading: Teaching Assistant and Graders: TBA

Questions and Complaints about grading

- to be directed to TA
- only if arbitration is necessary, contact the instructor

Communications with the instructor and TA

- office hours
- telephone and e-mail
  - email to TA or instructor; add a copy to the other, only if necessary
- do not hesitate to call or see TA with questions about the class material, homework, etc.

Contact Teaching Assistant (TA)! TA is here to be bothered!

Organization of the Class

- Class Attendance: Free walk in / walk out
  - If sleep, do not snore (on-campus rule only)
  - No food (on campus – DEN's rule)
  - Cell phones and pagers off (be nice)
- Questions
  - Any aspect of astronautics and rocketry can be discussed
  - Fear not! Questions are welcome.
- Academic Integrity

  See the statement in the Notes (Section 00, Part 1) and familiarize yourself with the Academic Integrity guidelines in the USC student handbook.

  - **Bottom line**

    Homework, exams, etc. are individual effort

Office Hours – ASTE-470

- Teaching Assistant's office hours

  to be announced (TBA)

- Instructor's office hours

Tuesday	**3:45 p.m. – 4:30 p.m.**
	5:15 p.m. – 6:00 p.m.
Friday	**2:30 p.m. – 4:00 p.m.**

Course Notes and Textbook(s)

Course Notes (~ 600 pages) – required

Mike Gruntman, *Rocket and Spacecraft Propulsion, Course Notes,* Fall 2017.

For your personal use only. Copyright protected.

Recommended textbooks

P. Hill and C. Peterson, *Mechanics and Thermodynamics of Propulsion,* Prentice Hall, 1991. – required for students without prior undergraduate coursework in thermodynamics and fluids

R.W. Humble, G.N. Henry, and W.L. Larson, eds., *Space Propulsion Analysis and Design*, McGraw-Hill, 1995 (and later editions).

G.P. Sutton and O. Biblarz, *Rocket Propulsion Elements*, Wiley, 2017 (and other editions)

Other books on rocket and spacecraft propulsion – see instructor's web site **http://astronauticsnow.com/AstroBooks/**

Course Notes

- Class notes are mandatory and essential for the class
- Download class notes from the class web site at DEN (http://courses.uscden.net).
  Password required (see slides 27–28).
- Teaching will be done directly from the notes – bring the required materials to the class.
- Homework assignments are posted at the class web site
- Class schedule and Homework submission schedule are in Section 00, Part 1
- Print the entire set of notes
  - Total number of pages ~ 600
  - Many students print two slides/pages per sheet of paper
  - You can later print selected pages one page per sheet

Other Sources of Information

- Several (course-related) video clips – links (YouTube) at http://astronauticsnow.com/vp/
- A large number of books can be recommended for this class – check the list of recommended books at
  http://astronauticsnow.com/AstroBooks/
- Publications of professional societies (journals, conference proceedings, etc)
- Trade pubs – usually good; mainstream media – often embarrassment
- World Wide Web (WWW)
  - Caution – a lot of unprofessional and inaccurate information (including pure, unmitigated garbage) out there

Course websites

Class web site at DEN: **http://courses.uscden.net**

Public (permanent) **class web site:** **http://astronauticsnow.com/aste470/**

Program frequently asked questions: http://astronauticsnow.com/msaste/faq.html

Professional Societies and Groups

- Highly advisable to become a member of professional societies and groups
- Membership helps professional growth, networking, etc.
- *Primary society* for rocket and spacecraft propulsion engineers –
  American Institute of Aeronautics and Astronautics (AIAA)
  http://www.aiaa.org
- Many other professional societies for scientists and engineers working in various fields related to space exploration and space technology
  ASME, SAE, AAS, IEEE, APS, OSA, SPIE, AGU, …. , ….

Professional networking group on LinkedIn
http://astronauticsnow.com/astrousc_linkedin/
USC Astronautics Students, Alumni, Faculty, and Friends

USC Astronautics

USC Astronautics

USC Astronautics networking group launched on 11 April 2009

>600 members
(as of Jan 2016)

http://astronauticsnow.com/astrousc_linkedin/

ASTE 470 on DEN

- Lecture webcasts

  All lectures are available through Distance Education Network (DEN) for all students, on-campus and distance, enrolled in the class during the entire semester

- PC or Mac

  DEN streams course videos using Microsoft Windows media encoders and servers. While streaming windows media files are supported by both the latest Mac and PC operating systems, using a Windows based system will usually provide a better experience. Additionally, DEN has recently added video download capabilities using Microsoft's Digital Rights Management supporting Windows operating systems.

Mike Gruntman Rocket and Spacecraft Propulsion Section 00, Part 2

On-Campus and DEN Students

- On all homework pages, put your name and course number ASTE-470
- On-campus (non-DEN) students must submit their homework in class; they will receive graded homework also in class
  - ➢ non-negotiable rule
- On-campus students must set up access to DEN webcasts. If you are going to be absent from a USC class, you can watch the class at a convenient time through webcast.
- DEN students: Final and Midterm exams are held on campus for students in the Los Angeles area (no exceptions). Outside this area, the exams are arranged at remote sites (contact DEN).
- If you absolutely have to be on a business trip during the exam – contact the instructor in advance.

All Students – Homework

- No homework can be submitted to the instructor's e-mail address or fax (unless specifically directed by the instructor).
- Do not copy (to the instructor) your submissions to DEN.

