BASICS OF SPACE FLIGHT 1.0 FOR WINDOWS DEMO

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Click the "Search" button on the menu bar, above, to use the index.

Access the Glossary at any time with the "hotkeys" A through Z.

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Quickstart

Throughout the program, clicking on the following icons will move you to other locations in the program (called hypertext links), as indicated below:

This icon moves deeper into the Table of Contents.

This icon moves to the text associated with the Table of Contents entry.

This icon, in the Recap sections at the end of each Chapter or Part, is a hypertext link to each entry's associated answer (they will appear in a popup window).

Chapter Summaries

Each chapter begins with a summary. These can be reviewed in popup windows for those who want to make a quick review of the contents of the chapters without going to each one. The summaries are accessible from the main Table of Contents window.

Using the Glossary

A Glossary is incorporated into the program with all the entries from the hardcopy version of the Workbook. A section of the Glossary can be accessed by pressing the first letter of the word to be looked-up (letters ***a*** through ***z,*** on the keyboard, are "hotkeys" for the related sections of the Glossary).

Using the Index

If you are using Windows 3.x, words in the text, which are included in the Index, can be located by clicking "Search", on the button bar, above. Selecting an indexed word will move you to the associated location in the text. Note that some words are indexed more than once. If you are using Windows 95, not only are the indexed words available, but also, the "Find" feature can locate any word in the text (it is a full text search).

Viewing the Spacecraft

Images of the spacecraft discussed in the text can be accessed by clicking "Spacecraft" on the button bar, above. This will take you to a window with a list of the various spacecraft with hypertext links to the individual images.

Annotating Text and Bookmarking File

This program has been created in the Windows Helpfile format. The various help features such as annotating the text and creating bookmarks are available to the user. For directions, click "Annotating Text" or "Bookmarking File" on the button bar, above.

Getting Help with Abbreviations and Units of Measure

See the "References" entry on the Table of Contents page to access a table that has the standard abbreviations for units of measure and a table of metric to English conversions.

Defining and Using Bookmarks

Just as you can place bookmarks in a book to mark specific references, you can place bookmarks in this program to help return to locations in the text you use frequently or to a location where you wish to resume. After you have placed a bookmark in the text, you can access that topic quickly from the Bookmark menu.

To place a bookmark in the current topic

1. From the Bookmark menu, above, choose Define.
2. In the Bookmark Name box, the topic title appears. If you want to use a different name to identify the bookmark, type a name in this box.
3. Choose the OK button.

   The bookmark name will now appear on the Bookmark menu when you open it.

To view a topic that has a bookmark

From the Bookmark menu, above, choose the bookmark name for the topic you want to view.

Underlined numbers precede the first nine bookmark titles. You can type the corresponding number to go quickly to a marked topic.

If more than nine bookmarks have been defined, choose More from the Bookmark menu. Select a bookmark in the Go To Bookmark box, and then choose the OK button.

To remove a bookmark

1. From the Bookmark menu, above, choose Define.
2. Select the bookmark you want to remove.
3. Choose the Delete button.

The bookmark name is removed from the Bookmark menu.

Annotating Text

You can add your own comments to text in the program. When you annotate text, a paper-clip icon is placed to the left of the topic title to remind you that you have added text to this topic.

Adding Text to a Topic

You can add your own comments and notes to a topic and view this information later.

To add text to the current topic

1. From the Edit menu, above, choose Annotate.
2. In the Annotate dialog box, type the text you want to add.

   If you make a mistake, press BACKSPACE to remove any unwanted characters, and continue typing.

   Text wraps automatically, but you can end a line before it wraps by pressing ENTER.
3. Choose the Save button.

Viewing an Annotation

If you have added comments to a topic, you can view them at any time.

To view an annotation

1. Click the paper-clip icon to the left of the topic title.

   Or press TAB to select the paper-clip icon, and then press ENTER.
2. When you finish viewing the annotation, choose the Cancel button.

Removing an Annotation

If you no longer need your comments about a topic, you can remove the annotation.

To remove an annotation

1. Click the paper-clip icon to the left of the topic title.

   Or press TAB to select the paper-clip icon, and then press ENTER.
2. Choose the Delete button.

Copying and Pasting an Annotation

You can copy text from an annotation and paste it into another annotation in the program or into a document. You can also paste text from documents into annotations.

To copy an annotation

1. Click the paper-clip icon to the left of the topic title.

   Or press TAB to select the paper-clip icon, and then press ENTER.
2. To copy the annotation to the Clipboard, choose the Copy button.

   If you want to copy only a portion of the annotation, select the text that you want to copy onto the Clipboard, and then choose the Copy button. You can drag the mouse pointer over text to select it. Or press and hold down SHIFT while you use the arrow keys to select text.

3. Choose the Save button.

To paste an annotation

1. Copy onto the Clipboard the text you want to paste into the annotation.
2. In the topic where you want to paste the annotation, click the paper-clip icon to the left of the title.

   Or press TAB to select the paper-clip icon, and then press ENTER.
3. To paste the contents of the Clipboard at the beginning of the topic, choose the Paste button.

   Or press SHIFT+INS.

   Or place the insertion point at the location you want to insert the new text, and then choose the Paste button.
4. Choose the Save button.

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Introduction

Chapter Summaries

Chapter 1 Summary

Upon completion of this chapter you will be able to state distances of objects within the solar system in terms of light-time, describe the sun as a typical star, relate its share of the mass within the solar system, and compare the terrestrial and jovian planets. You will be able to distinguish between inferior and superior planets, describe asteroids, comets, and the Oort cloud. You will be able to describe magnetic fields, particle and radiation environments in planetary vicinities and interplanetary space.

Chapter 2 Summary

Upon completion of this chapter you will be able to describe the system of terrestrial coordinates, the rotation of Earth, precession, and the revolution of Earth about the sun. You will be able to describe how the locations of celestial objects are stated in the coordinate systems of the celestial sphere. You will be able to describe various conventions of timekeeping.

Chapter 3 Summary

Upon completion of this chapter you will be able to describe the force of gravity, characteristics of ellipses, and the concepts of Newton's principles of mechanics. You will be able to recognize acceleration in orbit and explain Kepler's laws in general terms. You will be able to describe tidal effect and how it is important in planetary systems.

Chapter 4 Summary

Upon completion of this chapter you will be able to describe the use of Hohmann transfer orbits in general terms, and how spacecraft use them for interplanetary travel. You will be able to describe in general terms the exchange of angular momentum between planets and spacecraft on gravity assist trajectories.

Chapter 5 Summary

Upon completion of this chapter you will be able to describe, in general terms, the characteristics of various types of planetary orbits. You will be able to describe the general concepts and advantages of geosynchronous orbits, polar orbits, walking orbits, sun-synchronous orbits, and some requirements for achieving them.

Chapter 6 Summary

Upon completion of this chapter you will be able to describe in general terms characteristics of natural and artificial emitters of radiation. You will be able to describe bands of the spectrum from DC to gamma rays, and the particular usefulness radio frequencies have for deep-space communication. You will be able to describe the basic principles of spectroscopy, Doppler, reflection and refraction.

Chapter 7 Summary

Upon completion of this chapter you will be able to describe activities typical of the following mission phases: conceptual effort, preliminary analysis (proof of concept), definition, design, and development. You will be conversant with typical design considerations included in mission inception.

Chapter 8 Summary

Upon completion of this chapter you will be able to identify what is referred to as the scientific community, describe the typical background of principal investigators involved with space flight, and describe options for gathering science data. You will be aware that radio science applies sensing techniques to planetary atmospheres, rings, and mass, solar corona, and gravitational wave searches. You will be able to describe avenues for disseminating experiment results.

Chapter 9 Summary

Upon completion of this chapter you will be able to state the characteristics of various types of spacecraft: flyby spacecraft, orbiter spacecraft, atmospheric probe spacecraft, penetrator spacecraft, lander and surface rover spacecraft, and balloon experiments. You will be able to categorize several of JPL's spacecraft.

Chapter 10 Summary

Upon completion of this chapter you will be aware of the major factors involved in communicating across interplanetary distances. You will also be aware that detailed coverage of this subject appears in a separate course.

Chapter 11 Summary

Upon completion of this chapter you will be able to describe a typical spacecraft structural subsystem, the role of data handling subsystems, attitude and articulation control subsystems, telecommunications subsystems, electrical power and distribution subsystems, and propulsion subsystems on typical spacecraft. You will be able to list advanced technologies being considered for use on future spacecraft.

Chapter 12 Summary

Upon completion of this chapter you will be able to distinguish between remote and direct sensing, and state characteristics of remote sensing instruments, including radar, radiometers, and polarimeters. You will be able to state characteristics of direct-sensing instruments including plasma instruments, dust detectors, cosmic ray, energetic particle detectors, magnetometers, and planetary radio astronomy instruments.

Chapter 13 Summary

Upon completion of this chapter you will be able to describe basic principles of spacecraft navigation, including spacecraft velocity and distance measurement, angular measurement, and orbit determination. You will be able to describe spacecraft trajectory correction maneuvers and orbit trim maneuvers.

Chapter 14 Summary

Upon completion of this chapter you will be able to describe the role launch sites play in total launch energy, state the characteristics of various launch vehicles, list factors contributing to determination of launch windows. You will be able to describe how the launch day of the year and hour of the day affect interplanetary launch energy, and list the major factors involved in preparations for launch.

Chapter 15 Summary

Upon completion of this chapter, you will be able to list the major factors involved in spacecraft checkout and characterization, and preparation for encounter. You will be able to characterize typical daily flight operations.

Chapter 16 Summary

Upon completing this chapter, you will be able to describe major factors involved in flyby operations, planetary orbit insertion, planetary mapping, and gravity field surveying. You will be able to describe the unique opportunities for science data acquisition presented by occultation, and problems involved. You will be able to describe the concepts of using aerobraking to alter orbital geometry or decelerate for landing, atmospheric entry, balloon tracking, and sampling.

Chapter 17 Summary

Upon completion of this chapter, you will be able to describe completion of primary objectives of a mission, and obtaining additional science data after their completion. You will consider how depletion of resources contributes to the end of a mission, identify resources which affect mission life, and describe logistics of closeout of a mission.

References

Table of Measurement Abbreviations

Table of Metric to English Conversions

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- The Sun
- Interplanetary Space

Part 2

- The Terrestrial Planets
- The Jovian Planets
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- Asteroids
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Part 1
Electromagnetic Radiation

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Part 3
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Doppler Effect
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Part 5
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Part 6
Refraction
Phase

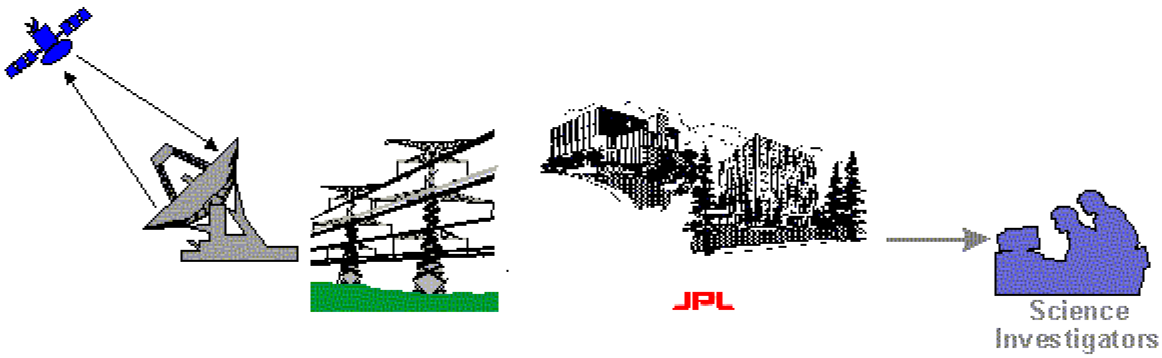
Preface to Basics of Space Flight 1.0 for Windows

The text and illustrations in this program are from a Workbook published by JPL as the "Basics of Space Flight Learners' Workbook, MOPS0513-02-00, JPL D-9774, Rev. A." It was created by the JPL Advanced Mission Operations Section Multi-team. The Training Module was written by David Doody and George Stephan of JPL in December 1995. The JPL publication is a public domain document that is not copyrighted.

This version of the Workbook was created by us with two goals in mind. First, we wanted to make available an enhanced hypertext version of the Workbook that runs in Windows 3.1 and Windows 95 without any additional software being required (e.g., a browser or reader). Second, we wanted a version with features not available in a hard copy or when using the hypertext version on JPL's website (for instance, we have added a nested table of contents, a hotkey glossary, a searchable index, a quick-access to spacecraft illustrations and popup answers in the Recap sections).

Introduction to JPL Hardcopy of Basics of Space Flight

(Note: This introduction is from the JPL hardcopy version. It is provided for general information only. For directions on using this Windows Version of the Workbook, see the "Quickstart" entry in the Table of Contents.)



Since Caltech's Jet Propulsion Laboratory (JPL) manages NASA projects that probe the deep space (translunar) environment of our solar system, operations people need to have an under-standing of the basics of space flight in order to perform effectively at JPL. This training module introduces concepts associated with these basics to employees new to the space flight operations environment.

This module is the first in a sequence of training modules that pertain to space flight operations activities. (See diagram below). There is no prerequisite. This module is a prerequisite for the next in the sequence, "End-to-End Information System."

The goal of this training module is to provide an aid for identifying and understanding the general concepts associated with space flight in general and deep space missions in particular. It offers a broad scope of limited depth, presented in 17 chapters. Specific learning objectives are listed at the beginning of each chapter in terms of what you are expected to be able to do upon finishing the chapter.

Acknowledgements

It was prepared by the Advanced Mission Operations Section (391) Training Group, including George Stephan and Dave Doody. Diane F. Miller has done the technical editing, maintained the text and illustrations, and created the online version. Cozette Parker assisted with the initial hardcopy publication. Special thanks to reviewers Ben Toyoshima, Larry Palkovic, Carol Scott, Rob Smith, Dan Lyons, and Bob Molloy, and to field testers Kathy Golden, Steve Annan, Linda Lee, and Paul Porter for their valuable comments. Thanks to Roy Bishop (Physics Department, Acadia University, and the Royal Astronomical Society of Canada) for his independent review.

Learning Strategy

As a participant, you receive your own copy of this self-administered workbook. It includes both learning materials and evaluation tools. The chapters are designed to be used in the order presented, since some concepts developed in later chapters depend on concepts introduced in earlier ones. It doesn't matter how long it takes you to complete it. What is important is that you accomplish all the learning objectives.

You evaluate your own progress in this training module. You are probably eager to learn about the subject and so will want to evaluate your progress as you go. Accomplishing the objectives will be especially important if you plan to participate in the next training module in the sequence, "End-to-End Information System." (Note: The End-to-End Information System module is intended for JPL internal use only.)

The frequent "Recap" (short for recapitulation) sections throughout this workbook will help you reinforce key points and help you evaluate your progress. They require you to fill in blanks. Please do so either mentally or in writing. Answers from the text are shown along the bottom of each Recap.

On page 144 of this book you will find a blank certificate of completion. When you have finished this training module, and you are satisfied that you have met the learning objectives stated in each chapter, please fill in the certificate, sign it, and give it, or a copy of it, to your supervisor for inclusion in your personal file.

Online Availability

This training module is also available on the World Wide Web at http://www.jpl.nasa.gov/basics In addition, this site has a link to a .pdf (for portable document format) file, readable and printable using Adobe™ Acrobat™ Reader. Acrobat Reader is available free from Adobe's Web site, to which there is also a link.

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Feedback or Questions

Feedback from participants is especially valuable to improving any self-administered training. To contribute your ideas to the next edition of this module or to ask a question about any of the material in this workbook, please contact the primary author at david.f.doody@jpl.nasa.gov .

Measurement Unit Abbreviations

Except for units of measure, all terms are spelled out completely the first time they are used, with abbreviations following in parentheses, when applicable. Thereafter, the abbreviations are generally used alone. Units of measure, used without such introduction, are listed below. Refer to the Glossary for further help. As with any study endeavor, the participant should also have a good English dictionary at hand.

bps	bits per second
G	Giga (billion, i.e., 10^9). Note that in the U.S. a billion is 10^9, while in other countries using the metric system, a billion is 10^{12}. However, "Giga" means 10^9 everywhere.
g	Gram
Hz	Hertz
k	Kilo
m	meter (USA spelling; elsewhere, metre)
M	mega (million)
N	Newton
W	Watt

Metric to English Conversions

Millimeters to inches:	mm	x	0.04	=	in
Centimeters to inches:	cm	x	0.4	=	in
Meters to feet:	m	x	3.3	=	ft
Meters to yards:	m	x	1.1	=	yds
Kilometers to miles:	km	x	0.6	=	mi
Grams to ounces:	g	x	0.035	=	oz
Kilograms to pounds:	kg	x	2.2	=	lbs
Celsius to Fahrenheit:	°C	x	9/5 + 32	=	°F
Newtons to Pounds Force:	N	x	1/4.448	=	lbf

Chapter 1 - Part 1 of 3

Objectives of this Chapter:

> Upon completion of this chapter you will be able to state distances of objects within the solar system in terms of light-time, describe the sun as a typical star, relate its share of the mass within the solar system, and compare the terrestrial and jovian planets. You will be able to distinguish between inferior and superior planets, describe asteroids, comets, and the Oort cloud. You will be able to describe magnetic fields, particle and radiation environments in planetary vicinities and interplanetary space.

The solar system has been a topic of study from the beginning of history. For nearly all that time, people have had to rely on long-range and indirect measurements of its objects. At first, almost all observations were based on visible light and, later, on radio waves received here on Earth from the objects under investigation. However, with the emergence of space flight, instruments can be sent to many solar system objects to measure their physical properties and dynamics directly and at close range. With the data collected from these measurements, knowledge of the solar system is advancing at an unprecedented rate.

The solar system consists of an average star we call the sun, the planets Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. It includes the satellites of the planets, numerous comets, asteroids, meteoroids, and the interplanetary medium. The sun is the richest source of electromagnetic energy in the solar system. The sun's nearest known stellar neighbor is a red dwarf star called Proxima Centauri, at a distance of 4.3 light years away (a light year is the distance light travels in a year, at the rate of 300,000 km per second).

The whole solar system, together with the local stars visible on a clear night, orbits the center of our home galaxy, a spiral disk of 200 billion stars we call the Milky Way. The Milky Way has two small galaxies orbiting it nearby, which are visible from the southern hemisphere. They are called the Large Magellanic Cloudand the Small Magellanic Cloud. Our galaxy, one of billions of galaxies known, is travelling through intergalactic space. On a cosmic scale, all galaxies are receding from each other. Galaxies relatively close together may exhibit motion toward or away from each other on a local scale.

The planets, most of the satellites of the planets, and the asteroids revolve around the sun in the same direction, in nearly circular orbits. The sun and planets rotate on their axes. The planets orbit the sun in or near the same plane, called the ecliptic. Pluto is a special case in that its orbit is the most highly inclined (17 degrees) and the most highly elliptical of all the planets. Because of this, for part of its orbit, Pluto is closer to the sun than is Neptune.

Distances Within the Solar System

The most common unit of measurement for distances within the solar system is the astronomical unit (AU). One AU equals the mean distance from the sun to Earth, about 150,000,000 km. JPL refined the precise value of the AU in the 1960s using radar echoes from Venus, since spacecraft navigation depended on its accuracy. Another way to indicate distances within the solar system is terms of light time, which is the distance light travels in a unit of time at the rate of 300,000 km per second. Distances within the solar system, while vast compared to our travels on Earth's surface, are comparatively small-scale in astronomical terms. For reference, Proxima Centauri, the nearest star at 4 light years away, is about 250,000 AU distant from the sun.

Light Time	Approximate Distance	Example
1 second	299,792 km	~0.75 Earth-Moon distance
1 minute	18,000,000 km	0.125 AU
8.3 minutes	150,000,000 km	Earth-Sun distance (1 AU)
1 hour	1,000,000,000 km	~1.5 x Sun-Jupiter Distance
4 years	(Included for reference)	Distance to nearest star

The Sun

The sun is best characterized as a typical star. The sun dominates the gravitational field of the solar system; it contains 99.85% of the solar system's mass. The planets, which condensed out of the same disk of material that formed the sun, contain only 0.135% of the mass of the solar system. Satellites of the planets, comets, asteroids, meteoroids, and the interplanetary medium constitute the remaining fraction. Even though the planets make up a small portion of the solar system's mass, they retain the vast majority of the solar system's angular momentum. This storehouse of momentum can be utilized by interplanetary spacecraft on so-called "gravity-assist" trajectories.

Mass Distributionwithin the Solar System

99.85%	Sun
0.135%	Planets
Remainder	Comets Satellites Minor Planets Meteoroids Interplanetary Medium

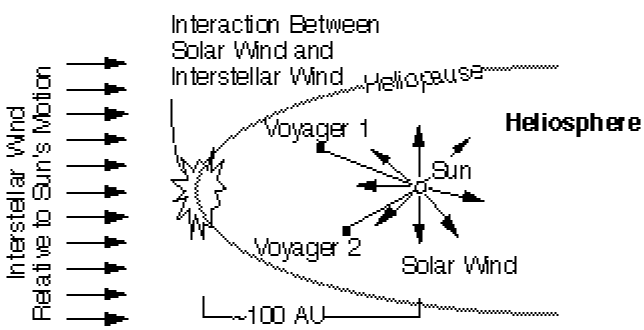
The gravity of the sun creates extreme pressures and temperatures within itself, sustaining a thermonuclear reaction fusing hydrogen nuclei and producing helium nuclei. This reaction yields tremendous amounts of energy, causing the material of the sun to be plasmaand gas. These thermonuclear reactions began about 5×10^9 years ago in the sun, and will probably continue for another 5×10^9 years. The sun has no distinct surface. The apparent surface of the sun is optical only and has no discrete physical boundary.

The sun rotates once on its axis within a period of approximately 28 days at its equator. Because the sun is a gaseous body, rotation speed varies with latitude, being slower at higher latitudes.

The sun has strong magnetic fields that are associated with sunspots. The solar magnetic field is not uniform and is very dynamic. Solar magnetic field variations and dynamics are targets of major interest in the exploration of the solar system.

Interplanetary Space

Nearly all the solar system by volume appears to be an empty void. Far from being nothingness, this vacuum of "space" comprises the interplanetary medium. It includes various forms of electromagnetic radiationand at least two material components: interplanetary dust and interplanetary gas. Interplanetary dust consists of microscopic solid particles. Interplanetary gas is a tenuous flow of gas and charged particles, mostly protons and electrons--plasma--which stream from the sun, called the solar wind.



The solar wind can be measured by spacecraft, and it has a large effect on comet tails. It also has a measurable effect on the motion of spacecraft. The speed of the solar wind is about 400 km per second in the vicinity of Earth's orbit. The speed approximately doubles at high solar latitudes. The point at which the solar wind meets the interstellar medium, which is the "solar" wind from other stars, is called the heliopause. It is a boundary theorized to be roughly circular or teardrop-shaped, marking the edge of the sun's influence perhaps 100 AU from the sun. The space within the boundary of the heliopause, containing the sun and solar system, is referred to as the heliosphere.

The solar magnetic field extends outward into interplanetary space; it can be measured on Earth and by spacecraft. The solar magnetic field is the dominating magnetic field throughout the interplanetary regions of the solar system, except in the immediate environment of planets that have their own magnetic fields.

Recap

1. The whole solar system, together with the local stars visible on a clear night, orbits the center of our home ___________________.

2. The planets, most of the satellites of the planets, and asteroids revolve around the sun in the same direction and nearly in the same ___________________________.

3. One AU equals the mean distance from the _______________________________.

4. The sun is best characterized as a ________________.

5. The gravity of the sun creates extreme pressures and temperatures within itself, sustaining a ___________________ reaction.

6. The Astronomical Unit is abbreviated _____________.

7. Even though the planets make up a small portion of the solar system's mass, they retain the vast majority of the solar system's ________________________.

galaxy

plane

sun to the earth

typical star

thermonuclear

AU

angular momentum

Chapter 1 - Part 2 of 3

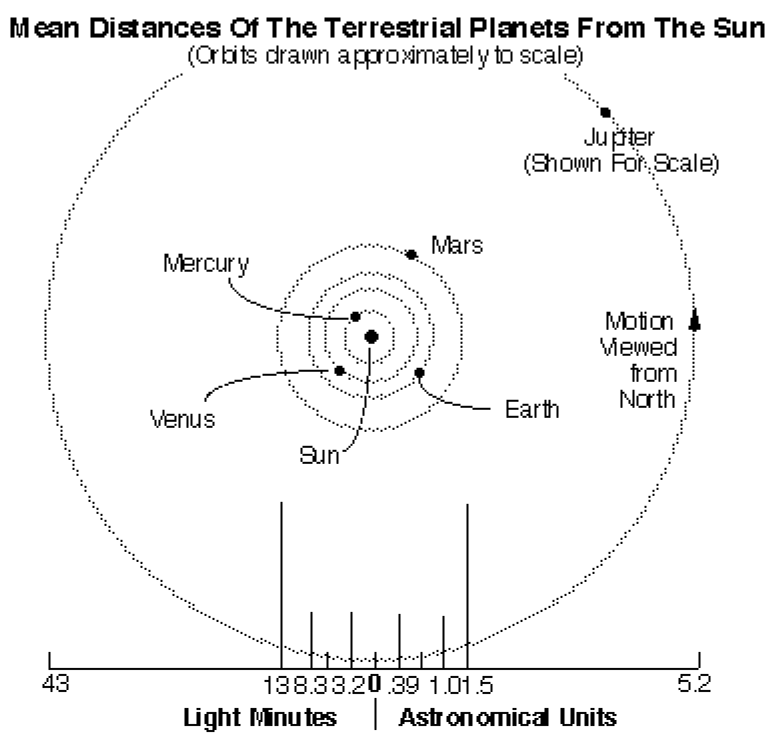
The TerrestrialPlanets

The terrestrial planets are Mercury, Venus, Earth, and Mars, and are called terrestrial because they have a compact, rocky surface like Earth's terra firma. The terrestrial planets are the four innermost planets in the solar system.

Light minutes are often used to express distances within the region of the terrestrial planets, useful because they indicate the time required for radio communication with spacecraft at their distances.

Of the terrestrial planets, Venus, Earth, and Mars have significant atmospheres. The gases present in a planetary atmosphere are related to a planet's size, mass, temperature, how the planet was formed, and whether life is present. The temperature of gases may cause their molecules or atoms to achieve velocities that escape the planet's gravitational field.

Earth is the most massive of the terrestrial planets. The ratios of mass for the terrestrial planets with respect to Earth (100%) are: Venus, 82%; Mars, 11%; and Mercury, 5%. In terms of Earth's radius, Venus is only slightly smaller, Mars is about 50% of Earth's, and Mercury's radius is only 40% of Earth's. In terms of Earth's 24-hour days, Mercury rotates on its axis in 59 days, Venus in 243 days, and Mars every 1.03 days. The slow rotation of Venus is retrograde, opposite the normal rotation of the planets.



