space sciences

VOLUME 1
Space Business

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Pat Dasch, Editor in Chief

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Macmillan Reference USA	Gale Group
300 Park Avenue South	27500 Drake Rd.
New York, NY 10010	Farmington Hills, MI 48331-3535

Library of Congress Cataloging-in-Publication Data
Space sciences / Pat Dasch, editor in chief.
p. cm.
Includes bibliographical references and indexes.
ISBN 0-02-865546-X (set : alk. paper)
1. Space sciences. I. Dasch, Pat.
QB500 .S63 2002
500.5—dc21
2002001707

Volume 1: ISBN 0-02-865547-8
Volume 2: ISBN 0-02-865548-6
Volume 3: ISBN 0-02-865549-4
Volume 4: ISBN 0-02-865550-8

Printed in the United States of America
1 2 3 4 5 6 7 8 9 10

Preface

Astronomers have studied the heavens for more than two millennia, but in the twentieth century, humankind ventured off planet Earth into the dark vacuum void of space, forever changing our perspective of our home planet and on our relationship to the universe in which we reside.

Our explorations of space—the final frontier in our niche in this solar system—first with satellites, then robotic probes, and finally with humans, have given rise to an extensive space industry that has a major influence on the economy and on our lives. In 1998, U.S. space exports (launch services, satellites, space-based communications services, and the like) totaled $64 billion. As we entered the new millennium, space exports were the second largest dollar earner after agriculture. The aerospace industry directly employs some 860,000 Americans, with many more involved in subcontracting companies and academic research.

Beginnings

The Chinese are credited with developing the rudiments of rocketry—they launched rockets as missiles against invading Mongols in 1232. In the nineteenth century William Congrieve developed a rocket in Britain based on designs conceived in India in the eighteenth century. Congrieve extended the range of the Indian rockets, adapting them specifically for use by armies. Congrieve's rockets were used in 1806 in the Napoleonic Wars.

The Birth of Modern Space Exploration

The basis of modern spaceflight and exploration came with the writings of Konstantin Tsiolkovsky (1857–1935), a Russian mathematics teacher. He described multi-stage rockets, winged craft like the space shuttle developed in the 1970s, space stations like Mir and the International Space Station, and interplanetary missions of discovery.

During the same period, space travel captured the imagination of fiction writers. Jules Verne wrote several novels with spaceflight themes. His book, *From the Earth to the Moon* (1865), describes manned flight to the Moon, including a launch site in Florida and a spaceship named Columbia—the name chosen for the Apollo 11 spaceship that made the first lunar landing in July 1969 and the first space shuttle, which flew in April 1981. In the twentieth century, Arthur C. Clarke predicted the role of communications satellites and extended our vision of human space exploration while television series such as *Star Trek* and *Dr. Who* challenged the imagination and embedded the idea of space travel in our culture.

The first successful test of the V-2 rocket developed by Wernher von Braun and his team at Peenemünde, Germany, in October 1942 has been described as the "birth of the Space Age." After World War II some of the Peenemünde team under von Braun came to the United States, where they worked at the White Sands Missile Range in New Mexico, while others went to Russia. This sowed the seeds of the space race of the 1960s. Each team worked to develop advanced rockets, with Russia developing the R-7, while a series of rockets with names like Thor, Redstone, and Titan were produced in the United States.

When the Russians lofted Sputnik, the first artificial satellite, on October 4, 1957, the race was on. The flights of Yuri Gagarin, Alan Shepard, and John Glenn followed, culminating in the race for the Moon and the Apollo Program of the 1960s and early 1970s.

The Emergence of a Space Industry

The enormous national commitment to the Apollo Program marked a new phase in our space endeavors. The need for innovation and technological advance stimulated the academic and engineering communities and led to the growth of a vast network of contract supporters of the aerospace initiative and the birth of a vibrant space industry. At the same time, planetary science emerged as a new geological specialization.

Following the Apollo Program, the U.S. space agency's mission remained poorly defined through the end of the twentieth century, grasping at major programs such as development of the space shuttle and the International Space Station, in part, some argue, to provide jobs for the very large workforce spawned by the Apollo Program. The 1980s saw the beginnings of what would become a robust commercial space industry, largely independent of government programs, providing communications and information technology via space-based satellites. During the 1990s many thought that commercialization was the way of the future for space ventures. Commercially coordinated robotic planetary exploration missions were conceived with suggestions that NASA purchase the data, and Dennis Tito, the first paying space tourist in 2001, raised hopes of access to space for all.

The terrorist attacks on the United States on September 11, 2001 and the U.S. recession led to a re-evaluation of the entrepreneurial optimism of the 1990s. Many private commercial space ventures were placed on hold or went out of business. Commentators suggested that the true dawning of the commercial space age would be delayed by up to a decade. But, at the same time, the U.S. space agency emerged with a more clearly defined mandate than it had had since the Apollo Program, with a role of driving technological innovation—with an early emphasis on reducing the cost of getting to orbit—and leading world class space-related scientific projects. And military orders, to fill the needs of the new world order, compensated to a point for the downturn in the commercial space communications sector.

It is against this background of an industry in a state of flux, a discipline on the cusp of a new age of innovation, that this encyclopedia has been prepared.

Organization of the Material

The 341 entries in *Space Sciences* have been organized in four volumes, focusing on the business of space exploration, planetary science and astronomy, human space exploration, and the outlook for the future exploration of space. Each entry has been newly commissioned for this work. Our contributors are drawn from academia, industry, government, professional space institutes and associations, and nonprofit organizations. Many of the contributors are world authorities on their subject, providing up-to-the-minute information in a straightforward style accessible to high school students and university undergraduates.

One of the outstanding advantages of books on space is the wonderful imagery of exploration and achievement. These volumes are richly illustrated, and sidebars provide capsules of additional information on topics of particular interest. Entries are followed by a list of related entries, as well as a reading list for students seeking more information.

Acknowledgements

I wish to thank the team at Macmillan Reference USA and the Gale Group for their vision and leadership in bringing this work to fruition. In particular, thanks to Hélène Potter, Cindy Clendenon, and Gloria Lam. My thanks to Associate Editors Nadine Barlow, Leonard David, and Frank Sietzen, whose expertise, commitment, and patience have made *Space Sciences* possible. My thanks also go to my husband, Julius, for his encouragement and support. My love affair with space began in the 1970s when I worked alongside geologists using space imagery to plan volcanological field work in remote areas of South America, and took root when, in the 1980s, I became involved in systematic analysis of the more than 3,000 photographs of Earth that astronauts bring back at the end of every shuttle mission. The beauty of planet Earth, as seen from space, and the wealth of information contained in those images, convinced me that space is a very real part of life on Earth, and that I wanted to be a part of the exploration of space and to share the wonder of it with the public. I hope that *Space Sciences* conveys the excitement, achievements, and potential of space exploration to a new generation of students.

Pat Dasch
Editor in Chief

For Your Reference

The following section provides information that is applicable to a number of articles in this reference work. Included in the following pages is a chart providing comparative solar system planet data, as well as measurement, abbreviation, and conversion tables.

SOLAR SYSTEM PLANET DATA

	Mercury	Venus[2]	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Mean distance from the Sun (AU): [1]	0.387	0.723	1	1.524	5.202	9.555	19.218	30.109	39.439
Siderial period of orbit (years):	0.24	0.62	1	1.88	11.86	29.46	84.01	164.79	247.68
Mean orbital velocity (km/sec):	47.89	35.04	29.79	24.14	13.06	9.64	6.81	5.43	4.74
Orbital essentricity:	0.206	0.007	0.017	0.093	0.048	0.056	0.047	0.009	0.246
Inclination to ecliptic (degrees):	7.00	3.40	0	1.85	1.30	2.49	0.77	1.77	17.17
Equatorial radius (km):	2439	6052	6378	3397	71492	60268	25559	24764	1140
Polar radius (km):	same	same	6357	3380	66854	54360	24973	24340	same
Mass of planet (Earth = 1):[3]	0.06	0.82	1	0.11	317.89	95.18	14.54	17.15	0.002
Mean density (gm/cm ^{3}):	5.44	5.25	5.52	3.94	1.33	0.69	1.27	1.64	2.0
Body rotation period (hours):	1408	5832.R	23.93	24.62	9.92	10.66	17.24	16.11	153.3
Tilt of equator to orbit (degrees):	0	2.12	23.45	23.98	3.08	26.73	97.92	28.8	96

[1]AU indicates one astronomical unit, defined as the mean distance between Earth and the Sun (~1.495 x 10^8 km).
[2]R indicates planet rotation is retrograde (i.e., opposite to the planet's orbit).
[3]Earth's mass is approximately 5.976 x 10^{26} grams.

SI BASE AND SUPPLEMENTARY UNIT NAMES AND SYMBOLS

Physical Quality	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
Plane angle	radian	rad
Solid angle	steradian	sr

Temperature

Scientists commonly use the Celsius system. Although not recommended for scientific and technical use, earth scientists also use the familiar Fahrenheit temperature scale (°F). 1°F = 1.8°C or K. The triple point of H_2O, where gas, liquid, and solid water coexist, is 32°F.

- To change from Fahrenheit (F) to Celsius (C):
  °C = (°F-32)/(1.8)
- To change from Celsius (C) to Fahrenheit (F):
  °F = (°C x 1.8) + 32
- To change from Celsius (C) to Kelvin (K):
  K = °C + 273.15
- To change from Fahrenheit (F) to Kelvin (K):
  K = (°F-32)/(1.8) + 273.15

UNITS DERIVED FROM SI, WITH SPECIAL NAMES AND SYMBOLS

Derived Quantity	Name of SI Unit	Symbol for SI Unit	Expression in Terms of SI Base Units
Frequency	hertz	Hz	s-1
Force	newton	N	m kg s-2
Pressure, stress	Pascal	Pa	N m-2 =m-1 kg s-2
Energy, work, heat	Joule	J	N m =m2 kg s-2
Power, radiant flux	watt	W	J s-1 =m2 kg s-3
Electric charge	coulomb	C	A s
Electric potential, electromotive force	volt	V	J C-1 =m-2 kg s-3 A-1
Electric resistance	ohm	_	V A-1 =m2 kg s-3 A-2
Celsius temperature	degree Celsius	C	K
Luminous flux	lumen	lm	cd sr
Illuminance	lux	lx	cd sr m-2

UNITS USED WITH SI, WITH NAME, SYMBOL, AND VALUES IN SI UNITS

The following units, not part of the SI, will continue to be used in appropriate contexts (e.g., angtsrom):

Physical Quantity	Name of Unit	Symbol for Unit	Value in SI Units
Time	minute	min	60 s
	hour	h	3,600 s
	day	d	86,400 s
Plane angle	degree	°	(π/180) rad
	minute	'	(π/10,800) rad
	second	"	(π/648,000) rad
Length	angstrom	Å	10^{-10} m
Volume	liter	l, L	1 dm^3 = 10^{-3} m^3
Mass	ton	t	1 mg = 10^3 kg
	unified atomic mass unit	u (=$m_a(^{12}C)/12$)	≈1.66054 x 10^{-27} kg
Pressure	bar	bar	10^5 Pa = 10^5 N m^{-2}
Energy	electronvolt	eV (= e X V)	≈1.60218 x 10^{-19} J

CONVERSIONS FOR STANDARD, DERIVED, AND CUSTOMARY MEASUREMENTS

Length

1 angstrom (Å)	0.1 nanometer (exactly) 0.000000004 inch
1 centimeter (cm)	0.3937 inches
1 foot (ft)	0.3048 meter (exactly)
1 inch (in)	2.54 centimeters (exactly)
1 kilometer (km)	0.621 mile
1 meter (m)	39.37 inches 1.094 yards
1 mile (mi)	5,280 feet (exactly) 1.609 kilometers
1 astronomical unit (AU)	1.495979×10^{13} cm
1 parsec (pc)	206,264.806 AU 3.085678×10^{18} cm 3.261633 light-years
1 light-year	9.460530×10^{17} cm

Area

1 acre	43,560 square feet (exactly) 0.405 hectare
1 hectare	2.471 acres
1 square centimeter (cm^2)	0.155 square inch
1 square foot (ft^2)	929.030 square centimeters
1 square inch (in^2)	6.4516 square centimeters (exactly)
1 square kilometer (km^2)	247.104 acres 0.386 square mile
1 square meter (m^2)	1.196 square yards 10.764 square feet
1 square mile (mi^2)	258.999 hectares

MEASUREMENTS AND ABBREVIATIONS

Volume

1 barrel (bbl)*, liquid	31 to 42 gallons
1 cubic centimeter (cm^3)	0.061 cubic inch
1 cubic foot (ft^3)	7.481 gallons 28.316 cubic decimeters
1 cubic inch (in^3)	0.554 fluid ounce
1 dram, fluid (or liquid)	⅛ fluid ounce (exactly) 0.226 cubic inch 3.697 milliliters
1 gallon (gal) (U.S.)	231 cubic inches (exactly) 3.785 liters 128 U.S. fluid ounces (exactly)
1 gallon (gal) (British Imperial)	277.42 cubic inches 1.201 U.S. gallons 4.546 liters
1 liter	1 cubic decimeter (exactly) 1.057 liquid quarts 0.908 dry quart 61.025 cubic inches
1 ounce, fluid (or liquid)	1.805 cubic inches 29.573 mililiters
1 ounce, fluid (fl oz) (British)	0.961 U.S. fluid ounce 1.734 cubic inches 28.412 milliliters
1 quart (qt), dry (U.S.)	67.201 cubic inches 1.101 liters
1 quart (qt), liquid (U.S.)	57.75 cubic inches (exactly) 0.946 liter

* There are a variety of "barrels" established by law or usage. For example, U.S. federal taxes on fermented liquors are based on a barrel of 31 gallons (141 liters); many state laws fix the "barrel for liquids" as 31½ gallons (119.2 liters); one state fixes a 36-gallon (160.5 liters) barrel for cistern measurment; federal law recognizes a 40-gallon (178 liters) barrel for "proof spirts"; by custom, 42 gallons (159 liters) comprise a barrel of crude oil or petroleum products for statistical purposes, and this equivalent is recognized "for liquids" by four states.

Units of mass

1 carat (ct)	200 milligrams (exactly) 3.086 grains
1 grain	64.79891 milligrams (exactly)
1 gram (g)	15.432 grains 0.035 ounce
1 kilogram (kg)	2.205 pounds
1 microgram (μg)	0.000001 gram (exactly)
1 milligram (mg)	0.015 grain
1 ounce (oz)	437.5 grains (exactly) 28.350 grams
1 pound (lb)	7,000 grains (exactly) 453.59237 grams (exactly)
1 ton, gross or long	2,240 pounds (exactly) 1.12 net tons (exactly) 1.016 metric tons
1 ton, metric (t)	2,204.623 pounds 0.984 gross ton 1.102 net tons
1 ton, net or short	2,000 pounds (exactly) 0.893 gross ton 0.907 metric ton

Pressure

1 kilogram/square centimeter (kg/cm^2)	0.96784 atmosphere (atm) 14.2233 pounds/square inch (lb/in^2) 0.98067 bar
1 bar	0.98692 atmosphere (atm) 1.02 kilograms/square centimeter (kg/cm^2)

Major Business Milestones in U.S. History

Apr. 1820	Federal law allows settlers to purchase lands in western United States.
Dec. 1823	Monroe Doctrine established.
Mar. 1824	Supreme Court establishes federal authority over interstate commerce.
May, 1824	United States raises tariff on foreign goods.
May, 1828	Congress passes high import duty on foreign goods.
July, 1832	President Andrew Jackson vetoes Bank of U.S. rechartering.
Nov. 1832	South Carolina voids Tariff Acts of 1828, 1832.
Mar. 1833	Congress passes bill giving president power to enforce tariffs.
Sept. 1833	U.S. Treasury Secretary removes deposits from Bank of U.S.
Mar. 1834	Congress censures president over removal of funds from Bank of U.S.
June, 1834	Second Coinage Act changes silver/gold ratio, which undervalues silver.
Dec. 1835	United States becomes debt-free.
Feb. 1836	Bank of U.S. rechartered.
June, 1836	Congress passes Deposit Act requiring federal deposit bank in every state.
July, 1836	Payments for purchase of public land required in gold or silver.
May, 1837	Panic of 1837 triggers seven-year depression in the United States.
Aug. 1841	Congress passes new bankruptcy law.
Sept. 1841	President John Tyler vetoes bill to reestablish national U.S. bank.
July, 1846	Tariff reduced by Congressional action.
Jan. 1848	Gold rush era begins.

Sept. 1850	Land grants established to help pay for U.S. transcontinental railroad.
Aug. 1854	Congress reduces purchase price of federal lands.
Jan. 1855	First U.S. petroleum company is established.
Apr. 1857	Panic of 1857 triggers run on U.S. banks.
July, 1858	Gold discovered near Pike's Peak Colorado.
Aug. 1859	Pennsylvania site of major oil discovery.
May, 1862	Homestead Act establishes farming on public lands.
Feb. 1863	Congress passes National Banking Act.
June, 1864	Tariffs slashed by Congress.
Mar. 1865	Congress creates 10 percent tax on state bank notes.
Apr. 1866	Funding Act passed, creates conversion of securities into bonds.
July, 1866	Congress reduces Civil War taxes.
Mar. 1867	Congress passes Internal Revenue Act.
Feb. 1868	Congress suspends greenback retirement.
Mar. 1868	Congress cancels excise taxes.
July, 1870	Congress announces end of U.S. income tax in two years.
Feb. 1873	Coinage of silver dollars ends.
Sept. 1873	Five-year depression begins.
	U.S. Stock Exchange closes for ten days following stock collapse.
June, 1874	Amount of greenbacks in circulation is fixed.
Jan. 1875	Greenbacks can be redeemed in gold.
Jan. 1878	First U.S. commercial telephone exchange starts in Connecticut.
Jan. 1881	Western Union company is formed.
	Income tax declared unconstitutional.
Dec. 1886	American Federation of Labor is created in Columbus, Ohio.
Feb. 1887	Congress created Interstate Commerce Commission.
Oct. 1890	Tariff Act raises tariffs.
Apr. 1893	U.S. Treasury suspends issuance of gold certificates.
Jan. 1894	Treasury sells $50 million in bonds to resupply gold reserves.
Aug. 1894	Tariff Act creates two percent federal income tax.
Nov. 1894	United States issues additional $50 million in bonds to buy gold.
Feb. 1895	United States buys $65 million in gold.

July, 1897	United States raises tariffs to record levels.
June, 1898	War Revenue Act passed; establishes excise taxes.
Jan. 1901	Huge oilfield discovery in Texas.
May, 1901	Wall Street Panic over control of Northern-Pacific railroad.
June, 1901	J. P. Morgan consolidates U.S. Steel.
Jan. 1907	U.S. immigration reaches peak.
Oct. 1907	"Banker's Panic" sweeps banking industry, causing widespread failures.
Feb. 1908	Supreme Court rules Sherman Anti-Trust Act applies to labor unions.
Aug. 1909	Payne-Aldrich Tariff Act signed and reduces tariff rates.
June, 1910	Postal Savings System to pay interest of two percent.
May, 1911	Supreme Court orders break-up of Standard Oil.
Jan. 1913	Postal Service establishes Parcel Post.
Mar. 1913	Ford opens auto assembly line.
July, 1914	Stock Exchange closes as Europe slides into war.
Nov. 1914	Federal Reserve opens.
1915	Carrier Engineering is founded, creating commercial air conditioning.
Jan. 1915	Telephone service between New York and San Francisco begins.
Oct. 1915	U.S. banks loan $500 million to Great Britain and France.
Sept. 1916	Emergency Revenue Act doubles U.S. income tax rates.
Mar. 1917	Excess Profits Tax instituted.
Apr. 1917	Congress passes Emergency Loan Act to issue bonds for war effort.
Dec. 1917	Federal government assumes control of railroads.
Apr. 1919	Congress passes loan authorization to pay off war debt.
1920	Recession begins in United States following end of World War I.
Feb. 1920	Federal Reserve issues 7 percent discount rate.
June, 1924	Federal government reduces federal income tax rates.
Apr. 1923	Commercial air passenger service begins in United States.
July, 1928	Interest rates soar to record highs.
Feb. 1929	Federal Reserve refuses to support stock speculation.
Oct. 1929	Stock market prices plunge.
Nov. 1929	New York Stock Exchange reports record stock devaluation.

Dec. 1929	President Herbert Hoover signs income tax reduction bill.
June, 1930	Stock market reports additional steep value losses.
Dec. 1930	Bank of U.S. fails.
	Banks across United States close.
Sept. 1931	Bank panic closes 800 banks.
July, 1932	Dow Jones Industrial Average falls to record lows.
Dec. 1932	Treasury Certificates reach record low interest.
Feb. 1934	Congress votes on massive civil works and relief aid.
June, 1934	Congress creates Securities and Exchange Commission.
Feb. 1934	Congress votes to regulate crude oil.
Apr. 1935	Congress votes on work relief program for unemployed.
Aug. 1935	Congress votes on increases to income, inheritance, and gift taxes.
Jan. 1936	Congress imposes payroll tax.
May, 1938	Congress cuts corporate taxes.
June, 1939	IRS establishes minimum flat-rate corporate tax.
June, 1940	Federal taxes raised.
Oct. 1940	Corporate tax rate raised to 24 percent.
Sept. 1941	All federal taxes increased to fund increases in defense spending.
June, 1945	Federal reserve reduces gold reserve.
Nov. 1945	Revenue Act passed, slashes taxes raised during World War II.
July, 1946	Stock prices begin decline after years of growth.
Aug. 1948	Consumer Price Index peaks at record high values.
Aug. 1950	Federal Reserve Board urges end to inflationary loan practice.
Mar. 1954	Excise taxes slashed.
Aug. 1954	IRS changes federal tax code to allow greater depreciation.
Jan. 1955	United States shows full employment, increased consumer spending.
Aug. 1955	Congress raised minimum wage to $1.00 per hour.
Sept. 1957	Recession starts.
May, 1958	Largest peacetime business growth begins.
Jan. 1959	President Dwight D. Eisenhower endorses 52 percent hike in corporate tax rates.
May, 1961	Minimum wage raised to $1.25 per hour.
Oct. 1962	Congress passes Revenue Act allowing for investment tax credits.

Jan. 1963	President John F. Kennedy proposes major reduction in tax rates.
Nov. 1966	Congress suspends Investment Tax Credit.
Jan. 1967	President Lyndon B. Johnson proposes 6 percent surtax on income taxes.
June, 1968	Revenue Act adds 10 percent tax surcharge to federal taxes.
June, 1969	Prime lending rate reaches highest level of 8.5 percent.
	Consumer prices rise more than 6 percent since January.
Dec. 1969	Taxes reduced for poor and low income earners.
Mar. 1971	Social security benefits raised 10 percent.
Aug. 1971	President Richard M. Nixon takes United States off gold standard.
Jan. 1973	Wage and price controls instituted.
June, 1973	Minimum wage increased to $2.20 per hour.
Sept. 1973	Congress creates new ration: U.S. dollar to gold $42 per ounce.
Oct. 1973	Oil embargo begins.
Apr. 1974	End of wage and price controls.
Oct. 1974	President Gerald R. Ford proposes 5 percent income tax surcharge.
Dec. 1974	Federal Reserve reduces discount rate to 7.5 percent.
July, 1975	Social Security payments increased 8 percent.
Nov. 1977	Minimum wage raised to $3.35 per hour.
May, 1980	Leading Economic Indicators posts 4.8 percent drop, largest on record.
Dec. 1980	Prime lending rate reaches 21.5 percent, highest in history.
July, 1981	Congress passes Reagan tax cut plan.
Aug. 1982	Bull Market begins on Wall Street.
Sept. 1986	Congress passes tax reform act.
Oct. 1987	Stock market crashes 508 points in single day.
Oct. 1989	Minimum wage increased to $3.80 per hour.
Apr. 1991	Dow Jones Industrial Average breaks 3000.
Dec. 1995	Dow Jones breaks 5117.
July, 1997	Congress passes largest tax cut package in 16 years.
Oct. 1997	Dow Jones falls 554 points in one day.
Aug. 1998	Dow Jones falls 512 points in single day.
Sept. 1998	Congress passes $80 billion tax cut.
Oct. 1998	Federal Reserve cuts rate by 0.025 to 5 percent.
2000	Internet dot.com businesses blossom.

May, 2000	Federal Reserve reduces prime rate to 6.5 percent.
Jan. 2001	Federal Reserve reduces prime rate to 6 percent.
Mar. 2001	Prime rate dropped to 5.5 percent.
Apr. 2001	Prime rate dropped to 5 percent.
	Dot.coms collapse, technology stocks plummet.
May, 2001	Prime rate dropped to 4.5 percent.
June, 2001	Prime rate dropped to 4 percent.
Aug. 2001	Prime rate dropped to 3.5 percent.
Sept. 2001	Terrorist attacks against the United States devastate economy.
	Prime rate dropped to 3 percent.
Oct. 2001	Prime rate dropped to 2.5 percent.
Nov. 2001	Prime rate dropped to 2 percent.
Dec. 2001	Prime rate dropped to 1.75 percent.

Frank Sietzen, Jr.

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Milestones in Space History

c. 850 The Chinese invent a form of gunpowder for rocket propulsion.

1242 Englishman Roger Bacon develops gunpowder.

1379 Rockets are used as weapons in the Siege of Chioggia, Italy.

1804 William Congrieve develops ship-fired rockets.

1903 Konstantin Tsiolkovsky publishes *Research into Interplanetary Science by Means of Rocket Power*, a treatise on space travel.

1909 Robert H. Goddard develops designs for liquid-fueled rockets.

1917 Smithsonian Institute issues grant to Goddard for rocket research.

1918 Goddard publishes the monograph *Method of Attaining Extreme Altitudes.*

1921 Soviet Union establishes a state laboratory for solid rocket research.

1922 Hermann Oberth publishes *Die Rakete zu den Planetenräumen*, a work on rocket travel through space.

1923 Tsiolkovsky publishes work postulating multi-staged rockets.

1924 Walter Hohmann publishes work on rocket flight and orbital motion.

1927 The German Society for Space Travel holds its first meeting.

Max Valier proposes rocket-powered aircraft adapted from Junkers G23.

1928 Oberth designs liquid rocket for the film *Woman in the Moon.*

1929 Goddard launches rocket carrying barometer.

1930 Soviet rocket designer Valentin Glusko designs U.S.S.R. liquid rocket engine.

1931	Eugene Sänger test fires liquid rocket engines in Vienna.
1932	German Rocket Society fires first rocket in test flight.
1933	Goddard receives grant from Guggenheim Foundation for rocket studies.
1934	Wernher von Braun, member of the German Rocket Society, test fires water-cooled rocket.
1935	Goddard fires advanced liquid rocket that reaches 700 miles per hour.
1936	Glushko publishes work on liquid rocket engines.
1937	The Rocket Research Project of the California Institute of Technology begins research program on rocket designs.
1938	von Braun's rocket researchers open center at Pennemünde.
1939	Sänger and Irene Brendt refine rocket designs and propose advanced winged suborbital bomber.
1940	Goddard develops centrifugal pumps for rocket engines.
1941	Germans test rocket-powered interceptor aircraft Me 163.
1942	V-2 rocket fired from Pennemünde enters space during ballistic flight.
1943	First operational V-2 launch.
1944	V-2 rocket launched to strike London.
1945	Arthur C. Clarke proposes geostationary satellites.
1946	Soviet Union tests version of German V-2 rocket.
1947	United States test fires Corporal missile from White Sands, New Mexico.
	X-1 research rocket aircraft flies past the speed of sound.
1948	United States reveals development plan for Earth satellite adapted from RAND.
1949	Chinese rocket scientist Hsueh-Sen proposes hypersonic aircraft.
1950	United States fires Viking 4 rocket to record 106 miles from USS Norton Sound.
1951	Bell Aircraft Corporation proposes winged suborbital rocket-plane.
1952	Wernher von Braun proposes wheeled Earth-orbiting space station.
1953	U.S. Navy D-558II sets world altitude record of 15 miles above Earth.
1954	Soviet Union begins design of RD-107, RD-108 ballistic missile engines.
1955	Soviet Union launches dogs aboard research rocket on suborbital flight.

1956 United States announces plan to launch Earth satellite as part of Geophysical Year program.

1957 U.S. Army Ballistic Missile Agency is formed.

Soviet Union test fires R-7 ballistic missile.

Soviet Union launches the world's first Earth satellite, Sputnik-1, aboard R-7.

United States launches 3-stage Jupiter C on test flight.

United States attempts Vanguard 1 satellite launch; rocket explodes.

1958 United States orbits Explorer-1 Earth satellite aboard Jupiter-C rocket.

United States establishes the National Aeronautics and Space Administration (NASA) as civilian space research organization.

NASA establishes Project Mercury manned space project.

United States orbits Atlas rocket with Project Score.

1959 Soviet Union sends Luna 1 towards Moon; misses by 3100 miles.

NASA announces the selection of seven astronauts for Earth space missions.

Soviet Union launches Luna 2, which strikes the Moon.

1960 United States launches Echo satellite balloon.

United States launches Discoverer 14 into orbit, capsule caught in midair.

Soviet Union launches two dogs into Earth orbit.

Mercury-Redstone rocket test fired in suborbital flight test.

1961 Soviet Union tests Vostok capsule in Earth orbit with dummy passenger.

Soviet Union launches Yuri Gagarin aboard Vostok-1; he becomes the first human in space.

United States launches Alan B. Shepard on suborbital flight.

United States proposes goal of landing humans on the Moon before 1970.

Soviet Union launches Gherman Titov into Earth orbital flight for one day.

United States launches Virgil I. "Gus" Grissom on suborbital flight.

United States launches first Saturn 1 rocket in suborbital test.

1962	United States launches John H. Glenn into 3-orbit flight.
	United States launches Ranger to impact Moon; craft fails.
	First United States/United Kingdom international satellite launch; Ariel 1 enters orbit.
	X-15 research aircraft sets new altitude record of 246,700 feet.
	United States launches Scott Carpenter into 3-orbit flight.
	United States orbits Telstar 1 communications satellite.
	Soviet Union launches Vostok 3 and 4 into Earth orbital flight.
	United States launches Mariner II toward Venus flyby.
	United States launches Walter Schirra into 6-orbit flight.
	Soviet Union launches Mars 1 flight; craft fails.
1963	United States launches Gordon Cooper into 22-orbit flight.
	Soviet Union launches Vostok 5 into 119-hour orbital flight.
	United States test fires advanced solid rockets for Titan 3C.
	First Apollo Project test in Little Joe II launch.
	Soviet Union orbits Vostok 6, which carries Valentina Tereshkova, the first woman into space.
	Soviet Union tests advanced version of R-7 called Soyuz launcher.
1964	United States conducts first Saturn 1 launch with live second stage; enters orbit.
	U.S. Ranger 6 mission launched towards Moon; craft fails.
	Soviet Union launches Zond 1 to Venus; craft fails.
	United States launches Ranger 7 on successful Moon impact.
	United States launches Syncom 3 communications satellite.
	Soviet Union launches Voshkod 1 carrying three cosmonauts.
	United States launches Mariner 4 on Martian flyby mission.
1965	Soviet Union launches Voshkod 2; first space walk.
	United States launches Gemini 3 on 3-orbit piloted test flight.
	United States launches Early Bird 1 communications satellite.
	United States launches Gemini 4 on 4-day flight; first U.S. space walk.

United States launches Gemini 5 on 8-day flight.

United States launches Titan 3C on maiden flight.

Europe launches Asterix 1 satellite into orbit.

United States Gemini 6/7 conduct first space rendezvous.

1966 Soviet Union launches Luna 9, which soft lands on Moon.

United States Gemini 8 conducts first space docking; flight aborted.

United States launches Surveyor 1 to Moon soft landing.

United States tests Atlas Centaur advanced launch vehicle.

Gemini 9 flight encounters space walk troubles.

Gemini 10 flight conducts double rendezvous.

United States launches Lunar Orbiter 1 to orbit Moon.

Gemini 11 tests advanced space walks.

United States launches Saturn IB on unpiloted test flight.

Soviet Union tests advanced Proton launch vehicle.

United States launches Gemini 12 to conclude two-man missions.

1967 Apollo 1 astronauts killed in launch pad fire.

Soviet Soyuz 1 flight fails; cosmonaut killed.

Britain launches Ariel 3 communications satellite.

United States conducts test flight of M2F2 lifting body research craft.

United States sends Surveyor 3 to dig lunar soils.

Soviet Union orbits anti-satellite system.

United States conducts first flight of Saturn V rocket (Apollo 4).

1968 Yuri Gagarin killed in plane crash.

Soviet Union docks Cosmos 212 and 213 automatically in orbit.

United States conducts Apollo 6 Saturn V test flight; partial success.

Nuclear rocket engine tested in Nevada.

United States launches Apollo 7 in three-person orbital test flight.

Soviet Union launches Soyuz 3 on three-day piloted flight.

United States sends Apollo 8 into lunar orbit; first human flight to Moon.

1969 Soviet Union launches Soyuz 4 and 5 into orbit; craft dock.

Largest tactical communications satellite launched.

	United States flies Apollo 9 on test of lunar landing craft in Earth orbit.
	United States flies Apollo 10 to Moon in dress rehearsal of landing attempt.
	United States cancels military space station program.
	United States flies Apollo 11 to first landing on the Moon.
	United States cancels production of Saturn V in budget cut.
	Soviet lunar rocket N-1 fails in launch explosion.
	United States sends Mariner 6 on Mars flyby.
	United States flies Apollo 12 on second lunar landing mission.
	Soviet Union flies Soyuz 6 and 7 missions.
	United States launches Skynet military satellites for Britain.
1970	China orbits first satellite.
	Japan orbits domestic satellite.
	United States Apollo 13 mission suffers explosion; crew returns safely.
	Soviet Union launches Venera 7 for landing on Venus.
	United States launches military early warning satellite.
	Soviet Union launches Luna 17 to Moon.
	United States announces modifications to Apollo spacecraft.
1971	United States flies Apollo 14 to Moon landing.
	Soviet Union launches Salyut 1 space station into orbit.
	First crew to Salyut station, Soyuz 11, perishes.
	Soviet Union launches Mars 3 to make landing on the red planet.
	United States flies Apollo 15 to Moon with roving vehicle aboard.
1972	United States and the Soviet Union sign space cooperation agreement.
	United States launches Pioneer 10 to Jupiter flyby.
	Soviet Union launches Venera 8 to soft land on Venus.
	United States launches Apollo 16 to moon.
	India and Soviet Union sign agreement for launch of Indian satellite.
	United States initiates space shuttle project.
	United States flies Apollo 17, last lunar landing mission.

1973	United States launches Skylab space station.
	United States launches first crew to Skylab station.
	Soviet Union launches Soyuz 12 mission.
	United States launches second crew to Skylab space station.
1974	United States launches ATS research satellite.
	Soviet Union launches Salyut 3 on unpiloted test flight.
	Soviet Union launches Soyuz 12, 13, and 14 flights.
	Soviet Union launches Salyut 4 space station.
1975	Soviet Union launches Soyuz 17 to dock with Salyut 4 station.
	Soviet Union launches Venera 9 to soft land on Venus.
	United States and Soviet Union conduct Apollo-Soyuz Test Project joint flight.
	China orbits large military satellite.
	United States sends Viking 1 and 2 towards landing on Martian surface.
	Soviet Union launches unpiloted Soyuz 20.
1976	Soviet Union launches Salyut 5 space station.
	First space shuttle rolls out; Enterprise prototype.
	Soviet Union docks Soyuz 21 to station.
	China begins tests of advanced ballistic missile.
1977	Soyuz 24 docks with station.
	United States conducts atmospheric test flights of shuttle Enterprise.
	United States launches Voyager 1 and 2 on deep space missions.
	Soviet Union launches Salyut 6 space station.
	Soviet Soyuz 25 fails to dock with station.
	Soyuz 26 is launched and docks with station.
1978	Soyuz 27 is launched and docks with Salyut 6 station.
	Soyuz 28 docks with Soyuz 27/Salyut complex.
	United States launches Pioneer/Venus 1 mission.
	Soyuz 29 docks with station.
	Soviet Union launches Progress unpiloted tankers to station.
	Soyuz 30 docks with station.
	United States launches Pioneer/Venus 2.
	Soyuz 31 docks with station.

1979	Soyuz 32 docks with Salyut station.
	Voyager 1 flies past Jupiter.
	Soyuz 33 fails to dock with station.
	Voyager 2 flies past Jupiter.
1980	First Ariane rocket launches from French Guiana; fails.
	Soviet Union begins new Soyuz T piloted missions.
	STS-1 first shuttle mission moves to launching pad.
1981	Soviet Union orbits advanced Salyut stations.
	STS-1 launched on first space shuttle mission.
	United States launches STS-2 on second shuttle flight; mission curtailed.
1982	United States launches STS-5 first operational shuttle flight.
1983	United States launches Challenger, second orbital shuttle, on STS-6.
	United States launches Sally Ride, the first American woman in space, on STS-7.
	United States launches Guion Bluford, the first African-American astronaut, on STS-8.
	United States launches first Spacelab mission aboard STS-9.
1984	Soviet Union tests advanced orbital station designs.
	Shuttle Discovery makes first flights.
	United States proposes permanent space station as goal.
1985	Space shuttle Atlantis enters service.
	United States announces policy for commercial rocket sales.
	United States flies U.S. Senator aboard space shuttle Challenger.
1986	Soviet Union launches and occupies advanced Mir space station.
	Challenger—on its tenth mission, STS-51-L—is destroyed in a launching accident.
	United States restricts payloads on future shuttle missions.
	United States orders replacement shuttle for Challenger.
1987	Soviet Union flies advanced Soyuz T-2 designs.
	United States' Delta, Atlas, and Titan rockets grounded in launch failures.
	Soviet Union launches Energyia advanced heavy lift rocket.

1988	Soviet Union orbits unpiloted shuttle Buran.
	United States launches space shuttle Discovery on STS-26 flight.
	United States launches STS-27 military shuttle flight.
1989	United States launches STS-29 flight.
	United States launches Magellan probe from shuttle.
1990	Shuttle fleet grounded for hydrogen leaks.
	United States launches Hubble Space Telescope.
1992	Replacement shuttle Endeavour enters service.
	United States probe Mars Observer fails.
1993	United States and Russia announce space station partnership.
1994	United States shuttles begin visits to Russian space station Mir.
1995	Europe launches first Ariane 5 advanced booster; flight fails.
1996	United States announces X-33 project to replace shuttles.
1997	Mars Pathfinder lands on Mars.
1998	First elements of International Space Station launched.
1999	First Ocean space launch of Zenit rocket in Sea Launch program.
2000	Twin United States Mars missions fail.
2001	United States cancels shuttle replacements X-33 and X-34 because of space cutbacks.
	United States orbits Mars Odyssey probe around Mars.
2002	First launches of United States advanced Delta IV and Atlas V commercial rockets.

Frank Sietzen, Jr.

Human Achievements in Space

The road to space has been neither steady nor easy, but the journey has cast humans into a new role in history. Here are some of the milestones and achievements.

Oct. 4, 1957 The Soviet Union launches the first artificial satellite, a 184-pound spacecraft named Sputnik.

Nov. 3, 1957 The Soviets continue pushing the space frontier with the launch of a dog named Laika into orbit aboard Sputnik 2. The dog lives for seven days, an indication that perhaps people may also be able to survive in space.

Jan. 31, 1958 The United States launches Explorer 1, the first U.S. satellite, and discovers that Earth is surrounded by radiation belts. James Van Allen, who instrumented the satellite, is credited with the discovery.

Apr. 12, 1961 Yuri Gagarin becomes the first person in space. He is launched by the Soviet Union aboard a Vostok rocket for a two-hour orbital flight around the planet.

May 5, 1961 Astronaut Alan Shepard becomes the first American in space. Shepard demonstrates that individuals can control a vehicle during weightlessness and high gravitational forces. During his 15-minute suborbital flight, Shepard reaches speeds of 5,100 mph.

May 24, 1961 Stung by the series of Soviet firsts in space, President John F. Kennedy announces a bold plan to land men on the Moon and bring them safely back to Earth before the end of the decade.

Feb. 20, 1962 John Glenn becomes the first American in orbit. He flies around the planet for nearly five hours in his Mercury capsule, Friendship 7.

June 16, 1963 The Soviets launch the first woman, Valentina Tereshkova, into space. She circles Earth in her Vostok spacecraft for three days.

Nov. 28, 1964 NASA launches Mariner 4 spacecraft for a flyby of Mars.

Mar. 18, 1965 Cosmonaut Alexei Leonov performs the world's first space walk outside his Voskhod 2 spacecraft. The outing lasts 10 minutes.

Mar. 23, 1965 Astronauts Virgil I. "Gus" Grissom and John Young blast off on the first Gemini mission and demonstrate for the first time how to maneuver from one orbit to another.

June 3, 1965 Astronaut Edward White becomes the first American to walk in space during a 21-minute outing outside his Gemini spacecraft.

Mar. 16, 1966 Gemini astronauts Neil Armstrong and David Scott dock their spacecraft with an unmanned target vehicle to complete the first joining of two spacecraft in orbit. A stuck thruster forces an early end to the experiment, and the crew makes America's first emergency landing from space.

Jan. 27, 1967 The Apollo 1 crew is killed when a fire breaks out in their command module during a prelaunch test. The fatalities devastate the American space community, but a subsequent spacecraft redesign helps the United States achieve its goal of sending men to the Moon.

Apr. 24, 1967 Tragedy also strikes the Soviet space program, with the death of cosmonaut Vladimir Komarov. His new Soyuz spacecraft gets tangled with parachute lines during reentry and crashes to Earth.

Dec. 21, 1968 Apollo 8, the first manned mission to the Moon, blasts off from Cape Canaveral, Florida. Frank Borman, Jim Lovell and Bill Anders orbit the Moon ten times, coming to within 70 miles of the lunar surface.

July 20, 1969 Humans walk on another world for the first time when astronauts Neil Armstrong and Edwin "Buzz" Aldrin climb out of their spaceship and set foot on the Moon.

Apr. 13, 1970 The Apollo 13 mission to the Moon is aborted when an oxygen tank explosion cripples the spacecraft. NASA's most serious inflight emergency ends four days later when the astronauts, ill and freezing, splash down in the Pacific Ocean.

June 6, 1971 Cosmonauts blast off for the first mission in the world's first space station, the Soviet Union's Salyut 1. The crew spends twenty-two days aboard the outpost. During reentry, however, a faulty valve leaks air from the Soyuz capsule, and the crew is killed.

Jan. 5, 1972 President Nixon announces plans to build "an entirely new type of space transportation system," pumping life into NASA's dream to build a reusable, multi-purpose space shuttle.

Dec. 7, 1972 The seventh and final mission to the Moon is launched, as public interest and political support for the Apollo program dims.

May 14, 1973 NASA launches the first U.S. space station, Skylab 1, into orbit. Three crews live on the station between May 1973 and February 1974. NASA hopes to have the shuttle flying in time to reboost and resupply Skylab, but the outpost falls from orbit on July 11, 1979.

July 17, 1975 In a momentary break from Cold War tensions, the United States and Soviet Union conduct the first linking of American and Russian spaceships in orbit. The Apollo-Soyuz mission is a harbinger of the cooperative space programs that develop between the world's two space powers twenty years later.

Apr. 12, 1981 Space shuttle Columbia blasts off with a two-man crew for the first test-flight of NASA's new reusable spaceship. After two days in orbit, the shuttle lands at Edwards Air Force Base in California.

June 18, 1983 For the first time, a space shuttle crew includes a woman. Astronaut Sally Ride becomes America's first woman in orbit.

Oct. 30, 1983 NASA's increasingly diverse astronaut corps includes an African-American for the first time. Guion Bluford, an aerospace engineer, is one of the five crewmen assigned to the STS-8 mission.

Nov. 28, 1983 NASA flies its first Spacelab mission and its first European astronaut, Ulf Merbold.

Feb. 7, 1984 Shuttle astronauts Bruce McCandless and Robert Stewart take the first untethered space walks, using a jet backpack to fly up to 320 feet from the orbiter.

Apr. 9–11, 1984 First retrieval and repair of an orbital satellite.

Jan. 28, 1986 Space shuttle Challenger explodes 73 seconds after launch, killing its seven-member crew. Aboard the shuttle was Teacher-in-Space finalist Christa McAuliffe, who was to conduct lessons from orbit. NASA grounds the shuttle fleet for two and a half years.

Feb. 20. 1986 The Soviets launch the core module of their new space station, Mir, into orbit. Mir is the first outpost designed as a module system to be expanded in orbit. Expected lifetime of the station is five years.

May 15, 1987 Soviets launch a new heavy-lift booster from the Baikonur Cosmodrome in Kazakhstan.

Oct. 1, 1987 Mir cosmonaut Yuri Romanenko breaks the record for the longest space mission, surpassing the 236-day flight by Salyut cosmonauts set in 1984.

Sept. 29, 1988 NASA launches the space shuttle Discovery on the first crewed U.S. mission since the 1986 Challenger explosion. The shuttle carries a replacement communications satellite for the one lost onboard Challenger.

May 4, 1989 Astronauts dispatch a planetary probe from the shuttle for the first time. The Magellan radar mapper is bound for Venus.

Nov. 15, 1989 The Soviets launch their space shuttle Buran, which means snowstorm, on its debut flight. There is no crew onboard, and unlike the U.S. shuttle, no engines to help place it into orbit. Lofted into orbit by twin Energia heavy-lift boosters, Buran circles Earth twice and lands. Buran never flies again.

Apr. 24, 1990 NASA launches the long-awaited Hubble Space Telescope, the cornerstone of the agency's "Great Observatory" program, aboard space shuttle Discovery. Shortly after placing the telescope in orbit, astronomers discover that the telescope's prime mirror is misshapen.

Dec. 2, 1993 Space shuttle Endeavour takes off for one of NASA's most critical shuttle missions: repairing the Hubble Space Telescope. During an unprecedented five space walks, astronauts install corrective optics. The mission is a complete success.

Feb. 3, 1994 A Russian cosmonaut, Sergei Krikalev, flies aboard a U.S. spaceship for the first time.

Mar. 16, 1995 NASA astronaut Norman Thagard begins a three and a half month mission on Mir—the first American to train and fly on a Russian spaceship. He is the first of seven Americans to live on Mir.

Mar. 22, 1995 Cosmonaut Valeri Polyakov sets a new space endurance record of 437 days, 18 hours.

June 29, 1995 Space shuttle Atlantis docks for the first time at the Russian space station Mir.

Mar. 24, 1996 Shannon Lucid begins her stay aboard space aboard Mir, which lasts 188 days—a U.S. record for spaceflight endurance at that time.

Feb. 24, 1997 An oxygen canister on Mir bursts into flames, cutting off the route to the station's emergency escape vehicles. Six crewmembers are onboard, including U.S. astronaut Jerry Linenger.

June 27, 1997 During a practice of a new docking technique, Mir commander Vasily Tsibliyev loses control of an unpiloted cargo ship and it plows into the station. The Spektr module is punctured, The crew hurriedly seals off the compartment to save the ship.

Oct. 29, 1998 Senator John Glenn, one of the original Mercury astronauts, returns to space aboard the shuttle.

Nov. 20, 1998 A Russian Proton rocket hurls the first piece of the International Space Station into orbit.

Aug. 27, 1999 Cosmonauts Viktor Afanasyev, Sergei Avdeyev, and Jean-Pierre Haignere leave Mir. The station is unoccupied for the first time in almost a decade.

Oct. 31, 2000 The first joint American-Russian crew is launched to the International Space Station. Commander Bill Shepherd requests the radio call sign "Alpha" for the station and the name sticks.

Mar. 23, 2001 The *Mir* space station drops out of orbit and burns up in Earth's atmosphere.

Apr. 28, 2001 Russia launches the world's first space tourist for a week-long stay at the International Space Station. NASA objects to the flight, but is powerless to stop it.

Irene Brown

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Accessing Space

A

The task of placing satellites into **orbit** has proven formidable, and current technology dictates that rockets be used to access space. A rocket is a cylindrical metal object containing inflammable material, which, when ignited, propels the rocket to a significant height or distance. Rocket-powered vehicles are quite different from jet aircraft, in that jets use the atmosphere as a source of oxidizer (oxygen in the air) with which to burn the fuel. Rocket-propelled vehicles must carry along all propellants (both fuel and oxidizer).

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Pre-Space Age Rocketry Developments

Many centuries ago the Chinese first employed crude rockets using solidified propellants to scare their enemies with the resulting loud noises and flashing overhead lights. Later, rockets became popular for displays and celebrations. Early devices, however, were crude, used low-energy propellants, and were largely uncontrollable. It was not until the 1900s that major technological advances in rocketry were realized.

Around the turn of the twentieth century, Konstantin Tsiolkovsky, a Russian schoolteacher, discovered the fundamental relationship between the amount of propellant needed in a rocket and the resulting change in speed. This remains the most fundamental relationship of rocketry and is referred to as the "rocket equation." In the 1920s American physicist Robert H. Goddard designed and built the first liquid-propelled rocket motor and demonstrated its use in flight. This was a significant step toward the development of modern missiles and space launchers.

The onset of World War II (1939–1945) created a sense of urgency in advancing the development and deployment of long-range, rocket-propelled artillery projectiles and bombs. In both Germany and the United States major efforts were begun to create rocket-propelled guided bombs, that is, missiles. By 1944 operational V-2 missiles were being launched by Germany toward England. Although these were the first successfully guided bombs, they lacked good terminal guidance and usually missed their primary targets. They were, however, very effective as instruments of mass intimidation.

After the war, one group of German rocket engineers and scientists defected to the United States and another to the Soviet Union. Wernher von

The European Space Agency's fifth-generation Ariane rocket, shown here launching in October 1997, was capable of delivering an 18-ton satellite into a low Earth orbit.

Braun led the group that went to the United States. The mission of these scientists was to continue work on missile technology, and by the 1950s, the V-2 had been improved and transformed into a variety of missiles. In order to create an intercontinental ballistic missile (ICBM) that could travel several thousand miles, however, improved guidance systems and multistage booster designs were needed, and these two areas of technology became the focus of 1950s rocketry research. Precise guidance systems ensure accurate **trajectories** and precision targeting, while two-stage vehicles can overcome the pull of Earth's strong gravity and low-propellant energies to achieve great distances. These same technologies were needed for orbital launcher vehicles.

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

Rocketry Advances During the Late Twentieth Century Space Age

When the Soviets launched the first artificial satellite in 1957 (Sputnik 1), the United States quickly followed by modifying its ICBM inventory to create orbital launchers, and the "space race" between the two countries was on in earnest. By 1960 both the United States and the Soviet Union were producing launch vehicles at will. In 1961 President John F. Kennedy challenged America to send humans, before the end of the decade, to the surface of the Moon and return them safely. As amazing as it seemed at the time, two American astronauts, Neil Armstrong and Buzz Aldrin, walked on the Moon in July 1969. By the end of Project Apollo, in 1972, a total of twelve astronauts had walked on the lunar soil and returned safely to Earth, and the United States was well established as the dominant spacefaring nation.

During the 1960s and 1970s both the Soviet Union and the United States developed several families of space launchers. The Soviet inventory included the Kosmos, Proton, Soyuz, and Molniya, and the U.S. inventory included the Titan, Atlas, and Delta. In terms of the number and frequency of satellite launches, the Soviets were far more prolific, until the breakup of the Soviet Union in 1991. Whereas the Soviets focused on putting large numbers of relatively crude satellites in orbit, the United States focused on sophistication and reliability. Thus, the West was very successful in collecting a good deal more science data with fewer satellites.

Early in the 1970s President Richard Nixon approved the development of the Space Transportation System, better known as the space shuttle. This was to be a reusable system to replace all U.S. **expendable launch vehicles**. Thus, when the shuttle started flying in 1981, production lines for the Delta and Atlas boosters were shut down. They stayed shut down until the 1986 Challenger disaster.✶ At that point it became clear that expendables were still needed and would be needed for a long time to come. By 1989 the shuttle and several expendables were back in business. The three-year U.S. launch hiatus, however, permitted other countries to enter the commercial launcher business. The most prominent of these is the European Space Agency's launcher family, Ariane, which launches roughly 40 percent of the world's largest communications satellites. Other competitors in the marketplace include Russia, Ukraine, China, and Japan. Even Israel, Brazil, and India have been active in developing and launching small booster vehicles.

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

✶On January 28, 1986, space shuttle Challenger was destroyed by a technical malfunction approximately 72 seconds after lift-off.

The Future of Rocketry in the Twenty-First Century

As the twenty-first century begins, there are more than twenty families of expendable launchers from Europe and eight countries outside Europe. Nevertheless, there remains only one operational reusable vehicle, the space shuttle. The high cost of space access continues to propel the launch industry toward better solutions. Thus, new vehicles are expected to be developed in the future, including a few more expendables and a new generation of **reusables**. While the new expendables should offer some relief in terms of launch prices, reusable vehicles hold the promise for the significant cost reductions that are needed for extensive expansion of applications, such as space tourism. In pursuit of this objective, a half-dozen

reusables launchers that can be used many times before discarding companies are trying to develop a fully reusable vehicle. Some of them propose to build a single-stage system in which the entire vehicle travels from the launch pad all the way to orbit, separates from the satellite, and returns to the launch site. Others propose two-stage vehicles in which a booster/**orbiter** combination leave the launch pad together and return separately. By 2010, at least one of these systems could be operating. SEE ALSO ALDRIN, BUZZ (VOLUME 1); APOLLO (VOLUME 3); ARMSTRONG, NEIL (VOLUME 3); GODDARD, ROBERT HUTCHINGS (VOLUME 1); LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); LAUNCH VEHICLES, REUSABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4); SPACE SHUTTLE (VOLUME 3); TSIOLKOVSKY, KONSTANTIN (VOLUME 3); VON BRAUN, WERNHER (VOLUME 3).

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

Marshall H. Kaplan

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Advertising

In the early days of human spaceflight in the 1960s, public curiosity about astronauts was fueled by regular headlines in the media. Products selected for the space program were perceived to be exceptional, and promoters were quick to exploit this by playing up the fascination and mystery surrounding spaceflight. A crystallized, dehydrated, orange-flavored beverage called Tang was touted as "what the astronauts drink," and sales skyrocketed as the public clamored to have what the astronauts had. With the space age, thus, came space-themed advertising.

Consumers are bombarded daily with multimedia advertisements, coaxing people to buy, choose, or react to a myriad of products and services. Advertisers are hired to promote these products and services to specific markets based on a careful calculation of a target population's propensity to consume. To appeal to this possibility, advertisers strive to stay in the mainstream of the target audience in fashion, entertainment, food, and new technology by implanting a brand with a message that is crafted to be remembered by the recipient. Over the years, space themes have been used as a backdrop for many new products.

Before humans were orbiting Earth, space-themed advertisements were uncommon because the general public did not connect with outer space. Now, in the early twenty-first century, with discussion of futuristic orbiting hotels and launch adventure trips within the realm of technological possibility, space as a backdrop or theme for advertising is well-established.

Pepsi Cola launched a new advertising campaign from the Mir space station on April 25, 1996. This particular campaign unveiled a new version of Pepsi's logo.

Some fantastic concepts have been considered for advertising in space. For example, one firm considered using an Earth-based laser to beam messages onto the Moon. They soon realized this was impractical, however, because the images needed to be about the size of Texas to be visible to earthlings!

Pizza Hut, Inc., contracted with a Russian launch firm to affix a 9-meter-high (30-foot-high) new corporate logo on a Proton rocket carrying aloft a service module to the International Space Station and scheduled for launch in November 1999. Advertising the event prior to the launch date gave Pizza Hut international recognition, and the company expected 500 million people to watch the live televised event. The launch was planned to coincide with a release of Pizza Hut's transformed millennium image; the launch, however, was postponed for eight months because of technical problems.

Pepsi, the soft drink company, paid a large sum of money so that Russian cosmonauts would unveil a newly designed brand logo on a simulated "can" during missions to the Russian space station Mir in May 1996. The company has also pursued smaller scale promotional ventures in the U.S. space program since 1984.

NASA and other outer space agencies have researched the profitability of permitting advertising through the display of logos on space hardware, such as the International Space Station. While there is a market for such advertising, studies suggest that demand would not necessarily be sustained beyond the novelty of the first few paying customers.

Space.com, one of several space-related web sites that appeared in the dot-com boom of the late 1990s, derived significant revenue from advertising banners at the web site. Interestingly, the advertising content tended to relate to very down-to-Earth necessities—credit cards, cars, goods and services—and not space merchandise or otherworldly creations.

SEE ALSO Commercialization (volume 1); International Space Station (volumes 1 and 3); Mir (volume 3).

Len Campaigne

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Aerospace Corporations

For most of history, humankind has had to study space from on or near the surface of Earth. This meant that most of our knowledge was limited to what could be deduced from observations conducted through dust and light pollution and the distorting and degrading effects of Earth's atmosphere. No **in situ** study or direct analysis of materials from space (except for studies of **meteorites**) was possible. These conditions changed drastically with the development of space technology. First machines, then humans, were able to enter space, beginning a new era in space study and exploration. This era has grown to include the exploitation of space for public and private purposes. Designing, building, and operating the systems that make this possible is the role of aerospace corporations of the twenty-first century.

in situ in the natural or original location

meteorite any part of a meteoroid that survives passage through Earth's atmosphere

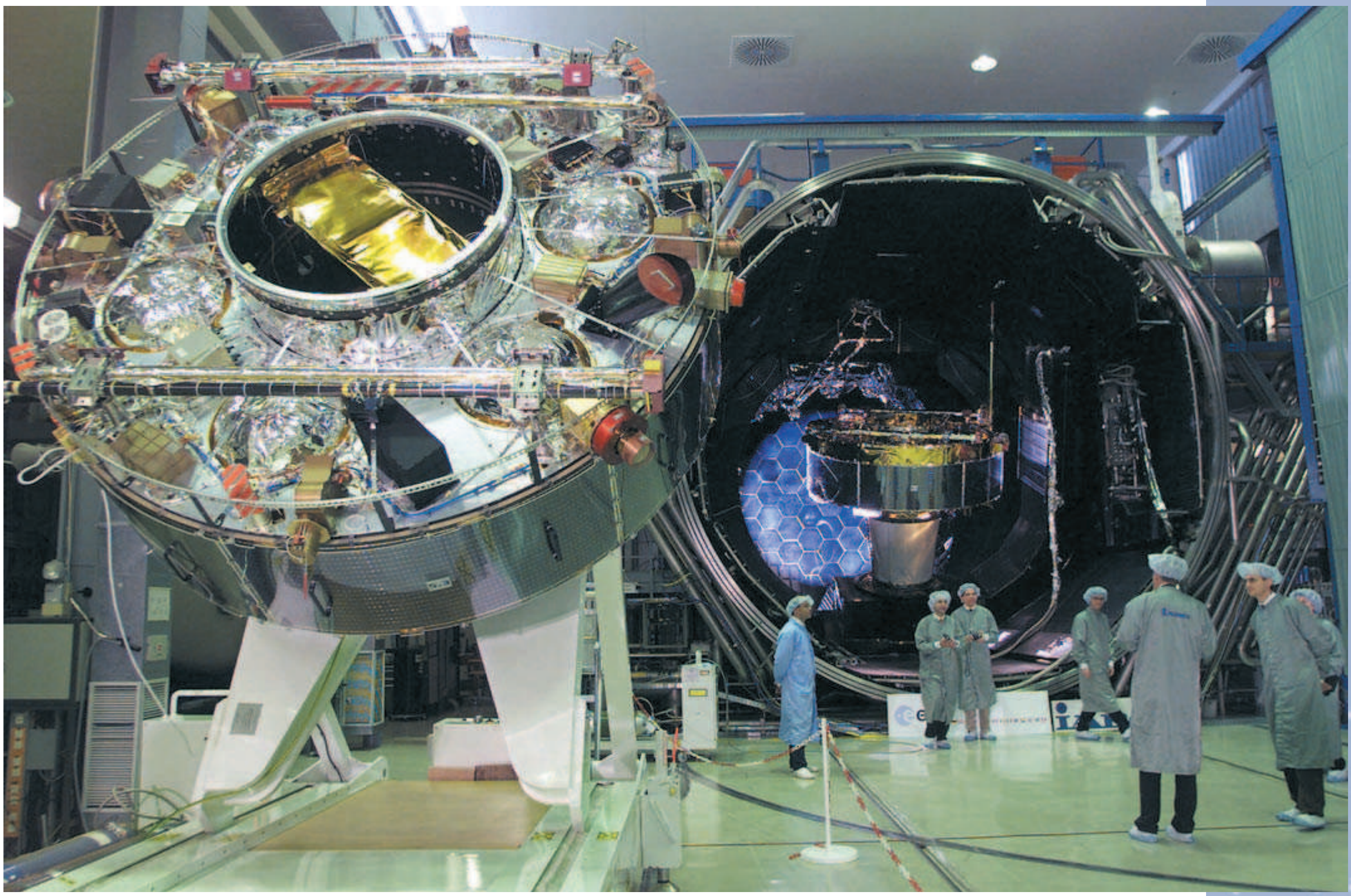
Historical Overview

The characteristics of aerospace corporations and the current structure of the aerospace industry result from the numerous political and economic forces that have created, shaped, and reshaped it. The first of these forces, and the one responsible in large part for creating the aerospace industry, was the Cold War. As World War II came to a close, the uneasy alliance between Russia and the United States began to disintegrate. Leaders on both sides sought to achieve a military advantage by capturing advanced German technology and the scientists and engineers who developed it. This included the German rocket technology that created the V-2 missile, the first vehicle to enter the realm of space.