GAPP/DEN – Students Resources

- VSoE Graduate Programs – http://gapp.usc.edu
- VSoE Distance Education Network (DEN) – Current Students
  http://gapp.usc.edu/graduate-programs/den/students
- Login to the class web site at DEN, homework submissions, etc. at
  http://courses.uscden.net
- GAPP/DEN resources – http://gapp.usc.edu/students/masters
  - Print names and telephone numbers of DEN contact persons
  - Use it! Do not be shy!
  - Call them!
  - E-mail them!
  - They are here to help!
  - They will be delighted to hear from you – trust me

☺

Survey and Password

E-mail the survey (next slide) to the instructor (mikeg@usc.edu) any time from August 12, 2017 as plain text in your message (do not attach as an MS Word or PDF file) with the subject line *ASTE 470 Survey.*

– Survey is important for communications with students

– In response to your survey, the instructor will e-mail you the password to the class notes and homework solutions (posted on the class web site at DEN)

– Do not email the survey earlier than instructed above. If emailed earlier, it will be deleted and disregarded.

Survey – email to Instructor

(as plain text in your e-mail message)

1. Name (no SSN or student ID, please!!!)
2. Degree(s) attained: university and field (e.g., AstronauticalE, AerospaceE, MechanicalE, ElectricalE, SystemE, Physics, Astronomy, …)
3. Degree sought (MS, PhD, Certificate, BS, Progressive 4+1, …) and field (AstroE, EE, ME, CompE, AE, CivilE, ChE, Phys, Chem, …)
4. Are you a full-time student? Or, do you work full time and study part time?

   If you work – tell me where (e.g., NASA–JPL, Aerospace Corp, NASA–JSC, SMC–LAAFB, Boeing–El Segundo, Orbital, VeryCoolRockets.com, etc., …)
5. Location of your place of work: city, state
6. Telephone
7. E-mail
8. Student status (regular admitted, limited status, …, undergrad)

The information in this survey is for your instructor only. It is in your interest to provide me with the ways to reach you if and when needed. I will also compile class statistics. You will thus know who (statistically) your peers are.

Units and Constants: Units

1 inch	=	2.540 cm		
1 mil	=	10^{-3} inch	=	25.4 μm
1 foot	=	30.48 cm		
1 statute mile	=	1609.344 m	=	1.609 344 km
1 nautical mile	=	1852 m	=	1.852 km
1 ounce	=	28.35 g		
1 lb (pound)	=	0.4536 kg		
1 lbf	=	4.448 N		
1 slug	=	1.459×10^4 g	=	14.59 kg
1 bar	=	10^5 Pa	=	10^5 N/m^2
1 atm	=	$1.013\,25 \times 10^5$ N/m^2	=	1.013 25 bar
1 atm	=	$1.013\,25 \times 10^5$ Pa	=	14.6959 psi
1 bar	=	10^5 Pa		
1 psi	=	$6.894\,76 \times 10^3$ N/m^2	=	6.805×10^{-2} atm
1 cal	=	4.184 J		

Units and Constants: Constants

Electron charge (e)	=	1.6022×10^{-19} C
Electron-volt (eV)	=	1.6022×10^{-19} J
Atomic mass unit	=	1.6605×10^{-27} kg
Gas constant	=	8.3145×10^3 J K^{-1} kmol^{-1}
Astronomical Unit (AU)	=	1.496×10^{11} m
Earth equatorial radius	=	6 378.14 km
Gravitational constant (G)	=	6.6726×10^{-11} m^3 kg^{-1} s^{-2}
Free fall acceleration (g)	=	9.80665 m/sec^2
μ_{EARTH}	=	3.9860×10^{14} m^3/sec^2
μ_{SUN}	=	1.3271×10^{20} m^3/sec^2

Units and Constants: References

- You must be confident in juggling units: *meter, mile, nautical mile, astronomical unit, pound, foot, tor, Newton, radian, ...* and prefixes kilo, nano, deka, femto, Giga, ...
- Conversion coefficients and physical constants (*G, c, h, k, ...*) can be found in many reference publications (e.g., *AIAA Aerospace Design Engineers Guidebook, Handbook of Chemistry and Physics, etc*).
- Important reference documents on the web site of the ***National Institute of Standards and Technology*** **(NIST)**

  A guide to the use of the [metric] International System of Units (SI)
  http://physics.nist.gov/Pubs/SP811/sp811.html

  Physical constants – http://physics.nist.gov/cuu/Constants/index.html

- Compile lists (or make a copy of the pages) with the conversion coefficients and physical constants as the class progresses and attach them to your notes. The lists will be exceptionally useful (and time-saving) for working on the homework assignments and exams.

Greek alphabet

α	Α	alpha	ι	Ι	iota	ρ	Ρ	rho
β	Β	beta	κ	Κ	kappa	σ	Σ	sigma
γ	Γ	gamma	λ	Λ	lambda	τ	Τ	tau
δ	Δ	delta	μ	Μ	mu	υ	Υ	upsilon
ε	Ε	epsilon	ν	Ν	nu	φ	Φ	phi
ζ	Ζ	zeta	ξ	Ξ	xi	χ	Χ	chi
η	Η	eta	ο	Ο	omicron	ψ	Ψ	psi
θ	Θ	theta	π	Π	pi	ω	Ω	omega
			ϖ	—	"curly pi," an alternative form of π			
			ς	—	an alternative form of σ			