Terrestrial Planetary Data (Approximate)

	Mercury	Venus	Earth	Mars
Mean distance from sun	0.39 AU	0.72 AU	1.0 AU	1.5 AU
Light minutes from sun	3.2	6.0	8.3	12.7
Mass in terms of Earth's	0.05	0.82	1.00	0.11
Radius in terms of Earth's	0.38	0.95	1.00	0.53
Rotation period in Earth days	59	243 (retrograde)	1.00	1.03
Natural Satellites	0	0	1	2

None of the terrestrial planets have rings. Earth does have a layer of rapidly moving charged particles known as the Van Allen belt, which is trapped by Earth's magnetic field in a doughnut-shaped region surrounding the equator. Of the terrestrial planets, Earth and Mars have natural satellites, Mercury and Venus do not.

The JovianPlanets

Jupiter, Saturn, Uranus, and Neptune are known as the jovian (Jupiter-like) planets, because they are all gigantic compared with Earth, and they have a gaseous nature like Jupiter's. The jovian planets are also referred to as the "gas giants," although some or all of them may have small solid cores.

Jupiter is about 43 light minutes from the sun (add or subtract up to 8.3 minutes to determine light time to Earth); Saturn about 1 hour 20 minutes, Uranus about 2 hours 40 minutes, and Neptune about 4 hours 10 minutes from the sun. By comparison, Pluto, when at its farthest point in orbit, is 5 hours 31 minutes light time from the sun.

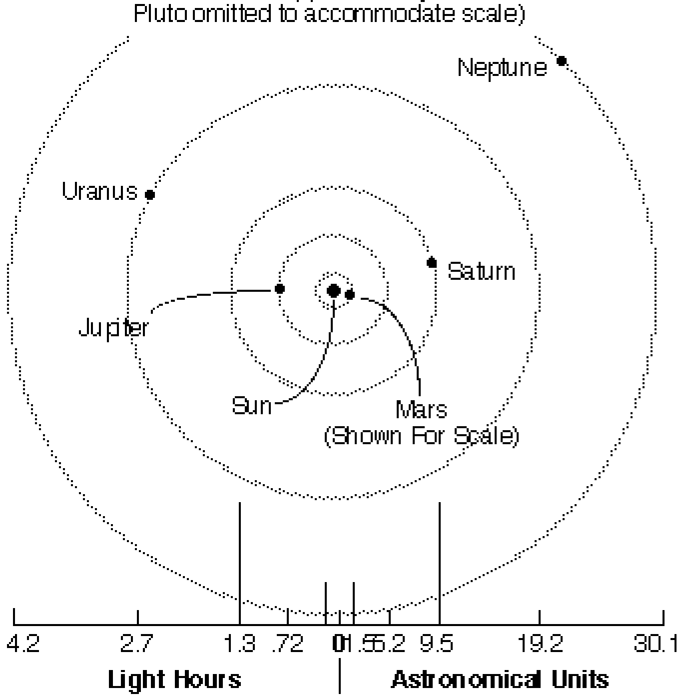
Jupiter is 318 times more massive than Earth. Its radius is 11 times Earth's. Jupiter emits electromagnetic energy from a vast number of charged atomic particles spiraling through the planet's magnetic field--its magnetosphere. Jupiter's magnetic field is 20 to 30 times stronger than Earth's. Jupiter has a single equatorial ring made up of particles probably less than 10 microns in diameter-- about the size of cigarette smoke particles.

Jupiter has many satellites. Each of the four Galilean satellites, so named because Galileo Galilei (1564-1642) discovered them when he turned his telescope toward

Jupiter, exhibits great diversity from the other. Io, the closest Galilean satellite to Jupiter, has active volcanoes, driven by the heat resulting from tidal forces(discussed further in Chapter 3) which flex its crust. Volcanoes are resurfacing the body continuously in the present time. They can now be monitored by Earth-based telescopes. Ganymedehas mountains, valleys, craters, and lava flows. Its ancient surface resembles Earth's moon. Callistois pocked all over with impact craters, revealing the fact that its surface has not changed since the early days of its formation. Europais covered with an extremely smooth shell of water ice. There may be an ocean of liquid water below the shell, warmed by the same forces that heat Io's volcanoes! (Could life exist there?) Saturn's largest moon,Titan, has a hazy nitrogen atmosphere about as dense as Earth's. All of Uranus's 5 largest moons have extremely different characteristics. The surface of Miranda, the smallest, shows evidence of extensive geologic activity. Umbriel's surface is dark, Titaniaand Umbrielhave trenches and faults, and Oberon's impact craters show bright rays similar to those on Callisto. Neptune's moon Tritonis partly covered with nitrogen ice and snow, with active geysers.

Saturn, Uranus, and Neptune all have rings made up of myriad particles of ice, ranging in size from sand to boulders. Jupiter has a thick ring of fine dust, which can be detected at close range in visible light, and from Earth in the infrared. Each particle within a ring is an individual satellite in its own right. When two satellites occupy orbits very close to each other within a ring system, one orbiting farther from the planet than a ring, and the other one orbiting closer to the planet than that ring, they perform like sheep dogs and "flock" the particles between their orbits into a narrow ring, by gravitationally interacting with the ring particles. Thus these satellites are called shepherd moons.

Mean Distances Of The Jovian Planets From The Sun
(Orbits drawn approximately to scale.
Pluto omitted to accommodate scale)

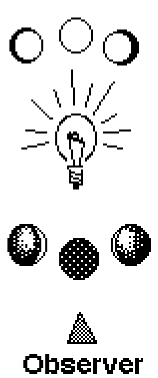


Jovian Planetary Data (Approximate)

	Jupiter	Saturn	Uranus	Neptune
Mean distance from sun	5.2 AU	9.5 AU	19.2 AU	30.1 AU
Light hours from sun	0.72	1.3	2.7	4.2
Mass in terms of Earth's	318	95	15	17
Radius in terms of Earth's	11	9	4	4
Rotation period in hours	9.8	10.7	17.2	16.1
Known natural satellites (1995)	16	18	15	8
Rings	Dust	Extensive system	Thin, dark	Broken ring arcs

Inferior and SuperiorPlanets

Mercury and Venus are referred to as inferior planetsbecause their orbits are closer to the sun than is Earth's orbit. Likewise, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto are known as superior planets because their orbits are farther from the sun than is Earth's. Viewed from Earth, Venus and Mercury go through phases of illuminationlike Earth's moon does. To visualize phases, in a dark room hold a tennis ball up in front of a light bulb, blocking out the bulb from your view (the tennis ball is now in inferior conjunctionwith the bulb, and occulting it).



The unlighted side of the ball that you see is in the new phase, like a new moon. Move the ball slightly off to one side. Watch a bright crescent appear on the ball. Since the ball can be located between you and the bulb, it can be called an inferior ball. You can see that if the ball were directly across on the other side of the light bulb from you (at superior conjunction), one whole side would be fully illuminated: the full phase. Now swivel around 180 degrees, placing your back to the light. Hold the ball out in front of you (it is now a superior ball). Notice its full or near-full phase. Since the superior planets never come between Earth and the sun, they always show a nearly full phase when viewed from Earth. Viewed from superior planets, Earth goes through phases. Superior planets can be seen as crescents only from the vantage point of a spacecraft that is beyond them.

Recap

1051. The terrestrial planets are called terrestrial because they have a compact, ____________________ surface like Earth's.

2. A layer of rapidly moving charged particles known as the __________ ____________ belt is trapped by Earth's magnetic field.

3. Jupiter, Saturn, Uranus, and Neptune are known as the jovian planets because they are all gigantic and have a ______________________ nature like Jupiter's.

4. Jupiter emits electromagnetic energy from a vast number of charged atomic particles spiraling through the _______________ __________________ associated with the planet.

5. Jupiter has satellites of great diversity. Io, which is the closest Galilean satellite to Jupiter, has active ________________.

6. Mars, Jupiter, Saturn, Uranus, and Neptune, and Pluto are known as _____________________ planets because their orbits are further from the sun than is Earth's.

rocky

Van Allen

gaseous

magnetic field

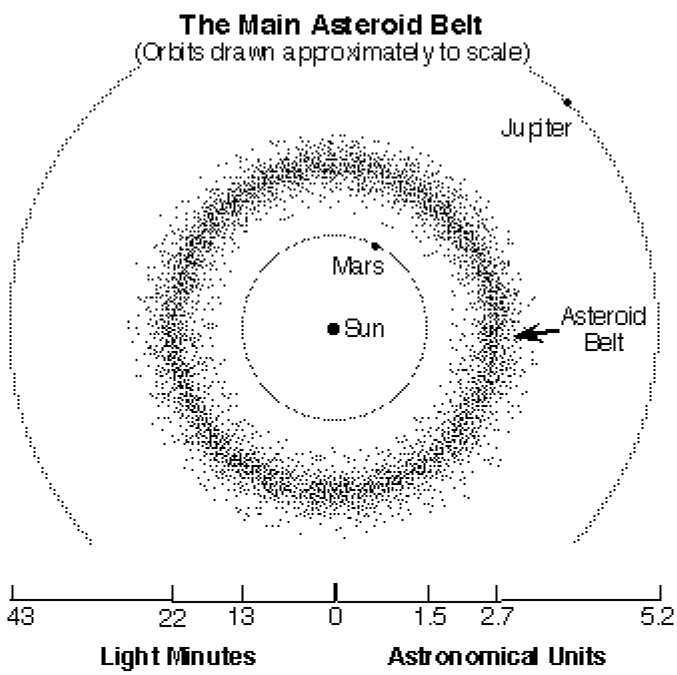
volcanoes

superior

Chapter 1 - Part 3 of 3

Asteroids

Asteroids, also called minor planets, are rocky objects in orbit around the sun. Most asteroids orbit the sun between Mars and Jupiter, moving in the same direction as the planets. Asteroids range in size from Ceres, which has a diameter of about 1000-km, down to the size of pebbles. Sixteen asteroids have a diameter of 240 km or greater. Some asteroids, called Apollo Asteroids, cross the orbit of Earth. It has been estimated that there are around 1000 Earth-crossing asteroids with a diameter of a kilometer or more.

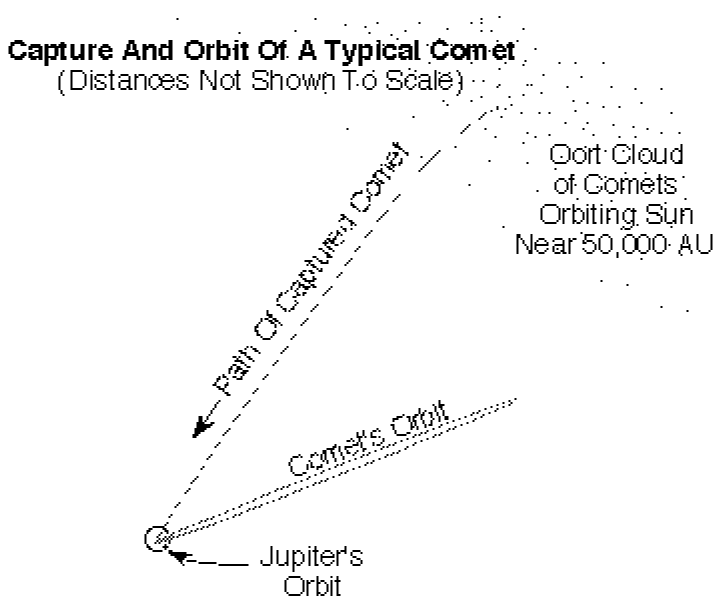


Comets

Most comets are believed to be composed of rocky material and water ice. A few have highly elliptical orbits that bring them very close to the sun and swing them deeply into space, often beyond the orbit of Pluto.

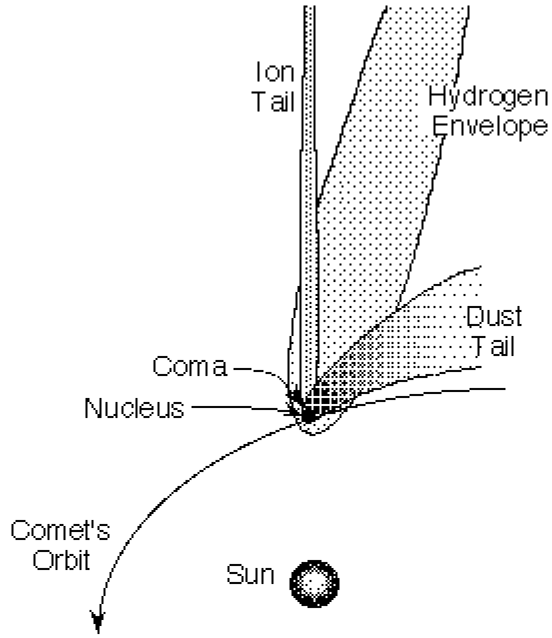
The most widely accepted theory of the origin of comets is that there is a huge cloud of comets called the Oort Cloud(after the Dutch Astronomer Jan H. Oort who proposed the theory), of perhaps 1011 comets orbiting the sun at a distance of about 50,000 AU (just under a light year). These comets are near the boundary between the gravitational forces of the sun and the gravitational forces of other stars with which the sun comes into interstellar proximity every several thousand years. According to the theory, these stellar passings perturb the orbits of the comets within the Oort cloud. As a result, some comets may be captured by the visiting star, some may be lost to interstellar space, and some may begin to "fall" toward the sun. Actually, the comet is still in orbit around the sun as it "falls." However, the orbit has been modified from a relatively circular orbit to an extremely elliptical one. These are the comets we observe.

A comet entering our planetary system may come under the gravitational influence of the planets as it comes within about 30 AU, especially Jupiter which is at about 5 AU, and its path may be perturbed again. A comet may be accelerated onto a hyperbolic (open) curve, which will cause it to leave the solar system. Unlike the planets that have orbits in nearly the same plane, comet orbits are oriented randomly in space. Comets have been known to break up on closest approach to the sun. Discovered early in 1993, comet Shoemaker-Levy9 had broken up apparently because of its close passage to Jupiter. It had been captured into orbit about Jupiter and would collide with the planet in July of 1994. The spectacular collision was widely observed.



Comet structures are diverse and very dynamic, but they all develop a surrounding cloud of diffuse material, called a coma, that usually grows in size and brightness as the comet approaches the sun. The dense, inner coma often appears point-like, but the actual nucleus is rarely seen from Earth because it is too small and dim. The coma and the nucleus together constitute the head of the comet.

Components Of Comets



As many comets approach the sun they develop enormous tails of luminous material that extend for millions of kilometers from the head, away from the sun. When far from the sun, the nucleus is very cold and its material is frozen solid within the nucleus. In this state comets are sometimes referred to as a "dirty iceberg" or "dirty snowball," since over half of their material is ice. When a comet approaches within a few AU of the sun, the surface of the nucleus begins to warm, and volatiles evaporate. The evaporated molecules boil off and carry small solid particles with them, forming the comet's coma of gas and dust.

When the nucleus is frozen, it can be seen only by reflected sunlight. However, when a coma develops, dust reflects still more sunlight, and gas in the coma absorbs ultraviolet radiation and begins to fluoresce. At about 5 AU from the sun, fluorescence usually becomes more intense than reflected light.

As the comet absorbs ultraviolet light, chemical processes release hydrogen, which escapes the comet's gravity, and forms a hydrogen envelope. This envelope cannot be seen from Earth because its light is absorbed by our atmosphere, but it has been detected by spacecraft.

The sun's radiation pressure and solar wind accelerate materials away from the comet's head at differing velocities according to the size and mass of the materials. Thus, relatively massive dust tails are accelerated slowly and tend to be curved. The ion tail is much less massive, and is accelerated so greatly that it appears as a nearly straight line extending away from the comet opposite the sun.

Each time a comet visits the sun, it loses some of its volatiles. Eventually, it becomes just another rocky mass in the solar system. For this reason, comets are said to be short-lived, on a cosmological time scale. Many scientists believe that some asteroids are extinct comet nuclei, comets that have lost all of their volatiles.

Meteoroids

Meteoroids are small, often microscopic, solid particles that are in orbit around the sun. We see meteoroids as bright meteors when they enter Earth's atmosphere at high speed as they burn up from frictional heat. Any part of a meteor that reaches the ground is called a meteorite. As volatiles boil off from comets they carry small solid particles with them. Particles released from comets in this way becomes a source for meteoroids, causing meteor showers as the Earth passes through them. Meteoroids also come from the asteroid belt.

Recap

1. Asteroids, also called minor planets, are ____________________ objects in orbit around the sun.

2. Most asteroids orbit the sun between ______________________ and _____________________________.

3. Close stellar passings perturb the orbits of the comets within the ___________________ cloud.

4. Unlike the planets that have orbits in nearly the same plane, comets are oriented _____________________ in space.

5. On a comet, when a coma develops, dust reflects still more sunlight, and gas in the coma absorbs ultraviolet radiation and begins to ______________________________.

6. Meteoroids are small (often microscopic) solid particles that are in orbit around the _______________________.

rocky

Mars and Jupiter

Oort

randomly

fluoresce

sun

Chapter 2 - Part 1 of 3

Objectives of this Chapter:

Upon completion of this chapter you will be able to describe the system of terrestrial coordinates, the rotation of Earth, precession, and the revolution of Earth about the sun. You will be able to describe how the locations of celestial objects are stated in the coordinate systems of the celestial sphere. You will be able to describe various conventions of timekeeping.

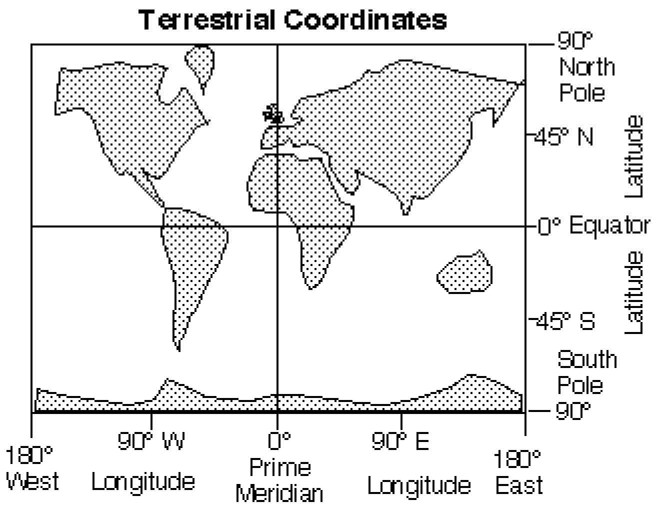
In order to explore the solar system, coordinates must be developed to consistently identify the locations of the observer, of the natural objects in the solar system, and of any spacecraft traversing interplanetary space or orbiting a planet.

Because space is observed from Earth, Earth's coordinate system must be established before space can be mapped. Earth rotates on its axis daily and revolves around the sun annually. These two facts greatly complicated the history of observing space. However, once known, accurate maps of Earth could be made using stars as reference points, since most of the stars' angular movements in relationship to each other are not readily noticeable during a human lifetime. Although the stars do move with respect to each other, this movement is observable for only a few close stars, using instruments and techniques of great precision and sensitivity (historically, the starry sky has been called "the firmament").

Terrestrial Coordinates

A great circle is an imaginary circle on the surface of a sphere whose center is at the center of the sphere. The equatoris a great circle. Great circles that pass through both the north and south poles are called meridians, or lines of longitude. For any point on the surface of Earth a meridian can be defined. The prime meridian, the starting point measuring the east-west locations of other meridians, marks the site of the old Royal Observatory in Greenwich, England. Longitude is expressed in degrees, minutes, and seconds of arc from 0 to 180 degrees eastward or westward from the prime meridian. For example, downtown Pasadena is located at 118 degrees, 8 minutes, 41 seconds of arc westward of the prime meridian: 118 degrees 8' 41" W.

The starting point for measuring north-south locations on Earth is the equator (the equator is the imaginary circle around the Earth which is everywhere equidistant from the poles). Circles in parallel planes to that of the equator define north-south measurements called parallels, or lines of latitude. Latitude is also expressed in degrees, minutes, and seconds of the arc subtended from the center of the Earth. Downtown Pasadena is located at 34 degrees, 08 minutes, 44 seconds of arc north of the equator: 34deg. 08' 44" N.



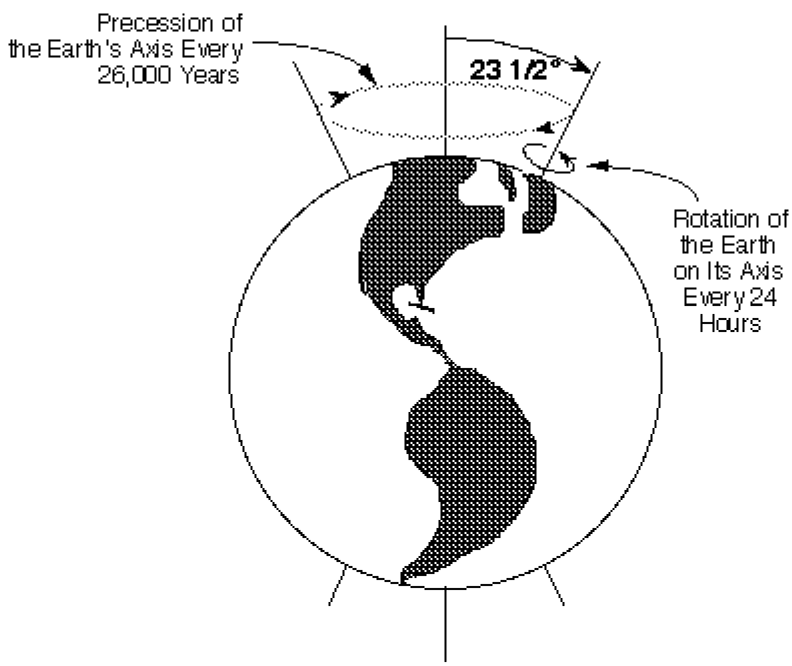
Rotation of Earth

The Earth rotates on its axis relative to the sun every 24.0 hours mean solar time, with an inclinationof 23.5 degrees from the plane of its orbit around the sun. Mean solar timerepresents an average of the variations caused by Earth's non-circular orbit. Its rotation relative to the other stars (sidereal time) is 3 minutes 56.55 seconds shorter than the mean solar day, the equivalent of one solar day per year. Forces associated with the rotation of Earth cause it to be slightly oblate, displaying a bulge (oblateness) at the equator.

Precessionof the Earth Axis

The moon's gravity, primarily, and to a lesser degree the sun's gravity acting on Earth's oblatenesstries to move Earth's axis perpendicular to the plane of Earth's orbit. However, due to gyroscopic action, Earth's poles do not "right themselves" to a position perpendicular to the orbital plane. Instead, they precess at 90 degrees to the force applied. This precession causes the axis of Earth to describe a circle having a 23.5 degree radius relative to a fixed point in space over about 26,000 years, a slow wobble reminiscent of the axis of a spinning top swinging around.

Precession of the Earth



Revolutionof Earth

Earth revolves around the sun in 365 days, 6 hours, 9 minutes with reference to the stars. Its mean orbital speed is about 100,000 km per hour. The 6 hours, 9 minutes adds up to about an extra day every fourth year, which is designated a leap year, with the extra day added as February 29th. Earth's orbit is elliptical and reaches its closest approach to the sun (perihelion) on about January fourth of each year.

Recap

1. Most of the stars' movements in relationship to each other are not readily noticeable during a ___________________ ________________________ .

2. Longitude is expressed in degrees, minutes, and seconds of arc from 0 to 180 degrees eastward or westward from the __________________ ______________________ .

3. North-south measurements on the surface of Earth are called _____________________ , or lines of ________________ .

4. Forces associated with the __________________________ of Earth cause it to be

slightly oblate.

5. Precession causes the axis of Earth to describe a circle having a ______________________ - degree radius over a period of about ____________________ years.

6. Earth's orbit is _______________________ (in shape).

human lifetime

prime meridian

parallels...latitude

rotation

23.5 ... 26,000

elliptical

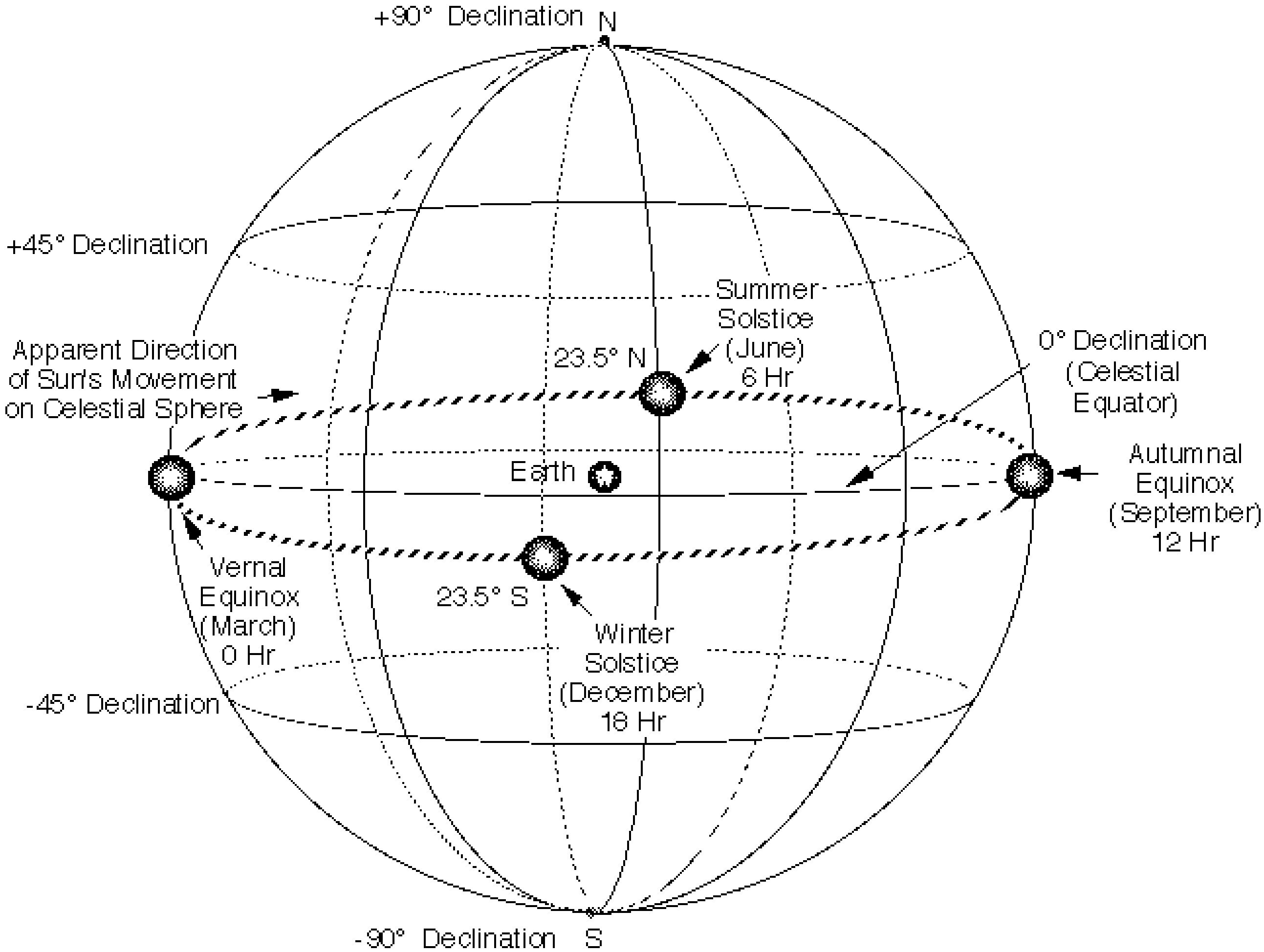
Chapter 2 - Part 2 of 3

The Celestial Sphere

To establish a consistent coordinate system for the sky, a celestial sphere has been conceived. The center of the celestial sphere is the center of Earth. The celestial sphere has an imaginary radius larger than the distance to the farthest observable object in the sky. The extended rotational axis of Earth intersects the north and south poles of the celestial sphere.