This competition was a precursor to the space race between the two superpowers, the United States and Russia. That competition began in earnest on October 4, 1957, when the Soviet Union launched the 184-pound Sputnik, Earth's first artificial satellite, into an **orbit** 805 kilometers (500 miles) above Earth. This demanded a response from the U.S. Department of Defense (DoD) and intelligence and scientific communities.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

To develop the systems needed to engage in this competition, the U.S. government established contracts with existing aircraft and aeronautics com-



panies. Martin Aircraft was the manufacturer of the B-26 Marauder, a World War II bomber. Its corporate successor, Martin Marietta, developed the Titan rocket that was used first as an intercontinental ballistic missile (ICBM) during the Cold War. The rocket was later modified to boost two astronauts in **Gemini** capsules into orbit during the space race. (Long after the end of the space race, the Cold War, and many years of storage, the Titan II ICBMs are being refurbished and modified for use as space launch vehicles to place DoD satellites into space.) The government turned to Pratt & Whitney, an aircraft engine manufacturer, to develop the first liquid hydrogen-fueled engine to operate successfully in space. It was used on the Surveyor lunar lander, the Viking Mars lander, and the Voyager outer-planet **flyby** missions. A derivative of this engine is used in the second stage of the Delta III satellite launch rockets.

The intelligence community was also interested in using space technology. The United States' first space-based overhead **reconnaissance** program, CORONA, began flight in 1959. It, too, relied on established companies. Lockheed, a prominent aircraft manufacturer, developed the launch vehicle's upper stage. Eastman Kodak (now Kodak) produced special film that would function properly in space and low-Earth-orbit (LEO) environments. General Electric designed and manufactured the recovery capsule to protect exposed film as it was deorbited and re-entered Earth's atmosphere for airborne capture and recovery.

The DaimlerChrysler automotive group contributes to the European Aeronautic Defence and Space Company's development by manufacturing Cluster II satellites.

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

reconnaissance a survey or preliminary exploration of a region of interest

The government's interest in, and contracts for, space systems also created new companies. TRW resulted from efforts to build the Atlas missile and the Pioneer I spacecraft, the first U.S. ICBM and satellite, respectively. Currently, commercial involvement in the aerospace industry is growing, but government involvement continues to be significant.

Space Systems Overview

Each space system is composed of a collection of subsystems, often grouped into segments. Typical groupings are the launch segment; the space segment; the ground, or control, segment; and the user segment. The launch segment includes the equipment, facilities, and personnel needed to place elements of the system into space. The space segment includes the spacecraft, other equipment, and personnel that are placed into space. The ground, or control, segment includes the equipment, facilities, and personnel that control and operate the spacecraft as it performs its mission. The user segment includes the equipment, facilities, and personnel using the products of the space system to accomplish other purposes. Aerospace corporations✶ are the source of virtually all of the equipment and facilities that these segments require. Moreover, these corporations frequently train or provide personnel to operate and maintain them.

✶In 2002, the leading U.S. aerospace corporations included Boeing, Hughes, Lockheed Martin, TRW, Raytheon, Orbital Sciences Corporation, and Spectrum Astro.

The Launch Segment. The most visible activity associated with space missions is usually the launch of the space elements of the system. Television and film coverage has often featured footage of the space shuttle with its large boosters gushing fire and smoke as it rises slowly into the sky. The launch vehicle and upper stages, along with the facilities, equipment, and team at the launch site and associated range, are part of the launch segment. The two U.S. aerospace corporations that provide the most frequently used large launch vehicles are the Boeing Company (Delta) and Lockheed Martin Corporation (Atlas and Titan). The United Space Alliance, which manages and conducts space operations and maintenance of the National Aeronautics and Space Administration's (NASA) Space Transportation System (space shuttle), is a joint venture between Boeing and Lockheed Martin.

Other companies that provide launch systems include Orbital Sciences Corporation, which manufactures and operates small launch systems, the Pegasus (an air-launched rocket capable of placing more than 1,000 pounds in LEO), and the Taurus (a small rocket launched from a "bare" pad to minimize operating costs). Sea Launch is an international partnership that launches Russian-made Zenit boosters from a floating, oceangoing platform. Boeing, a 40 percent partner, manufactures the **payload fairing**, performs spacecraft integration, and manages overall mission operations. RSC Energia (Russia) provides the third stage, launch vehicle integration, and mission operations. KB Yuzhnoye/PO Yuzhmash (Ukraine) provides the first two Zenit stages, launch vehicle integration support, and mission operations.

payload fairing structure surrounding a payload and designed to reduce drag

Since the mid-1990s the industry has seen a number of newcomers, many with partially or fully reusable systems but so far without any space launches. These companies include Kistler Aerospace Corporation, Beal Aerospace Technologies, and several others with launchers using unique approaches, such as Rotary Rocket Company, Kelly Space and Technology, and Pioneer Rocketplane.

Most launch vehicles use liquid propellants, but some use motors with solid fuels. The large, white strap-on boosters straddling the rust-orange main fuel tank of the space shuttle are solid-fuel boosters, as are the strap-on motors used with the Atlas, Delta, and Titan. In addition, most upper stages that are used to propel systems to high orbits or even into **interplanetary trajectories** are also solid-fuel systems. Thiokol Corporation, Pratt & Whitney, and others make many of these motors.

The Space Segment. The space segment consists of all the hardware, software, and other elements placed into space. Examples include spacecraft that orbit Earth, such as NASA's Tracking and Data Relay Satellite, or an interplanetary probe, such as the **Cassini mission** to Saturn. Spacecraft used by humans, such as the space shuttle **orbiter** and the International Space Station, are also included. Even the smallest spacecraft are complex machines. They must operate with limited human interaction for long periods of time, in a very hostile environment, and at great distances. Designing, manufacturing, and testing these spacecraft can be very demanding and requires many specialized facilities and an experienced staff.

Some of the established leaders in this segment include Hughes Aircraft Company, Boeing, Lockheed Martin, and TRW. Hughes is the primary manufacturer of communications satellites. Boeing is a major developer of spacecraft for the Global Positioning System (GPS), a space-based navigation system operated by the DoD.✶ Lockheed Martin's heritage includes support for missions studying every planet in the solar system (so far excepting Pluto). TRW has been a key contractor for spacecraft such as Pioneer I, the Chandra X-ray Observatory, and the Defense Support Program ballistic missile warning satellites.

Relative newcomers to this segment include Spectrum Astro and Orbital Sciences Corporation. Spectrum Astro worked with NASA's Jet Propulsion Laboratory to develop Deep Space I, a new technology demonstrator. They are teamed with the University of California, Berkeley, to design and develop the **spacecraft bus** and to integrate and test the **payload** of the High Energy Solar Spectroscopic Imager (HESSI) spacecraft. HESSI will investigate the physics of particle acceleration and energy release in solar **flares**, observing X rays and **gamma rays**. Orbital Sciences Corporation designs and manufactures small, low-cost satellites for LEO, medium Earth orbit (MEO), and **geosynchronous** Earth orbit (GEO) missions. They have developed, built, and launched more than seventy satellites delivering communications, broadcasting, imagery, and other services and information.

The Ground, or Control, Segment. The ground, or control, segment is probably the least glamorous and least public element of any space system. Although it lacks the showmanship of a launch or the mystique of traveling through space, it is critical to mission success. This segment consists of all the hardware, software, and other elements used to command the spacecraft and to **downlink**, distribute, and archive science and spacecraft systems status data. This segment serves as a combined control center and management information system for the mission. Aerospace corporations build and often operate these systems.

Lockheed Martin Federal Systems manages a team of subcontractors to support the Air Force Satellite Control Network. This network provides

LIQUID VS. SOLID FUELS

Liquid fuels generally provide more energy than solid fuels and are easier to control. Liquid fuel engines can be throttled up and down during a flight. Solid fuels are easier to handle. They do not give off toxic vapors or require extreme cooling during storage and pre-launch operations.

interplanetary trajectories the solar orbits followed by spacecraft moving from one planet in the solar system to another

Cassini mission a robotic spacecraft mission to the planet Saturn scheduled to arrive in July 2004, when the Huygens probe will be dropped into Titan's atmosphere while the Cassini spacecraft studies the planet

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

✶**The Global Positioning System consists of 24 satellites that orbit over 10,000 miles above Earth.**

spacecraft bus the primary structure and subsystems of a spacecraft

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

flares intense, sudden releases of energy command-and-control services for many DoD and other government space programs. Harris was responsible for the development, integration, and installation of the command, control, and communications system for the U.S. Air Force's Defense Meteorological Satellite Program (a DoD weather satellite). Orbital Sciences Corporation has been involved in the construction of most of the world's major nonmilitary imaging satellite ground stations. Orbital's commercial satellite ground stations are used to receive, process, archive, and distribute images of Earth acquired by remote-imaging satellites.

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

downlink the radio dish and receiver through which a satellite or spacecraft transmits information back to Earth

The ground/control segment functions are often similar for different space programs. For this reason, cost savings from combined, multifunctional ground/control systems can be significant. Lockheed Martin leads NASA's Consolidated Space Operations Contract to help combine operations for many of the current and planned space science missions.

The User Segment. Although all segments of a space system are necessary, the user segment is the most important. It is here that the mission of a space program is achieved. The user segment consists of all the hardware, software, and other elements required to make use of the data. A very public example of user segment equipment is the GPS receiver. Many of these units are sold to campers, hikers, boaters, and others who desire an easy and accurate means of determining their location. The user segment is also where science data are processed, formatted, and delivered to the scientists and other investigators for study and analysis. The U.S. Geological Survey's Earth Resources Observation Systems (EROS) Data Center near Sioux Falls, South Dakota, is a major scientific data processing, archive, and product distribution center for spacecraft, shuttle, and aerial land sciences data and imagery. Data are processed into usable formats and made available to researchers and other users. Many aerospace corporations perform further processing and formatting of EROS data to generate information for sale.

Cross-Segment Approaches

Most aerospace corporations design, develop, and operate facilities and equipment in more than one segment. Often a specific space program will have one aerospace corporation serve as a lead or prime contractor, managing or integrating the work of many other companies. The International Space Station provides an excellent example. Boeing is the prime contractor of a space station team that includes a number of partners. Major U.S. teammates and some of their contributions include: Lockheed Martin, providing **solar arrays** and communications systems; Space Systems/Loral, providing batteries and electronics; Allied Signal, providing **gyroscopes** and other navigational gear; Honeywell, providing command and data systems as well as **gimbal motors**; and United Technologies, providing pumps and control valve assemblies.

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

gimbal motors motors that direct the nozzle of a rocket engine to provide steering

One of the newest and more unusual competitors spanning all segments is SpaceDev. SpaceDev is a commercial space exploration and development company for small, low-cost, commercial space missions, space products, and affordable space services. It offers fixed-price missions using proven, off-the-shelf components and an inexpensive mission design approach.

Other Industry Roles

In addition to designing, developing, and operating space systems in and across the various segments, some aerospace corporations perform more focused roles, such as providing systems engineering and other technical assistance or producing subsystems, components, and parts for systems. Many of these corporations are not as readily recognized as other members of the aerospace industry.

Systems Engineering and Technical Assistance. Systems engineering and technical assistance (SETA) is a role performed by a number of aerospace corporations. As a SETA contractor, an aerospace corporation may develop, review, analyze, or assess concepts and designs for space missions, programs, and systems. Typically, SETA contractors do not provide hardware for the programs they support. Instead, they provide valuable expertise and a viewpoint independent of those manufacturing the system's components. For example, Raytheon ITSS Corporation is the technical support contractor to the U.S. Geological Survey's EROS Data Center discussed previously. Science Applications International Corporation provides a variety of SETA services to NASA, the DoD, and some commercial space programs. Dynamics Research Corporation and OAO Corporation are examples of other companies that provide SETA support to NASA, the DoD, and aerospace prime contractors.

Parts, Components, or Subsystems Providers. Another role for an aerospace corporation is that of parts, components, or subsystems provider. This category encompasses the greatest number of aerospace corporations. Many of these corporations provide a broad range of subsystems and components and may also manufacture complete spacecraft. Others specialize in a specific type of space hardware, software, or service. Space products from Ball Aerospace and Technologies Corporation include antennas, fuel cell systems, mirrors, pointing and tracking components (such as star trackers), and reaction/momentum wheels. Malin Space Science Systems designs, develops, and operates instruments to fly on unmanned spacecraft. Thermacore Inc. works on heat pipes for space applications. These pipes are used to move heat from one location to another with little loss in temperature. Analytical Graphics, Inc., produces a commercial computer program, Satellite Tool Kit, which possesses extensive space mission and system analysis and modeling capabilities.

Nonaerospace Corporations

Many corporations that support aerospace programs are not commonly recognized as members of the aerospace industry. Kodak, a world-famous film and camera manufacturer, has been involved with aerospace almost since the beginning. Kodak developed the special film used in CORONA's orbiting cameras to photograph Soviet missile sites, air and naval bases, and weapons storage facilities. Its charge-coupled device image sensors were used on NASA's Mars Pathfinder Rover, which visited Mars in 1997. Today, Kodak manufactures digital cameras used from space to capture images of Earth's surface. These images are of value to scientists, farmers, and many others. IBM, another well-known corporation, supports many aerospace programs. During the 1999 space shuttle mission that returned John Glenn to space, twenty IBM ThinkPads (notebook computers) were onboard.

BACK FOR MORE

John Glenn was the first American to orbit Earth. In February of 1962 he piloted a Mercury capsule, Friendship 7, during a 3 orbit, 4 hour and 55 minute flight. In 1998, when he was 77 years old, Glenn returned to orbit on the space shuttle Discovery.

Other "unsung heroes" of aerospace include insurance and finance companies that are growing in importance as the primary revenue source for aerospace corporations shifts from government to the commercial sector. SEE ALSO Getting to Space Cheaply (volume 1); Insurance (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Navigation from Space (volume 1); Reusable Launch Vehicles (volume 4); Satellite Industry (volume 1).

Timothy R. Webster

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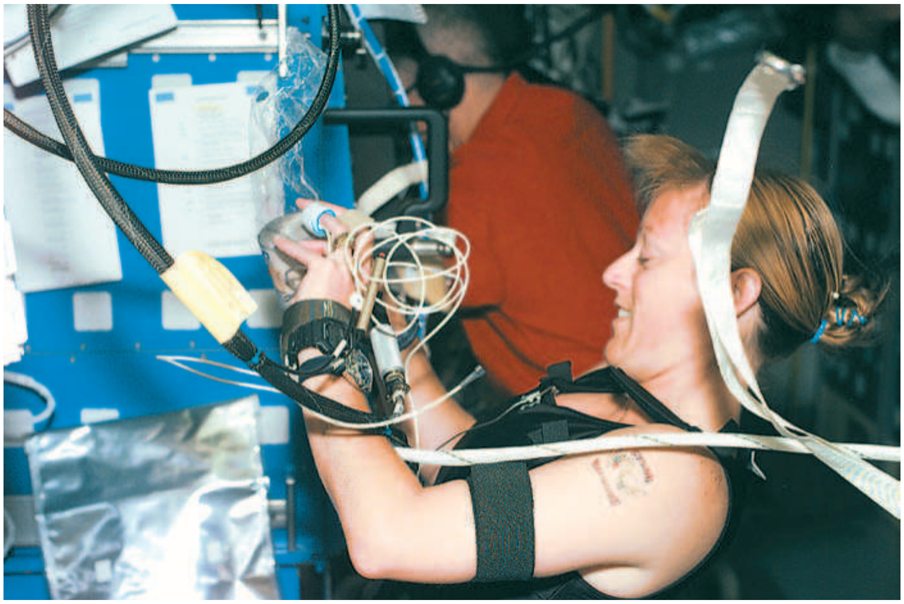
Aging Studies

Soon after entry into space, physical changes occur within the human body, and these changes become more severe and diverse as flight duration increases. When in space, humans experience early signs of a decrease in blood volume and red cell mass, aerobic capacity, endurance, strength, and muscle mass. Moreover, there is a reduction of bone density in the lower limbs, hips, and spine, and in the absorption of calcium through the gut. Visual-spatial orientation and eye-hand coordination are also affected.

When humans return to Earth's gravity, this reduction in physical fitness manifests itself through the body's inability to maintain the blood pressure control necessary to prevent fainting. This inability occurs because the heart and blood vessels are less responsive. Balance, gait, and motor coordination are also severely affected. Similar but less-intense symptoms occur during and after complete bed rest.

Bed Rest Studies

Researchers study bed rest to understand the mechanisms that bring about these symptoms, and to develop preventive treatments. Both astronauts and men and women volunteers for these bed rest studies recover, with the speed of recovery being proportional to the duration of the flight or the bed rest. Research into the mechanisms that contribute to these symptoms has



Astronaut Kathryn P. Hire undergoes a sleep study experiment in the Neurolab on the space shuttle Columbia. Bed rest studies are used to examine the physical changes that occur during human spaceflight.

pointed to the variety of ways humans use Earth's gravity to promote stimuli the body needs to maintain normal physiology.

In space, where the influence of gravity is negligible, the load we normally feel on Earth from our weight is absent. Exercise, such as walking, is ineffective, because we are not working against the force of gravity. Signals to the parts of our nervous system that control blood pressure from changing position (such as standing or lying down) are also absent, and we can no longer sense what is up and what is down.

Bed rest studies have been conducted to determine the minimum daily exposure to gravity's stimuli needed to maintain normal physiology. This research indicated that a change in posture from lying down to upright—a total of two to four hours of being upright so gravity pulled maximally in the head-to-toe direction—at least eight to sixteen times a day could prevent the decline in blood pressure control, aerobic capacity, blood volume, and muscle strength. As little as thirty minutes a day of walking at a pace of three miles per hour prevented the increased loss of calcium produced by bed rest. These results suggested that intermittent exposure to gravity in space, as provided by a **centrifuge**, may be an effective way to keep astronauts healthy on long trips.

Are the Effects of Aging Irreversible?

The similarity of the set of symptoms resulting from going into space to those associated with aging is striking. In the elderly, these symptoms have been assumed to be part of the normal course of aging and therefore irreversible. Space and bed rest research argues against this assumption. Research indicates that the symptoms of aging are due to an increasingly **sedentary lifestyle** rather than aging and are thus also reversible in the elderly. In the mid-1990s, Maria Fiatarone and her coworkers reported that weight training and nutritional supplements reversed muscle and bone **atrophy** of aging in people aged seventy-three to ninety-eight. ✶

centrifuge a device that uses centrifugal force caused by spinning to simulate gravity

sedentary lifestyle a lifestyle characterized by little movement or exercise

atrophy condition that involves withering, shrinking or wasting away

✶John Glenn's second trip to space in 1998 at the age of seventy-seven on shuttle mission STS-95 helped increase understanding of the effects of a healthy lifestyle on aging.

It remains to be seen if space will also help us understand the more fundamental mechanisms of aging. Preliminary research suggests cell cycle and cell death may be affected. But it will only be through the conducting of experiments long enough to explore life span and chromosomal and genetic mechanisms that these questions will be answered. SEE ALSO Careers in Space Medicine (volume 1); Glenn, John (volume 3).

Joan Vernikos

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AIDS Research

Since 1985 the National Aeronautics and Space Administration (NASA) has supported fundamental studies on the various factors that affect protein crystal growth processes. More than thirty principal investigators from universities throughout the United States have investigated questions such as why crystals stop growing, what factors cause defect formations in growing crystals, and what influence parameters such as protein purity, temperature, pH (a solution's degree of acid or base properties), protein concentration, and fluid flows exert around growing crystals.

The majority of these studies were conducted in Earth-based laboratories, with a limited number of experiments performed on U.S. space shuttle flights. The purpose of the space experiments is to determine the effect that a **microgravity** environment has on the ultimate size and quality of protein crystals. This research was propelled by the need to improve success rates in producing high-quality crystals to be used for X-ray **crystallography** structure determinations. X-ray crystallography involves exposing a protein crystal to powerful X-ray radiation. When this occurs, the crystal produces a pattern of diffracted spots that can be used to mathematically determine (using computers) the structure of the protein (i.e., the positions of all the atoms that comprise the protein molecule).

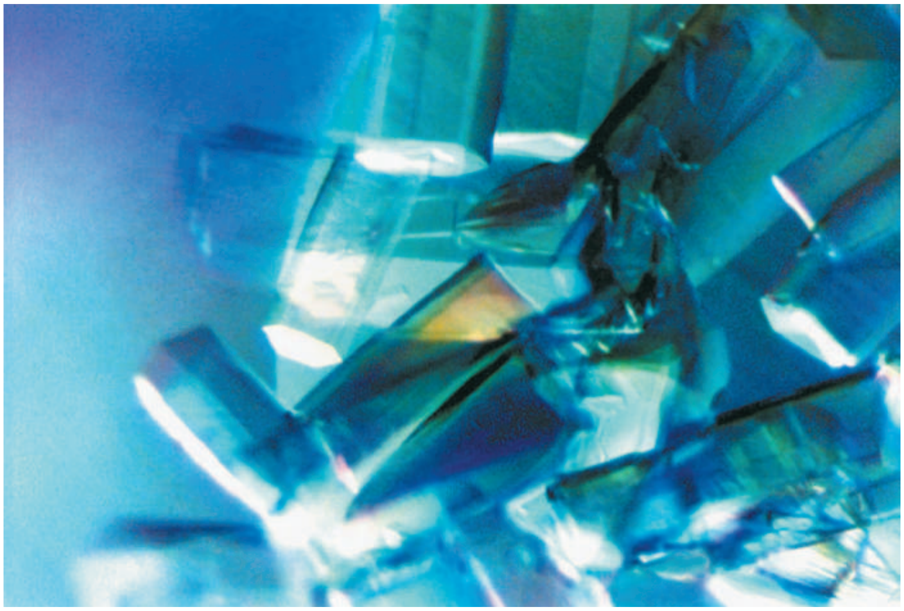
microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

crystallography the study of the internal structure of crystals

Structure-Based Drug Design

The three-dimensional structure of a protein is useful because it helps scientists understand the protein's function in biological systems. In addition, most known diseases are based on proteins that are not working properly within the human body or on foreign proteins that enter the body as part of harmful bacteria, viruses, or other pathogens. The three-dimensional structure of these disease-related proteins can aid scientists in designing new pharmaceutical agents (drugs) that specifically interact with the protein, thereby alleviating or lessening the harmful effects of the associated diseases.

This method of designing new and more effective pharmaceuticals, known as structure-based drug design, was used to develop many of the new-generation AIDS drugs. These drugs were developed using Earth-grown



Studies indicate that space-grown crystals, such as these HIV Reverse Transcriptase crystals, are larger and better ordered than comparable Earth-grown crystals.

crystals. There are, however, a number of other protein targets in the HIV virus as well as in most other pathogens that have yet to be crystallized. Attempts to grow crystals large enough and of sufficient quality are often unsuccessful, thereby preventing the use of structure-based drug design.

On Earth, when crystals begin to grow, lighter molecules float upward in the protein solution while heavier molecules are pulled down by gravity's forces (a process known as buoyancy-induced fluid flow). This flow of solution causes the protein to be swept to the surface of the crystal where it must align in a very perfect arrangement with other protein molecules. It is believed that the rapid flow of solution causes the protein molecules to become trapped in misalignments, thereby affecting the quality of the crystal and, eventually, even terminating crystal growth.

Crystal Growth in Microgravity

In a microgravity environment, these harmful flows are nonexistent because gravity's influence is minimal.✶ Thus, the movement of protein molecules in microgravity is much slower, caused only by a process known as random diffusion (the inherent vibration of individual molecules). It is believed that the lack of buoyancy-induced fluid flows (as occurs on Earth) creates a more **quiescent** environment for growing crystals. The protein molecules have sufficient time to become more perfectly ordered in the crystal before being trapped by additional incoming molecules.

✶The gravity level on the space shuttle equals one-millionth of that existing on Earth.

quiescent inactive

The scientific community is divided about the role that microgravity can play in improving the size and quality of protein crystals. In addition, the excessive cost of performing experiments in space has caused scientists to question the value of these experiments. Proponents of the space protein crystal growth program are optimistic that the longer growth times that will be available on the International Space Station will significantly improve microgravity success rates for producing crystals of significantly higher quality. SEE ALSO Careers in Space Medicine (volume 1); Crystal Growth (volume 3); Microgravity (volume 2); Zero Gravity (volume 3).

Lawrence J. DeLucas

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Buzz Aldrin, along with Neil Armstrong, became the first humans to land on the Moon.

Aldrin, Buzz

American Astronaut and Engineer 1930–

On July 20, 1969, Edwin "Buzz"✶ Aldrin and his fellow astronaut Neil Armstrong became the first humans to land on another world: Earth's Moon. This achievement is arguably the technological high-water mark of the twentieth century.

✶Aldrin's sister nicknamed him "Buzz," and it is now his legal name.

Aldrin's passion for exploration and quest for excellence and achievement began early in his life. Born on January 20, 1930, in Montclair, New Jersey, Aldrin received a bachelor of science degree from the U.S. Military Academy in 1951, graduating third in his class. After entering the U.S. Air Force, Aldrin earned his pilot wings in 1952.

As an F86 fighter pilot in the Korean War, Aldrin flew sixty-six combat missions. He later attended the Massachusetts Institute of Technology (MIT), where he wrote a thesis titled "Guidance for Manned Orbital Rendezvous." After his doctoral studies, Aldrin was assigned to the Air Force Systems Command in Los Angeles.

Aldrin's interest in space exploration led him to apply for a National Aeronautics and Space Administration tour of duty as an astronaut. Aldrin was selected as an astronaut in 1963. The research expertise in the new field of space rendezvous he had acquired during his studies at MIT were applied in the U.S. Gemini program.

On November 11, 1966, Aldrin, with James Lovell, flew into space aboard the two-seater Gemini 12 spacecraft. On that mission the Gemini astronauts rendezvoused and docked with an **Agena** target stage. During the linkup Aldrin carried out a then-record 5.5-hour space walk. Using handholds and foot restraints while carefully pacing himself, Aldrin achieved a pioneering extravehicular feat in light of the many difficulties experienced by earlier space walkers.

Agena a multipurpose rocket designed to perform ascent, precision orbit injection, and missions from low Earth orbit to interplanetary space. It also served as a docking target for the Gemini spacecraft

Aldrin's unique skills in developing rendezvous techniques were tested again in July 1969. Aldrin and his fellow Apollo 11 astronauts, Neil Armstrong and Mike Collins, were the first crew to attempt a human landing on the Moon. Once in lunar orbit, Armstrong and Aldrin piloted a landing craft, the Eagle, to a safe touchdown on the Moon's Sea of Tranquility. After joining Armstrong on the lunar surface, Aldrin described the scene as "magnificent desolation." They explored the landing area for two hours, setting up science gear and gathering rocks and soil samples. The two astronauts then rejoined Collins for the voyage back to Earth.

Aldrin returned to active military duty in 1971 and was assigned to Edwards Air Force Base in California as commander of the Test Pilots School. He retired from the U.S. Air Force as a colonel in 1972. Aldrin is a spokesman for a stronger and greatly expanded space program. He still advances new ideas for low-cost space transportation and promotes public space travel. Aldrin continues to spark new ideas for accessing the inner solar system. One of his concepts is the creation of a reusable cycling spaceship transportation system linking Earth and Mars for the routine movement of people and cargo.

Aldrin has written several books, sharing with readers his experiences in space. As a cowriter, Aldrin has authored science fiction novels that depict the evolution of space exploration in the far future. SEE ALSO Apollo (Volume 3); Armstrong, Neil (Volume 3); Gemini (Volume 3); NASA (Volume 3); Space Walks (Volume 3).

Leonard David

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Artwork

Astronautics owes much of its existence to the arts. On the one hand, literary works by authors such as Jules Verne (1828–1905) were directly responsible for inspiring the founders of modern spaceflight; on the other hand, artists such as Chesley Bonestell (1888–1986)✶ made spaceflight seem possible. When Bonestell's space art was first published in the 1940s and early 1950s, spaceflight to most people still belonged in the realm of comic books and pulp fiction. Bonestell, working with such great space scientists as Wernher von Braun, depicted space travel with such vivid reality that it suddenly no longer seemed so fantastic. Emerging as it did when the United States was first taking an interest in astronautics, these paintings went a long way toward encouraging both public and government support.

✶The artwork in this article is courtesy of Bonestell Space Art.

Space Art Comes of Age

Since Bonestell's time, there have been many other artists who have specialized in space art, though even in the early twenty-first century there are probably fewer than a hundred who work at it full-time. Some have been able to develop specialties within the field. Robert McCall and Pat Rawlings, for example, devote themselves to rendering spacecraft, while others, such as Michael Carroll and Ron Miller, concentrate on astronomical scenes, including views of the surface of Mars✶ or the moons of Saturn. Some artists are interested in how we are going to explore space, while others are more interested in what we are going to find once we get there.

✶Go to Volume 4's article on Terraforming to see Michael Carroll's rendering of a "Blue Mars."

Speculative artwork, such as this depiction of spacecraft assembly in Mars orbit, can make the theoretical seem possible.

Although most space artists have a background in art, either as gallery artists or commercial artists, there are some notable exceptions. William K. Hartmann (b. 1939), for example, is a professional astronomer who happens to also be an excellent painter. He is able to combine his artistic talent with his expert knowledge of astronomy. Only a very few space artists have ever flown in space. Alexei Leonov, a Russian cosmonaut who was also the first man to walk in space, is a very fine painter who took drawing supplies with him into orbit. Vladimir Dzhanibekov is another cosmonaut who has translated his experiences in space onto canvas. Of the American astronauts, only one has had a serious interest in art. Alan Bean, who walked on the Moon in 1969, has devoted himself since retiring from the astronaut corps to painting and has become extraordinarily successful depicting scenes from his experiences in the Apollo program.

Beyond Aesthetics

meteorology the study of atmospheric phenomena or weather

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

flyby flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

The artists who specialize in astronomical scenes perform a very valuable service. In one sense, they are like the artists who re-create dinosaurs. By taking astronomical information and combining this with their knowledge of geology, **meteorology**, and other sciences, as well as their expertise in light, shadow, perspective, and color, they can create a realistic landscape of some other world. Most often these are places that have never been visited by human beings or unmanned probes. In other instances, an **orbiter** or a spacecraft on a **flyby** mission may have already taken photographs of a moon or planet. In this case, the artist can use these photos to create an impression of what it might look like to stand on the surface. Since it can be very difficult to interpret orbital photos—which look down on their subjects—paintings like these are very useful in helping to understand what the features actually look like.

Into the Twenty-First Century

Until recently, most space artists worked in the same traditional materials, such as oil paint, acrylics, and watercolors, as other artists and illustrators. Many space artists now also use the computer to either enhance their traditionally rendered work or to generate artwork from scratch. Don Davis (b. 1952)✶, one of the twenty-first century's best astronomical artists, no longer works with brushes at all, choosing instead to work exclusively on a computer. There are advantages, both technically and aesthetically, to both methods but it is very unlikely that the computer will ever entirely replace traditional tools. It is the wise artist, however, who is at least familiar with computer techniques.

Saturn's rings, as seen from the upper reaches of the planet's atmosphere.

✶Don Davis's artwork can be seen in the Volume 2 article "Close Encounters" and Volume 4's article on "Impacts."

An International Genre

There are space artists, both professional and amateur and both women and men, working in almost every nation. Indeed, one of the first great artists to specialize in the field, and who helped create it, was a French artist named Lucien Rudaux (1874–1947), who created beautiful space paintings in the 1920s and 1930s. Rudaux set a standard not exceeded until Bonestell published his first space art in the 1940s. Ludek Pešek (1919–1999), a Czechoslovakian expatriate who lived in Switzerland, was probably the best and most influential space artist to follow Bonestell. Pešek illustrated a dozen books with paintings of the planets that looked so natural and realistic it seemed as though they must have been done on location. David A. Hardy (b. 1936) of Great Britain is as adept at depicting spacecraft as he is landscapes of other worlds.

Notable women artists include Pamela Lee, who is highly regarded for her meticulously rendered depictions of astronauts at work, and MariLynn Flynn, who creates planetary landscapes in the tradition of Bonestell and Pešek. The membership roster of the International Association of Astronomical Artists, an organization of space artists, includes people from Germany, Armenia, Sweden, Japan, Russia, Canada, Belgium, and many other countries, all united by their mutual interest in space travel, astronomy, and art. SEE ALSO BONESTELL, CHESLEY (VOLUME 4); LITERATURE (VOLUME 1); MCCALL, ROBERT (VOLUME 1); RAWLINGS, PAT (VOLUME 4); VERNE, JULES (VOLUME 1); VON BRAUN, WERNHER (VOLUME 3).

Ron Miller

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Augustine, Norman

Space Industry Leader
1935–

Norman R. Augustine was chairman and chief executive officer (CEO) of Lockheed Martin Corporation prior to his retirement in 1997. Augustine

Norman Augustine served as chief executive officer of Lockheed Martin, a well-respected and established aerospace firm, before retiring in 1997.

was undersecretary of the army in the administration of President Gerald R. Ford in 1975, having previously served as assistant secretary of the army for President Richard M. Nixon in 1973. Augustine held a variety of engineering assignments during his career. In 1958, following his graduation from Princeton University with both bachelor's and master's degrees in engineering, Augustine joined Douglas Aircraft Company as program manager and chief engineer. In 1965 he was appointed assistant director for defense research and engineering in the Office of Secretary of Defense and then was named vice president for advanced programs and marketing for LTV Missiles and Space Company.

After joining Martin Marietta Corporation in 1977, Augustine was promoted to CEO and then chairman in 1987 and 1988, respectively. Following the formation of Lockheed Martin from the 1995 merger of Martin Marietta and Lockheed Corporation, he initially served as Lockheed Martin's president before becoming CEO and chairman in 1996.

In 1990 Augustine played a major role in defining the issues facing the U.S. space industry as head of President George H. W. Bush's Space Task Force. The group's report called for substantial increases in U.S. space spending, as well as setting new national goals in space exploration. The administration responded to the report in part by announcing a series of advanced space goals. However, funding for the projects was not supported by Congress, and the initiatives were abandoned.

Augustine has written several books, including *Augustine's Laws* (1990), a humorous chronicle of his experiences in defense contracting. He received the Distinguished Service Medal of the Department of Defense four times, the Defense Meritorious Service Medal, the Army Distinguished Service Medal, the Air Force Exceptional Service medal, and ten honorary degrees. SEE ALSO LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); MARKET SHARE (VOLUME 1).

Frank Sietzen, Jr.

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B

Barriers to Space Commerce

remote sensing the act of observing from orbit what may be seen or sensed below Earth

Space commerce exists in the early twenty-first century as a $100 billion industry. It consists primarily of firms providing commercial telecommunication and **remote sensing** services using satellites, as well as the manufacture and launch of those satellites. Space commerce also includes many organizations that provide products and services (including satellites, satellite services, launch, operations, and research) to government agencies in support of national civil and military space programs. Finally, a small number of firms provide other space services on a commercial basis, including space station access, on-orbit experimentation using a commercial module carried on space shuttles, and the launch of ashes for "burial" in space.

After key barriers to space commerce have been overcome, profit can be made through the development of new spacecraft, such as this theoretical depiction of a lunar freighter, which would be used in transport.

Efforts by space advocates, aerospace firms, and government agencies to further expand space commerce generally focus on extending the scope of commercial space activities beyond today's space telecommunications by fostering new space industries. Ongoing ventures propose expanding space services into new realms: high bandwidth Internet connectivity, on-orbit research and manufacturing, entertainment, education, power, and even routine space tourism. It is often asserted that the development of these industries is hindered by economic and policy barriers, and that these barriers can be overcome with appropriate government policy or industry initiatives.

SECONDARY INDUSTRIES ENABLED BY SPACE

Many secondary industries are enabled by space assets and capabilities, such as television broadcasting, weather forecasting, tracking and navigation using satellites, and many types of voice and data communication.

Economic Barriers to Entry

There are three major economic barriers to the growth of space commerce: the cost of entry, the risk associated with space activities, and the cost of transportation. These factors are closely interrelated.

The Cost of Entry. Space is an expensive business. The cost of manufacturing and launching a routine telecommunications satellite exceeds $150 million. The cost to establish a new capability, such as a reusable launch vehicle or an on-orbit manufacturing facility, is likely to be in the multi-billion dollar range. The need to acquire a very high level of start-up capital✶ creates a barrier to entry into the space industry, especially for small and/or start-up firms.

✶**The high level of capital required to establish a new capability is needed to build facilities, develop and test hardware and software, staff up with a specialized engineering team, and ultimately get to orbit.**

High Risk Factors. The risks associated with space activities also increase the difficulty of entering the business. Risks arise from both technical factors and market factors. Technical risks exist because space systems are complex, often requiring new technology, and because space activities occur in a hazardous, challenging, and distant environment where maintenance and repair are expensive and may not be possible.

Market risks arise because in many cases the services being offered are new and it is difficult to predict what the customer response will be. In addition, complex systems and new technology make managing costs a challenge, which can negatively affect prices. Finally, for some space services, cheaper terrestrial alternatives may be developed. These risks are exacerbated by the timing and schedule associated with space projects. Major system expenditures have to be made years prior to the beginning of operations and, as a result, financing costs are high and the time frame for achieving a return on investment is fairly long.

The Cost of Transportation. Many in the industry characterize the high cost of transportation—typically expressed as the price per pound or kilogram to orbit—as the primary economic barrier, based on the premise that significantly reduced transportation costs to **orbit** would make new space business activities financially feasible. In theory, this would then lead to increased launch rates, which would further reduce launch costs, and this cycle would help reduce costs of entry. This basic logic—reduce the cost of getting to space and space commerce will grow rapidly—underlies many government and industry efforts to foster space commerce. The development of reusable commercial launch vehicles, for example, is generally supported by the contention that reusing vehicles (as opposed to using a vehicle only once, as is the case with today's commercial rockets) will ultimately provide lower costs to orbit. **Reusable launch vehicles** will, however, be expensive to develop. The costs and benefits of reusable launch vehicles will be a major issue for space commerce in the coming years.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

Government Policy

Government policies affect space commerce and, in the minds of many industry observers, create the greatest barriers. Government barriers to commercial space come in two varieties: areas where government regulation and oversight are perceived as restrictive or inappropriately competitive (i.e., the government should do less in order to foster space commerce) and areas where government policies and actions are perceived as insufficiently supportive (i.e., the government should do more in order to foster space commerce).

Export/import restrictions, safety and licensing regulations, and launch range use policies are examples of areas that have been criticized as too restrictive. This has led to some reforms. For example, in 1984 a single licensing entity for commercial launch services was created in the U.S. Department of Transportation, so that commercial launch service providers were relieved of the requirement to interact with more than a dozen government agencies in order get permission to launch. However, other policy barriers still exist. In the United States, for instance, export/import controls aimed at limiting the transfer of valuable or sensitive technology to other countries affect U.S. commercial satellite and launch firms competing in international markets.

Sometimes government agencies, in their conduct of space activities, are viewed as competing with industry. These concerns typically arise from government operation of systems or programs for which there is a commercial demand. For example, the space shuttle launched commercial satellites in the 1980s, but it no longer competes with expendable launch providers for these customers. Concerns may also emerge regarding systems or programs operated directly by government agencies, when they could be operated by industry. In the 1990s, the daily operation and management of the space shuttle were contracted out to an industry consortium.

Government policies generally express the intent to support commercial space. However, space advocates often criticize the implementation of this intent as inadequate. They seek government policies that will support commercial space, such as the government procuring commercial launch services rather than conducting government launches (an area in which the United States has made significant progress), undertaking technology development programs to reduce the risks to industry associated with advanced space concepts, serving as an anchor customer for new ventures, and providing loan guarantees, tax credits, and other financial incentives to space firms.

The impact of government policy and activities on space commerce should be viewed in a balanced way. All spacefaring nations have implemented some level of supportive government policy. While efforts to eliminate barriers to space commerce result in media attention and high-visibility policy discussion, it is important to note that many government policies have in fact been enabling space commerce. For example, government agencies have borne a significant proportion of the development costs of the major commercial launch vehicles worldwide. In the United States, Russia, and China, many vehicle families began as government launch systems that were eventually privatized; in Europe and Japan, commercial launchers were developed as government activities. Government agencies provide access to launch facilities and support new technology development and programs to reduce technology risks. Government acquisition of satellites and launch vehicles provides important economies of scale to manufacturing and launch firms. Intense international competition in space commerce has raised the issue of the fairness of different levels of government support for commercial space activities and given rise to international agreements✶ aimed at leveling the playing field.

WILL LOWER LAUNCH COSTS LEAD TO A SPACE BOOM?

Is it true that space commerce will boom if launch costs are significantly reduced? No one knows for sure. There have been several analyses that have assessed the demand for launch services by proposed space businesses (on-orbit manufacturing, space tourism, and so on) as a function of lower launch prices.

The most widely used data come from a study conducted in the mid-1990s by six large aerospace companies in conjunction with the National Aeronautics and Space Administration. The "Commercial Space Transportation Study" projected that if launch prices were reduced from modern levels of $4,000 to $10,000 per pound (depending on the destination orbit) to less than $500 to $1,000 per pound, there could be significant growth in launch activity.

✶**For more information on these agreements, see the Volume 1 article "Careers in Space Law."**

Conclusions

Barriers to space commerce are both economic and policy-based. The costs and risks of space activities create barriers to entry and limit the viability of new space industries. Despite the increasing commercial focus of space activities, government expenditures and policies will continue to have a major impact on space commerce. The greatest potential impact of government policies will arise from expenditures to reduce the costs of access to space, most likely through the development of reusable launch vehicles. The magnitude of this impact, even if launch costs drop dramatically, is difficult to predict. This uncertainty about potential benefits may inhibit government and industry willingness to commit significant resources to fostering new space markets. Finally, decision-making in both government and industry regarding space commerce will be increasingly shaped by international competition. SEE ALSO Accessing Space (volume 1); Burial (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Legislative Environment (volume 1); Remote Sensing Systems (volume 1); Reusable Launch Vehicles (volume 4); Space Tourism, Evolution of (volume 4); Tourism (volume 1).

Carissa Bryce Christensen and Deborah Pober

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Burial

The first space burial took place on April 21, 1997, when the cremated remains (cremains, or ashes) of twenty-four people were launched into Earth orbit. The Houston-based company Celestis, Inc. performed this historic space memorial service. Approximately seven grams of ashes from each individual were placed into a lipstick-sized flight capsule. Each capsule was inscribed with the person's name and a personal message. The capsules were then placed in the memorial satellite—a small satellite about the size of a coffee can. The memorial satellite was launched into space aboard a commercial rocket and placed into Earth orbit.

Celestis has continued to launch a memorial satellite every year since 1997. Many families choose the space burial because their loved ones had wanted to travel in space in their lifetimes. Each successive satellite has included more individuals as news has spread of this unique space-age service.

As of this writing, Celestis is the only company in the world launching ashes into space. The high cost of getting goods into Earth orbit (thus the small amount of ashes actually launched) and the strict regulations and permits necessary to conduct this novel business have helped to limit competition. In addition, as the space memorial service itself is new and unusual, it requires increased public knowledge and acceptance for the industry to grow.

Factors that encourage the growth of space memorials include the rising numbers of cremations worldwide. According to the Cremation Association of North America, almost seven million cremations a year take place in industrialized nations, and that number is increasing. Canada experienced a 25 percent increase in cremations from 1996 to 2000, and the United States had a 24 percent increase in the same time period. Presently, 45 percent of all deaths in Canada, 26 percent of all deaths in the United States, and almost all deaths in Japan (99 percent) lead to cremation.

There are several reasons for the increase of cremations over burials. The 1995 Wirthlin Report, sponsored by the Funeral and Memorial Information Council, states that one-fourth of survey respondents would choose cremation because it is less expensive than a traditional burial. The next rea-

A TRUE SPACE BURIAL

On July 31, 1999, the Lunar Prospector spacecraft finished its mission of mapping the Moon and was directed by NASA scientists to impact the Moon's surface. Aboard the spacecraft were the ashes of noted planetary geologist Eugene Shoemaker, the codiscoverer of the comet Shoemaker-Levy 9. The crash of the Lunar Prospector essentially buried Shoemaker's ashes on the Moon, where they remain today.

These lipstick-sized capsules contain cremated remains. Celestis, Inc. pioneered spaceflight memorials whereby a commercial rocket would carry and deposit this small payload in outer space.

son cited, by 17 percent of the respondents, was for environmental considerations—cremations use less land, which could be better used, for example, for agriculture to feed the world's population.

One might wonder about the space environment and all the memorial satellites in orbit—are they a type of orbital debris cluttering space? The memorial satellites do not remain in **orbit** forever. They are eventually drawn by gravity back to Earth, where they burn up harmlessly in the atmosphere. SEE ALSO Roddenberry, Gene (volume 1); Space Debris (volume 2).

Charles M. Chafer and Cynthia S. Price

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Internet Resources

Celestis, Inc. <http://www.celestis.com>.

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Business Failures

Many companies have built successful businesses sending television programs, computer data, long-distance phone calls, and other information around the world via satellite. Satellites are able to send information to people across an entire continent and around the world. Orbiting high above Earth, a satellite can simultaneously send the same information to a vast number of users within its coverage area. In addition, satellites are not affected by geography or topography and can transmit information beyond the reach of ground-based antennas. This characteristic, in particular, attracted entrepreneurs eager to make a profit by using satellites to provide telephone service for people who live or work in remote locations or in developing nations that have underdeveloped terrestrial communications systems.

A Chinese Long March 2C rocket carrying two U.S.-made Iridium satellites launches on March 26, 1998.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Failures in the Satellite Telephone Industry

But while some satellite systems have proven successful by offering advantages not matched by ground-based systems, the satellite telephone business has had a more difficult time. This difficulty is in part because cellular telephone companies greatly expanded their reach while the satellite systems were being built. Cellular systems use ground-based antennas, and it is generally much less expensive to use a cellular phone than to place a call with a satellite phone.

Two satellite telephone companies were forced into bankruptcy in mid-1999 because of limitations in their business plans, and because the communications business evolved while the companies were still in development. One of the companies, Iridium LLC, began service in 1998. The firm, however, could not attract enough customers to pay back the $5 billion it had borrowed to place sixty-six satellites in **orbit** to provide a global satellite phone system that would work anywhere on Earth. In late 2000, the newly formed Iridium Satellite LLC purchased the Iridium satellite system and associated ground systems for $25 million, a fraction of its original cost. Iridium Satellite soon began selling Iridium phone service at much lower prices than those of its predecessor.

Another satellite phone company, ICO Global Communications Ltd., had to reorganize and accept new owners, who bought the company at a large discount. ICO found it difficult to raise money from lenders after the failure of Iridium. ICO evolved into New ICO and developed a new, more diversified business plan that was not limited to satellite phone service. As of early 2002, New ICO had not yet started commercial service.

A third satellite phone venture, Globalstar LP, also ran into financial difficulty shortly after beginning commercial operations in 2000, and the company filed for bankruptcy protection in February 2002. Two other firms, Constellation Communications Inc. and Ellipso Inc., were unable to raise enough money to build their planned satellite phone systems.

The Reasons for the Difficulties

Iridium, ICO, and Globalstar ran into trouble because of the high cost of building a satellite system compared to the relatively low cost of expanded multicontinent cellular service, which relies on less expensive ground-based antennas. Satellites are expensive to build, and a complete satellite system can take years to complete. In addition, rockets can cost tens of millions of dollars to launch and they sometimes fail, requiring companies to buy insurance in case a rocket fails and destroys the spacecraft it was supposed to take into orbit.

These costs helped make satellite telephone systems much more expensive to use than cellular systems, while at the same time cellular networks were rapidly expanding the amount of territory for which they provided coverage. The cost difference, combined with the rapid growth of cellular networks, helped reduce the size of the potential market for satellite phone service during the very time that systems such as Iridium's were being developed.

In addition, satellite telephones are bigger and costlier to buy than cellular phones, and they must have an unobstructed view of the sky in order to work. Cellular phones, by contrast, work even indoors. These disadvantages further hurt the satellite phone industry.

Not all satellite phone companies have been unsuccessful. One, Inmarsat Ltd., has run a strong business providing mobile voice and data services for more than twenty years. But Inmarsat uses just a few satellites in **geostationary orbit** to serve most of the world, whereas Iridium, ICO, and Globalstar designed their systems around relatively large fleets of spacecraft located much closer to Earth. Such low- or medium-Earth orbit systems are intended to reduce the satellite delay associated with geostationary satellites, but they are also more costly and complex to build and operate.

geostationary orbit a specific altitude of an equatorial orbit, where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

The Related Failures of Launch Vehicle Makers

In addition to costing investors billions of dollars, the satellite phone industry's difficulties also deflated the hopes of several companies hoping to build a new series of launch vehicles designed to carry satellites into space. For example, Iridium and Globalstar each have several dozen satellites in their systems, and the expectation that the companies would have to replenish those spacecraft after several years helped inspire several firms to propose reusable rocket systems to launch new satellites.

The satellite phone systems in service in the early twenty-first century were launched using conventional rockets, which carry their **payloads** into space and then are discarded. Reusable rockets are intended to save money by returning to Earth after transporting a load into orbit and embarking on additional missions. But uncertainty about the satellite phone industry's future hurt the prospects of companies such as Rotary Rocket Co., Kistler Aerospace Corp., and Kelly Space & Technology Inc., which had looked to the satellite phone industry as a key source of business. Short of funds from investors, these firms have yet to develop an operational launch vehicle. SEE ALSO COMMUNICATIONS SATELLITE INDUSTRY (VOLUME 1); FINANCIAL MARKETS, IMPACTS ON (VOLUME 1); INSURANCE (VOLUME 1); LAUNCH VEHICLES, REUSABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4).

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Samuel Silverstein

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Business Parks

Humans have been doing business in orbit since the early 1960s, with "business" loosely defined in this context as any useful activity. Trained specialists, within the safety of small orbiting spacecraft, studied the Earth below and the heavens above. They conducted medical tests to see how their bodies responded to weightlessness. They did experiments on various materials to see how the lack of gravity affected their interactions. They studied the growth and behavior of plants and small animals. This early orbital activity would become the seed of today's space stations, which in turn may lead to tomorrow's space business parks.

Precursors to Space-Based Business Parks

For serious work, more spacious, dedicated orbiting laboratories were needed. The Soviets launched a series of Salyut stations beginning in 1971.

Astronaut Charles "Pete" Conrad Jr. completes an experiment activity checklist during training for a Skylab mission. Space business parks may include modules the size of Skylab.

The American Skylab, built from the casing of a leftover Saturn I booster, was launched in 1973 and was staffed in three missions of twenty-eight, fifty-nine, and eighty-four days.

Through the 1980s and 1990s, the National Aeronautics and Space Administration (NASA) used the space shuttle orbiter's **payload bay** to conduct orbital observations and experiments for periods of up to two weeks. Commercially built SpaceHab modules and the European-built Spacelab, both riding in the payload bay, allowed scientists to conduct more serious work. Meanwhile, the Soviet's historic Mir space station grew from a single module to an ungainly but productive complex.

payload bay the area in the shuttle or other spacecraft designed to carry cargo

Scientists experimented, **synthesizing** chemicals, crystals, and proteins impossible to produce in full gravity. Through such experiments it is possible that scientists might discover products valuable enough to warrant orbiting factories.

synthesis the combination of different things so as to form new and different products or ideas

Orbit is "the" place to do some useful things with proven economic impact: create global communications grids; monitor the atmosphere, weather, oceans, and changing land-use patterns; and search for unsuspected submarine and subterranean features. Much of this has been accomplished with automated satellites. Human activities in orbit have been directed at investigating the effects of **microgravity** on humans, animals, plants, and inanimate substances. Astronauts have also launched, retrieved, and repaired satellites and deep-space probes. The International Space Station (ISS) is being built to ramp up all these activities to the next level. Open for business with a crew of three, ISS's final design configuration would allow for a crew of seven. Further expansion of the current design is possible.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Elements of Business Parks in Space

Orbit is also an ideal place to service satellites, refuel probes on deep-space missions, and assemble large spacecraft and platforms too big to launch whole. For these activities humans will need: a fuel depot with the capacity to scavenge residual fuel, robotic tugs to take satellites to higher orbits and fetch them for servicing, a well-equipped hangar bay in which to perform such services safely under optimum lighting, and a personnel taxi for spacecraft parking nearby.

Supporting humans in space requires a growing mix of services to keep labs busy, bring people to orbit and back, supply equipment and parts, resupply consumables, and handle wastes. These are all businesses that can be provided more effectively at less cost by for-profit enterprises, given proper incentives. Physically, the ISS is similar to Mir in being a government-built metal maze. Operationally, the ISS could host considerable entrepreneurial activity.

A favorable climate of legislation, regulation, and taxation will foster such development. Privatizing American contributions could lead the way in this international endeavor. NASA could be mandated to use commercial providers for additional modules not in the original final design of the ISS as well as for the transfer of cargoes between orbits.

The ISS could evolve into a business park. As more people live and work aboard the ISS, additional quarters will be needed for visiting scientists, policymakers, and journalists. A modular six-berth "hotel" could grow with

The International Space Station, where astronauts live and conduct research for significant stretches of time, is the next step towards realizing integrated business parks in orbit.

demand. An open-door policy would welcome private individuals who had paid for or won their fares and who had passed physical and psychological tests.

berth space the human accommodations needed by a space station, cargo ship, or other vessel

Along with **berth space**, demand will grow for adequate recreation and relaxation "commons." A voluminous sports center, built in a shuttle external tank or large inflatable structure (sphere, cylinder, or torus), could be subsidized by naming rights and paid for by television advertising. Zero-G space soccer, handball, wrestling, ballet, and gymnastics might command respectable audiences on Earth. The first players will be regular staff, but telecasting these events would feed the demand among would-be tourists.

As on-location service providers join the action, they too will need residential and recreational space. As the population grows, treating and recycling wastes in-orbit will become more attractive. This will help build the know-how needed for future Moon and Mars outposts.

Managing a Growing Space Business Park

The operating agency should be a marina/port authority–type entity, acting as park "developer," anticipating growth and demand. The expansion of the station's skeletal structure and power grid must be planned, along with additional piers, slips, and docking ports. Haphazard growth can lead to an early dead end!

Clustering activities—scientific, commercial, industrial, and tourist—will aim at creating a critical mass of goods and services providers, including frequently scheduled transportation. If collective station keeping proves feasible, a station-business park could expand to include co-orbiting satellite clusters, orbiting Earth in formation. Laboratories may choose to relocate to such parks for isolation from unwanted vibrations.

If microgravity experiments identify products that could be profitably mass-produced in orbit, manufacturing complexes may develop. Raw materials mined on the Moon or the asteroids could be processed at orbiting industrial parks into building materials and manufactured goods. These products will not be aimed at consumers on Earth, where they would not be able to compete on price. Instead, they will feed the construction and furnishing of ever-more orbiting labs, business parks, factories, and tourist resorts. If Earth-to-orbit transportation costs remain high, space-sourced goods could have a cost advantage for orbital markets. This need to support increasing activities in Earth orbit will in turn support mining settlements on the Moon and elsewhere.

The Mir, deactivated and then recommissioned, had taken the lead in encouraging for-profit space activities, including tourism. Unfortunately, the Russian Space Agency decided to end its operation, and the aging space station re-entered Earth's atmosphere in 2001.

Given favorable changes in climate, bursts of commercial and business activity could vitalize the ISS core complex. The ISS is now in a high-inclination Earth orbit, an orbit chosen for its ease of access as well as to allow observation of most populated landmasses on Earth. Such orbits, however, are not optimum as staging points for higher **geosynchronous** orbit or deep space. Rising demand for such crewed services should lead to another depot-business park in **equatorial orbit**. Business and tourist activities in orbit are emerging from these tiny seeds. The future for business parks in orbit is bright. SEE ALSO Commercialization (volume 1); Habitats (volume 3); Hotels (volume 4); TransHab (volume 4).

Peter Kokh

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

equatorial orbit an orbit that lies in the same plane as Earth's equator

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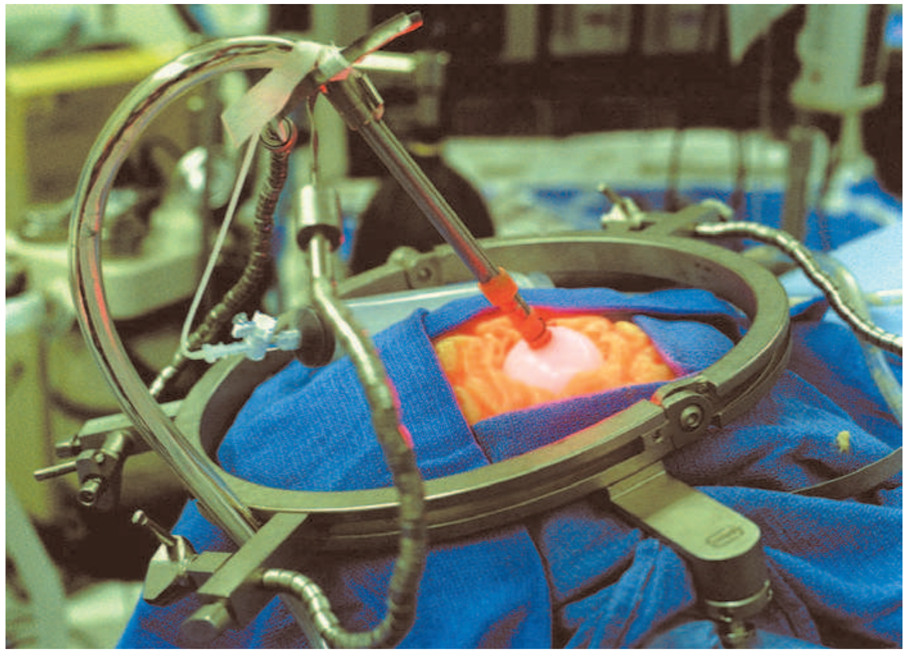
Cancer Research

The potential use of the **microgravity** environment for inroads in cancer research is both important and promising. Research opportunities are broad and will include many areas of examination for investigators who are trained in both basic and clinical sciences. As one example, studies have shown that mammalian **cell culture** conducted in a manner that does not allow cell settling as a result of gravitational forces holds promise in the propagation of three-dimensional tissue **cellular arrays** much like those that normally comprise tissue specimens in the intact body. The space shuttle and the International Space Station have only a minute fraction of the gravitational force present on Earth. Culture of tissues with a three-dimensional architecture on these research platforms provides a unique and powerful opportunity for

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

NASA's light-emitting diode (LED) developed out of a need for a light that could promote plant growth in space. Surgeons now use LED technology in cancer treatments involving surgery.



cell culture a means of growing mammalian (including human) cells in the research laboratory under defined experimental conditions

cellular array the three-dimensional placement of cells within a tissue

convection the movement of heated fluid caused by a variation in density; hot fluid rises while cool fluid sinks

X-ray diffraction analysis a method to determine the three-dimensional structure of molecules

studies of anti-cancer drug action with a more complex and natural tissue ultrastructure than can be attained in terrestrial laboratories.

Even the production and analysis of new anticancer drugs may be conducted in a superior manner in microgravity. Studies already conducted on the space shuttle have shown that, in at least some instances, superior crystal growth can be achieved in microgravity when compared to crystals grown on Earth. This success primarily is the result of a lack of liquid **convection** currents in microgravity that subsequently leads to a quieter liquid environment for a gradual and more orderly growth of crystals. The quality of crystal products is an important feature in the determination of the three-dimensional structure of the molecules by **X-ray diffraction analysis**. Until the three-dimensional structure of new and existing anti-cancer compounds is established, the design of superior candidates for cancer treatment is severely hampered.

