Comprehensive Rocket Science

Draft Syllabus

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24 May 2024

Introduction

Programs focusing on space can come in many varieties, to include those more focused on launch vehicles, space systems, dynamics, and astronomy. Here we will attempt to provide content to take the reader from very little knowledge of space systems to a detailed understanding of launch vehicles and space systems.

Introductory and/or mandatory classes in most programs of study include systems design and systems engineering, orbital mechanics, propulsion, and the space environment. Mission design, dynamics, modeling and simulation, telecommunication, structures, power, and thermal control round out the basic elements of a space systems program.

Courses in space systems are quite rigorous and require considerable preparation prior to entry of advanced courses. Fundamental understanding of mathematics, statics, aerodynamics, materials, spherical trigonometry, chemistry, and thermodynamics is needed to be adequately prepared. Where required, we will point out introductory material to provide a foundation for study.

The Basics

1. Space Systems Fundamentals

A grasp of the fundamentals is essential prior to embarking on this learning journey. Anyone who does not have a background in space engineering will benefit heavily from first studying the fundamentals broadly. Luckily, good material abounds.

Prerequisites: Algebra, trigonometry, vectors.

Recommended Textbook:

Understanding Space: An Introduction to Astronautics. Sellers, Jerry Jon.

Other Resources:

Kerbal Space Program (intuition for orbital mechanics and delta v)

Space channels on YouTube: Scott Manley, Everyday Astronaut

2. Astronomy

While not directly related to space engineering, a working knowledge of astronomy will benefit you with useful background and contextual information for the study of space systems, and may interest you as well.

Advanced Topics

General prerequisites for advanced topics:

For learning specific topics, considerable prerequisite knowledge may be desired or required. Some resources are pointed out where available.

Calculus – most topics. Khan Academy

Differential equations – most topics. Khan Academy

Physics – most topics. Khan Academy. Free textbooks at OpenStax, University Physics volumes 1-3.

Chemistry – propulsion.

Spherical geometry – orbital mechanics, attitude control and dynamics.

Thermodynamics – propulsion, re-entry.

Gas dynamics – propulsion, re-entry.

Materials and loads – launch vehicle design, structures.

Aerodynamics – launch vehicle design, re-entry.

Reliability – as needed.

Systems Engineering – as needed.

Communications – as needed.

Specific Topics

Orbital Mechanics

Prerequisites: Differential, integral, and multivariable vector Calculus, linear algebra desired.

Recommended Textbook:

Orbital Mechanics for Engineering Students, Howard Curtis.

Other resources:

Orbital mechanics in Python videos by Alfonso Gonzalez on YouTube.

Rocket Propulsion

Prerequisites: Chemistry, Thermodynamics.

Recommended Textbook:

Rocket Propulsion Elements. Sutton, George and Biblarz, Oscar.

Other resources:

Youtube, Josh the Engineer (CD nozzles)

Advanced Topics:

Gas dynamics, liquid propulsion, solid propulsion, advanced propulsion, future propulsion.

Thermodynamics

Further reading:

Fundamentals of Thermodynamics, 2013

Space Environment

Recommended textbook:

The Space Environment and its Effect on Space Systems. Pisacane, Vincent.

Aerodynamics

Attitude control and dynamics

Navigation

Structures

Hypersonic Gas and Plasma Dynamics

A necessary topic for exploring orbital re-entry.

Recommended textbook:

Hypersonic and High-temperature Gas Dynamics. Anderson, John D.

Launch Vehicle Design

Recommended Textbook:

Design of Rockets and Space Launch Vehicles. Edberg, Don and Costa, Willie.

Spacecraft power systems

Spacecraft Sensors

Spacecraft Cryogenic Systems

Spacecraft thermal control

Life support systems

Launch infrastructure and ground systems

Space weather

Spacecraft avionics

Spacecraft flight software systems

General Areas of Study for Space Knowledge

Mission Design

Thermodynamics

Further reading: Fundamentals of Thermodynamics, 2013

Rocket Propulsion

1. Converging-diverging nozzles and supersonic flow.
   Source: Josh the Engineer Youtube
2. Impact of fuel choice and ratios
3. Starting liquid fueled engines, gas generators and turbines
4. Characteristic energy
5. Combustion instability

Space Environment

Aerodynamics

Orbital Mechanics

Attitude control and dynamics

Navigation

Structures

Plasma Dynamics (orbital re-entry)

Launch Vehicle Design

Spacecraft power systems

Spacecraft Sensors

Spacecraft Cryogenic Systems and applications

Spacecraft thermal control

Life support systems

Launch infrastructure and ground systems

Space weather

Spacecraft avionics

Spacecraft flight software systems

Proposed / Future Learning Content at CRS:

Course Listing:

Foundations Course 001

Space Engineering 101

Systems Engineering 101

Reliability 100

Astronomy 100

Space Policy 100

Propulsion 200

Orbital Mechanics 200

Space Environment 200

Spacecraft 200

Communications and Telemetry 210

Launch Vehicles 200

Launch Operations 210

Liquid Propulsion 310

Feed Systems 311

Thrust Chambers 312

Solid Propulsion 320

Structures 310

Thermal Management 310

Electrical Power Systems 310

Attitude Determination and Control 310

Navigation 310

Proposed / Future Learning Content at CRS:

Foundations (FND)

FND 001 – Mathematics

1. Algebra
2. Geometry
    a. Law of Sines and Cosines
3. Basic Trigonometry
4. Spherical Geometry / Trigonometry
5. Vectors
6. Differential Calculus
7. Integral Calculus
8. Multivariable Calculus
9. Vector Calculus
10. Differential Equations
11. Linear Algebra
12. Coordinate Systems and Transformations
13. Numerical Methods