The direction to any star or other object can be plotted in two dimensions on the inside of this sphere. The apparent constancy of observed stellar positions allows the preparation of long-lived sky almanacs that identify the direction on the celestial sphere to the observable stars. The apparent direction to the sun, moon, planets, spacecraft, or any object in our solar system can also be plotted on the inside of the celestial sphere. However, these objects all move fairly rapidly in apparent angular distance with respect to the "stationary" stars plotted on the celestial sphere, causing their plots to need regular updating.

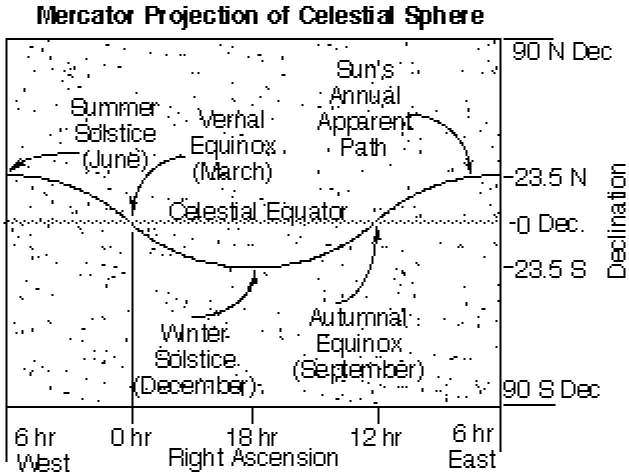
A coordinate system analogous to Earth's latitude and longitude has been devised for the celestial sphere to designate positions on the sphere.



Right Ascension, Declination, and Related Terms

Right ascension (RA)is angular distance measured in hours, minutes, and seconds of the 24-hour circle along the celestial equator eastward from the vernal equinox. The vernal equinox is that point of the celestial sphere where the sun's path crosses the celestial equator going from south to north each year. Declination (DEC)is angular distance measured in degrees north or south of the celestial equator (+90 to -90 degrees). Zenithis imagined as a point straight up from any point on the surface of Earth. Observer's Meridianis an arc on the celestial sphere extending from the north to the south celestial poles that passes through the observer's zenith. The Nadiris the direction opposite the zenith: for example, straight down from a spacecraft to the center of the planet.

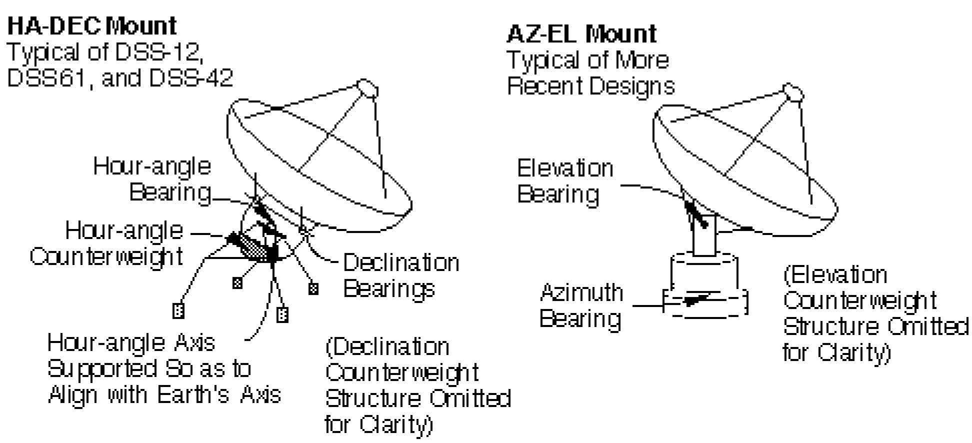
Hour angle (HA)is the angular distance measured westward along the celestial equator from the zenith crossing. In effect, HA represents the RA for a particular location and time of day.



RA, HA and DEC are references within a system based on the Earth's equator and poles. There is a simpler system, which uses the local horizon as its reference. Its measurements are elevation (or altitude), EL (or ALT), in degrees above the horizontal, and azimuth (AZ), in degrees clockwise around the horizon from true north. In such a system East is 90 degrees AZ, and halfway up in EL or ALT would be 45 degrees. AZ-EL and ALT-AZ are simply different names within the same reference system.

Telescopes, radio telescopes, and JPL's Deep Space Station antennas are designed with mountings that are engineered to take best advantage of either the HA-DEC coordinate system or the AZ-EL (ALT-AZ) system.

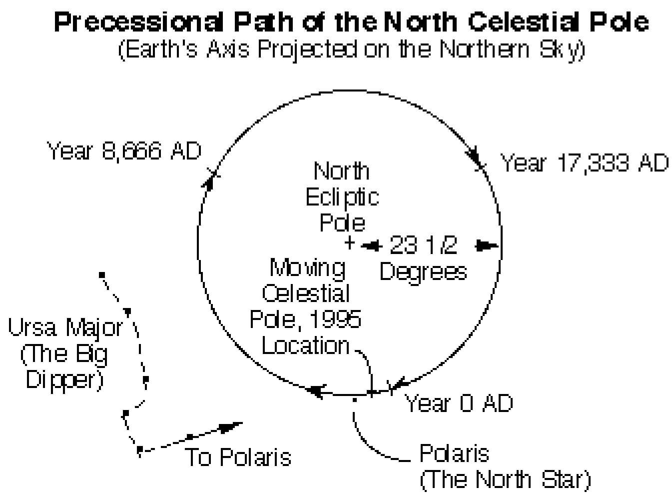
In an HA-DEC system, the HA axis is parallel to the Earth's rotational axis. Thus the mounting built for a telescope near the equator would appear different from one built for use in high latitudes. ALT-AZ or AZ-EL systemswould appear the same no matter where on Earth they are being used.



HA-DEC antenna mounting systems require an asymmetrical structural design unsuited to the support of very heavy structures. Their advantage is that motion is required mostly in only one axis to track an object as the Earth rotates, although this advantage has largely been obviated by the use of digital computers that can drive both axes of

AZ-EL systems properly while they track.

Because of the precession of the poles over 26,000 years, all the stars appear to shift over time, and sky almanacs must be occasionally updated. Precession causes the stars to appear to shift west to east at the rate of .01 degree (360 degrees/ 26,000 years) with respect to the vernal equinox each year. Sky almanacs identify the date and time of the instant used as the date of reference, or epoch, when preparing the almanac, and provide equations for updating data based on the almanac to the current date.



At the present time in Earth's 26,000 year precession cycle, a bright star coincidentally happens to be very close (less than a degree) from the north celestial pole. This star is called Polaris, or the North Star.

Recap

1. The center of the celestial sphere is the center of the ______________________ .

2. The ____________________ _______________________ is the point of the celestial sphere where the Sun's path crosses the celestial equator going from south to north.

3. A coordinate system analogous to Earth's longitude and latitude to designate positions on the celestial sphere (uses) measurements called _______________________ and _______________________ .

4. ________________________ is the angular distance measured north or south of the celestial equator (+90 to -90deg.).

5. Because the precession of the poles over a period of 26,000 years, all the stars appear to move very slowly, and sky almanacs must be occasionally ___________________________.

Earth

vernal equinox

RA ... DEC

DEC

updated

Chapter 2 - Part 3 of 3

Time Conventions

Various measurements of time are used in interplanetary space flight:
Universal Time Coordinated (UTC)is the world-wide scientific standard of timekeeping. It is based upon carefully maintained atomic clocks and is kept accurate to within microseconds. The addition or subtraction of leap seconds, as necessary, at two opportunities every year keeps UTC in step with Earth's rotation. Being the most precise worldwide time system, it is used by astronomers, navigators, the Deep Space Network(DSN), and other scientific disciplines. Its reference point is Greenwich, England: when it is midnight there on Earth's prime meridian, it is midnight (00:00:00.000000) -- "all balls"--UTC.

UT1, or simply UT, Universal Time, was previously called Greenwich Mean Time, GMT. It is based on the imaginary "mean sun," which averages out the effects on the length of the solar day caused by Earth's slightly non-circular orbit about the sun. UT is not updated with leap seconds as is UTC. Its reference point is also Greenwich, England: when it is noon on the prime meridian, it is noon (12:00:00) UT.

Local timeis adjusted for location around the Earth or other planets in time zones. On Earth, many countries adjust for standard time or daylight-savings time. Its reference point is one's immediate locality: when it is 12:00:00 noon Pacific Daylight Time (PDT) at JPL, it is 19:00:00 UTC, and 13:00:00 in Denver. Local time on another planet is conceived as the equivalent time for the height of the sun above the horizon, corresponding to the same local time on Earth. It has no bearing to the planet's rotation rate. Thus around 11:30 am or 12:30 pm at a particular location on Venus, the sun would be nearly overhead. At 5:00 pm at a particular location on Mars, the sun would be low in the west.

Earth-received time (ERT)is the UTC of an event received at a DSN station. One-way light time (OWLT)is the elapsed time it takes for light, or a radio signal, to reach a spacecraft or other body from Earth (or vice versa). Knowledge of OWLT is maintained to an accuracy of milliseconds. OWLT varies continuously as the spacecraft's distance from the Earth changes. Its reference points are the center of the Earth and the immediate position of a spacecraft or the center of a celestial body. Transmission time (TRM)is the UTC time of uplink from Earth.

Round-trip light time (RTLT)is the elapsed time it takes for a signal to travel from Earth, be received and immediately transmitted or reflected by a spacecraft or other body, and return to the starting point. It is roughly equal to 2 x OWLT, but not exactly, because of the different amount of distance the signal must travel on each leg due to the constant motions of both Earth and spacecraft. RTLT from here to the Earth's Moon is around 3 seconds, to the sun, about 17 minutes. Voyager 1's RTLT at this writing in December 1995 is over 17 hours.

Spacecraft event time (SCET)is the UTC time onboard the spacecraft. It is equal to TRM + OWLT. ERT is equal to SCET + OWLT. Spacecraft clock time (SCLK), is the value of a counter onboard a spacecraft as described in Chapter 11. SCET has a nearly-direct relationship with SCLK, although the units of measurement are different, and SCLK is not as constant and stable as the UTC-derived SCET. Tracking the exact relationship between SCLK and SCET is accomplished by analyzing telemetered SCLK values and trends with respect to UTC-derived SCET, and producing a SCLK/SCET coefficients file which tracks the gradual drift of SCLK versus SCET.

Terrestrial Time (TT)was previously called Terrestrial Dynamical Time (TDT), which replaced EphemerisTime. TT is a measurement of time defined by Earth's orbital motion. It equates to Mean Solar Time corrected for the irregularities in Earth's motions.

This excerpt from a flight project's Integrated Sequence of Events (ISOE)illustrates use of UTC, ERT, TRM, RTLT, SCET, and SCLK. (ISOE is discussed further in Chapter 15.).

ID: 93-24 F SOE YEAR-DAY: 93-171 PRINTED ON DAY 93-168 PAGE 142
MAGELLAN MISSION OPERATIONS
SEQUENCE OF EVENTS WEEK: 24 DOY: 169-175 RTLT = 12:56.354

ITEM NO.	GND TIME DOY/HH:MM:SS	T B	EVENT - DESCRIPTION	COMMAND	DSN	SCE TIME DOY/HH:MM:SS	S/C CLOCK
02518	171/01:28:56	E	<< STAR SCANNER PULSE TST >>	7PULS		171/01:22:28	2159880:90:0
02519	171/01:28:58	E	<< STAR SCANNER PULSE TST >>	7PULS		171/01:22:30	2159881:02:0
02520	171/01:28:58	E	<< NO OPERATION >>	6NOP		171/01:22:30	2159881:02:0
02521	171/01:32:37	E	MISC,NOTE,391AG99A,, 93-171/01:26:09.131,APOAPS,GOTHER, A7931			171/01:26:09	2159884:58:0
02522	171/01:33:59	T	ACQ U/L - DSS 42 S BAND		42	171/01:40:27	
02523	171/01:34:21	E	END OF MEMORY READOUT	6MROH			
02524	171/01:34:57	E	MISSION PHASE ORB OPS S/W MODE*ATT REF HOLD	AACS		171/01:28:29	2159886:86:0
02525	171/01:35:01	E	STAR,FSTAR; << MANEUVER SPECIFICATION >>	7MNVR		171/01:28:33	2159887:00:0
02526	171/01:35:01	E	MISSION PHASE ORB OPS S/W MODE*SLEW TO ATT	AACS		171/01:28:33	2159887:00:0

Recap

1. Universal Time (UT) is the mean or average value of UTC: It is a not updated with ________________ seconds as is UTC.

2. When it is 12:00:00. noon Pacific Daylight Time (PDT) at JPL, it is ___________________ UTC.

3. (The abbreviation) __________________ is the UTC time on board the spacecraft. It is equal to UTC + OWLT.

4. Spacecraft Clock time (SCLK) is the value of a ________________________ on board a spacecraft.

leap

1900

SCET

counter

Chapter 3 - Part 1 of 4

Objectives of this Chapter:

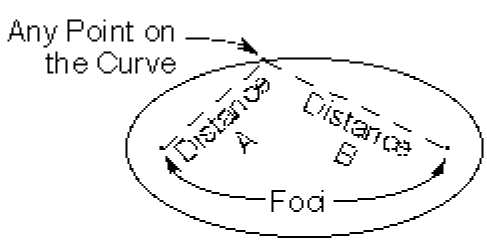
Upon completion of this chapter you will be able to describe the force of gravity, characteristics of ellipses, and the concepts of Newton's principles of mechanics. You will be able to recognize acceleration in orbit and explain Kepler's laws in general terms. You will be able to describe tidal effect and how it is important in planetary systems.

Gravitation is the mutual attraction of all masses in the universe. The concepts associated with planetary motions developed by Johannes Kepler (1571-1630) describe the positions and motions of objects in our solar system. Isaac Newton (1643-1727) explained why Kepler's laws worked, in terms of gravitation. Since planetary motions are orbits, and all orbits are ellipses, a review of ellipses follows.

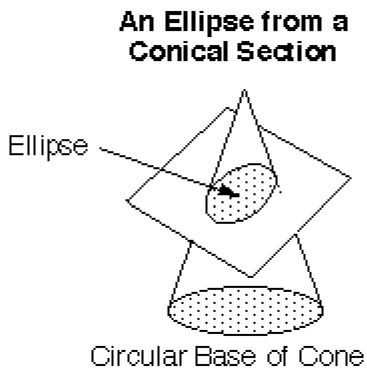
Ellipses

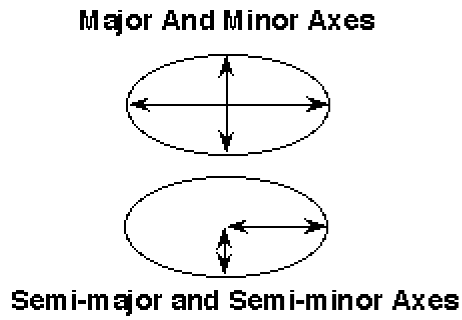
An ellipse is a closed plane curve generated in such a way that the sums of its distances from two fixed points (called the foci) is constant. In the illustration below, Distance A + B is constant for any point on the curve.

Ellipse Foci

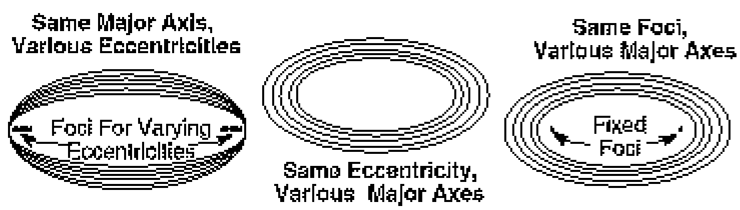


An ellipse also results from the intersection of a circular cone and a plane cutting completely through the cone. The maximum diameter is called the major axis. It determines the size of an ellipse. Half the maximum diameter, the distance from the center of the ellipse to one end, is called the semi-major axis.





The shape of an ellipse is determined by how close together the foci are in relation to the major axis. Eccentricityequals the distance between the foci divided by the major axis. If the foci coincide, the ellipse is a circle. Therefore, a circle is an ellipse with an eccentricity of zero.



Recap

1. The definition of an ellipse is a closed plane curve generated in such a way that the sums of its distances from the two fixed points (the foci) is ___________________ .

2. Eccentricity equals the distance between the foci divided by the __________________ axis.

3. If the foci coincide, the ellipse is a ____________________ .

constant

major

circle

Chapter 3 - Part 2 of 4

Newton's Principles of Mechanics

Newton realized that the forcethat makes apples fall to the ground is the same force that makes the planets "fall" around the sun. Newton had been asked to address the question of why planets move as they do. He established that a force of attraction toward the sun becomes weaker in proportion to the square of the distance from the sun.

Newton postulated that the shape of an orbit should be an ellipse. Circular orbits are merely a special case of an ellipse where the foci are coincident. Newton described his work in the *Mathematical Principles of Natural Philosophy* (often called simply the Principia), which he published in 1685. Newton gave his laws of motion as follows:

1. Every body continues in a state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.

2. The change of motion (linear momentum) is proportional to the force impressed and is made in the direction of the straight line in which that force is impressed.

3. To every action there is always an equal and opposite reaction; or, the mutual actions of two bodies upon each other are always equal, and act in opposite directions.

(Notice that Newton's lawsdescribe the behavior of inertia, they do not explain its nature.)

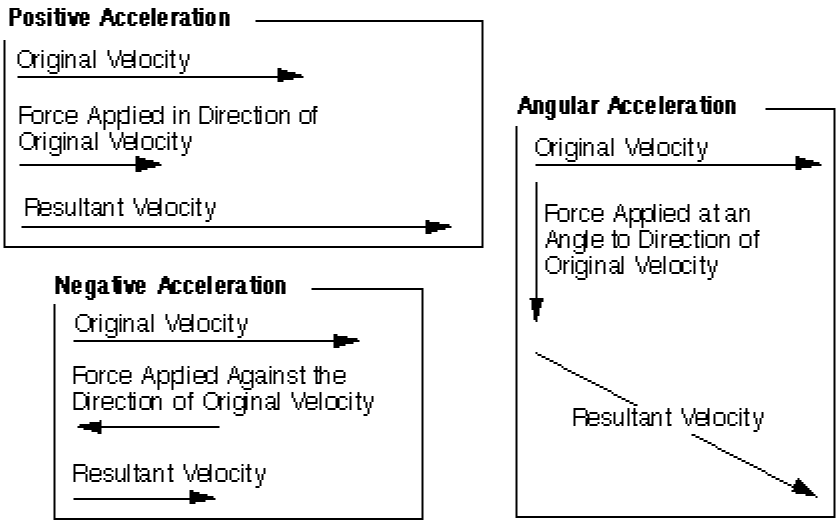
There are three ways to modify the momentum of a body. The mass can be changed, the velocity can be changed (acceleration), or both:

mass (M) x change in velocity (acceleration, A) = force (F)

or

F = MA

Acceleration may be produced by applying a force to an object. If applied in the same direction as an object's velocity, the velocity increases in relation to an unaccelerated observer. If acceleration is produced by applying a force in the opposite direction from the object's original velocity, it will slow down. If the acceleration is produced by a force at some other angle to the velocity, the object will be deflected.



In order to measure mass, we must agree to a standard. The world standard of mass is the kilogram, whose definition is based on the mass of a metal cylinder kept in France. Previously, the standard was based upon the mass of one cubic centimeter of water being one gram (this is approximately correct). Force can now be expressed numerically. A unit of force is the dyne, which is equal to the force required to accelerate a mass of 1 gram 1 cm per second per second. Another is the Newton, the force required to accelerate a 1-kg mass 1 m/sec^2 A Newton is equal to the weight of about 100 g of water or about 1/2 cup.

Recap

1. Gravitation is the mutual _________________ of all masses in the universe.

2. Newton postulated that the shape of an orbit should be an______________________ .

3. Circular orbits are merely a special case of an ellipse where the foci are ____________________ .

4. If acceleration is produced in the opposite direction of velocity, the object will ______________ ___________ .

attraction

ellipse

coincident

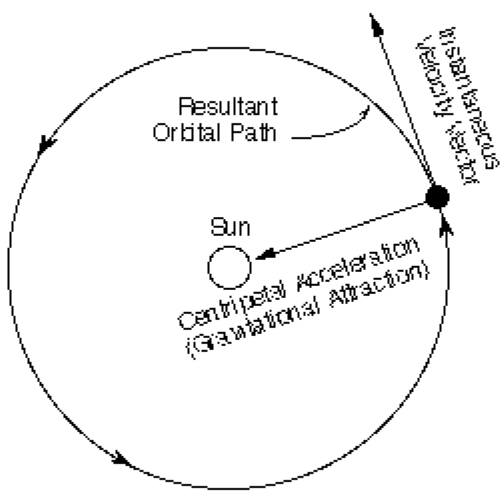
slow down

Chapter 3 - Part 3 of 4

Acceleration in Orbit

Newton's first law describes how, once in motion, planets remain in motion. What it does not do is explain how the planets are observed to move in nearly circular orbits rather than straight lines. Enter the second law. To move in a curved path, a planet must have an acceleration toward the center of the circle. This is called centripetal accelerationand is supplied by the mutual gravitational attraction between the sun and the planet.

Motion in a Circular Orbit



Kepler's Laws

Kepler's laws, as expressed by Newton, are:

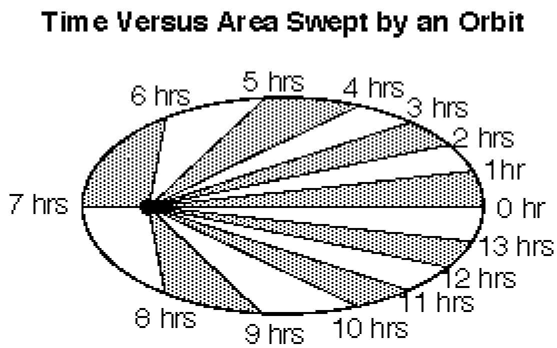
1. If two bodies interact gravitationally, each will describe an orbit that is a conic section about the common mass of the pair. If the bodies are permanently associated, their orbits will be ellipses. If they are not permanently associated with each other, their orbits will be hyperbolas (open curves).

2. If two bodies revolve around each other under the influence of a central force (whether or not in a closed elliptical orbit), a line joining them sweeps out equal areas in the orbital plane in equal intervals of time.

3. If two bodies revolve mutually about each other, the sum of their masses times the square of their period of mutual revolution is in proportion to the cube of the semi-major axis of the relative orbit of one about the other.

The major application of Kepler's first law is to precisely describe the geometric shape of an orbit: an ellipse, unless perturbed by other objects. Kepler's first law also informs us that if a comet, or other object, is observed to have a hyperbolic path, it will visit the sun only once, unless its encounter with a planet alters its trajectory again.

Kepler's second law addresses the velocity of an object in orbit. Conforming to this law, a comet with a highly elliptical orbit has a velocity at closest approach to the sun that is many times its velocity when farthest from the sun. Even so, the area of the orbital plane swept is still constant for any given period of time.



Kepler's third law describes the relationship between the masses of two objects mutually revolving around each other and the determination of orbital parameters. Consider a small star in orbit about a more massive one. Both stars actually revolve about a common center of mass, which is called the barycenter. This is true no matter what the size or mass of each of the objects involved. Measuring a star's motion about its barycenter with a massive planet is one method that has been used to discover planetary systems associated with distant stars.

Obviously, these statements apply to a two-dimensional picture of planetary motion, which is all that is needed for describing orbits. A three-dimensional picture of motion would include the path of the sun through space.

Gravity Gradients (Tidal Forces)

Gravity's strength is inversely proportional to the square of the objects' distance from each other. For an object in orbit about a planet, the parts of the object closer to the planet feel a slightly stronger gravitational attraction than do parts on the other side of the object. This is known as gravity gradient. It causes a slight torque to be applied to any mass which is non-spherical and non-symmetrical in orbit, until it assumes a stable attitude with the more massive parts pointing toward the planet. An object whose mass is distributed like a bowling pin would end up in an attitude with its more massive end pointing toward the planet, if all other forces were equal.

In the case of a fairly massive body such as our moon in Earth orbit, the gravity gradient effect has caused the moon, whose mass is unevenly distributed, to assume a stable rotational rate which keeps one face towards Earth at all times, like the bowling pin described above.

The moon acts upon the Earth's oceans and atmosphere, causing two bulges to form. The bulge on the side of Earth that faces the moon is caused by the proximity of the moon and its relatively stronger gravitational pull on that side. The bulge on the opposite side of Earth results from that side being attracted toward the moon less strongly than is the central part of Earth. Earth's crust is also affected to a small degree. Other factors, including Earth's rotation and surface roughness, complicate the tidal effect. On planets or satellites without oceans, the same forces apply, but they cause slight deformations in the body rather than oceanic tides. This mechanical stress can translate into heat as in the case of Jupiter's volcanic moon Io.

Recap

1. To move in a circular path a planet must have applied a constant acceleration toward the center of the circle. This acceleration is called ______________________ acceleration.

2. When closest to the sun, an object is moving at higher velocity than when it is farthest from the sun; however, the _________________________ of the orbital plane swept is constant for any given period of time.

3. (Two) stars actually revolve about a common center of mass, which is called the ________________________ .