It is generally recognized that cancers arise in the body more often than clinically troublesome cancer diseases occur. In many cases the primary cancer growth is restricted in further development and the victim's immune system plays an important role in limiting cancer progression, sometimes even eradicating the cancer cells altogether. It seems that the mammalian immune system may not function as efficiently in the microgravity environment when compared to Earth.

On one hand, a weakened immune response to infectious diseases and cancer could present a serious obstacle for space travelers of the future. On the other hand, a compromised immune system in microgravity, and a subsequent increased efficiency of tumor progression, may provide a valuable test bed for research on the immune system with regard to cancer development. The microgravity environment, where immune function is less efficient, may also provide an excellent opportunity to develop and assess new chemotherapeutic measures that can strengthen the host's immune response.

Of course, there are biomedical applications well beyond cancer research since the progression of many diseases may reflect a compromised immune function.

The life-threatening radiation exposure away from the protective atmosphere of Earth, and the ensuing increase in cancer cell development, is more than a casual concern for long-distance space travel. The means to protect space travelers from increased radiation will be necessary before such adventures are common.✶ SEE ALSO AIDS Research (volume 1); Living in Space (volume 3); Made in Space (volume 1); Medicine (volume 3); Microgravity (volume 2).

Terry C. Johnson

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✶In 2002 NASA announced an expanded 10-year program to study space radiation issues.

Career Astronauts

In the future, passenger flight into space is likely to become as routine as air travel. In the early twenty-first century, however, opening up the space frontier is the duty of a select cadre of highly trained individuals. In the United States, the early pioneering days of human spaceflight gave rise to individuals with what author Tom Wolfe called the "right stuff." These individuals were tough-as-nails experimental aircraft test pilots. They were critical to getting America's human spaceflight program, quite literally, off the ground. During the 1960s, and continuing through the 1970s, a unique corps of astronauts flew in the U.S. **Mercury**, **Gemini**, **Apollo**, and Skylab programs.

Today, after some forty years of human sojourns into **low Earth orbit** and to the Moon, roughly 400 people have departed Earth, heading for orbit. Beginning in 1981, a majority of these individuals have been boosted there courtesy of a U.S. space shuttle. Space travel has come a long way, from the early single-person "capsule" to the winged flight of a space shuttle.

Types and Duties of NASA Astronauts

The National Aeronautics and Space Administration (NASA) recruits pilot astronaut candidates and mission specialist astronaut candidates to support the space shuttle and International Space Station programs. Persons from both the civilian sector and the military services are considered. Applicants for the NASA Astronaut Candidate Program must be citizens of the United States.✶

Pilot astronauts serve as both space shuttle commanders and pilots. During flight the commander has onboard responsibility for the vehicle, crew, mission success, and the safety of the flight. The pilot assists the commander

Mercury the first American-piloted spacecraft, carrying a single astronaut into space; six Mercury missions took place between 1961 and 1963.

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

✶Readers interested in an astronaut career may request an application package by writing to: NASA Johnson Space Center, Attn: AHX/Astronaut Selection Office, Houston, Texas 77058.

Since astronaut Buzz Aldrin's historic steps on the lunar surface in July 1969, more than 400 people—astronauts, cosmonauts, and even "space tourists"—have ventured into space.

in controlling and operating the vehicle. In addition, the pilot may assist in the deployment and retrieval of satellites using the **remote manipulator system**, in extravehicular activities (**spacewalking**), and in other **payload operations**.

remote manipulator system a system, such as the external Canada2 arm on the International Space Station, designed to be operated from a remote location inside the space station

spacewalking moving around outside a spaceship or space station, also known as extravehicular activity

payload operations experiments or procedures involving payload or "cargo" carried into orbit

Mission specialist astronauts, working with the commander and pilot, have overall responsibility for the coordination of shuttle operations in the areas of crew activity planning, consumables usage, and experiment and payload operations. Mission specialists are required to have detailed knowledge of shuttle systems, as well as detailed knowledge of the operational characteristics, mission requirements and objectives, and supporting systems and equipment for each **payload** element on their assigned missions. Mission specialists perform space walks, use the remote manipulator system to handle payloads, and perform or assist in specific experiments.

Space shuttle crews have demonstrated that operation and experimental investigations in space are a challenging endeavor. A basic shuttle crew normally consists of five people: the commander, the pilot, and three mission specialists. On occasion, additional mission specialists, **payload specialists**, or other crewmembers are assigned. The commander, pilot, and mission specialists are NASA astronauts.

An exciting new era of space exploration is underway with the building of the International Space Station (ISS). The development of this orbital facility has been called the largest international scientific and technological endeavor ever undertaken.

The ISS is designed to house six to seven people, and a permanent laboratory will be established in a realm where gravity, temperature, and pressure can be manipulated in a variety of scientific and engineering pursuits that are impossible in ground-based laboratories. The ISS will be a test bed for the technologies of the future and a laboratory for research on new, advanced industrial materials, communications technology, and medical research.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

payload specialists scientists or engineers selected by a company or a government employer for their expertise in conducting a specific experiment or commercial venture on a space shuttle mission

Requirements for Applicants

What minimum requirements must an individual meet prior to submitting an application for astronaut status at NASA?

For a mission specialist astronaut candidate, an individual must have a bachelor's degree from an accredited institution in engineering, a biological or physical science, or mathematics. The degree must be followed by at least three years of related, progressively responsible, professional experience. An advanced degree is desirable and may be substituted for part or all of the experience requirement (a master's degree is considered equivalent to one year of experience, while a doctoral degree equals three years of experience). The quality of the academic preparation is important. Individuals must also pass a NASA Class II space physical, which is similar to a military or civilian Class II flight physical, and includes the following specific standards:

- Distance visual acuity: 20/200 or better uncorrected, correctable to 20/20, each eye
- Blood pressure: 140/90 measured in a sitting position
- Height: between 148.6 and 193 centimeters (58.5 and 76 inches)

The minimum requirement for a pilot astronaut candidate is a bachelor's degree from an accredited institution in engineering, a biological or physical science, or mathematics. An advanced degree is desirable. The quality of the academic preparation is important. At least 1,000 hours pilot-in-command time in jet aircraft is necessary. Flight test experience is highly desirable. Applicants must pass a NASA Class I space physical, which is similar to a military or civilian Class I flight physical, and includes the following specific standards:

- Distant visual acuity: 20/70 or better uncorrected, correctable to 20/20, each eye
- Blood pressure: 140/90 measured in a sitting position
- Height: between 162.6 and 193 centimeters (64 and 76 inches)

Screening and Training

Beyond the initial application requirements, NASA's astronaut selection involves a rigorous screening process designed to cull the best and brightest from those who are applying. In fact, in July 1999, a NASA call for astronauts produced more than 4,000 applicants. A mere 3 percent made the first cut. From there, further screening by the Astronaut Selection Board led to a final twenty candidates.

Those who make the grade as astronaut trainees are located at NASA's Lyndon B. Johnson Space Center in Houston, Texas. The selected applicants are designated astronaut candidates and undergo a one- to two-year training and evaluation period during which time they participate in the basic astronaut training program. This effort is designed to develop the knowledge and skills required for formal mission training upon selection for a flight. During their candidate period, pilot astronaut candidates must maintain proficiency in NASA aircraft.

As part of the astronaut candidate training program, trainees are required to complete military water survival exercises prior to beginning their flying studies and become scuba qualified to prepare them for spacewalking training. Consequently, all astronaut candidates are required to pass a swimming test during their first month of training. They must swim three lengths of a 25-meter (82-foot) pool without stopping, and then swim three lengths of the pool in a flight suit and tennis shoes. The strokes allowed are freestyle, breaststroke, and sidestroke. There is no time limit. The candidates must also tread water continuously for ten minutes.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

parabolic trajectory trajectory followed by an object with velocity equal to escape velocity

To simulate **microgravity**, astronaut candidates board the infamous "Vomit Comet," a converted KC-135 jet aircraft. Flown on a **parabolic trajectory**, this airplane can produce periods of microgravity for some twenty seconds. Akin to an airborne version of a roller coaster, the parabolic maneuvers are repeated up to forty times a day. Those riding inside the aircraft experience microgravity similar to that felt in orbital flight, although in short bursts.

One very important note: Selection as a candidate does not ensure selection as an astronaut. Final selection is based on the satisfactory completion of the one-year program.

Salaries

Salaries for civilian astronaut candidates are based on the federal government's general schedule pay scales for grades GS-11 through GS-14 and are set in accordance with each individual's academic achievements and experience. Selected military personnel are assigned to the Johnson Space Center but remain in an active duty status for pay, benefits, leave, and other similar military matters. SEE ALSO Astronauts, Types of (Volume 3); KC-135 Training Aircraft (Volume 3); Mission Specialists (Volume 3); NASA (Volume 3); Payload Specialists (Volume 3).

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Careers in Business and Program Management

One of the most interesting and potentially exciting trends in space exploration in the late twentieth and early twenty-first century has been the move towards the privatization and commercial exploitation of space. Privatization refers to the transfer of operations from the government or public agency to private sector management. Several organizations have suggested that many aspects of the U.S. space program's involvement in the International Space Station (ISS) and all Space Transport System (shuttle) operations should be privatized. The commercial exploitation of space has been a key topic of interest since the space program began. Commercialization and privatization of space go hand-in-hand, but the words have somewhat different meanings.

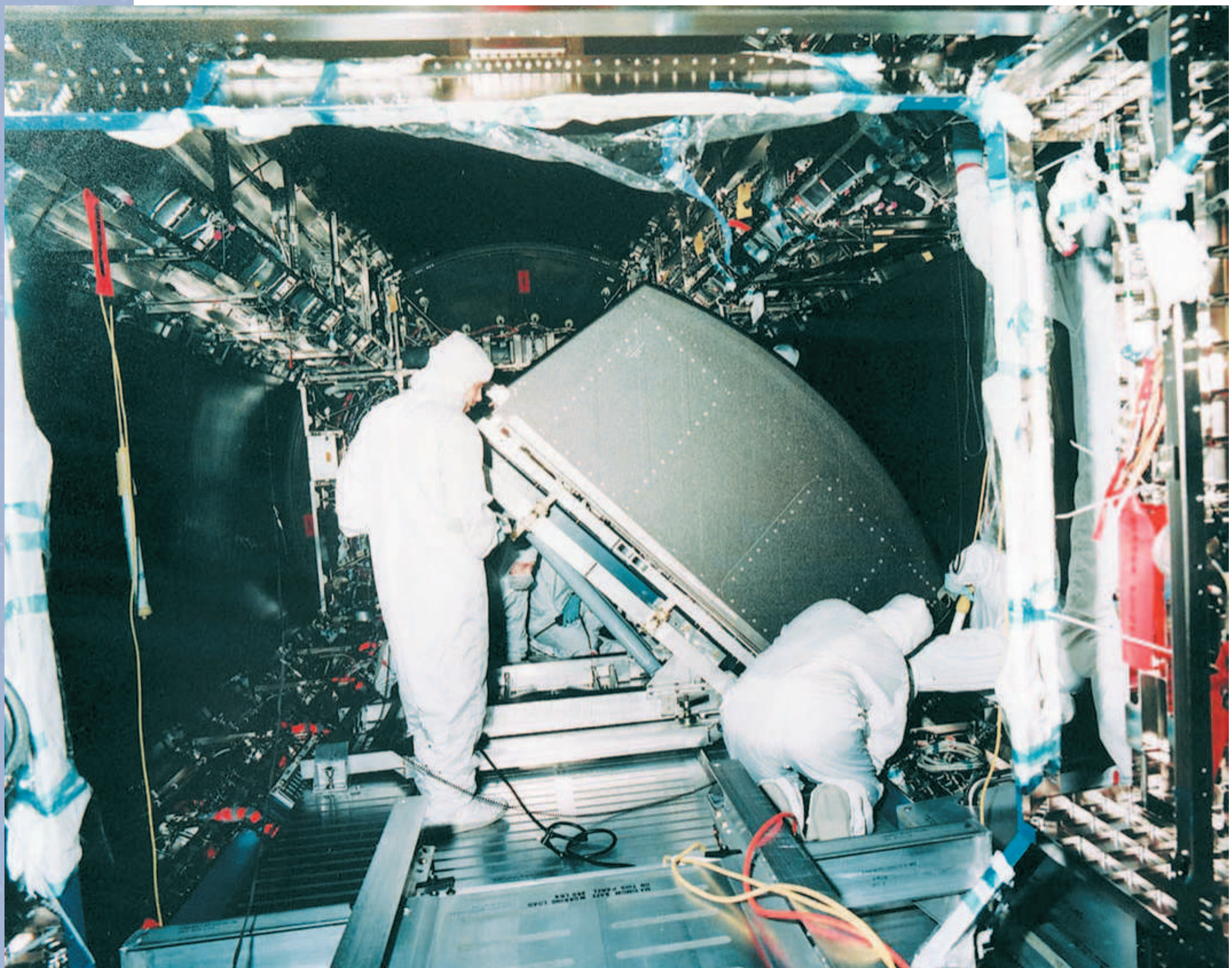
"Commercialization of space" is the term used by the National Aeronautics and Space Administration (NASA) and the U.S. Department of Commerce to describe the technology transfer program, where technologies developed by NASA are transferred to the private sector. The term is also used to describe purely private ventures that seek to use space as a resource for making a profit. This includes satellite delivery systems, asteroid mining, space-waste disposal, space tourism, and medical or commercial uses of the ISS. One of the earliest satellites launched was a giant balloon named Echo, which was used as a test of satellite communications. In the early twenty-first century, the space around Earth is filled with orbiting communications satellites, mostly owned and operated by private industry.

The commercialization of space offers new opportunities for private enterprise. While the large aerospace corporations continue to dominate the industry, several companies have been formed in recent years with the intention and stated goal of commercially exploiting space. Many former astronauts, and former NASA scientists and engineers, have moved on to these companies, suggesting that people with knowledge of space exploration consider privatization and commercial development of space enterprise the way of the future.

Careers in Aerospace

Individuals well suited for a career in aerospace tend to enjoy figuring out how things work; math and science; solving puzzles, especially mechanical puzzles; building flying model rockets, model airplanes, or trains; learning new things; and working with computers. There are several different ways to prepare for a career in aerospace, including taking plenty of math and science courses in high school. For those interested in design, research, or development of new aerospace systems, a college degree is desirable, preferably in engineering or science, but not necessarily aerospace engineering. After completing a degree, many seek a job in the aerospace or related industry and immediately apply for on-the-job training for specialized aerospace fields. Because jobs in the aerospace industries are very competitive, enlisting in one of the armed forces and applying for specialized training or even flight school are also recommended.

For the most part, everything that flies in the air or that orbits Earth is made by an aerospace industry. The aerospace industry is one of the largest employers in the United States, with over 750,000 employees. The aero-



The aerospace industry is one of the largest employers in the United States. Here, Boeing technicians install the first of 24 system racks into the U.S. laboratory module for the International Space Station at the Marshall Space Flight Center in Huntsville, Alabama.

space industry works very closely with the federal government on many projects. National defense and space exploration together account for over three-fourths of aerospace industries production. The aerospace industry hires more than 20 percent of the scientists and engineers in the United States.

It is almost impossible to get a job in the aerospace industry without a high school diploma. However, there are many different opportunities for employment in the aerospace industry, at many different levels from high school graduates to persons with advanced degrees in science, mathematics, and engineering. At whatever level a person is employed, special training or skill preparation is required. Administrative assistants working in the aerospace industry must be able to handle the complex technical language used by the industry. Union workers must be trained in the special manufacturing techniques used in aircraft and spacecraft, including ceramics, fiber composites, and exotic metals. Many workers must obtain a security clearance including extensive background checks.

Many companies hire more electrical engineers, mechanical engineers, and computer specialists than aerospace engineers. Also in high demand are materials scientists (to develop new alloys and composites), civil engineers (for site design and development), and chemical engineers (to study new fuels). Companies also hire safety engineers, manufacturing engineers (to help design efficient manufacturing processes), test and evaluation engineers, and quality control engineers.

A technical degree or advanced degree is not essential to work in the aerospace industry. Many jobs do not require a degree at all. Engineers and scientists represent less than one-third of the workforce. The remaining two-thirds are nontechnical support personnel. In production companies that primarily manufacture hardware, the proportion of engineers and technicians may be as low as 10 to 15 percent.

The large portion of employees at a typical aerospace company includes 10 to 20 percent professional employees, such as managers, salespeople, and contract administrators. Mechanics, electricians, and drafters are another 5 to 10 percent of the employees. The remainder include human resource specialists, engineering records employees, secretaries, and assembly line workers.

Aerospace Program Management

The aerospace industry has managed some of the largest, most expensive, and complex projects ever undertaken by humans. Projects such as the Apollo missions, with the goal of landing humans on the Moon within a decade, and the ISS involved thousands of people working all over the globe on different aspects of the project who had to all come together at the right time and place. Learning to manage such huge projects requires excellent technical comprehension and outstanding management abilities.

Some people have blamed NASA's management approach to the "faster, better, cheaper" series of "Discovery" class missions for the spectacular failures of the Mars Climate Orbiter and Mars Polar Lander. Former NASA administrator Daniel Goldin has commented that in the 1990s NASA dramatically increased its number of missions and decreased the time for each, while at the same time reducing the size of its staff. This resulted in less experienced program managers who received insufficient training and mentoring.

The lack of qualified managers has led to the development of specialized training in program management. Programs in space-related industries have traditionally been managed by scientists or engineers who learned to manage programs while on the job, or by former astronauts or others working in the aerospace industry. Although this approach has led to some spectacular successes in the space program, it has also led to some notable failures.

In response to criticism and recent failures of NASA in particular and the aerospace industry in general, the National Academy of Sciences recently completed a study and published a white paper with a suggested new design for program management. While the report specifically addresses human exploration of space and a potential Mars mission, its principles are applicable to any large-scale endeavor. The report grouped its recommendations into three broad areas.

The first recommendation made by the study group was that scientific study of specific solar system objects be integrated into an overall program of solar system exploration and science and not be treated as separate missions of exploration simply because of the interest in human exploration. All scientific solar system research would be grouped into a single office or agency.

The second recommendation made in the report was that a program of human spaceflight should have clearly stated program goals and clearly stated priorities. These would include political, engineering, scientific, and technological goals. The objectives of each individual part of a mission would have clearly stated priorities. These would be carefully integrated with the overall program goals.

The last recommendation made by the study group was that human spaceflight programs and scientific programs should work with a joint program office that would allow collaboration between the human exploration and scientific components. As a model, the study group suggested the successful Apollo, Skylab, and Apollo-Soyuz missions. SEE ALSO Career Astronauts (volume 1); Careers in Rocketry (volume 1); Careers in Space Law (volume 1); Careers in Space Medicine (volume 1); Careers in Writing, Photography, and Filmmaking (volume 1).

Elliot Richmond

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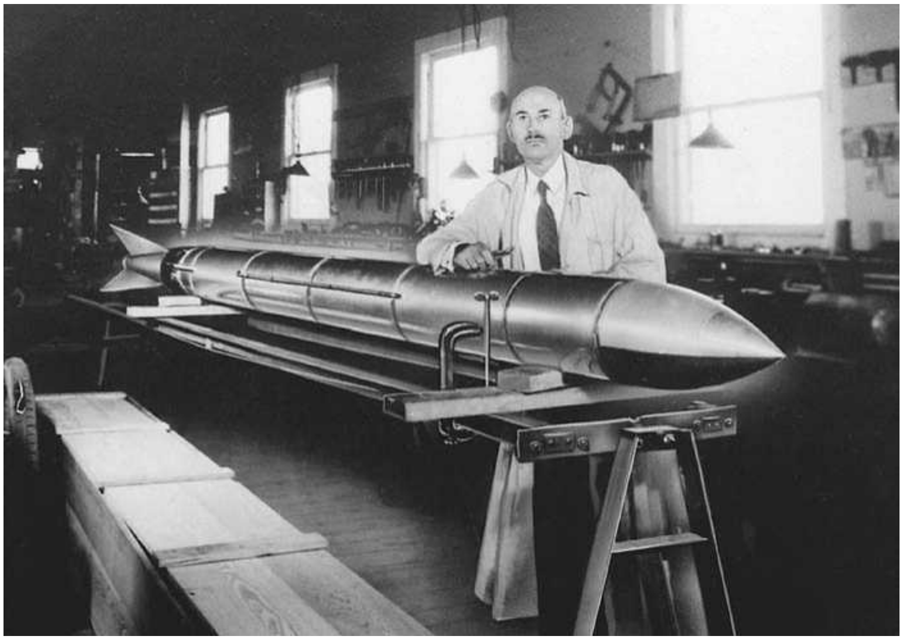
Careers in Rocketry

Three important developments during the first half of the twentieth century laid the foundation for both modern rocketry and careers within the field. The first was the inspired scientific and engineering work performed by Robert H. Goddard on solid propellant rockets, and subsequently on liquid propellant rockets, during the years 1915 through 1942. Remembered as the "Father of Modern Rocketry," Goddard was a physics professor at Clark University in Massachusetts. Working mostly alone, with limited



Robert Goddard, one of America's first rocket scientists, poses with one of his rockets at Roswell, New Mexico in 1938.

funds, he built and launched experimental solid and liquid propellant rockets and established the physical principles that enabled future rocket development to proceed.

The second event took place in Germany in the early 1930s. Goddard's work generated little interest in the United States, but it excited a small organization of young German rocket enthusiasts called *Verein Zur Forderung Der Raumfahrt* (VFR). One of the leaders of that group was Wernher von Braun, who ultimately helped the United States in the space race against the Soviet Union to place men on the Moon. The VFR built successful experimental liquid propellant rockets and captured the interest of the German army. VFR members were then assigned to develop a long-range **ballistic** missile that could deliver bombs to London. This huge effort ultimately resulted in the development of the V-2 rocket, which caused great devastation when it was used during World War II (1939–1945). In the space of a few months, over 1,300 V-2s were launched toward England. Technologically, the V-2 was an impressive development. It formed the prototype for most of the liquid-fueled rockets that were built over the next fifty years.

The third important development was the atomic bomb and the onset of the Cold War between the Soviet Union and the United States. This occurred immediately after the conclusion of World War II in 1945. Using V-2 technology, both nations embarked on enormous efforts to develop ballistic missiles that could deliver atomic bombs to any target. Coincidentally, that effort helped develop rockets capable of carrying **payloads** into space.

Rocket Development

Professionals in the field of rocketry work on two general types of rockets: liquid propellant and solid propellant. Each type has applications where it is best suited. A third type, called a hybrid, combines a solid fuel with a liquid **oxidizer**. At the beginning of the twenty-first century, hybrids were in

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

payloads the cargo carried into orbit by a space vehicle, usually a scientific experiment, satellite, or space station module

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion early development by the National Aeronautics and Space Administration (NASA).

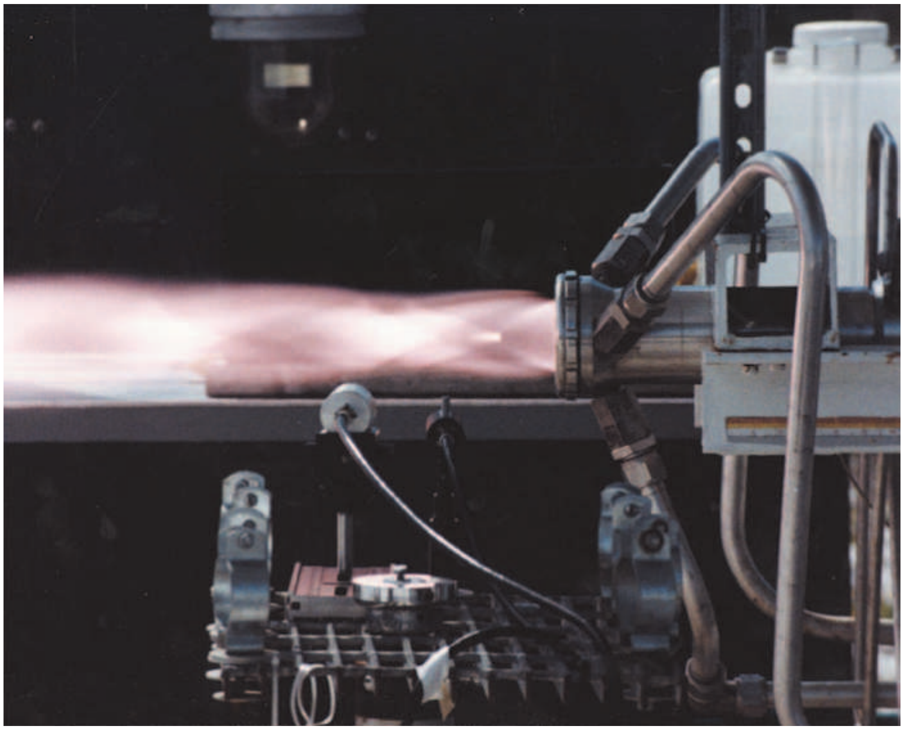
Liquid propellant rockets are generally preferred for space launches because of their flexibility of operation and better performance. For instance, the engines can be shut off and restarted, and the thrust can be throttled. On the other hand, solid propellant rockets have some tactical advantages. They do not require propellant loading on the launch pad, and they can be stored for long periods. Liquid propellant and solid propellant rockets can be used jointly to advantage in such cases as the Space Transportation System, better known as the space shuttle. The shuttle is initially boosted by two solid motors, working in tandem with the shuttle's liquid-fueled engines. Other liquid rockets that employ solid propellant boosters are the Delta, Titan IV, and Atlas space launchers.

The design and development of a rocket always begins with a requirement. That is, what is the nature of the mission that it is going to perform? The requirement could be established by the military, by NASA, or by a commercial enterprise concerned with exploiting opportunities in space. For the military, such a requirement might be a communications or spy satellite. For NASA it might be a spacecraft to Jupiter or a Mars lander. For commercial enterprises, the requirement usually centers on communications satellites or Earth-observation spacecraft.

As an example of the work involved in the field of rocketry, consider what happens when NASA comes up with a new requirement, and no existing rocket is capable of handling the mission. An entirely new rocket design is needed. Working to the requirements, a team of designers and systems engineers synthesize several different concepts for the new rocket, which, like all rockets, basically consists of a propulsion system, propellant tanks to hold the propellant, guidance and electronics equipment to control and monitor the rocket in flight, structure to hold the parts together, and miscellaneous components, valves, and wiring needed to make the rocket function. An advanced rocket that could complete the mission in a single stage might be included in the investigations, as well as various arrangements of two or more stages. In this phase of work, coordination with rocket engine and electronics systems manufacturers begins. Working together, the designers, engineers, and manufacturing professionals determine what is available, or what would need to be developed to make a particular concept work. Then the various concepts are compared in what are called trade studies, to determine which one can be built with the least cost, with the least risk, and on time, with the additional consideration of operational costs. Eventually each team will submit its best technical proposal and business plan, and subsequent evaluations and negotiations with NASA will culminate in placing a development contract with the winner.

Professions in Rocketry

Looking back to the beginnings of rocketry, Goddard served the functions of inventor, scientist, engineer, machinist, and test engineer, all combined into one. Modern design, development, manufacture, and operation of rockets require a broad array of professionals, including: mechanical, chemical, electronics, and aerospace engineers; thermodynamicists; aerodynamics and structural designers and analysts; manufacturing and tooling engineers; sys-



The design and development of a rocket is always guided by the nature of the mission that it is supposed to perform, and it is carefully tested to ensure its suitability.

tems engineers; project engineers; and test engineers. Rocketry is now heavily computer oriented, so persons preparing for a career in this field should become proficient in computer-aided analysis, design, and manufacturing.

The Future of Rocketry

As the twenty-first century unfolds, rocketry is still in its infancy, and there are many important areas in which professionals will be needed in the field in the future. It is too expensive to travel to space, and technology must be directed toward reducing space launch costs. One way this could occur is with the development of intercontinental ballistic travel. The development of a rocket engine that can operate on air and fuel will make this possible. With this innovation, hundreds of daily flights across continents can be envisioned. Travel to space in similar vehicles will be economical. In space travel, we can forecast nuclear propulsion, particularly if it turns out that water on the Moon can be readily mined. Nuclear steam rockets will then become common. Pulse plasma rockets, huge butterfly-shaped rockets that collect electrical energy from the Sun, will also be used. Ultimately, for travel to distant star systems, the tremendous energy available in particle annihilation will be applied in propulsion. Practical containers for **antimatter** may be impossible to achieve. But the secret may be to use antimatter as fast as it is generated—a challenge for rocketeers of the twenty-first century. SEE ALSO Goddard, Robert Hutchings (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Nuclear Propulsion (volume 4); Reusable Launch Vehicles (volume 4); Rocket Engines (volume 1); Rockets (volume 3); Space Shuttle (volume 3); von Braun, Wernher (volume 3).

Edward Hujsak

antimatter matter composed of antiparticles, such as positrons and antiprotons

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Careers in Space Law

Attorneys have been involved in space law since the early 1960s, when the legal community started addressing many rules and regulations relating to outer space activities. Space law practice deals with the legally related behavior of governments and private individuals who have interacted in some manner with outer space.

Issues that Space Lawyers Address

Many situations requiring legal expertise crop up in the world of space. Space lawyers rely on already established space law but still enter into uncharted territory. An example of such an undefined area that affects what space attorneys do is the designation of where space begins. The Outer Space Treaty and most of the other international conventions do not define the boundary between Earth's atmosphere and outer space. Another dilemma confronting space lawyers is the many provisions of the treaties, such as the ban on claims of sovereignty and property rights in space as well as the prohibition against military operations in outer space.

Generally speaking, space law attorneys handle two areas of outer space law:

- International space law, which governs the actions of countries as they relate to other states.
- Domestic space law, which governs actions within the state.

The Five Core Space Treaties

Space attorneys conduct most of their legal activities in keeping with space treaties, which resulted from the establishment of the United Nations Committee on the Peaceful Uses of Outer Space in 1958. Many countries have ratified five major international treaties and conventions, which guide space law attorneys in international and domestic space law.

The first major space treaty was the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (known as the Outer Space Treaty). This treaty addresses many liability issues that attorneys would be involved in litigating. Countries that did not ratify the 1972 Liability Convention may still be legally obligated to abide by this treaty.

The 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space (known as the Rescue Agreement) was the next major treaty. Attorneys play an important role with respect to this treaty by providing counsel to government and public organizations concerning rescue and recovery efforts.

This was followed by the 1972 Convention on International Liability for Damage Caused by Space Objects (known as the Liability Convention). One of the biggest concerns space attorneys deal with regarding these five treaties is the issue of liability. Therefore, space law practice is to a great extent involved with such issues. Among the issues space law attorneys currently handle is damage caused by spacecraft and satellites, as well as indirect effects such as causing pollution in outer space that adversely affects Earth. In the future, as private tourism expands into space and private citizens go into outer space for pleasure, a very strong interest will arise in liability provisions and indemnification through the insurance industry.

Specifically, the Liability Convention requires payment of damages making restitution for "loss of life, personal injury or other impairment of health, or loss or damage to property of States or of persons, natural or juridical, or property of international governmental organizations" (Liability Convention, Article 1). A "launching state" is explicitly defined as a state that launches or procures the launching of a space object or a state from whose territory or facility a space object is launched, regardless of whether the launch was in fact successful.

The 1976 Convention on Registration of Objects Launched into Outer Space (known as the Registration Convention) requires adherence to regulations regarding the tracking of all spacecraft and satellites. Attorneys counsel organizations on how to comply with these requirements.

The final major space treaty was the 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (known as the Moon Agreement). The United States has not ratified this treaty, but legal counsel still needs to be aware of its ramifications, especially when working with ratifying countries on joint projects. SEE ALSO LAW (VOLUME 4); LAW OF SPACE (VOLUME 1); LEGISLATIVE ENVIRONMENT (VOLUME 1).

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Careers in Space Medicine

Outer space has a very different environment from that of Earth. The atmosphere, radiation, and gravity levels are so drastically varied that several adjustments are made to protect astronauts from the deadly effects of the space environment on the human body. In particular, gravitational effects are not well controlled and the effects of long-term exposure to **microgravity** are unknown.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Several experiments have already indicated that major biological changes begin in the human body within minutes of spaceflight. For example, when

When in space, humans experience decreased aerobic capacity, endurance, strength, and muscle mass. Physicians in space medicine conduct tests to determine what types of exercise will most benefit astronauts who spend extended periods of time in space.

malady a disorder or disease of the body

a person is exposed to microgravity, there is less blood volume in the legs and more in the upper body. This change makes the brain sense that there is too much fluid in the body and triggers an adaptive response such as increased urine production. This is similar to the sensation experienced by many people upon entering a swimming pool. Even the chemical composition of blood and urine is altered, which perhaps reflects that other body tissue and organ changes are taking place in response to the loss of gravity. Given all of the effects of spaceflight upon the human body, several career opportunities exist to study and treat future space travelers.

Medical Challenges

Several questions remain about the scope of space medicine because scientists do not understand all of the changes that take place in the human body either on Earth or in space. Can all of the problems be treated? Is a treatment really needed? Is the prevention of adaptive changes that occur when humans go to space better than treatment after a change has already taken place? How can medical problems in space be prevented? Will the body's cells, tissues, and organs return to normal at different rates upon landing back on Earth or on another planet with similar gravity?

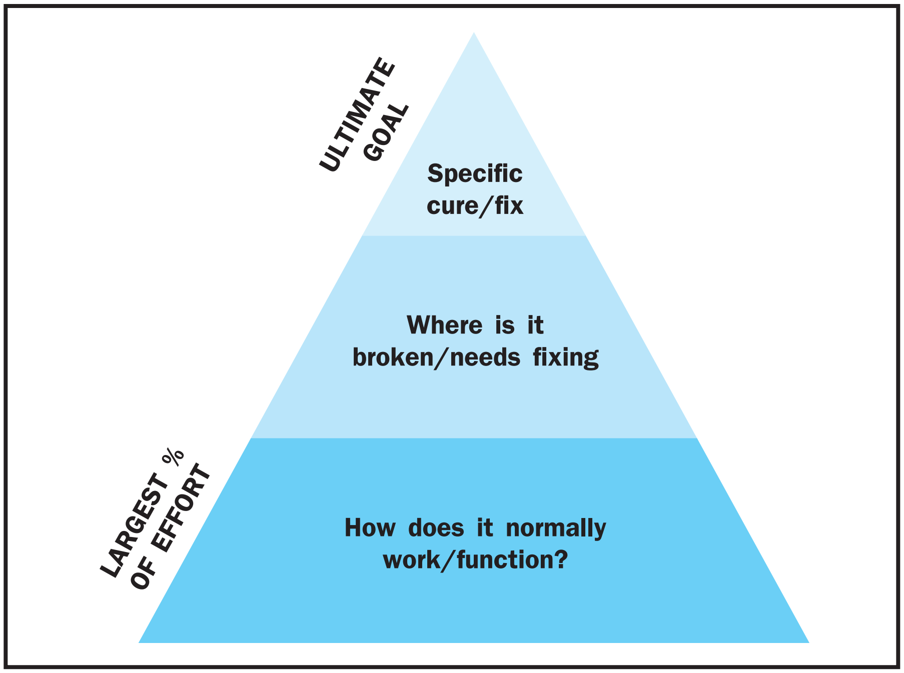
Because scientists understand so little about how the human body works in normal gravity on Earth, few specific cures have been found for medical conditions. Doctors often can only treat symptoms and not the causes of diseases. For instance, allergy medication eliminates the symptoms of the **malady**, but when a patient stops taking the medicine, the symptoms may return. A heart may no longer be able to beat properly, but a device such as a pacemaker can assist in doing the job. In neither of these cases has the underlying disease been either treated or cured. If the main objective is to find a cure for a problem, how can this be done if what needs to be fixed is unknown? And how does one know what to fix if it is not known how the body normally works?

Scientists must therefore conduct experiments on Earth and in space to: (1) understand how the body normally functions in these two environments, (2) determine how diseases and other medical conditions develop, and (3) either find a specific cure or prevent the disease (see accompanying figure). Perhaps scientists will also discover that, in some instances, the adaptations the human body makes in space are not all necessarily bad or in need of medical attention.

Lessons from Experience

During the late 1950s to early 1960s, in the early years of spaceflight exploration, it was impossible to anticipate every change in bodily function that would occur to those venturing into space. It was unclear if even simple tasks such as swallowing would become a health hazard for the astronauts (i.e., is gravity needed to "pull down" food and water into the stomach?). The answers to this and other questions were found by successfully sending animals and then Russian cosmonauts and U.S. astronauts into short spaceflights.

By the early twenty-first century, scientists had gained a better understanding about how day-to-day, bodily activities are affected by micrograv-



The distribution of current efforts by researchers to solve medical problems on Earth and in space.

ity. Though some negative side effects are indeed experienced (e.g., difficulty with eyesight focus, loss of balance, nausea), astronauts have by and large returned to live healthy lives on Earth.

Longer flights and numerous experiments later, scientists have a better idea of what may pose as a medical threat during long-term exposure to microgravity. These issues must be resolved to enable extended stays on the International Space Station (ISS) and flights to land humans on other planets such as Mars. The problems include a loss and reorganization of bone mass as well as loss of muscle strength and mass. If muscles are heavily used on Earth (such as with weight lifters), they become stronger and larger. Under the weightless conditions of space, the muscles no longer work as hard and become smaller (a condition known as atrophy). In space, the blood itself becomes weightless, and the heart will eventually atrophy because it has to work less to pump blood through the body. After a long trip in space, a sudden return to Earth might make an astronaut appear to have heart failure. Similarly, if bone does not sense the need to support the body against the effects of gravity, then spaceflight-induced bone loss might lead to osteoporosis-like problems upon a return to Earth.

Future Trends

To prevent microgravity-associated health problems and to ensure a safe return to normal bodily function, more studies are needed. Among the key areas for current and future research are diet, exercise, genetics, and whether or not hormones can produce their normal effects, both during and after spaceflight. Scientists and physicians trained to deal with these issues are needed both on the ground (e.g., in preparation for spaceflight) and as part of the flight team. Furthermore, understanding how the body changes in space will aid in the development of cures here on Earth, in addition to helping maintain the medical health of space travelers. For example, once it is known how bone is altered in space, would the discovery of a treatment also be useful to prevent or reverse osteoporosis?

The collective efforts of many biomedical-related fields are needed to fully understand and develop ways of coping with the effects of microgravity on the human body. The body is an integrated system in which different cells, tissues, and organs affect or interact with one another. When one system is altered, there are usually consequences to another system. Simply getting out of bed in the morning leads to many integrated changes—blood flows and pools in the legs, the blood vessels counteract this by contracting to "push" the blood upward, heart rate increases, and various hormones are released to prepare for the day's activities. Because of the integrative nature of human bodily functions, there are many career opportunities for basic research in such disciplines as pharmacology, biochemistry, biology, chemistry, physiology, and genetics. Physicians and other health-care professionals can then apply newly discovered biomedical information to ensure the continued improvement of human health on Earth and in space. SEE ALSO AGING STUDIES (VOLUME 1); AIDS RESEARCH (VOLUME 1); CANCER RESEARCH (VOLUME 1); MEDICINE (VOLUME 3).

Michael Babich

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Careers in Writing, Photography, and Filmmaking

The ability to communicate with others is necessary in all avenues of life, but in space science and technology it is critical to the successful furtherance of spaceflight objectives because of the lesser importance that most individuals assign to the endeavor. Indeed, a central feature of communication efforts throughout the space age has been the coupling of the reality of spaceflight with the American imagination for exploring the region beyond Earth. Without it, humans might never have slipped the bonds of Earth, ventured to the Moon, and sent robots to the planets. In the process, the dreams of science fiction afficionados have been combined with developments in technology to create the reality of a spacefaring people.

An especially significant spaceflight "imagination" came to the fore after World War II (1939–1945) and urged the implementation of an aggressive spaceflight program. It was seen in science fiction books and film, but more important, serious scientists, engineers, and public intellectuals fostered it. The popular culture became imbued with the romance of spaceflight, and the practical developments in technology reinforced these perceptions that for the first time in human history space travel might actually be possible.

Gene Roddenberry wrote scripts for television series such as *Dragnet* before creating *Star Trek.* His series would lead to movies featuring the Borg and its queen, shown here with the starship Enterprise's captain, Jean-Luc Picard.

There are many ways in which the American public may have become aware that flight into space was both real and should be developed. The communication of space exploration possibilities through the written, photographic, and electronic media began very early in the history of the space age. Since the 1940s science writers such as Arthur C. Clarke and Willy Ley had been seeking to bring the possibilities of spaceflight to a larger audience. They had some success, but it was not until the early 1950s that spaceflight really burst into the public consciousness.

Wernher von Braun's Role in Promoting Spaceflight

In the early 1950s the German émigré scientist Wernher von Braun, working for the army at Huntsville, Alabama, was a superbly effective promoter of spaceflight to the public. Through articles in a major weekly magazine, *Collier's*, von Braun urged support for an aggressive space program. The *Collier's* series, written in 1952, catapulted von Braun into the public spotlight as none of his previous activities had done. The magazine was one of the four highest-circulation periodicals in the United States during the early 1950s, with over 3 million copies produced each week. If the readership extended to four or five people per copy, as the magazine claimed, something on the order of 15 million people were exposed to these spaceflight ideas.

Von Braun next appeared on a variety of television programs, including a set of three highly rated Disney television specials between 1955 and 1957. These reached an estimated audience of 42 million each and immeasurably added to the public awareness of spaceflight as a possibility. As a result, von Braun became *the* public intellectual advocating space exploration, an individual recognized by all as an expert in the field and called upon to explain the significance of the effort to the general population.

The coming together of public perceptions of spaceflight as a near-term reality with rapidly developing technologies resulted in an environment more conducive to the establishment of an aggressive space program. Convincing the American public that spaceflight was possible was one of the most critical components of the space policy debate of the 1950s and 1960s. For realizable public policy to emerge in a democracy, people must both recognize the issue in real terms and develop confidence in the attainability of the goal. Without this, the creation of the National Aeronautics and Space Administration (NASA) and the aggressive piloted programs of the 1960s could never have taken place.

2001: A Space Odyssey

The powerful spaceflight concepts championed by von Braun found visual expression in a wide-screen Technicolor feature film released in 1968, *2001: A Space Odyssey.* Director Stanley Kubrick brought to millions a stunning science fiction story by Arthur C. Clarke about an artificially made monolith found on the Moon and a strange set of happenings at Jupiter. With exceptional attention to science fact, this film drew the contours of a future in which spaceflight was assisted by a wheel-like space station in orbit, a winged launch vehicle that traveled between Earth and the station, a Moon base, and aggressive exploration to the other planets. All of this was predicted to be accomplished by 2001, and the director and the technical advisors were concerned that their vision might be outdated within a few years by the reality of space exploration. It was not, and their vision still is far from becoming reality.

The Impact of Photography

The photographic record of spaceflight has also served to sustain interest in the endeavor. For example, the photographs taken of Earth from space sparked a powerful reaction among those who viewed them for the first time. Project Apollo forced the people of the world to view planet Earth in a new way. In December 1968 Apollo 8 became critical to this sea change, for the image taken by the crew, "Earthrise," showed a tiny, lovely, and fragile "blue marble" hanging in the blackness of space with the gray and desolate lunar surface in the foreground as a stark contrast to a world teeming with life.✶ Poet Archibald MacLeish summed up the feelings of many people when he wrote, "To see the Earth as it truly is, small and blue and beautiful in that eternal silence where it floats, is to see ourselves as riders on the Earth together, brothers on that bright loveliness in the eternal cold—brothers who know now that they are truly brothers." (MacLeish, December 25, 1968) The modern environmental movement was galvanized in part by this new perception of the planet and the need to protect it and the life that it supports.

✶The Apollo image "Earthrise" can be seen in the Volume 4 article "Earth—Why Leave?".

Carl Sagan as Public Intellectual

Astronomer Carl Sagan emerged as a public intellectual on behalf of space exploration in the 1970s in much the same way that von Braun had in the 1950s. An academic on the faculty at Cornell University, Sagan eschewed the scholarly trappings of the "ivory tower" to engage the broadest possible audience directly through writing, speaking, and television appearances. His brilliant thirteen-part *Cosmos* series on public television in 1980, like the *Collier's* series of von Braun, captured the imagination of a generation of Americans about the wonders of the universe and energized the public debate concerning space exploration in the 1980s. In part, the increases in federal budgets for space activities could be related to the excitement generated by Sagan's compelling arguments.

Sagan went on to fill von Braun's shoes as a public intellectual with verve until his death in 1996. He wrote best-selling nonfiction, such as *Cosmos* (1980) and *Pale Blue Dot: A Vision of the Human Future in Space* (1994), and a novel, *Contact* (1985). Always he drew a tight relationship among technical capabilities, philosophical questions, and human excitement and destiny. He rarely wrote for academic audiences, as was normal for other scholars, and published more articles in *Parade* magazine, reaching millions of readers, than in professional journals. He also took on the proponents of **pseudoscience**, especially efforts to convince individuals of extraterrestrial visitations to Earth, publishing a major work on the subject, *The Demon-Haunted World* (1995), near the end of his life. Sagan appeared on popular talk shows such as "The Tonight Show" with Johnny Carson and Jay Leno to espouse his vision of a hopeful future in space. His belief in a universe filled with life, and humanity's place in that universe, came to the big screen in 1997 with the making of *Contact* into a feature film starring Academy Award winner Jodie Foster.

pseudoscience a system of theories that assumes the form of science but fails to give reproducible results under conditions of controlled experiments

Opportunities in the Field

Opportunities to expound a compelling vision of a future in space exist in all arenas available for communication. Using written, photographic, and multimedia forms of communication, future writers and visual artists have the opportunity to become public intellectuals whose ideas expressed in these forms will shape the future of spacefaring in the United States. Indeed, it is largely up to such individuals to frame the debate on the future of spaceflight. Will the astronauts and their voyages to the Moon be remembered as being akin to Italian explorer Christopher Columbus and his voyages to the Americas—as vanguards of sustained human exploration and settlement? Or will their endeavors prove to be more like Leif Eriksson's voyages from Scandinavia several hundred years earlier, stillborn in the European process of exploration to new lands? No one knows yet, but the public intellectuals of the future using all of the tools of communication available to them will be the ones to prompt both the policymakers and the public to make decisions about sustained exploration. SEE ALSO CLARKE, ARTHUR C. (VOLUME 1); ENTERTAINMENT (VOLUME 1); LITERATURE (VOLUME 1); LUCAS, GEORGE (VOLUME 1); MOVIES (VOLUME 4); RODDENBERRY, GENE (VOLUME 1); SAGAN, CARL (VOLUME 2); SCIENCE FICTION (VOLUME 4); *STAR TREK* (VOLUME 4); *STAR WARS* (VOLUME 4); VON BRAUN, WERNHER (VOLUME 3).

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Clarke, Arthur C.

British Science Fiction Writer
1917–

Born at Minehead, Somerset, United Kingdom, on December 17, 1917, Arthur C. Clarke was fascinated by science fiction and astronomy at an early age. In the 1930s he joined the British Interplanetary Society. After enlisting in the Royal Air Force in 1941, he became a **radar** instructor and participated in the development of ground-controlled landings of aircraft under zero-visibility conditions.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

equatorial orbit an Earth orbit parallel to Earth's geographic equator

angular velocity the rotational speed of an object, usually measured in radians per second

In 1945 the technical journal *Wireless World* published Clarke's article "Extra-Terrestrial Relays," which proposed the use of three broadcast satellites in **equatorial orbit** to provide worldwide communication. Clarke chose an orbital altitude of 35,786 kilometers (22,300 miles) because at that distance the **angular velocity** of Earth's rotation would match that of the satellite. As a result, the satellite would remained fixed in the sky. Twenty years later, Early Bird was launched, the first of the commercial satellites that provide global communications networks for telephone, television, and high-speed digital communication, including the Internet.

After World War II, Clarke obtained a bachelor of science degree in physics and mathematics at King's College, London. In 1954 he became enchanted by underwater scuba diving, which simulated weightlessness in spaceflight. In 1969 Clarke moved to Sri Lanka.

Clarke has written eighty books on science and technology, along with their sociological consequences.✶ He collaborated with the director Stanley Kubrick on the film *2001: A Space Odyssey* (1968), which was based on his short story "The Sentinel." Clarke has received many honors and awards, including knighthood, the Franklin Institute Gold Medal, the UNESCO-Kalinga Prize, honorary fellow memberships and awards from major scientific and astronautical organizations, and a nomination for the Nobel Peace Prize in 1994.

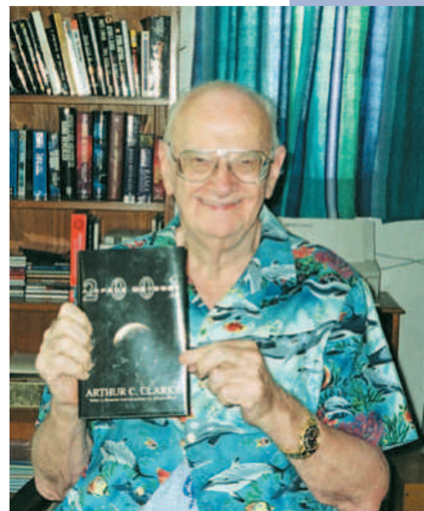
✶Clarke once said that his chief aim was an old science fiction cliché: "The search for wonder."

Among Clarke's works are the following books:

Nonfiction

- *Ascent to Orbit, a Scientific Autobiography: The Technical Writings of Arthur C. Clarke.* New York: John Wiley & Sons, 1984.
- *Astounding Days: A Science Fictional Autobiography.* New York: Bantam, 1989.
- *The Exploration of Space.* New York: Harper, 1951.

- *Greetings, Carbon-Based Bipeds!: Collected Essays, 1934–1998.* New York: St. Martin's Press, 1999.
- *How the World Was One: Beyond the Global Village.* New York: Bantam, 1992.
- *The Making of a Moon: The Story of the Earth Satellite Program.* New York: Harper, 1957.
- *Profiles of the Future: An Inquiry into the Limits of the Possible.* New York: Harper, 1962.
- *The Promise of Space.* New York: Harper, 1968.
- *Voices from the Sky: Previews of the Coming Space Age.* New York: Harper, 1965.



Arthur Clarke's published article "Extra-Terrestrial Relays" formed the basis for current global communications systems.

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- *Childhood's End.* New York: Ballantine, 1953.
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- *The Hammer of God.* New York: Bantam, 1993.
- *Islands in the Sky.* Philadelphia: Winston, 1952.
- *Rendezvous with Rama.* New York: Harcourt, 1973.
- *The Sands of Mars.* London: Sidgwick & Jackson, 1951.
- *2001: A Space Odyssey.* New York: New American Library, 1968.
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SEE ALSO CAREERS IN WRITING, PHOTOGRAPHY, AND FILMMAKING (VOLUME 1); COMMUNICATIONS SATELLITE INDUSTRY (VOLUME 1); ENTERTAINMENT (VOLUME 1); SCIENCE FICTION (VOLUME 4).

Frederick C. Durant III

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Commercialization

"Space commercialization" is a general term that distinguishes private activities from those of the government in enabling the use of space from either an Earth-based operation or from space itself. Private-sector use of space involves activities that are expected to return a profit to investors, such as building, launching, and operating communications satellites or taking pictures of Earth from space to monitor crops.

In contrast to the private sector, government activities are performed to carry out specific missions for the public good. Examples range from national defense activities to scientific missions studying the planets, and also include satellites that monitor Earth's environment.

Because space research, development, and exploration are very expensive and risky, governments have funded most activities. During the 1990s, private companies began to expand beyond the already profitable communications satellite services, and develop the use of the space environment for the introduction of new products. The U.S. government requires a license for a U.S. firm to launch spacecraft and do business in space. Often when there is an overlap between a government mission and a private activity, will the government partner with a private company.

"Commercialization of space" is frequently confused with "privatization of space." Sometimes commercialization of space is used by the government to mean that a function previously performed by the government has been shifted to a private company, often with the government as a paying customer. "Privatization of space" involves the government reallocating authority, responsibility, and the risk of operations using government-owned assets and ultimately transferring asset ownership itself to the private sector. Because privatization is a process, there are many intermediate steps possible between total government management, control, and asset ownership and full privatization. And, because this process involves firms that are providing services for a profit, privatization and commercialization sometimes are used as synonyms even when they are not precisely the same.

Examples of Space Commercialization

The largest commercial use of space is by satellite communications and associated services. Long-distance communications are dependent on two major transmission modes: satellites and **fiber-optic cables**. Satellites are the cheapest and best providers of point to multipoint communications while fiber-optic cables provide efficient high-capacity point-to-point services. In 2000, estimated revenues from satellite communications operations, including direct-broadcast TV services, were greater than $25 billion annually. Commercial revenues are expected to grow very fast as new broadband satellites are developed that will be able to transmit Internet and other services. Global Positioning System (GPS) satellites that broadcast detailed location coordinates to handheld units, as well as to airplanes, ships, and automobiles, have provided many terrestrial commercial opportunities and this area is likely to grow very rapidly. (The GPS satellite system itself is government-owned and operated.)

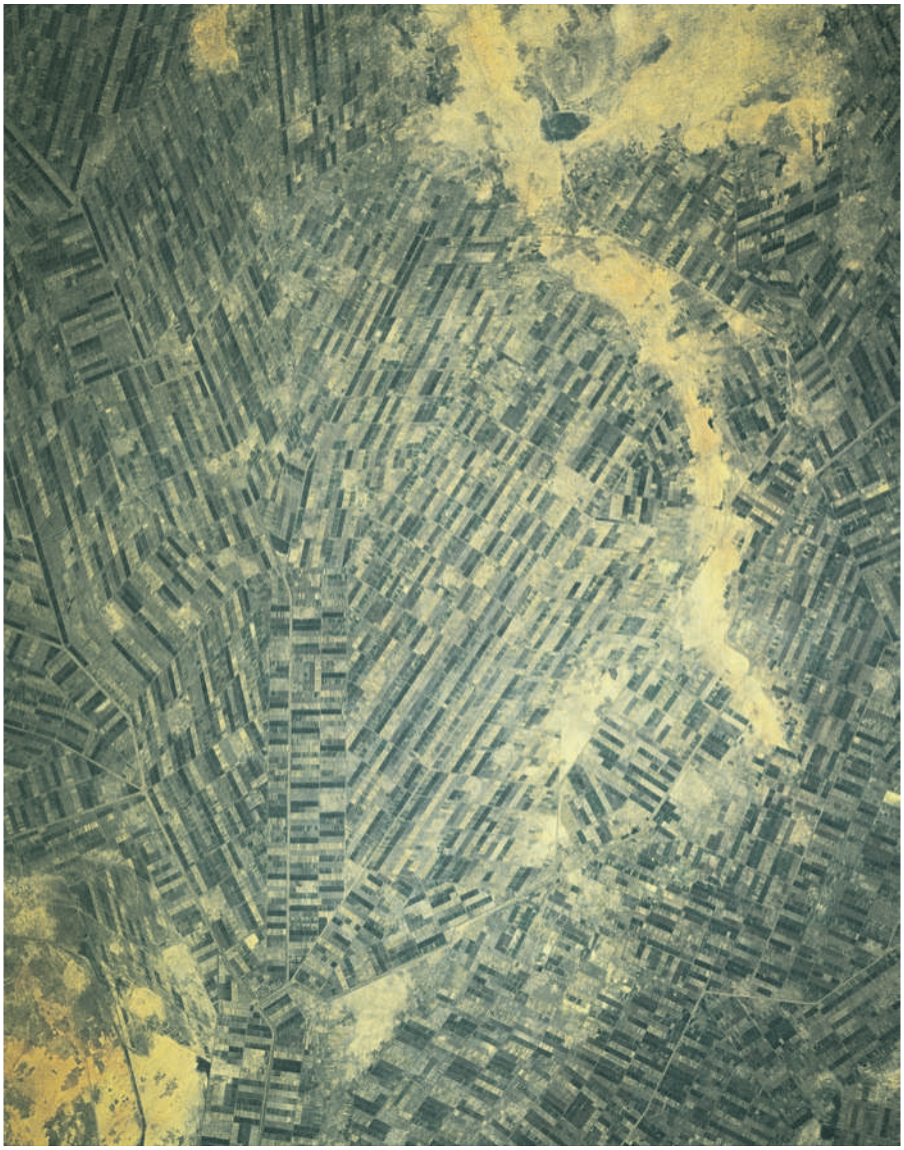
fiber-optic cable a thin strand of ultrapure glass that carries information in the form of light, with the light turned on and off rapidly to represent the information sent

Other uses of space for commercial purposes generate relatively small revenues but hold growth potential. Remote sensing (taking digital pictures of Earth from satellites) is used to monitor Earth and for mapping and discovering new sources of natural resources.

Launch vehicles that boost **payloads** into space also provide business opportunities for firms. Since the late 1980s, **expendable launch vehicles** (ELVs) have been privately manufactured and operated in the United States. Of course, the need for launch vehicles is determined by the need to put payloads in space. Worldwide, commercial ELV companies earned more than $10 billion in revenues in 2001. Several firms are designing and developing commercial reusable launch vehicles (RLVs); eventually some will even be capable of launching people into space. However, commercial versions of a human-rated RLV are many years in the future.

payloads the cargo carried into orbit by a space vehicle, usually a scientific experiment, satellite, or space station module

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused



One area of growth potential in space commercialization is remote sensing—taking digital pictures of Earth from satellites. This orbital image is of Gezira Scheme in Sudan, Africa, one of the world's largest irrigation systems.

Finally, the International Space Station (ISS) is being built and assembled in space. The ISS is the result of an international partnership between governments, which is promoting a wide variety of commercial opportunities. Companies are being encouraged to perform research and development onboard the ISS. There are proposals to have private firms provide power and other "utilities" for the ISS. One company is building a module that would attach to the ISS. This module could be a broadcast facility, feeding news, entertainment, and educational markets with pictures and happenings from space. There will also be a market for boosting cargo and human beings to and from the ISS, perhaps creating modest business opportunities.

The Value of Technology Spinoffs from Space

When technologies developed for the space program are used for other purposes, they are termed "spinoffs." Since the beginning of the space program, the cutting-edge research and development required for the unique environment of space has generated inventions and innovations. Many of the

The Covie, a compact electric concept vehicle, comes with a Global Positioning Satellite receiver linked to electronic machines at home, allowing the driver to remotely control and monitor home appliances.

technologies have their largest applications within the aerospace industry, but many also find their way into industrial applications and retail stores.

Examples of space spinoffs fall into several categories. First are the new products and services that consumers can purchase. Beyond satellite-based voice, television, and paging communication services, there are many other spinoff products. Materials such as lightweight **carbon-fiber composites** used in tennis racquets, boats, and other products were developed for the doors of the space shuttle. Insulating fabrics and thermal protection equipment used in space suits and onboard space equipment are now available for household uses as well as for firefighters and industrial safety equipment.

carbon-fiber composites combinations of carbon fibers with other materials such as resins or ceramics; carbon fiber composites are strong and lightweight

Second, the need for precision instruments to remotely monitor astronauts' health and to conduct other space activities has generated a vast new array of scientific and medical applications that permit better research and more accurate and less invasive medical procedures.

Many less obvious procedures and equipment developed for space have resulted in manufacturing improvements. For example, advanced clean room procedures needed for assembling satellites have been used to manufacture high-technology electronics. Research into new lubrication techniques has made industrial equipment last longer. Cheaper and more efficient water purification devices aid people in remote areas.

It is difficult to precisely measure the economic impact of space spinoffs. However, various studies clearly illustrate that the income and jobs created from these space technologies have contributed greatly to the long-run productivity of the economy and to improving the quality of everyday life. SEE ALSO International Space Station (volumes 1 and 3); Made with Space Technology (volume 1); Space Shuttle, Private Operations (volume 1).

Henry R. Hertzfeld

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Communications Satellite Industry

The beginning of the satellite communications era began with the publication of a paper written by Arthur C. Clarke in 1945. The paper described human-tended space stations designed to facilitate communications links for points on Earth. The key to this concept was the placement of space stations in **geosynchronous Earth orbit** (GEO), a location 35,786 kilometers (22,300 miles) above Earth. Objects in this orbit will revolve about Earth along its equatorial plane at the same rate as the planet rotates. Thus, a satellite or space station in GEO will seem fixed in the sky and will be directly above an observer at the equator. A communications satellite in GEO can "see" about one-third of Earth's surface, so to make global communications possible, three satellites need to be placed in this unique orbit.

geosynchronous Earth orbit orbit of a satellite that revolves around the Earth without changing its position in the sky relative to the planet

Clarke envisioned a space station, rather than a satellite, as a communications outpost because he felt that astronauts would be needed to change vacuum tubes for the receivers and transmitters. However, the concept became extraordinarily complex and expensive when life support, food, and living quarters were factored in. For this reason, and because telephone and television services were perceived as adequate, Clarke's idea was not given much attention. In 1948 the vacuum tube was replaced by longer-lived solid-state transistors, marking the dawn of microelectronics. Humans, it seemed, might not be required to tend space-based communications systems after all. Nonetheless, questions remained: Would there be a demand for communications satellites, and, if so, how would they be placed in orbit?