FND 002 – Physics

- Physical Mechanics
- Electromagnetism
- Heat, Sound, and Light

FND 003 – Chemistry

FND 004 – Thermodynamics

FND 005 – Aerodynamics

FND 006 – Fluid Mechanics

FND 007 – Statics / Dynamics

FND 008 – Electrical Engineering / Signals

FND 020 – Reliability

FND 100 – Systems Engineering

FND 101 – Introduction to Space Engineering

1. Space History
2. The Universe, the stars, and the solar system

3. The Space Environment
4. Orbital Mechanics
5. Rocket and Spacecraft Propulsion
6. Launch Vehicles
7. Attitude Determination and Control
8. Electrical Power Systems
9. Communications, Telemetry, Tracking, and Command
10. Thermal Management
11. Spacecraft Sensors
12. Spacecraft Structures
13. Manned Spaceflight and Life Support
14. Re-entry and Landing
15. Interstellar travel

FND 110 – Space Policy

Space Systems (SYS)

SYS 201 – Spacecraft

SYS 210 – Attitude Determination and Control

SYS 220 – Thermal Management

SYS 230 – Spacecraft Structures

SYS 240 – Communications, Telemetry, Tracking, and Control

SYS 250 – Spacecraft Sensors

SYS 260 – Electrical Power Systems

SYS 270 – Life Support

SYS 280 – Cryogenic Systems

Propulsion (PROP)

PROP 201 – Spacecraft and Rocket Propulsion

1. Basics Review
    a. Coordinate systems
    b. Orbital mechanics
    c. Space environment
2. Rocket Dynamics
    a. Rocket Equation
    b. Sounding rocket problem

    c. Staging
3. Thermodynamics
4. Combustion
5. Isentropic flow in nozzles
6. Real nozzles
7. Heat transfer
8. Liquid Propulsion Fundamentals
9. Liquid Propulsion Feed Systems
10. Solid Propulsion Fundamentals
11. Hybrid Propulsion
12. Solar Electric Propulsion
13. Nuclear Propulsion
14. Other Propulsion

PROP 301 – Spacecraft and Rocket Propulsion II

1. Review
    a. Rocket Dynamics
    b. Thermodynamics
    c. Combustion
    d. Isentropic Flow
    e. Heat Transfer
2. Combustion Chambers
3. Propellant selection
4. Isentropic Nozzles – Frozen Flow
5. Isentropic Nozzles – Shifting Equilibrium
6. Isentropic Nozzles – Finite Rate Combustion
7. Real Nozzles – Boundary Layers
8. Real Nozzles – Multiphase Flow
9. Real Nozzles – Correction Factors
10. Rocket Exhaust Plumes

PROP 310 – Liquid Propulsion

PROP 311 – Liquid Propellants

PROP 312 – Feed Systems

PROP 313 – Liquid Thrust Chambers

PROP 314 – Liquid Propellant Combustion Stability

PROP 315 - Liquid Engine Design

PROP 320 – Solid Propulsion

PROP 321 – Solid Propellants

PROP 322 – Solid Propellant Combustion Stability

PROP 323 – Solid Rocket Motor Design

PROP 330 – Electric Propulsion

PROP 340 – Nuclear Propulsion

PROP 341 – Nuclear Engineering I

PROP 342 – Nuclear Reactions

PROP 441 – Nuclear Reactor Physics

PROP 343 – Nuclear Thermal Propulsion

PROP 344 – Nuclear Electric Propulsion

PROP 345 – Vehicle Design for Nuclear Propulsion

PROP 346 – Mission Design for Nuclear Propulsion

PROP 442 – Nuclear Propulsion Cooling and Heat Transfer

PROP 350 – Advanced Propulsion

PROP 360 – Gas Dynamics

PROP 370 – Combustion

Space Environment (ENV)

ENV 201 – Introduction to the Space Environment

ENV 210 – The Universe, Galaxies, and Formation of Stars

ENV 220 – The Sun

ENV 230 – The Radiation Environment

ENV 240 – The Magnetosphere

ENV 250 – Space Debris and Meteoroids

Orbital Mechanics (ORB)

ORB 201 – Introduction to Orbital Mechanics

ORB 301 – Orbital Mechanics II

ORB 310 – Navigation

ORB 311 – Solar System Navigation

Launch Vehicles (LV)

LV 201 – Introduction to Launch Vehicles

LV 210 – Launch Operations

LV 211 – Launch Ground Systems

LV 320 – Trajectory Optimization

LV 330 – Launch Vehicle Aerodynamics

LV 340 – Launch Vehicle Structures

LV 350 – Launch Vehicle Payload Environment

Re-entry and Landing (REL)

REL 201 – Introduction to Re-entry and Landing

REL 221 - Thermal Protection Systems I

REL 230 – Spacecraft Recovery

REL 310 – Compressible Aerodynamics

REL 320 – Heat Transfer

REL 321 – Thermal Protection Systems II

REL 330 – Hypersonic Gas Dynamics

REL 340 – Airfoils and parachutes

REL 350 – Propulsive landing technologies

Astronomy (ASMY)

ASMY 101 – Introduction to Astronomy

- The Universe
- Galaxies
- Stars
- Exoplanets
- The Death of Stars
- Black Holes
- The Sun
- The Solar System
- Planets
- Comets and Asteroids
- Coordinate Systems
- Time and Reference Systems
- Astronomical Instruments