4. For an object in orbit about a planet, the parts of the object closer to the planet feel a slightly stronger attraction than do parts on the other side of the object. This is known as _____________________ __________________.

centripetal

area

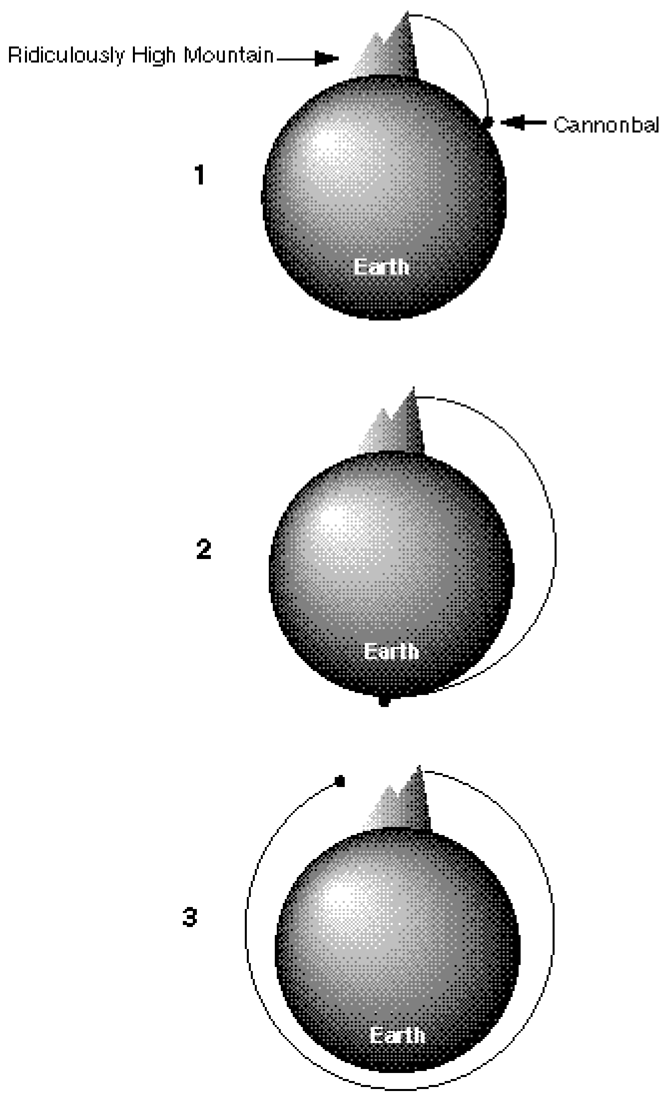
barycenter

gravity gradient

Chapter 3 - Part 4 of 4

How Orbits Work

The drawings below simplify the physics of orbiting Earth. We see Earth with a huge, tall mountain rising from it. The mountain, as Isaac Newton first envisioned, has a cannon at its summit. When the cannon is fired, the cannonball follows its ballistic arc, falling as a result of Earth's gravity, and it hits Earth some distance away from the mountain. If we put more gunpowder in the cannon, the next time it's fired, the cannonball goes halfway around the planet before it hits the ground. With still more gunpowder, the cannonball goes so far that it just never touches down at all. It falls completely around Earth. It has achieved orbit.



If you were riding along with the cannonball, you would feel as if you were falling. The condition is called free fall. You'd find yourself falling at the same rate as the cannonball, which would appear to be floating there (falling) beside you. You'd just never hit the ground. Notice that the cannonball has not escaped Earth's gravity, which is very much present--it is causing the mass to fall. It just happens to be balanced out by the speed provided by the cannon.

In the third drawing in the figure, you'll see that part of the orbit comes closer to Earth's surface that the rest of it does. This is called the periapsisof the orbit. It also has various other names, depending on which body is being orbited. For example, it is called perigee at Earth, perijove at Jupiter, periselene or perilune in lunar orbit, and perihelion if you're orbiting the sun. In the drawing, the mountain represents the highest point in the orbit. That's called apoapsis(apogee, apojove, aposelene, apolune, aphelion). The time it takes, called the orbit period, depends on altitude. At space shuttlealtitudes, say 200 kilometers, it's 90 minutes.

The cannonball provides us with a pretty good analogy. It makes it clear that to get a spacecraft into orbit, you need to raise it up (the mountain) to a high enough altitude so that Earth's atmosphere isn't going to slow it down too much. You have to accelerate it until it is going so fast that as it falls, it just falls completely around the planet. In practical terms, you don't generally want to be less than about 150 kilometers above the surface of Earth. At that altitude, the atmosphere is so thin that it doesn't present much frictional drag to slow you down. You need your rocket (or cannon) to speed the spacecraft up to the neighborhood of 30,000 kilometers (about 19,000 miles) per hour. Once you've done that, your spacecraft will continue falling around Earth. No more propulsion is necessary, except for occasional minor adjustments. These very same mechanical concepts apply whether you're talking about orbiting Earth, the moon, the sun, or anything. Only the terms and numbers are different. The cannonball analogy is good, too, for talking about changes you can make to an orbit. Looking at the third drawing, imagine that the cannon has still more gunpowder in it, sending the cannonball out a little faster. With this extra speed, the cannonball will miss Earth's surface by a greater margin. The periapsis altitude is raised by increasing the spacecraft's speed at apoapsis.

This concept is very basic to space flight. Similarly, decrease the speed when you're at apoapsis, and you'll lower the periapsis altitude. Likewise, if you increase speed when you're at periapsis, this will cause the apoapsis altitude to increase. Decelerating at periapsis will lower the apoapsis.

Recap

1. Periapsis is also called _______________ at Jupiter and _______________ orbiting the sun.

2. The periapsis altitude is _______________ by increasing speed at apoapsis.

3. Decelerating at periapsis will ______________ the apoapsis altitude.

perijove . . . perihelion

raised

lower

Chapter 4   Part 1 of 1

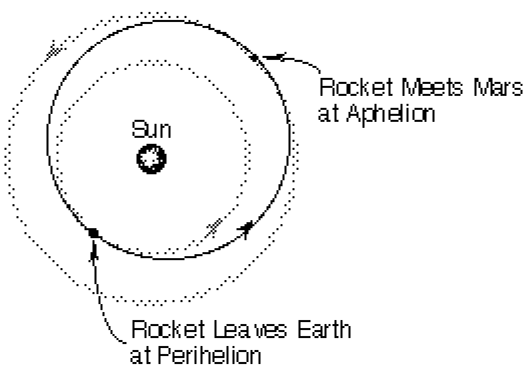
Objectives of this Chapter:

Upon completion of this chapter you will be able to describe the use of Hohmann transfer orbits in general terms, and how spacecraft use them for interplanetary travel. You will be able to describe in general terms the exchange of angular momentum between planets and spacecraft on gravity assist trajectories.

Hohmann TransferOrbits

To launch a spacecraft to an outer planet such as Mars, using the least propellant possible, first consider that the spacecraft is already in solar orbit as it sits on the launch pad. Its existing solar orbit must be adjusted to cause it to take the spacecraft to Mars. In other words, the spacecraft's perihelion (closest approach to the sun) will be Earth's orbit, and the aphelion (farthest distance from the sun) will intercept the orbit of Mars at a single point. This is called a Hohmann Transfer Orbit. The portion of the solar orbit that takes the spacecraft from Earth to Mars is called its trajectory.

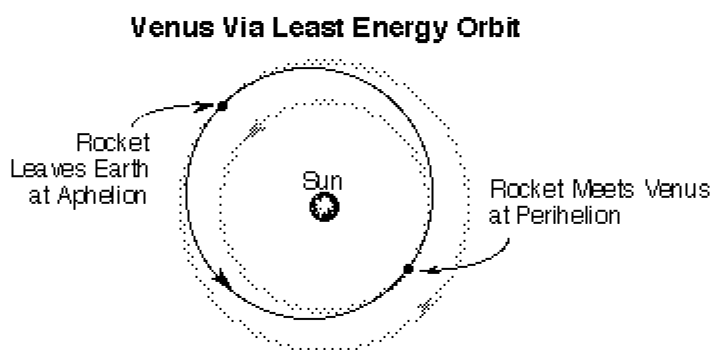
Mars Via Least Energy Orbit



To achieve such a trajectory, the spacecraft lifts off the launch pad, rises above Earth's atmosphere, and is accelerated in the direction of Earth's revolution around the sun to the extent that it becomes free of Earth's gravitation, and that its new orbit will have an aphelion equal to Mars' orbit. After a brief acceleration away from Earth, the spacecraft has achieved its new orbit, and it simply coasts the rest of the way. To get to the planet Mars, rather than just to its orbit, requires that the spacecraft be inserted into the interplanetary trajectory at the correct time to arrive at the Martian orbit when Mars will be at the point where the spacecraft will intercept the orbit of Mars. This task might be compared to throwing a dart at a moving target. You have to lead the aim point by just the right amount to hit the target. The opportunity to launch a spacecraft on a transfer orbit to Mars occurs about every 25 months.

To be captured into a Martian orbit, the spacecraft must then decelerate relative to Mars (using a retrograde rocket burn or some other means). To land on Mars, the spacecraft must decelerate even further (using a retrograde burn, or spring release from a mother ship) to the extent that the lowest point of its Martian orbit will intercept the surface of Mars. Since Mars has an atmosphere, final deceleration may be performed by aerodynamic braking, and/or a parachute, and/or further retrograde burns.

To launch a spacecraft to an inner planet such as Venus using the least propellant possible, its existing solar orbit must be adjusted so that it will take it to Venus. In other words, the spacecraft's aphelion will be on Earth's orbit, and the perihelion will be on the orbit of Venus. As with the case of Mars, the portion of this orbit that takes the spacecraft from Earth to Venus is called a trajectory. To achieve an Earth to Venus trajectory, the spacecraft lifts off of the launch pad, rises above Earth's atmosphere, and is accelerated opposite the direction of Earth's revolution around the sun (decelerated) to the extent that its new orbit will have a perihelion equal to Venus's orbit. Of course the spacecraft will end up going in the same direction as Earth orbits, just a little slower. To get to Venus, rather than just to its orbit, again requires that the spacecraft be inserted into the interplanetary trajectory at the correct time to arrive at the Venusian orbit when Venus will be at the point where the spacecraft will intercept the orbit of Venus. Venus launch opportunities occur about every 19 months.

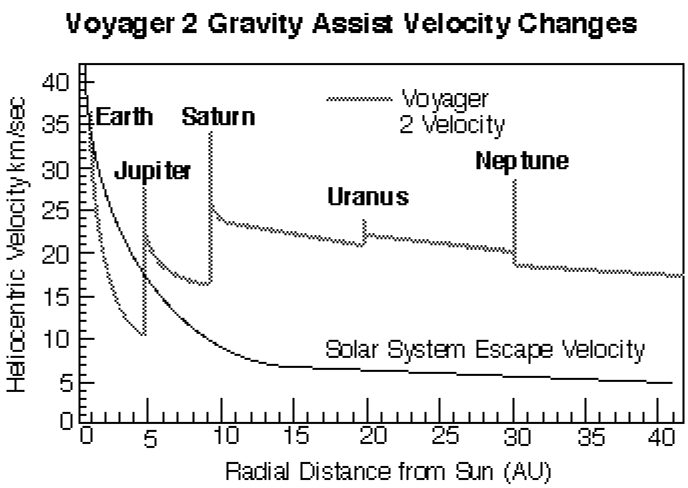


Gravity Assist Trajectories

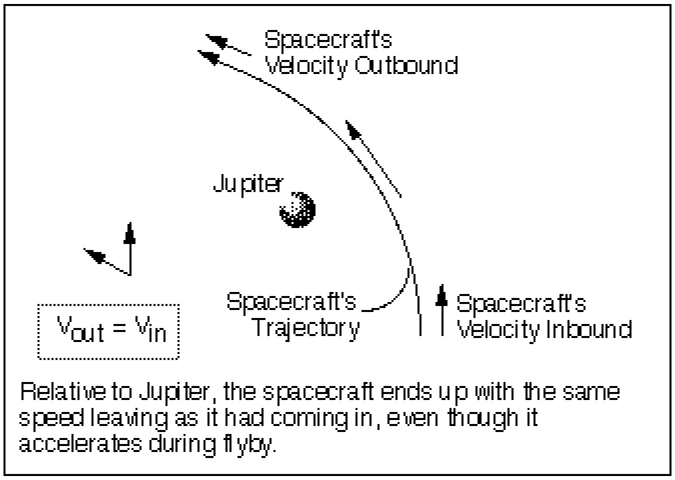
The first chapter pointed out that the planets retain the vast majority of the solar system's angular momentum. It is this momentum that is used to accelerate spacecraft on so-called "gravity-assist" trajectories. It is commonly stated in newspapers that spacecraft such as Voyager and Galileouse a planet's gravity during a flyby to slingshot it farther into space. How does this work? In a gravity-assist trajectory, angular momentum is transferred from the orbiting planet to a spacecraft approaching from behind. Gravity assists would be more accurately described as angular-momentum assists.

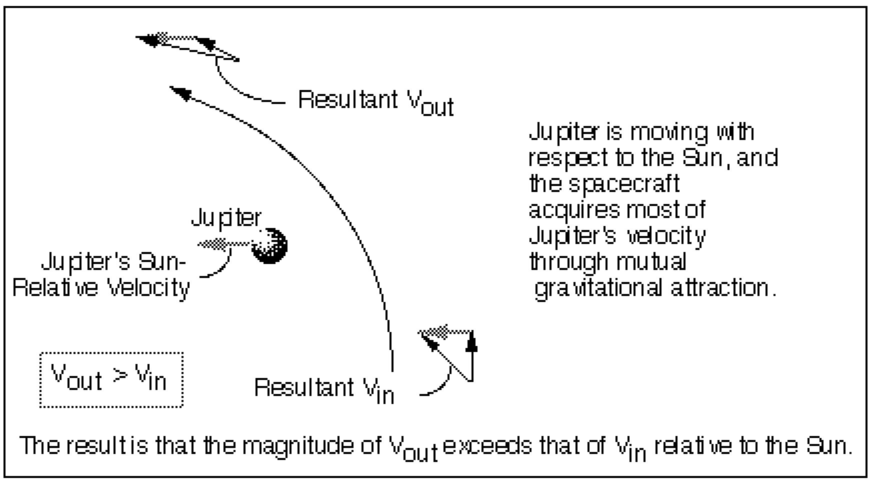
Consider Voyager 2, which toured the Jovian planets. The spacecraft was launched on a standard Hohmann transfer orbit to Jupiter. Had Jupiter not been there at the time of the spacecraft's arrival, the spacecraft would have fallen back toward the sun, and would have remained in elliptical orbit as long as no other forces acted upon it. Perihelion would have been at 1 AU, and aphelion at Jupiter's distance of about 5 AU.

However, the spacecraft's arrival was carefully timed so that it would pass behind Jupiter in its orbit around the sun. As the spacecraft came into Jupiter's gravitational influence, it fell toward Jupiter, increasing its speed toward maximum at closest approach to Jupiter. Since all masses in the universe attract each other, Jupiter sped up the spacecraft substantially, and the spacecraft slowed down Jupiter in its orbit by a tiny amount, since the spacecraft approached from behind. As the spacecraft passed by Jupiter (its speed was greater than Jupiter's escape velocity), of course it slowed down again relative to Jupiter, climbing out of Jupiter's gravitational field. Its Jupiter-relative velocity outbound was the same as its velocity inbound. But relative to the sun, it never slowed all the way to its initial approach speed. It left the Jovian environs carrying an increase in angular momentum stolen from Jupiter. Jupiter's gravity served to connect the spacecraft with the planet's huge reserve of angular momentum. This technique was repeated at Saturn and Uranus.



The same can be said of a baseball's acceleration when hit by a bat: angular momentum is transferred from the bat to the slower-moving ball. The bat is slowed down in its "orbit" about the batter, accelerating the ball greatly. The bat connects to the ball not with the force of gravity from behind as was the case with a spacecraft, but with direct mechanical force (electrical force, on the molecular scale, if you prefer) at the front of the bat in its travel about the batter, translating angular momentum from the bat into a high velocity for the ball.





Gravity assists can be also used to decelerate a spacecraft, by flying in front of a body in its orbit, donating some of the spacecraft's angular momentum to the body. When the Galileo spacecraft arrived at Jupiter, passing close in front of Io in its orbit, Galileo experienced deceleration, helping it achieve Jupiter orbit insertion.

The gravity assist technique was pioneered by Michael Minovitch in the early 1960s. He was a UCLA graduate student who worked summers at JPL.

Recap

1. To launch a spacecraft to an outer planet such as Mars its existing _________________ __________________ must be adjusted to cause it to take it to Mars.

2. The portion of the solar orbit that takes the spacecraft from Earth to Mars is called a _____________________ .

3. To get to Mars, rather that just its orbit, will require that the spacecraft be inserted into the interplanetary trajectory at the correct ____________________ .

4. To orbit Mars, the spacecraft must ______________________ sufficiently to be captured in a martian orbit.

5. In a gravity-assist trajectory, ____________________ ______________________ is transferred from the orbiting planet to a spacecraft approaching from behind.

solar orbit

trajectory

time

decelerate

angular momentum

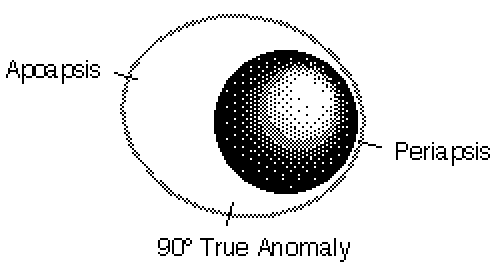
Chapter 5   Part 1 of 1

Objectives of this Chapter:

Upon completion of this chapter you will be able to describe, in general terms, the characteristics of various types of planetary orbits. You will be able to describe the general concepts and advantages of geosynchronous orbits, polar orbits, walking orbits, sun-synchronous orbits, and some requirements for achieving them.

Orbital Parameters and Elements

(Note: The terms orbit period, periapsis, apoapsis, etc., were introduced at the end of Chapter 3). The direction a body travels in orbit can be direct, or prograde, in which the spacecraft moves in the same direction as the planet rotates, or retrograde, going in a direction opposite the planet's rotation. True anomalyis a term used to describe the locations of various points in an orbit. It is the angular distance of a point in an orbit past the point of periapsis, measured in degrees. For example, a spacecraft might cross a planet's equator at 10° true anomaly. Nodesare points where an orbit crosses a plane. As an orbiting body crosses the ecliptic plane going north, the node is referred to as the ascending node; going south, it is the descending node.



To completely describe an orbit mathematically, six quantities must be calculated. These quantities are called orbital elements, or Keplerian elements. They are: Semi-major axis (1) and eccentricity (2), which are the basic measurements of the size and shape of the orbit's ellipse (described in Chapter 3. Recall an eccentricity of zero indicates a circular orbit). The orbit's inclination(3) is the angular distance of the orbital plane from the plane of the planet's equator (or from the ecliptic plane, if you're talking about heliocentric orbits), stated in degrees: an inclination of 0 degree. means the spacecraft orbits the planet at its equator, and in the same direction as the planet rotates. An inclination of 90 degrees indicates a polar orbit, in which the spacecraft passes over the north and south poles of the planet. An inclination of 180 degrees indicates an equatorial orbit in which the spacecraft moves in a direction opposite the planet's rotation (retrograde). The argument of periapsis (4) is the argument (angular distance) of periapsis from the ascending node. Time of periapsis passage(5) and the celestial longitude of the ascending node (6) are the remaining elements. Generally, three astronomical or radiometric observations of an object in an orbit are enough to pin down each of the above six Keplerian elements.

Elements of Magellan's Initial Orbit at Venus

(1)	Semimajor Axis:	10434.162 km
(2)	Eccentricity:	0.2918967
(3)	Inclination:	85.69613°
(4)	Argument of Periapsis:	170.10651°
(5)	1990 Day of Year	222 19:54 UTC ERT
(6)	Longitude of Ascending Node:	-61.41017°
	(Orbital Period:	3.26375 hr)

Types of Orbits

GeosynchronousOrbits

A geosychronous orbit (GEO) is a direct, circular, low inclination orbit about Earth having a period of 23 hours 56 minutes 4 seconds . A spacecraft in geosynchronous orbit maintains a position above Earth constant in longitude. Normally, the orbit is chosen and station keeping procedures are implemented, to constrain the spacecraft's apparent position so that it hangs motionless above a point on Earth. In this case, the orbit may be called geostationary. For this reason this orbit is ideal for certain kinds of communication satellites, or meteorological satellites. To attain geosynchronous orbit, a spacecraft is first launched into an elliptical orbit with an apoapsis altitude in the neighborhood of 37,000 km. This is called a Geosynchronous TransferOrbit (GTO). It is then circularized by turning parallel to the equator and firing its rocket engines at apoapsis.

Polar Orbits

Polar orbits are 90 degrees inclination orbits, useful for spacecraft that carry out mapping or surveillance operations. Since the orbital plane is, nominally, fixed in inertial space, the planet rotates below a polar orbit, allowing the spacecraft low-altitude access to virtually every point on the surface. The Magellan spacecraft used a nearly-polar orbit at Venus. Each periapsis pass, a swath of mapping data was taken, and the planet rotated so that swaths from consecutive orbits were adjacent to each other. When the planet rotated once, all 360 degrees longitude had been exposed to Magellan's surveillance.

To achieve a polar orbit at Earth requires more energy, thus more propellant, than does a direct orbit of low inclination. To achieve the latter, launch is normally accomplished near the equator, where the rotational speed of the surface contributes a significant part of the final speed required for orbit. A polar orbit will not be able to take advantage of the "free ride" provided by Earth's rotation, and thus the launch vehicle must provide all of the energy for attaining orbital speed.

Walking Orbits

Planets are not perfectly spherical, and they do not have evenly distributed mass. Also, they do not exist in a gravity "vacuum"--other bodies such as the sun, or satellites, contribute their gravitational influences to a spacecraft in orbit about a planet. It is possible to choose the parameters of a spacecraft's orbit to take advantage of some or all of these gravitational influences to induce precession, which causes a useful motion of the orbital plane. The result is called a walking orbit or a precessing orbit, since the orbital plane moves slowly with respect to fixed inertial space.

Sun Synchronous Orbits

A walking orbit whose parameters are chosen such that the orbital plane precesses with nearly the same period as the planet's solar orbit period is called a sun synchronous orbit. In such an orbit, the spacecraft crosses periapsis at about the same local time every orbit. This can be useful if instruments on board depend on a certain angle of solar illumination on the surface. Mars Global Surveyor's intended orbit at Mars is a 2-pm Mars local time sun-synchronous orbit. It may not be possible to rely on use of the gravity field alone to exactly maintain a desired synchronous timing, and occasional propulsive maneuvers may be necessary to adjust the orbit.

Recap

1. An inclination of zero means the spacecraft orbits the planet at its ______________________, and an inclination of 90 degrees indicates a ____________________ orbit.

2. A spacecraft in __________________________ orbit appears to hang motionless above one position on the Earth.

3. __________________________ orbits are high-inclination orbits, useful for spacecraft that carry out planetary mapping or surveillance operations.

4. To completely describe an orbit mathematically, _________________________

quantities must be calculated.

5. A walking orbit whose orbital plane precesses with nearly the same period as the planet's solar day is called a ___________ ___________________________ orbit.

equator... polar

geostationary

Polar

six

sun-synchronous

Chapter 6 - Part 1 of 6

Objectives of this Chapter:

Upon completion of this chapter you will be able to describe in general terms characteristics of natural and artificial emitters of radiation. You will be able to describe bands of the spectrum from DC to gamma rays, and the particular usefulness radio frequencies have for deep-space communication. You will be able to describe the basic principles of spectroscopy, Doppler, reflection and refraction.

Electromagnetic Radiation

Electromagnetic radiation (radio waves, light, etc.) consists of interacting, self-sustaining electric and magnetic fields that propagate through empty space at the speed of 299,792 km per second. Thermonuclear reactions in the cores of stars (including the sun) provide the energy that eventually leaves stars, primarily in the form of electromagnetic radiation. These waves cover a wide spectrum of frequencies. Sunshine is a familiar example of electromagnetic radiation that is naturally emitted by the sun. Starlight is the same thing from "suns" that are much farther away.

When a direct current (DC) is applied to a wire (conductor) the current flow builds an electromagnetic field around the wire, propagating a wave outward from the wire. When the current is removed the field collapses, again propagating a wave. If the current is applied and removed repeatedly over a period of time, or if the applied current is made to alternate its polarity with a uniform period of time, a series of waves is propagated at a discrete frequency. This phenomenon is the basis of electromagnetic radiation.

Electromagnetic radiation is propagated nominally in a straight line at the speed of light in a vacuum, and does not require a medium for transmission. It is slowed as it passes through a medium such as air, water, glass, etc. The amount of energy arriving at a detecting device of fixed area located at a given distance from an isotropic source is proportional to the amount of energy passing the surface of an imaginary sphere with a radius of the given distance.

Therefore, the amount of electromagnetic energy passing through a unit area decreases with the square of the distance from the source. This relationship is known as the inverse-square lawof (electromagnetic) propagation. It accounts for loss of signal strength over space, called space loss.

The inverse-square law is significant to the exploration of the universe, because it means that the observable electromagnetic radiation decreases very rapidly as the distance from the emitter is increased. Whether the emitter is a spacecraft with a low-power transmitter or an extremely powerful star, it will deliver only a small amount of electromagnetic energy to a detector on Earth because of the very great distances, and the small area that Earth subtends on the huge imaginary sphere.

Recap

1. When a current is applied to a wire the current flow builds an ___________________________ field around the wire propagating a wave outward.

2. If the applied current were made to alternate with a uniform period of time, a series of waves will be propagated at a discreet ________________________________ .

3. The amount of electromagnetic energy passing through a unit area decreases with the ______________________ of the distance from the source.

electromagnetic

frequency

square

Chapter 6 - Part 2 of 6

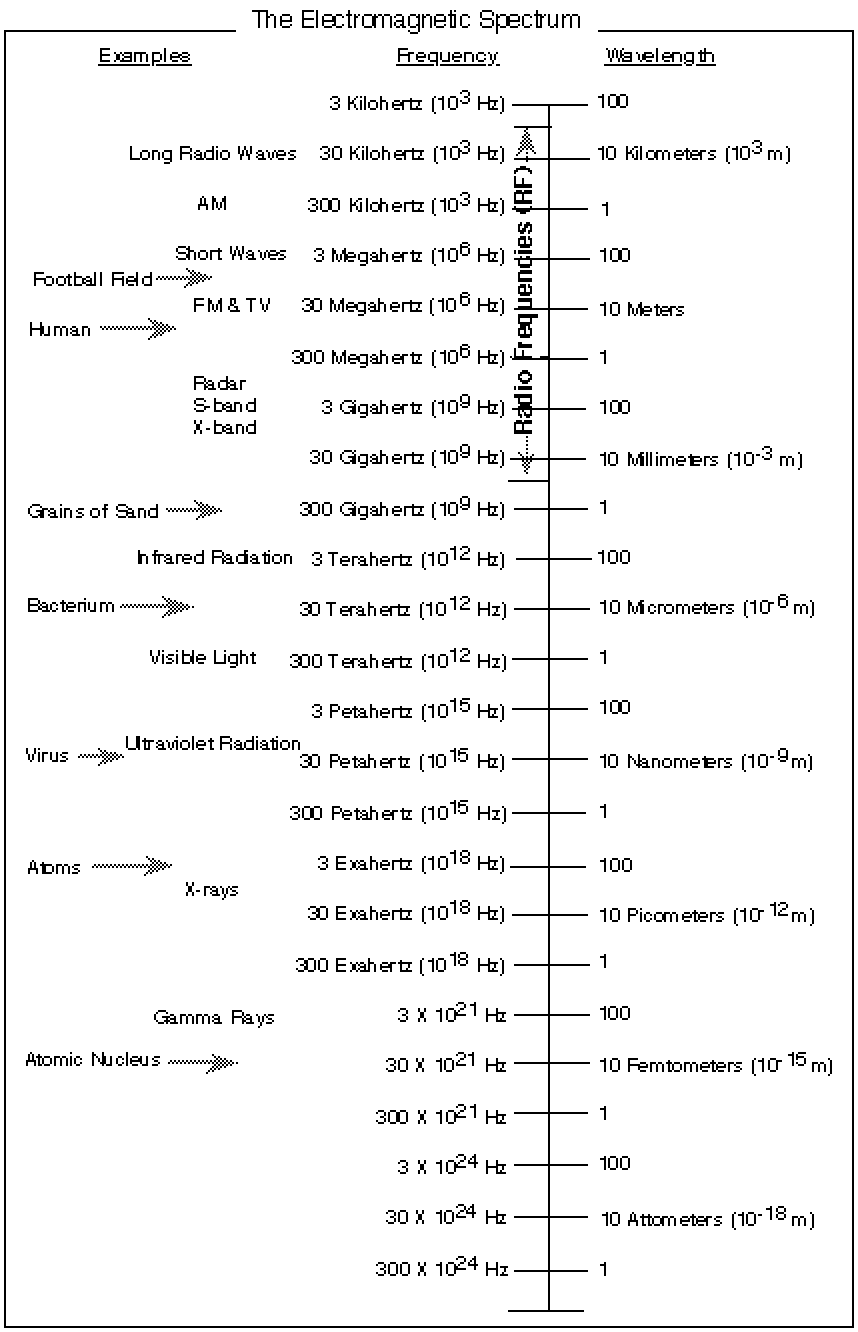
Electromagnetic Spectrum

Light is electromagnetic radiation at those frequencies that can be sensed by the human eye. But the electromagnetic spectrum has a much broader range of frequencies than the human eye can detect, including, in order of increasing frequency: radio frequency (RF), infrared (IR, meaning "below red"), light, ultraviolet (UV, meaning "above violet"), X rays, and gamma rays. These designations describe only different frequencies of the same phenomenon: electromagnetic radiation.