During the mid-twentieth century, people were generally satisfied with telephone and television service, both of which were transmitted by way of cable and radio towers. However, telephone service overseas was exceptionally bad, and live television could not be received or transmitted over great distances. Properly positioned satellites could provide unobstructed communications for nearly all points on Earth as long as there was a method to put them in orbit.

Shortly after World War II, the United States acquired the expertise of German rocket engineers through a secret mission called Operation Paperclip. The German rocket program, which produced the world's first true

A Juno I rocket is launched from Cape Canaveral, Florida, carrying Explorer I, the first American artificial satellite, into orbit in 1958.

✶ **In 1944 and 1945, the Nazis launched V-2 ballistic missiles toward England, but the assault came too late to turn the war in Germany's favor.**

rocket, the V-2,✶ was highly valuable to the United States. These engineers were sent to New Mexico to work for the army using hundreds of acquired V-2 missiles. Within a decade, the German engineers produced powerful missiles called Jupiter, Juno, and Redstone. At the same time, the U.S Air Force was interested in fielding intercontinental ballistic missiles (ICBMs) and was separately developing the Atlas, Thor, and Titan rockets to meet this mission. The navy also had a rocket program and was working on a medium-range missile called Vanguard.

On October 4, 1957, the Soviet Union launched Sputnik I, a satellite whose purpose was to demonstrate Soviet technology. Americans were alarmed and demanded that the government establish a space program to regain prestige. President Dwight Eisenhower, they felt, did not do enough to prevent the United States from lagging behind the Soviets technologically. In truth, Eisenhower had directed the navy to launch a satellite on Vanguard, but the rocket was encountering setbacks. The mission to launch the first American satellite fell to the army, whose Juno instrument was doing remarkably well. The satellite Explorer 1 finally went up on January 31, 1958. Launching satellites was possible, and communications satellite concepts were now seriously being considered.

The First Communications Satellites

On December 18, 1958, the military's Satellite Communications Repeater (SCORE) was launched into **low Earth orbit** (LEO) by a U.S. Air Force Atlas. SCORE was designed to receive a transmission, record it on tape, and then relay the transmission to another point on Earth within hours. President Eisenhower used the opportunity to demonstrate American technology by transmitting a recorded Christmas greeting to the world, the first time in history a satellite was used for communications.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Recognizing the potential of satellite communications, John Pierce, director of AT&T's Bell Telephone Laboratories, developed projects designed to test various communications satellite concepts. The National Aeronautics and Space Administration (NASA), only two years old, planned to send an inflatable sphere into space for scientific research. Pierce wanted to use the opportunity to reflect signals off the balloon's metallic surface. On August 12, 1960, the sphere, called Echo 1, was successfully launched, and Pierce was encouraged by the reflective signal tests. Because Echo 1 had no electronic hardware, the satellite was described as passive. For communications to be effective, Pierce felt that active satellites were required.

Meanwhile, the military was continuing with the tape-recorded communications concept, developing new satellites called Courier. The first one was destroyed when the rocket exploded. Courier 2 was successfully launched on October 4, 1960, but failed after seventeen days of operation. During this time, significant military resources were being allocated to Atlas, Titan, and intelligence satellites, which took priority.

Two years after the Echo 1 experiments, Bell Laboratories created Telstar, an active communications satellite designed to operate in medium Earth orbit (MEO), about 5,000 kilometers (3,107 miles) above Earth's surface. During this time, NASA selected a satellite design from RCA called Relay to test MEO communications but agreed to launch Telstar as soon as it was ready. Telstar 1 was launched on July 10, 1962, and Relay 1 was sent up on December 13 of the same year. Both were successful, and despite Relay 1's greater sophistication, people remembered Telstar's live television broadcasts from the United States to locations in Europe.

Advantages and Disadvantages. Soon the advantages and disadvantages regarding LEO and MEO communications satellites were being studied. One problem with communications satellites in orbits lower than geosynchronous is the number of satellites required to sustain uninterrupted transmissions. Whereas a single GEO satellite can cover 34 percent of Earth's surface, individual LEO and MEO satellites cover only between 2 and 20 percent. This means that a fleet of satellites, called a "constellation," is required for a communications network.

The major advantage in using LEO and MEO communications satellites is a minimization of latency, or the time delay between a transmitted signal and a response, often called the "echo effect." Even though transmissions travel at the speed of light, a time delay of 0.24 seconds for a round-trip signal through a GEO satellite can make phone calls problematic. Despite this drawback, sending three communications satellites to GEO would save money, and people would not need to wait years for an LEO or MEO constellation to be complete.

Comsat

✶ On April 12, 1961, Soviet cosmonaut Yuri Gagarin became the first human in space, making a one-orbit, ninety-minute flight around Earth.

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

Shortly after the Soviet Union launched the first human into space,✶ President John Kennedy wanted a national plan for space exploration and settled on a series of programs that included the famous **Apollo** missions to the Moon. Less familiar but perhaps more significant for the long term, Congress, with the support of President Kennedy, authorized the establishment of an organization designed to integrate the nation's space-based communications network.

Formed in February 1963 by the Communications Satellite Act of 1962, the Communications Satellite Corporation, or Comsat, was given the task of creating a national communications satellite system in the earliest possible time. Half of Comsat would be publicly traded, and the other half would be purchased by satellite manufacturers. Comsat's first major hurdle was deciding what kind of satellite system it would pursue: LEO, MEO, or GEO. Because Telstar and Relay were successful, these MEO systems seemed the default choice. For uninterrupted communications service, however, about twenty satellites such as Telstar or Relay were needed, costing an estimated $200 million. The president of Comsat, Joseph Charyk, a veteran of satellite engineering programs, was not sure that this was the right way to proceed.

Meanwhile, Hughes Aircraft Company was developing the Syncom series of satellites, each designed to test communications technologies in GEO. The first two satellites were not entirely successful, but Syncom 3, launched on August 19, 1964, achieved a stationary GEO. Charyk was aware of the Syncom project early on and followed its progress closely. Comsat was beginning to realize that a GEO communications satellite network was the

President Kennedy speaks at Rice University, Texas, on September 12, 1962 on the space effort: "We choose to go to the moon. We choose to go to the moon in this decade and do other things, not because they are easy, but because they are hard. . ."

most practical in terms of cost. Nevertheless, Comsat asked a variety of companies to study the feasibility of LEO communications constellations in the event that a GEO system was unsuccessful. AT&T and RCA researched the merits of a random system, in which satellites drifted freely without any particular relationship to one another. STL and ITT studied the phased approach, where strings of satellites orbiting at LEO were spaced in such a way to allow for continuous, uninterrupted communications. Comsat finally decided on a GEO system, and on April 6, 1965, it launched Early Bird. This satellite also became a test bed for the latency problem, and methods to suppress the echo effect were successfully employed.

Bandwidth Capacity

During this time, NASA continued to fund research in communications satellite technology, contributing to programs such as Applications Technology Satellites (ATS). Six ATS units were developed and launched, and each was designed to test various technologies related to bandwidth capacity and new components. Of particular importance was bandwidth capacity, the range of **frequencies** used in a satellite.

Satellite communications providers were particularly interested in boosting the capacity of transponders used for telephone conversations and television broadcasts. A telephone call, for example, uses about 5 kilohertz of bandwidth. A satellite with 50 kilohertz of bandwidth can handle ten calls simultaneously. Early satellites could only handle about thirty calls at one time and were easily overwhelmed. Research continued to improve the capacity problems, and digital technologies have significantly increased the number of simultaneous calls. Satellite engineers also designed antennas that did not interfere with systems orbiting nearby and recommended adequate separation between satellites to prevent signals from interfering.

Becoming Global

After the establishment of Comsat, efforts were under way to approach the international community about setting up a global communications satellite network. Comsat dispatched several key people, along with U.S. State Department officials, to a dozen nations interested in the communications satellite market. In 1964, Intelsat was formed, and it started operations using part of the new Early Bird satellite launched in 1965. Comprised originally of twelve members, Intelsat is an organization that owns and operates global communications networks providing voice, video, and data services. Intelsat collects investment capital from its members and makes a profit from the sale or lease of satellite services. In 2000, Intelsat had 143 member countries and signatories, with Comsat still representing the United States.

Other international communications satellite organizations have since formed, such as Eutelsat, a cooperative formed in 1977 providing regional communications services for Europe. France, England, and Germany established the European Space Research Organization (ESRO) and the European Launch Development Organization (ELDO) shortly after the launch of an experimental communications satellite called Symphonie in 1967. ESRO was responsible for research, development, construction, and operation of **payloads** and ELDO handled launch activities. Because of management and

WHAT IS BANDWIDTH?

Bandwidth capacity refers to the range of frequencies. All frequencies are classified according to the electromagnetic spectrum and are measured in hertz (Hz). At one end, where frequencies are low, the spectrum includes radio and microwaves. In the middle, the spectrum is characterized by infrared radiation (IR), visible light, and ultraviolet (UV) radiation. High-frequency energy, such as X rays, gamma rays, and cosmic rays, occupies the other end of the spectrum. Within the radio spectrum, which is divided into eight segments ranging from extremely high frequency (EHF) to very low frequency (VLF), lies the communications spectrum.

This spectrum, which is important to communications satellites, is divided into ten parts. These are—from the highest frequency to the lowest—millimeter (in the EHF range), W, V, Ka, K, Ku, X, C, S, and L (in the ultra-high-frequency, or UHF, range). A typical communications satellite in orbit today will have a series of bandwidth-specific transmitter-receiver units, called transponders, classified as C-band or Ku-band.

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

system integration concerns, ESRO and ELDO merged to form the European Space Agency in 1974. Three years later, the Conference of European Posts and Telecommunications (CEPT) approved the formation of Eutelsat, which by 2000 had nearly fifty members.

Comsat was also asked to assist in the development of a regional communications satellite organization for southwestern Asia, northern Africa, and areas of southern Asia. Comsat agreed and was contracted to develop and build what later became known as Arabsat. Inmarsat, founded in 1982, is another international organization providing global communications services to seagoing vessels and oil platforms.

The Soviet Union, recognizing the benefits of a global communications satellite network, was not interested in a GEO system because of the country's northern location. A GEO system comprised of three satellites would miss parts of the Soviet Union. The Soviets developed an ingenious solution by launching communications satellites into highly **elliptical** orbits. The orbit consisted of a very close and fast approach over the Southern Hemisphere while tracing a slow and lengthy arc over the Soviet mainland. In 1965 the Soviet Union launched its first communications satellite as part of an ongoing system called Molniya, a name also assigned to the unusual orbit it occupies.

elliptical having an oval shape

The Soviet Union, despite being approached by representatives of Comsat and the State Department to join Intelsat, declined membership and initiated a regional network in 1971 called Intersputnik. Intersputnik was successful during the following decades with its Gorizont, Express, and Gals satellites but experienced funding difficulties after the collapse of the Soviet Union in 1991. In the 1990s, however, Intersputnik was revitalized with a membership of twenty-three nations and the recent introduction of a new series of satellites, the Express-A.

Back to LEO?

In the early 1990s, LEO communications satellite constellations were revisited. Microelectronics was allowing for smaller satellites with greater capacities, and the launch industry was stronger than it was thirty years earlier. Two companies that pursued this concept were Iridium and Teledesic.

Iridium's plan was to loft about 100 satellites into several LEOs to provide uninterrupted cell phone and pager services anywhere on Earth. Iridium became the first company to provide these services on November 1, 1998. Sixty-six Iridium satellites, all built by Motorola, were launched in the late 1990s. Unfortunately, Iridium filed for bankruptcy in 1999. ✶

✶ **In 2000 Iridium Satellite LLC purchased the Iridium satellite system and began selling satellite phone service at much lower prices than its predecessor, Iridium.**

Despite the anticipated effect of Iridium's 1999 bankruptcy on the market, Teledesic, a company planning to provide computer networking, wireless Internet access, interactive media, and voice and video services, will use LEO satellites developed and built by Motorola. Founded by Craig McCaw and Microsoft founder Bill Gates with $9 billion in 1990, Teledesic also experienced financial troubles but by 2000 was prepared to tap into part of the market originally pursued by Iridium. With Lockheed Martin contracted to provide launch services for all 288 satellites plus spares, Teledesic plans to be operational in 2005.

By 1998 satellite communications services included telephone, television, radio, and data processing, and totaled about $65.9 billion in revenues, or almost 7 percent of the total telecommunications industry. During that year, about 215 communications satellites were in GEO and 187 in LEO. SEE ALSO CLARKE, ARTHUR C. (VOLUME 1); COMMUNICATIONS, FUTURE NEEDS IN (VOLUME 4); GROUND INFRASTRUCTURE (VOLUME 1); SATELLITE INDUSTRY (VOLUME 1).

Phil Smith

A refugee from Kosovo uses an Iridium satellite phone to contact loved ones while in a refugee camp outside of Tetovo, Macedonia. The satellite communications company donated phones for the refugees' use.

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Crippen, Robert

American Astronaut
1937–

Robert Crippen has been a major contributor to America's space exploration efforts. From making the first historic flight of the space shuttle, to directing the Kennedy Space Center, to exploring opportunities in the private sector, Crippen has provided experience and leadership for both piloted and unpiloted spaceflight.

Crippen was born in Beaumont, Texas, on September 11, 1937. He graduated from New Caney High School in Caney, Texas, and received a bachelor of science degree in aerospace engineering from the University of Texas in 1960.

Crippen received his commission through the U.S. Navy's Aviation Officer Program at Pensacola, Florida. He continued his flight training at Whiting Field, Florida, and went from there to Chase Field in Beeville, Texas, where he received his "wings," becoming a qualified pilot. From June 1962 to November 1964, he was assigned to Fleet Squadron VA-72, where he completed two and a half years of duty as an attack pilot aboard the aircraft carrier USS Independence. He later attended the U.S. Air Force (USAF) Aerospace Research Pilot School at Edwards Air Force Base, California, and remained there as an instructor after his graduation. In October 1966,

Robert Crippen on April 29, 1979, in a photo taken prior to his first spaceflight in 1981.

Crippen was among the second group of aerospace research pilots to be selected to the USAF Manned Orbiting Laboratory Program.

Crippen joined the National Aeronautics and Space Administration (NASA) as an astronaut in September 1969 following the cancellation of the Manned Orbiting Laboratory program. He was a crewmember of the Skylab Medical Experiments Altitude Test, a fifty-six-day simulation of the Skylab mission. He was also a member of the astronaut support crew for the Skylab 2, 3, and 4 missions and the Apollo-Soyuz Test Project mission. Crippen's first spaceflight was in 1981, as pilot of STS-1, the first space shuttle mission. In 1983 Crippen was spacecraft commander of STS-7. He completed two more space shuttle flights as commander in 1984.

In 1987 Crippen was stationed at NASA's John F. Kennedy Space Center (KSC) serving as the deputy director of shuttle operations for NASA Headquarters. He was responsible for final shuttle preparation, mission execution, and the return of the **orbiter** to KSC following landings at Edwards Air Force Base. From 1990 to 1992, he was responsible for the overall shuttle program at NASA Headquarters in Washington, D.C. From 1992 to 1995, during his tenure as director of KSC, Crippen presided over the launch and recovery of twenty-two space shuttle missions, establishing and developing new quality management techniques while ensuring the highest safety standards in an extremely hazardous environment.

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

Crippen left NASA in 1995 and joined the Lockheed Martin Information Systems Company as their vice president of automation systems. The following year he became their vice president of simulation and training systems. In October of that year he was named to the newly created position of president of the Thiokol Aerospace Group.

Crippen's accomplishments have earned him many awards. Among them are the NASA Exceptional Service Medal, the Department of Defense Distinguished Service Award, the American Astronautical Society of Flight Achievement Award, and four NASA Space Flight Medals. SEE ALSO History of Humans in Space (Volume 3); Skylab (Volume 3); Space Shuttle (Volume 3).

Vickie Elaine Caffey

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D

Data Purchase

Congressional funding for space science has been steady at a few billion dollars per year, so there is a known, existing market. Until the early 1990s, each deep-space mission cost taxpayers about $2.5 billion. Since the National Aeronautics and Space Administration (NASA) introduced the concept of "faster, better, cheaper," the cost of deep-space missions has dropped to $250 million and less. The Near Earth Asteroid Rendezvous (NEAR) and the Lunar Prospector missions had full lifecycle costs of about $250 million and $100 million, respectively. Both had five science experiments, so the average taxpayer cost of the new knowledge per mission was about $50 million for each data set for NEAR and about $20 million each for Lunar Prospector.

Beginning in 1997, commercial space companies such as SpaceDev have offered to collect desired space science data at their own corporate risk and to sell it to NASA, which is the agency responsible for collecting scientific data in space. NASA's Lunar Prospector had instruments orbiting the Moon looking for evidence of water, and NEAR had five science experiments examining the properties of the visited asteroid. SpaceDev proposed to collect similar science data for sale to NASA at prices far below NASA's costs.

Even though commercial companies build most of the components and subsystems that make up a deep-space spacecraft, no commercial mission beyond Earth **orbit** has ever been performed. This is mainly because NASA allocates money to its own deep-space missions. NASA managers fear their budgets will be cut if missions fail, so managers are very conservative in their mission and spacecraft designs, and they try to control all mission decisions. This results in more expensive spacecraft and missions because the components are generally older, heavier, and more expensive and require more power. This equipment is specified because it has flown before, and therefore has "heritage," and managers believe they cannot be punished if they use this "proven" hardware.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Commercial companies have to make profits if they are to perform space missions. Companies wishing to fly commercial missions use modern business practices and smaller, less expensive hardware to reduce costs below NASA's. These practices cause government managers to fear increased risk from commercial missions. If companies insure their missions, however, the government should consider the taxpayer risk eliminated, and the cost savings could then be achieved. An additional problem in performing commercial deep-space missions is that some NASA employees are afraid the private sector will take over all such missions in the future, reducing the need for NASA employees.

If companies do not make a profit, they cannot raise money because investors expect to make a competitive return on their investment that is equal to or better than other investment opportunities at that time. If the two main sources of revenue are science and entertainment data, then a commercial space mission must focus on these areas. To get NASA to purchase space science data, a company must first know exactly what data are important to NASA, as determined by committees of scientists that advise NASA. Unfortunately, these committees do not publish a list of desired space science ranked by importance. This, however, is set to change with the establishment of science-driven exploration priorities starting in 2002.

NASA has no contracting mechanism set up through which it can purchase space science data, so commercial companies have to navigate a very time-consuming (i.e., years-long) process of submitting proposals when NASA is ready. NASA proposal reviewers do not approve data purchases unless they are completely convinced a mission will fly, even though there is no risk in such cases because the data do not have to be paid for until they are delivered. The Catch-22 problem with this reasoning is that it is impossible for a commercial company to raise tens of millions of dollars to fully fund a mission unless the investors are convinced the mission will sell its data at a profit. This has resulted in a stalemate, and no commercial deep-space missions have been flown, even though such endeavors could be a clear win-win situation for taxpayers, scientists, and the commercial companies. SEE ALSO NASA (VOLUME 3); PLANETARY EXPLORATION (VOLUME 1); PLANETARY EXPLORATION, FUTURE OF (VOLUME 2).

James W. Benson

Internet Resources

SpaceDev: The World's First Commercial Space Exploration and Development Company. <http://www.spacedev.com>.

E

Education

In the 1960s many young people in the United States were inspired to pursue aerospace-related careers because of the U.S. commitment to send humans to the Moon. Universities saw an influx of enthusiastic students ready to take on the challenges of the Apollo program. Six Apollo Moon landings brought twelve astronauts to explore the lunar surface. But Moonwalkers are prehistory to students in the twenty-first century. Consequently, universities today put forth the challenge of a human mission to Mars to attract students.

Rapid advances in technology and computers have influenced more students to pursue courses of study in the sciences and space-related engineering and technology programs. Many computer experts who lost their jobs in the crash of the "dot-com" industry subsequently explored the field of aerospace engineering. Even if students do not decide on a space-related career, an aerospace engineering degree provides them with a wide variety of employment choices.

What are these students looking for in a college or university? They not only want a good selection of courses in the fields of their interests, but students also want exposure to innovative research in the field. Colleges and universities are addressing these needs largely by building valuable relationships with space-related organizations, aerospace companies, government agencies like the National Aeronautics and Space Administration (NASA), and other colleges and universities. Internships are frequently beneficial experiences for students, and often lead to employment opportunities at the sponsoring facility.

How Universities Attract New Students to Space Sciences

The public affairs departments at some universities have realized the potential of promoting their students' and professors' accomplishments. A good example of this is the University of Arizona in Tucson, which sends out weekly press releases about discoveries made by faculty and student astronomers using their Kitt Peak Observatories and astronomical spacecraft.

A university whose graduates become astronauts or known in a field of space science or aerospace engineering is also a pull for students. This is

The Discovery Laboratory at NASA's Marshall Space Flight Center provides hands-on educational workshops for teachers and students.

not only true for the University of Arizona at Tucson, but also the Massachusetts Institute of Technology, the California Institute of Technology, and Purdue University, among others.

One of the opportunities Purdue University affords both its graduate and undergraduate students is the chance to be a part of a tight-knit academic community with top professors in the aerospace field. This personal attention makes their program a popular one with students. Purdue claims to have produced more astronauts than any other university.

A New Array of Space Courses

Many colleges and universities have expanded their degree programs and course offerings in the fields of space sciences, astronomy, and Earth sciences to attract more students, as well as professors and research grants. The future holds a vast array of space-related careers. For example, space tourism in the decades to come will require a wide range of careers, and students at Rochester Institute of Technology are getting ready. In the departments of hotel management, food management, and travel programs, students are enrolled in what is likely the world's first college course on space tourism.

Promoting Space in Universities

National Space Grant Consortium. One of the most effective programs for bringing more space research and related projects, as well as funding, to universities is NASA's National Space Grant College and Fellowship Program. This program funds space research, education, and public service projects through a network of consortia in each of the fifty states, Puerto Rico, and the District of Columbia.

Each state's space grant consortium provides the students with information about local aerospace research and financial assistance. They also develop space education projects in their states. Some space grant projects, such as the one at the University of Colorado in Boulder (CU Boulder), involve students in current space missions. Students at CU Boulder are monitoring a spacecraft from their own mission control room on campus. At the Colorado School of Mines, students can enroll in courses on space resources and work with former and current NASA experts.

Universities Space Research Association. The Universities Space Research Association (USRA) is a private nonprofit corporation formed under the auspices of the National Academy of Sciences. All member institutions have graduate programs in space sciences or aerospace engineering. Besides eighty-two member institutions in the United States, there are two member institutions in Canada, two in England, and two in Israel.

USRA provides a mechanism through which universities can cooperate effectively with one another, with the government, and with other organizations to further space science and technology and to promote education in these areas. A unique feature of USRA is its system of science councils, which are standing panels of scientific experts who provide program guidance in specific areas of research. Most of USRA's activities are funded by grants and contracts from NASA.

Universities Worldwide

The International Space University (ISU), through both its summer courses and its permanent campus in France, has made major contributions to establishing new curricula. It draws the top students worldwide, because their professors are leading figures from space-related industries, government and international organizations, and universities around the world. ISU students come to the university with their specialist backgrounds and broaden their perspectives through increased knowledge in other relevant fields. Another example of international efforts to attract students is found at Saint Louis University at its Madrid campus in Spain, whose aerospace program has drawn students from abroad to study in St. Louis, Missouri.

Student Space Competitions

Universities are also involved in efforts to reach out to younger students and expose them to space sciences. Space-related projects and competitions for kindergarten through twelfth-grade students sponsored by a university member of the National Space Grant—or in collaboration with other organizations such as the National Space Society, the Challenger Center for Space Science Education, the Space Foundation and the Planetary Society—can make an impression on students that will influence their career decisions much later.

The experience of being involved in science fair projects also provides students with a sense of ownership and interest that lasts throughout their careers. Many university scientists and engineers, as well as experts from aerospace companies, are involved in helping and judging science fairs.

Through space-related professional organizations like the American Institute of Aeronautics and Astronautics, the aerospace division of American Society of Civil Engineers, and the Institute of Electrical and Electronics Engineers, universities are providing opportunities for students to submit papers and projects to be judged by experts in the field. These competitions, which are held at the organizations' conferences, provide an avenue for building relationships with aerospace professionals, as well as other students. These relationships can form an essential network of colleagues as students launch into their careers.

NASA and other organizations sponsor an array of design projects for students of all ages. Projects can include flying their experiment on a KC-135 airplane that provides 25 seconds of **microgravity** at a time. Other competitions involve designing space settlements and Moon and Mars bases.

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

NASA's Commercial Space Centers

NASA's commercial space centers are a consortia of academia, government, and industry who partner to develop new or improved products and services, usually through collaborative research conducted in space. The NASA Space Product Development office manages 11 of the 17 centers that perform research in the areas of biotechnology, agribusiness, structure-based drug design, and materials research. Topics of interest at the centers include space power, satellite communication networks, **remote sensing**, mapping, microgravity materials processing, medical and biological research and development, **crystallography**, space automation and robotics, engineering, space technology, and combustion in space. SEE ALSO Career Astronauts (volume 1); Careers in Astronomy (volume 2); Careers in Business and Program Management (volume 1); Careers in Rocketry (volume 1); Careers in Space (volume 4); Careers in Space Law (volume 1); Careers in Space Medicine (volume 1); Careers in Space Science (volume 2); Careers in Spaceflight (volume 3); Careers in Writing, Photography, and Filmmaking (volume 1); International Space University (volume 1).

remote sensing the act of observing from orbit what may be seen or sensed below Earth

crystallography the study of the internal structure of crystals

Barbara Sprungman

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Universities Space Research Association. <http://www.usra.edu>

ELV ***See Launch Vehicles, Expendable (Volume 1).***

Energy from Space

base load the minimum amount of energy needed for a power grid

Forecasts indicate that worldwide demand for new **base-load** electrical power generation capacity will continue to grow throughout the twenty-first century. However, evidence is mounting to show that the use of fossil fuels—coal, oil, and natural gas—and the resulting increase in greenhouse gas emissions may be leading to measurable global climate change. New energy technologies are needed to offset the future growth in fossil fuel use.

One concept that would provide power on a significant scale for global markets is energy from space. Earth is about 150 million kilometers (93 million miles) from the Sun. Sunlight constantly delivers 1,358 watts of energy per square meter of area to the part of Earth facing the Sun. However, by the time the sunlight reaches the surface of Earth, atmospheric filtering has removed about 30 percent of the initial energy even on a clear day. Moreover, the effects of the seasons and the day-night cycle further reduce the average energy received by an additional 90 percent. Often, the remaining 100 to 200 watts per square meter can be blocked completely by weather for days at a time.

A solar power satellite, by contrast, could collect sunlight in space and convert the energy into electrical current to drive a wireless power transmission system, which would in turn beam the power down to receiving antennas on Earth. Earth-bound receiving antennas could capture the transmitted energy—almost twenty-four hours a day, seven days a week—and deliver it to local electrical grids as base-load power. This approach could eliminate the need for extremely large **solar arrays** on the ground and dramatically expensive energy storage systems, but would require a number of new technological advances.

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

multi-bandgap photovoltaic cells photovoltaic cells designed to respond to several different wavelengths of electromagnetic radiation

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

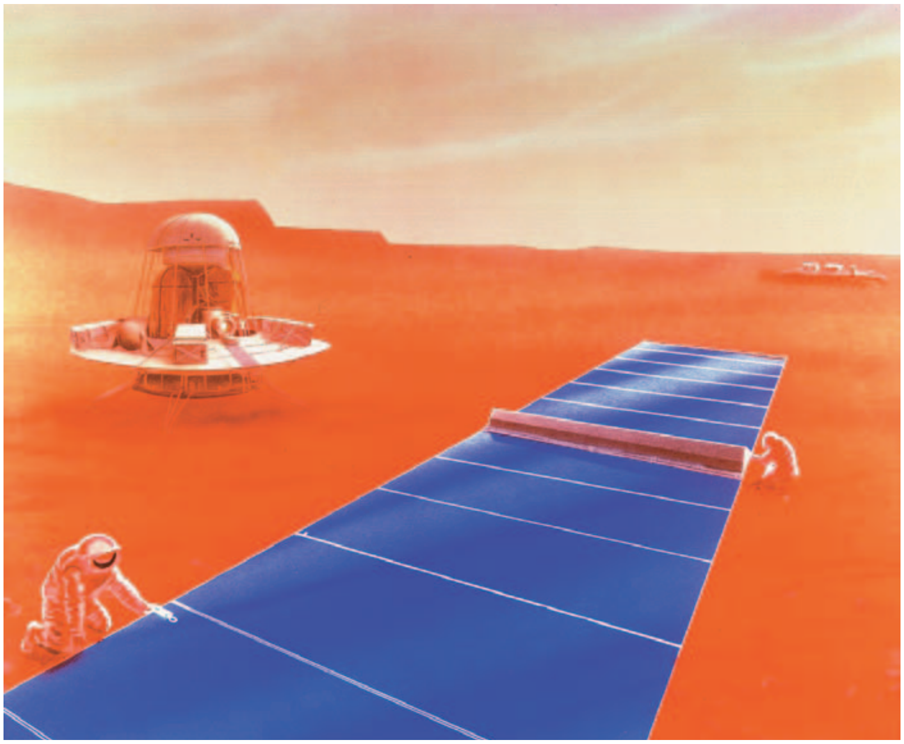
high-power klystron tube a type of electron tube used to generate high frequency electromagnetic waves

phased array a radar antenna design that allows rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

Details of the Concept of Energy from Space

Power Generation in Space. Typically, photovoltaic arrays are used to generate power in space. These are solid-state devices that exploit the characteristic of semiconductors such as silicon to allow incoming photons to readily dislodge electrons, a process that creates voltage. Key measures of the effectiveness of these technologies are the specific power (e.g., watts produced per kilogram of solar array mass) and the efficiency (e.g., watts produced per square meter of solar array area). By the early twenty-first century, space solar power technology research programs were using concentrating lenses and **multi-bandgap photovoltaic cells** to achieve specific power levels approaching 200 watts per kilogram and efficiencies of almost 30 percent. These figures represent advances of more than a factor of three over the state-of-the-art technology of the late 1990s.

Wireless Power Transmission. Power can be transmitted using either radio **frequencies** or visible light. In the case of radio frequencies, a wide range of devices could be used to generate the power beam, including **high-power klystron tubes**, low-power solid-state devices, and magnetrons, which are a type of vacuum tube providing in-between levels of power (and are also used in household microwave ovens). In all of these cases, a number of the devices would be arranged and operated in a lockstep **phased array** to create a coherent, collimated (parallel) beam of energy that would be transmitted from space to the ground. The efficiency of the transmitter



Energy collection in space from other planets or satellites could revolutionize the method of power delivery on Earth.

can be as high as 80 percent or more. On the ground, a radio frequency power beam would be converted back to voltage by a rectifying antenna (also known as a "rectenna") operating at about 80 percent efficiency. Taking into account losses of the collimated beam at the edges of the rectenna and small levels of interference from the atmosphere, a power beam might generate about 100 watts per square meter on the ground on average.

The Challenge of Large Systems in Space. A central challenge of space solar power is that of launching and building these exceptionally large systems in space. As of the early twenty-first century, the cost of space transportation ranged from $5,000 to $22,000 per kilogram of **payload**, launched to Earth orbit. In order to be economically viable, space solar power systems must be launched at costs of no more than $400 per kilogram. Such a dramatic improvement requires the development of a range of new technologies and new types of space transportation systems.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Base-load Solar Power Systems: Ground and Space. The projected costs of base-load solar power using ground-based solar arrays are clearly dominated by the cost of the energy storage system needed to allow energy received during a clear day to be delivered to customers at night—or during several consecutive days of cloudy weather. These costs can be greater than $15,000 per kilowatt-hour of energy stored. In other words, to power a house using 2 kilowatts of power over five days of cloudy weather would require about $4 million to build the energy storage system alone. Conversely, the installation cost for a space-based solar power system (providing power for hundreds of thousands of homes) might be expected to range between $100,000 and $300,000 per home, for a comparable power-using home. This is still much greater than the cost of installing new fossil-fuel power-generating capacity, but the cost of a space-based solar power system could be as little as 1 percent of the cost of a comparable ground-based system.

History and Future Directions

In the 1970s the U.S. Department of Energy and the National Aeronautics and Space Administration (NASA) extensively examined large solar power satellite systems that might provide base-load power into terrestrial markets. From 1995 to 1997 and in 1998, NASA reexamined space solar power (SSP), with both encouraging technical results and cautionary findings concerning the economics of introducing the technology during the first two decades of the twenty-first century. As a result, from 1999 to 2000, NASA conducted the SSP Exploratory Research and Technology program, which refined and modeled SSP systems concepts, conducted research and development to yield "proof-of-concept" validation of key technological concepts, and laid the foundation for the creation of partnerships, both national and international. A number of innovative concepts and technology advances have resulted from these efforts, including a new solar power satellite concept, the Integrated Symmetrical Concentrator, and new technologies such as lightweight, high-efficiency photovoltaic arrays, inflatable heat radiators, and new robots for space assembly. Future technology efforts will focus on providing the basis for better-informed decisions regarding solar energy in space and related research and development. SEE ALSO Power, Methods of Generating (volume 4); Solar Power Systems (volume 4).

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Entertainment

Outer space is big business for the entertainment world. The earliest record of a work of science fiction, written to fuel the imagination and entertain the public, was the Greek satirist Lucian's *Vera historia* (True history), penned around C.E. 170. In Lucian's tale, a sailing vessel is caught up by a whirlwind and after a journey of eight days arrives at the Moon. Lucian's description of this imaginary lunar voyage set the scene for many stories, films, and even computer games that have followed.

Science fiction novels sell in phenomenal numbers, appealing to the reader's wish to escape the everyday and stimulating the imagination with the possibilities of tomorrow. Many novelists such as Ben Bova and Neil Ruzic have made careers in science fiction writing. Others, such as James Michener (author of *Space*), Isaac Asimov, and Arthur C. Clarke have been lured by the theme of space, as one compass of a much broader writing career. Science fiction conventions celebrate this genre and allow fans an op-

Hollywood's depictions of alien life forms have ranged from the gentle extraterrestrial E.T. to the terrifying alien of *Aliens* (pictured).

portunity to meet with famous authors, hear how they develop their themes related to the future of space exploration, and dissect the plots. These conventions are also major business enterprises.

In modern times the most notable entertainment of the first half of the twentieth century was Orson Welles's broadcast of *The War of the Worlds.* English novelist and historian H. G. Wells wrote this tale of a Martian invasion as a magazine serial in 1897, but Welles's eerie radio rendition of the tale in 1938 sent shock waves through the United States as listeners tuned in to what they thought was a serious report of alien invasion.

Television: From *Star Trek* to *Nova*

Some of the most successful and longest-running series on television have had themes of space exploration. *Star Trek*, the brainchild of the legendary Gene Roddenberry, through its various generational formats has made the careers of several actors and actresses and met with so much enthusiasm that it has spawned Star Trek conventions. The British invention, *Dr. Who*, also met with universal, long-term success and was assimilated as one of the "cult" shows of the twentieth century. *Babylon Five* also developed a very significant following, and the Jim Henson–backed series *Farscape*, featuring a lost astronaut thrown into the distant regions of space, is the Sci-fi channel's longest running original series.

Space themes are not confined to futuristic fictional series on television, although these are by far the best known and the greatest revenue generators. Aliens are a common theme both as a dramatic effect in a storyline and as the subject matter of serious newsmagazine programs about scientific exploration and **pseudoscience**. Educational programs about space exploration have great popular appeal and, by extension, attract significant advertising dollars to television stations. One of the great television successes of the 1990s was Tom Hanks's HBO series *From the Earth to the Moon*, the story of the Apollo missions that landed twelve humans on the Moon.

pseudoscience a system of theories that assumes the form of science but fails to give reproducible results under conditions of controlled experiments

In 2000 the Discovery Channel's in-depth study of the International Space Station represented a significant programming investment. Finally, news magazine programs such as *Nova* frequently return to stories of space exploration because the human fascination with the unknown and the "great beyond" of the universe draws a large audience.

Films: Special Effects and Special Stories

microgravity the condition experienced in free fall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Outer space can be daunting, fascinating, and mysterious—a gift to moviemakers. Facing the challenges of working in **microgravity** calls for fearless heroes and feats of courage. And re-creating outer space for the motion picture audience offers numerous possibilities for the special effects department.

People may snicker at the title of the 1956 film *Invasion of the Body Snatchers*, but this movie is an influential classic and still very scary. It tells the story of residents of a small town who are replaced by inert duplicates, which are hatched from alien "pods."

2001: A Space Odyssey, Stanley Kubrick's influential 1968 masterpiece (with the screenplay written by Arthur C. Clarke), opened the imagination to the possibility of other intelligent entities developing in time frames different from the evolution of humans on Earth, while also featuring alien encounters and a computer with an attitude called HAL. In *2001*, possibly the most influential space movie to date, Kubrick enticed the audience with the vastness and timelessness of space in comparison to the current human condition.

From the days of the earliest space-themed movies, directors have been awed by the subject matter and have worked studiously to be as authentic as possible in the representation of spaceflight and off-world locations. This is how space historian Fred Ordway and space artist Robert McCall (who painted the lunar mural in the National Air and Space Museum in Washington, D.C.) found themselves in London, consulting on the making of *2001*, and how countless astronauts have been called upon to advise actors on how to realistically simulate behavior in microgravity.

The 1977 blockbuster *Star Wars*, and the two subsequent episodes in the trilogy, *The Empire Strikes Back* (1980) and *Return of the Jedi* (1983), opened a new era in opening the imagination of moviegoers to space. In this series, and *Episode I: The Phantom Menace* (1999), legendary producer George Lucas introduced audiences to tales of life and conflict in a vast universe populated by creatures of mind-boggling diversity and cunning. ✶

✶ **In May 2002, *Episode 2: Attack of the Clones* was released.**

The 1977 film *Close Encounters of the Third Kind*, directed by Steven Spielberg, describes a first contact with alien beings. Impressive cinematography won an Oscar for Vilmos Zsigmond. Spielberg's *E.T. The Extra-Terrestrial*, released in 1982, cemented Spielberg's reputation as a director and won John Williams an Academy Award for his score, with additional Oscars going to the sound and visual effects teams. *E.T.* is a classic of the sympathetic alien genre of movies, which developed along with the growing understanding of the unique nature of human life in the solar system and with the increasing knowledge about the origins of life. Its enduring influence is demonstrated by its rerelease to the big screens in 2002.

The blockbuster of the 1990s was *Apollo 13*, based on the book *Lost Moon* by Apollo 13 commander Jim Lovell and Jeffrey Kluger. This exhilarating story of the ill-fated Apollo 13 Moon mission was directed by Ron Howard and starred Tom Hanks, Bill Paxton, Kevin Bacon, Gary Sinise, and Kathleen Quinlan. Sticking painstakingly close to the true story of Apollo 13, this 1995 movie told the tale of the human ingenuity, fast thinking, and enormous courage that brought the crew of Apollo 13 back from the Moon safely after a catastrophic explosion deprived them of the majority of their air supply. The film provided a marked contrast with the media headlines of failure (because the crew failed to land on the Moon) that had formed public opinion about the mission twenty-five years earlier.

In the late 1990s, as scientific understanding of asteroids grew as a result of better telescopes and the detailed images from robotic missions such as Galileo and the Near Earth Asteroid Rendezvous mission, a crop of movies about the threat of asteroid or comet collisions with Earth were released. Both *Deep Impact* and *Armageddon* did well at the box office and served to broaden the public debate on the threat of asteroid impacts.

Space Cowboys, released in 2000, reflected growing concern with the amount of space debris circling the planet and, on occasion, falling uncontrolled to Earth. And movies telling of the human exploration of Mars—one of the great space challenges for the human race in the twenty-first century—were on the rise.

It is impossible to discuss films about space without mentioning the large-scale IMAX films on a range of space topics that are screened at numerous science museums around the world. These films trace the history of the human exploration of space with awe-inspiring visual effects provided by Mother Nature.

Exhibits and Theme Parks

The best-known visitor attractions with space themes include the most visited museum in the world, the National Air and Space Museum in Washington, D.C.; the Epcot Center at Disney World in Orlando, Florida; and Tomorrowland in California. Space theme parks, which allow visitors to sample the technologies of the future or simulate a spaceship ride or a walk on the surface of the Moon or Mars, have been developed by visionaries who foresee hundreds of thousands of people routinely traveling in space in the future.

Video and Computer Games

Computers play a major role in simulating complex rendezvous, docking, and landing maneuvers for space missions. They also provide exciting games that test a player's skill in retrieving a satellite, docking or maneuvering a spacecraft in zero gravity, and much more. If the majority of people cannot experience space travel themselves, some of the computer games available are the next best thing. SEE ALSO Apollo (Volume 3); Careers in Writing, Photography, and Filmmaking (Volume 1); Clarke, Arthur C. (Volume 1); Impacts (Volume 4); *Star Trek* (Volume 4); *Star Wars* (Volume 4).

Pat Dasch

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Expendable Launch Vehicles

See Launch Vehicles, Expendable (Volume 1).

F

Financial Markets, Impacts on

The space industry is in the midst of a rapid evolution whose growth is being driven by mainstream commercial forces, with some Wall Street analysts projecting the market to grow to more than $150 billion in the next ten years.

If these analysts are correct, the fuel that will propel the commercial space industry to such heights is the venture capital—the "lifeblood" of every emerging industry—that individuals and institutions are willing to invest in a variety of endeavors. The financing of space projects, once thought by many observers as too risky, has been substantial. More than $100 billion is expected to flow into the space industry between 1995 and 2010.

Until the mid-1990s, most investment organizations were relatively unsophisticated about space projects. In the early twenty-first century, most investment organizations are willing to review business plans on the basis of business prospects and revenue forecasts. As space attracts greater amounts of venture capital, the field will act as a **catalyst** for economic expansion worldwide in a variety of ways.

catalyst a chemical compound that accelerates a chemical reaction without itself being used up; any process that acts to accelerate change in a system

For starters, commercial space is spawning a plethora of innovative start-up companies that think of space less as a scientific frontier than as a place to make money. Most of these fledgling businesses are not traded on any stock exchange. However, many plan to "go public," meaning that they intend to sell common shares to the public. That is how Microsoft, Biogen, and many other industry leaders began in the 1980s, when the biotechnology and information technology industries were still in their infancy. Like those industries, space will serve as an engine for job growth and wealth creation.

Satellites: A Driving Force

Of all the activities associated with commercial space, satellites are likely to drive the space industry's growth for the foreseeable future. Satellites have the advantage of speed, mobility, and costs, independent of their Earth orbit. A single satellite system can reach every potential user across an entire continent. For many applications, satellite technology provides the most cost-effective way of providing service over a wide area. As a result, satellites will be instrumental in helping to raise the standard of living in many underdeveloped countries where there is little or no **communications infrastructure**. In that role, the economic impact of commercial space may be incalculable.

communications infrastructure the physical structures that support a network of telephone, Internet, mobile phones, and other communicaton systems

Satellites provide a broad menu of services. These range from mobile telephony to direct-to-home broadcast of television, cable, and video pro-

Satellites are likely the force that will drive the space industry, as they have advantages that are independent of their Earth orbit, such as speed and mobility.

gramming. The wave of the future is broadband, which refers to a frequency on the **electromagnetic spectrum** that will allow satellites to provide high-speed Internet access, interactive video, and video on demand.

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

In 1998 a combination of failed attempts to launch satellites, in-orbit satellite failures, and business plans gone awry sent investors scrambling as they pulled their support from ventures. This could happen again. On the other hand, commercial space is still in an early stage of development, and if recent history is any guide, investors' understanding of this unique business will continue to increase, and sufficient venture capital will remain available. SEE ALSO COMMERCIALIZATION (VOLUME 1); COMMUNICATIONS SATELLITE INDUSTRY (VOLUME 1); MARKET SHARE (VOLUME 1).

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Getting to Space Cheaply

It costs a lot to get to space—in 2001 it cost as much to put something in **low Earth orbit** ($22,000 per kilogram [$10,000 per pound]) as it did in 1957. Anyone who wants to do things in space (e.g., such as experimenters and scientists) has a cost hurdle to overcome that is not encountered in any other area of human endeavor.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Low Earth orbit (LEO) is a few hundreds miles up. To get to LEO, it takes 30,000 feet per second of velocity change; the total energy needed to get to the Moon is about 45,000 feet per second. LEO is therefore two-thirds of the way to the Moon.

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

aerodynamic heating heating of the exterior skin of a spacecraft, aircraft, or other object moving at high speed through the atmosphere

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Two factors make the step from Earth to LEO hard. First is Earth's atmosphere, which causes **drag** and **aerodynamic heating**. Second is the gravity gradient, or the change in the force of gravity as one moves away from Earth. The force of gravity declines inversely as the square of the distance from Earth, meaning that the farther away one gets from Earth, the easier it is to overcome the force of gravity. As a result, it is harder to get from Earth to LEO than from LEO to almost anywhere else in the solar system.

Expendable Launch Vehicles and Single-Stage-to-Orbit Reusable Rockets

Throughout the twentieth century, getting to space was accomplished almost exclusively with expendable launch vehicles (ELVs)—rockets that are used once and then discarded in the process of putting their **payloads** into orbit. ELVs are inherently incapable of providing cheap access to space for the same rationale that throwing away an automobile after each use is also not economical. Nevertheless, ELVs are here for the foreseeable future (i.e., the early twenty-first century).

As of February 2002, every rocket used to place payloads into orbit has used multiple parts, or stages. Each stage is itself a working rocket. One or more stages are discarded and dropped off as the vehicle ascends, with each discard eliminating mass, enabling what is left over to make orbit.

However, a single-stage-to-orbit (SSTO) reusable rocket would probably be the best technical solution to inexpensively get to LEO. Even when all parts of a multistage rocket are reused, the rocket still needs to be put back together again. An SSTO rocket would not have to be reassembled, reducing the number of people required for operations.

Unfortunately, it is hard to get to LEO without staging. To get to LEO with a single stage, a rocket has to be 90 percent fuel, leaving only 10 percent for everything else. Such a rocket has proven difficult in practice to build, leading to the continued use of multistage rockets.

In 1994 the National Aeronautics and Space Administration (NASA) decided to develop technologies to lead to a reusable launch vehicle (RLV) with a single-stage rocket. Its major step toward this goal was the $1.4 billion X-33 program, which aimed to fly a vehicle to demonstrate some of these technologies. Like many X-vehicle programs before it, the X-33 encountered severe technical difficulties as well as budget overruns and schedule delays. As a result, NASA terminated the X-33 program in early 2001.

NASA is also planning to investigate technical paths to SSTO other than conventional rockets. All involve air-assisted propulsion, such as ramjets, supersonic combustion ramjets ("scramjets"), or liquid air cycle rockets, and all lie in the future.

The Marketplace

There is only one commercial space market: geostationary communications satellites, a market that has had dependable growth for decades. There are several possible new markets, such as remote sensing and space tourism. Remote sensing is the act of observing from orbit what may be seen or sensed below on Earth. But remote sensing requires only a few additional launches a year. Another possible new market, LEO communications satellite con-

The X-33, an unpiloted vehicle, was designed to launch vertically like a rocket and land horizontally like an airplane.

stellations, was halted by the business failure of Iridium, the first such system.✶ Without new markets there are no business needs for anything but ELVs and no incentives to develop new launch systems to get payloads to space cheaply.

✶**For more on Iridium, see the Volume 1 article "Business Failures."**

ELVs available at the beginning of the twenty-first century include the two EELV ("Evolved ELV") families paid for by the U.S. Air Force: the Atlas V and Delta IV. Still available for purchase are the Delta II and III, as well as the Atlas II and III ELVs, and the Boeing SeaLaunch ELV, a converted Zenit rocket launched from a ship at sea. There is also the market leader, the French Ariane 4 and 5 ELV family. The Russian Proton and Rokot ELVs are also available, as are the Chinese Long March families of throwaway boosters.

New Beginnings

Kistler Aerospace is designing and building a two-stage-to-orbit RLV. The company will need investments of $200 million to $400 million above the $500 million already spent to achieve a first flight in 2002 or 2003. There

The X-34 Technology Testbed Demonstrator is delivered here to NASA on April 16, 1999. Results gleaned from this technology will contribute to the development of lower-cost reusable launch vehicles.

suborbital trajectory the trajectory of a rocket or ballistic missile that has insufficient energy to reach orbit

are also small company start-ups such as Kelly Space and Technology and Pioneer Rocketplane, which are involved in developing technologies to get to space cheaply. Kelly wants to develop the Astroliner, a winged rocket towed into the air by a 747 jet and released at altitude to soar on a **suborbital trajectory** under its own power. At the high point of its trajectory, an upper stage is released and injected into LEO. The Astroliner descends and then lands using onboard jet engines.

Pioneer Rocketplane also has an airplane-like RLV it wants to develop, the Pathfinder, which would take off using jet engines. Once at altitude the Pathfinder meets a tanker carrying liquid oxygen, which air-to-air refuels the Pathfinder's liquid oxygen tanks, which are empty at takeoff. After the Pathfinder and the tanker disconnect, the Pathfinder's rocket engines fire, putting it in a suborbital trajectory. At its high point, an upper stage is released and injected into LEO. The Pathfinder descends and then lands using its jet engines.

Space Access LLP will need $5 billion to get to first flight. The company's SA-1 winged vehicle is designed to take off using an ejector ramjet—a ramjet that can also convert to function as a "pure" rocket engine. Once at higher altitude and speed, the vehicle would switch to rocket propulsion and exit the atmosphere where, at the high point of its trajectory, an upper stage would be released and be injected into LEO. This particular upper stage would descend and land for reuse using rocket propulsion to de-orbit, space shuttle–style heat shield tiles, and a parachute. In the meantime, the main SA-1 vehicle would descend and land using its onboard ramjets.

Both the Astroliner and the Pathfinder will need about $300 million to get to first flight. But all of the small RLV companies have had incomes of only a few million dollars a year, and while most of them manage to stay in business, none have yet been able to obtain sufficient funding to begin full development. (A few have small NASA study contracts.) Several other RLV start-ups, such as Rotary Rocket, have failed to obtain sufficient funding and have been forced out of business. The problem is that as of the early twenty-first century, all of the RLV start-up firms have been able to obtain funding only from "angels"—investors who are personally interested in the project. It is only the large established aerospace companies (e.g., Boeing, Lockheed Martin, Orbital Sciences) that manage to secure significant amounts of funding. SEE ALSO Launch Industry (volume 1); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Spaceports (volume 1).

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Global Industry

From the earliest forays into commercial space, competition has been fierce. The United States has an established lead in the design, construction, and marketing of satellites. At the end of the twentieth century, U.S. satellites were being launched routinely for a significant number of nations by launch vehicles provided by eight different nations from launch sites all around the world. The transfer of export license processing from the U.S. Department of Commerce to the U.S. Department of State in 1999 resulted in a conspicuous slowdown in satellite exports, but even this impediment did not compromise U.S. leadership in this world market. The decision to change licensing authority arrangements in the United States was a response to instances of transfer of technological information to China by U.S. companies that the American government deemed inappropriate. This article will explain how space business enterprises had become internationally interwoven to a deep degree by the opening of the twenty-first century.

Changes Following the Challenger Disaster

Space business underwent some major changes between the mid-1980s and the end of the twentieth century. Following the explosion of the space shuttle Challenger because of a technical malfunction in 1986, the United States decided to no longer use the space shuttle to carry commercial **payloads** into orbit. It quickly became clear that the United States had put too much reliance on one launch vehicle, the shuttle. Lack of a good alternative launch system sent aerospace companies scurrying to develop suitable rockets to fill the gap. More importantly, it meant that the United States had lost its dominant position in the launch business to the growing competition from other nations.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Initially the main competition came from the European Ariane launchers. Over time, more and more nations became involved in the commercial launch business, most notably Russia (after the end of the Cold War), Japan, and China. By 2000, eight nations boasted satellite-launching capabilities and several multinational commercial launch services had been established.

Odyssey, a self-propelled, commercial, floating launch pad, combines the resources of the world's leading aerospace companies.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Much of the expertise in rocketry developed in the period between World War II (1939–1945) and the glory days of the Saturn V rocket and the Apollo missions to the Moon was lost in subsequent years as the United States limited its civilian space activities to **low Earth orbit** (LEO). The development of new launch vehicles was marred by expensive failures, raising questions about U.S. reliability in the launch business and forcing insurance rates higher. Loss of domination of the world space launch business coupled with a cutback in U.S. government space contracts resulted in a slew of mergers and acquisitions as aerospace companies streamlined to remain competitive.

Mergers and Acquisitions

In the largest American mergers of the 1990s, Lockheed Corporation merged with Martin Marietta Corporation to become Lockheed Martin Corporation, and the Boeing Company absorbed McDonnell Douglas Corporation as well as elements of Rockwell International Corporation (the corporation that had built the space shuttles) and Hughes Electronics Corporation. This climate of mergers and acquisitions started in response to events in the United States but continues as the industry reacts to events worldwide that impact this global market. For example, two significant companies merged in 2000 when Honeywell Inc. acquired AlliedSignal Inc. in an all-stock deal valued at $14 billion.

The focus on LEO communications networks and on the design of launch vehicles limited in capability to delivery to near-Earth space was another shaping factor in the development of the global industry. Companies such as the unsuccessful Iridium planned to provide worldwide communications capability primarily for an international business clientele. This market initiative stalled because of a combination of technological developments in fiber-optic networks (greatly undercutting the cost of space-based communication systems), and a poor assessment of the market niche. The push toward LEO networks, however, increased emphasis on the global marketplace.

Globalization—the worldwide expansion of corporate business activity—also became a factor in the space industry towards the turn of the century. The creation of companies such as International Launch Services, which combined American business savvy with access to customers and merchandizing from Lockheed Martin and with the technical reliability of Russian rocketry, was typical of the trend towards international leveraging of assets for market success. Another company, Sea Launch, brought even more partners together, teaming another Russian rocket, U.S. corporate business leadership, operations and management from Boeing, a Norwegian-built oceangoing launch platform, and initially, a Cayman Islands registry. The trend of mergers and acquisitions was not confined to the United States. In 1999 Aérospatiale Matra, DaimlerChrysler AG, and Construcciones Aeronauticas S.A. merged their space capabilities to create the transnational firm EADS, the European Aeronautic Defence and Space Company. In 2000, Matra, BAE Systems, and DaimlerChrysler formed Astrium, covering the whole spectrum of space business. Further refinements of European consolidations have responded to changing trends in the aerospace industry related to economic slowdowns in both Japan and the United States, and the terrorist attacks of September 11, 2001.

The Global Nature of the Commercial Space Business

Even before the trend for mergers and acquisitions and the development of corporations geared to worldwide operation in a global market, the commercial aerospace industry was intensely internationally interconnected. For example, while a launch vehicle might be built in the United States or Japan, some component parts would come from elsewhere and payloads—the satellites that were lofted into space by the launch vehicles—frequently brought together instruments and components from several additional nations. Furthermore, each launch and its payload has to be insured against catastrophic failure of the launch vehicle, failure of the launch vehicle to place the satellite in the correct orbit, and malfunction of the satellite itself. Whereas the United States develops the majority of the world's satellites and has regained a significant share of the launch market, the majority of launch insurance comes from Europe. Australian-based insurance companies have also been a significant provider of insurance and reinsurance for the space business. Insurers require detailed knowledge of the vehicle and payload to be insured, resulting in the necessary transfer of detailed information about a planned launch to individuals outside the originating nation. The insurance element provides one more illustration of the global nature of the space industry with its many component parts.

A Sea Launch Ukrainian/ Russian–built Zenit rocket carries a satellite into space. In 1999 a total of 128 spacecraft launched.

Growth Trends in the Global Space Industry

The first year in which commercial space revenues exceeded revenues from government space contracts was 1998. In subsequent years, the growth of commercial space business has widened the gap between commercial revenues and government revenues from space commerce. A total of 128 spacecraft were launched in 1999. Seventy-six of those launches were for commercial customers and fifty-two were government missions, highlighting that the industry driver has changed from the government sector to the commercial sector. Eight countries were responsible for the 128 launches, which had a success rate of 89.7 percent.

In 1999 direct broadcast satellite television was the fastest-growing consumer electronics product in history, and more then 35 million people worldwide received their TV via satellite. Digital audio radio was predicted to be the hot electronics product for the first decade of the twenty-first century, with an audience of more than 49 million subscribers expected by 2009. Worldwide, the space industry employed nearly 1.1 million people in 1999 and posted revenues of $87 billion. Worldwide space revenues for the years 2000 to 2005 were projected to total $619.4 billion. SEE ALSO AEROSPACE CORPORATIONS (VOLUME 1); BUSINESS FAILURES (VOLUME 1); INSURANCE (VOLUME 1).

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Global Positioning System

One hazard of human existence is being geographically lost, which can sometimes mean the difference between life and death. The ability to know one's position was considerably enhanced on February 22, 1978, when members of the U.S. Air Force (USAF) Space Division based in Los Angeles, California, launched the first NAVSTAR (Navigation Satellite with Timing and Ranging) satellite in the Global Positioning System (GPS). This satellite-based navigation system enables users anywhere on Earth to determine their location to a high degree of accuracy.

Components of the System

GPS is a satellite-based navigation system consisting of three segments: space, ground, and user. The space and ground segments are run by a military organization called the United States Space Command, which is located in Colorado Springs, Colorado. This command, composed of components of the USAF, the U.S. Army, and the U.S. Navy, launches the NAVSTAR satellites and is responsible for space and ground operations. The user segment includes any organization, ship, person, or airplane that uses GPS.

The space segment consists of a constellation of twenty-four satellites based in six different orbital planes at an altitude of 20,000 kilometers (12,400 miles). In this orbit, each satellite circles the planet twice in twenty-four hours and travels at the speed of 3.89 kilometers per second (8,640 miles per hour). Each satellite has an inclination of 55 degrees with respect to the equator, which means that it flies to a maximum of 55 degrees north latitude and 55 degrees south latitude during its orbits. The ground segment consists of the **radar** stations that monitor the satellites to determine the position and clock accuracy of each satellite. The locations of these ground stations are: Hawaii; Ascension Island, located in the southern Atlantic; Diego Garcia, an island in the Indian Ocean; Kwajalein, part of the Marshall Islands of the western Pacific; and Schriever Air Force Base, Colorado.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

The Global Positioning System enables users anywhere on Earth to determine their location via a receiver, such as this GPS wristwatch by Casio Computer.

The stations are staffed continuously to ensure that GPS broadcasts the most accurate data possible.

Each NAVSTAR satellite weighs about 1,000 kilograms (2,200 pounds) and is 5.25 meters (17 feet) long with its **solar arrays** extended. The spacecraft transmits its timing information to Earth with the power of 50 watts, obtained from the solar panels and augmented battery power. Using its 50 watts, the satellite transmits two signals called "Links," L_1 and L_2, shorthand for Link1 and Link2. L_1 and L_2 are "downlinks" because their signals go to Earth. Two cesium and two rubidium atomic clocks provide signal timing. Atomic clocks are not powered atomically; they measure the precise **oscillations** of cesium and rubidium atoms. These oscillation measurements are so accurate that an atomic clock, if left unadjusted, would gain or lose one second every 160,000 years. But how does accurate timing from a satellite at an altitude of 20,000 kilometers translate into a position within meters on Earth?

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

oscillations energy that varies between alternate extremes with a definable period

How Positions Are Determined

Distance to the satellite—the range—is the key for determining positions on Earth. Time is related to range by a very simple formula: Range = Velocity × Time. For GPS, the range is the distance from the receiver to the satellite; the velocity equals the speed of light (300,000 kilometers per second [186,300 miles per second]); and the time is the time it takes to synchronize the satellite signal with the receiver. Because the speed of light is so fast, the key to measuring range is the accurate timing provided by the atomic clocks.

