

Please consider suggesting the book to your institutional and local libraries.

# Fundamentals of Space Missions: Problems with Solutions

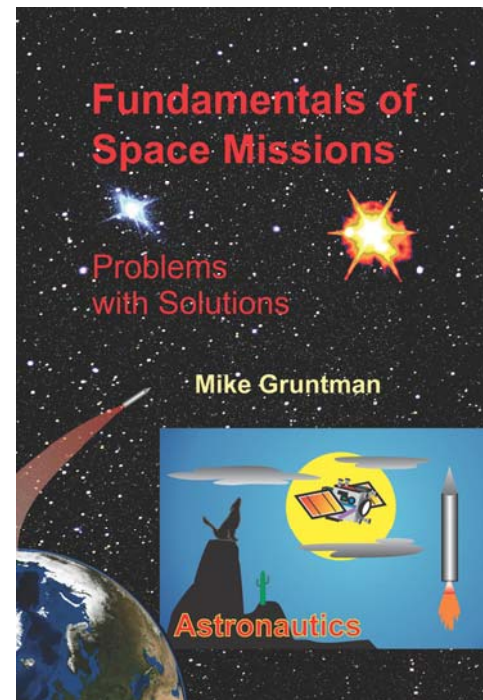
Mike Gruntman

Interstellar Trail Press, California, 2022

available on *Amazon, etc.*

Paperback ISBN 979-8-9856687-4-2

478 pages with 175+ figures; references  
160+ problems with solutions



This book includes more than 160 typical homework and exam problems that *were* given, *could* have been given, or *should* have been given (had the time allowed) in a graduate-level introductory astronautics “boot camp” course on the fundamentals of space systems at the University of Southern California.

The problems cover the first half of the course, focused on mission-related subjects such as the solar system, coordinate systems, space environment and interactions, the Earth, the gravitational field, orbital

mechanics, common orbits, and mission geometry. All problems include detailed solutions. Consequently, it is a how-to guide for making basic estimates in planning and designing space missions and systems.

The book is for students and instructors in undergraduate and graduate courses in astronautical engineering. It will also serve as an aid for practicing space engineers and managers, especially system engineers, involved in the planning, design, and operation of space missions, space systems, and payloads.

**About the author.** Mike Gruntman is a professor of astronautics and the founder of a space engineering program at the University of Southern California (USC). He is an accomplished specialist actively involved in R&D programs in space science and space technology and has authored and coauthored more than 300 scholarly publications, including six books. Mike is an associate fellow of the American Institute of Aeronautics and Astronautics and a member of the International Academy of Astronautics

More details at <http://astronauticsnow.com/fsm2022/>

Please consider suggesting the book to your institutional and local libraries.

# Fundamentals of Space Missions: Problems with Solutions

## Chapter 1. Universe, Stars, and Solar System

- 1.1 Light year
- 1.2 Parsec
- 1.3 Sun's galactic motion
- 1.4 Interstellar wind
- 1.5 Interstellar Probe
- 1.6 Apparent and absolute magnitudes of stars
- 1.7 Difference in apparent magnitude
- 1.8 Apparent and absolute magnitudes of the Sun
- 1.9 Apparent and absolute magnitudes of  $\alpha$ -Centauri A
- 1.10 Apparent magnitude of the Sun as seen from a departing starship
- 1.11 Two brightest stars for navigation
- 1.12 The number of square degrees in the sky
- 1.13 Star mappers
- 1.14 Visual magnitude of a satellite in orbit
- 1.15 GEO satellite visible by the unaided eye
- 1.16 Sphere of influence and patched-conic orbits
- 1.17 Sphere of influence of the Moon