The speed of light in a vacuum, 299,792 km per second, is the rate of propagation of all electromagnetic waves. The wavelength of a single oscillation of electro-magnetic radiation is the distance that the wave will propagate during the time required for one oscillation. There is a simple relationship between the frequency and wavelength of electromagnetic energy. Since electromagnetic energy is propagated at the speed of light, the wavelength equals the speed of light divided by the frequency of oscillation.

$$\text{Wavelength} = \frac{\text{Speed of Light}}{\text{Frequency of Oscillation}}$$

$$\text{Frequency of Oscillation} = \frac{\text{Speed of Light}}{\text{Wavelength}}$$



Natural and Artificial Emitters

Deep space communication antennas and receiversare capable of detecting many different kinds of natural emittersof electromagnetic radiation, including the stars, the sun, molecular clouds, and gas giant planets such as Jupiter. Although these sources do not emit at truly random frequencies, without sophisticated signal processing, their signals appear as "noise" (pseudo-random frequencies and amplitude). Radio astronomyis the term given to the activities of acquiring and processing electromagnetic radiation from natural emitters. The JPL Deep Space Network (DSN) participates in radio astronomy research.

All deep space vehicles are equipped with radio transmittersand receivers for sending signals (electromagnetic radiation) to and from Earth-based tracking stations. These signals are at pre-established discrete frequencies. Various natural and human-made emitters combine to create a background level of electromagnetic noise from which the spacecraft signals must be detected. The ratio of the signal level to the noise level is known as the signal-to-noise ratio(SNR).

Recap

1. Radio, infrared, light, ultraviolet, X rays, and gamma rays describe only a difference in frequency of the same phenomenon: ________________________ _________________________ .

2. Since electromagnetic energy is always propagated at the speed of light, the wavelength equals the speed of light divided by the ______________________.

3. The ratio of the signal level to the noise level is known as the (abbreviation) ___ ___ ___ .

electromagnetic radiation

frequency

SNR

Chapter 6 - Part 3 of 6

Radio Frequencies

Electromagnetic radiation with frequencies between about 10 kHz and 100 GHz are referred to as radio frequencies (RF). Radio frequencies are divided into groups which have similar characteristics, called "bands," such as "S-band," "X-band," etc. The bands are further divided into small ranges of frequencies called "channels," some of which are allocated for the use of deep space tele-communications. Many deep-space vehicles use S-band and X-band frequencies which are in the neighborhood of 2 to 10 GHz. These frequencies are among those referred to as microwaves, because their wavelength is short, on the order of centimeters. Deep space telecommunicationssystems are being developed for use on the even higher frequency Kband.

Band	Range of Wavelengths (cm)	Frequency (GHz)
L	30 -15	1 -2
S	15 - 7.5	2 -4
C	7.5 - 3.75	4 - 8
X	3.75 - 2.4	8 -12
K	2.4 - 0.75	12 - 40

Note: Band definitionsvary slightly among different sources.
These are ballpark values.

Spectroscopy

The study of the production, measurement, and interpretation of electromagnetic spectra is known as spectroscopy. This branch of science pertains to space exploration in many different ways. It can provide such diverse information as the chemical composition of an object, the speed of an object's travel, its temperature, and more--information that cannot be gleaned from photographs. Today, spectroscopy deals with closely-viewed sections of the electromagnetic spectrum. For purposes of introduction, imagine sunlight passing through a glass prism, casting a bright rainbow (spectrum) onto a piece of paper. Imagine bands of color going from red on the left to violet on the right. Frequencies of the light increase from left to right; the wavelengths decrease. Each band of color is actually a wide range of individual frequencies which cannot be discerned by the human eye, but which are detectable by instruments.

Now, instead of the green band near the middle, imagine a dark band, like a shadow at that point, as if something had absorbed all the green out of the sunlight. Call this a "dark line." What is spoken of as a "bright line" could be imagined as an excessively bright color band, say for example if the green were several times brighter than it normally would appear, as though the sunlight were somehow augmented at this band. In actuality, the bright and dark lines spoken of in spectroscopy are extremely narrow, representing only a very specific shade of color, one discreet frequency at a time. In principle, a bright line represents the emission of radiation at a particular frequency, and a dark line indicates the absorption of a frequency otherwise expected to be seen at that point.

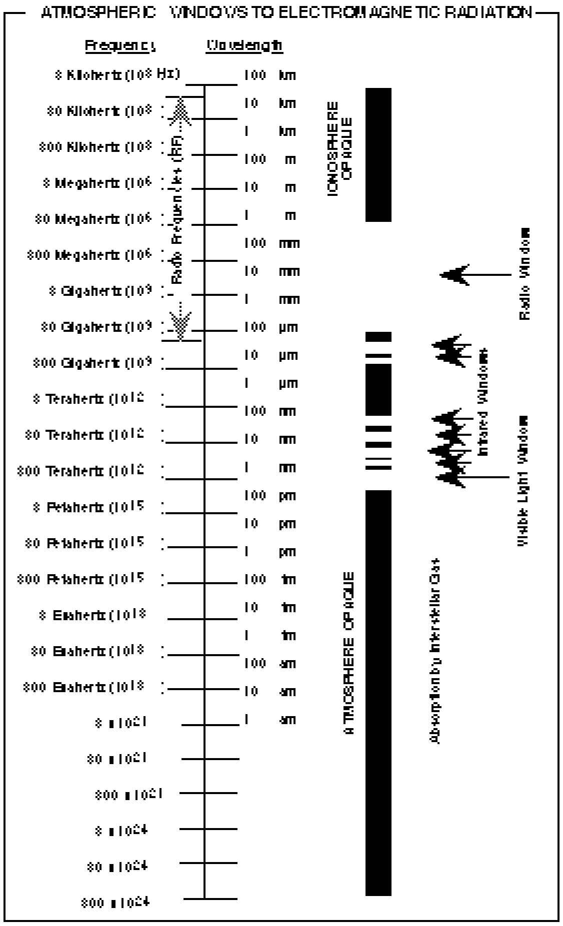
In 1859, Gustav Kirchhoff(1824-1887) described spectroscopy in terms of the three laws of spectral analysis:

> I. A luminous (glowing) solid or liquid emits light of all wavelengths (white light), thus producing a continuous spectrum.
>
> II. A rarefied luminous gas emits light whose spectrum shows bright lines (indicating light at specific wavelengths), and sometimes a faint superimposed continuous spectrum.
>
> III. If the white light from a luminous source is passed through a gas, the gas may absorb certain wavelengths from the continuous spectrum so that those wavelengths will be missing or diminished in its spectrum, thus producing dark lines.

By studying the bright and dark lines (emission and absorption lines) in the spectra of stars, in the spectra of sunlight reflected off planetary surfaces, or of starlight passing through planetary atmospheres, much can be learned about the composition of these bodies. Historically, spectral observations have taken the form of photographic prints showing spectral bands, in which light and dark lines can be discerned. Modern spectrometers (discussed again under Chapter 12, Typical Science Instruments) have largely done away with the photographic process, producing their high-resolution results in the form of X-Y graphic plots, whose peaks and valleys reveal intensity on the vertical axis versus frequency or wavelength along the horizontal. Peaks of high intensity in this scheme represent bright spectral lines, and troughs of low intensity represent dark lines.

Atmospheric Transparency

Because of the absorption phenomena, observations are impossible at certain wavelengths from the surface of Earth, since they are absorbed by the Earth's atmosphere. There are a few "windows" in its absorption characteristics which make it possible to see visible light, and receive radio frequencies, for example, but the atmosphere presents an opaque barrier to much of the electromagnetic spectrum.



Even though the atmosphere is transparent at X-band frequencies as seen above, there is a problem when liquid or solid water is present. Water exhibits noise at X-band frequencies, so precipitation at a receiving site increases the system noise temperature, and this can drive the SNR too low to permit communications reception.

Radio Frequency Interference

In addition to the natural interference which comes from water at X-band, there may be other sources, such as man-made radio interference. Welding operations on an antenna produce a wide spectrum of radio noise. Many Earth-orbiting spacecraft have strong downlinks near the frequency of signals from deep space. Goldstone Solar System Radar (described further in this chapter) uses a powerful transmitter, which can interfere with reception at a nearby station. Whatever the source of radio frequency interference (RFI), its effect is to increase the noise, thereby decreasing the SNR and making it more difficult, or impossible, to receive valid data from a deep-space craft.

Recap

1. A luminous solid or liquid emits light of all wavelengths, producing a ______________________________ spectrum.

2. A luminous gas emits light whose spectrum shows bright lines indicating light emitted at _________________ wavelengths.

3. Gas may absorb certain wavelengths from a continuous spectrum so that those wavelengths will be _____________________ or ________________________ in its spectrum, producing dark lines.

continuous

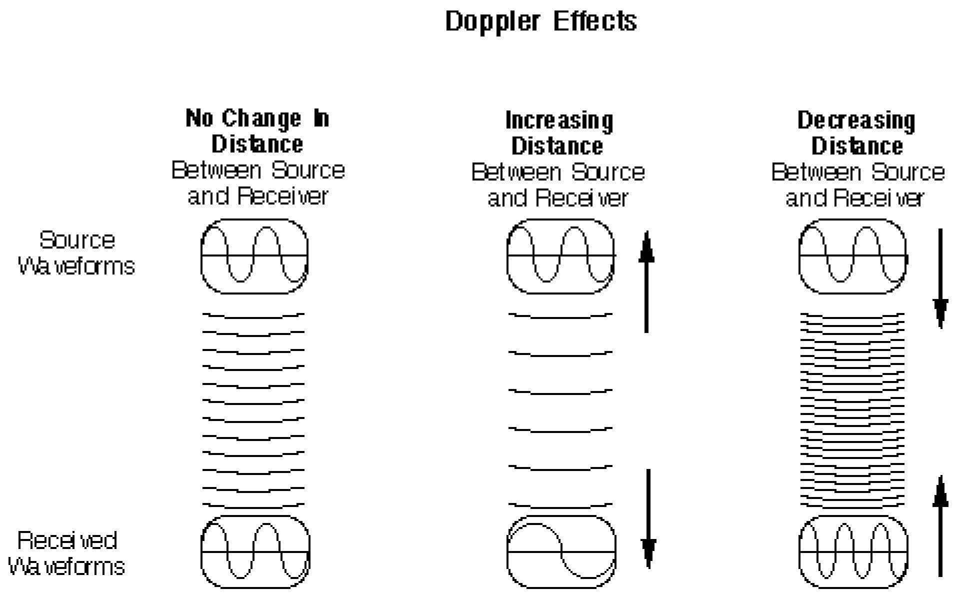
specific

missing ... diminished

Chapter 6 - Part 4 of 6

Doppler Effect

Regardless of the frequency of a source of electromagnetic waves, they are subject to the Doppler effect. The Doppler effect causes the observed frequency of a source to differ from the radiated frequency of the source if there is motion that is increasing or decreasing the distance between the source and the observer. The same effect is readily observable as variation in the pitch of sound between a moving source and a stationary observer, or vice-versa.



When the distance between the source and receiver of electromagnetic waves remains constant, the frequency of the source and received wave forms is the same. When the distance between the source and receiver of electromagnetic waves is increasing, the frequency of the received wave forms is lower than the frequency of the source wave form. When the distance is decreasing, the frequency of the received wave form will be higher than the source wave form.

The Doppler effect is routinely observed in the frequency of the signals received by ground receiving stations when tracking spacecraft. The increasing or decreasing of distances between the spacecraft and the ground station may be caused by the spacecraft's trajectory, its orbit around a planet, Earth's revolution about the sun, or Earth's daily rotation on its axis. A spacecraft approaching Earth will add a positive frequency bias to the received signal. However, if it flies by Earth, the received Doppler bias will become zero as it passes Earth, and then become negative as the spacecraft moves away from Earth. A spacecraft's revolutions around another planet such as Mars adds alternating positive and negative frequency biases to the received signal, as the spacecraft first moves toward and then away from Earth. The Earth's rotation adds a positive frequency bias to the received signal as the spacecraft rises in the east at a particular tracking station, and adds a negative frequency bias to the received signal as the spacecraft sets in the west.

Differenced Doppler

If two widely-separated tracking stations on Earth observe a single spacecraft in orbit about another planet, they will each have a slightly different view, and there will be a slight difference in the amount of Doppler shift observed by each station. For example, if one station has a view exactly edge-on to the spacecraft's orbital plane, the other station would have a view slightly to one side of that plane. Information can be extracted from the differencing of the two received signals that describes the spacecraft's arc through space in three dimensions. This data type, differenced Doppler, is a useful form of navigation data which can yield a very high degree of spatial resolution. It is further discussed in Chapter 13, Spacecraft Navigation.

Recap

1. The observed frequency of a source will differ from its radiated frequency if there is ________________ which is increasing or decreasing the distance between the source and the observer.

2. When the distance is increasing between the source and receiver of electromagnetic waves, the frequency of the received waves will ________________________.

3. Earth's rotation adds a positive frequency bias to the received signal when the spacecraft rises in the east at a particular tracking station, and adds a ______________________ frequency bias to the received signal as the spacecraft sets in the west.

motion

decrease

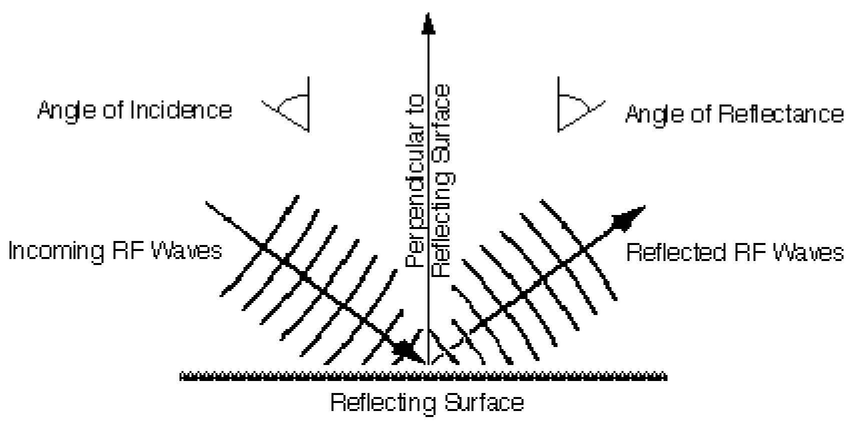
negative

Chapter 6 - Part 5 of 6

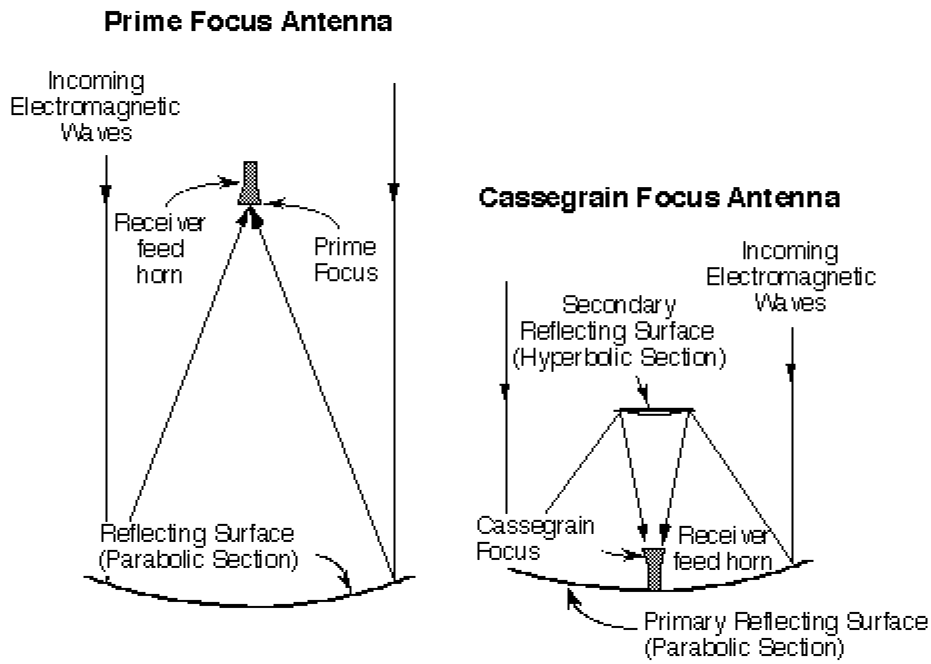
Reflection

RF electromagnetic radiation generally travels through space in a straight line. The exception is that it is bent slightly by the gravitation of large masses in accordance with general relativity. RF waves can be reflected by certain substances, much in the same way that light is reflected by a mirror. The angle at which RF is reflected from a smooth metal surface, for example, will equal the angle at which it approached the surface. In other words, the angle of reflectance of RF waves equals their angle of incidence.

RF Reflected



This principle of RF reflection is used in antenna design to focus transmitted waves into a narrow beam and to collect and concentrate received RF signals for a receiver. If a reflector is designed with the reflecting surface shaped like a paraboloid, electromagnetic waves approaching on-axis will be reflected and will focus above the surface of the reflector at the feed horn.



This arrangement is called prime focus, and provides the large aperture necessary to receive very weak signals. The same configuration allows the narrow focusing of signals transmitted from the feed horn, concentrating the transmitted electro-magnetic waves into a narrow beam. A major problem with prime focus arrangements for large aperture antennas is that the equipment required at the prime focus is heavy and the supporting structure tends to sag under the weight of the equipment, thus affecting calibration. A solution is the Cassegrain Focusarrangement. Cassegrain antennas add a secondary reflecting surface to "fold" the electromagnetic waves back to a prime focus near the primary reflector. The DSN's antennas are of this design because it accommodates large apertures and is structurally strong, allowing bulky equipment to be located nearer the structure's center of gravity.

The reflective properties of electromagnetic waves have also been used to investigate the planets using a technique called planetary radar. With this technique, electromagnetic waves are transmitted to the planet, where they reflect off the surface of the planet, and are received at one or more Earth receiving stations. Using very sophisticated signal processing techniques, the receiving stations dissect and analyze the signal in terms of time, amplitude, phase, and frequency. JPL's application of this radar technique, called Goldstone Solar System Radar (GSSR), has been used to develop images of the surface features of Venus, eternally covered with clouds, Mercury, difficult to see in the glare of the sun, and some of the satellites of the Jovian planets.

Recap

1. Radio frequency electromagnetic radiation generally travels through space in a ________________ _____________ .

2. The angle of reflectance of RF waves equals their angle of ____________________________ .

3. DSN's antennas are of the Cassegrain design because it accommodates large apertures, and is structurally ______________________ allowing bulky equipment to be located nearer the structure's center of gravity.

4. JPL's application of this radar technique, called _____________________ _________________ _________________ _________________ (GSSR), has been used to develop images of the surface features of Venus.

straight line

incidence

strong

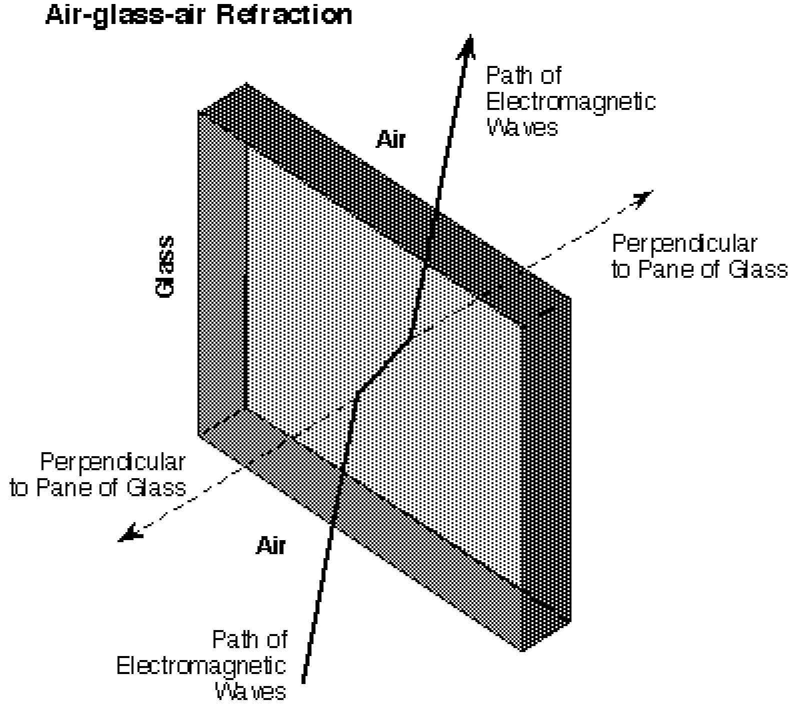
Goldstone Solar System Radar

Chapter 6 - Part 6 of 6

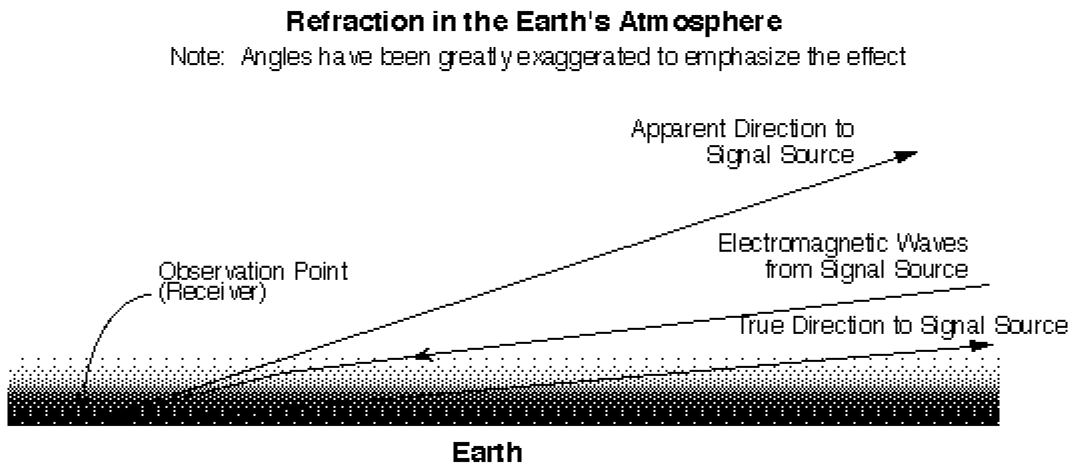
Refraction

Refraction is the deflection or bending of electromagnetic waves when they pass from one kind of transparent medium into another. The index of refraction is the ratio of the speed of light in a vacuum to the speed of light in the substance of the observed medium. The law of refraction states that electromagnetic waves passing from one medium into another (of a differing index of refraction) will be bent in their direction of travel. Air and glass have different indices of refraction. Therefore, the path of electromagnetic waves moving from air to glass at an angle will be bent toward the perpendicular as they travel into the glass. Likewise, the path will be bent to the same extent away from the perpendicular when they exit the other side of glass.

Air-glass-air Refraction



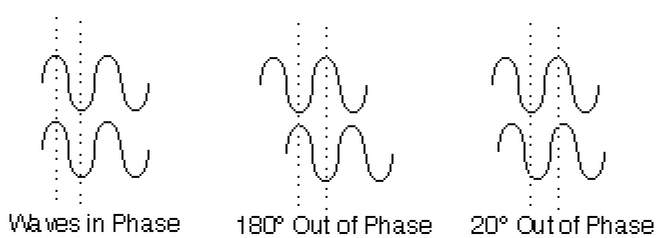
In a similar manner, electromagnetic waves entering Earth's atmosphere from space are slightly bent by refraction. Atmospheric refraction is greatest for signals near the horizon, and cause the apparent altitude of the signal to be on the order of half a degree higher than the true height. As Earth rotates and the object gains altitude, the refraction effect reduces, becoming zero at zenith (directly overhead). Refraction's effect on the sun adds about 5 minutes to the daylight at equatorial latitudes, since it appears higher in the sky than it actually is.



If the signal from a spacecraft goes through the atmosphere of another planet, the signals leaving the spacecraft will be slightly bent by the atmosphere of that planet. This bending will cause occultation (spacecraft moving into a planet's RF shadow of Earth) to occur later than otherwise expected, and exit from occultation will occur prior to when otherwise expected. Ground processing of the received signals reveals the extent of atmospheric bending (and also of absorption at specific frequencies and other modifications), and provides a basis for inferring the composition and structure of a planet's atmosphere.

Phase

As applied to waves of electromagnetic radiation, phase is the relative measure of the alignment of two waveforms of similar frequency. They are said to be in phase if the peaks and troughs of the two waves match up with each other in time. They are said to be out of phase to the extent that they do not match up. Phase is expressed in degrees from 0 to 360.



Recap

1. Refraction is the ______________________ of electromagnetic waves when they pass from one kind of transparent medium into another.

2. The path of electromagnetic waves moving from air to glass at an angle will be bent toward the ______________________ as they travel into the glass.

3. If the signal from a spacecraft goes through the atmosphere of another planet, the signals leaving the spacecraft will be slightly ________________________ by the atmosphere of that planet.