What is meant by synchronizing the satellite signal with the receiver? First, imagine that a GPS satellite begins to play the song "Twinkle, Twinkle, Little Star." Simultaneously, a GPS receiver starts playing the same song. The satellite's signal has to travel 20,000 kilometers to the receiver, and by the time it does, the words are so late that when the receiver says

"Star" the satellite's signal starts its first "Twinkle." If two versions of the song were played simultaneously, they would interfere with one another. Consequently, the receiver determines the delay time when it receives the satellite's first "Twinkle" and then starts to play the receiver's tune with a delay time calculated, thereby synchronizing with the satellite's signal. The amount of delay time is the signal travel time. This signal travel time is multiplied by the speed of light to determine the range.

Obviously, the GPS does not use "Twinkle, Twinkle, Little Star," but rather it generates an electronic signal. This signal is similar to the interference heard on the radio when one cannot tune in the correct station or the "snow" one sees on one's television when the set is not on an operational channel. This electronic signal from the GPS satellite is called the Pseudo Random Code (PRC).

A PRC is a very complex electronic signal that repeats its pattern. The pattern of zeros and ones in the digital readouts ensures that the user segment receivers synchronize only on a NAVSTAR satellite downlink and not on some other electronic signal. Because each satellite has its own unique PRC, the twenty-four satellites do not jam each other's signals. This allows all the satellites to use the same GPS **frequencies**. Each satellite transmits two PRCs, over L_1 and L_2. The L_1 PRC is known as Coarse Acquisition (CA), and it allows civilian receivers to determine position within 100 meters (330 feet). The second PRC is called the precise code, or "P," and is transmitted on L_2. The P combines with the CA for orientation and then encrypts the signal to permit only personnel with the correct decoding mechanism, called a key, to use it. When L_2 is encrypted, it is called the Y code and has an accuracy of 10 meters (33 feet).

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

Besides clock accuracy and PRC reception, the receiver needs to know the satellite's location. A typical receiver anywhere on Earth will see about five satellites in its field of view at any given instant. The USAF uses the GPS Master Plan for satellites to ensure that a minimum number are always in view anywhere on Earth. Additionally, all GPS receivers produce an almanac that is used to locate each GPS satellite in its orbital slot. The USAF, under the control of U.S. Space Command, monitors each satellite to check its altitude, position, and **velocity** at least twice a day. A position message, a clock correction, and an ephemeris (the satellite's predicted position) are also updated and uplinked to the GPS satellite daily.

velocity speed and direction of a moving object; a vector quantity

A receiver needs ranges and satellite location information from three satellites to make a position determination. To obtain this, the receiver determines the range while synchronizing its internal clock on the first satellite's correct **Universal time**, which is based on the time in Greenwich, England. Once the clocks have been synchronized and the range to the first satellite has been determined, the receiver also determines the ranges to two other satellites. Each satellite's range can be assumed to be a sphere with the receiver at the center. The intersection of the three spheres yields two possible positions for the receiver. One of these positions must be invalid because it will place the user either in outer space or deep inside Earth, so the receiver has to be at the second position. Then the receiver compares the satellite's ephemeris and current almanac location to obtain the receiver's latitude and longitude. A fourth GPS satellite's range synchronizes the receiver's clock with all the atomic clocks aboard the spacecraft, narrows the

Universal time current time in Greenwich, England, which is recognized as the standard time on which Earth's time zones are based accuracy of the receiver's position to only one intersecting point, and determines the receiver's altitude.

Selective Availability and Differential GPS

There are several errors in timing, ephemeris, and the speed of light for which the system must correct. However, the crews of U.S. Space Command occasionally must induce errors to keep the accuracy of the GPS system from falling into the hands of a hostile force. This error inducement is called "selective availability." To accomplish this, the crew inserts either intentional clock or ephemeris errors. On May 1, 2000, President Bill Clinton ordered the removal of selective availability, greatly enhancing the public use of GPS. However, the probability that access to data would be blocked in times of hostilities has led to a proposal for an independent European GPS-style system called Galileo.

When selective availability was introduced, a number of people wanted more accurate GPS readings, leading to the invention of Differential GPS. This system uses a known surveyed position, such as an airport tower, upon which is placed a GPS receiver. The GPS receiver determines its position constantly and compares the GPS position to the surveyed position and develops a "correction" factor that can be applied to make the accuracy of the GPS in the range of inches. Applications of Differential GPS include precision landings with aircraft and precision farming, which allows a farmer to know exactly where to apply fertilizer or pesticide, or both, within a field. Differential GPS is so accurate that it also permits scientists to accurately measure the movement of Earth's tectonic plates, which move at the speed of fingernail growth.

GPS receivers are currently on ships, trains, planes, cars, elephant collars, and even whales. This system promises to change the way we live, and satellite-based navigation is predicted to become a multibillion-dollar industry in the early twenty-first century.

Commercial Enterprises Involved in GPS

There are a number of commercial companies involved in the GPS industry. The largest are the companies that make the satellite itself, Lockheed Martin, Hughes (recently taken over by Boeing), Rockwell (also recently taken over by Boeing), and Boeing Space. The survivor of the takeover business will probably build the next block of GPS satellites, the 2-F block that will be without selective availability.

Commercial possibilities in GPS are in the following areas: aviation, geosciences, marine applications, mapping, survey, outdoor recreation, vehicle tracking, automobile navigation, and wireless communications. Since there are a number of companies involved in GPS, only four of these will be reviewed. Companies that are selling their GPS services for other than space support include Garmin, which is headquartered in Olathe, Kansas, and has subsidiary offices in the United Kingdom and Taiwan. Garmin sells navigation receivers that are portable and have brought navigation to the masses for hiking, motor boat operation, and other recreational vehicle arenas.

Another large company that employs over 500 workers in the manufacture of receivers is Magellan Systems Corporation, located in San Dimas, California. Magellan brought into market the world's first handheld commercial receiver for ordinary uses. Since 1989, Magellan has shipped more than one million of these units and has produced annual sales that now top $100 million. In 1995, Magellan introduced the first hand-held GPS receiver under $200 which led to even greater market expansion. Trimble Navigation Limited, located in Sunnyvale, California, offers services very similar to those of Garmin and Magellan. Trimble also has a subsidiary in the United Kingdom. Trimble has a particularly accurate receiver called the Scoutmaster, which has been used since 1993 with great success. The receiver allows an individual to not only determine latitude and longitude, but also speed on Earth's surface and distances to input navigation points.

Motorola Corporation has been very cooperative in their affiliation with universities putting **payloads** on satellites and on balloons. Using Motorola GPS units such as the Viceroy and the Monarch, university students have tracked balloon payloads over 240 miles and have used the navigation information to determine the jet stream speed and balloon altitudes over the United States. As the GPS system continues, so too, will ideas from small companies about how to use this information commercially, thus developing industries that people can only dream about at this time in our history. SEE ALSO MILITARY CUSTOMERS (VOLUME 1); NAVIGATION FROM SPACE (VOLUME 1); RECONNAISSANCE (VOLUME 1); REMOTE SENSING SYSTEMS (VOLUME 1).

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

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American Inventor and Educator
1882–1945

Robert Hutchings Goddard was born in Worcester, Massachusetts, on October 5, 1882. After reading science fiction as a boy, Goddard became excited about exploring space. He pioneered modern rocketry in the United States and founded a field of science and engineering. Goddard received a Ph.D. from Worcester Technical University in 1911 and joined the faculty at Clark University.

As a physics graduate student, Goddard conducted static tests with small solid-fuel rockets, and in 1912 he developed the mathematical theory of rocket propulsion. In 1916 the Smithsonian Institution provided funds for

Robert Goddard, pictured here next to a liquid-propellant rocket, launched the first payload-carrying rocket.

velocity speed and direction of a moving object; a vector quantity

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

✶In 1927 Charles A. Lindbergh became the first pilot to make a nonstop solo flight from New York to Paris.

his work on rockets and in 1919 published his research as "A Method of Reaching Extreme Altitudes." Goddard argued that rockets could be used to explore the upper atmosphere and suggested that with a **velocity** of 11.18 kilometers per second (6.95 miles/second), without air resistance, an object could escape Earth's gravity and head into infinity or to the Moon or other celestial bodies. This became known as Earth's escape velocity.

Goddard's ideas were ridiculed by some in the popular press, prompting him to become secretive about his work. However, he continued his research, and on March 16, 1926, Goddard launched his first liquid-fueled rocket, an event that heralded modern rocketry. On July 17, 1929, he flew the first instrumented **payload**, consisting of an aneroid barometer, a thermometer, and a camera. This was the first instrument-carrying rocket. After rising about 27 meters (90 feet), the rocket turned and struck the ground 52 meters (171 feet) away, causing a large fire.

Charles A. Lindbergh✶ visited Goddard and was sufficiently impressed to persuade philanthropist Daniel Guggenheim to award Goddard a grant of $50,000, with which Goddard set up an experiment station near Roswell, New Mexico. From 1930 to 1941 Goddard launched rockets of ever-greater complexity and capability. The culmination of this effort was the launch of a rocket to an altitude of 2,743 meters (9,000 feet) in 1941. Late in 1941 Goddard entered naval service and spent the duration of World War II developing a jet-assisted takeoff rocket to shorten the distance required for heavy aircraft launches. This work led to the development of the throttlable Curtiss-Wright XLR25-CW-1 rocket engine that later powered the Bell X-1 and helped overcome the **transonic barrier** in 1947. Goddard died in Baltimore on August 10, 1945. SEE ALSO Careers in Rocketry (volume 1); Rocket Engines (volume 1); Rockets (volume 3).

Roger D. Launius

transonic barrier the aerodynamic behavior of an aircraft moving near the speed of sound changes dramatically and, for early pioners of transonic flight, dangerously, leading some to hypothesize there was a "sound barrier" where drag became infinite

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Ground Infrastructure

The ground-based infrastructure for a satellite is responsible for a number of support functions, such as commanding the spacecraft, monitoring its health, tracking the spacecraft to determine its present and future positions, collecting the satellite's mission data, and distributing these data to users. A key component of the infrastructure is the ground station, which is an Earth-based point of contact with a satellite and a distributor of user data.

Spacecraft and **payload** support consists of maintaining a communications link with the satellite to provide satellite and payload control. The ground station collects satellite telemetry (transmitted signals) to evaluate its health, processes state of health information, determines satellite **orbit** and attitude, and issues satellite commands when required.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

Mission data receipt and relay is a vital function of the ground station. This includes receiving mission data and payload telemetry. The ground station computers process these data into a usable format and distribute them to the users by way of electronic communication lines such as satellite or ground-line data link or even the Internet.

A generic ground station consists of an antenna to receive satellite signals; radio frequency receiving equipment to process incoming raw electronic signals; and mission data recovery equipment, computers, and data interface equipment to send data to users. Additionally, telemetry, tracking, and control equipment monitors the spacecraft's health status, and radio frequency transmitting equipment sends commands to the satellite via the station antenna.

Station Personnel

A large satellite control station has several types of centers staffed by a diverse range of qualified personnel. The Control Center (CC) accomplishes

This complex in Madrid, Spain, is one of three complexes that comprise the NASA Deep Space Network, which spans the world and tracks spacecraft throughout the solar system.

overall control of the ground station, and all other station centers are responsible to the CC. A senior individual who has several years' experience working with the satellite systems and the station leads this center. The Satellite Operations Control Center (SOCC) is responsible for satellite health. A senior engineer leads this team, which tracks the satellite and its telemetry. The Payload Operations Control Center (POCC) is responsible for the payload's status and health. A senior engineer also leads this team, which monitors the spacecraft's payload and the quality of data it is collecting. The SOCC and POCC must also determine causes for spacecraft malfunctions and corrections that might be required. The Mission Control Center is responsible for reviewing mission data to ensure their quality for the users. Because it is the last link before the users obtain their data, this center is led by an expert such as a scientist. The Station Control Center is responsible for the ground station upkeep, such as distributing power, providing cooling for the computers, and taking care of general maintenance on all other station equipment. This team is usually led by a civil engineer with a number of years of maintenance experience.

For a smaller satellite operation many of these jobs are combined. One computer might run the CC and the Mission Control Center functions while another accomplishes the SOCC and POCC jobs. If the operation is small, three people and two computers can run the entire ground station.

Commercial Satellite Ground Stations

Depending upon the size, commercial satellite ground stations are available from several corporations with different price structures. This section examines two large processing facility manufacturers: Raytheon and Honeywell; one transportable ground station company, Datron; and one foreign company, RDC ScanEx.

Raytheon Corporation of Denver, Colorado, offers large ground stations including antennas, satellite command and control, mission planning, management, front-end processing, and terminal equipment. One example of their extensive capability for satellite ground station operations is their software, which uses over three million lines of code in operations activities. With their 1800 Denver-based employees, Raytheon has built and supplied more than 40 international ground stations. The large ground stations are prohibitively expensive for any organizations other than governments or very large universities.

Another example of commercial ground stations is Honeywell's Data Lynx series of ground stations. Honeywell offers antennas, tracking, data acquisition, commanding, satellite management, and data processing. The U.S. Navy has taken advantage of Honeywell's expertise by employing their ground stations for the Naval Earth Map Observer satellite system that employs **hyperspectral** sensors. Lockheed Martin has also used Honeywell's ground stations in the Poker Flats Satellite Tracking facility located near Fairbanks, Alaska. Similar to the Raytheon system, the Data Lynx is very expensive to operate and maintain.

hyperspectral imaging technique in remote sensing that uses at least sixteen contiguous bands of high spectral resolution over a region of the electromagnetic spectrum; used in NASA spacecraft Lewis' payload

There are several examples of companies that build small satellite tracking ground stations that require few people. Datron from Simi Valley, California, has built a transportable satellite station that can be used for military tactical intelligence gathering, disaster area assessment, and remote area coverage. The Datron portable ground station is compatible with the Landsat, SPOT, RADARSAT, IKONOS, and Quickbird satellites. Although not as expensive as the Raytheon and Honeywell ground stations, Datron requires a substantial sum for its transportable ground station.

An example of a foreign commercial company that uses minimum equipment to create a ground station is the Russian private company known as RDC ScanEx. This company focuses on personal computers to acquire, track, and download data from several different weather satellites such as the National Oceanic & Atmospheric Administration polar satellites and the Russian Earth remote sensing satellites. The Liana system uses a small, omnidirectional antenna to acquire satellite signals that are sent direct to a personal computer (PC) for processing and distribution. This system requires one person with no special training to run the system as all components are within a small PC area. This company has sold more than 80 of these systems, at very competitive prices of less than $5,000 per station. SEE ALSO COMMUNICATIONS FOR HUMAN SPACEFLIGHT (VOLUME 3); COMMUNICATIONS

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John F. Graham

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H

Human Spaceflight Program

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The first human to go into space, Soviet cosmonaut Yuri Gagarin, made a one-orbit, ninety-minute flight around Earth on April 12, 1961. Up to mid-2001, only 407 additional humans (370 men and 37 women) have gone into orbit, some of them making multiple journeys into space. Most of these individuals were a mixture of career astronauts, trained either to pilot space vehicles or to carry out a changing variety of tasks in orbit, and **payload** specialists, who also went through extensive training in order to accompany their experiments into space. In addition, there were a few people who got the opportunity to go into space because of their jobs on Earth (e.g., U.S. politicians). Other individuals flew into space because their country or company had paid for access to space, thereby getting the right to name someone to participate in the spaceflight in exchange for that funding. For example, a prince from Saudi Arabia went into space aboard a space shuttle and helped launch a Saudi communications satellite. A Japanese jour-

Human spaceflight is becoming increasingly diverse, with an emphasis on international cooperation. Clockwise from right are Curtis L. Brown Jr., commander; Steven W. Lindsey, pilot; Stephen K. Robinson, mission specialist; Pedro Duque, mission specialist representing the European Space Agency; Chiaki Mukai, payload specialist representing Japan's National Space Development Agency; Scott F. Parazynski, mission specialist; and U.S. Senator John H. Glenn Jr. (D-Ohio), payload specialist.

nalist, representing his television network, went aboard the Soviet space station Mir.

Citizens in Space

The United States began a "citizen in space" program in the 1980s. The goal of the program was to identify ordinary individuals who could communicate the experience of spaceflight to the general public. The first person selected was a teacher, Christa McAuliffe. Unfortunately, she and six other astronauts were killed when the space shuttle Challenger exploded seventy-three seconds after liftoff on January 28, 1986. After the disaster, the United States abandoned the idea of taking ordinary people into space, and limited trips aboard the space shuttle to highly trained specialists. The restriction was relaxed in 2002, when Barbara Morgan, another teacher, was assigned to flight status.

The Challenger disaster was a vivid reminder that taking humans into space is a difficult and risky undertaking. It is also very expensive; the launch of a space shuttle, for example, costs several hundred million dollars. Only two countries, the United States and Russia (from 1922 to 1991 known as the Soviet Union), have developed the expensive capabilities required for human spaceflight. In 1999 China tested, without people on board, a spacecraft that could support humans in orbit.

Low Earth Orbit

Human spaceflight since 1961 has been limited to **low Earth orbit** (LEO) with the exception of the period from December 1968 to December 1972, when twenty-seven U.S. astronauts (three per mission) traveled to the vicinity of the Moon during Project Apollo. Of these astronauts, twelve actually landed on the Moon's surface and carried out humanity's first exploration of another celestial body.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Project Apollo was the result of a 1961 Cold War political decision by U.S. President John F. Kennedy to compete with the Soviet Union in space. Since the end of Apollo, advocates have argued for new exploratory missions to the Moon and especially to Mars, which is considered the most interesting accessible destination in the solar system. However, the lack of a compelling rationale for such difficult and expensive missions has meant that no nation, or group of nations, has been willing to provide the resources required to begin such an enterprise. A major human spaceflight issue is: Under what circumstances, if any, will people once again journey beyond Earth orbit?

The Soviet Program

During the 1960s the Soviet Union attempted to develop the capability to send people to the Moon, but abandoned its efforts after three test failures with no crew aboard. Beginning in the early 1970s the Soviet Union launched a series of Salyut space stations, which were capable of supporting several people in space for many days. Then in March 1986 the Soviet Union launched the larger Mir space station. Mir was continuously occupied for most of the subsequent fifteen years until it reached the end of its lifetime; it was de-orbited into the Pacific Ocean in March 2001. Soviet cosmonaut Valery Polyakov spent 438 days aboard Mir, the longest spaceflight


Canadian mission specialist Chris A. Hadfield stands on space shuttle Endeavour's remote manipular system, attached to the portable foot restraint.

by any person. After the United States and Russia began cooperating in their human spaceflight activities in 1992, U.S. astronaut Shannon Lucid visited Mir, and spent 188 days in orbit, the longest spaceflight by an American.

Human Spaceflight at the Turn of the Century

Human spaceflight at the turn of the twenty-first century thus remained a government monopoly. The possibility of privately operated, profit-oriented human spaceflight activities remained an elusive objective, though it was advocated by a variety of groups and individuals. However, a significant step in the direction of private spaceflight occurred in April 2001 when American millionaire Dennis Tito paid Russia to send him for a six-day visit to the International Space Station.

In the United States, the National Aeronautics and Space Administration (NASA) in 1996 began to turn over much of the responsibility for operating the space shuttle to a private company, United Space Alliance, which was jointly owned by Boeing and Lockheed Martin, the two largest U.S. aerospace firms. But NASA limited United Space Alliance's freedom to market space shuttle launch services to nongovernment customers, and NASA retained control over which people could fly aboard the shuttle. However, after Tito's flight, this policy was re-evaluated, and NASA decided to accept applications from paying customers for such flights. A privately funded corporation called MirCorp worked with Russia to try to keep the Mir station in operation, perhaps by selling trips to the space station for tens of millions of dollars to wealthy individuals or by other forms of private-sector use of the facility. Tito was Mircorp's first customer, but he could not be launched in time to travel to Mir before it was de-orbited.

The International Space Station and Beyond

The International Space Station, developed and funded by a sixteen-nation partnership, will offer opportunities for privately financed experiments in its various laboratories. It may be possible for those carrying out such experiments to pay NASA to send their employees to the space station to carry out such experiments. If research or other activities aboard the International Space Station prove to have economic benefits greater than the cost of operating the facility, it is conceivable that it could be turned over to some form of commercial operator in the future. If the International Space Station were fully or partially commercialized, and the various ways of transporting experiments, supplies, and people to and from the station were operated in whole or part by the private sector, the future could see the overall commercialization of most activities in LEO. If this were to happen, governments would act as customers for the transportation and on-orbit services provided by the private sector on a profit-making basis.

The most exciting vision for the future is widespread public space travel, sometimes called space tourism.✶ If this vision were to become reality, many individuals, not just millionaires or those with corporate sponsorship, could afford to travel into space, perhaps to visit orbiting hotels or other destinations. Much has to happen, however, before this would be possible. Most fundamentally, different forms of space transportation, much less expensive and much less risky to operate, need to be developed. Although there have been many proposals for such transportation systems, none of these proposals has yet come close to becoming reality. The technological challenges to developing such a system are formidable and are likely to require a government-industry partnership, given the high costs associated with overcoming those challenges. Until these challenges are met, human spaceflight is likely to remain restricted to a fortunate few. SEE ALSO ASTRONAUTS, TYPES OF (VOLUME 3); CAREER ASTRONAUTS (VOLUME 1); COSMONAUTS (VOLUME 3); HISTORY OF HUMANS IN SPACE (VOLUME 3); INTERNATIONAL SPACE STATION (VOLUMES 1 AND 3); TOURISM (VOLUME 1).

✶On April 25, 2002, South African Mark Shuttleworth followed in Dennis Tito's footsteps, traveling into space to become the world's second space tourist.

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Insurance

I

Every ten days, on average, another rocket carrying a telecommunications satellite thunders heavenward. This satellite might be destined to become part of the international telephone network, or to provide direct-to-home television, or be designed to provide a new type of cellular phone service or Internet backbone links. Regardless of its eventual purpose, a wide range of people around the world will be focused on its progress as its fiery plume streaks upward. Flight controllers monitor its position while the manufacturers of the satellite check critical systems. The satellite owners wait anxiously

It can cost hundreds of millions of dollars to build and launch a satellite. Because there is a 10 percent rocket failure rate, insurance is a critical element of space business.

to see if their critical investment will successfully reach its orbital destination. But there is another group of people, often overlooked, who also intensely monitor the fate of the rocket and satellite—the space insurance community.

The commercial space industry would not exist today without the space insurance industry. For example, in the case of a satellite slated for launching, unless the owners of and investors in the satellite are able to obtain insurance, the satellite will never be launched. A typical telecommunications satellite costs around $200 million. Another $80 million to $100 million is needed to launch this satellite into its proper orbit. Given the historic 10 percent failure rate of rockets, very few private investors or financial institutions will place this amount of money at risk without insurance to cover potential failures. Insurance is an essential part of the financing for any commercial space venture.

The Growth and Development of the Space Insurance Industry

The growth of the commercial space industry and the growth of the space insurance industry go hand in hand. National governments did not require insurance at the beginning of the space age, so it was not until the early 1970s, when companies decided to build the first commercial satellites for the long-distance phone network, that space insurance was born. In these early years the few space insurance policies were usually underwritten as special business by the aviation insurance industry.

The explosion of the space shuttle Challenger in 1986 marked a dramatic new phase in space insurance. The National Aeronautics and Space Administration (NASA) decided that the shuttle would no longer be used to launch commercial satellites. This forced commercial satellites onto **expendable launch vehicles**, which had a higher risk of failure than the relatively safe shuttle. Owners and investors actively sought insurance to protect their satellite assets, and this growing demand established space insurance as a class of insurance of its own.

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

The success of commercial satellites led to strong growth in the space insurance industry, which exceeded $2 billion revenue annually worldwide by 2001. Similarly, the ability to obtain insurance against failures enabled investors to achieve commercial financing for space projects. In turn, this stimulated the growth of the commercial space industry such that commercial spending on space projects equaled government spending in 1998. The role of space insurance in securing commercial financing is so well-established that government agencies, such as NASA and the European Space Agency, now also insure selected projects. This trend will continue and space insurance will play a central role in unlocking financing for new commercial ventures on the International Space Station and beyond.

Insurance—A Global Industry

Space insurance, like other forms of insurance, is a global industry. The largest concentration of companies is in London, where space insurance and insurance in general originated. Major companies exist all over the world, however, including in the United States, Germany, France, Italy, Australia, Japan, and Scandinavia. Virtually every country that has commercial satellites participates in the space insurance industry, either through direct underwriters or reinsurers. Reinsurers insure the insurance companies, agreeing to accept some of the risk for a fee. This spreading of risk is crucial, as it is difficult for one company or country to absorb a loss in the hundreds of millions of dollars from a single event. The global spreading of risk takes advantage of worldwide financial resources and is a fundamental aspect of the insurance industry.

Insurance premiums can vary from 4 percent to 25 percent of the project's cost depending on the type of rocket and satellite, previous history, and new technology being used and policy term. Accurate and up-to-date information is essential in setting rates and a major issue is government restrictions on the flow of technical information. Market forces and recent losses also affect rates. Rates were increasing in the early twenty-first century as companies adjusted to the very high insurance losses incurred from 1998 to 2000.

Brokers and Underwriters

The space insurance industry is essentially made up of two types of companies: the brokers and the underwriters. The broker's task is to put together an appropriate insurance program for the satellite owner, while the underwriter puts up security in the form of insurance or reinsurance. The broker identifies the client's insurance needs over the various phases of a satellite's life: manufacture, transport to the launch site, assembly onto the rocket, launch, in-orbit commissioning, and in-orbit operations. The broker then approaches the underwriting companies and asks how much coverage they will provide and what premium rate they will charge. Most underwriting companies will not take more than $50 million of any one risk. Hence the broker must often contact several underwriters to place the client's total risk at consistent rates. Once the package is agreed to, legal contracts complete the arrangements.

Jobs in Space Insurance

The space insurance industry can offer fascinating work for those interested in space. There are two main roles: the broker, who has a business development role—finding clients and negotiating insurance programs; and the underwriter, who leads the complex task of establishing the insurance rates. Experience in the space insurance industry is essential for both of these roles, and often a business, legal, financial, or technical background is required. Companies also have technical experts who understand satellites and rockets, a legal department for writing contracts, a finance department handling the accounts and money transfers, and a claims department for assessing losses and processing claims. Actuaries, who generally have a mathematics background, model the expected losses and help the underwriter and the technical experts set the rates.

As permanent habitation of space through the International Space Station leads to the discovery of new commercial opportunities, space insurance will evolve to cover these new commercial realities. Insurance remains an essential ingredient for commercial space business and will continue to play a vital role in humanity's growing commercial exploration of space. SEE ALSO COMMUNICATIONS SATELLITE INDUSTRY (VOLUME 1); LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); LAUNCH VEHICLES, REUSABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4); SATELLITE INDUSTRY (VOLUME 1); SEARCH AND RESCUE (VOLUME 1).

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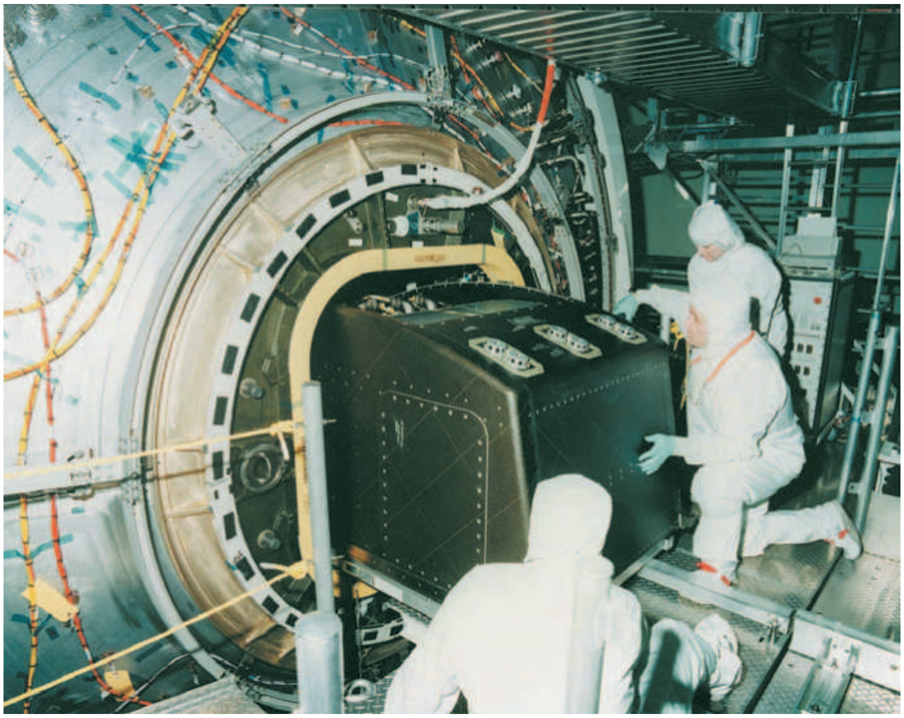
International Space Station

The International Space Station (ISS) is a scientific and technological wonder. It is a dream being realized by a multinational partnership. The ISS provides a permanent human presence in space and a symbol of advancement for humankind.✶ There is great promise and discovery awaiting those who will use the space station.

✶**The ISS has a wingspan that is over a football field long.**

Just as the global explorers of the fifteenth century circled the globe in their square-sailed schooners in search of riches—gold, spices, fountains of youth, and other precious resources—so too is the space station a wind-



Boeing technicians slide a systems rack into the U.S. Laboratory module intended for the International Space Station. The laboratory will contain 13 racks with experiments and 11 racks with support systems, with each rack weighing nearly 1,200 pounds.

jammer plowing the waves of space, exploration the riches it holds. The space station brings together the adventure of fifteenth-century explorers with twenty-first-century technology and industry. The space station is, at its essence, an infrastructure that will facilitate and transmit new knowledge, much like that provided through the virtual world of the Internet. In regard to the space station, the question is: From where will the value of this virtual world come? Or, put in terms of the fifteenth-century explorers, "What is the spice of the twenty-first century in the new frontier of space?"

At this stage, no one can guess what the most valuable and profound findings from space station research will be. Space research done to date, however, does point the way to potential areas of promise that will be further explored on the ISS. The space environment has been used to observe Earth and its ecosphere, explore the universe and the mystery of its origin, and study the effects of space on humans and other biological systems, on fluid flow, and on materials and pharmaceutical production.

The space station creates a state-of-the-art laboratory to explore ourselves and the world. The discoveries we have made to date in space, while significant, are only the foundation for what is to come. Research in **microgravity** is in its infancy. Throughout the thousands of years that physical phenomena have been observed, including the relatively recent 400 years of documented observations, it has been only in the period since the 1960s that experiments in microgravity of more than a few seconds have been observed; only since the late 1990s has there been a coordinated set of microgravity experiments in space. The most telling indicator is that by the end of 2001 more than half of all microgravity experiments had been conducted since 1998.

microgravity the condition experienced in free fall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

History is rife with failed predictions. Nevertheless, perhaps the best way to try to predict the future is to look at the evolution of the past, using

The view from space shuttle Atlantis following undocking from the International Space Station, after sucessfully outfitting the station for its first resident crew.

history and the current situation as a jumping-off point, while recognizing the challenge in predicting the future. The following represents an attempt to peer into the future, to see what promise lies ahead for the space station by looking at the past and the present.

Previous Advances from Space Activities

In the twentieth century, space exploration had a profound impact on the way we viewed ourselves and the world in which we live. Viewing our planet from space for the first time gave us a unique perspective of Earth as a single, integrated whole. Observations of Earth's atmosphere, land, and oceans have allowed us to better understand our planet as a system and, in doing so, our role in that integrated whole. Many aspects of our lives that are now taken for granted were enabled, at least in part, by investments in space. Whether making a transpacific telephone call, designing with a computer-aided design tool, using a mobile phone, wearing a pacemaker, or going for an MRI, we are using technology that space exploration either developed or improved.

In the early twenty-first century, commercial interests offer a myriad of products and services that either use the environment of space or the results of research performed in microgravity. Just a few examples include:

- *Satellite communications:* Private companies have operated communications satellites for decades. Today, private interests build, launch, and operate a rapidly expanding **telecommunications infrastructure** in space. The initial investment in space of the United States helped fuel the information revolution that spurs much of the nation's economy today.
- *Earth observation/remote sensing:* A growing market for Earth imagery is opening up new commercial opportunities in space. Private interests now sell and buy pictures taken from Earth orbit. Land-use planners, farmers, and environmental preservationists can use the commercially offered imagery to assess urban growth, evaluate soil health, and track deforestation.
- *Recombinant human insulin:* The Hauptman-Woodward Medical Research Institute, in collaboration with Eli Lilly and Company, has used structural information obtained from crystals grown in space to better understand the nuances of binding between insulin and various drugs. Researchers there are working on designing new drugs that will bind to insulin, improving their use as treatments for diabetic patients.

What all these discoveries have in common is that they use space as a resource for the improvement of human conditions. Efforts aboard the ISS will continue this human spirit of self-improvement and introspection. And the twenty-first century holds even greater promise with the advent of a permanent human presence in space, allowing that same spirit to be a vital link in the exploration process. The space station will maximize its particular assets: prolonged exposure to microgravity and the presence of human experimenters in the research process.

THINGS ARE CLEARER WITH HINDSIGHT

The commissioner of the U.S. Office of Patents said, "Everything that can be invented has been invented"—in the year 1899. In 1962 the Decca Recording Co. rejected the Beatles stating: "We don't like their sound, and guitar music is on the way out." More recently, in 1981 Microsoft Chairman Bill Gates said in reference to the computer, "64K ought to be enough for anybody."

telecommunications infrastructure the physical structures that support a network of telephone, Internet, mobile phones, and other communicaton systems

Potential Space Station–Based Research

The ISS will provide a laboratory that can have profound implications on human health issues on Earth. Many of the physiological changes that astronauts experience during long-term flight resemble changes in the human body normally associated with aging on Earth. Bone mass is lost and muscles **atrophy**, and neither appear to heal normally in space. By studying the changes in astronauts' bodies, scientists might begin to understand more about the aging process. Scientists sponsored by the National Aeronautics and Space Administration are collaborating with the National Institutes of Health in an effort to explore the use of spaceflight as a model for the process of aging. This knowledge may be translated into medical wonders, such as speeding the healing of bones and thereby reducing losses in productivity. By beginning to understand the process by which bones degenerate, scientists might be able to reverse the process and expedite the generation of bone mass.

atrophy condition that involves withering, shrinking, or wasting away

The microgravity environment offers the opportunity to remove a fundamental physical property—gravity—in the study of fluid flow, material growth, and other phenomena. The impacts on combustion, chemistry, biotechnology, and material development are promising and exciting. The combustion process, a complex reaction involving chemical, physical, and thermal properties, is at the core of modern civilization, providing over 85 percent of the world's energy needs. By studying this process on the ISS, commercial enterprises could realize significant savings by introducing newfound efficiencies.

Researchers have found that microgravity provides them with new tools to address two fundamental aspects of biotechnology: the growth of high-quality crystals for the study of proteins and the growth of three-dimensional tissue samples in laboratory cultures. On Earth, gravity distorts the shape of crystalline structures, while tissue cultures fail to take on their full three-dimensional structure.

The microgravity environment aboard the ISS will therefore provide a unique location for biotechnology research, especially in the fields of protein crystal growth and cell/tissue culturing. Protein crystals produced in space for drug research are superior to crystals that can be grown on Earth. Previous research performed on space-grown crystals has already increased knowledge about such diseases as AIDS, emphysema, influenza, and diabetes. With help from space-based research, pharmaceutical companies are testing new drugs for future markets.

In addition to these scientific findings, the ISS serves as a real-world test of the value of continuous human presence in space. There are already companies focused on space tourism and the desire to capitalize on the human presence in space. A myriad of future scenarios are possible, and the imagination of entrepreneurs will play a key role.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

Inevitably, private interests will move to develop orbital infrastructure and resources in response to a growing demand for space research and development. The permanent expansion of private commerce into **low Earth orbit** will be aided as the partners of the ISS commercialize infrastructure and support operations such as power supply and data handling. This trend is already under way with several commercial payloads having flown on the space shuttle and on the ISS.

The ISS is an unparalleled, international collaborative venture. In view of the global nature of the ISS, the international partners (sixteen countries) recognize the value of consulting on and coordinating approaches to commercial development. Each international partner retains the autonomy to operate its own commercial program aboard the ISS within the framework of existing international agreements, and mechanisms of cooperation are possible where desired. SEE ALSO Aging Studies (volume 1); Crystal Growth (volume 3); History of Humans in Space (volume 3); International Space Station (volume 3); Made with Space Technology (volume 1); Microgravity (volume 2); Mir (volume 3); Skylab (volume 3).

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International Space University

As space programs become increasingly international and commercial in nature, the education of the space-sector workforce needs to continually adapt to maintain this pace. The International Space University (ISU) is dedicated to meeting this challenge by training the world's next generation of professionals who will lead the way into space.

The ISU provides postgraduate training for students of all nations who are interested in space. Each year, the ISU conducts a two-month summer program in various locations around the world. Examples of past ISU Summer Session locations include Thailand, Chile, Sweden, and the United States. In addition, the ISU provides a master of space studies program at its central campus in Strasbourg, France.

Because specialist knowledge alone is no longer sufficient to meet the challenges of complex space programs implemented by governments and companies from around the world, the ISU presents an interdisciplinary, international, and intercultural approach. The university provides participants with a thorough appreciation of how space programs and space business work. This is accomplished through extensive coursework in science, engineering, law and policy, business and management, and other space-related fields. In addition, all ISU students participate in a student design project that allows them to integrate their classroom learning in a complex, hands-on, practical exercise. Because this design project is conducted with classmates from all over the world, it allows ISU students to master the challenges of working with international teammates in an intercultural environment.

Since the first summer session in 1988, more than 1,500 students from more than 75 countries have reaped the benefits of an ISU education. Most of these students have gone on to work in successful careers in space and related fields. Universally, ISU alumni credit their professional success to the broad intellectual perspectives gained at the university as well as to their extensive international network of contacts in the space community. The university's interactive, international environment provides its students with continuous opportunities to forge professional relationships with colleagues and with its faculty, who also come from many different countries.

At an International Space University summer session, students learn about space suit design.

The Origins of the International Space University

✶ **Peter H. Diamandis, Todd B. Hawley, and Robert D. Richards founded the International Space University.**

The ISU was the brainchild of three young men✶ in their early twenties who, as college students, became interested in space exploration. Passionate about space, they proposed a university dedicated to a broad range of space-related subjects for graduate students from all parts of the world. With their enthusiasm, they succeeded in winning over important players in the space field, including science fiction author Arthur C. Clarke, who became chancellor of ISU. The founders' vision for the university was that it would be an institution dedicated to a peaceful, prosperous, and boundless future through the study, exploration, and development of space for the benefit of all humanity.

The ISU began to materialize in the summer of 1988 as participants in the first ISU summer session gathered at the Massachusetts Institute of Technology in Cambridge. Four years after this initial session, Strasbourg, France, was selected as the site for the ISU central campus. The first master of space studies program was initiated in September 1995 following the move of the campus to Europe. SEE ALSO Careers in Space Science (volume 2); Education (volume 1).

Margaret G. Finarelli

Internet Resources

International Space University. <http://www.isunet.edu>.

Launch Industry

The process by which satellites, space probes, and other craft are launched from the surface of Earth into space requires equipment, machinery, hardware, and a means, usually a rocket vehicle of some sort, by which these materials are lifted into space. The businesses that exist to service these launching needs form an international space transportation industry. That launch industry, also referred to as space launch service providers, has been estimated to generate $8 billion in total annual sales, with the United States earning about half of that amount. By comparison, the total U.S. sales of all aerospace equipment, including aircraft, missiles, and other space equipment amounted to $151 billion in 1999.

The space launch services industry is currently dominated by three firms: Arianespace in Europe, Boeing Launch Services in California, and International Launch Services of Reston, Virginia, which is owned by Lockheed Martin Corporation of Littleton, Colorado. While the three firms account for more than 80 percent of the world's commercial space launches, they are by no means the only firms in the business today. While the types of satellites being launched remain mainly civil, military, and large commercial communications craft, the evolution of the use of space may change that makeup in the decades ahead. Should that mix of cargo change, so too may the dominant launch service providers. There is a saying in the launch industry—"You are only as good as your last launch"—that may apply to this shifting outlook.

Launching this rocket requires equipment, machinery, and hardware, all of which are provided by businesses within the launch industry.

Complicating the degree to which specific businesses have specialized in the launching of different types of spacecraft is the nature of the competition itself. Experts and analysts in space transportation suggest as the twenty-first century begins that there are too many launch firms seeking too few satellites that need launching. Should such a trend continue, several of the smaller firms, and possibly elements of the larger ones, may go out of business in the years ahead.

The Origins of the Industry

The commercial launch industry has its roots in the Cold War missiles that formed the launching rockets of the early space age. Following the launching of the world's first artificial satellite of Earth, Sputnik 1, by the Soviet Union on October 4, 1957, the governments of the USSR and the United

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

States were the only entities that possessed space launch vehicles. The fleets of intercontinental **ballistic** missiles developed by the two nations served as the basis for the only rockets big and powerful enough to **orbit** satellites into space. The launching rockets were mainly used to place government spacecraft into Earth orbit or towards the Moon or other planets. During the period of the late 1950s to early 1960s there were no commercial satellites in existence for which commercial launchers were needed. All spacecraft were owned by the civil or military part of the governments of the Soviet Union and the United States.

When foreign nations that were aligned with either country needed a satellite launch in the mid-1960s, the satellite was shipped to the launching site of the United States or USSR and launched. But eventually the technology of satellites matured to the point where other nations sought to have their own space programs. In Europe, the United Kingdom, France, and Germany each developed varying types of spacecraft that were launched by the United States from its existing sites at either Cape Canaveral in Florida or Vandenberg Air Force Base in southern California. Japan, Brazil, and China also developed satellite technology. Nations aligned with the USSR included Mongolia, China, and other Southeast Asian nations. France and China were among the first nations other than the United States and USSR to develop their own independent space-launching rockets. Japan developed a version of the U.S. Delta space booster under a licensing agreement with McDonnell Douglas Corporation, although the technology of the launching rocket was carefully protected by the United States.

The Development of Arianespace

Eventually, by the mid-1970s, Europe sought to develop a commercial means of launching European-made military, civil, and commercial satellites. The United States had begun the development of the partially reusable space shuttle during this period, and France was left out of the shuttle's development. In partial response, France and several European countries came together to establish the European Space Agency and an entity called the European Launch Development Organization. Among their first objectives was the development of a commercial space-launching rocket that would be entirely made within the nations that were part of the space organization. The company that emerged from that effort was named Arianespace, and its family of throwaway expendable rockets was called Ariane.

Ariane was unlike the Soviet R-7 and Proton rockets and U.S. Delta and Atlas rockets because it was not based on an existing ballistic missile design but was instead created from the start as a commercial launching vehicle. The company was established in March 1980 and conducted its first launch on May 24, 1984.

Arianespace has evolved to capture about half of the existing market for space launch services, conducting more than 130 commercial launches of different types of Ariane rockets by 2000. The company, based in France with a staff of 350 employees, launched forty-four satellites during a three-year period from 1995 to 1997, a world's record. In the first years of the twenty-first century, Arianespace was in the process of phasing out a smaller rocket called Ariane 4 and phasing in a larger replacement rocket called Ariane 5. At the end of 2001, Arianespace reported that it had contracts for

Arianespace of Europe is one of three firms that currently dominate the global launch services industry. The Ariane 4 rocket, seen here, is being replaced by the larger Ariane 5.

the launch of 216 satellites and nine automated flights of cargoes to the International Space Station. Its launching base is in Kourou, French Guiana, on Earth's equator.

The Rise of Delta and Atlas

In the United States, government-controlled launches of expendable rockets were to end in the early 1980s as the space shuttles became operational. By a national decision made by the National Aeronautics and Space Administration (NASA) in 1972, the shuttles were to become the sole means by which U.S. satellites of any type could be launched into orbit. The throw-away expendable rockets, all based on earlier generations of ballistic missiles, were to be completely replaced by the shuttles. But the development of the shuttle took longer and was both more expensive and less reliable than was promised. By the mid-1980s the U.S. Department of Defense, a major customer for space shuttle launches, elected to continue production of the Delta and Titan launching rockets as alternates to the shuttles for launches of military spacecraft. In 1985 President Ronald Reagan announced a shift in U.S. space policy that would allow both civil and government satellites to be launched on these expendable rockets as well as the shuttles.

Following the explosion of the space shuttle Challenger in January 1986, a further shift in policy diverted satellite launches away from shuttles entirely. The shuttles would launch only those satellites that could not be flown aboard any other vehicle. This policy shift in the mid-1980s would serve to reinvigorate the U.S. space launch industry, which had lost most of its share of space-launching services during the period when the shuttles were taking over the launching of all U.S. satellites.

Commercial versions of the Delta and Atlas rockets, partially funded by the Defense Department and NASA, soon entered service to compete against the Arianespace vehicles. McDonnell Douglas began offering a commercial Delta II rocket as a launching vehicle. General Dynamics Corporation and Convair Astronautics began selling larger Atlas rockets. A third commercial rocket based on the huge military Titan III booster was also sold commercially but only for a brief period. Its builder, Martin Marietta Corporation, could find only two customers before it was phased out. Titans were relegated to missions for the U.S. military.

Following the end of the Cold War in the early 1990s, the U.S. aerospace industry contracted through a series of mergers and acquisitions. Martin Marietta acquired the line of Atlas rockets, adding them to its stable of military Titan boosters. The Boeing Company acquired McDonnell Douglas and its Delta boosters. Eventually, Martin Marietta was itself acquired by Lockheed Corporation, forming Lockheed Martin Corporation. By the mid-1990s the U.S. launch industry was comprised of Boeing, Lockheed Martin, and a smaller firm called Orbital Sciences, which sold two smaller rockets, the winged Pegasus and the Taurus.

Russian Launchers

The changes wrought by the end of the Cold War affected the Soviet Union's space-launching programs as well. Commercial sales of the Proton rocket were conducted initially by a government-industry partnership called Glavcosmos in the early 1980s. But after the Cold War ended, Protons were made commercially available as part of the rocket catalog being assembled by Lockheed Martin. A separate firm called International Launch Services (ILS) was established in June 1995 to sell both Atlas and Proton rockets on the world's commercial market. ILS, jointly owned by the U.S. firm Lockheed Martin and the Russian rocket design companies Khrunichev, and Energyia, reported a backlog of $3 billion worth of rocket contracts in 2000 and conducted six Proton and eight Atlas launches during that year.

But the Proton rockets were not the only commercial launching vehicles available from Russian space factories. A modified version of the Russian Zenit rocket was being sold by a consortium comprised of Boeing, Ukrainian rocket firms, and a Norwegian company that builds drilling ships. The resulting company, called Sea Launch, launches the Zenit rockets from a floating launching pad towed to the mid-Pacific Ocean. Starting in 1999, Sea Launch began conducting annual launches with only one failure through 2001.

Yet a third commercial rocket is being marketed from Russia, and this one has an historic pedigree. The R-7 space booster, which launched the Sputnik 1 in 1957 and the world's first human in space, Yuri Gagarin, in 1961, is also for sale today. Starsem, a company partly owned by Arianespace, is selling the R-7 in various designs and launching them for customers from the same launching pads used in 1957 and 1961. Starsem officials say their business plan requires only one launch per year to be viable. Through 2001 the Starsem R-7 rockets, called Soyuz, have been commercially launched without any failures. Other versions of the Russian Soyuz rockets used by the Russian government carry cosmonauts to the International Space Station—and also carried space tourist Dennis Tito to the space station in April 2001.

Japan in Space Launch

Following the use of a licensed version of the Delta rocket, the Japanese government developed its own series of space launchers. In 1977 Japan began a series of studies aimed at creating a wholly Japanese-made commercial rocket. The first of the resulting rockets, called H-I, was flown in 1986, and eventually nine of the boosters were flown until 1992. A much larger rocket, called H-II, was developed for the Japanese government. While chiefly intended for Japan's own government satellites and other **payloads**, a commercial version was planned. Development of the H-II, however, was slowed by launch failures, and the program was terminated in 1999. It was replaced by the more advanced—and cheaper—H-IIA. The H-IIA made its first test flight in 2001 with commercial sales planned by 2003. This rocket would compete against the larger series of Delta, Atlas, and Ariane launchers.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

China Tries to Compete

China also has sought to develop commercial launching vehicles, with all of them based on the nation's early missile design programs. The Long March series of rockets, available in different sizes, each capable of lifting different types of satellites, became available in July 1990 following the first test flight of the Long March 2E. A second commercial vehicle, the 3B, was also offered for commercial flights. American satellites using the Long March as launching vehicles require special export licenses. Geopolitical issues have also occasionally made sales of the rocket difficult or impossible for Western customers. Several spectacular failures of the vehicles have also hampered sales. By 2001, however, advanced systems had restored the Long March to flight without failure, and a larger version began launching test versions of a future Chinese piloted space capsule. Chinese government officials have indicated that systems from the space capsule versions will be used on commercially available craft, further strengthening China's position as a provider of space launch services.

India Enters the Fray

polar orbits orbits that carry a satellite over the poles of a planet

The Indian government has also been developing a family of space launch vehicles that will also be offered for commercial sales. The PSLV and GSLV expendable rockets have been tested for launching satellites into **polar orbits** as well as launching larger commercial communications craft. A successful flight of the GSLV occurred in 2001. India has created a commercial company to market the GSLV, but a flight rate of only one or two a year is expected by around 2005.

Other Competitors in the Industry

Brazil planned to also develop and market a smaller commercial rocket called the VLS. A launch failure, however, placed the project's future in doubt. Israel also has developed a commercial rocket, adapted in part from its ballistic missile program. Thus far, launches of the rocket, called the Shavit, have been limited to Israeli satellites. Efforts to base the Shavit at launch sites other than in Israel have not been successful. Pakistan and Indonesia have expressed interest in developing space-launching rockets, but neither has yet developed a final configuration for commercial sales. The Indonesian government made an announcement in 2000 that development of a commercial space booster was a major priority, but no reports have been seen as to the project's fate. North Korea claimed a test flight of a satellite launcher in 1998. Many Western observers believe, however, that the rocket is a ballistic missile and is not yet in a launch vehicle design configuration.

Russia has several new designs of expendable rockets on the drawing boards, including a rocket called Angara that may replace the Proton for commercial sales late in the new century's first decade. In 2001 the United States began fielding a new family of rockets called the evolved expendable launch vehicle (EELV). Both Boeing and Lockheed Martin were selling EELV versions, called the Delta IV and Atlas V, respectively.

Since the failed attempt at selling commercial launching services aboard the space shuttles, no nation has yet offered launches aboard a reusable launch vehicle. Many companies are hard at work in the United States and Canada, trying to be among the first to offer commercial launching services for space tourists or others aboard a reusable craft. With changes continuing to affect the space industries of the world, and new technologies in development, no one can predict the future direction of the space launch industry. The people and equipment seeking rides to space are as varied—and unpredictable—as the evolution of the rocket itself. SEE ALSO AUGUSTINE, NORMAN (VOLUME 1); GLOBAL INDUSTRY (VOLUME 1); LAUNCH FACILITIES (VOLUME 4); LAUNCH SITES (VOLUME 3); LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); SATELLITES, TYPES OF (VOLUME 1); SPACEPORTS (VOLUME 1).

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Launch Services

Commercial launch services are used to place satellites in their respective orbits. Launch services represent, by far, the most lucrative aspect of the launch-for-hire business. The European Space Agency (ESA), United States, Russia, People's Republic of China, India, and some international organizations supply or plan to supply launch vehicles for the purpose of placing satellites in orbit. Although the majority of launch vehicles are used for

A Delta rocket lifts off at Cape Kennedy carrying the world's first commercial communications satellite, Early Bird. The satellite, launched in 1965, was intended to operate as a switchboard relaying radio, television, teletype, and telephone messages between North America and Europe.

broadcast satellites, satellites are also launched for wireless telephony. For example, the mobile communications systems Globalstar and Iridium Satellite LLC are cell phone satellite networks for global use.

Europe

By 2000 the ESA's Arianespace Consortium had 125 launchings of orbit communications satellites (comsats). The basic first stage of a launch vehicle has four liquid propellant engines, but the Ariane launch vehicle has great versatility because of the number of engines that can be attached to its first stage. Two solid or two liquid propellant or two solid and two liquid propellant or four liquid propellant engines can be added to the first stage. This permits a wide variety of payloads to be placed in orbit. Arianespace also operates a heavy-lift rocket, the Ariane 5, which is intended mostly for commercial use but can be used for other purposes: the launching of scientific and military spacecraft, for example.

United States

In the United States two companies dominate the launching business, Lockheed Martin (LM) and Boeing. LM supplies the various configurations of the Atlas/Centaur launch vehicle, and Boeing offers the Delta class of launch vehicles, including Delta II, Delta III, and Delta IV. The mass of payload that each Delta can lift into **orbit** distinguishes them from other launch vehicles. The Delta vehicles can have various additional solid propellant engines attached to their first stage, allowing still further variations in payload-lifting capability. For example, three or six or nine solids may be attached to the first stage of the Delta II.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

LM's Atlas/Centaur can have variations in the type of first stage engines used or the size of first stage propellant tanks. LM has a business arrangement with the Khrunichev and Energia companies of Russia for the manufacture and use of a rocket engine developed by Russia that will be used in the first stage of the Atlas. It will be a replacement for the less powerful engines that have been used in the past.

In conjunction with Russian companies, LM uses the Russian four-stage Proton launch vehicle to launch payloads mostly to **geosynchronous orbit**. Proton has also been used to launch Iridium satellites, seven at a time, into a 800-kilometer (480-mile) orbit.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Russia

The Russians use their Proton launch vehicle for their own launches as well. In addition, a French-Russian company called Starsem uses the Russian Soyuz to launch commercial payloads. Soyuz is a modification, largely in its upper (third) stage, of the launch vehicle used to send cosmonauts to the Mir space station.

Eurokot, a German-Russian organization, uses modified Russian intercontinental ballistic missiles, known in the Western world (i.e., the North Atlantic Treaty Organization [NATO]) as the SS-19, Stiletto, to place payloads in **low Earth orbit**. All stages of these are made of solid propellants. They are launched from silos buried deep in the ground (like the U.S.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

The European Infra-Red Space Observatory (ISO) was launched by the Ariane 44P from Kourou space center in French Guiana in 1995. The launch was the rocket's eightieth.

Minuteman missiles). They have seen very limited use for payloads of about two tons, which means they are restricted to launching wireless telephony satellites and other small payloads.

Russia is developing a new series of rockets called Angara, which are intended to replace many of Russia's present stable of launch vehicles both for commercial and private use. The payload capability can range across the entire spectrum of currently available Russian rocketry and extend beyond to larger payloads.

China

The People's Republic of China has developed a series of rockets, all called Long March. The rockets range from a two-stage Long March 2C used to launch a pair of Iridium satellites to the three-stage Long March 3B used for launching comsats to geosynchronous orbit. China's ability to launch comsats, most of which are manufactured in the United States, has been hampered by political differences between the two countries. During the period 1998 to early 2000 very few U.S.-built satellites were exported to China for launching because of changes in U.S. export controls for space hardware.

Other International Organizations

A number of other launch vehicles are available which have seen limited use in very specific areas. The Pegasus and Taurus, built by the Orbital Sciences Corporation of the United States, have launched small payloads of 400 kilograms (880 pounds), among which have been clusters of seven small comsats used for the transmittal of data for business.

The country of Ukraine together with a division of Boeing, the Russian Energia Company, and the Norwegian company Kvaerner Maritime (a ship and oil rig builder) have formed Sea Launch. Sea Launch consists of a command ship, a former oil rig converted to a seagoing launching platform, a two-stage rocket called Zenit, and a third stage for the Zenit. The platform and the ship are based at Long Beach, California, and travel to longitude 154 degrees west on the equator for launching. This procedure takes advantage of Earth's rotation speed, thus adding 1,524 feet/second at the equator for the Zenit 3SL, either reducing the amount of propellant needed or permitting an increase in payload weight. Sea Launch has successfully flown a simulated payload and has launched five commercial communications satellites.

Reusable Launch Vehicles

The only reusable rocket to date is the U.S. space shuttle. The system that launches it is only partially reusable because the large tank holding liquid propellant is discarded after each launching and the solid rockets that are recovered from the ocean need extensive refurbishment at considerable expense before their reuse. Reusability is a much desired but not a realized concept. There have been paper studies, but nothing has been fully tested, leaving the commercial worth of reusable launch vehicles still in question.

SEE ALSO Launch Facilities (volume 4); Launch Industry (volume 1); Launch Sites (volume 3); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Rockets (volume 3); Spaceports (volume 1).

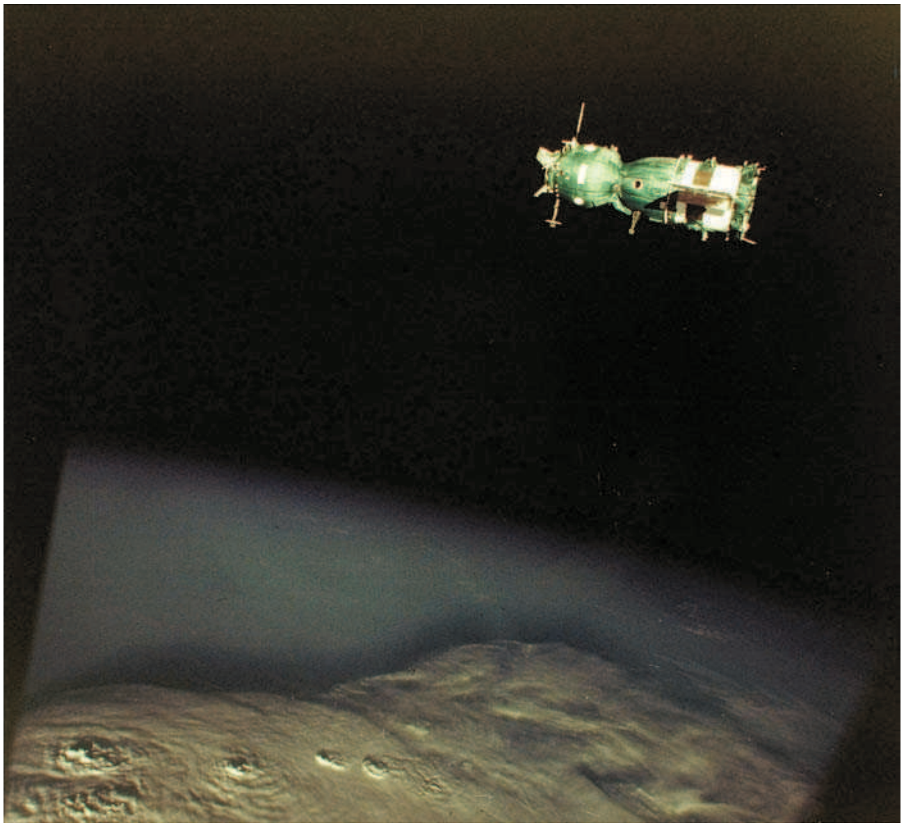
Saunders B. Kramer

Internet Resources

Arianespace. <http://www.arianespace.com>.
Boeing. <http://www.boeing.com>.
Lockheed Martin. <http://www.lockheedmartin.com>.

Launch Vehicles, Expendable

Expendable launch vehicles (ELVs) are rockets that carry satellites, people, and space probes but are not recovered or reused. These rockets are ex-



The Soviet Soyuz spacecraft as photographed from the American Apollo spacecraft in Earth orbit in July 1975. The three major components of the Soyuz craft are easily visible: the Orbital Module (sphere-shaped), the Descent Vehicle (bell-shaped), and the Instrument Assembly Module (cylinder-shaped).

pendable, meaning that they are thrown away after their flights are completed. Expendable rockets can take many forms, but the most commonly used ones are powered by either liquid fuel or solid fuel and use multiple stages to propel their cargoes of spaceships, probes, or satellites into outer space.

Each of the rocket's stages consists of a self-contained rocket engine or motor and the fuel such as hydrogen, kerosene, or a solid fuel that looks a lot like the eraser on a pencil. Along with the engine and fuel are tanks to hold the materials, lines and pumps, and electrical systems to move the engine while in flight. Once the fuel in the stage has been used up, the stage is usually dropped away and the next stage ignited. These rockets continue to burn stage by stage until the right altitude or speed for its designated space mission has been reached.

Evolution from Military Missiles

Expendable rockets are used today by the United States, France, China, Brazil, Russia, India, and Israel to place satellites into Earth **orbit** and toward the Moon and planets. Most of the rockets now in use as launching vehicles evolved from missiles developed during military conflicts such as World War II (1939–1945). Beginning with a German missile called the V-2, these weapons were created to carry large high-energy explosives to hit cities or troop encampments. Later, after World War II ended, larger

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object and more powerful missiles were created to carry nuclear weapons to targets on the other side of Earth.