## Chapter 2. Coordinate Systems, Time, Angles

- 2.1 Inertial reference frames
- 2.2 Subtended plane angle
- 2.3 Earth as viewed from geostationary and GPS orbits
- 2.4 Angular diameters of the Sun, Earth, and Moon
- 2.5 Solid and plane angles
- 2.6 Vernal equinox vector
- 2.7 Earth at perihelion
- 2.8 Vernal equinox precession
- 2.9 Sidereal year and tropical year
- 2.10 Mean solar day and sidereal day
- 2.11 Orbit eccentricity and apparent solar day
- 2.12 Geostationary satellite orbital period
- 2.13 Julian day
- 2.14 Apparent rotation period of the Sun
- 2.15 Spherical and Cartesian systems of coordinates
- 2.16 Geocentric celestial system of coordinates
- 2.17 Heliocentric ecliptic system of coordinates
- 2.18 Rotation matrices
- 2.19 Transformation between celestial and ecliptic systems of coordinates
- 2.20 Sirius and Canopus for space navigation
- 2.21 Orientation of the Earth's orbit with respect to the Galaxy
- 2.22 Angle and distance between two Voyager spacecraft
- 2.23 Distance between two points on the globe
- 2.24 Distance between North Korea and the United States
- 2.25 Distance between Iran and the United States

## Chapter 3. Space Environment and Interactions

- 3.1 Radiation flux density and the solar constant
- 3.2 Solar radiation flux densities at the Earth's orbit
- 3.3 Solar radiation flux densities at Mars
- 3.4 Solar radiation pressure force for normally incident radiation
- 3.5 Solar radiation pressure force for non-normally incident radiation
- 3.6 Solar radiation pressure force for non-normally incident radiation
- 3.7 Solar radiation pressure on a foil in interplanetary space
- 3.8 Solar sail
- 3.9 Solar radiation pressure torque on a spacecraft
- 3.10 Equal normal and lateral solar radiation pressure forces
- 3.11 Solar electromagnetic radiation (light) and solar wind for electric power generation and exerting force on spacecraft
- 3.12 Time to reach 1 AU and interstellar boundary of the solar system
- 3.13 Wavelength of the peak of solar radiation
- 3.14 Wavelength of the peak of spacecraft thermal emission
- 3.15 Airburst of extraterrestrial bodies
- 3.16 Atmosphere scale height
- 3.17 Atmosphere scale heights at sea level and ISS altitude
- 3.18 Atmospheric drag and satellite velocity loss
- 3.19 Brushing up integration
- 3.20 Maxwell-Boltzmann distribution
- 3.21 Thermal velocities of atoms, ions, and electrons in low Earth orbit
- 3.22 Debye length (radius)
- 3.23 Debye length in low Earth orbit and interplanetary space
- 3.24 Spacecraft floating potential
- 3.25 Plasma frequency
- 3.26 Plasma frequency in the ionosphere
- 3.27 Gyrofrequency (cyclotron frequency) and gyroradius (Larmor radius)
- 3.28 Radiation (Van Allen) belt electrons and protons
- 3.29 Drift velocity
- 3.30 Drift velocities of radiation belt particles
- 3.31 Area density and shielding thickness of aluminum
- 3.32 Solar radiation pressure on interplanetary dust

## Chapter 4. Gravitational Field and Earth

- 4.1 Gauss's law for gravity
- 4.2 Gauss's law in the differential form
- 4.3 Spherically symmetric body and point mass
- 4.4 Thin spherical shell and point mass
- 4.5 Semimajor and semiminor axes and eccentricity of the Earth ellipsoid

More details at <http://astronauticsnow.com/fsm2022/>

Please consider suggesting the book to your institutional and local libraries.

- 4.6 Spinning Earth
- 4.7 Heights of mountain peaks
- 4.8 Geopotential of the Earth
- 4.9 Gravitational force due to the Earth's oblateness
- 4.10 "Pear-like" shape of the Earth
- 4.11 Zonal harmonic (2,0) and principal moments of inertia of the Earth
- 4.12 Mass, moment of inertia, and normalized moment of inertia of a sphere with a uniform density
- 4.13 Radius of the Earth's dense core
- 4.14 Precession period of the Earth's spin axis