4. Waves are said to be in _______________________ if their peaks and troughs match up.

deflection or bending

perpendicular

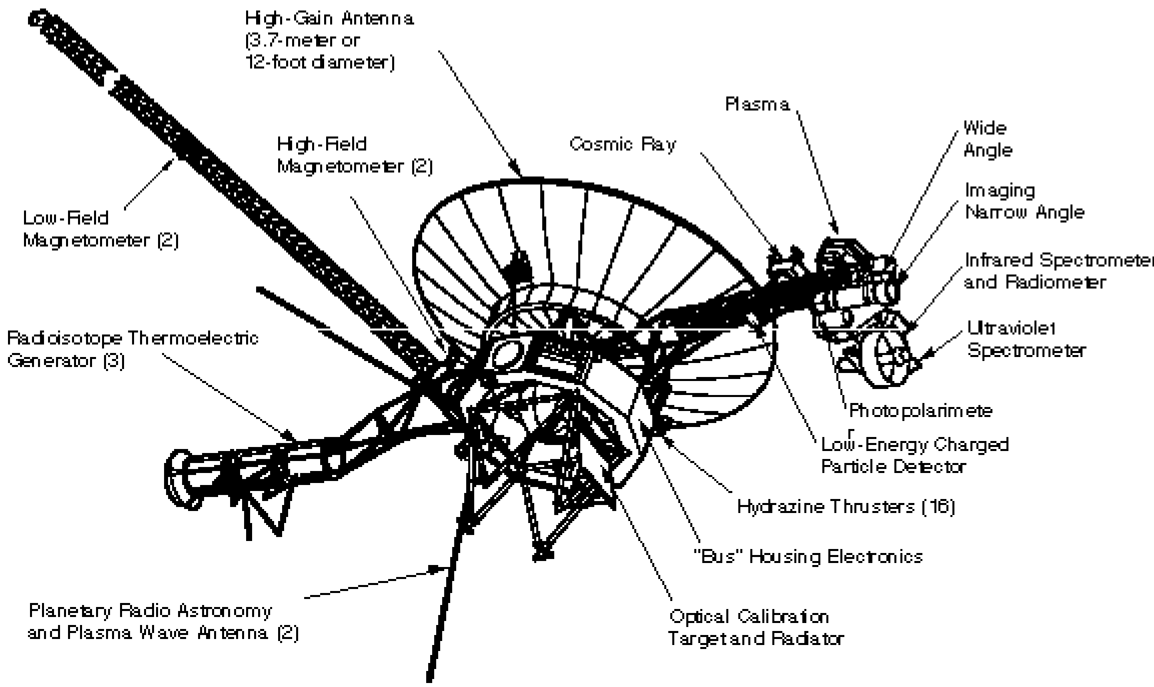
bent

phase

SPACECRAFT

Voyagers
Ulysses
Pioneers
Magellan
Cassini
Mars Observer
Galileo Orbiter
Huygens Probe
Mars Pathfinder
Viking Lander
TOPEX/Poseidon
Mars Balloon
Galileo Atmospheric Probe
Galileo Spacecraft Detailed Image
Mars Global Surveyor
Mars Lander Deployed

Voyagers 1 and 2



Classification: Flyby spacecraft.

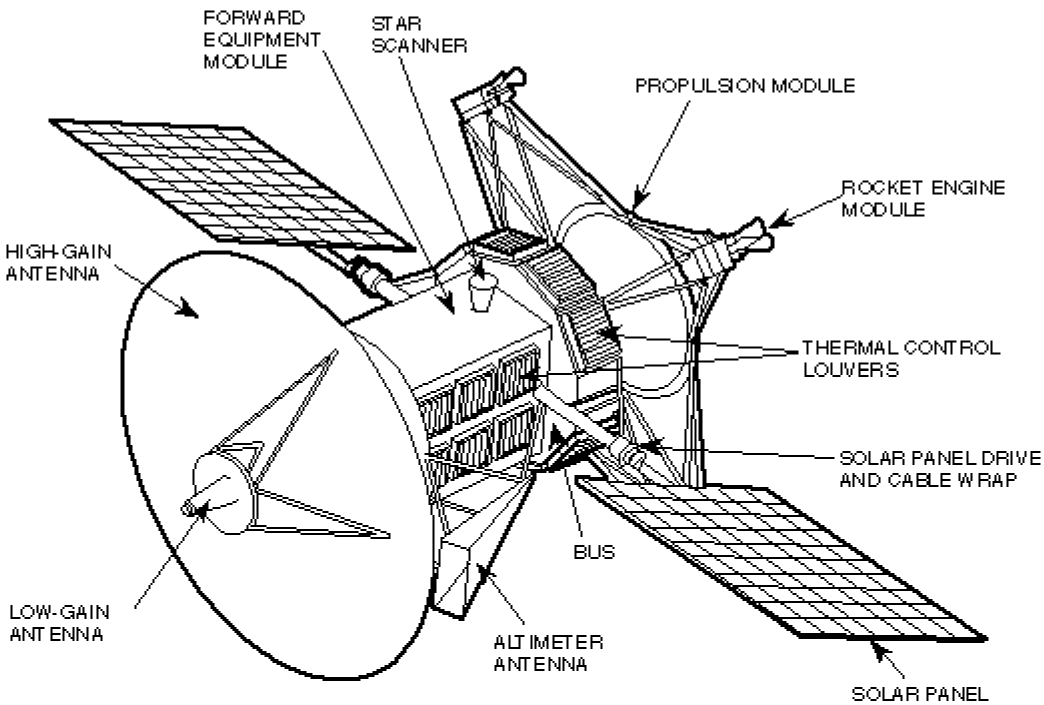
Mission: Jovian planets and interstellar space.

Features: The Voyager 1 and Voyager 2 spacecraft were launched in late 1977 aboard Titan III launch vehicles with Centaur upper stages. They completed highly successful prime mission flybys of Jupiter in 1979 and Saturn in 1980 and 1981. Voyager 2's extended mission succeeded with flybys of Uranus in 1986 and Neptune in 1989. Both spacecraft are still healthy in 1993, and are conducting studies of interplanetary space enroute to interstellar space. Voyager 1 and Voyager 2 recently identified low frequency radio emissions from the heliopause, estimated to be about 50 AU away from the spacecraft. Science data return is expected to continue well into the next century.

Stabilization: Three-axis stabilized via thrusters.

Also see JPL's Voyager Project Home Page.

Magellan



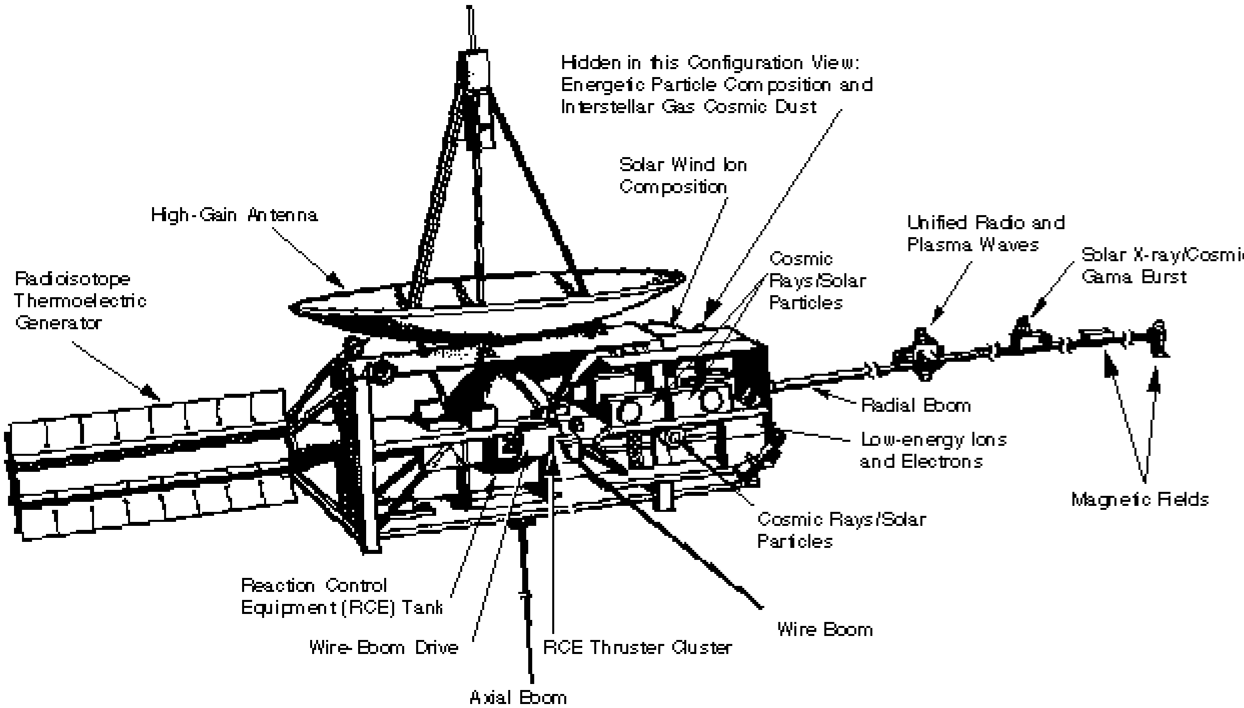
Classification: Orbiter spacecraft.

Mission: Venus mapping.

Features: The Magellan spacecraft was launched in early 1989 via the Space Shuttle Atlantis and an IUS upper stage. By the end of its fourth Venus-rotation cycle (243 days each) four years after launch, Magellan had mapped 98% the surface of Venus with imaging, altimetry, and radiometry, performed several radio science experiments, and had surveyed the gravity field at low latitudes all the way around the planet. The imaging resolution was about 100 m, close enough to discern the various geologic processes for the first time. Magellan's periapsis was lowered into Venus's atmosphere for a thousand orbits, aerobraking into a nearly circular orbit. Magellan's periapsis was then raised out of the atmosphere, and it completed high-resolution mapping of the planet's gravity field from low circular orbit. Magellan was then intentionally flown to its destruction in Venus's atmosphere in October 1994, all the while carrying out additional experiments.

Stabilization: Three-axis stabilized via reaction wheels and thrusters.

Ulysses



Classification: Orbiter spacecraft.

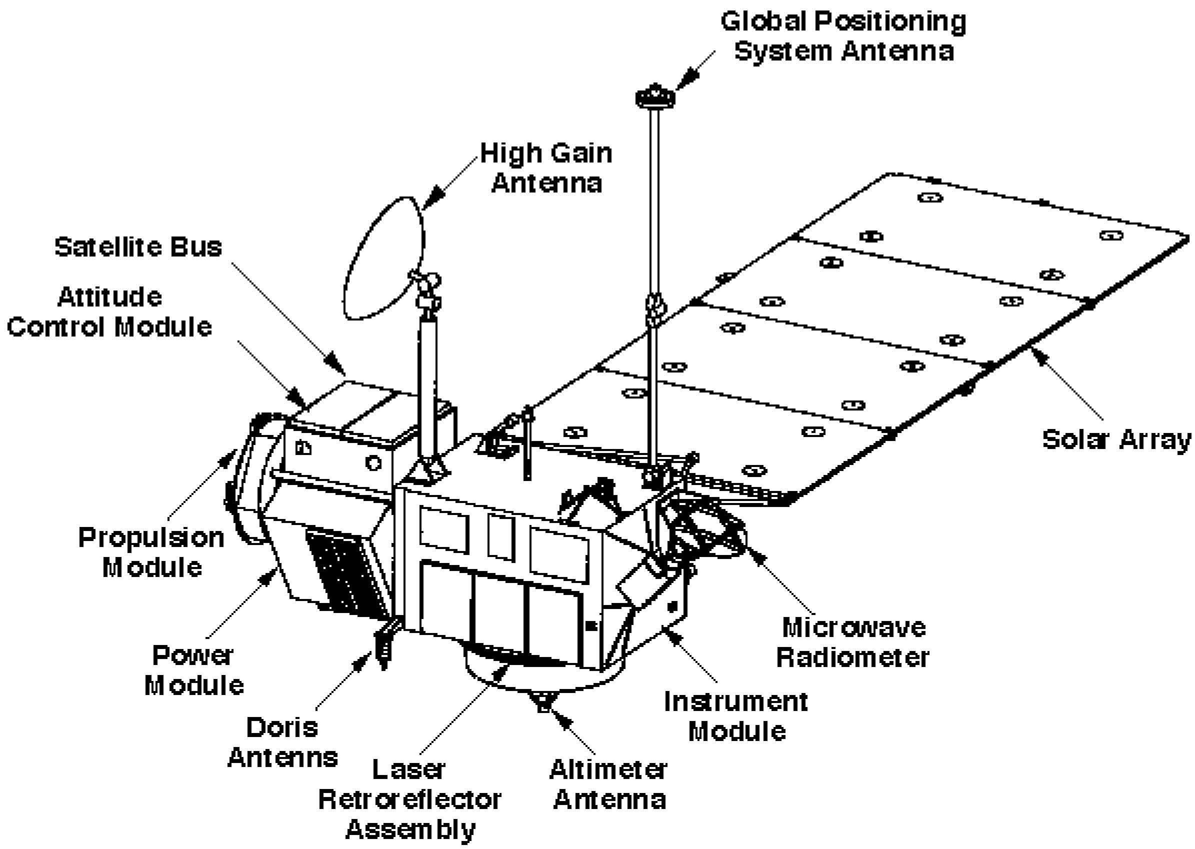
Mission: Study the sun from solar polar latitudes.

Features: The Ulysses spacecraft is a joint project between NASA and the European Space Agency (ESA). It was launched in late 1990 via the Space Shuttle with an IUS upper stage and Payload Assist Module (PAM-S). It encountered Jupiter early in 1992 for a gravity assist to achieve a trajectory at nearly right angles to the ecliptic plane. It will undertake exploration of the Sun's high southern latitudes June through October 1994. It will make a pass over the Sun's north polar region between June and September 1996. At no time will it approach less than 1 AU from the sun. While within Jupiter's environs for its gravity assist, it made significant observations of the Jovian system. Ulysses carries fields and particles instruments. Its U.S. counterpart, a second spacecraft with imaging instruments, designed to travel simultaneously over the opposite Solar poles, was cancelled by the U.S.

Stabilization: Spin stabilized.

Also see JPL's Ulysses Project Home Page.

TOPEX/Poseidon



Classification: Orbiter spacecraft.

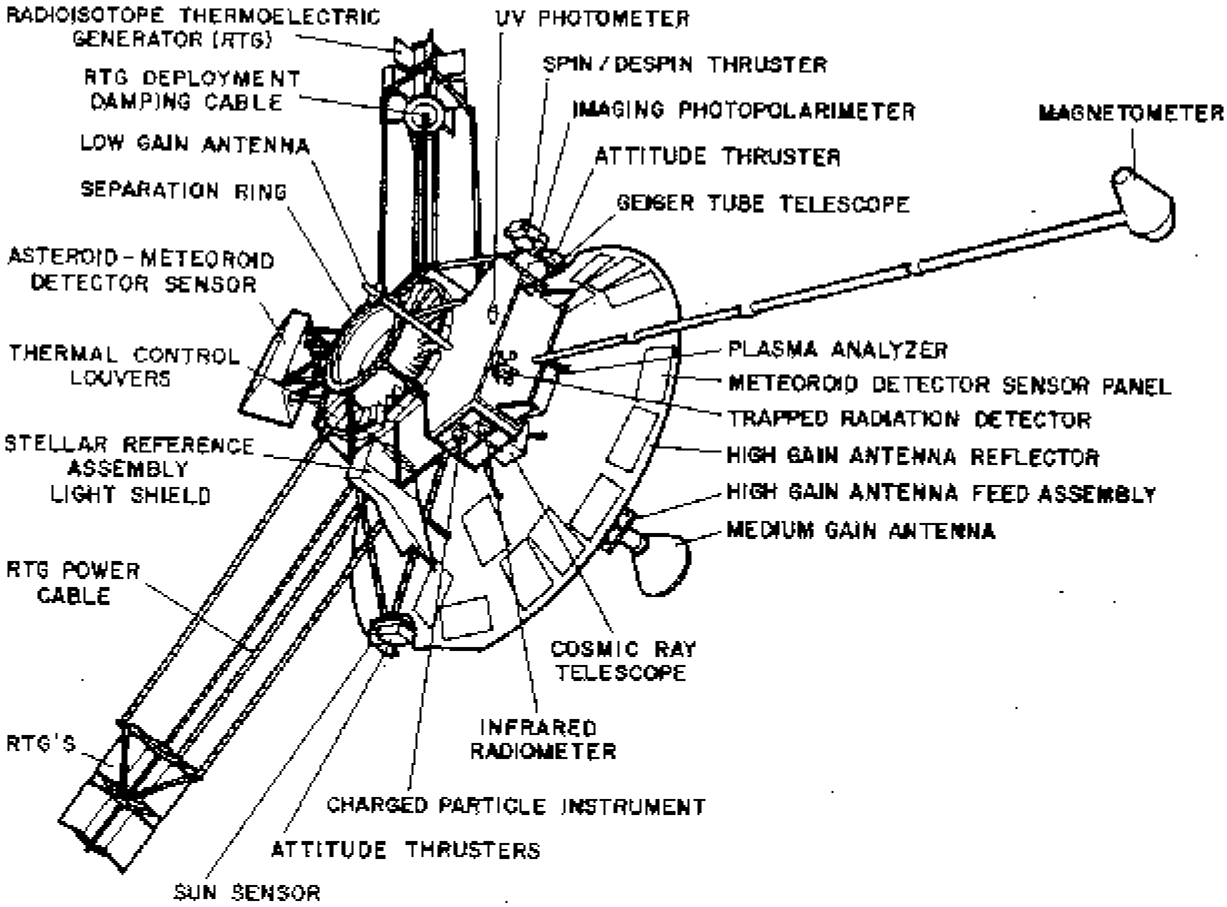
Mission: Global view of Earth's oceans.

Features: Topex/Poseidon is a joint project between NASA and Centre National d'Etudes Spatiales (CNES)launched in mid 1992 aboard an Ariane 4. The spacecraft occupies a 1336-km-high Earth orbit inclined 66 degrees. Revealing minute differences in the oceans' heights, Topex/Poseidon's data should lead to improved understanding of oceanic circulation and forecasting of global environment.

Stabilization: Three-axis stabilized via reaction wheels and thrusters.

Also see the Topex/Poseidon Project Home Page.

Pioneers 10 and 11



Classification: Flyby spacecraft.

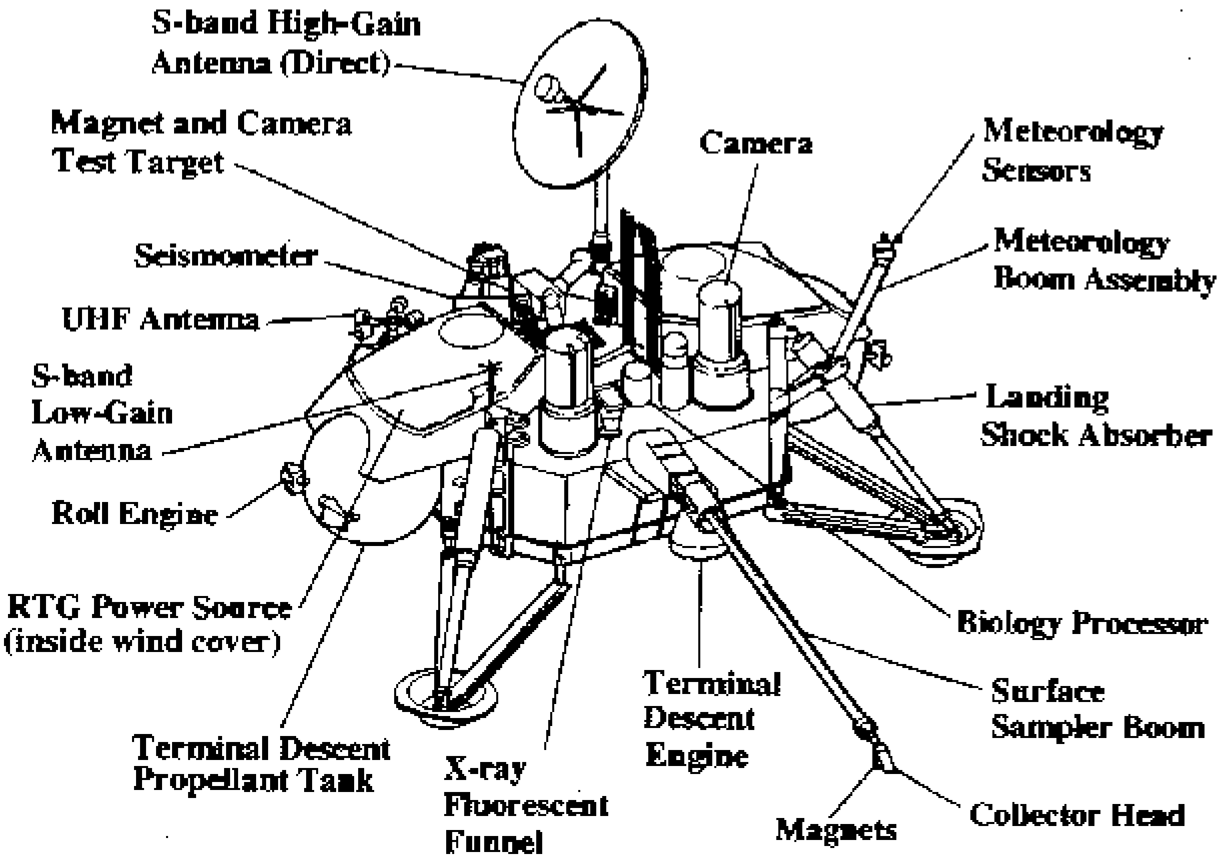
Mission: Jupiter, Saturn, and interstellar space.

Features: Pioneer 10 and 11 launched in 1972 and 1973, and penetrated the asteroid belt. Pioneer 10 was the first spacecraft to study Jupiter and its environment, and obtain spin-scan images of the planet. Pioneer 11 also encountered Jupiter, and went on to become the first to encounter Saturn, its rings and moons. Pioneers 10 and 11 are still operative in the far reaches of the outer solar system, and are still being tracked in November 1995. Pioneer 11 has insufficient electrical power to continue operations, and is expected to lose communications with Earth within a few months. It is likely that Pioneer 10 will follow suit within a few years.

Stabilization: Spin stabilized.

Also see the Pioneer Project Home Page.

Viking Lander



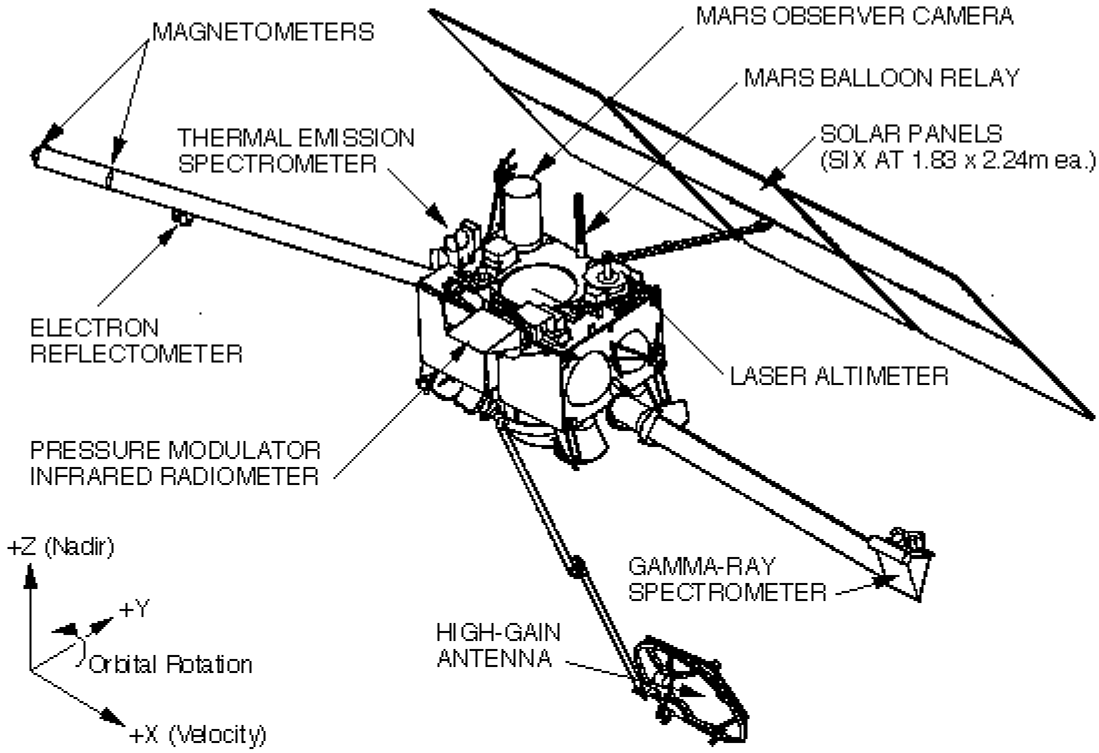
Classification: Lander spacecraft.

Mission: Survey Martian landscape.

Features: The Viking Lander 1 spacecraft touched down on Mars in July 1976, followed by the Viking 2 Lander the following month. These automated scientific laboratories photographed their surroundings, and gathered data on the structure, surface, and atmosphere of the planet, and carried out an investigation into the possibility of past and present life forms.

Also see the Viking Mission Home Page.

Mars Observer



Classification: Orbiter spacecraft.

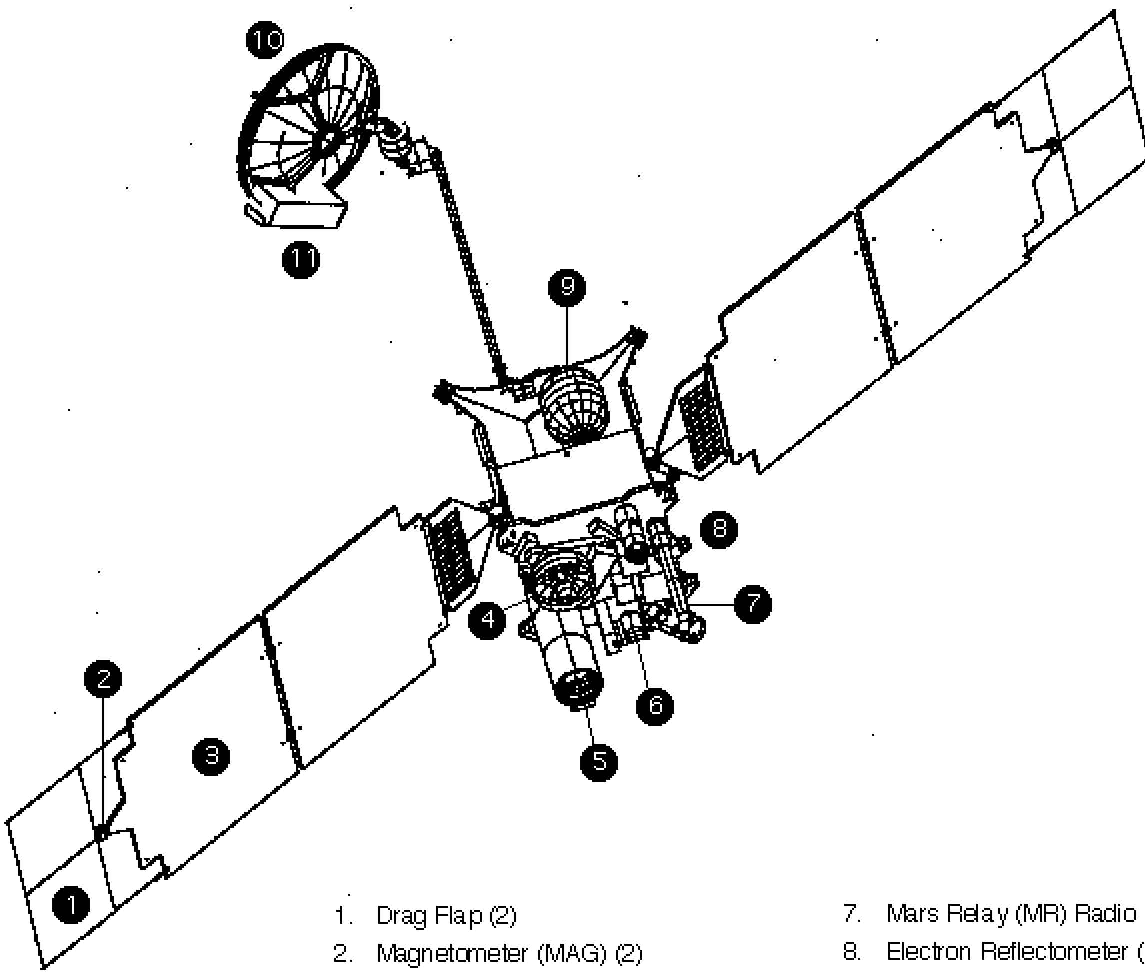
Mission: Mars mapping.