Two nations, the United States and the Soviet Union, were the first to develop these large bomb-carrying missiles. After World War II ended, the German scientists who designed the V-2 missile fled Germany. Some of them surrendered to the United States, while others escaped to the Soviets. Each group of German scientists, engineers, and technicians sought to continue the development of rocketry and missiles in their new countries. In the Soviet Union, missile development was made a top priority by the Communist government. Part of the reason for the emphasis on missiles was the Soviet Union's lack of jet-powered bombers that could carry atomic bombs from Russia to targets in the United States. If large missiles could be built successfully, they could carry the bombs to their targets.

In America, Wernher von Braun headed the group of German rocket and missile experts. Von Braun was the head of the German missile program and was considered to be the most advanced expert on rocketry designs during and after the war. In the Soviet Union, his counterpart was Sergei Korolev, who was designated by the Soviet government as the "Chief Designer" of human-carrying and large expendable rockets.

Korolev became the head of a large central design bureau, and his "customers" were the specific missions assigned to his bureau. These included the design, manufacture, and test of the first Soviet intercontinental **ballistic** missile, the R-7; the first- and second-generation human-carrying space capsules, called Vostok and Soyuz; and a series of larger and more advanced liquid-powered expendable rockets, called Proton and N-1. These latter rockets were to be used in the Soviet lunar-landing program. The original purpose for the Proton, however, was as a very large missile that could fly from Russian bases and attack targets in the United States. The missile version of Proton was never developed, and instead it became a launching rocket for heavy **payloads** and space probes to the planets. Proton was also designated as the carrier rocket for the Soviet piloted lunar space capsule, called Zond.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

In America, von Braun developed a series of liquid-fueled rockets called Juno and a large army missile called Redstone. These rockets were adapted for scientific space missions by von Braun's team working at the Redstone Arsenal in Huntsville, Alabama. By emplacing a small basket of solid rockets on the nose of the Juno II, von Braun was able to insert a small U.S. satellite into Earth orbit on January 31, 1958, marking the first U.S. artificial Earth satellite. Korolev did the same with the R-7, launching the Sputnik satellite three months earlier, on October 4, 1957.

Improvements to U.S. and Soviet Rockets

Increasingly, both the United States and the Soviet Union made improvements to their missiles that made them capable satellite and space capsule launchers. The U.S. equivalent to the Soviet R-7 was an intercontinental ballistic missile named Atlas. Developed initially for the U.S. Air Force to carry atomic warheads to targets in the Soviet Union, the air force and the newly created National Aeronautics and Space Administration (NASA) modified the missile's design to replace its bomb-carrying nosecone. In the nosecone's place, with reinforced nose sections, the Atlas could carry an ad-

Expendable rockets similar to this Ariane 4 rocket are critical to civil, military, and commercial satellite launches.

ditional liquid-fueled rocket stage that could send payloads—satellites, capsules, or space probes—into orbit or to the Moon or Mars.

In 1959 the Atlas missiles were modified to carry Project Mercury one-person space capsules, just as Korolev had done with the R-7 and its Vostok and Soyuz capsules. Eventually the Atlas and R-7 each received more powerful engines and larger upper stages. While the Mercury and Vostok projects have long since ended, both the Atlas and R-7 rockets are still in service, using advanced subsystems and powerful upper stages. Both are being sold today on the commercial space launch market, competing with each other for commercial sales.

The Atlas and R-7 were not the only throwaway rockets to evolve during the Cold War. The United States took a smaller and more limited intermediate range rocket called the Thor and adapted it for launching scientific space probes, beginning in 1960. Eventually the Thor grew to become, under the name Delta, one of the most reliable space launchers in history. In its Delta II, III, and IV variants it is still in government, military, and commercial use today.

Von Braun also developed the only U.S. throwaway rocket that was created from scratch and not evolved from missiles. From October 1961 until May 1973 three versions of a rocket called Saturn were used by NASA to support the man-on-the-Moon program called Project Apollo. The larger of these rockets, the Saturn V, sent Apollo astronauts to the surface of the Moon from 1969 to 1972 and lifted America's first space station, Skylab, in May 1973. Skylab itself was developed from the upper stage of the Saturn V rocket.

Briefly, the Soviet Union developed an expendable rocket called Energyia that was not developed from a missile. It flew in 1988 and 1989, in one flight carrying the unpiloted Buran space shuttle. The collapsing economic situation in Russia forced the abandonment of the Energyia program after those two flights.

The Evolution of Other Nations' Expendable Rockets

The launch vehicles used by China also evolved from ballistic missile designs. But the expendable rockets developed and flown by Japan, Brazil, and India are all new designs that had no direct missile ancestor, although all were strongly influenced by missile systems in use at the time. Israel's expendable rocket, a small booster named Shavit, is believed to have evolved from that nation's Jericho missile program.

France's fleet of commercial Ariane rockets were also created entirely apart from any missile project. Since 1979, Ariane rockets have been launching commercial satellites for customers worldwide, French military and government payloads, and payloads for the European Space Agency and the French Space Agency, CNES.

Today, expendable rockets are the mainstay of civil, military, and commercial satellite launches. The R-7 is still flying as the booster that lifts the Soyuz piloted space capsules. A commercial version is also for sale, flying from the same launching pad where the first satellite, Sputnik 1, and the first human, aboard Vostok 1, were launched in 1957 and 1961, respectively. The U.S. Atlas and Delta rockets are expected to be flying well into the twenty-first century, as are the Chinese missile-derived space boosters. The era of the expendable rocket may prove to be a long one in the evolving history of the space age. SEE ALSO LAUNCH FACILITIES (VOLUME 4); LAUNCH VEHICLES, REUSABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4); ROCKETS (VOLUME 3); SPACEPORTS (VOLUME 1); VON BRAUN, WERNHER (VOLUME 3).

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Launch Vehicles, Reusable

A reusable launch vehicle (RLV) is a craft designed to place **payloads** or crews into Earth orbit, and then return to Earth for subsequent launches. RLVs are designed to reduce launch costs by reusing the most expensive components of the vehicle rather than discarding them and building new

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The aim of the X-34 program was the development of low-cost space access through reusable launch vehicles.

ones for each mission (as is the case with expendable launch vehicles, known as ELVs). The definition of RLVs does not include reusable craft launched from expendable launch vehicles. As of 2001, the only operational RLV was the U.S. space shuttle. A number of concepts were being developed or studied. Some were partially reusable. Most employed rockets, while others used jet engines, aircraft, or high-speed rail systems.

RLVs may be categorized by whether the vehicle takes off horizontally or vertically and whether it lands horizontally or vertically. An RLV may also be described as single-stage-to-orbit (SSTO) or two-stage-to-orbit (TSTO). Vehicles such as the space shuttle, which takes off vertically using a two-stage system and lands horizontally, have the easiest design because horizontal takeoff involves more demanding flight loads, vertical landing requires the craft to carry enough propellants to land, and SSTO requires a higher ratio of propellant to vehicle weight. Nevertheless, the economics of preparing a single stage, rather than two stages, have kept space engineers interested in SSTO designs. Future RLVs also are expected to employ more advanced, reliable systems, making them safer than expendable launch vehicles, and thus allow launches from inland sites (i.e., no stages to splash down into the ocean), perhaps even airports, where weather is less of a concern than at coastal spaceports.

Early Concepts

Because it was easier to adapt existing military missiles, which are designed for a single flight, most launchers have been expendable. Nevertheless, space visionaries have often focused on RLVs. One of the most significant early concepts was a three-stage vehicle designed by German-born American engineer Wernher von Braun in 1952 and popularized in his book *Across the Space Frontier*. The first two stages would parachute into the ocean for recovery while the winged third stage, carrying crew and cargo, landed like an airplane. The 1951 movie *When Worlds Collide* depicted a rocket-powered sled that gives a vehicle its initial boost.

Several RLV concepts were advanced in the 1960s. Notable among these was a reusable design by a man named Philip Bono, then with Douglas Aircraft Company. His design comprised a core vehicle holding a payload bay, liquid oxygen tank, and a ring of small rocket engines around the base. Liquid hydrogen was carried in external tanks that could be hinged outward to enhance atmospheric control during entry. This unique engine arrangement followed the aerospike concept developed by Rocketdyne. In this approach, the pressure from the shock wave produced by the vehicle's high-speed ascent becomes the outer wall of the engine nozzle from which the exhaust streams. The resulting exhaust appears to be a spike of hot gas, thus leading to the nickname "aerospike."

In the late 1960s the U.S. aerospace industry offered a number of reusable designs as the National Aeronautics and Space Administration (NASA) sought ways to reduce the cost of space launches. Maxwell Hunter, then with Lockheed Missiles & Space Co., proposed a wedge-shaped reusable vehicle with main engines in its tail, and a large external tank that was shaped like an inverted V and was wrapped around the nose of the vehicle. The tank would be discarded after its propellants had been consumed, leaving the main body to return to Earth.

Space Shuttle

Following the Apollo 11 Moon landing in 1969, NASA proposed a space program that would provide the basic building blocks in support of a wide range of human space missions: a space shuttle, a space station, a space tug, and a nuclear interplanetary stage. In this plan, the space shuttle was a fully reusable vehicle. The booster would fly back to the launch site after launch, and the orbiter at the end of the mission; both would be quickly prepared for the next mission. NASA soon realized that such a massive craft would cost more than it could afford. A series of redesign efforts traded the high development cost and low per-flight cost of the original design for a lower development cost and a higher per-flight cost. Literally dozens of variations were studied before arriving at the final design. One interesting variation employed two piloted flyback boosters and a piloted orbiter outwardly identical to the boosters. The concept was to reduce costs by designing one airframe for two purposes. This design meant, however, that three vehicles had to be prepared for each launch. The Soviet Union largely copied the final space shuttle design for its Buran shuttle, which flew only once.

Advanced RLVs

Even before the shuttle started flying, designers continued to look at advanced reusable concepts, such as North American Rockwell's immense winged StarRaker, which was envisioned as taking off and landing like a jetliner. The SSX (Space Ship eXperimental) proposed by Hunter in 1984 was based on an earlier design of a passenger vehicle. Hunter's efforts helped lead to a U.S. Department of Defense (DoD) project that opened the current reusable era. The DoD's purpose was to design a single-stage vehicle that could orbit military replacement satellites during a national emergency.

NASA and several private ventures have initiated the development of reusable launch vehicles, such as this artist's concept of an express rocket, for the promotion of space tourism.

McDonnell Douglas Corporation was contracted to build and test fly the DC-X, a one-third-scale suborbital model of the Delta Clipper, a larger version that would launch satellites on short notice. While not capable of spaceflight, the DC-X incorporated many of the technologies needed for an SSTO vehicle, including highly automated systems enabling a quick turnaround (just twenty-six hours) between launches. It made eight successful test flights between August 18, 1993, and July 7, 1995, and then was taken over by NASA and flown four times as the DC-XA between May 18 and July 31, 1996. It was destroyed on its last flight when one landing strut failed to deploy and the vehicle tipped over at landing.

The DC-X led NASA to a broader launch vehicle technology program to reduce the cost of putting a payload in space from $22,000 per kilogram ($10,000 per pound) to $2,200 per kilogram ($1,000 per pound) or less. The principal programs as of the early twenty-first century were the X-33 and X-34. The X-33 was a one-third-scale test model of the Lockheed Martin concept for VentureStar, an automated vehicle capable of launching up to 18,650 kilograms (50,000 pounds). In operation, VentureStar would launch, orbit, and land much as the shuttle does, but without discarding boosters or tanks. Other major differences include systems that can be readied for reflight with less maintenance (or no maintenance) than the shuttle requires. Significant structural and other problems raised the cost of the X-33 project and in 2001 NASA canceled the project. Also canceled was the X-34, a demonstration vehicle built largely from commercially available parts. It would have been launched from a jumbo jet, flown to an altitude of 76,200 meters (250,000 feet) and then glided to Earth for landing. It, too, encountered severe technical problems.

In place of the X-33 and X-34 programs, NASA initiated the Space Launch Initiative (SLI) program to study more conventional two- or three-stage-to-orbit second-generation RLV, possibly using the aerospike engine concept, which looked promising in the X-33 project. The important underlying features would be new electronics and materials that would allow automated preparation and checkout of vehicles and more rapid launches, and highly automated manufacturing processes. Goals include reducing the risk of crew loss to once per 10,000 missions, and the cost of launches to less than $1,000 per pound of payload in orbit. Beyond the second-generation RLV, NASA is looking at advanced space transportation concepts that could realize the earlier dreams of combining jet rocket combustion cycles in a single power plant, use electromagnetic railways as an Earthbound booster stage, or even laser- and microwave-powered craft.

In addition to NASA's efforts, several private ventures have initiated activities to develop RLVs for business, including space tourism. Most have stalled or failed for lack of financial backing. The Roton, conceived by Rotary Rocket, would employ high-speed helicopter blades to provide controlled flight following reentry (a concept studied by NASA in the 1960s). The vehicle would have a two-person crew, would launch vertically, and could place a 2,600-kilogram (7,000-pound) payload into orbit.

In 1996 the X PRIZE was announced. Like the Orteig prize, which stimulated aerial flight across the Atlantic Ocean (and was won by Charles Lindbergh with the first nonstop New York–Paris flight in 1927), the X PRIZE is intended to stimulate nongovernmental space travel, including tourism. It will award $10 million to the first entrant that achieves a nongovernmental, suborbital flight reaching 100 kilometers (62 miles) in altitude with pilot and payload equivalent to three people total, and makes a repeat flight within two weeks. Burt Rutan, creator of the Voyager round-the-world aircraft, is designing the Proteus vehicle, which will air-launch one of the competing spacecraft. SEE ALSO Launch Services (volume 1); Launch Vehicles, Expendable (volume 1); Reusable Launch Vehicles (volume 4); Rockets (volume 3); Spaceports (volume 1); von Braun, Wernher (volume 3); X PRIZE (volume 1).

Dave Dooling

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Law of Space

The law of space is the field of the law that relates to outer space or outer space-related activities conducted by governments, international organizations, and private individuals. International space law governs the activities of states and international organizations, whereas domestic, or national, space law governs the activities of individual countries and their citizens. Both areas of space law govern the activities of private persons and businesses.

International Space Law

Soon after the launch of the Soviet satellite Sputnik in 1957, the United Nations became active in the creation, development, and implementation of a system for studying the legal problems that may result from the exploration and use of outer space. Since the establishment of the United Nations Committee on the Peaceful Uses of Outer Space in 1958, five major multilateral treaties and conventions have been adopted or ratified by many countries to establish the framework to address concerns about outer space matters:

1. The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (1967), commonly known as the Outer Space Treaty, established basic principles regarding outer space and its exploration and use, including the conduct of activities pursuant to international law;
2. The Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (1968), commonly known as the Rescue Agreement, safeguarded the prompt return of astronauts to the host country;
3. The Convention on International Liability for Damage Caused by Space Objects (1972), commonly known as the Liability Convention, established an international legal regime to assess liability and compensation for damage, injury, or death resulting from space activities and objects;
4. The Convention on Registration of Objects Launched into Outer Space (1976), commonly known as the Registration Convention, provides for a centralized registry of space objects maintained by the Secretary General of the United Nations; and
5. The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (1979), commonly known as the Moon Agreement, declares the Moon to be the "common heritage of all mankind." It has not been ratified by states that have or are likely to develop the ability to **orbit** around or land on the Moon.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

These treaties provide the framework for international space law. Their principles and provisions relate to the exploration and use of outer space and are binding upon the countries that have ratified them. Together, these principles and provisions guide countries that have not ratified the international treaties. Space law includes international arms control treaties that

The United Nations has developed international treaties that act as space law for most countries.

prohibit or restrict the deployment or use of certain rocket and missile weapon systems. Space law also includes agreements, treaties, conventions, rules and regulations of nations and international organizations, executive and administrative orders, and judicial decisions.

The International Telecommunications Union (ITU), an agency of the United Nations, is the world's regulatory body for the coordination and regulation of the radio frequency spectrum and the space-based and land-based facilities that provide global telecommunications services. Nearly every country in the world is a member of the ITU. The launching of commercial satellites, particularly those that provide telecommunications services, is the most common space activity. The ITU's management of the orbital positions of these satellites and prevention of harmful interference caused by radio frequency transmissions are accomplished by the adherence of the member countries to the provisions of the International Telecommunication Convention (1973).

In the United States the Federal Communications Commission is the regulatory authority for private, commercial, and state and local government use of the radio frequency spectrum. The commission controls the licensing of space satellites and ground Earth stations and regulates their use of radio **frequencies** to ensure that telecommunications services are free from interference by other transmissions.

frequency the number of oscillations or vibrations per second of an electromagnetic wave or any wave

Domestic Space Law

Launches of commercial satellites for telecommunications, **remote sensing**, and **global positioning systems** are governed by the regulatory regimes of the countries that conduct those launches. As the launching state, a country that has launched a rocket or missile is liable under the international treaties for any damage caused by the launch activity to third parties. Each launching state's domestic regulations also address the responsibilities and liabilities of the launching entity.

remote sensing the act of observing from orbit what may be seen or sensed below Earth

global positioning system a system of satellites and receivers that provide direct determination of the geographical location of the receiver

The conduct of space launches from U.S. territory or by U.S. citizens or businesses from anywhere outside the national territory is governed by the Commercial Space Launch Act of 1984. This act supplies the legal framework for the relationship between the government and the commercial space launch industry. The act directs the secretary of transportation to regulate space transportation and streamline the licensing process for commercial space activities pursuant to international treaty obligations and national policy. This statute is implemented by the Office of the Associate Administrator for Commercial Space Transportation of the Federal Aviation Administration. Commercial launch providers are required by the act to obtain insurance for death, injury, or property damage suffered by third parties. If an accident occurred during the launch activity, the U.S. government would pay any international claims in excess of the insurance level.

Other laws of the United States apply to the operation of private remote sensing satellites (the Land Remote Sensing Commercialization Act of 1984); the encouragement of commercial activity on the space station and government purchases of commercially produced scientific data (the Commercial Space Act of 1998); the protection of intellectual property and the patenting of inventions made, used, sold, or practiced in space (Public Law 101-580 on Inventions in Outer Space, 1990); and attempts to minimize the amount of orbital debris (the National Aeronautics and Space Administration Authorization Act, 1994 and 1995).

As the space industry has expanded from a niche market benefiting a limited high-tech scientific and military base to a global concern affecting geographically dispersed industries and consumers, the scope of space law has grown. From the initial steps of establishing the principles for the exploration and use of outer space by nations and governments, space law in the twenty-first century encompasses rational and reasonable approaches to representing the demands of persons in virtually every part of the world for enhanced communications, education, entertainment, environmental, and transportation services. As space commerce grows, space law will continue to address the unique problems posed by commercial activities in space. SEE ALSO CAREERS IN SPACE LAW (VOLUME 1); LAW (VOLUME 4); LEGISLATIVE ENVIRONMENT (VOLUME 1); REGULATION (VOLUME 1); SPACEPORTS (VOLUME 1).

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Legislative Environment

When Congress created the National Aeronautics and Space Administration (NASA) in 1958, it did not consider the need to commercialize space. At the time, the United States was fighting the Cold War against the Soviet Union. The purpose of the new space agency was to bring together America's many space programs to compete with the Soviet Union, which had launched the first satellite into orbit.

NASA's missions, as defined by Congress, were to expand human knowledge of Earth and space, to preserve America's role as a leader in "aeronautical and space science and technology," and to cooperate with other nations in the pursuit of these goals. Not until 1984 did Congress add the requirement for NASA to "seek and encourage to the maximum extent possible the fullest commercial use of space."

The Legal Framework to Support Commercial Space Activities

The legal framework to support commercial space enterprises gradually evolved in response to the development of space technologies and the maturing of space industries. The U.S. Defense Department set the first major space business into motion by launching the Satellite Communications Repeater (SCORE) in 1958. The orbiting vehicle could receive and record audio signals from ground stations, then rebroadcast them to other locations around Earth, creating a rudimentary global communications delivery system.

Arthur C. Clarke was the first to suggest using space to facilitate communications. In 1945, in a paper titled "Extraterrestrial Relays," Clarke proposed a three-satellite constellation, placed in **geosynchronous orbit** 35,786 kilometers (22,300 miles) above Earth, in which the satellites could send and receive audio signals. Although SCORE operated only two weeks before its batteries died, it validated the concept of space communications and opened the way for private industry to build a network in space.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Private industry subsequently developed two communication satellites, Telstar and Relay, which NASA launched in 1962. The satellites were powered by solar cells and relayed telephone, television, and data signals between ground stations on Earth. The success of the new technology led Congress to pass the Communications Satellite Act—the first commercial space legislation. The act established the Communications Satellite Corporation (Comsat), a partnership between government and private industry that in turn brought 12 other countries into a consortium to fund and operate a nonprofit global communication satellite network dubbed Intersat.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

The creation of additional satellite communication networks followed, including Eurosat, Arabsat, and Inmarsat. Government was involved in all these systems. Not until 1974 did private industry place into **orbit** a purely commercial satellite—Westar—which was financed by Western Union. The

The U.S. Congress, forty-three years after creating the National Aeronautics and Space Administration in 1958, seeks to commercialize space.

satellite offered video, audio, and data services. Soon after, RCA launched Satcom, designed with solid-state transmitters.

At the beginning of the twenty-first century there were some 500 satellites orbiting Earth. In addition to communications, satellites are used for remote sensing, navigation, and military purposes. The Federal Communications Commission licenses communication satellites.

Facilitating Commercial Payloads

Space launch vehicles, like satellites, were originally developed in partnership with the federal government. Until 1984 U.S. private industry relied on NASA to boost commercial **payloads** to space. With the passage of the Commercial Space Act, NASA was removed from the launch business—except for the space shuttle—and the industry was allowed to operate as a commercial enterprise. Thereafter, satellite producers could contract directly with launcher providers to deliver payloads to space. To ensure public safety, the government requires all launches to be licensed. Originally, this was the responsibility of the Department of Transportation, but it was later transferred to the Office of Commercial Space Transportation at the Federal Aviation Administration.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Commercial space enterprises have grown to include remote sensing. From space, satellites can collect spectral data that has commercial applications in such fields as natural resource management, urban planning, and precision agriculture. The licensing of remote sensing satellites is the responsibility of the National Oceanic & Atmospheric Administration.

The Commercial Space Act of 1998

In 1998 Congress passed a series of amendments to the Commercial Space Act to further promote the commercial development of space. One provision authorized the licensing of space vehicles that re-enter the atmosphere—a response to the development of **reusable launch vehicles**. The legislation encouraged the commercial purchase of remote sensing data for science applications, instead of reliance on government employees to build and gather such data. It also required NASA to establish a market-based price structure for commercial enterprises aboard the International Space Station (ISS).

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

NASA and the Department of Defense

Congress annually enacts legislation to fund NASA and space programs in the Department of Defense (DoD). These bills often contain policy directives. For instance, legislation in 1999 to fund NASA included a provision to allow the space agency to retain funds generated from commercial activities on the ISS.

Jurisdiction over NASA and DoD space programs is spread among several congressional committees. The Armed Services Committees in the House and the Senate consider policy issues involving defense space programs. Oversight of NASA is the responsibility of the Science Committee in the House and the Commerce Committee in the Senate. The Appropriations Committees in both the House and Senate provide funding for space programs.

Finally, the president issues legal directives that affect the development of space commerce. Presidential order has increasingly opened to the public the Global Positioning System (GPS), a constellation of navigational satellites built for military purposes. For instance, on May 1, 2000, President Bill Clinton directed the military to stop scrambling GPS signals, thereby improving the accuracy and marketability of commercial GPS devices.

The president and Congress annually determine how much the federal government will spend on space research and development. The presidential administration submits to Congress comprehensive budget plans for NASA and the DoD space programs that contain proposed funding for individual research and development projects. Congress reviews and often changes the amounts requested. In seven of its eight years, the Clinton administration cut NASA's budget. Congress, during the Clinton years, generally supported additions to the budget, but not enough to reverse the general downward trend.

In 1998 revenue generated from space commerce eclipsed, for the first time, the investment in space from government. This trend is expected to continue, with government increasingly moving to the sidelines and private industry leading the way in the development of space. New regulations and legislation will be needed to provide a clear legal framework for the expansion of space commerce. SEE ALSO Clarke, Arthur C. (Volume 1); Law (Volume 4); Law of Space (Volume 1); Regulation (Volume 1); Spaceports (Volume 1).

Bill Livingstone

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Licensing

All commercial launches (or re-entries or landings) conducted by a U.S. company are regulated by the Commercial Space Launch Act (CSLA) of 1984 and its 1988 and 1998 amendments. Under the CSLA, each launch (or re-entry) must have a license. This is true even when launching offshore, as is the case with Kistler Aerospace, which is headquartered in Seattle but launches in Australia, or Sea Launch, a venture composed of Boeing, a Russian company, and a Norwegian company that launches from a ship. These regulations are an outcome of the United Nations's 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, which places responsibility for any liabilities that might result from a space launch and/or reentry (for instance, if a person or building is hit by a spent rocket stage) on the launching state.

To assure "the public health and safety, safety of property, and the national security and foreign policy interests of the United States," Congress enacted the CSLA and established FAA/AST. The Office of the Associate Administrator Commercial Space Transportation (AST), is part of the Federal Aviation Administration (FAA). Its web site, ast.faa.gov, lists all relevant rules, laws, regulations, and documents necessary to obtain a launch license.

FAA/AST is organized as the Office of the Associate Administrator (the headquarters office of AST); the Space Systems Development Division (SSDD); and the Licensing and Safety Division (LASD). SSDD develops regulations and policy and provides engineering support and forecasting; LASD is the organization that actually evaluates applications and issues licenses. Helping advise FAA/AST is an industry group, the Commercial Space Transportation Advisory Committee (COMSTAC), which FAA/AST established and sponsors. COMSTAC meets quarterly. FAA/AST also licenses spaceport operators (and their spaceports), such as at Cape Canaveral, Florida, and at Vandenberg Air Force Base, California.

FAA/AST officials encourage those seeking a launch license to meet with the organization in "pre-licensing consultations" before submitting an actual license application. FAA/AST conducts a policy review, a **payload** review, a safety evaluation, an environmental review, and a financial responsibility determination based on the data in the license application. It contacts the applicant if it needs more data or if it requires the applicant to change something to qualify for the license.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Once the official application arrives, FAA/AST has 180 days to issue a license. Since 1984 officials have issued the license in almost every case. There have been only two or three exceptions, and in these cases FAA/AST initially rejected the application because of technical lapses. Once applicants made corrections, the FAA/AST granted the license and the rocket flew. After FAA/AST issues a license, it monitors the licensee through launch to assure compliance with regulations and requirements. SEE ALSO Law (volume 4); Law of Space (volume 1); Legislative Environment (volume 1); Regulation (volume 1).

Timothy B. Kyger

Internet Resources

Federal Aviation Administration. <http://ast.faa.gov>.

Literature

Long before Sputnik 1 became humankind's first orbiting spacecraft in 1957 and before the first astronauts landed on the Moon in 1969, science fiction and science fact writers provided the theories, formulas, and ideas that gave birth to space travel. Some of these thinkers and storytellers wrote fancifully. Others expressed their ideas in precise mathematical equations with intricate scientific diagrams. All of them succeeded in helping to make space travel a reality by the mid-twentieth century.

Early Works of Science Fiction

Early works of science fiction relied more on whimsical solutions to spaceflight. During the seventeenth century, Francis Godwin's *The Man in the Moon* employed a flock of swans to transport a voyager to the lunar surface. Frenchman Cyrano de Bergerac (1619–1655) wrote space travel novels that described bottles of morning dew lifting people into the sky.

Far more serious scientific thought went into the works of two nineteenth-century space fiction writers. In 1869 American Edward Everett Hale wrote a novel called *The Brick Moon.* This book was the first that detailed the features and functions of the modern Earth-orbiting artificial satellite. French science fiction writer Jules Verne penned two space travel works, *From the Earth to the Moon*, in 1865, and, five years later, *Round the Moon.* In both books, Verne chronicled the adventures of explorers from post–Civil War America who take a trip to the Moon. Although the form of propulsion was unrealistic (the explorers were shot into space by a gigantic cannon), many other aspects of the stories anticipated the actual lunar missions undertaken by the National Aeronautics and Space Administration (NASA) in the 1960s and 1970s. Verne correctly predicted everything from the phenomenon and effects of weightlessness in space to the shape of the capsule used by the Apollo astronauts. He even proved uncannily accurate in anticipating the Florida launch site, Pacific Ocean splashdown, and recovery by U.S. naval forces of the Apollo missions.

Twentieth-Century Rocket Pioneers

Verne's novels had a strong impact on the three most important rocket pioneers of the twentieth century. One of them was American Robert H. Goddard. As a boy, Goddard was so inspired by the Frenchman's tales of lunar trips that he dedicated his life to achieving spaceflight. As a young physics professor in Massachusetts, Goddard designed and constructed solid-propellant-like rockets. In 1917 the Smithsonian Institution agreed to provide funding for his high-altitude rocket tests. Two years later, Goddard wrote a paper for the Smithsonian titled "A Method of Reaching Extreme Altitudes." This pamphlet discussed the mass required to propel objects beyond Earth's atmosphere—even to the Moon. He also theorized that liquid propellant made for a far more powerful and efficient fuel for rockets than solid propellant. Goddard launched the world's first liquid-fueled rocket in 1926. Ten years later, he published the results of this historic event in his second Smithsonian paper, "Liquid-Propellant Rocket Development."

The second father of modern rocketry was Russia's Konstantin Tsiolkovsky. His works focused on liquid-propellant rockets, kerosene as a fuel, and space station design. Tsiolkovsky's *Investigation of Universal Space by Means of Reactive Devices*, published in 1891, proposed the use of multistage rockets for space travel. Through his science fiction and mathematical study, he laid the foundation for the Soviet Union's successes in spaceflight, which began in the 1950s.

The third great pioneer of rocket theory was the Romanian-born Hermann Oberth. Like Goddard and Tsiolkovsky, Oberth espoused the virtues of liquid-fueled rockets for space voyages. In 1923, he wrote a book called *The Rocket into Planetary Space*. Besides advertising the use of liquid oxygen and alcohol for rocket fuel, he also stressed the importance of using strong yet lightweight alloys for constructing launch vehicles and spacecraft. His *Ways to Spaceflight*, written in 1929, discussed the possibility of building large orbiting space mirrors that could transmit energy to Earth and illuminate cities at night.

There were several other key spaceflight writers and theoreticians of the early twentieth century. In 1929 Hermann Noordung of Croatia wrote *The Problem of Space Travel*, which discussed the engineering requirements for a space station. Eugene Sänger of Austria developed basic concepts in rocketry and aerodynamics in his work *Rocket Flight Technology*, published in 1933. Sänger almost single-handedly invented the idea of an "aerospaceplane"—a direct ancestor of today's space shuttle. Germany's Fritz von Opel also contributed much to the field of rocketry. In 1929, he made the first documented flight of a rocket-powered airplane.

Von Braun, Clarke, and Beyond

In the post–World War II era, two important science fact and science fiction authors stood out. The first was the German-born Wernher von Braun. As a gifted young rocket engineer, von Braun was instrumental in building the V-2 rockets that Germany fired at Britain and Belgium late in the war. After World War II ended in 1945, he moved to the United States where he directed the design and construction of NASA's Saturn rockets, which propelled astronauts into space and to the Moon. In between these two periods in his life, von Braun penned numerous books, essays, and articles about spaceflight. In 1952 he published *Prelude to Space Travel*, which greatly expanded upon Noordung's research in space station development. Four years earlier, he had written *The Mars Project* (published in 1962). In this book, von Braun detailed the first fully comprehensive plan for a human mission to Mars. During the early 1950s, he contributed to a popular series of space-related articles in *Collier's* magazine.

The other key literary figure during this period was Arthur C. Clarke. In 1945 the British-born writer published a paper in *Wireless World*, titled "Can Rocket Stations Give Worldwide Radio Coverage?" This was the first work to discuss the concept of communications satellites that stay in the same position above Earth. Such satellites made instant worldwide television, telephone, fax, e-mail, and computer services possible. In 1968 the film based upon his science fiction book *2001: A Space Odyssey* captured the very mood and spirit of the space age.

Today, science fiction and fact authors continue the efforts begun by Verne, Goddard, Oberth, von Braun, and others. Through their imagination, knowledge, and words, the frontiers of space exploration are pushed forward. SEE ALSO Artwork (Volume 1); Careers in Writing, Photography, and Filmmaking (Volume 1); Clarke, Arthur C. (Volume 1); Mars Missions (Volume 4); Oberth, Hermann (Volume 1); Rockets (Volume 1); Sänger, Eugene (Volume 3); Science Fiction (Volume 4); Tsiolkovsky, Konstantin (Volume 3); von Braun, Wernher (Volume 3).

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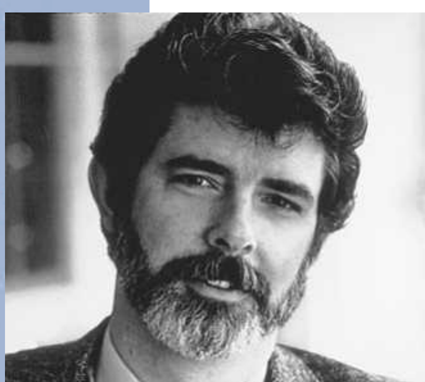
Lucas, George

American Screenwriter, Producer, and Director
1944–



George Lucus, author and producer of the movie trilogy *Star Wars* (1977), *The Empire Strikes Back* (1980), and *Return of the Jedi* (1983), sees himself as a storyteller and filmmaker who works within the limitations of technology.

Born on May 14, 1944, in Modesto, California, film director George Lucas studied film at the University of Southern California. His first feature film was *THX 1138.* The executive producer was Francis Ford Coppola, who would later gain fame directing *The Godfather* trilogy and *Apocalypse Now*. In 1973 Lucas cowrote and directed *American Graffiti*, which won a Golden Globe and garnered five Academy Award nominations.

Within the space fraternity Lucas is recognized for the Star Wars movies. *Star Wars*, the first in the initial trilogy of tales about life and conflict in the universe, was released in 1977. The film broke box-office records and won seven Academy Awards. Lucas went on to write *The Empire Strikes Back* (1980) and *Return of the Jedi* (1983), and was executive producer for both. Lucas worked for twenty years developing a prequel to the trilogy, *Episode 1: The Phantom Menace*, released in 1999, for which he was writer, director, and executive producer. A second prequel, *Attack of the Clones*, was released in May, 2002.

Lucas sees himself as a storyteller and professes not to be particularly keen on technology. He admits that he has had to invent the necessary technology to tell his tales and believes the mark of a talented filmmaker is how well one works within the limitations imposed by the available technology. SEE ALSO Careers in Writing, Photography, and Filmmaking (Volume 1); Entertainment (Volume 1); *Star Wars* (Volume 4).

Pat Dasch

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Lunar Development

The spectacular advances of science and engineering in the twentieth century established the basis for creating permanent human settlements in space in the twenty-first century. Since the Moon is our closest celestial neighbor and is in **orbit** around Earth, it will logically be the next principal focus of human exploration and settlement. The Moon is an excellent platform for astronomical and other scientific investigations, for technological development, and for human habitation. It also has access to the virtually unlimited energy and material resources of space, which can be applied to the development needs of both the Moon and Earth. These opportunities, combined with the universal desire of humankind to explore and settle new lands, assure that the global transformation of the Moon into an inhabited sister planet of Earth will become a reality in this century.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

A major impediment to the exploration of space is the high cost of delivering cargoes from the surface of Earth into space. For example, the cost of launching a **payload** into **low Earth orbit** by the space shuttle is approximately $22,000 per kilogram ($10,000 per pound), and that figure will be higher for missions to the Moon. Thus, it appears that lunar projects will be prohibitively expensive, even if launch costs to low Earth orbit are reduced to less than $2,200 per kilogram ($1,000 per pound).

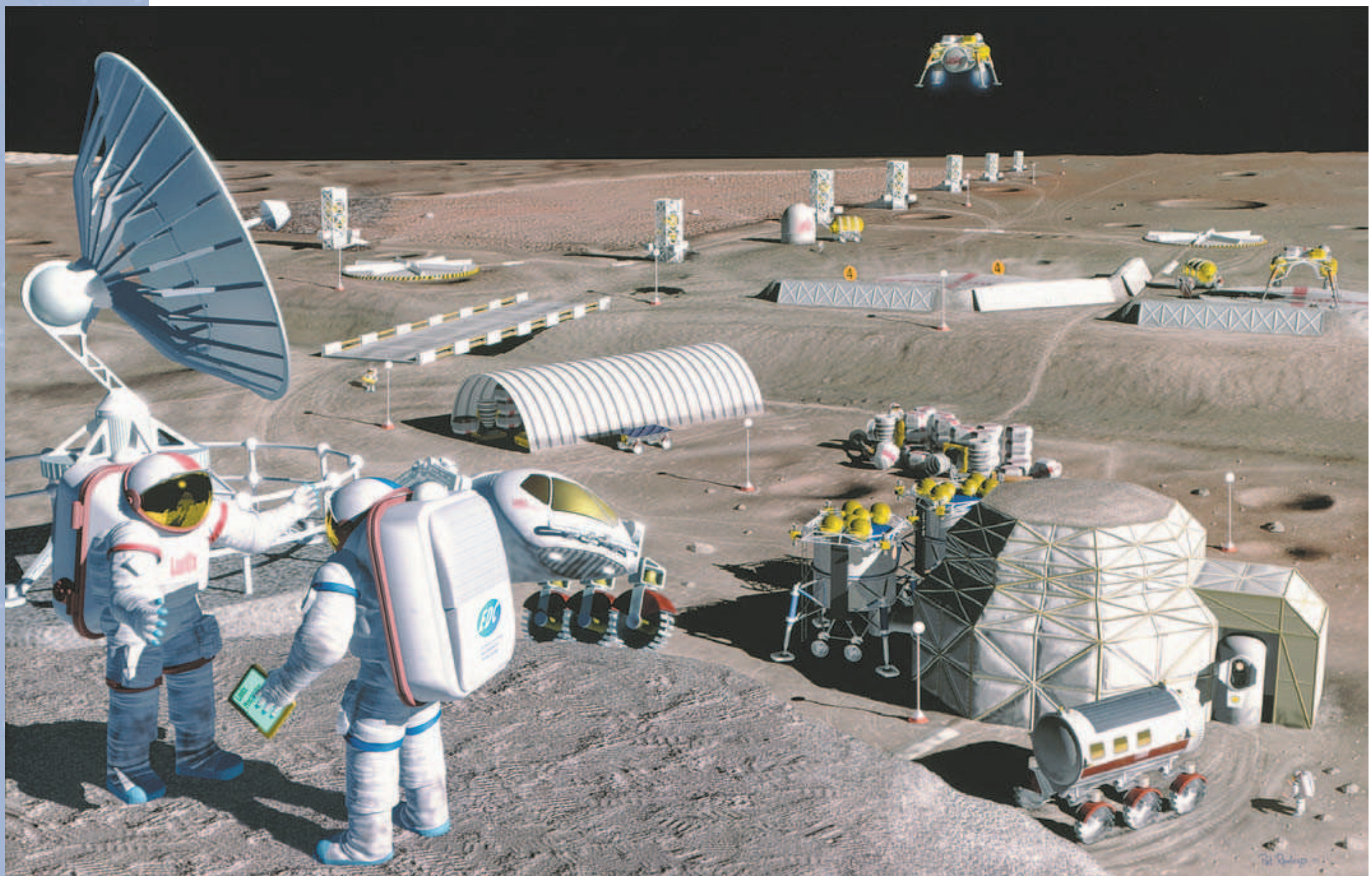
payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

The exploration and development of the Moon, however, will be marked by a dramatic reduction in the cost of space exploration through the process known as in situ resource utilization, which means "living off the land." Industrial processes on Earth use energy, raw materials, labor, and machines to manufacture sophisticated products such as computers, medical imaging devices, rockets, and communication satellites. By the end of the first or second decade of the twenty-first century, it will become possible to use lunar materials to manufacture equally sophisticated products on the Moon.

The Moon has a reliable supply of energy in the form of sunlight, and the lunar regolith (Moon dirt) contains abundant supplies of iron, silicon, aluminum, and oxygen as well as traces of carbon, nitrogen, and other light elements. In addition, the U.S. Lunar Prospector satellite detected increased hydrogen concentrations in the polar areas of the Moon, suggesting the presence of water-ice in those regions. Thus a significant reduction in the cost of space projects can be achieved by simply transporting the basic components of Earth's industrial base, such as lathes, drills, ovens, and control devices, to the Moon. The lunar industrial base will then use solar energy and lunar materials to manufacture the products that are needed for the exploration and human habitation of the Moon. By this means, the high cost of transporting materials from Earth to the Moon will be eliminated, and large-scale space projects will become possible.

Initially, tele-operated robots that have been delivered to the Moon will serve as the "labor" component for lunar industrial processes. Tele-operation is the process by which robots are controlled by scientists or technicians at remote locations using radio links and television monitors. Tele-operation procedures are widely used on Earth for diverse applications such as mining, undersea projects, and certain forms of surgery. It is fortuitous that the Moon always has the same face directed to Earth and that the round-trip time for communications between Earth and the Moon is less than three



An artist's conception of a lunar mining facility illustrates possible exploration programs for the future.

seconds. These conditions will allow Earth-bound operators of lunar robots to have a virtual presence on the Moon twenty-four hours per day, 365 days per year.

Establishing a Lunar Base

The site for the first unmanned base will likely be on the Earth-facing side of the south polar region of the Moon. There are several sites in this region that always have Earth in view for continuous telecommunications and that receive as much as 340 days of sunlight per year for the generation of solar electric power. A south polar base would also have access to increased concentrations of hydrogen (possibly water-ice), which would be useful for industrial operations and eventual human habitation.

Many countries have rockets that can be modified to place useful payloads on the Moon. In one scenario for the establishment of a lunar base, one or more of these existing rocket systems will be used to transport solar panels, communication systems, scientific equipment, and robots from Earth to the south polar region of the Moon. When these components are in place, tele-operated rover vehicles will explore and analyze the lunar surface. Protocols for the preservation of unique features of the lunar environment will be observed, and scientific data will be obtained before local materials are used for experiments. When surveys and analyses have been completed, tele-operated robots will then begin experiments with the production of bricks, wires, transistors, and glass products from lunar dirt.

In the preceding scenario, priority will be given to the fabrication of solar cells for the generation of electric power. The demonstration that electric power can be produced on the Moon from the first lunar-made solar cell will be a milestone in space exploration because it will mean that human enterprises can be self-supporting in space. From that beginning, lunar-made solar cells will be added to the electric power system of the lunar base. As electric power levels grow, additional scientific and manufacturing equipment will be delivered from Earth, and the lunar base will expand in all of its capacities. Iron rails may then be made from lunar iron to construct a simple two-track rail line from the first base to other areas in the south polar region, including the geographic south pole. A "southern rail line" would greatly expand the ability to carry out exploratory missions and would facilitate the growth of lunar power and communication networks.

Humans Return to the Moon

Within a decade after the first unmanned base has been established, humans will return to the Moon. During the build-up of the first unmanned lunar base, controlled ecological life support systems will undergo continued research and development on Earth and the International Space Station. Work will also commence on the development of reusable rocket systems that can ferry people between Earth and the Moon. When a reliable lunar electric power system is in place and underground chambers (for protection from radiation, temperature extremes, and micrometeorites) have been constructed, life support systems and agricultural modules will be delivered to the lunar base. Humans will then return to the Moon for sixty- to ninety-day periods, and all aspects of lunar base activities will be expanded.

As experience with lunar operations increases, the scientific and industrial capability of the Moon will reach parity with Earth, perhaps within two to three decades after the founding of the first base. Widely separated, permanent human settlements will be established, and the only cargoes that will need to be transported from Earth will be humans—the scientists, engineers, tourists, and immigrants who will explore, develop, and inhabit the Moon.

Future Lunar Development

Geological expeditions will explore the mountain ranges, mares (plateaus), craters, and rills (narrow valleys) of the Moon, and investigate lava tubes that have been sealed for billions of years. Thousands of lunar-made telescopes will be placed at regular intervals on the Moon so that any object of interest in the universe may be observed continuously under ideal viewing conditions. People will live and work in large underground malls that have Earth-like living conditions. A rail system will provide high-speed access to all areas of the Moon and lunar tourism will be a growth industry. Millions of megawatts of low-cost environmentally sound electric energy will be beamed from the Moon to Earth and other locations in space by the lunar power system.

By the mid-twenty-first century, thousands of spacecraft will be manufactured on the Moon and launched by electromagnetic "mass drivers" to all points of interest in the solar system, and robotic missions to nearby stars will be underway. Communication, power, and transportation systems will be built on the Moon and launched to Mars in support of the global human exploration and development of that planet. Asteroids and "burned out" comets in Earth's orbital vicinity, especially those that pose a threat of collision with Earth or the Moon, will be maneuvered out of harm's way and mined for their hydrocarbon, water, and mineral contents, which will then be delivered to Earth or the Moon.

The transformation of the Moon into an inhabited sister planet of Earth is an achievable goal that will be highly beneficial to the people of Earth. It will provide the following:

- An expansion of scientific knowledge;
- The advancement of all engineering disciplines;
- Access to the virtually unlimited energy and material resources of space;
- Job and business opportunities;
- International cooperation;
- A greatly expanded program of solar system exploration; and
- The opening of endless frontiers.

The binary Earth-Moon planetary system will thus draw upon and benefit from the vast energy and material resources of space, and the spacefaring phase of humankind will be firmly established. SEE ALSO LUNAR BASES (VOLUME 4); LUNAR OUTPOSTS (VOLUME 4); NATURAL RESOURCES (VOLUME 4); SETTLEMENTS (VOLUME 4); SPACE TOURISM, EVOLUTION OF (VOLUME 4); TELEPRESENCE (VOLUME 4); TOURISM (VOLUME 1).

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Made in Space

History characterizes the various eras of civilization in terms of available materials technology, leading to the recognition of such eras as the Stone Age, Bronze Age, Steel Age, and Silicon Age. One of the areas of intense research in the present era has been the processing of materials in the space environment to develop new or improved products for use on Earth. In the 1960s, during the early phase of this effort, the advent of a new industry was predicted based on the promising initial results obtained, and it was anticipated that by the 1980s "made in space" would be a common label on a large number of products.

That new manufacturing industry based in space is still in the future, primarily because of the high cost of placing the carrier vehicles into orbit—$35,000 per pound at the beginning of the twenty-first century. Advances in propulsion technology, however, will reduce the cost of transportation to space in the future. Currently the emphasis is on making better products here on Earth based on the knowledge and processes discovered through space research. To understand the great potential of space we must examine what it is that makes the space environment so unique in the processing of materials.

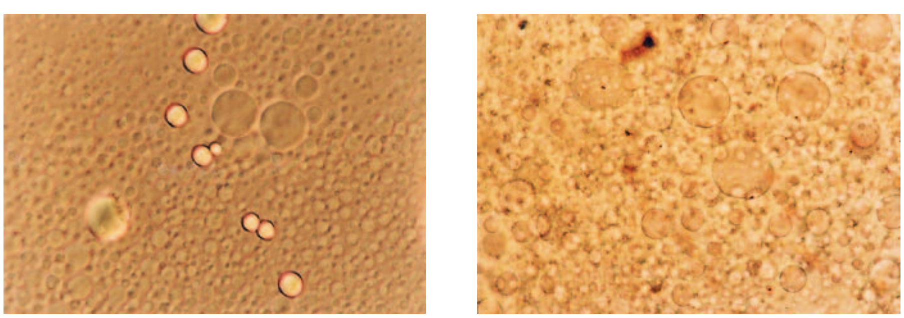
The Advantages of Space-Based Manufacturing

There are two primary effects on Earth that can be reduced to almost zero in the microgravity environment (nominally one-thousandth to one-millionth of Earth's gravitation) present in orbiting vehicles: sedimentation and thermal **convection**. Sedimentation makes heavier liquids or particles settle at the bottom of a container, as when sugar added to coffee settles at the bottom of the cup. Thermal convection establishes currents where cooler fluids fall to the bottom and warmer ones rise to the top.

convection the movement of heated fluid caused by a variation in density

Because many chemical, fluid-physics, biological, and phase-change (e.g., changing from a liquid to a solid state) processes are affected by the effects of sedimentation and thermal convection, the form and size properties of materials formed under these influences are different in space compared to those formed under the influence of Earth's gravitation. A close examination of the accompanying images shows the impact of things made in space.

A study conducted for the National Aeronautics and Space Administration (NASA) in the early 1970s identified seventy-seven representative unique products or applications that can be obtained in space. Since that early study, the list of potential applications has at least doubled. Most of the items have been the subject of many investigations conducted on rockets, the space shuttle, and the Mir space station by scientists and engineering teams from many countries, particularly the United States, Germany, Russia, France, Italy, Canada, and Japan (see table on page 141 for a representative subset of the space applications that have been investigated or are in the process of being investigated). The following two examples in the medical area serve to illustrate the current research.



Microgravity encapsulation of drug experiments conducted in space (image on the left) have more uniform size and sphericity, plus unique multilamellar microspheres. By contrast, Earth experiments (image on the right), show random size and single-walled unilamellar microcapsules. The space data were obtained in ITA's automated laboratory flown on shuttle flight STS-56 on the CMIX-2 payload.

Bence-Jones protein crystals grown in space. The picture on the left was taken on the CMIX-5 payload, on shuttle flight STS-80, while the image on the right was taken on the CBIX-1 payload, on shuttle flight STS-95.

Protein Crystal Growth

Growing crystals in microgravity has the advantage of virtually eliminating the thermal convection that produces poor crystal quality and increases the time required to grow a useful crystal. This advantage of microgravity is particularly important in obtaining crystals that have the size and high degree of structural perfection necessary to determine, through X-ray analysis, the three-dimensional structure of those complex organic molecules. For instance, long before the space era the structure of **DNA** was determined using **crystallography**, but there are many protein crystals that are difficult to grow under the influence of gravitational forces. Urokinase, a significant protein in cancer research, is an example of a protein that is difficult to grow on Earth and that benefits from microgravity. Complete three-dimensional characterization, that is, determining the relative location of the approximately 55,000 atoms in this molecule, would permit pharmaceutical scientists to design drugs to counteract the harmful effects of urokinase in promoting the spread of cancer throughout the body, particularly in the case of cancerous breast tumors. Research being conducted in the space shuttle is seeking to grow urokinase crystals in space for subsequent X-ray analysis in Earth-based laboratories.

DNA deoxyribonucleic acid; the molecule used by all living things on Earth to transmit genetic information

crystallography the study of the internal structure of crystals

Microcapsules for Medical Applications

Experiments conducted in space have shown more spherical perfection and uniformity of size distribution in microcapsules, which are capsules with diameters of 1 to 300 micrometers (0.00004 to 0.012 inches). The size and shape of microcapsules are key factors in how effective they are at delivering medicinal drugs directly to the affected organs by means of injections or nasal inhalations. The feasibility of newly developed processes for producing multilayered microcapsules has been limited because of the effects of density differences in the presence of gravity. In order to circumvent this, a series of experiments has been performed onboard the space shuttle to produce superior microcapsules in space. If these experiments prove successful, large-scale demand for these types of microcapsules may require future development of ground manufacturing equipment that counteracts the effects of gravity.

Student Experiments in Space-Based Material Processing

Since the initial activity in materials processing in space, student participation has been an important part of the effort. Since the early space shuttle

EXAMPLES OF MATERIALS INVESTIGATIONS IN SPACE IN VARIOUS CATEGORIES

Category	Examples	Description
Materials Solidification	Vapor Deposition of Silicates	Vapor deposited on a substrate as a coating of metallic particles imbedded in a matrix.
	Crystal Growth	Organic or inorganic crystal growth in a liquid solution or through evaporation or osmosis.
	Directional Solidification of Metals	A metallic rod has a molten zone that is moved along the rod to produce a superior metal cell structure.
	Micro-encapsulation of Medicinal Drugs	Chemicals are combined in a chamber to form microcapsules containing various layers.
Chemical and Fluids Phenomena	Multiphase Polymers for Composite Structures	Very sensitive separation of cell group subpopulations using processes that do not work with the gravitation on Earth.
	Production of Catalysts	To use controlled gravitational acceleration in the formation of catalytic materials.
	Convective Phenomena Investigations	A family of experiments, dealing with convection due to surface tension, vibration, and electrical fields.
Ceramics and Glasses	Immiscible Glasses for Advanced Applications in Optics	Investigates the role of gravity in the inability to mix glasses having dissimilar densities.
Biological	Continuous Electrophoresis for Biological Separations	Provide continuously flowing separation of biological materials by *electrophoresis*, applying an electric field across the solution.
	Human Cell and Antibody Research	Determines the difference in cell behavior, for use in cancer research and investigation of aging processes.

flights, the NASA-sponsored Getaway Special program has provided experiment containers in the shuttle cargo bay capable of accommodating 50 to 200 **payloads** of 23 to 90 kilograms (50 to 200 pounds), with the primary focus on student experiments. Industry also plays an important role in student education. One U.S. space company pioneered a hands-on student experiment program for microgravity experiments onboard the space shuttle. Several industrial concerns have since donated space accommodations in scientific equipment on the shuttle and on rockets, as well as engineering and scientific manpower during integration of the experiments in the spacecraft.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The Role of the International Space Station

The advent of the International Space Station during the first decade of the twenty-first century will be an important milestone in the growth and maturing of the research phase of the materials processing in space program. The International Space Station will provide continuing, long-duration microgravity capability to conduct experiments with the participation of astronauts and cosmonauts. This is an international endeavor the scope of which reaffirms the important role that our society places on materials development. Our rapid technological advancement continues to place great demands on the development of new materials; space is an important tool in meeting those challenges. SEE ALSO Crystal Growth (volume 3); International Space Station (volumes 1 and 3); Microgravity (volume 2); Zero Gravity (volume 3).

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Made with Space Technology

To meet the many goals of space exploration and aeronautical development, the National Aeronautics and Space Administration (NASA) and the aerospace industry sought many innovations in a number of science and technology fields. This storehouse of knowledge has provided a broad technical foundation for stimulating secondary applications of these different developments. Each application is a result of "spinoffs" of both space and aeronautical research.

A spinoff is a technology that has been transferred to uses other than the purpose for which it was developed. In the early twenty-first century, it is difficult to find an area in everyday life into which a spinoff has not penetrated, yet many people are unaware of the existence of these breakthroughs.

Spinoffs in Medical Applications

Walking through the emergency ward of modern hospitals reveals many changes in equipment stemming from early U.S. manned space programs like **Apollo**.

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

Materials in Wheelchairs. The spacecraft and rockets used to take humans to the Moon were developed from new materials that were lightweight yet very strong. Engineers developed new methods of construction and new alloys and composite materials for these missions. Many of these new developments found use in everyday life here on Earth.

An advanced wheelchair is one example. To address the needs of the wheelchair user, researchers at the NASA Langley Research Center in Virginia and the University of Virginia's Rehabilitation Engineering Center developed a wheelchair made from aerospace composite materials much lighter but stronger than common metals.

This 25-pound wheelchair offers the strength and weight-bearing capability of a normal 50-pound wheelchair, which can also be collapsed for storage and transport. Robotic and teleoperator technologies for space-related programs have also been adapted to develop a voice-controlled

Christopher Cole, age 13, was born without sweat glands. A cool suit, orginally made for astronauts re-entering the atmosphere, can aid him in ordinary activities that would otherwise be life-threatening.

wheelchair and manipulator as an aid to paralyzed and severely handicapped people. At the heart of this system is a voice-controlled analyzer that uses a minicomputer. The patient speaks a command into a microphone connected to a computer that translates the commands into electrical signals, which then activates appropriate motors to cause the desired motion of the wheelchair or manipulator. The manipulator can pick up objects, open doors, turn knobs, and perform a variety of other functions.

The Unistick. Another breakthrough for the handicapped from the space program is called Unistick. For the later Apollo Moon landings in the early 1970s, NASA developed a Lunar Rover that allowed astronauts to drive around on the lunar surface, greatly enhancing their ability to explore more of the Moon around their landing site. The rover was designed to allow an astronaut to drive one-handed, using an aircraft-like joystick to steer, accelerate, and brake the vehicle. On Earth, this technology is being applied to a system that allows people who have no lower limbs to drive with the use of a joystick, which combines the functions of a steering wheel, brake pedal, and accelerator.

MRI Technology. Another spinoff into the medical field is magnetic resonance imaging (MRI), which enables magnetic field and radio waves to peer inside the body. Unlike X rays, MRI is able to see into bones. By applying computerized image enhancement technology developed to read Earth-resources satellite photographs, experts have been able to provide thermatic maps of the human body, using color to indicate different types of tissue, making tumors or blood clots easy to find.

Nitinol in Dentistry. In dentistry, straightening teeth requires months or even years of applying corrective pressure by means of arch wires, or braces. A new type of arch-wire material called Nitinol now helps reduce the number of brace changes because of its elasticity. This new material, an alloy of titanium and nickel, has an ability to return to its original shape after bending. Many satellite antennas or other hardware could be compacted inside

The suits worn by these firefighters at the Guiana Space Center were adapted from space suit technology. The varying protective gear has been specifically designed to be able to handle different types of emergency situations.

a satellite during launch, then later expanded to full size when in space. This same property allows braces made of Nitinol to exert continuous pull on teeth, reducing the number of dentist visits and changes in braces.

Spinoffs in Other Applications

The field of firefighting and fire prevention has benefited greatly from aerospace spinoffs. Spinoff applications include protective outer garments for workers in hazardous environments, a broad range of fire-retardant paints, foams and ablative coatings for outdoor structures, and different types of flame-resistant fabrics for use in the home, office, and public transportation vehicles. Many new flame-resistant materials, primarily developed to minimize fire hazards in the space shuttle, have resulted in new, lightweight substances that resist ignition. When exposed to open flame, the material decomposes. This same material is now used in the production of seat cushions and panels for doors, walls, floors, and ceilings. This new fire-resistant material has particular application to commercial aircraft, ships, buses, and rapid-transit trains, where toxic smoke is the major cause of fire fatalities.

One of the biggest fire-related technology transfers is the breathing apparatus worn by firefighters for protection against smoke inhalation. Until the 1970s the breathing apparatus used by firefighters was large, heavy, and restrictive. The Johnson Space Center in Houston, Texas, developed a breathing system weighing one-third less than conventional systems. The system included a face mask, frame and harness, warning device, and an air bottle. In the early twenty-first century, many breathing systems incorporate space technology in some form.

Anticorrosion paints, developed for many structures at the Kennedy Space Center in Florida, have found a market in an easily applied paint that incorporates a high ratio of potassium silicate, but which is water-based, nontoxic and nonflammable. With these properties, a hard ceramic finish with superior adhesion and abrasion resistance is formed within an hour of application. Once applied to many structures that are exposed to salt spray and fog (such as bridges, pipelines, and ships), the lifespan of these structures can be dramatically increased.

As of the early years of the twenty-first century, more than 30,000 applications of space technology have been brought down to Earth to enhance our everyday life. SEE ALSO Made in Space (volume 1).

Nick Proach

Internet Resources

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Market Share

Although space commercialization in the United States began as far back as 1964, commercial initiatives did not begin to build momentum until the early 1980s. Worldwide, companies such as Arianespace in France and RSC Energia in Russia provide strong competition in the commercial marketplace to U.S. contractors such as Lockheed Martin Corporation. For the most part, large contract companies still share a large segment of the commercial marketplace.

The U.S. Department of Commerce reported total U.S. commercial space revenues in 1988 of an estimated $1.8 billion, primarily in the area of satellite communications and related ground support. This number doubled in 1990, with the United States retaining about 60 percent of the world market in communications satellites. By 2000, other services, such as remote sensing (photographic imaging from space), were still in their infancy commercially, but the market for such services was expected to grow substantially by 2005. The market for satellite imagery in the United States had already grown from a $39 million industry in 1988 to $139 million in 1998. The Carnegie Endowment for International Peace projected that remote sensing revenues would reach $420 million by 2005.