#### Chapter 5. Basics of Orbital Mechanics

- 5.1 Two-body equation of motion
- 5.2 Conservation of energy
- 5.3 Orbital velocity and period in low Earth orbit (LEO)
- 5.4 Escape velocity
- 5.5 Properties of Deimos
- 5.6 Spacecraft in orbit around the Earth with an orbit radius equal to that of the Moon
- 5.7 Conservation of angular momentum
- 5.8 Trajectory equation: Kepler's first law
- 5.9 Energy and vis-viva equations
- 5.10 Orbit eccentricity
- 5.11 Kepler's second and third laws
- 5.12 Radial and transverse velocities in orbit
- 5.13 Orbit with a satellite radial velocity larger than its transverse velocity
- 5.14 Flight-path angle
- 5.15 Earth orbit
- 5.16 Perihelion of orbits of Neptune and Pluto
- 5.17 Maximum altitude for a given radial velocity
- 5.18 Comet and interstellar body
- 5.19 Eccentric anomaly and true anomaly
- 5.20 Position in orbit as a function of time. Kepler's equation. Mean anomaly
- 5.21 Hyperbolic escape velocity and C3
- 5.22 C3 for launch from aphelion and perihelion of the Earth orbit
- 5.23 Orbits around the barycenter
- 5.24 Motion of stars in  $\alpha$ -Centauri system
- 5.25 Lagrange points
- 5.26 Trajectory deflection in planetary flyby
- 5.27 Body capture radius for the Earth
- 5.28 Poynting-Robertson effect (simplified)

#### Chapter 6. Orbital Elements and Maneuvers – I

- 6.1 Determine orbital characteristics
- 6.2 Orbit inclination change
- 6.3 Inclination change at apogee and perigee
- 6.4 Geostationary satellite north-south stationkeeping
- 6.5 Determine orbital characteristics
- 6.6 Determine orbital characteristics
- 6.7 Lowering satellite apogee
- 6.8 State vector and classical orbital elements
- 6.9 Velocity increment at a wrong point
- 6.10 Velocity vector change at apogee

- 6.11 Convert classical orbital elements to the state vector
- 6.12 Two-line element format
- 6.13 Flight time between two points in an orbit
- 6.14 Coplanar intercept of a geostationary satellite
- 6.15 Orbiting object breakup and Gabbard diagram

#### Chapter 7. Orbital Elements and Maneuvers – II

- 7.1 Hohmann transfer
- 7.2 Hohmann transfer and C3 to Mars
- 7.3 Missions to planets
- 7.4 Graveyard orbit
- 7.5 Repositioning of a geostationary satellite
- 7.6 Bi-elliptic transfer
- 7.7 Getting close to a central body (Sternfeld transfer)
- 7.8 Deorbiting satellites
- 7.9 Transfer from low Earth orbit to geostationary orbit
- 7.10 Deployment to geostationary orbit from various launch sites
- 7.11 Transfer to Sun-Earth Lagrange point L1
- 7.12 Rotation of the line of apsides in a one-burn maneuver
- 7.13 Rotation of the line of apsides in a two-burn maneuver

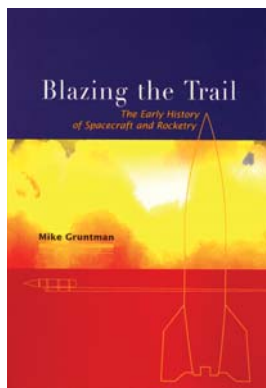
#### Chapter 8. Orbit Evolution and Common Orbits

- 8.1 Atmospheric drag and satellite drag paradox
- 8.2 Atmospheric drag in low Earth orbit
- 8.3 Atmospheric drag effect on the International Space Station
- 8.4 Atmospheric drag in prograde and retrograde orbits
- 8.5 Atmospheric drag and solar radiation pressure
- 8.6 Regression of nodes and rotation of apsides
- 8.7 Sun-synchronous orbit (simplified)
- 8.8 Maximum altitude of a circular sun-synchronous orbit
- 8.9 Sun-synchronous orbit on Mars
- 8.10 Molniya orbit (simplified)
- 8.11 Ground track shift (simplified)
- 8.12 Repeat ground track orbits (simplified)
- 8.13 Magic orbit (simplified)
- 8.14 Nodal period