Features: The Mars Observer spacecraft was launched in 1992 aboard a Titan III with a Transfer Orbit Upper Stage. Unfortunately, communications with the spacecraft were lost just before its orbit insertion maneuver. Based upon the design for an Earth-orbiting spacecraft, it was to observe Mars for one continuous Martian year (687 Earth days), studying surface mineralogy and morphology, topography, atmospheric circulation and the movement of water, dust, fog and frost. It would have characterized the gravitational field and the magnetic field. It also would have provided Earth relay capability for Russian landers and the Mars Balloon.

Stabilization: Three-axis stabilized via reaction wheels and thrusters.

Also see the Mars Observer Project Home Page.

Mars Global Surveyor



1. Drag Flap (2)
2. Magnetometer (MAG) (2)
3. Solar Array (4 Panels)
4. Mars Orbiter Laser Altimeter (MOLA)
5. Mars Orbiter Camera (MOC)
6. Thermal Emission Spectrometer (TES)
7. Mars Relay (MR) Radio System
8. Electron Reflectometer (ER)
9. Propellant Tank (3)
10. High-Gain Antenna/Radio Science Investigation
11. Radio-Frequency Power Amplifiers

Classification: Orbiter spacecraft.

Mission: Mars mapping.

Features: The Mars Global Surveyor spacecraft will be launched in November 1996 on a Delta 7925 launch vehicle. It will carry all but two of the eight science instruments that were aboard Mars Observer, providing high-resolution, global maps of the Martian surface, profiling the planet's atmosphere, and studying the nature of the magnetic field. Mars Global Surveyor will take ten months to reach Mars, entering a polar orbit around the planet in September 1997.

Stabilization: Three-axis stabilized via reaction wheels and thrusters.

Also see the Mars Global Surveyor Project Home Page.

Galileo Spacecraft Detailed Image

Following is the large, detailed illustration of the Galileo Orbiter referred to in Chapters 11 and 12. Also, see the Galileo Home Page on the World Wide Web.

The Galileo Spacecraft

Science experiments are described in italics, and have blue connecting lines. Engineering components are shown with red connecting lines.

Spacecraft Spun Section: The spun bus houses electronics and computers for attitude control, command processing, and flight science data processing. Also houses components such as radios, data storage tape recorder, and support systems.

Retro Propulsion Module (RPM): The entire propulsion system is a single module provided by the Federal Republic of Germany. It consists of twelve 10N attitude control thrusters on two A/C thruster booms, one central 400N thruster, four tanks of fuel and oxidizer, and two tanks of helium pressurant. The HGS, RTGs, and Science Boom are also part of the spun section.

Spin Bearing Assembly (SBA): Connects the spun and the despun sections of the spacecraft. In addition to mechanical coupling, 48 slip-rings provide transfer of power and low-rate data, and rotary transformers provide a coupling for high-rate data. An optical encoder provides relative position information.

Spacecraft Despun Section: The scan platform and its optical instruments and the probe radio relay hardware are despun via the SBA so they can be pointed at their targets. The atmospheric probe is carried as part of the despun section.

High-gain Antenna (HGA): Consists of a deployable reflector dish 4.8 m in diameter (similar to those on the TDRSS earth satellites), and a reflector/feed structure supported above it. Designed to suport a communications rate of 134 kbps, the HGA has not been able to unfurl due to an anomaly, and is currently unusable. (Shown in its deployed configuration, which has not been achieved.)

Extreme Ultraviolet Spectrometer (EUV): On the spun bus, is sensitive to wavelengths of 50-170 nm. Investigates emmissions from the Io plasma torus and auroral and airglow phenomena on Jupiter.

Star Scanner: Observes stars as the spacecraft spins, providing the primary reference for the Attitude Control Computer which refers to an onboard star catalog for attitude determination (partly hidden in this view.)

Radioisotope Thermoelectric Generators (RTGs): Produce a supply of roughly 500 watts of electricity from banks of thermocouples heated by the decay of radioactive material.

Linear Boom Actuator (LBA): On each RTG boom. Extends or contracts on command to allow minute adjustments in the RTG boom's angle, for minimizing spacecraft wobble.

A/C Thrusters: Two groups of size 10N attitude control thrusters are used for attitude and spin changes and small adjustments to velocity.

Low-gain Antenna 2 (LGA2): Used for communication with the high-gain antenna furled, while the spacecraft is pointing generally away from Earth.

Temperature Control Louvers: Mechanical devices that open and close automatically to control radiation of heat from within the spacecraft.

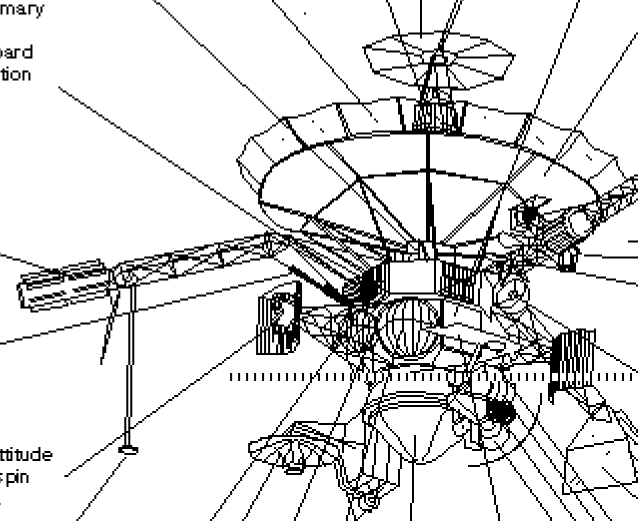
Radio Relay Hardware (RRH): Antenna and electronics tracked and received data from the atmospheric probe during its short operational life descending into Jupiter's atmosphere. These data were relayed to Earth via the LGA.

Helium Tank: Provides helium to pressurize the fuel and oxidizer tanks.

Reflector Structure: Part of the high-gain antenna which focuses and feeds the incoming and outgoing radio signals.

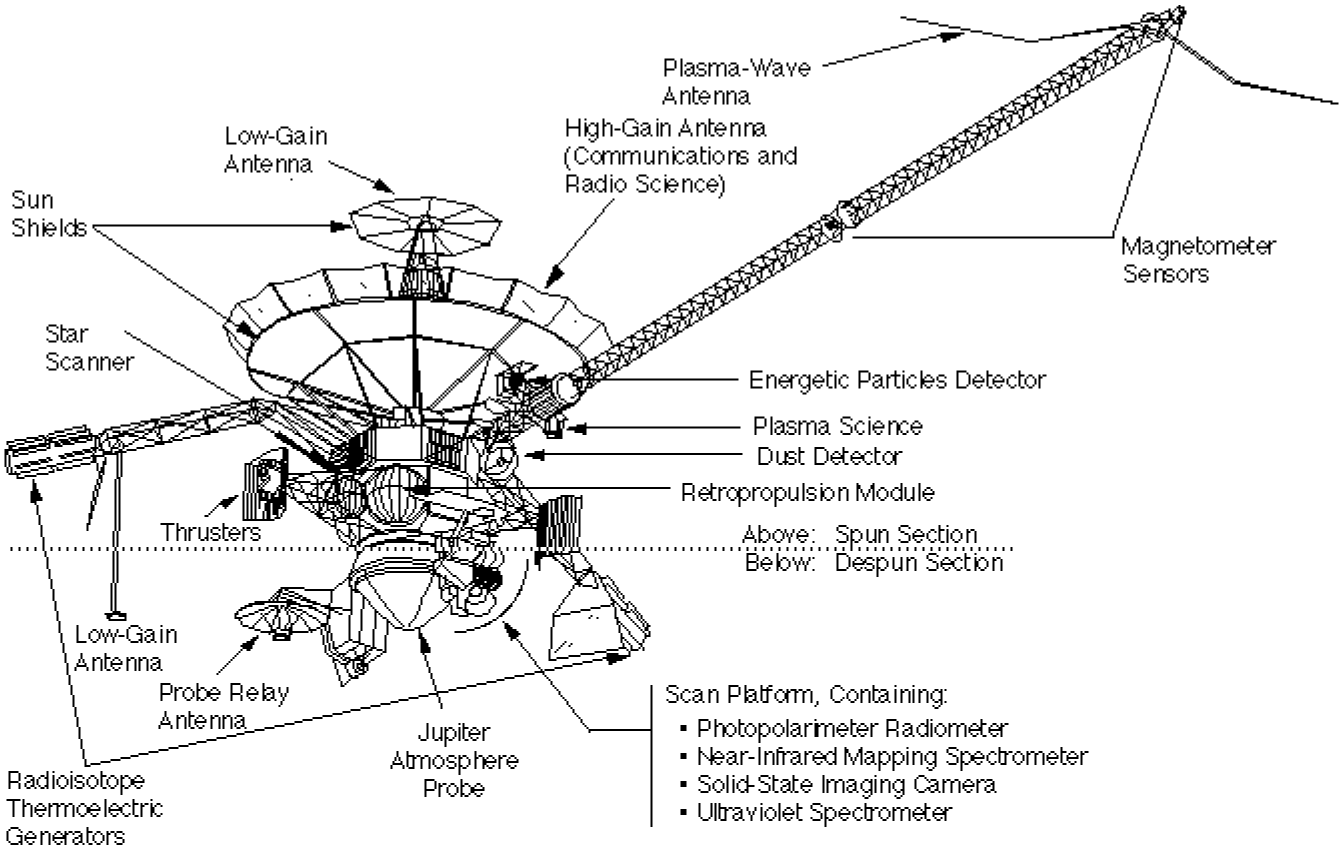
HGA Sunshade: Designed to
the High-gain Antenna (when f
from direct solar radiation while
in the inner parts of the solar s

Low-gain Anten
while the spacec
Radio signals ar
spacecraft to Ea
commands from
these signals are
spacecraft's spe



Scan Pla
instrumen
flight. Als
PPR instr
feature po

Galileo Orbiter



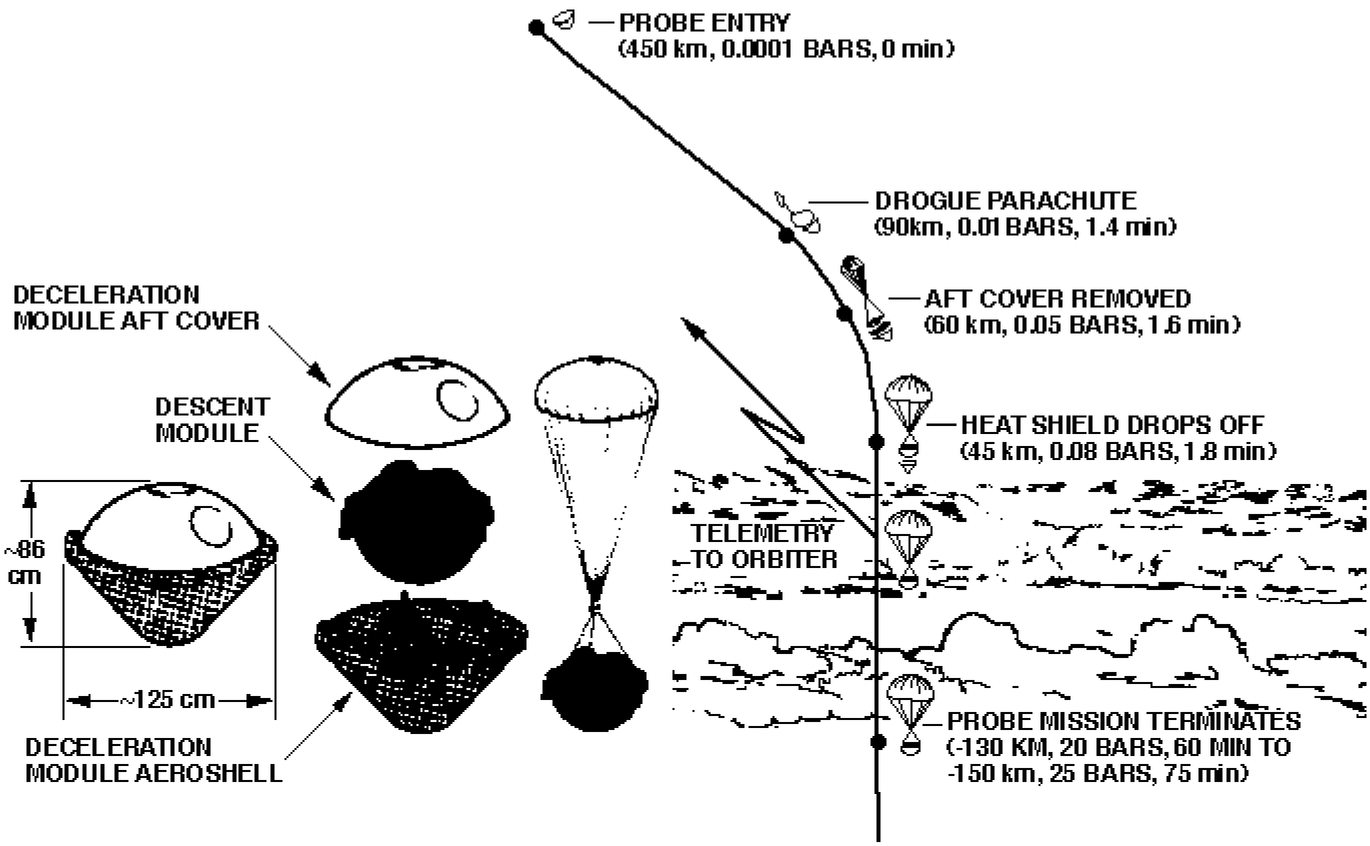
Classification: Orbiter spacecraft.

Mission: Investigate Jupiter's atmosphere, magnetosphere, and satellites.

Features: Galileo was launched aboard the Space Shuttle in October 1989. It executed science observations during gravity-assist flybys of Venus and Earth, as well as during two asteroid flybys. It observed Comet Shoemaker-Levy 9's impact with Jupiter in July 1994. Galileo entered Jovian orbit December 1995 shortly after receiving the data from its atmospheric probe, which entered Jupiter's atmosphere.

Stabilization: Spin stabilized.

Galileo Atmospheric Probe



Classification: Atmospheric probe spacecraft

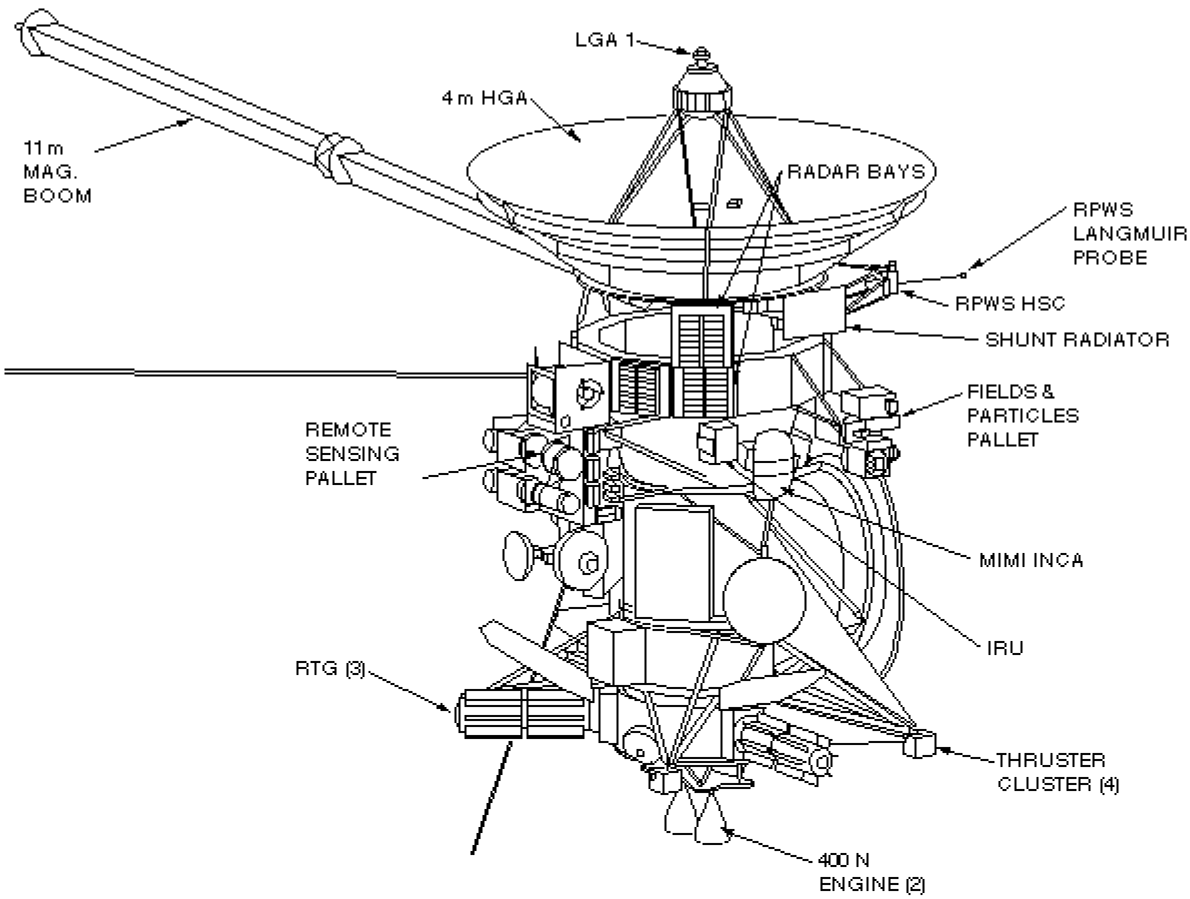
Mission: Investigate Jupiter's atmosphere

Features: The Galileo Atmospheric Probe was released from the Galileo orbiter spacecraft in July 1995, about 100 days before arrival at Jupiter. Atmospheric entry took place on 7 December, 1995, as the orbiter tracked the probe and recorded its data for later relay to Earth. Probe instruments investigated the chemical composition and the physical state of the atmosphere. The probe returned data for just under an hour before it was overcome by the pressure of Jupiter's atmosphere.

Stabilization: Spin stabilized.

See also the Galileo Probe Home Page.

Cassini



Classification: Orbiter spacecraft.

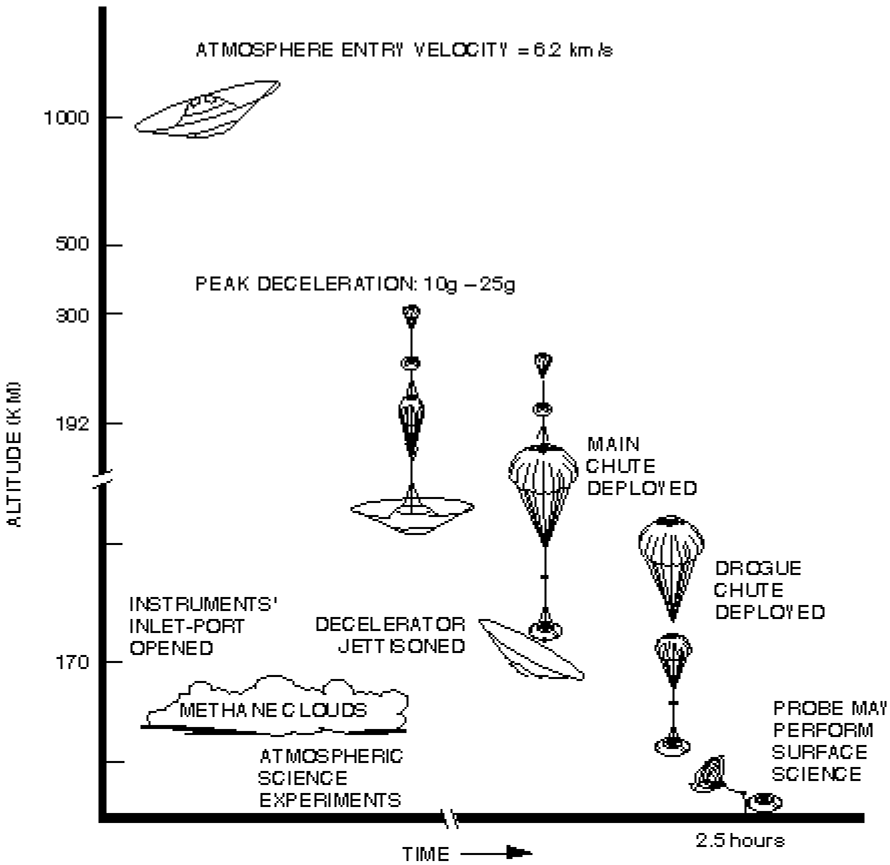
Mission: Explore Saturnian system.

Features: Cassini is scheduled for launch aboard a Titan IV with a Centaur upper stage in 1997. It will encounter Venus, Earth and Jupiter for gravity assists, and will reach Saturn in 2004. It will spend four years conducting a detailed examination of Saturn's atmosphere, rings, and magnetosphere, and close-up studies of its satellites. It will radar map portions of Titan's surface. Cassini will also carry the Huygens probe which will be deployed into the atmosphere of Titan.

Stabilization: Three-axis stabilized via reaction wheels and thrusters.

See also the Cassini Mission Home Page.

Huygens Probe



Classification: Atmospheric probe spacecraft.

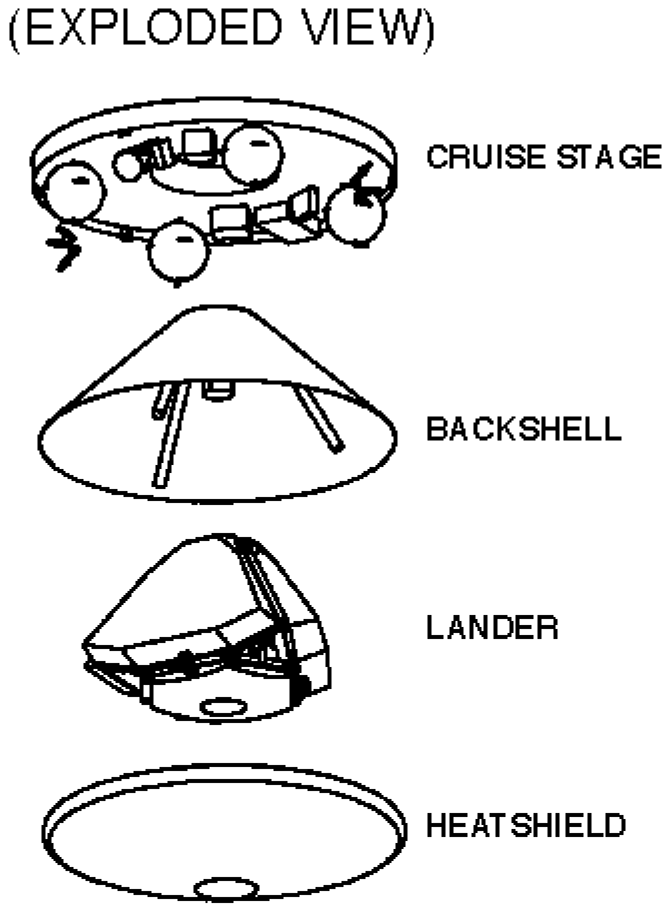
Mission: Investigate Titan's atmosphere.

Features: The Huygens Probe, supplied by ESA, will be carried by the Cassini spacecraft to Titan, Saturn's largest moon, and deployed carrying six science instruments into Titan's atmosphere in the year 2004. If it survives impact with the surface of Titan, it may be able to continue to transmit science data from the surface.

Stabilization: Spin stabilized.

See also the Huygens Probe Home Page.

Mars Pathfinder



Classification: Lander spacecraft carrying surface rover.

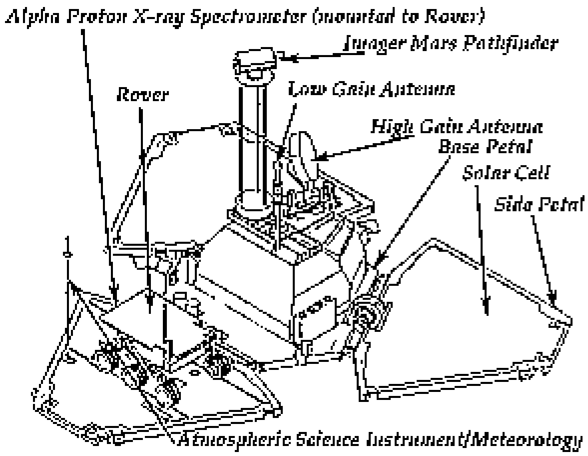
Mission: Analyze Martian soil and atmosphere.

Features: Pathfinder is a low-cost mission with a single flight system to be launched in December 1996 or January 1997 aboard a Delta rocket for a Mars landing in July 1997. The spacecraft will enter the atmosphere directly from its transfer trajectory, and will analyze the atmosphere on the way in. It will carry a small rover, which will perform technology, science, and engineering experiments on the surface of Mars.

Stabilization: Spin stabilized.

See also the Mars Pathfinder Home Page.