According to *Facts and Figures: The European Space Industry in 1998*, European companies generated $5.1 billion in total revenue in 1998, comprising 47 percent of the total European market. This was an increase from 1996 when government programs constituted two-thirds of the European market. Worldwide, the French consortium Arianespace held approximately 50 percent of the total market for launching satellites in 1988. Proven rocket families, such as the French Ariane, the U.S. Delta, and the Russian Proton, still maintain great success in the transportation industry. New partnerships by known industry leaders, such as the Sea Launch partnership of Energia and Boeing, are creating greater competition in the marketplace.

New Initiatives

Early in 2000, several media agreements were signed to provide wider public access to space through the Internet and high-definition television. The National Aeronautics and Space Administration inked a $100 million deal with an Internet start-up to create high-definition images from the space

The floor of the New York Stock Exchange on December 31, 1997, buzzed with activity. The market for satellite imagery in the United States increased by $100 million over the 10-year period between 1988 and 1998.

shuttle and the International Space Station (ISS), while the U.S. company Spacehab Incorporated signed with Russia's RSC Energia to form a commercial partnership to utilize future resources on the ISS. Other historical milestones are also being achieved commercially, such as the successful mission of two Russian cosmonauts to the space station Mir beginning in April 2000. This was the first privately funded, piloted space mission in history.

In 1999, 128 spacecraft were launched worldwide, with a total of seventy-six, or 59 percent, from commercial companies. Total space revenues for 1999 reached $87 billion, with the International Space Business Council estimating growth of 93 percent through 2005.

History has shown that one of the biggest hurdles for space commercialization in any country is a government's willingness and ability to implement policies to promote and assure commercial participation and success. Such cooperation will ensure diversity and competition in future technologies. Because of the complexities of space technology, new products influence such issues as national defense and international import and export policies. These issues will continue to influence progress and profit in space commerce. SEE ALSO Legislative Environment (volume 1); Marketplace (volume 1); Regulation (volume 1); Space Industries (volume 4).

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Marketplace

Since the 1960s, the market for commercial space operations has been limited almost entirely to communications satellites and commercial rocket launchers, with some tentative ventures in the areas of **remote sensing** and weather observation. Because of the value of the information they carry—television signals, some telephone links, and all sorts of digital data—communication satellites have been able to support a fleet of costly launch vehicles. Some time around the year 2007, the available radio frequency spectrum for communication satellites will be saturated. After that, the industry will consist only of maintenance and upgrades to the existing **infrastructure**.

remote sensing the act of observing from orbit what may be seen or sensed below Earth

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

Over the next few decades, the most lucrative industry in space will probably be tourism. On Earth in the early twenty-first century, tourism is the second largest export industry. (The largest is energy, in the form of oil.) A tourist industry in space will reduce the cost of getting into orbit because of the sheer volume of launches required. This industry will require launch vehicles not only for transporting people but also for transporting the space-borne facilities tourists will be visiting and for resupplying those facilities. Demand for low-cost launchers will increase by orders of magnitude, promoting competition and driving costs down.

Less costly launchers promise new markets for industrial processes in space. Many industrial processes may benefit dramatically from operating in the weightless environment. So far, no such venture has been cost-effective; the cost of getting the machines and materials into space and the finished products back exceeds the potential sales of the materials produced.

Electrophoresis is a process that uses electric fields to separate fluids; it is used especially in the pharmaceuticals industry to make very valuable (and very expensive) drugs. A team made up of Johnson & Johnson and McDonnell Douglas flew a prototype electrophoresis system on four space shuttle flights, with an eye to making it a commercial venture. Initially, it looked as if producing pharmaceuticals in orbit would make sense from a business standpoint, but the companies ultimately determined that it would be less costly to make their products on the ground. Dramatically lower launch costs would turn the business equations around.

Lower launch costs open space to a host of other industries. Most of the potential markets identified to date are in esoteric high-tech fields, such as super-strength drawn fibers, single-crystal metals, and protein crystals. Others are more familiar, such as movie and television production, for which space would provide an excellent shooting location. These markets are only forerunners of new markets that will open as commercial business moves into space. Current research in space processing methods might lead to some surprising markets for both industrial and consumer products.

New Markets

Transgenic plants, which are made by crossing the genes from diverse species, promise to create whole new species with new flavors and dramatically increased crop yields. In an experiment flown on the space shuttle, a rose plant produced some new, very desirable fragrances in the zero gravity environment. Moreover, several prototype systems have been developed that may one day lead to the deployment of huge electrical power plants in orbit, or even on the Moon, that collect energy directly from the Sun and transmit the power to Earth on microwave beams. Zeolite crystals are yet another product that might one day be produced in space. These crystals command high prices in the chemical processing industry because of their ability to selectively filter out specific chemicals. Though they are scarce on Earth, they can be manufactured efficiently in space.

Opportunities for new markets in space extend to the medical industry as well, which will benefit from improved efficiency in the production of pharmaceuticals and entire new technologies, such as components for bone replacement.

Finally, developing industries in space create new markets to meet the demands of the space-borne industries. People working in space need places to live, work, and play; they need food to eat, clothes to wear, and transportation systems to get around. In short, they need everything that people need on Earth, and each of these needs is a new market for the space entrepreneur. SEE ALSO Launch Industry (Volume 1); Launch Services (Volume 1); Made in Space (Volume 1); Space Tourism, Evolution of (Volume 4); Tourism (Volume 1).

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McCall, Robert

American Illustrator
1919–

Robert T. (Bob) McCall, one of the world's leading illustrators of space themes, was named to the Society of Illustrators Hall of Fame in 1988. His bold, colorful canvases depict the visions of America's space program since its beginnings.

McCall was born in 1919 in Columbus, Ohio, and now lives in Paradise Valley, Arizona. During World War II, McCall enlisted in the Army Air Corps and became a bombardier instructor. After the war, he and his wife, artist Louise McCall, moved to Chicago and later New York, where he worked as an advertising illustrator. Through the Society of Illustrators, McCall was invited to produce paintings for the U.S. Air Force.

In the early 1960s, McCall was one of the first artists selected for the National Aeronautics and Space Administration's (NASA) fine arts program after producing future space concepts for *Life* magazine. This connection has led to a number of patch designs for space missions, a U.S. Postal Service commemorative stamp set, and murals at NASA field centers. Several astronauts include his artwork in their collections.

McCall's most visible work is a six-story mural in the Smithsonian's National Air and Space Museum in Washington, D.C., which is seen by over six million visitors annually. His most widely recognized work is the painting of a massive double-ringed space station for the Stanley Kubrick and Arthur C. Clarke film *2001: A Space Odyssey* (1968).

McCall's training included studies at the Columbus School of Art and Design and the Art Institute in Chicago in the late 1930s. SEE ALSO ARTWORK (VOLUME 1); BONESTELL, CHESLEY (VOLUME 4); RAWLINGS, PAT (VOLUME 4).

Pat Rawlings

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Military Customers

The military space program is a significant but largely unseen aspect of space operations. Nearly a dozen countries have some kind of military space program, but the U.S. program dwarfs the efforts of all these other countries combined.

Military space operations are divided into five main areas: **reconnaissance** and surveillance, signals intelligence, communications, navigation, and **meteorology**. Only the United States and Russia operate spacecraft in all five areas. Several other countries have long used communications satellites for military purposes. In the 1990s, several countries in addition to Russia and the United States began developing reconnaissance satellites.

reconnaissance a survey or preliminary exploration of a region of interest

meteorology the study of atmospheric phenomena or weather

Reconnaissance and Surveillance

Reconnaissance and surveillance involve the observation of Earth for various purposes. Dedicated reconnaissance satellites, like the United States's Improved CRYSTAL and the Russian Terilen, take photographs of targets on the ground and relay them to receiving stations in nearly real time. These satellites, however, cannot take continuous images like a television camera. Instead, they take a black-and-white photograph of a target every few seconds. Because they are in low orbits and are constantly moving, they can photograph a target for only a little over a minute before they move out of range. The best American satellites, which are similar in appearance to the Hubble Space Telescope, can see objects about the size of a softball from hundreds of miles up but they cannot read license plates. The Russians also occasionally use a system that takes photographs on film and then returns the film to Earth for processing. This provides them with higher-quality photos. The United States abandoned this technology in the 1980s after developing superior electronic imaging technology.

Other nations, such as France and Japan, operate or plan on operating reconnaissance satellites that can see images on the ground about one to three feet in length. From the late 1970s until the mid-1990s, China had a film-based system, which is no longer operational. India, Israel, and Brazil also operate satellites capable of making visual observations of the ground. Some private companies operate commercial imagery satellites and sell images on the World Wide Web. These satellites are much less capable than the larger military satellites but their products have improved significantly and are in demand.

Other surveillance satellites, such as the American DSP and Space-Based Infrared System (SBIRS, pronounced "sibirs") and the Russian Oko (or "eye"), are equipped with **infrared** telescopes and scan the ground for the heat produced by a missile's exhaust. They can be used to warn of missile attack and can predict the targets of missiles fired hundreds or thousands of miles away. There are also satellites that look at the ground in different **wavelengths** to peer through camouflage, try to determine what objects are made of, and analyze smokestack emissions.

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

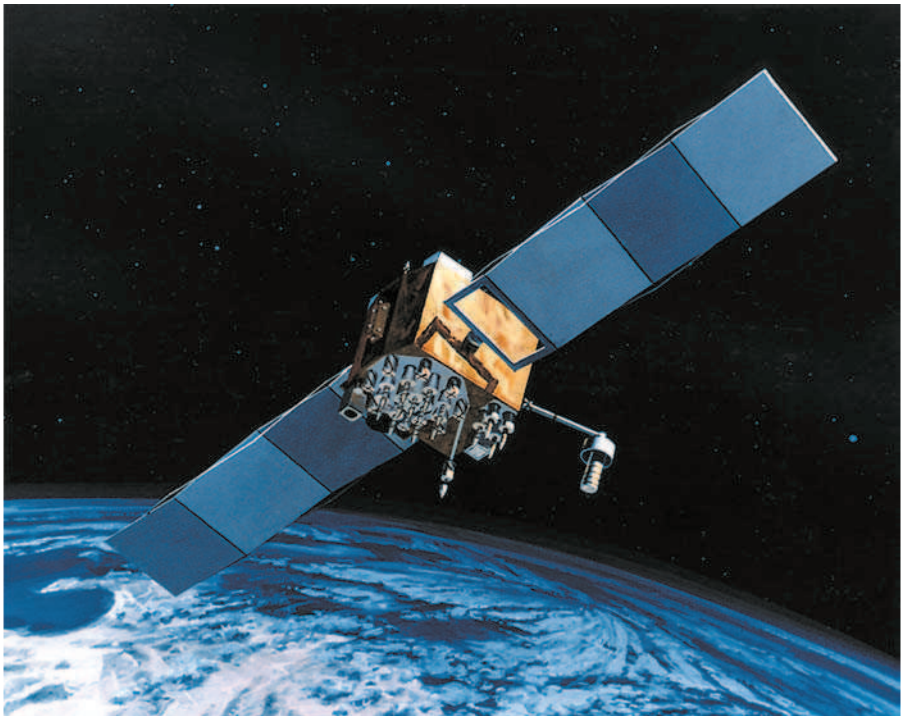
wavelengths the distance from crest to crest on a wave at an instant in time

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Signals Intelligence

Signals intelligence satellites can operate either in **low Earth orbit** or in extremely high, **geosynchronous orbit**, where they appear to stay in one



Satellites such as this artist's rendering of an Air Force NAVSTAR Global Positioning System (GPS) BlockIIF, are used increasingly in military operations by countries with global interests.

spot in the sky. These satellites listen for communications from cellular telephones, walkie-talkies, microwave transmissions, radios, and **radar**. They relay this information to the ground, where it is processed for various purposes. Contrary to popular myth, these satellites do not collect every conversation around the world. There is far more information being transmitted every day over the Internet than can be collected by even the best spy agency.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Communications

Communications satellites operate in several different orbits for various purposes. The most common communications satellites operate in geosynchronous orbit. Some, like the U.S. Navy's UHF-Follow On satellite, are used to communicate with ships at sea. Others, like the air force's massive Milstar satellite, are used to communicate with troops on the ground and submarines equipped with small dish antennas. Still other communications satellites are used to relay reconnaissance pictures to ground stations or to troops in the field. Some satellites are used to relay data and commands to and from other satellites.

Russia operates a number of military communications satellites, including some that store messages for a brief period before relaying them to the ground. Several other countries, such as the United Kingdom, Spain, and France, have either military communications satellites or a military communications package installed on a commercial satellite. But few countries have the global military communications requirements of the United States.

Navigation and Meteorology

Navigation satellites are also vital to military forces. Sailors have used the stars to navigate for centuries. Beginning in the early 1960s, the U.S. Navy developed a satellite system to help it navigate at sea. This was particularly important for **ballistic** missile submarines that stayed submerged for most of their patrols and could only occasionally raise an antenna above the waves to determine their position.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

In the 1980s the U.S. Air Force started operating the Global Positioning System (GPS), which allowed anyone equipped with a receiver to locate his or her position on Earth to within about thirty feet or less. GPS uses a constellation of twenty-four satellites that circle Earth every twelve hours. From any point on Earth, there are usually three or four GPS satellites above the horizon at any one time. A handheld receiver detects radio emissions from these satellites.

Commercial receivers are available in sporting goods stores and in many new cars. Using a special civilian GPS signal, they provide less precise location information than the military receivers but still allow a user to navigate accurately. Civilian users can locate their position on Earth to an accuracy of about thirty feet. Russia operates a system similar to GPS, but virtually every military on the planet uses the civilian GPS signal.

Accurate weather information is critical to military operations. The United States and Russia operate **meteorology satellites** for military use. However, since the end of the Cold War, separate military and civilian meteorology satellites have been viewed as an unnecessary expense, and the military systems have gradually been merged with their similar civilian counterparts.

meteorology satellites satellites designed to take measurements of the atmosphere for determining weather and climate change

Antisatellite Defense ("Star Wars")

Antisatellite (ASAT) and missile defense (Strategic Defense Initiative [SDI] or "Star Wars") satellites are not currently part of any nation's arsenal. ASAT weapons are difficult to develop and operate and they have limited usefulness. It is extremely precarious to use a satellite to shoot down ballistic missiles. In the future, satellites may be used to intercept missiles, but it is unlikely that this will happen for a long time.

During the Cold War, both superpowers studied the possibility of placing nuclear weapons in orbit, but neither country did so. A bomb in orbit will spend most of its time nowhere near the target it needs to hit, unlike a missile on the ground, which will always be in range of its target. In addition, controlling a system of orbiting bombs would be difficult.

Military Role of Humans in Space

There has never been a clear military role for humans in space, despite decades of study by both superpowers. During the 1960s, the United States explored several piloted military space systems. One of these was the Dyna-Soar spaceplane, which was canceled in 1963 after the air force could find no clear mission for it. Another of these was the Manned Orbiting Laboratory (MOL). MOL was to carry a large reconnaissance camera, and two astronauts were to spend up to a month in orbit, photographing objects on the ground. The United States canceled MOL in 1969 after it became clear that humans were not needed for the job and robotic systems could perform the task reliably and in many cases better than humans. The Soviet Union briefly operated crewed space stations similar to MOL but abandoned these for the same reason as the United States.

Summary

Around the world, military operations are increasingly using commercial satellites to accomplish their missions. Commercial communications satellites are particularly useful and cheap. In addition, commercial reconnaissance satellites are finding many military uses, enabling countries that cannot afford their own satellites to buy photos of their adversaries.

Satellites are not required for many local military operations. But if a country is operating far from its borders or has global interests, they are a necessity. Only a few countries are willing to pay the expense of operating military space systems, but that number is growing. SEE ALSO Global Positioning System (volume 1); Military Exploration (volume 2); Military Uses of Space (volume 4); Navigation from Space (volume 1); Reconnaissance (volume 1); Satellites, Types of (volume 1).

Dwayne A. Day

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Mueller, George

American Engineer and Corporate Leader
1918–

George E. Mueller is an American engineer and corporate leader whose work and career span the development of the U.S. space program. Born July 16, 1918, Mueller holds a master's degree in electrical engineering from Ohio State University, and worked at Bell Laboratories before subsequently earning his doctorate degree in physics from Purdue University. His career has focused on the development and success of the U.S. space program.

As head of the National Aeronautics and Space Adminsitration's (NASA) Apollo Manned Space Flight Program from 1963 to 1969, Mueller led the program that put Americans on the Moon. He was in charge of the **Gemini**, **Apollo**, and Saturn programs. In addition, he coordinated the activities of 20,000 industrial firms, 200 universities and colleges, and hundreds of thousands of individuals into one concerted effort. His leadership made it possible to meet the challenge set in 1961 of not only landing men on the Moon before the end of the decade, but also their safe return to Earth.

After the successful completion of the second landing on the Moon by Apollo 12, Mueller returned to industry where he was senior vice president of General Dynamics Corporation and chairman and president of System Development Corporation. At press time, he is the chief executive officer of Kistler Aerospace Corporation, and has been leading the development

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

George Mueller headed NASA's Apollo Manned Space Flight Program from 1963 to 1969. He is known as the "Father of the Space Shuttle."

and operations of the Kistler K-1, the world's first fully reusable aerospace vehicle. Mueller is the recipient of many prestigious awards, including the Rotary National Award for Space Achievement, which was awarded to him in 2002. SEE ALSO Apollo (Volume 3); Apollo Lunar Landing Sites (Volume 3); Gemini (Volume 3); NASA (Volume 3).

Debra Facktor Lepore

Internet Resources

Kistler Aerospace Corporation. <http://www.kistleraerospace.com>.

N

Navigation from Space

For hundreds of years, travelers have looked to the sky to help navigate their way across oceans, deserts, and land. Whether using the angle of the Sun above the horizon or the night stars, celestial bodies guided explorers to their destinations. In the twenty-first century, people still look to the sky for direction, but now they are using satellites that orbit Earth to determine their location. In fact, it is quite common to see people using what is called the Global Positioning System (GPS), which is a satellite navigation system, to answer the age-old question: Where am I?

Evolution of Satellite Navigation

The idea of using satellites for navigation was conceived when the satellite Sputnik 1 was launched in 1957. At that time, U.S. scientists developed a way to track Sputnik's orbit using the time delay or Doppler shift of the radio signal being broadcast by the satellite. The scientists proposed that this process could be used in the opposite way for navigation. Specifically, using a satellite with a known orbit, one's position could be determined by observing the time delay or Doppler shift of a radio signal coming from that satellite.

The position that this soldier obtains through his Global Positioning System receiver is communicated through the triangulation of the signals of twenty-four orbiting satellites.

The concept of being able to determine a position from satellites appealed to the U.S. Navy. To test the idea, they developed the Transit satellite navigation system. By 1964 Transit was being used by Polaris submarines to update the inertial navigation systems onboard the submarines. During roughly the same period, the U.S. Air Force also had a satellite navigation program under development. In the early 1970s, the navy and air force programs merged into one program called the Navigation Technology Program. This program evolved into the NAVSTAR (Navigation System with Timing and Ranging) GPS—the space navigation system used today.

How the Global Positioning System Works

GPS uses twenty-four satellites that circle Earth in a 20,000–kilometer high (12,400–mile high) orbit. The satellites are in orbits that are inclined at 55 degrees with respect to the equator. The satellites are in six orbital planes, each of which has four operational satellites. In March 1994 the full twenty-four-satellite constellation was in place in orbit and the network became fully functional the following year. Users of this navigational system need a

GPS receiver. There are many commercial manufacturers of these devices. They are sold in most stores that sell electronic equipment and cost as little as $150.

Each satellite in the GPS transmits a signal with information about its location and the current time. Signals from all of the satellites are transmitted at the same time. These signals are received at different times by a GPS receiver because some satellites are closer than others. The distance to the satellite is determined by calculating the amount of time it takes the signal to reach the receiver. The position of the receiver is determined by triangulation, except that in this case, the distance to four GPS satellites is used to determine the receiver's position in three dimensions.

Alternatives to the Global Positioning System

The United States allows anyone around the world to use the GPS system as a free resource. For many years, however, there has been a concern in other countries that the United States could deny access to the GPS system at any time. This has led to attempts by other nations at developing alternative satellite navigation systems. The most notable of these emerging systems is a European Space Agency venture called Galileo. The European Union transport ministers approved the initial funding of 100 million euros in April 2001. Proposed as a civilian satellite navigation system, Galileo may be fully operational by 2008. One difference between Galileo and GPS is that some of the satellites in Galileo's constellation will be in orbits with greater inclination to the equatorial plane than the GPS satellites. This will give northern Europe better coverage than that provided by GPS today.

Russia has developed a military satellite navigation system called Glonass. This system, which entered service in 1993, used twenty-four satellites when it began operation. Because of the country's financial problems that began later in the 1990s, however, older satellites were not replaced. As a result, by 2001 only six of the original twenty-four satellites were still in use, although Russia had plans to launch three new satellites in the early twenty-first century.

China is also planning to develop its own satellite navigation system. In 2000 China launched two experimental navigational satellites. These satellites, called the Beidou navigation satellites, are named after the constellation the Big Dipper. They continue to be used for some limited functions. China hopes to build a more extensive satellite navigation system by around 2010. SEE ALSO Global Positioning System (volume 1); Military Customers (volume 1); Navigation (volume 3); Reconnaissance (volume 1); Satellites, Types of (volume 1).

Salvatore Salamone

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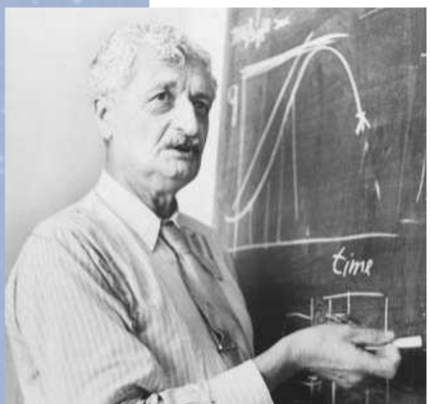
TWO FOR ONE

The GPS system was originally developed for use by the military and government agencies, but the U.S. government has made it available for commercial use. The first nongovernment users were surveyors and commercial trucking and seagoing shipping firms. Today, with GPS receivers becoming increasingly affordable, their use has expanded to the general public, allowing recreational boaters, hikers, even people just driving their cars, to determine their location via satellite. This dual-purpose role is supported through the use of two different GPS services levels. The Standard Positioning Service (SPS) is available to nongovernment users, while military and federal government users utilize the more accurate Precise Positioning Service.

O

Oberth, Hermann

Austro-Hungarian Physicist
1894–1989



Hermann Oberth, in his office at the Army's Redstone Arsenal in Alabama, working on a mathematical formula in 1958. Oberth came to the United States in 1956 from Germany as a consultant on space travel.

Hermann Julius Oberth, who was born on June 25, 1894, in the Transylvanian town of Hermannstadt, is considered a founding father of rocketry and astronautics. In the 1920s Oberth, whose childhood fantasies had been inspired by the novels of Jules Verne, wrote an influential publication *The Rocket into Planetary Space*, which discussed many aspects of rocket travel. Later he expanded that work into a larger volume, *The Road to Space Travel*, which won wide recognition.

After World War I, Oberth studied physics at the University of Munich, where he realized that the key to space travel was the development of multistage rockets. Despite this important insight, Oberth's doctoral thesis on rocketry was rejected in 1922. However, in 1923, he published *The Rocket into Planetary Space*, which was followed by a longer version in 1929. In the final chapter Oberth foresaw "rockets . . . so [powerful] that they could be capable of carrying a man aloft."

In the 1930s, Oberth proposed to the German War Department the development of liquid-fueled, long-range rockets. Oberth worked with the rocket pioneer Wernher von Braun during World War II to develop the V-2 rocket for the German army. During this period Robert Goddard was launching liquid-fueled rockets in the United States. After the war Oberth and von Braun collaborated again at the U.S. Army's Ballistic Missile Agency in Huntsville, Alabama. Oberth contributed many important ideas regarding spaceflight, including the advantages of an orbiting telescope. Oberth died in 1989 at the age of 95. SEE ALSO GODDARD, ROBERT HUTCHINGS (VOLUME 1); VERNE, JULES (VOLUME 1); VON BRAUN, WERNHER (VOLUME 3).

John F. Kross

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Internet Resources

Hermann Oberth: Father of Space Travel. <http://www.kiosek.com/oberth/>.

P

Payloads and Payload Processing

The machines, equipment, hardware, and even people that are carried into space atop rockets or inside space shuttles are often called payloads. The term originated in World War I (1914–1918) during efforts to determine the amount of cargoes and people that could be carried by land tanks. The term is also often applied to the amount of useful weight that can be lifted

by airplanes and inside trucks. Without a useful amount of payload—the "pay" carrying load—any transportation system would be of minimum value since the objective of a transport is to carry cargoes from destination to destination. This is true whether the transport in question is a rocket or a car and the payload consists of satellites or groceries. Payloads can consist of nearly anything that researchers, government, or industry seek to place into space. Satellites, robotic probes, or instrument packages can act as payloads. In human spaceflight programs, payloads can be the astronauts themselves, along with their life-sustaining equipment and supplies.

Space shuttle payloads can include experiment packages, satellites for deployment, or space station hardware or supplies.

Mission specialists assemble a structure in the payload bay of space shuttle Endeavour.

In space transportation, payloads arrive in space with minimum activity involving people. If the transport is an expendable, throwaway rocket, there are no people present when the craft arrives in space. Even if the space shuttles are used for launching the payload, astronaut interaction with the payload during a flight is kept at a minimum except under unusual circumstances. Thus all of the payloads sent into space are carefully prepared before the launching and their checkouts and activation automated to the maximum extent possible. Because people will not be present when these payloads arrive in space, payload processing and prelaunching preparation is an important part of the flight itself.

Payload Design and Storage

Payload preparation actually begins when the payload is under design. Space engineers often design a satellite to absorb the types of effects that the launching system—a rocket or shuttle—places upon the machine. These can include the effects of the thrust of the rocket and the amount of gravity that its thrust into space generates on the payload and everything else aboard the rocket. Depending on the flight path chosen, the type of rocket, and the final destination planned for the payload, this can be many times the pull of gravity experienced on Earth's surface. Other effects, such as friction, heat, vibration, and **vacuum**, also affect the payloads as they rise through the atmosphere and move out into the space environment.

vacuum an environment where air and all other molecules and atoms of matter have been removed

Once the craft reaches its planned destination in space, designers must factor in the final environmental conditions, such as radiation and the surface conditions of a planet if a landing is planned. If the planetary destination is far away, engineers must build the craft to sustain the long flight. If the spacecraft is flying toward the Sun, it must be shielded from the harsh and continuous heat streaming out from the Sun. If the craft is flying in the opposite direction, then the craft and its electronics must be heated to keep warm during its long cruise in the cold dark of space.

Once a payload has been designed and manufactured, it must be kept in storage until the time draws near for its launch. Usually the manufacturer prepares a storage container and location that maintains the payload in environmentally friendly conditions as the launch is awaited. This is a period that could last months or even years. For example, when the space shuttle Challenger exploded in 1986 all shuttle missions were placed on hold. Their payloads had to be stored for several years because of this unexpected delay. Such large satellites as the Hubble Space Telescope and other military spacecraft bound for a shuttle ride had to be specially stored during the delay.

Preparation for Launch

As the date of a planned launch draws nearer, payloads are shipped to the launching base where the flight will take place. Following its arrival from the manufacturer, the payload is rechecked to assure that it has not been damaged or affected in transit. Sometimes this includes partially dismantling the payload and conducting extensive recheckouts. More complicated payloads such as the Russian modules to the International Space Station are shipped only partially built, with construction completed at the launching site itself. Once engineers have assured themselves that the payload has arrived at the launch site without damage, the next phase of preparation usually consists of readying the payload for mating with its rocket transport.

Shuttle Launches. If the launching vehicle is a space shuttle, much of the preparation process serves to ensure that the payload poses no risk to astronauts on the shuttle. Careful review of the payload's fuels, its electrical systems, and any rocket engines that might be part of its design are conducted. Once that step is completed, the craft is then checked for the method by which it is to be attached to the shuttle's cargo bay. Attachments, release mechanisms, and other devices that will act to deploy the payload away from the shuttle or allow it to be operated while still attached inside the bay are tested and verified ready for flight.

At a certain stage in the final launch preparations the payload is moved from its preparation facility to the launching pad and installed inside the shuttle. Once in place, many of the tests and verifications are repeated to assure workers that the payload and its shuttle interfaces are working together. Unlike cargoes that fly inside commercial airliners, cargoes that are launched aboard the space shuttles are partially integrated with the shuttle itself. This even includes the selection of the location where the payload is attached to the shuttle bay.

When all of these steps have been completed, a complete dress rehearsal of the final days of the countdown and liftoff is conducted. Called a Terminal Countdown Demonstration Test, this simulated launching even includes suiting up the astronaut crew and having them board the shuttle just as they will do on the day of the actual flight. The payload is activated at the same level it will be on launch day, and the test goes all the way up to the point where the rocket engines would be ignited to start the actual mission into space. If all goes well with this test, the payload and the shuttle are deemed ready for their space mission.

Expendable Rocket Launches. If the launching vehicle is an expendable rocket, the process is somewhat less complex. Once at the launching site, the checkout and testing is conducted and the craft made ready for installation atop the rocket. In the United States, France, and China, the test and integration procedure is done with the rocket and payloads stacked vertically. Russian space launch vehicles use a horizontal integration technique. Whichever method is used, the payload is attached to the final propulsive stage of the rocket or to its own rocket stage, and the completed assembly is carried to the rocket pad or final assembly building and becomes part of the overall launch vehicle.

As is the case with the shuttle, tests are conducted to verify that the attachments have been correctly made and that the rocket's computers are "talking," or exchanging data, with the payload computers. A dress rehearsal of the launch is also conducted, although it is usually less extensive than that done for the shuttles. A successful completion of this test clears the way for the final countdown. Rocket fuels and explosive devices to separate the rocket's stages in flight or to destroy the craft if it veers off course are loaded into the rocket. Checks of the weather along the vehicle's flight path are also conducted.

When liftoff occurs, information on the health of the payload is sent by radio to tracking stations along the path that the rocket takes towards space. When the point in the flight is reached where the payload becomes active, it comes alive through radio commands, and begins its own role in achieving its space mission goal. If a malfunction occurs, radio data give mission controllers and engineers information on the cause, so that future versions of the rocket and payload can be redesigned to avoid the trouble.

Present-day launching rockets have an average of one chance in ninety-five or ninety-seven of experiencing an actual launching disaster. The most reliable rockets thus far designed have been the Apollo Saturn lunar boosters and the space shuttles. The Saturns had a perfect flight record in their missions from 1961 through 1973. The space shuttle has failed once in 100 missions. SEE ALSO Launch Services (volume 1); Launch Vehicles, Expandable (volume 1); Launch Vehicles, Reusable (volume 1); Payload Specialists (volume 3); Payloads (volume 3); Satellites, Types of (volume 1); Spaceports (volume 1); Space Shuttle (volume 3).

Frank Sietzen, Jr.

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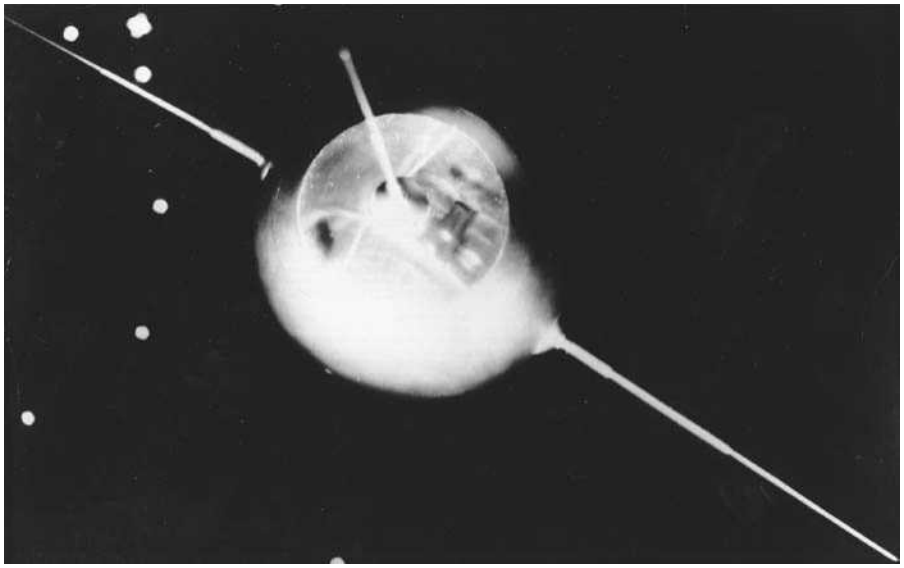
Planetary Exploration

The exploration of space has been of interest to people since Nicholas Copernicus (1473–1543) and Galileo Galilei (1564–1642) discovered and described the true nature of the solar system. About 100 years ago, Russian Konstantin Tsiolkovsky (1857–1935) was the first scientist to describe the modern concepts of rocket engines and space travel. Tsiolkovsky, who wrote books about space travel, stated: "Earth is the cradle of humanity, but one cannot remain in the cradle forever."

In 1957 the Soviet Union surprised everyone by launching the world's first satellite, Sputnik. Only four years later, American amateur radio operators (hams) built and launched the world's first volunteer- and citizen-built satellite, Oscar I. Oscar I weighed about 3.7 kilograms (10 pounds) and transmitted the word "Hi" in Morse code as it orbited Earth.

Government-Backed Exploration

In the beginning, national space programs were exclusively military. While Robert H. Goddard (1882–1945) was experimenting with small and unsuccessful rockets in the United States, the German Nazi war effort progressed to the point where the Nazis were able to bomb downtown London with their V-2 rockets. When the Nazis were defeated, the armed forces of the Soviet Union and the United States raced to obtain valuable German



A model of Sputnik 1 at the Prague, Czechoslovakia, exhibition on October 7, 1957, in celebration of the 40th anniversary of Russia's October Revolution. The real Sputnik 1 was launched three days earlier, becoming the first human-made object launched into space, starting the space race between the Soviet Union and the United States.

U.S. President Dwight D. Eisenhower (1890–1969) urged the formation of the National Aeronautics and Space Administration (NASA).

engineers to gain their knowledge of advanced rocketry. After World War II (1939–1945), the programs of both countries were based on former German rocket scientists, such as Wernher von Braun (1912–1977), who was brought to the United States.

The National Aeronautics and Space Administration (NASA) was formed in 1958 at the urging of President Dwight D. Eisenhower (1890–1969). President Eisenhower wanted a civilian and not a military agency to challenge the Soviet Union in the race to space. NASA's first challenge was to beat the Soviet Union to the Moon, which it successfully accomplished with the Apollo 11 mission in 1969.

Moving Beyond Government-Sponsored Space Programs

The excitement generated by humans walking on the surface of another planetary body resulted in many nongovernment people dreaming and working toward the private exploration and development of space. A leader during the 1970s was Gerard O'Neill of Princeton University, who imagined and described the possibility of people working, living, and playing in space. Much research was done on his concepts of space colonies orbiting Earth, but because his designs depended on large amounts of materials being launched to Earth orbit, and because of the very high cost of government technology and launches, such space colonies never materialized.

In 1965, Comsat launched the first commercial communications satellite. Today, college students design, build, and launch smaller, more powerful satellites. These "nano-sats" and other small microsatellites are usually launched as "hitchhikers" on large expensive rockets. Many space entrepreneurs today believe that a revolution may be happening with the introduction of smaller, more modern technology into space products. With college students building 1-pound satellites, and with the introduction of the concept of formation-flying dozens or hundreds of nano-satellites in orbits close to each other, it is possible to think of small satellites being like the personal computers linked together in local area networks that replaced the big expensive mainframe computers.

Also during the mid-1990s, a number of companies were started with the hope of designing and producing dramatically less expensive launch vehicles. Each company began with the hope that it had some kind of breakthrough technology that would revolutionize launch vehicles and reduce the cost of orbiting material from $22,000 per kilogram ($10,000 per pound) to as little as $220 per kilogram ($100 per pound). Because of the expense and risk involved in developing new technologies, these companies have not yet made much progress.

While many people are beginning to understand that space is a place and not a government program, there are many hurdles to overcome in making space happen for large numbers of nongovernment people—workers, tourists, and others wanting to experience space. Those interested in seeing space blossom feel that there are two primary paths. The first involves more government spending on large programs, such as an Apollo-like human mission to Mars. It appears, however, that taxpayers are not willing to fund such an expensive program. The other commercial and entrepreneurial paths to space may be encompassed in the slogan: "If we want to go to space to stay, space has to pay."

Difficult and expensive ventures often need to start with baby steps: learning to crawl and then walk before being able to run. Space may be like that. Many companies are starting with the goal of finding ways to make space pay in order to generate profits that can be used to conduct increasingly bolder and larger space ventures, without government intervention or taxpayer subsidies. Sources of revenue include planetary science data, returned samples, delivery of science instruments to planetary destinations, use of the abundant natural resources in space, delivery of television and Internet content in the form of photos and videos, manufacture of materials in space, and space tourism. All of these can be done commercially.

Robert A. Heinlein (1907–1988), an American writer and scientist, said that getting to Earth orbit is halfway to anywhere in the solar system. He meant that the energy required to lift off the ground and get up enough speed to achieve Earth orbit is about the same amount of energy required to leave Earth orbit and head for any other destination in the solar system. In other words, when we reach Earth orbit today, we are running on empty, our tanks are empty, and about the best we can do is go around in circles, as with the shuttle. Even with more expensive, larger rockets, we can just manage enough energy to break away from Earth's gravity. Our deep-space missions then coast, on empty, to their destination whether it is Venus, Mars, Jupiter, or the boundaries of the solar system itself.

What some believe is needed for serious exploration of space are filling stations in Earth orbit where a spacecraft could refill its tanks and could then power its way through space and not just coast for years. Earth-bound society is dependent on concentrated, portable energy such as gasoline, petroleum (black gold), natural gas, and coal. Space is no different: concentrated, portable energy is needed to explore space. Water is the most abundant substance in the universe and in the solar system. Scientists know that Earth travels in a cloud of inner belt asteroids called near-Earth objects. Many planetary scientists, such as John S. Lewis of the University of Arizona in Tucson, believe that 20 percent or more of these objects may be **dormant comets**. These space icebergs, then, might be considered "white gold."

dormant comet a comet whose volatile gases have all been vaporized, leaving behind only the heavy materials

With the cost of lifting anything into space at about $22,000 per kilogram ($10,000 per pound), it can be understood that anything already in space is already worth $10,000 per pound. If private exploration companies were to find water in near-Earth asteroids, the water could be extracted and converted to its constituent parts—oxygen and hydrogen—with simple electrolysis. Like Earth, space is filled with **diffused** energy: solar energy. This energy could be captured by satellite **solar arrays** and converted into electricity to power spacecraft, and could also be used to generate rocket fuel: specifically, hydrogen and oxygen, which, for example, are used in the main engines of the space shuttle.

diffused spread out; not concentrated

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

By 2000 the international space sector of the global economy exceeded $100 billion per year with about one launch per week somewhere in the world. Since about 1998 over half of that space activity has been commercial and not military or governmental. With smaller modern technology and entrepreneurial space companies starting, we may be on the verge of the real space age. SEE ALSO Apollo (volume 3); Data Purchase (volume 1); Earth—Why Leave? (volume 4); Exploration Programs (volume 2); Planetary Exploration, Future of (volume 2); Satellite Industry (volume 1).

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Privatization *See Commercialization (Volume 1).*

R

Reconnaissance

The first military space mission was reconnaissance, and that remains the most important mission, offering capabilities that cannot be obtained by any other means. A number of countries possess military satellite reconnaissance systems, including the United States, Russia, France (in cooperation with Germany, Italy, and Spain), and Israel. China apparently has abandoned its reconnaissance satellite system. Japan has plans to develop an extensive reconnaissance satellite capability, and Canada, India, and Brazil operate "civilian remote sensing satellites" that have limited military uses. Since the late 1990s several private companies have offered to sell satellite imagery of increasingly high quality. Virtually any country can now buy detailed pictures of any place it wants to see.

At the most basic level, reconnaissance involves looking at an area of Earth to determine what is there. Among the ways this can be done from space, the primary methods are visual and **radar** reconnaissance. Visual reconnaissance can be conducted in black and white or in color, although black-and-white images provide more detail. The major problem is that visual reconnaissance is impossible when the target is covered by clouds. Radar can penetrate cloud cover, but the images it returns are of lower quality. Radar reconnaissance is more challenging, and fewer countries operate dedicated radar satellites.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

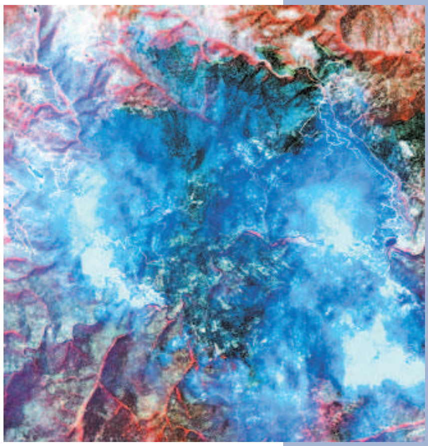
The United States was the first country to consider the use of satellites for reconnaissance. In 1946 the RAND Corporation conducted a study for the U.S. Air Force of the potential military uses of satellites, and reconnaissance was high on the list. However, the high cost of launching a satellite into orbit was prohibitive. In 1954 RAND conducted a much more extensive study of reconnaissance satellites and their capabilities. RAND proposed an atomic-powered satellite carrying a television camera. When the U.S. Air Force began a reconnaissance satellite program, the television camera proved impractical, and a "film-scanning" system was chosen instead. That system would take a photograph, develop the film aboard the satellite, and then scan the image and transmit it to Earth. Solar panels were substituted for the atomic power supply. The Atlas ICBM was to be used to launch the satellite into orbit, but the U.S. Air Force was unwilling to fund the program until after Sputnik was launched in October 1957.

After the advent of the space age, satellite reconnaissance received much more attention in the United States, which feared that the Soviet Union had large numbers of **ballistic** missiles at sites deep within that country. The U.S. Air Force funded a series of film-scanning satellites called SAMOS,

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

and the Central Intelligence Agency was placed in charge of an "interim" program called CORONA. Unlike SAMOS, CORONA returned its film to Earth in a small capsule that was caught in midair by an airplane trailing a cable.

After a string of failures, the first CORONA satellite returned its film to Earth in 1960. The pictures were grainy and showed relatively little detail but provided a wealth of information on the Soviet Union, including the fact that the Soviet Union did not have more missiles than the United States did. CORONA became more successful, and its images improved in quality, whereas SAMOS experienced numerous failures. At its best CORONA could photograph objects on the ground that were a minimum of 6 to 9 feet long. That did not allow observations and measurements, and so the U.S. Air Force canceled SAMOS and began a satellite program called GAMBIT. GAMBIT, like CORONA, returned its film to Earth, but it could photograph much smaller objects. CORONA was discontinued in 1972, but GAMBIT kept flying until 1985, and late models of the satellite could photograph objects as small as a baseball.



From space, the examination of an area of Earth to determine what is there can be accomplished through visual and radar reconnaissance.

Developments in Reconnaissance Technology

The next major leap in reconnaissance satellite technology occurred in 1976, when the United States launched a satellite known as KENNAN, later renamed CRYSTAL. KENNAN could transmit images directly to the ground, using a camera similar to a common digital camera. The images were black and white and took several minutes to transmit, but this was far faster than the days or weeks required with the film-return system. These satellites could see objects no smaller than a softball. With the increase in speed came a change in the ways the satellites were employed. Instead of being used to prepare long-range plans and studies, they could now be used in crisis situations, and the president could make instant decisions based on satellite photographs.

Later versions of KENNAN probably are still in use, but these satellites are limited by their inability to see through clouds. In the late 1980s the United States launched a radar satellite called LACROSSE (later renamed ONYX) that could look through clouds and smoke. The major drawback of LACROSSE was that it could see objects no less than 3 three feet long.

Soviet Reconnaissance Satellites

The Soviet Union developed similar systems, usually trailing about three to seven years behind the United States. Its first reconnaissance satellite, Zenit, was similar to the first Soviet spacecraft to launch a man into orbit, Vostok. Unlike CORONA, Zenit returned both the film and the camera to the ground in a large capsule. The Soviets later developed a higher-resolution system called Yantar. It was not until the 1980s that the Soviets had a satellite, Terilen, capable of transmitting images to the ground in "real time." The Russians still use modified versions of Zenit and Yantar, although economic problems have limited the number of satellites they can launch.

The United States is gradually shifting from using a few large reconnaissance satellites to employing more smaller satellites as part of its Future Imagery Architecture. The purpose of this shift is to decrease the amount of time it takes to photograph any spot on the ground. It now requires a day or more before a photograph of a potential trouble spot is taken by a reconnaissance satellite.

Commercial Reconnaissance Technology

The United States will be helped in this shift by the proliferation of commercial reconnaissance satellites. In the early twenty-first century, commercial satellites such as Ikonos-1, operated by an American company, can provide satellite imagery of virtually any place on Earth for a fee. Commercial satellites generally show objects on the ground that are as small as 3 feet long, and this is useful for many civilian and military purposes. As with the military satellites, these images are still pictures, not the moving images shown in spy movies. They sometimes are referred to as "the poor man's reconnaissance satellite," but they can dramatically increase the power of a military force by allowing the users to know what their adversaries are doing from a vantage point that the vast majority of the world cannot reach. SEE ALSO Global Positioning System (volume 1); Military Customers (volume 1); Military Exploration (volume 2); Military Uses of Space (volume 4); Remote Sensing Systems (volume 1); Satellites, Types of (volume 1).

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Regulation

remote sensing the act of observing from orbit what may be seen or sensed below Earth

Commercial space activities conducted by U.S. companies are regulated by the federal government in four major areas: space launches, **remote sensing**, communications, and limitation of the transfer of technology for reasons of national security and industrial policy.

Communications are regulated by the Federal Communications Commission (FCC). The FCC was established in the 1930s to regulate radio (and later television) and the use of spectrum, assuring that the signals from one station would not interfere with those from another station. When commercial communications satellites arrived in the mid-1960s, the FCC had had three decades of regulatory experience.

The office within the FCC that issues licenses for satellites is the Satellite and Radiocommunications Division of the International Bureau. Licensing assures that any proposed new satellite will not interfere with other satellites or with any other operating radio applications, on Earth or in space. All commercial launches, reentries, or landings conducted by U.S. companies are regulated by the Commercial Space Launch Act (CSLA). Under the CSLA, each launch or reentry must have a license. FAA/AST, the Office of Commercial Space Transportation, is part of the Federal Aviation Administration and is the federal government agency that issues these licenses. Its web site (ast.faa.gov) contains all the relevant rules, laws, regulations, and documents needed to obtain a launch license. FAA/AST conducts a policy review, a **payload** review, a safety evaluation, an environmental review, and a financial responsibility determination based on the data in the license application before issuing or refusing a license. The purpose of a launch license is to assure that "the public health and safety, safety of property, and the national security and foreign policy interests of the United States" are properly considered.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Commercial remote sensing from space is regulated under the 1992 Remote Sensing Policy Act and its associated regulations and administration policies. The act directs the secretary of commerce to administer its provisions, and those duties have been delegated to the National Environmental Satellite, Data, and Information Service (NESDIS) of the National Oceanic and Atmospheric Administration (NOAA), an agency of the Department of Commerce. NESDIS runs the nation's weather satellites, and the International and Interagency Affairs Office (IIAO) within NESDIS issues the licenses needed to operate private space-based remote sensing systems (www.licensing.noaa.gov/).

NESDIS/IIAO reviews these applications in consultation with the Department of Defense (national security), the Department of State (foreign policy), and the Department of the Interior (which has an interest in archiving remote sensing data). Once an application has been determined by NESDIS/IIAO to be complete (all the required documents and data have been submitted), by law NOAA has to issue an up-or-down license determination within 120 days. Documents, background data, instructions, and examples are available at NESDIS/IIAO's web site to aid license seekers.

Under the law, a licensee must operate its space-based remote sensing system(s) so that the national security interests of the United States are respected and the international obligations of the nation are observed. A licensee must maintain positive control of its system(s) and maintain clear records of the sensing those systems have done. A U.S. licensee also must agree to "limit imaging during periods when national security or international obligations and/or foreign policies may be compromised." This is called "shutter control": The federal government can, in time of international stress (war or conflict) tell licensees what they can and cannot take pictures of.

The major law in the area of trade control is the Arms Export Control Act (AECA) and its associated regulations, the International Traffic in Arms Regulations (ITAR). Virtually anything involving space falls under ITAR. Equipment for ground stations for satellite control; transmitters; rocket engines; computer software for controlling a rocket, a satellite, or a ground station; rockets; and satellites are all subject to control and licensure under ITAR.

Licenses and regulation under the AECA and ITAR are administered by the U.S. Department of State and its Office of Defense Trade Controls (DTC), which is part of the Bureau of Political Military Affairs. These organizations are aided in their work by the Defense Threat Reduction Agency of the Department of Defense. DTC's web site (www.pmdtc.org) contains documents, background data, and instructions to aid license seekers, including electronic means for the filing and tracking of license applications.

The United States is a party to the Missile Technology Control Regime (MTCR), to which twenty-eight other countries, including Russia, Greece, Hungry, and Spain, also belong. Equipment and technology are controlled under this regime to limit the proliferation of weapons of mass destruction through efforts to control the availability of delivery systems (rockets). The State Department and the Department of Defense attempt to assure that space companies that export services or products adhere to the goals of the MTCR.

During most of the 1990s, space-related trade control was the responsibility of the Department of Commerce, specifically the Bureau of Export Administration (www.bxa.doc.gov) and the International Trade Administration (www.ita.doc.gov). Both of these agencies now play a reduced role in regulating the export of space-related trade products and services, but their main role at present is primarily to support the activities of the Department of State.

The shift of the regulation and licensing of space-related trade from the Department of Commerce to the Department of State resulted from a law passed by Congress, which wanted to eliminate what it felt was a looseness in U.S. trade control that had led to the transfer of sensitive space technology. This statutory change had unintended consequences, making it extremely difficult for a company such as Orbital Sciences Corporation to communicate with a division of its own company based in a foreign country. Under this regime, satellite engineers cannot talk to their counterparts in the United Kingdom without a license. These restrictions became so stringent that Orbital sold its Canadian-based division because of the difficulties presented by these mandated trade restrictions. Congress has since passed new legislation to address this problem. SEE ALSO LAW (VOLUME 4); LAW OF SPACE (VOLUME 1); LEGISLATIVE ENVIRONMENT (VOLUME 1); LICENSING (VOLUME 1).

Timothy B. Kyger

Internet Resources

Office of Commercial Space Transportation. Federal Aviation Administration. <http://ast.faa.gov>.

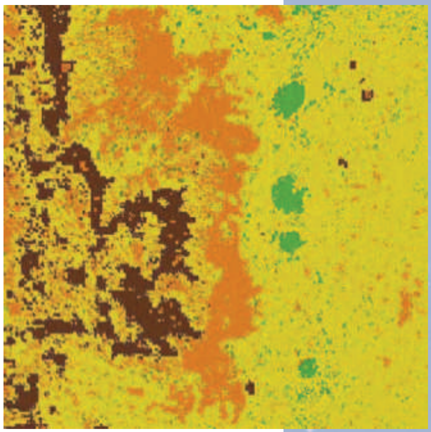
Satellite and Radiocommunications Division of the International Bureau. Federal Communications Commission. <http://www.fcc.gov/ib/srd>.

Remote Sensing Systems

International research efforts have been undertaken to study the complex and interconnected processes that affect Earth's atmosphere, oceans, and land. Essential information for this research is provided by fleets of satellites and aircraft equipped with sensors that collect enormous amounts of Earth data. These systems are called remote sensing systems.

The variety of data that can be obtained through remote sensing systems is vast. The world scientific community uses remote sensing systems to obtain information about ocean temperature, water levels and currents, wind speed, vegetation density, ice sheet size, the extent of snow cover, rainfall amounts, aerosol concentrations in the atmosphere, ozone levels in the

stratosphere, and many other important variables to better understand how natural phenomena and human activities impact global climate. Remote sensing systems may also be used by decision makers such as environmental resource managers, city planners, farmers, foresters and many others to better run their businesses and to improve people's quality of life. This article presents a number of applications of remote sensing systems to farming, water quality analysis, water resources in arid regions, noxious weed detection, urban sprawl, urban heat islands, and many others. This field is in rapid evolution and many new applications may appear in the years to come.



Data obtained through remote sensing systems show some of New Mexico's variegated terrain. Remote sensing systems can also be used to collect data varying from vegetation density to aerosol concentrations in the atmosphere.

stratosphere a middle portion of Earth's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

Satellite Remote Sensing

Space is an excellent vantage point from which to study air, sea, and land processes both locally and globally. It provides the bird's-eye view that captures all the information in a single image. Satellite observations have definite advantages over ground or aircraft observations. Ground observations are labor intensive, time consuming, and costly. Aircraft observations require less labor and time but are still costly. In spite of their high initial cost, satellites are a cheaper way to do observations as they may take data continuously during their lifetime over the whole globe. Satellites can also observe areas difficult to access on the ground and provide regular revisits of the same areas showing surface feature changes over time.

Satellite observations are made with sensors that measure the brightness of electromagnetic radiation either reflected or emitted by ground features. Electromagnetic radiation includes not only visible light with its various colors but also many colors invisible to the human eye such as **ultraviolet** and **infrared**, as well as radar and radio waves.

Resolution refers to the smallest size object that can be identified. A 1-kilometer (0.6-mile) resolution satellite will produce images made of small squares with uniform brightness representing 1-kilometer by 1-kilometer squares on the ground. In general, objects smaller than 1 kilometer cannot be distinguished in such an image.

Whereas visible and near-infrared radiation observed by sensors is actually **solar radiation** *reflected* by ground features, thermal infrared radiation is radiation *emitted* by ground features. Thermal infrared radiation provides information about the temperature of the emitting objects. Other sensors actively illuminate Earth and measure the reflected signal. Radar is an active remote sensing system that is very useful in areas that are often covered with clouds. Whereas visible and infrared radiation is blocked by clouds, radar waves penetrate clouds, thus enabling observations of Earth from space in almost all weather conditions.

Remote sensing data can be compared to an ore that contains gold (information) from which a piece of jewelry can be made (knowledge). Remote sensing is at its best when it is used to answer specific and well-posed questions. The end result of the processing of data, information extraction, and analysis is the answer to these questions.

Many remote sensors are placed onboard aircraft. Satellites may take several days, even weeks before revisiting a specific area on Earth, whereas aircraft can be commissioned to take remote sensing data over that area on a moment's notice. They also operate at significantly lower altitudes and produce higher resolution data than satellites when fitted with the same type of sensor. Finally, many new National Aeronautics and Space Administration (NASA) sensors are tested on aircraft before being put on satellites. Aircraft remote sensing has an important role to play both for global climate change studies and for more immediate applications such as the ones described below.

Global Environmental Observations

We live in a rapidly changing world facing major global challenges. A rapidly increasing world population demanding accelerated economic development strains Earth's resources. Remote sensing systems are being used to investigate a number of areas related to the global environment, including global climate change, rain forest deforestation, the health of the oceans, the size of polar ice covers, and coastal ecosystem health.

Global Climate Change. One of the most ambitious and far-reaching programs of environmental investigation is the U.S. Global Change Research Program. This effort is part of a worldwide program to study global climate change, which involves changes in the global environment that could affect Earth's ability to support life.

A strongly debated climate change issue is global warming, which results from increased atmospheric levels of greenhouse gases—such as carbon dioxide—that trap heat in the lower atmosphere, preventing it from escaping into space.

The Carbon Dioxide Information Analysis Center estimates that fossil fuel use and other industrial activities have resulted in the release of 265 billion tons of carbon into the atmosphere since 1751, with half of the total occurring since the mid-1970s. Worldwide levels of carbon dioxide in the atmosphere have increased by 25 to 30 percent since 1850. The average global surface temperature of Earth is up. The year 1997 was the warmest of the twentieth century and possibly the warmest of the past 1,000 years. The question that some people debate is whether this warming is directly related to the human production of carbon dioxide or due to natural processes. Whatever the answer to this question, the trend is clear and the consequences may be severe for the human species.

Plants grow by absorbing atmospheric carbon dioxide, storing the carbon in their tissue. Rain forests and ocean phytoplankton are great carbon dioxide absorbers. So are corals and shellfish, which make calcium **carbonates** that end up in the bottoms of oceans.

carbonates a class of minerals, such as chalk and limestone, formed by carbon dioxide reacting in water

Trees and plankton may grow faster—left to themselves—if the level of carbon dioxide in the atmosphere increases. This could provide a mechanism limiting atmospheric carbon dioxide concentrations. Unfortunately, people pollute the oceans, which kills phytoplankton and coral reefs, and destroy tropical rain forests.

Scientists worldwide inventory and monitor rain forests, phytoplankton, and coral reefs in an effort to estimate their impact on the concentration of carbon dioxide in the atmosphere. Their main sources of information are from satellite remote sensing data. The warming of Earth's lower atmosphere results in the melting of glaciers and polar ice sheets. The extra liquid water produced raises ocean water levels. Indeed, sea level rose 10 to 25 centimeters (4 to 10 inches) during the last century and glaciers are melting. Data from a number of satellites are used by the National Oceanic and Atmospheric Administration (NOAA) to measure the rate of ice melting in Antarctica and Greenland, two major causes of sea level rising.

Rain Forests. The Global Observations of Forest Cover is an international effort to inventory worldwide forest cover and to measure its change over time. From these observations, which are based on high-resolution satellite remote sensing, scientists produce digital deforestation maps.

Deforestation is a politically sensitive topic. Developed nations pressure developing countries such as Brazil and Indonesia to stop the deforestation process, arguing that the rain forests in these countries are virtual lungs for the world's atmosphere. Developing countries with tropical rain forests argue that the deforested areas are important and necessary sources of revenue and food as they are used for agricultural activities. The debate prompted an international meeting, the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, in June 1992. This conference resulted in the Rio Declaration on Environment and Development that sets the basis for a worldwide sustainable development—an economic development that does not deplete natural resources and that minimizes negative impact on the environment.

Oceans. Phytoplankton and coral reefs in the oceans significantly contribute to the removal of atmospheric carbon dioxide. Acid rain and other pollutants adversely affect coral reefs and phytoplankton. Satellite remote sensing is used to inventory coral reefs and phytoplankton worldwide.✶ Indeed, because of their wide distribution and remote locations, coral reefs can practically be inventoried and monitored only from space.

✶Phytoplankton is easy to recognize from space because it has a distinctive green color.

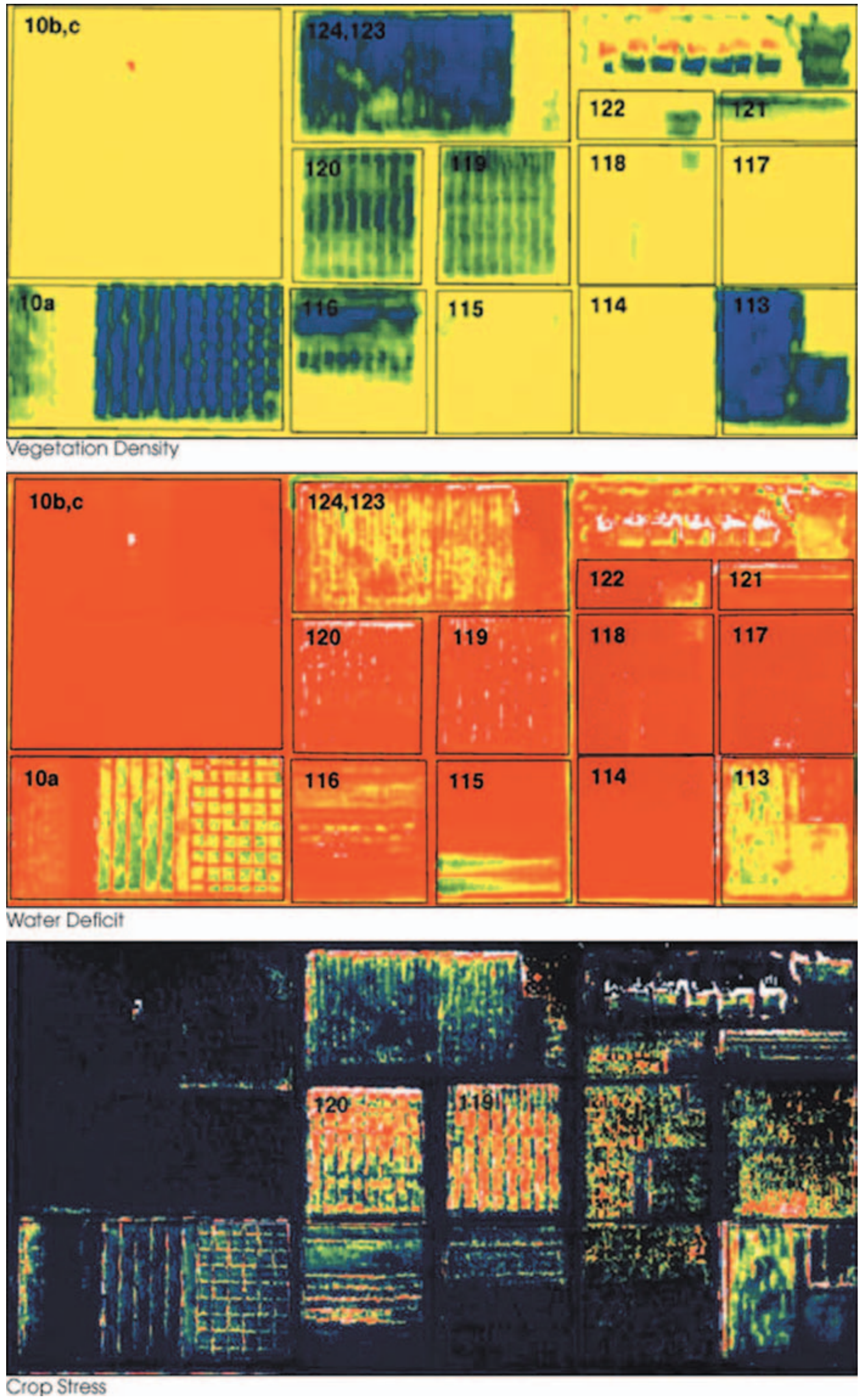
Satellite sensors are also used to measure other ocean characteristics such as topography and ocean temperature. For example, a partnership between the United States and France developed *TOPEX-Poseidon*, a satellite that monitors global ocean circulation and global sea levels in an effort to better understand global climate change, specifically the links between the oceans and the state of the atmosphere.