#### Chapter 9. Mission Geometry

- 9.1 Satellite viewing conditions
- 9.2 Satellite communication (visibility) time
- 9.3 Geostationary orbit coverage
- 9.4 Elevation angle to a GEO satellite
- 9.5 Communication time with a satellite in a sun-synchronous orbit
- 9.6 Apparent angular rate of satellite motion
- 9.7 Groundtrack azimuth
- 9.8 Launch azimuth and orbit inclination
- 9.9 Overflight of two sites on the ground in the same orbit
- 9.10 Eclipse duration

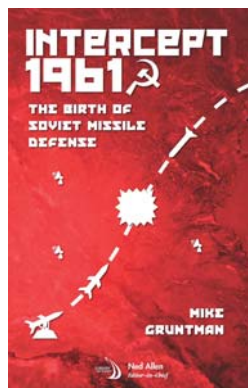
More details at <http://astronauticsnow.com/fsm2022/>



Winner of the Luigi Napolitano Award (2006) from the International Academy of Astronautics

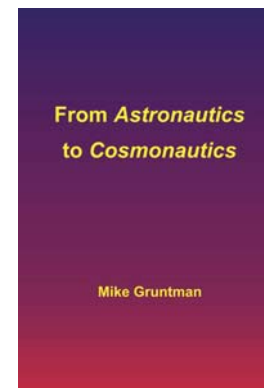
Mike Gruntman, *Blazing the Trail: The Early History of Spacecraft and Rocketry*, AIAA, Reston, Va., 2004

ISBN 978-1-56347-705-8  
475 pages, 340 figures, 250+ references



Mike Gruntman, *Intercept 1961. The Birth of Soviet Missile Defense*, AIAA, Reston, Va., 2015

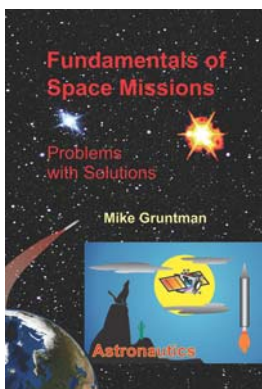
ISBN 978-1-62410-349-0 (print)  
eISBN: 978-1-62410-350-6  
(electronic; pdf at <http://arc.aiaa.org>)  
330 pages, 120+ figures, 200+ references



Nominated for the Eugene M. Emme Astronautical Literature Award (2007) of the American Astronautical Society

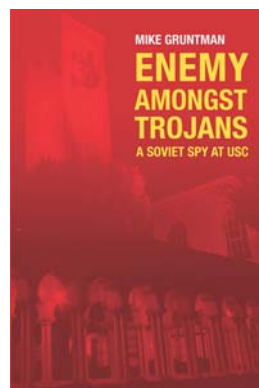
Mike Gruntman, *From Astronautics to Cosmonautics*. Space Pioneers Robert Esnault-Pelterie and Ary Sternfeld, Booksurge, North Charleston, S.C., 2007

ISBN 978-1-4196-7085-5  
ASIN: B002E19WDO (Kindle)  
84 pages, 24 photographs, 75 references



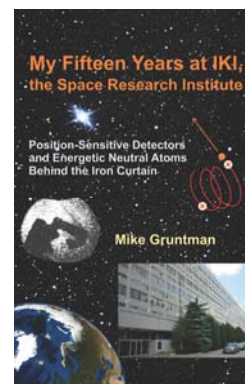
Mike Gruntman, *Fundamentals of Space Missions: Problems with Solutions*, Interstellar Trail Press, 2022.

ISBN 979-8-9856687-4-2  
478 pages, 160+ problems; 175+ figures, references



Mike Gruntman, *Enemy Amongst Trojans. A Soviet Spy at USC* (a WWII story), Figueroa Press, Los Angeles, Calif., 2010

ISBN-13: 978-1-932800-74-6  
88 pages, 12 figures, 94 references



Mike Gruntman, *My Fifteen Years at IKI, the Space Research Institute: Position-Sensitive Detectors and Energetic Neutral Atoms Behind the Iron Curtain*, Interstellar Trail Press, 2022.

ISBN 979-8-9856687-0-4  
328 pages, 150+ figures, 180+ references

<http://astronauticsnow.com/books/>