Mars Lander Deployed

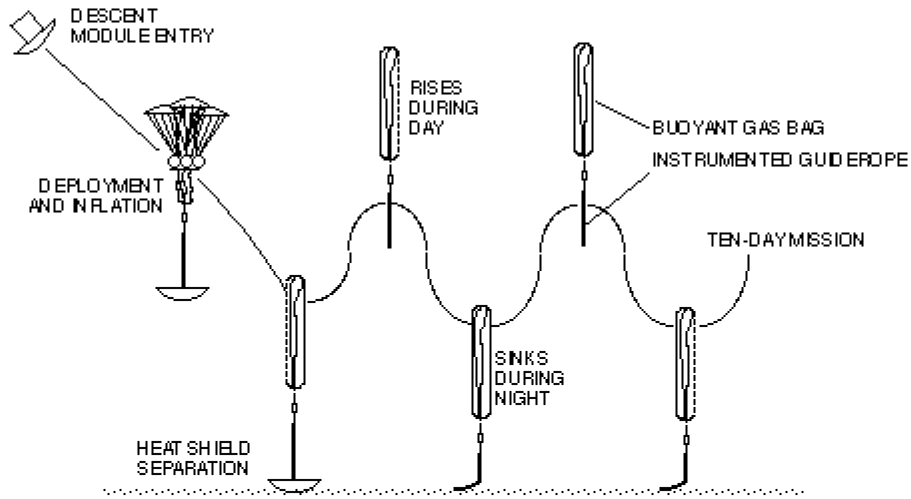


Classification: Lander spacecraft with surface rover.

Mission: Analyze Martian soil.

Features: The lander will parachute to the surface. One second before impact on the Martian surface, three airbags will inflate on each of the three folded "petals" of the lander, cushioning its impact. After the airbags have deflated, the petals then deploy, exposing solar panels to the sunlight, and righting the lander. The rover is then deployed by driving off the solar panel and onto the Martian soil. The lander is designed to operate on the surface for over 30 Martian days and nights, and return a panoramic view of the Martian landscape. It will also measure the soil's chemistry and characterize the seismic environment.

Mars Balloon

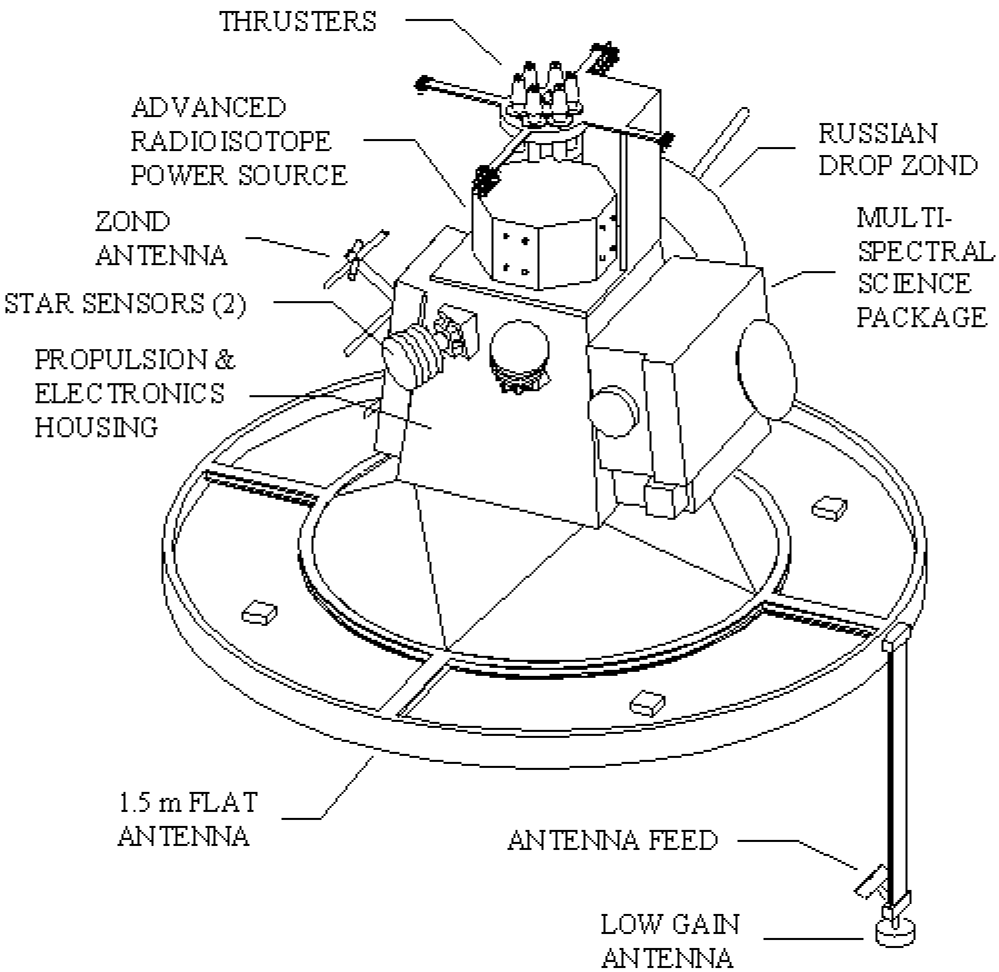


Classification: Balloon package.

Mission: Explore the Martian landscape.

Features: The balloon is designed to become buoyant enough to lift its instrumented guide rope when heated by the sun in the daytime, and to sink when cooled at night, letting the guide rope contact the surface. Electronics are fitted within 24 interconnected, partially nested, articulated conical titanium segments which make up the snake or guide rope. It carries various sensors and spectrometers, radar, data management system, transmitter, and batteries. It is intended to survive for ten Martian days and nights.

Pluto Spacecraft



Classification: Flyby spacecraft.

Mission: Conduct the first reconnaissance of Pluto.

Features: Two low-mass spacecraft are being considered for separate launches on fast, direct trajectories to reach the Pluto-Charon system in 7 to 10 years. Science objectives established by NASA's Outer Planets Science Working Group and the Solar System Exploration Subcommittee include characterizing the global geology and geomorphology, and mapping the surface composition of both bodies, and characterize the tenuous atmosphere. It would carry an imaging camera, and UV and IR spectrometers. The fast trajectories would allow the spacecraft to reach their target before the atmosphere precipitates to the surface, which is predicted to occur around the year 2015 as Pluto moves farther from the sun. The proposed spacecraft would have a mass of about 150 kg including propellant, would operate on 60 watts of electrical power, and provide a downlink at a maximum of 40 bps. The launch vehicle candidates are Titan IV with Centaur upper stage, or Proton.

Stabilization: Three-axis stabilized by thrusters.

GLOSSARY

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z

A

A

Acceleration.

Å

Angstrom (0.0001 micrometer, 0.1 nm).

AAAS

American Association for the Advancement of Science.

AACS

Attitude and Articulation Control Subsystem onboard a spacecraft.

AAS

American Astronomical Society.

AC

Alternating current.

ALT

Altitude.

ALT

Altimetry data.

AM

Ante meridiem (Latin: before midday), morning.

am

Attometer (10-18 m).

AMMOS

Advanced Multi-mission Operations System.

AO

Announcement of Opportunity.

AOS

Acquisition Of Signal, used in DSN operations.

Aphelion

Apoapsis in solar orbit.

Apoapsis

The farthest point in an orbit from the body being orbited.

Apogee

Apoapsis in Earth orbit.

Apojove

Apoapsis in Jupiter orbit.

Apolune

Apoapsis in lunar orbit.

Apselene

Apoapsis in lunar orbit.

Argument

Angular distance.

Argument of periapsis

The argument (angular distance) of periapsis from the ascending node.

Ascending node

The point at which an orbit crosses the ecliptic plane going north.

Asteroids

Small bodies composed of rock and metal in orbit about the sun.

Attometer

10-18 meter.

AU

Astronomical Unit, mean Earth-to-sun distance, approximately 150,000,000 km.

AZ

Azimuth.

B

Barycenter

The common center of mass about which two or more bodies revolve.

BOT

Beginning Of Track, used in DSN operations.

BPS

Bits Per Second, same as baud rate

C

c

The speed of light, 299,792 km per second.

Caltech

California Institute of Technology.

Carrier

The main frequency of a radio signal generated by a transmitter prior to application of modulation.

C-band

A range of microwave radio frequencies in the neighborhood of 4 to 8 GHz.

CCD

Charge Coupled Device, a solid-state imaging detector.

C&DH

Command and Data Handling subsystem on board a spacecraft, similar to CDS.

CCS

Computer Command subsystem on board a spacecraft, similar to CDS.

CDS

Command and Data Subsystem onboard a spacecraft.

CDU

Command Detector Unit onboard a spacecraft.

Centrifugal force

The outward-tending apparent force of a body revolving around another body.

Centimeter

10-2 meter.

Centripetal acceleration

The inward acceleration of a body revolving around another body.

CIT

California Institute of Technology, Caltech.

CMC

Complex Monitor and Control, a subsystem at DSCCs.

CNES

Centre National d'Études Spatiales, France.

Coherent

Two-way communications mode wherein the spacecraft generates its downlink frequency based upon the frequency of the uplink it receives.

Coma

The cloud of diffuse material surrounding the nucleus of a comet.

Comets

Small bodies composed of ice and rock in various orbits about the sun.

CRAF

Comet Rendezvous / Asteroid Flyby mission, cancelled.

CRT

Cathode ray tube video display device

D

DC

Direct current.

DEC

Declination, the measure of a celestial body's apparent height above or below the celestial equator.

Descending node

The point at which an orbit crosses the ecliptic plane going south.

Downlink

Signal received from a spacecraft.

DSCC

Deep Space Communications Complex, one of three DSN tracking sites at Goldstone, California; Madrid, Spain; and Canberra, Australia; spaced about equally around the Earth for continuous tracking of deep-space vehicles.

DSN

Deep Space Network, JPL's worldwide spacecraft tracking facility.

DSS

Deep Space Station, the antenna front-end equipment at DSCCs.

Dyne

A unit of force equal to the force required to accelerate a 1-g mass at 1 cm per second per second (1cm/sec2). Compare with Newton.

E

E

East.

Earth

Third planet from the sun, a terrestrial planet.

Eccentricity

The distance between the foci of an ellipse divided by the major axis.

Ecliptic

The plane in which Earth orbits the sun.

EDR

Experiment Data Record.

EHz

ExaHertz (1018 Hz)

EL

Elevation.

Ellipse

A closed plane curve generated in such a way that the sums of its distances from the two fixed points (the foci) is constant.

ELV

Expendable launch vehicle.

EOT

End Of Track, used in DSN operations.

Equator

An imaginary circle around a body which is everywhere equidistant from the poles, defining the boundary between the northern and southern hemispheres.

ERT

Earth-received time, UTC of an event at DSN receive- time, equal to SCET plus OWLT.

ESA

European Space Agency.

ET

Ephemeris time, a measurement of time defined by orbital motions. Equates to Mean Solar Time corrected for irregularities in Earth's motions.

eV

Electron volt, a measure of the energy of subatomic particles

F

F

Force.

FDS

Flight Data Subsystem.

FE

Far Encounter phase of mission operations.

Femtometer

10-15 meter.

Fluorescence

The phenomenon of emitting light upon absorbing radiation of an invisible wavelength.

fm

Femtometer (10-15 m)

FM

Frequency modulation.

FY

Fiscal year.

G

G

Giga (billion).

g

Gram, a thousandth of the metric standard unit of mass (see kg). The gram was originally based upon the weight of a cubic centimeter of water.

Gal

Unit of gravity field measurement corresponding to a gravitational acceleration of 1 cm/sec2.

Galaxy

One of billions of systems, each composed of numerous stars, nebulae, and dust.

Galilean

The four large satellites of Jupiter so named because Galileo discovered them when he turned his telescope toward Jupiter: Io, Europa, Ganymede, and Callisto.

Gamma rays

Electromagnetic radiation in the neighborhood of 100 femtometers wavelength.

GCF

Ground Communications Facilities, provides data and voice communications between JPL and the three DSCCs.

GDS

Ground Data System, encompasses DSN, GCF, MCCC, and project data processing systems.

GEO

Geosynchronous Earth Orbit.

Geostationary

A geosynchronous orbit in which the spacecraft is constrained to a constant latitude.

Geosynchronous

A direct, circular, low inclination orbit about the Earth having a period of 23 hours 56 minutes 4 seconds.

GHz

Gigahertz (109 Hz).

GLL

Galileo spacecraft.

GMT

Greenwich Mean Time, similar to UTC but not updated with leap seconds.

Gravitation

The mutual attraction of all masses in the universe.

Great circle

An imaginary circle on the surface of a sphere whose center is at the center of the sphere.

GSSR

Goldstone Solar System Radar, a technique which uses very high-power X and S-band transmitters at DSS 14 to illuminate solar system objects for imaging.

GTL

Geotail spacecraft.

GTO

Geostationary (or geosynchronous) Transfer Orbit.

Gravitational waves

Einsteinian distortions of the space-time medium predicted by general relativity theory (not yet detected as of November 1995).

Gravity waves

Certain atmospheric waves within a planet's atmosphere

H

HA

Hour Angle, the angular distance of a celestial object measured westward along the celestial equator from the zenith crossing. In effect, HA represents the RA for a particular location and time of day.

Heliopause

The boundary theorized to be roughly circular or teardrop-shaped, marking the edge of the sun's influence, perhaps 100 AU from the sun.

Heliosphere

The space within the boundary of the heliopause, containing the sun and solar system.

HGA

High-Gain Antenna onboard a spacecraft.

Horizon

The line marking the apparent junction of Earth and sky.

h

Hour.

Hz

Hertz, cycles per second

I

ICE

International Cometary Explorer spacecraft.

Inclination

The angular distance of the orbital plane from the plane of the planet's equator, stated in degrees.

Inferior planet

Planet which orbits closer to the Sun than the Earth's orbit.

Inferior conjunction

Alignment of Earth, sun, and an inferior planet on the same side of the sun.

Ion

A charged particle consisting of an atom stripped of one or more of its electrons.

IPC

Information Processing Center, JPL's computing center on Woodbury Avenue in Pasadena.

IR

Infrared, meaning "below red" radiation. Electromagnetic radiation in the neighborhood of 100 micrometers wavelength.

IRAS

Infrared Astronomical Satellite.

ISOE

Integrated Sequence of Events.

Isotropic

Having uniform properties in all directions.

IUS

Inertial Upper Stage

J

JGR

Journal Of Geophysical Research.

Jovian

Jupiter-like planets, the gas giants Jupiter, Saturn, Uranus, and Neptune.

JPL

Jet Propulsion Laboratory, operating division of the California Institute of Technology.

Jupiter

Fifth planet from the sun, a gas giant or Jovian planet

K

k

Kilo (thousand).

K-band

A range of microwave radio frequencies in the neighborhood of 12 to 40 GHz.

kg

Kilogram, the metric standard unit of mass, based on the mass of a metal cylinder kept in France. See g (gram).

kHz

kilohertz.

Kilometer

103 meter.

km

Kilometers.

KSC

Kennedy Space Center, Cape Canaveral, Florida.

KWF

Keyword file of events listing DSN station activity

L

LAN

Local area network for inter-computer communications.

Laser

Light Amplification by Stimulated Emission of Radiation.

Latitude

Circles in parallel planes to that of the equator defining north-south measurements, also called parallels.

L-band

A range of microwave radio frequencies in the neighborhood of 1 to 2 GHz.

Leap Year

Every fourth year, in which a 366th day is added since the Earth's revolution takes 365 days 5 hr 49 min.

LECP

Low-Energy Charged-Particular Detector onboard a spacecraft.

LEO

Low Equatorial Orbit.

LGA

Low-Gain Antenna onboard a spacecraft.

Light

Electromagnetic radiation in the neighborhood of 1 nanometer wavelength.

Light speed

299,792 km per second, the constant c.

Light time

The amount of time it takes light or radio signals to travel a certain distance at light speed.

Light year

The distance light travels in a year.

LMC

Link Monitor and Control subsystem at the SPCs.

Local time

Time adjusted for location around the Earth or other planets in time zones.

Longitude

Great circles that pass through both the north and south poles, also called meridians.

LOS

Loss Of Signal, used in DSN operations.

LOX

Liquid oxygen.

M

M

Mass.

M

Mega (million).

m

Meter (U.S. spelling; elsewhere metre), the international standard of linear measurement.

Major axis

The maximum diameter of an ellipse.

Mars

Fourth planet from the sun, a terrestrial planet.

Maser

Microwave Amplification by Stimulated Emission of Radiation.

MC-cubed

Mission Control and Computing Center.

MCCC

Mission Control and Computing Center.

MCT

Mission Control Team, Section 391 project operations.

Mean solar time

Time based on an average of the variations caused by Earth's non-circular orbit.

Mercury

First planet from the sun, a terrestrial planet.

Meridians

Great circles that pass through both the north and south poles, also called lines of longitude.

MESUR

The Mars Environmental Survey project at JPL, the engineering prototype of which is called MESUR Pathfinder.

Meteor

A meteoroid which is in the process of entering Earth's atmosphere.

Meteorite

Rocky or metallic material which has fallen to Earth or to another planet.

Meteoroid

Small bodies in orbit about the sun which are candidates for falling to Earth or to another planet.

MGA

Medium-Gain Antenna onboard a spacecraft.

MGN

Magellan spacecraft.

MHz

Megahertz (106 Hz).

Micrometer

μm, 10-6 meter.

Micron

Obsolete terms for micrometer, μm (10-6 m).

Milky Way

The galaxy which includes the sun and Earth.

Millimeter

10-3 meter.

MIT

Massachusetts Institute of Technology.

mm

millimeter (10-3 m).

MO

Mars Observer spacecraft.

Modulation

The process of modifying a radio frequency by shifting its phase, frequency, or amplitude to carry information.

Moon

A small natural body which orbits a larger one. A natural satellite.

MOSO

Multimission Operations Systems Office at JPL.

µm

Micrometer (10-6 m)

N

N

Newton, a unit of force equal to the force required to accelerate a 1-kg mass 1 m per second per second (1m/sec2). Compare with dyne.

N

North.

Nadir

The direction from a spacecraft directly down toward the center of a planet. Opposite the zenith.

NASA

National Aeronautics and Space Administration.

NE

Near Encounter phase in flyby mission operations.

Neptune

Eighth planet from the sun, a gas giant or Jovian planet.

NIMS

Near-Infrared Mapping Spectrometer onboard the Galileo spacecraft.

nm

Nanometer (10-9 m).

nm

Nautical Mile, equal to the distance spanned by one minute of arc in latitude, 1.852 km.

Nodes

Points where an orbit crosses a plane.

Non-coherent

Communications mode wherein a spacecraft generates its downlink frequency independent of any uplink frequency.

Nucleus

The central body of a comet

O

OB

Observatory phase in flyby mission operations encounter period.

One-way

Communications mode consisting only of downlink received from a spacecraft.

Oort cloud

A large number of comets theorized to orbit the sun in the neighborhood of 50,000 AU.

OPCT

Operations Planning and Control Team, "OPSCON."

OSR

Optical Solar Reflector, thermal control component onboard a spacecraft.

OSSA

Office Of Space Science and Applications, NASA.

OTM

Orbit Trim Maneuver, spacecraft propulsive maneuver.

OWLT

One-Way Light Time, elapsed time between Earth and spacecraft or solar system body

P

PAM

Payload Assist Module upper stage.

Parallels

Circles in parallel planes to that of the equator defining north-south measurements, also called lines of latitude.

Pathfinder

The Mars Environmental Survey (MESUR) engineering prototype.

PDS

Planetary Data System.

PDT

Pacific Daylight Time.

PE

Post Encounter phase in flyby mission operations.

Periapsis

The point in an orbit closest to the body being orbited.

Perigee

Periapsis in Earth orbit.

Perihelion

Periapsis in solar orbit.

Perijove

Periapsis in Jupiter orbit.

Perilune

Periapsis in lunar orbit.

Periselene

Periapsis in lunar orbit.

Phase

The angular distance between peaks or troughs of two waveforms of similar frequency.

Phase

The particular appearance of a body's state of illumination, such as the full phase of the moon.

Photovoltaic

Materials that convert light into electric current.

PHz

Petahertz (1015 Hz).

PI

Principal Investigator, scientist in charge of an experiment.

Picometer

10-12 meter.

PIO

JPL's Public Information Office.

Plasma

Electrically conductive fourth state of matter from solid, liquid, and gas, consisting of ions and electrons.

PLL

Phase-lock-loop circuitry in telecommunications technology.

Pluto

Ninth planet from the sun, sometimes classified as a small terrestrial planet.

pm

Picometer (10-12 m).

PM

Post meridiem (Latin: after midday), afternoon.

PN10

Pioneer 10 spacecraft.

PN11

Pioneer 11 spacecraft.

PST

Pacific Standard Time.

PSU

Pyrotechnic Switching Unit onboard a spacecraft

Q

No Entries

R

RA

Right Ascension, the angular distance of a celestial object measured in hours, minutes, and seconds along the celestial equator eastward from the vernal equinox.

Radian

Unit of angular measurement equal to the angle at the center of a circle subtended by an arc equal in length to the radius. Equals about 57.296 degrees.

RAM

Random Access Memory.

Red dwarf

A small star, on the order of 100 times the mass of Jupiter.

Refraction

The deflection or bending of electromagnetic waves when they pass from one kind of transparent medium into another.

RF

Radio Frequency.

RFI

Radio Frequency Interference.

ROM

Read Only Memory.

RPIF

Regional Planetary Imaging Data Facilities.

RTG

Radioisotope Thermo-Electric Generator onboard a spacecraft.

RTLT

Round-Trip Light Time, elapsed time roughly equal to 2 x OWLT

S

S

South.

SA

Solar Array, photovoltaic panels onboard a spacecraft.

SAF

Spacecraft Assembly Facility, JPL Building 179.

SAR

Synthetic Aperture Radar.

Satellite

A small body which orbits a larger one. A natural or an artificial moon. Earth-orbiting spacecraft are called satellites. While deep-space vehicles are technically satellites of the sun or of another planet, or of the galactic center, they are generally called spacecraft instead of satellites.

Saturn

Sixth planet from the sun, a gas giant or Jovian planet.

S-band

A range of microwave radio frequencies in the neighborhood of 2 to 4 GHz.

SC

Steering Committee.

SCET

Spacecraft Event Time, equal to ERT minus OWLT.

SCLK

Spacecraft Clock Time, a counter onboard a spacecraft.

Sec

Second.

SEDR

Supplementary Experiment Data Record.

SEF

Spacecraft event file.

SEGS

Sequence of Events Generation Subsystem.

Semi-major axis

Half the distance of an ellipse's maximum diameter, the distance from the center of the ellipse to one end.

Shepherd moons

Moons which gravitationally confine ring particles.

Sidereal time

Time relative to the stars other than the sun.

SIRTF

Space Infrared Telescope Facility.

SOE

Sequence of Events.

SNR

Signal-to-Noise Ratio.

SP-100

JPL's Space Power-100 Project developing nuclear reactors for use in space.

SPC

Signal Processing Center at each DSCC.

SSA

Solid State Amplifier in a spacecraft telecommunications subsystem, the final stage of amplification for downlink.

SSI

Solid State Imaging Subsystem, the CCD-based cameras on Galileo.

SSI

Space Services, Inc., Houston, manufacturers of the Conestoga launch vehicle.

STS

Space Transportation System (Space Shuttle).

Subcarrier

Modulation applied to a carrier which is itself modulated with information-carrying variations.

Superior planet

Planet which orbits farther from the sun than Earth's orbit.

Superior conjunction

Alignment between Earth and a planet on the far side of the sun.

SWG

Science Working Group

T

TAU

Thousand AU Mission.

TCM

Trajectory Correction Maneuver, spacecraft propulsive maneuver.

TDM

Time-division multiplexing.

Three-way

Coherent communications mode wherein a DSS receives a downlink whose frequency is based upon the frequency of an uplink provided by another DSS.

THz

Terahertz (1012 Hz).

TOS

Transfer Orbit Stage, upper stage.

Transducer

Device for changing one kind of energy into another, typically from heat, position, or pressure into a varying electrical voltage or vice-versa, such as a microphone or speaker.

Transponder

Electronic device which combines a transmitter and a receiver.

TRC

NASA's Teacher Resource Centers.

TRM

Transmission Time, UTC Earth time of uplink.

True anomaly

The angular distance of a point in an orbit past the point of periapsis, measured in degrees.

TWNC

Two-Way Non-Coherent mode, in which a spacecraft's downlink is not based upon a received uplink from DSN.

Two-way

Communications mode consisting of downlink received from a spacecraft while uplink is being received at the spacecraft. See also coherent.

TWT

Traveling Wave Tube, downlink power amplifier in a spacecraft telecommunications subsystem, the final stage of amplification for downlink (same unit as TWTA).

TWTA

Traveling Wave Tube Amplifier, downlink power amplifier in a spacecraft telecommunications subsystem, the final stage of amplification for downlink (same unit as TWT).

U

μm

Micrometer (10-6 m).

ULS

Ulysses spacecraft.

Uplink

Signal sent to a spacecraft.

Uranus

Seventh planet from the sun, a gas giant or Jovian planet.

USO

Ultra Stable Oscillator, in a spacecraft telecommunications subsystem.

UTC

Universal Time, Coordinated.

UV

Ultraviolet (meaning "above violet") radiation. Electromagnetic radiation in the neighborhood of 100 nanometers wavelength

V

Venus

Second planet from the sun, a terrestrial planet.

VGR1

Voyager 1 spacecraft.

VGR2

Voyager 2 spacecraft.

VLBI

Very Long Baseline Interferometry

W

W

Watt, a measure of electrical power equal to potential in volts times current in amps.

W

West.

Wavelength

The distance that a wave from a single oscillation of electromagnetic radiation will propagate during the time required for one oscillation.

WWW

World-Wide Web

X

X-band

A range of microwave radio frequencies in the neighborhood of 8 to 12 GHz.

X-ray

Electromagnetic radiation in the neighborhood of 100 picometers wavelength.

Y

No Entries.

Z

Z

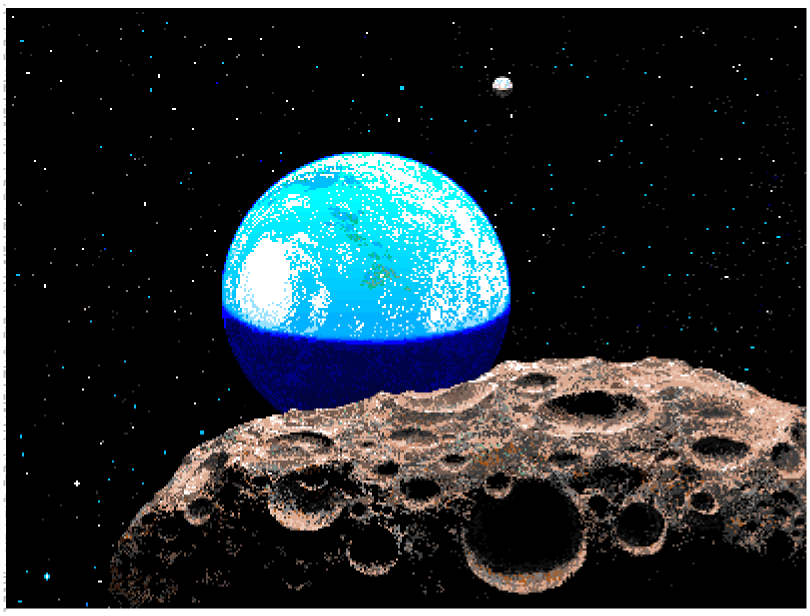
Zulu in phonetic alphabet, stands for GMT.

Zenith

The point on the celestial sphere directly above the observer; opposite the nadir.

BASICS OF SPACE FLIGHT 1.0 FOR WINDOWS

DEMO VERSION



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