Ocean monitoring by satellites enables NASA and NOAA to predict the El Niño weather patterns. El Niño is a global weather pattern that is driven by conditions in the Pacific Ocean. During an El Niño, countries in the western Pacific experience severe droughts, whereas the eastern Pacific is drenched by torrential rains, leading to mudslides in California and South America.

Ocean observations are undertaken not only to estimate pollution and ocean health but also for commercial purposes. The OrbImage company, for example, provides fish finding maps to fishing companies based on plankton concentration information from their OrView-2 satellite and on sea surface-temperature information from U.S. weather satellites. This information is radioed to the boats that use it for their fishing operations.

Radar remote sensing has several important uses over oceans. Reflected signals from radar are sensitive to water surface roughness. The rougher areas reflect the radar signal better and appear brighter. Smooth areas are dark as they barely reflect radar signal. This feature helps locate and monitor oil

Remote sensing can be used to aid farmers in making decisions about irrigation and fertilization. Color variations show crop density in the top image, whereas the middle and bottom images indicate water deficits. Fields 120 and 119 indicate a severe need to be irrigated.



radar images images made with radar illumination instead of visible light that show differences in radar brightness of the surface material or differences in brightness associated with surface slopes

spills on the ocean surface because oil makes the ocean surface smooth and thus appears dark on **radar images**.

Polar Ice Covers. The U.S. Landsat satellites, the Canadian RADARSAT spacecraft, and the European radar satellite ERS have been actively used to monitor the ice sheets in Antarctica and Greenland. The Landsat program has been ongoing since the early 1970s and has shown a significant modification of coastal regions in Antarctica during that period. Although it is not clear if there is a net gain or loss of ice volume in Antarctica, some of the ice shelves present in 1970s images have since disintegrated.

The Land-Sea Interface. Beaches provide a lively, productive habitat for wildlife and a buffer against coastal storms. Salt marshes produce nutrient-rich "sludge" as a basis for the food chain while providing nurseries for juvenile fishes and habitat for shrimp, crabs, shellfish, turtles, and waterfowl. Coastal habitats are essential to the feeding, reproduction, and migration of fish and birds. But development, and the sand pumping, jetties, and seawalls that come with it, is overwhelming beaches. Salt marshes are under constant threat from short-sighted development schemes that require they be drained and filled.

NOAA has a Coastal Remote Sensing program that is using remote sensing, along with other technologies, to help coastal resource managers improve their management of aquatic and coastal ecosystems. The data sets and products provided by this program include ones dealing with ocean color, coastal topography and erosion, water quality, and the monitoring and tracking of harmful algal bloom.

Satellite remote sensing can thus play a central role in monitoring the health of coastal waters. The challenge is to provide decision makers with the knowledge derived from the remotely sensed data and to educate them about the mechanisms at work in coastal waters using satellite images.

Several commercial companies also provide remote sensing images and data from satellites for **littoral** water and ocean monitoring. The DigitalGlobe company will launch 1-meter (39-inch) resolution satellites that are intended to show detailed coastal features, including beach structure, sandbars, and wave patterns.

littoral the region along a coast or beach between high and low tides

OrbImage has launched a commercial satellite, OrbView-2, to measure phytoplankton and sediment concentration in oceans and inland lakes, data that are useful for environmental applications such as coastal pollution monitoring and "red tide" tracking. Red tides are the result of dying **algae** producing a rapid multiplication of the bacteria that feed on them. These bacteria in turn deplete the water of its oxygen, killing marine life. Red tides can make mussels and oysters dangerous to eat as they produce toxins that can be life threatening to consumers.

algae simple photosynthetic organisms, often aquatic

These examples are by no means exhaustive of the many applications of satellite remote sensing, the numerous satellites in orbit, or the large number of new satellites planned. Satellite remote sensing is a business in rapid expansion, particularly on the commercial side. Earth data have been provided mainly by government-sponsored satellites until recently, but commercial satellite providers have entered the scene and will play an increasingly important role. This in turn has spurred the geographic information business.

Land Features

Satellite remote sensing was first used by the intelligence communities of the United States and the Soviet Union to spy on each other's military targets, starting in the early 1960s. In the 1970s, the United States initiated the Landsat program—a civilian program monitoring Earth's land resources—and in the 1980s NASA launched the Mission to Planet Earth program with an emphasis on understanding the global climate and monitoring the human impact on it.

In the late 1970s and in the 1980s, several other countries—such as India and France—launched remote sensing satellites to gather land surface data in an effort to monitor their agriculture and land use processes. Remote sensing information helps these countries establish national policies and monitor compliance. Since these satellites **orbit** over the whole Earth, they can provide data about many other locations. Both Indian Remote Sensing and the French Satellites Pour l'Observation de la Terre (SPOT) data are sold in the United States. Radar remote sensors have been put into space by Canada, the European Union, and Japan. Recently, several U.S. companies (Space Imaging, OrbImage, and DigitalGlobe being the leading companies) have obtained permission from the U.S. government to launch very-high-resolution satellites capable of seeing objects on the ground as small as 1 meter (39 inches). This may spur another information revolution similar to the personal computer explosion of the 1980s and the burgeoning of the Internet in the 1990s.

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

The enabling factors this so-called spatial information revolution include higher resolution, more reliable sensors, more powerful personal computers, the Internet, the civilian use of the Global Positioning System (GPS), and significantly improved geographic information system (GIS) software. Very-high-resolution, color images of any part of the world are predicted to become available on the Internet in almost real time for a modest fee. Anyone with a computer connected to the Internet would then be able to monitor his or her crops in a field, observe traffic jams in a big city in real time, and so forth.

Environmental Observations. Land observations from space have an endless list of applications. A few examples are watershed analysis (including water resources inventory and water quality analysis), noxious weed detection, monitoring land use change over time, tracking urban sprawl and the loss of agricultural land, erosion monitoring, observing desertification in semiarid lands, tracking natural hazards such as floods and fires, agricultural land inventory, and crop yield prediction. Many of these observations have a significant economic impact and enhance the quality of life of citizens and user communities.

In the Middle East and in Africa water scarcity has become a serious geopolitical issue. Ecosystems rarely recognize political boundaries and several countries share common water resources. The Nile River, for example, flows through eight countries before reaching Egypt, a country that experiences very little rainfall and relies almost entirely on the waters of the Nile for its agriculture and drinking water resources. Actions upstream by other governments can severely impact Egypt. Similar problems exist in the Middle East between Syria, Jordan, and Israel, countries that share common aquifers (natural underground water reservoirs) and other water resources.

Satellite remote sensing may play an essential role for peace by providing information about new water resources as well as accurate maps of existing known resources and a means to monitor use. Radar remote sensing in particular can be helpful in discovering new water resources in arid areas. For instance, the Canadian RADARSAT system has discovered new underground water flows in the African desert.

THE POWER OF RADAR

Radar can penetrate 1 to 4 meters (3 to 13 feet) of sand, revealing covered-up structures invisible to the eye and to other remote sensing bands. Radar remote sensing from the space shuttle has uncovered lost cities under the desert sands of Egypt and Arabia.

In the American West, noxious weeds spread at an alarming rate, overcoming other species of vegetation, destroying ecological balance, and even killing livestock. It is very impractical and costly to locate these weeds from the ground in the semiarid expanses of Arizona, New Mexico, and Utah. Satellite remote sensing helps locate these weeds either through their spectral reflectance pattern or by observing their blooming at specific times of the year when no other vegetation blooms. This information can then be used to eradicate the weeds.

Agricultural Applications. The agricultural applications of remote sensing are particularly useful. French SPOT satellites are used to determine what crops are planted where and how many acres of a given crop are planted in a region. Crop health is monitored over time, and claims of crop loss to drought or other natural disaster can be verified using satellite images.

The Earth Satellite Corporation uses remote sensing data to provide weekly information about worldwide crop conditions on the Internet. The company, for example, claims to make 95 percent correct yield predictions for cocoa, sugar, and coffee crops, two months ahead of harvest. Information such as this is extremely useful to growers needing to decide what crops to plant. If a wheat glut is predicted in South America in winter, informed farmers in the Northern Hemisphere will not plant wheat in early spring. Spatial technologies also give farmers new tools to better manage crops. A yield map over a field shows areas of higher and lower productivity.

In precision farming, a field is not treated as a homogeneous whole. Rather, as conditions—such as soil composition and soil fertility—vary across fields, the farmer's treatment of the field also varies. Thus irrigation, liming, fertilizers, and pesticides are not applied uniformly across a field but are varied according to need using a variable spreader with a GPS antenna and a computer program that has in its memory information about the local needs of the field. High-resolution satellite images can provide information about crop health. This information is put on a GIS used by the farmer to divide his fields into zones, each zone being treated differently. Precision farming has several advantages over traditional farming. As a result of differential treatment of field zones, there is less fertilizer, water, and/or pesticides used because applications are made in response to local needs only. There is thus economic benefit to the farmer. There is also less impact on the environment because fertilizer is not squandered in areas where it is not needed, reducing leaching into runoff water.

In the late 1990s thermal remote sensing data of fields in Alabama and Georgia showed a strong correlation between temperature maps of corn fields in June and yield maps of the same fields at harvest, at the end of August. These data were obtained using the NASA ATLAS sensor onboard a Stennis Space Center Lear Jet. Results indicate that thermal infrared remote sensing may predict crop yields with high accuracy several months before harvest. Thermal infrared emission from plants is a measure of their temperature. A healthy plant pumps water from the ground, vaporizes it (perspires), and stays cool by doing so. Less-healthy plants exposed to the hot summer Sun cannot keep cool and show a "fever."

Urban Observations. Whereas in 1950 less than one-third of the world's population lived in urban areas, almost half the population lives in cities at the beginning of the twenty-first century. Projections indicate that in 2025 two-thirds of the growing world population will be city dwellers. Most of the city population increase will occur in developing countries where serious challenges are expected. In rich countries such as the United States, city development is characterized by urban sprawl using up an ever-increasing proportion of available land. A 1997 U.S. Department of Agriculture study reported that nearly 6.5 million hectares (16 million acres) of American forestland, cropland, and open spaces were converted to urban use between 1992 and 1997.

Rapid growth and changes of urban geography require detailed, accurate, and frequently updated maps. Such maps can be produced faster, cheaper, and with considerably less manpower by using very-high-resolution satellites such as Space Imaging's IKONOS than by using ground-based data acquisition. A number of satellite remote sensing companies, such as the French company, SPOT, provide services and products for land and urban planners and for businesses such as real estate and insurance companies.

This information may be used to decide in which region to expand urbanization, where to build roads, and how to develop transportation infrastructure. Frequently updated and accurate maps from very-high-resolution satellites will also be useful for infrastructure designs—power cables, water lines, sewer lines, urban transportation systems, and so on.

Businesses can use very-high-resolution urban satellite observations in conjunction with other data—such as demographics—to choose the right location for a franchise or a new store by extrapolating information about urban growth trends. Construction companies can use images taken by satellites, such as Space Imaging's IKONOS or DigitalGlobe's QuickBird to plan large-scale construction projects. These very-high-resolution satellites are able to identify and locate, with a great deal of accuracy, such surface features as buildings, parking lots, and their elevation.

Urban expansion and loss of farmland can also be monitored using radar remote sensing, such as that provided by the Canadian RADARSAT system. The advantage of radar is that it "sees" through clouds and at night. Thus, regions that are often covered with clouds and do not lend themselves to visible light and near-infrared remote sensing can be imaged using radar illumination.

Wireless communications in cities require a judicious distribution of relays atop tall buildings to avoid blind spots. A three-dimensional model of the cityscape is thus essential. Currently, such models are produced from radar and stereoscopic remote sensing from aircraft. Since cityscapes change rather quickly as new skyscrapers or other tall buildings are built, there is a need for updates. High-resolution radar or stereoscopic visible data from space-based satellites may in the future prove cheaper than aircraft for such applications.

REMOTELY SENSING THE HEAT ISLAND EFFECT

The replacement of vegetated areas with concrete cover in high-density urban areas has a number of environmental drawbacks. One of these problems is known as the heat island effect. Pavement and concrete-covered areas can raise the temperature of cities 10°C (50°F) above the temperature in surrounding areas that have kept their vegetation. Such microclimates in cities are not only uncomfortable for the people who live there but also significantly increase power consumption for cooling purposes and increase levels of harmful ground-level ozone. The heat island effect has been studied extensively with remote sensing data obtained from airborne sensors over cities such as Atlanta, Sacramento, Salt Lake City and Baton Rouge.

Conclusion

This rapid tour of satellite and airborne remote sensing applications shows how useful this technology can be to resolve global, regional, or very local challenges when combined with GIS. It also gives a flavor of a future where **geospatial** information will permeate all activities on Earth and create tremendous business opportunities. SEE ALSO Global Positioning Sys-

geospatial relating to measurement of Earth's surface as well as positions on its surface tem (volume 1); Military Customers (volume 1); Military Uses of Space (volume 4); Natural Resources (volume 4); Reconnaissance (volume 1); Satellites, Types of (volume 1).

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RLV ***See Launch Vehicles, Reusable (Volume 1).***

Rocket Engines

From the first rockets built by the Chinese over a millennium ago to the precision engines used by modern missiles, rocket engines all work in accordance with Isaac Newton's Third Law of Motion: For every action there is an opposite and equal reaction. In a rocket engine, hot gas expelled at high **velocity** generates thrust in the opposite direction. The most common means of doing so uses chemical reactions to produce the hot gas. The first rockets used solid propellants, such as black powder, but they were very inefficient. Liquid-propellant rocket engines, first developed in 1926 by Robert H. Goddard, are much more powerful and opened the way to spaceflight.

velocity speed and direction of a moving object; a vector quantity

The Origins of Modern Engines

Atlas and Delta launch vehicles were originally U.S. Air Force (USAF) rockets developed in the 1950s. To power these missiles, Rocketdyne developed a family of rocket engines that burned kerosene and liquid oxygen (LOX) based on German V-2 rocket technology obtained after World War II. As

A close-up view of a space shuttle's main engine test firing shows how hot gas is expelled. At a high velocity the expelled gas generates thrust in the opposite direction, enabling liftoff.

these rockets were adapted to their new role as launch vehicles in the 1960s, still larger versions of their engines (such as Rocketdyne's 1.5 million-pound thrust F-1) were built for the Saturn rockets that sent Apollo missions to the Moon.

Delta II and III use the 200,000-pound thrust RS-27A, which is an updated descendant of the MB-3 used in the original Delta. The Rocketdyne-built MA-5 power plant in the Atlas 2A, in use since 1961, has also been upgraded. The Atlas has a distinctive stage-and-a-half design, which allows it to **jettison** a pair of booster engines when they are no longer needed, leaving a smaller sustainer engine to power the stage. The booster engines of the new MA-5A are a pair of RS-27 thrust chambers, giving the core of the new Atlas 2AS a liftoff thrust of 490,000 pounds. The Russians have also incrementally improved their long-used launch vehicles' engines over the decades. Energomash, the corporate descendant of the Soviet design bureau that developed many Russian rocket engines, worked with the American firm Pratt & Whitney to build the 585,000-pound thrust RD-180 to power the American Atlas 3 and 5.

jettison to eject, throw overboard, or get rid of

Boosting Performance

While modern solid rockets are less efficient than liquid-propellant engines, their simplicity and relatively low cost make them ideal for certain roles. For decades many American launch vehicles used solid rocket upper stages. The Delta II, with its Star 48B motor built by Thiokol, continues this series's use of solid rocket third stages. Some small launch vehicles, such as the American Pegasus, Taurus, and Athena, as well as the Japanese J-1 and M-5, use solid rockets in all their stages to reduce costs.

Solid rocket motors strapped to the first stage of a launch vehicle have also proved to be an economical means of increasing a rocket's **payload** capability. Since 1964 the Delta has used increasingly larger clusters of Castor solid rocket motors built by Thiokol to help enhance the design's performance. The new Delta II and III use as many as nine GEM-40 motors built by Alliant Techsystems. Even the Atlas 2AS uses four Castor 4A rockets to increase liftoff thrust, a first for this series.

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

The use of solid rocket boosters is most apparent in the Titan family of launch vehicles. A pair of 120-inch-in-diameter solid rocket motors made by Thiokol were attached to the USAF Titan II missile core in 1965 to produce the Titan IIIC, which had over four times the payload capability. The Titan uses Aerojet-General LR87 and LR91 engines burning liquid **hypergolic** propellants that ignite spontaneously on contact. Successive Titans have used more powerful solid boosters attached to upgraded cores to further increase the payload. The Titan 4B uses a pair of solid rocket motor units built by Alliant Techsystems to produce 3.4 million pounds of thrust at liftoff.

hypergolic fuels and oxidizers that ignite on contact with each other and need no ignition source

Another means of boosting rocket performance is by using **cryogenic** propellants, such as liquid hydrogen and LOX, which have twice the efficiency of most other propellants. The first engine to use these cryogenic propellants was the 15,000-pound thrust RL-10 engine built by Pratt & Whitney and used in the high-performance Centaur upper stage since 1960. The Centaur, with improved versions of the RL-10, has been used in combination with the Atlas and Titan. The RL-10B-2 has been used in the second stage of the Delta III and IV.

cryogenic related to extremely low temperatures, the temperature of liquid nitrogen or lower

The most efficient engines have been nuclear ones. While other engines use chemical reactions to produce heat, in nuclear engines a compact nuclear reactor heats liquid hydrogen or other fluid to generate thrust with more than twice the efficiency of conventional chemical rocket engines. During the 1960s the National Aeronautics and Space Administration (NASA) developed the Nuclear Rocket for Rocket Vehicle Applications (NERVA) with a reactor built by Westinghouse Electric and the engine itself built by Aerojet-General. Before work stopped in 1972, in part due to post-**Apollo** budget cuts, NERVA was intended for use in advanced lunar and interplanetary missions.

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

A New Generation

The space shuttle makes the ultimate use of solid rocket motor technology and high-efficiency cryogenic rocket engines. A pair of solid rocket motors built by Thiokol generate 5.3 million pounds of thrust for liftoff while a trio of Rocketdyne-built space shuttle main engines (SSMEs), generating

375,000 pounds of thrust each, supply most of the energy needed to reach orbit. Other launch vehicles use similar arrangements of solid boosters and cryogenic engines, such as the European Ariane 5 and Japanese H-2. The Delta IV uses the cryogenic RS-68 engine with various boosters. Built by Rocketdyne, the RS-68✶ was the first totally new American rocket engine design since the SSME was designed in 1971.

✶**The RS-68 will fly for the first time on the maiden flight of the Delta IV scheduled for July 2002.**

More innovations are in store for launch vehicles. One of the more novel designs is the XRS-2200 linear aerospike developed by Rocketdyne for the X-33. Here the engine's nozzle is replaced with an exhaust ramp, allowing the engine to work efficiently at all altitudes, unlike conventional engines. A larger version of the linear aerospike would power the VentureStar single-stage-to-orbit vehicle. SEE ALSO LAUNCH INDUSTRY (VOLUME 1); LAUNCH SERVICES (VOLUME 1); LAUNCH VEHICLES, EXPENDABLE (VOLUME 1); LAUNCH VEHICLES, REUSABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4); ROCKETS (VOLUME 3).

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Roddenberry, Gene

American Writer and Futurist
1921–1991

Gene Roddenberry sits with creatures from his television series *Star Trek,* the first television series to have an episode preserved in the Smithsonian Institution.

Gene Roddenberry, creator of the television series *Star Trek*, saw space as a place for learning new ideas and ways of thinking. Born in El Paso, Texas, on August 19, 1921, Roddenberry was a pre-law student in college for three years before becoming interested in aeronautical engineering. In 1941 he trained as a flying cadet in the U.S. Army Air Corps. During World War II, he took part in eighty-nine missions and sorties and was decorated with the Distinguished Flying Cross and the Air Medal.

During the war Roddenberry began to write, selling stories to flight magazines. Back in the United States, he went to Hollywood intending to write for television. He joined the Los Angeles Police Department to gain life experiences and soon sold scripts to such shows as *Goodyear Theater*, *Dragnet*, and *Have Gun Will Travel.*

Roddenberry's creation, the series *Star Trek*, debuted in 1966. The series developed a loyal following and was the first television series to have an episode preserved in the Smithsonian Institution, where a 3.3-meter (11-foot) model of the U.S.S. Enterprise is also exhibited on the same floor as the Wright brothers' original airplane. The first space shuttle was named Enterprise in honor of this fictional spacecraft.

While making *Star Trek*,✶ Roddenberry gained a reputation as a futurist, speaking on the subject at universities, the Smithsonian, meetings of the National Aeronautics and Space Administration, and Library of Congress gatherings.

✶ ***Star Trek*** **became a motion picture in 1978, leading to a number of movie sequels and prompting a popular new series, *Star Trek: The Next Generation,* in the late 1980s. Three other spinoff series would follow, the most recent, *Enterprise,* debuted in 2001.**

Roddenberry died in 1991. A year later a canister of his ashes was taken into space aboard the space shuttle Columbia. SEE ALSO BURIAL (VOLUME 1); CAREERS IN WRITING, PHOTOGRAPHY, AND FILMMAKING (VOLUME 1); ENTERTAINMENT (VOLUME 1); STAR TREK (VOLUME 4).

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Satellite Industry

When you watch the Olympics do you think of satellites? Maybe you should. For many years satellites have been televising sporting events such as the Olympic games, which popularized the phrase "live via satellite" and helped create a common impression of what commercial satellites do for us here on Earth. It was, in fact, a boxing match pitting Muhammad Ali ("The Greatest") against ("Smokin") Joe Frazier in 1975 when satellites were first used to broadcast a single sporting event to the entire world. While satellites still bring us sports, news, and entertainment programming from around the world each day, the commercial satellite industry can and will do much, much more—from delivering high-speed Internet content to taking pictures from space of objects on Earth that are as small as a soccer ball.

Historical Development of the Industry

While you are probably familiar with movies such as *Apollo 13* (1995) and *The Right Stuff* (1983), which chronicled the beginnings of the National Aeronautics and Space Administration (NASA) and its civilian space program, you probably did not know that the commercial satellite industry actually developed right alongside the government space program in the early 1960s. The satellite industry got kick-started back in July 1962, when scientists at AT&T Bell Laboratories decided to build the world's first commercial satellite, dubbed Telstar, after losing a competition for NASA's active satellite program. NASA later offered to launch the Telstar satellite into a two-hour and forty-minute **elliptical** orbit during which it transmitted brief live television transmissions across the Atlantic Ocean for the first time. Telstar had a tremendous worldwide impact by showing the amazing potential of satellite communications.

elliptical having the shape of an ellipse (curved oval)

A few years later, in April 1965, the International Telecommunications Satellite Organization (INTELSAT) launched Early Bird, the world's first

This Intelsat VI satellite, one of five contracted to replace less capable satellites, can carry up to 120,000 two-way telephone calls, along with three television channels.

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

commercial **geosynchronous** satellite. So-called "GEO" (geosynchronous Earth orbit) satellites **orbit** Earth at 35,786 kilometers (22,300 miles) in a belt directly above Earth's equator. At that point in space, the satellite orbits Earth at the same speed as Earth's rotation—making the satellite appear to be fixed in the same location in the sky. It was futurist Arthur C. Clarke, author of *2001: A Space Odyssey* (1968), who first predicted back in 1945 that you could connect the world by placing three communications satellites in geosynchronous orbit.

The Early Bird satellite was built by Hughes Aircraft, the company founded by eccentric billionaire Howard Hughes. The satellite had a total capacity to carry only 480 telephone channels (240 simultaneous calls) and had the power of an ordinary household light bulb. It was impressive considering that the largest undersea transoceanic telephone cable at the time carried only 256 channels. By comparison, today's largest telecommunications satellites are more than 500 times more efficient and generate more than 15 kilowatts of power, allowing a single spacecraft to carry ten of thousands of simultaneous telephone calls or hundreds of channels of television programming to dishes on the ground as small as 46 centimeters (18 inches).

It was really in the 1990s that we observed the greatest changes in satellite technology and with them fundamental changes in the commercial industry. For the first two decades of its existence, the satellite industry worked to connect large companies to other large companies across oceans, deserts, and great distances. Telephone companies first employed satellites to connect calls where there were no undersea cables. Later it was television networks, such as ABC, NBC, and CBS in the United States, which used satellites to transmit programs to their local affiliate stations—so-called point-to-multipoint distribution—and helped the satellite industry grow. In the late 1970s cable television companies began to get into the act, using satellites to downlink channels such as CNN and MTV, and then retransmit the signals over coaxial cables to homes.

The satellite industry can mark 1976 as the year it began to evolve from a purely business-to-business model to one that also included business-to-consumer or so-called retail services. That year a Stanford University professor named Taylor Howard designed and built the first backyard satellite dish. Howard used his 4.9-meter (16-foot) home satellite dish to receive HBO and other television programs that previously were carried only by cable television companies. By 1980 Howard had sold the blueprints on how to build his dish to over 5,000 people, and the direct-to-home (DTH) satellite industry was born. By 1985 several DTH equipment companies were shipping more than 500,000 home satellite systems to consumers across the United States.

The introduction in 1994 of high-powered direct broadcast satellite (DBS) services, which used new digital compression technology and more powerful spacecraft, allowed consumers to receive hundreds of channels of digital-quality programming on a dish about the size of a pizza pan. The DTH industry has since continued to grow with more than 14 million American homes and another 25 million homes outside the United States subscribing to DTH satellite television services by the early twenty-first century.

Key Segments of Today's Satellite Industry

History aside, the best way to understand the satellite industry today is to divide it into four key segments: satellite services—transmitting voice, data, and television signals to businesses and consumers; ground equipment—designing and manufacturing satellite dishes, large Earth stations, software, and consumer electronics; satellite manufacturing—building spacecraft, components, and electronics; and launch—building space launch vehicles and carrying satellites into orbit.

Each year, the Satellite Industry Association (SIA) surveys over 700 companies around the world to determine the state of the industry. The SIA reports worldwide employment and revenue in each of the segments. The SIA reported in 2001 that the commercial satellite industry generated $69.1 billion in revenue in 1999, an 8 percent increase over adjusted 1998 revenue. The U.S. satellite industry accounted for $31.9 billion of the total, or roughly 46 percent of worldwide revenue.

Satellite Services. The largest and fastest growing segment of the industry is satellite services, which generated $30.7 billion in revenue in 1999, a 25 percent increase over 1998. More than $8 billion in revenue in this sector was generated by companies that lease **transponder** capacity to programming companies such as the Discovery Channel and ESPN, as well as to long-distance telephone companies such as MCI WorldCom and AT&T. The bulk of the services revenue, nearly $23 billion, comes from consumer/retail services including DTH satellite television.

transponder bandwidth-specific transmitter-receiver units

While traditional satellite service providers such as PanAmSat, Eutelsat, GE American Communications, and SES Astra continue to lease capacity to television and telephone companies, a growing portion of their business now comes from data services. Internet service providers (ISPs) are now using satellites in countries throughout the developing world to link directly to the Internet backbone in the United States. Those providers set up a small 1- to 3-meter (3.3- to 10-foot) dish and in one hop can link directly to a **point of presence** (POP) on a fiber-optic backbone. Another new application being pursued by satellite operators is to broadcast common content—such as Stephen King's latest short story or streaming audio/video clips—over the web to local ISPs around the world where the content can be retrieved by nearby web surfers. In using satellites for the same kind of point-to-multipoint distribution service used by television broadcasters, popular web sites can manage the flow of traffic on the World Wide Web and avoid crashing their servers or networks.

point of presence an access point to the Internet with a unique Internet Protocol address; Internet service providers like AOL generally have multiple POPs on the Internet

Mobile satellite services such as those offered by Globalstar, ICO, Inmarsat, Motient, and ORBCOMM are yet another emerging part of the services business. These companies provide voice and data service to thousands of ships, planes, cars, and people in parts of the world that are not served by cellular or traditional wired telephone networks. These systems often use constellations of satellites in either GEO or **low Earth orbit** to serve laptop- and handset-sized mobile terminals. Such systems allow pipeline workers, merchant ships, and other mobile users to communicate even in the most remote places on Earth.

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

A new service offering launched in 2001 is satellite digital audio radio services (DARS). Three new companies—XM Satellite Radio and Sirius in the United States and WorldSpace in other regions of the world—began delivering hundreds of channels of digital music, news, sports, and entertainment programming to cars, homes, and boom boxes. Satellite-ready radios will become standard equipment in many new cars sold in the United States starting in 2003, and the subscription-based service—at approximately $10 per month—is expected to be popular with commuters and others who spend a lot of time in their cars.

Ground Equipment. Along with the growth in new services, we have seen a corresponding increase in the demand for more earthly products such as satellite dishes, mobile satellite phones, and Earth stations that control satellites in orbit. The manufacture of satellite-related ground equipment in 1999, from satellite control systems to DBS dishes, accounted for $16 billion of the industry's total revenue—an increase of 15 percent over 1998. An increasing portion of the ground equipment market is made up of DTH systems. Since its introduction to American consumers in 1994, DBS dishes and set-top boxes have been the fastest-selling consumer electronics product of all time—outselling VCRs, personal computers, and color televisions during their first year on the market.

Companies such as Hughes, RCA, Sony, and Gilat manufacture these dishes for both consumers and large corporations that own private satellite networks called very small aperture terminals (VSATs). VSATs are a little-known but important part of our telecommunications network. They allow retail companies, such as Target and Blockbuster, as well as gas stations such as those run by Exxon Mobil, to verify credit cards and control their inventories. More than 2,200 shopping malls in America use VSAT dishes to transmit and receive data. Prices for VSAT dishes dropped from $10,000 to

Television networks that used satellites to transmit programs to their local affiliate stations helped the satellite industry grow.

$20,000 per terminal in 1980 to $1,000 to $3,000 in 2001, helping fuel sales to many large and small corporations. Next time you are at a gas station or grocery store, look up at the roof and you will likely see a small satellite dish at work connecting that business to its corporate headquarters.

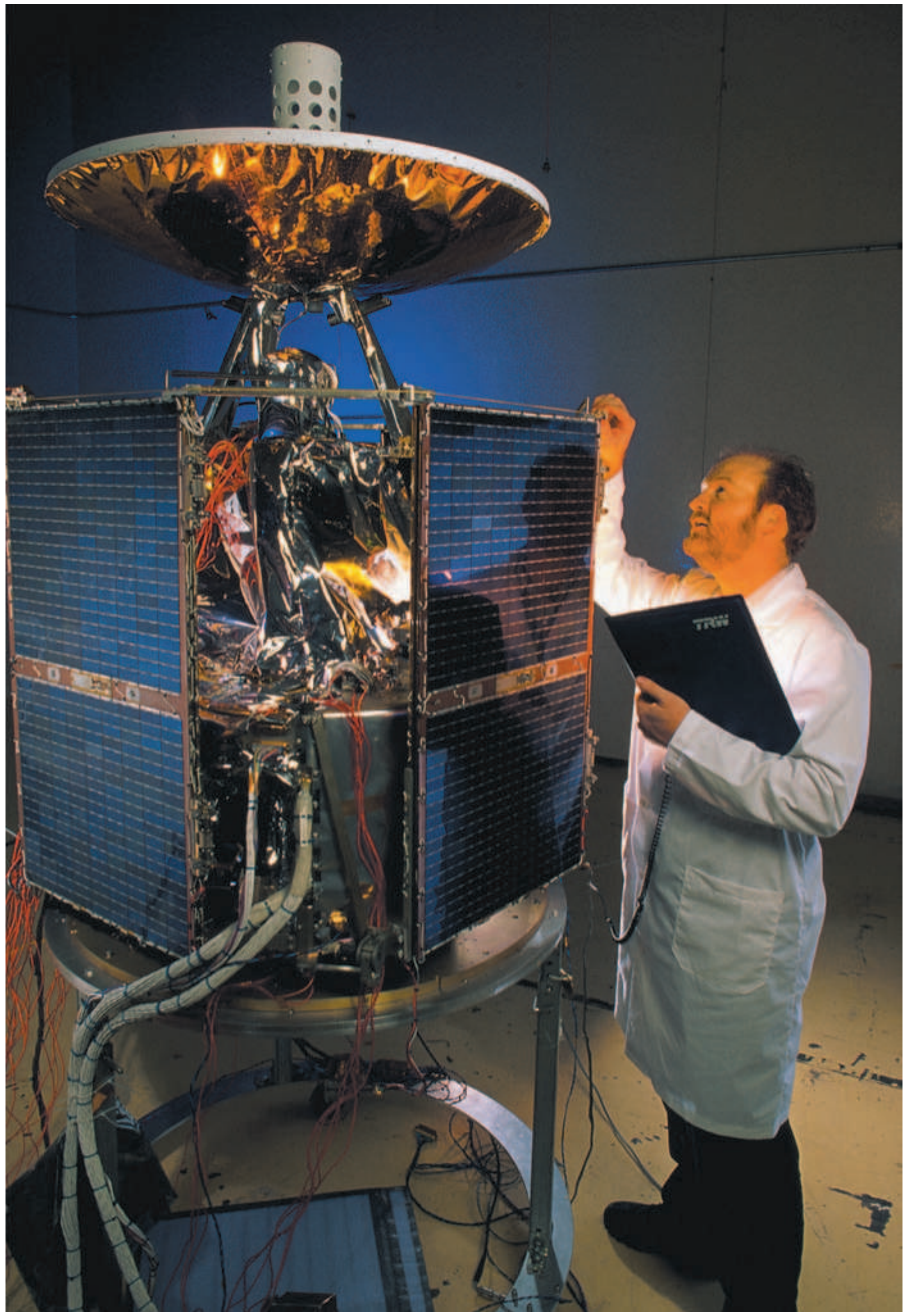
Satellite Manufacturing. Exciting new satellite services, such as DBS and DARS, would not be possible without advances in satellite manufacturing. In terms of power, capacity (bandwidth), and lifetime in orbit, large telecommunications satellites at the turn of the millennium were twenty times more capable than satellites manufactured only a decade previous. This capability figure was expected to increase by another factor of five by 2002 when new larger satellites incorporating **spot beam technology** are put into full production. While the prices of communications satellites have stayed relatively constant during this period, and were possibly declining when factoring in inflation, their capabilities increased dramatically.

spot beam technology narrow, pencil-like satellite beam that focuses highly radiated energy on a limited area of Earth's surface (about 100 to 500 miles in diameter) using steerable or directed antennas

Both the number of transponders and the overall power of satellites increased. Each transponder that used to be able to carry a single analog channel can now carry several simultaneous digital channels. Increases in power are tied to more efficient solar panel and battery technology. By increasing the power of the satellite in space, satellite operators can dramatically reduce the size of receiving dishes on Earth. Another major achievement is the use of **ion propulsion** technology for satellite station-keeping. By using ion propulsion to generate the thrust that keeps the satellite oriented towards Earth, satellite manufacturers have been able to increase the number of years that a satellite is able to provide service before it runs out of fuel. Altogether, these technologies have had a major impact on the ability of satellites to compete with terrestrial telecommunications technologies.

ion propulsion a propulsion system that uses charged particles acclerated by electric fields to provide thrust

Satellite manufacturing, including payments to prime contractors and their subcontractors, accounted for $10.4 billion of the $69.1 billion industry total in 1999. Leading satellite manufacturers include Astrium, Alcatel, Hughes, Lockheed Martin, Motorola, Orbital Sciences, Space Systems Loral, and TRW. This segment of the industry has experienced rapid



At the Goddard Spaceflight Center, a TRW worker examines a satellite. TRW, as well as Astrium, Alcatel, Hughes, Lockheed Martin, Motorola, Orbital Sciences, and Space Systems Loral, is a leading satellite manufacturer.

consolidation in the past few years as several European companies have merged in order to compete with U.S. companies, which have historically built over two-thirds of the communications satellites in orbit.

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

Launch. Of course, the satellite industry would not exist if it were not for the **expendable launch vehicles** (ELVs; commonly called rockets) that launch commercial spacecraft into orbit. The worldwide launch industry generated revenues of $6.6 billion in 1999, with $4.3 billion paid to launch service providers and another $2.3 billion earned by subcontractors engaged in vehicle construction. Companies such as Arianespace, International Launch Services, Boeing Launch Services, Sea Launch, Orbital Sciences, Rocket Systems Corporation, and China Great Wall sell rides into outer space.

The launch segment of the industry has also changed dramatically since the 1970s when U.S. Air Force rockets were used to launch commercial satellites. The U.S. decision to shift all satellite launches from ELVs to the space shuttle helped spur the Europeans to develop their own ELV—the Ariane rocket. In the wake of the space shuttle Challenger tragedy in 1986, the United States decided to fly satellites aboard ELVs once again, and U.S. companies got back into the launch services market. In the 1990s, Chinese, Russian, and Ukrainian rockets began to be used to launch commercial satellites. The market in the early twenty-first century is more competitive than ever, resulting in lower launch costs for satellite operators.

Meanwhile, launch service companies have worked steadily to increase the lift capabilities of their rockets to accommodate the heavier, more powerful satellites. Vehicles such as the Ariane 5 rocket are capable of delivering 6.5 metric tons (7.2 tons) to **geostationary orbit**, and their ability is expected to only increase in the coming years. Sea Launch—an international cooperative venture including Boeing (United States), RSC Energia (Russia), Yushnoye (Ukraine), and Kvaerner (Norway)—launches satellites from a converted offshore oil drilling platform and command ship that motor to a site on the equator in the middle of the Pacific Ocean in an effort to increase lift capability. International Launch Services now uses powerful Russian-built RD-180 engines to increase the lift capability of the workhorse Atlas ELV.

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

Emerging Technologies

Outside of the four major industry segments—communication services, ground equipment, satellite manufacturing, and launch—there are a host of other emerging technologies that are beginning to generate revenue and interest. Commercial remote sensing satellites, such as Space Imaging's Ikonos spacecraft, are now capable of taking pictures from space clear enough to see objects on the ground less than 1 meter (39 inches) in size. Such images are used by farmers, geologists, and urban planners to assist them in their jobs. Software that links these images with maps generated using coordinates from the U.S. Air Force global positioning satellite fleet provides an important new source of information to businesses that use scarce natural resources here on Earth.

The satellite industry has come a long way since AT&T's Telstar satellite first proved that space could be used for moneymaking commercial ventures. The continued growth in Internet data and new information technologies are expected to drive the commercial satellite industry in the coming decades. The growth in these services markets will fuel demand for more satellites, dishes, and launches. Arthur C. Clarke's vision of a world connected via satellite has become a reality. Today's visionaries see viable markets for solar power generation and tourism within our reach. Do not count them out—many people thought President John F. Kennedy's pledge to put a man on the Moon would never be fulfilled. SEE ALSO Communication Satellite Industry (volume 1); Navigation from Space (volume 1); Reconnaissance (volume 1); Remote Sensing Systems (volume 1); Satellites, Types of (volume 1); Small Satellite Technology (volume 1).

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Satellites, Types of

Not long after the Soviet Union launched the first satellite in 1957, satellites began to play an increasingly important role in our lives. The first satellites were small because of the lack of powerful launch vehicles, and almost all had scientific missions. However, as larger rockets became available and engineers used new technologies to build more efficient **payloads**, the first prototypes of many of the satellites that were still in use in 2001 were launched and changed our world.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

reconnaissance a survey or preliminary exploration of a region of interest

polar orbits orbits that carry a satellite over the poles of a planet

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

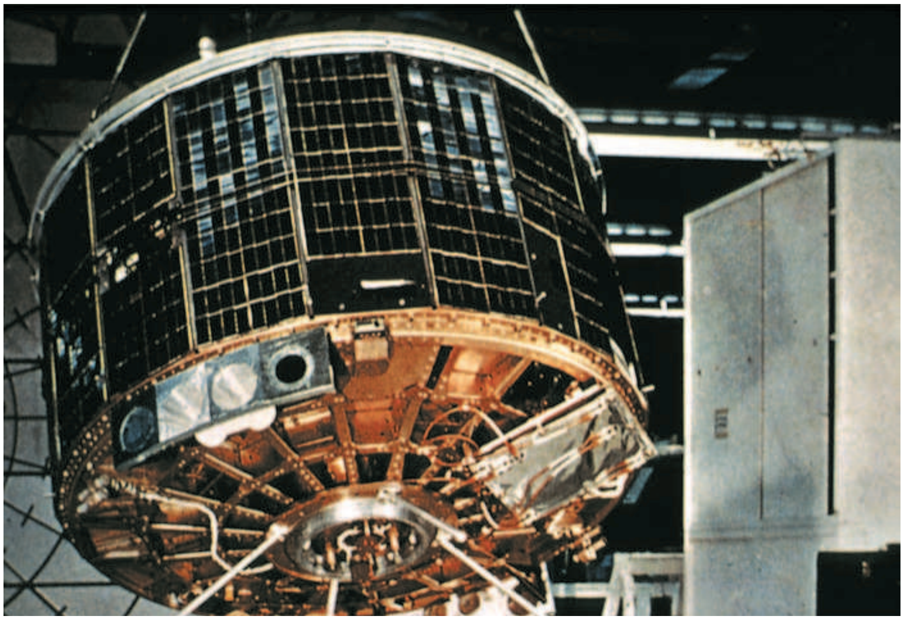
remote sensing the act of observing from orbit what may be seen or sensed below Earth

Observing Earth

One of the earliest classes of satellites was designed to observe Earth from orbit. Among the first were military **reconnaissance** satellites, such as the American Corona and the Soviet Zenit, which took photographs with film that had to be returned to Earth to be developed. Over the years more sophisticated electronic imaging technology made it possible for spy satellites to obtain very high-resolution images and transmit them almost immediately to analysts. This technology has been useful in gauging a potential adversary's intentions, for verifying compliance with treaties, and in other important ways.

In 1960 early television surveillance technology was used for the first weather satellites. By 2001 those satellites (flying in **polar orbits** and **geosynchronous orbits**) were equipped not only with cameras but with a range of sensors that employed the latest **infrared** technology. In addition to providing the weather pictures that people see every day on television, these satellites supply meteorologists with the highly detailed information they need to track storms and predict the weather. This application of satellite technology alone has saved countless lives.

Starting in the 1970s some of this technology was applied to **remote sensing** satellites such as Landsat. Instead of monitoring military targets at high resolution, these satellites monitor Earth's natural resources on a more moderate scale. These data provide the information needed to locate new sources of raw materials and determine the effects of natural disasters and pollution on the environment. Because this information is so valuable, many commercial remote sensing satellites, such as the French SPOT, have been launched and their data have been sold to a wide range of government and private users.



This early weather satellite used television surveillance technology of the 1960s.

Recently declassified reconnaissance and **cartographic** photographs from American and former Soviet spy satellites are now available, giving researchers more varied long-term data on the environment. Radar mapping technology originally used by the military to make observations through clouds has found numerous civilian applications.

cartographic relating to the making of maps

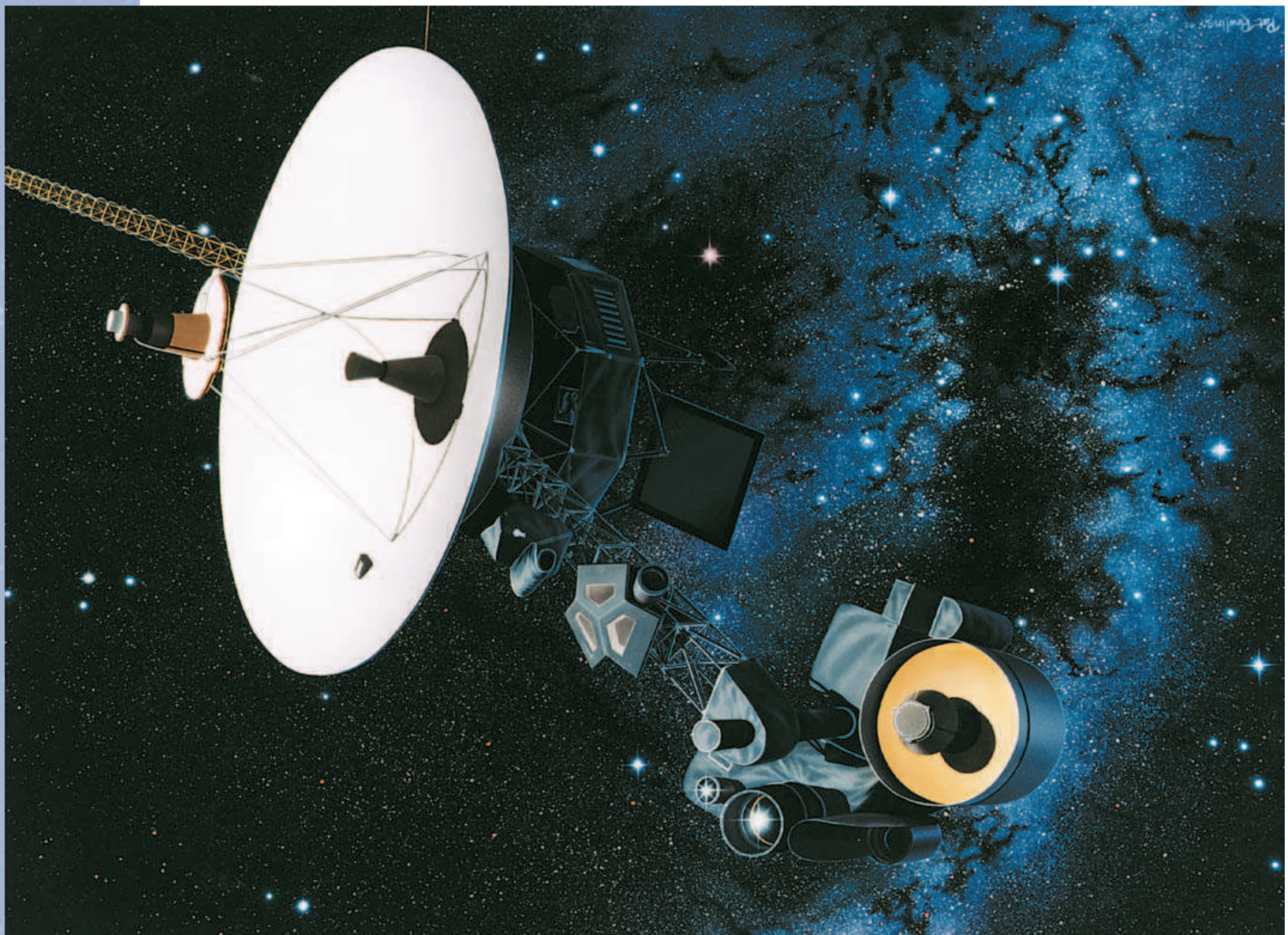
Voices in the Sky

By far the most common satellite type launched, and perhaps the one that has had the greatest impact on people's lives, is the communication satellite, or "comsat." Beginning in 1958 early experimental comsats operated as relays or repeaters in relatively low orbits, in part because of the lack of powerful launch vehicles and the crude nature of their electronics. Although such low orbiting comsats still have a place, a large number of them are required to provide continuous coverage around the globe.

As early as 1946 the space visionary and author Arthur C. Clarke recognized the value of placing comsats in geosynchronous orbits. From an altitude of 35,786 kilometers (22,300 miles) above the equator, satellites match Earth's spin and appear to hang motionless in the sky. From this great height over one-third of the planet's surface can be seen, allowing a satellite to relay signals over long distances. After several successful experiments the first commercial geosynchronous comsat, Early Bird, was launched in 1965. In the succeeding decades, improved rockets allowed larger comsats to be launched. Combined with major advances in microelectronics, each of the dozens of active comsats in orbit in 2001 had thousands of times the capacity of their earliest ancestors.

Although geosynchronous comsats are useful at low latitudes, they appear too close to the horizon at high or polar latitudes. To overcome this problem, since 1965 the Soviet Union (and later Russia) has launched Molniya satellites into highly **elliptical** 12-hour orbits inclined to the equator. This type of orbit allows them to be seen high above the horizon over most

elliptical having the shape of an ellipse (curved oval)



Voyager 2 is an example of a science satellite, designed to collect data that enabled scientists to discover more about the outer solar system.

of Russia's territory for long periods. From this vantage point, Molniya satellites can relay television and telephone signals across that nation's vast expanses. During the Cold War, such orbits were used by some signal intelligence, or sigint, satellites to intercept radio signals. Sigint satellites also are used to track ships at sea, locate radar installations, and monitor other activities such as various types of radio transmissions.

A type of comsat known as a navigation satellite, or navsat, has become important to military and civilian users. Operating in precisely known orbits thousands of miles above Earth, these satellites broadcast a precise timing signal. Signals from three or more navsats can be used to determine a position on or above the Earth's surface within a few feet. The first experimental navsats were built by the U.S. Navy in the 1960s and were used by ships to determine their exact positions at sea. Today a constellation of satellites forming the Global Positioning System (GPS) allows military and civilian users to accurately determine their locations anywhere in the world.

Science in Space

Whereas a large number of satellites with practical applications have been launched, science satellites still provide important information about the space environment and the universe beyond. Satellites monitoring Earth's **magnetosphere** can provide warnings about communications blackouts and other effects of solar storms. Since the 1960s larger, more capable observatories employing increasingly advanced technologies have been launched to observe the Sun and the rest of the heavens over the entire **electromagnetic spectrum**. The Hubble Space Telescope is a well-known example. As a result of the data returned from these satellites, much more has been learned about everything from the Sun and how it affects Earth to the origins of the universe. SEE ALSO CLARKE, ARTHUR C. (VOLUME 1); NAVIGATION FROM SPACE (VOLUME 1); RECONNAISSANCE (VOLUME 1); REMOTE SENSING SYSTEMS (VOLUME 1); SATELLITE INDUSTRY (VOLUME 1); SATELLITES, FUTURE DESIGNS (VOLUME 4); SMALL SATELLITE TECHNOLOGY (VOLUME 1).

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field; it is formed by the interaction of the solar wind with the planet's magnetic field

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

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Search and Rescue

Commercial search and rescue missions to retrieve and repair valuable satellites may become commonplace in the twenty-first century. Telecommunications companies and other businesses typically spend between $50 million and $300 million to manufacture and launch a new satellite. If all goes well, the spacecraft may function reliably for ten to twenty years. In the harsh environment of space, however, satellites may fail prematurely because of mechanical breakdowns, damage from **solar flares**, or collisions with orbiting debris. Companies may reduce their economic losses from such perils by salvaging damaged or obsolete satellites at a cost lower than what they would pay for replacement spacecraft.

solar flares explosions on the Sun that release bursts of electromagnetic radiation, such as light, ultraviolet waves, and X rays, along with high speed protons and other particles

The National Aeronautics and Space Administration (NASA) successfully performed the first satellite search and rescue missions in 1984. In April of that year, astronauts on the space shuttle Challenger rendezvoused with the Solar Maximum satellite, walked in space, and replaced electronics and other parts on the damaged spacecraft. They then released it back into orbit to continue its scientific mission of solar flare observations. Six months later, the crew of the space shuttle Discovery captured two commercial communications satellites and stowed them in the shuttle's cargo bay for return to Earth. Equipment malfunctions in February 1984 had left these satellites, the American Westar-6 and the Indonesian Palapa-B2, in improper orbits.

Technicians on the ground repaired both satellites and successfully launched them back into orbit in April 1990.

NASA reconsidered astronaut safety after the Challenger explosion on January 28, 1986. The agency decided to reduce the risk to astronauts by restricting most shuttle operations to scientific or military missions that required a human presence in space. In the fourteen-year period following the Challenger disaster, NASA rescued only one more commercial satellite, the International Telecommunication Satellite Organization's Intelsat VI F-3.

Despite NASA's successes, satellite salvage is not one of its primary missions. Furthermore, NASA does not have enough shuttles to meet the growing demand for search and rescue operations. The revenues generated by space commerce exceeded government expenditures for space exploration for the first time in 1996. Rapid growth of global telecommunications swelled space business revenues to about $80 billion by 2000, more than five times NASA's annual budget. That same year, about 200 commercial satellites were insured for more than $16 billion, and industry analysts predicted that space commerce would grow steadily, with about seventy new satellites launched annually.

Satellite owners and insurance companies are therefore motivated to find new and creative ways to safeguard their business assets. In 1998, for example, insurers declared a loss on the HGS-1 Asian television satellite, which had been stranded in a useless orbit after launch. Later, engineers at the Hughes Space and Communications Company found a way to boost the satellite on two looping orbits around the Moon, finally placing it in a useful parking orbit around Earth.

Because commercial salvage may be a profitable venture, several start-up space businesses began offering new products and services to satellite owners by 1999. To be successful, however, these companies must find inexpensive solutions to the difficult challenge of search and rescue operations in space. For example, one company developed a wire tether that may be attached to a satellite prior to launch. If the tether is later extended in space like an antenna, an electric current will be generated as it passes through the Earth's magnetic field, and enough power may be produced to operate the spacecraft or to change its orbit. A valuable satellite that is stranded in space, or at risk of burning up in a premature reentry into Earth's atmosphere, may yet be saved by this simple and elegant solution. SEE ALSO SATELLITES, TYPES OF (VOLUME 1); SERVICING AND REPAIR (VOLUME 1); TETHERS (VOLUME 4).

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Servicing and Repair

When the space shuttle system became operational in the 1980s, access to space began to take on a whole new outlook. Space was about to become a place to carry out work as well as to explore. A key element in America's newest human-rated space vehicle was the ability to provide access to space on a number of commercial fronts, including in-orbit satellite and spacecraft servicing and repair.

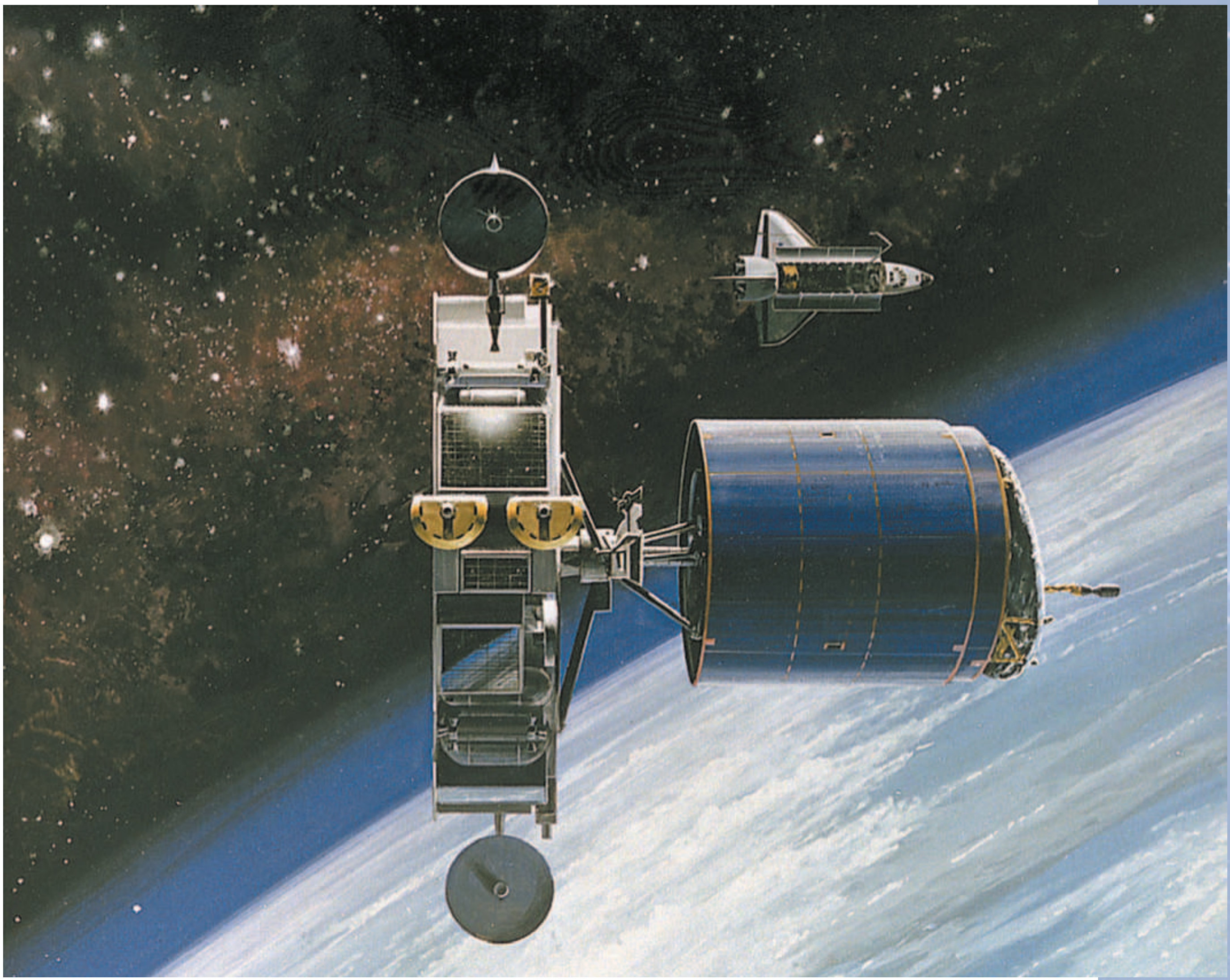
One of the workhorses onboard the shuttle is the robot arm called the Remote Manipulator System (RMS). The RMS is capable of placing large items in or removing them from the shuttle's cargo bay. This 15-meter (50-foot) robot arm was used for a number of satellite repair and retrieval missions during the shuttle's first twenty years of operations.

During shuttle mission 41-C in April 1984, the Long Duration Exposure Facility (LDEF) was left in orbit, deployed by the remote arm. During that same mission, astronauts were able to retrieve the ailing Solar Max satellite and repair it in the **payload bay** of the shuttle. Later that year two communications satellites stranded in a useless **low Earth orbit** (LEO) were

payload bay the area in the shuttle or other spacecraft designed to carry cargo

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

This artist's concept of a Orbital Transfer Vehicle (OTV) illustrates a vehicle that would serve as a free-flying "space tug," and it is shown here towing a satellite.



successfully retrieved and brought back to Earth by the shuttle. Eventually, these two satellites, Westar 6 and India's Palapa B-2, were successfully relaunched and deployed. In 1985 the Syncom IV-3 communications satellite, also stranded in a useless orbit, was retrieved, repaired, and deployed by a shuttle crew in Earth orbit.

In the 1990s, there was a crucial repair mission carried out on the Hubble Space Telescope. Hubble had been deployed in 1990 with what was later discovered to be a flawed imaging system. In December 1993 astronauts carried out an emergency repair mission aboard the shuttle to correct Hubble's fault. During a series of space walks, the crew successfully repaired the imaging system, and the Hubble Space Telescope was able to continue its mission, making many outstanding astronomical discoveries over the next decade.

The shuttle, however, is capable of achieving a maximum altitude of only 1,125 kilometers (700 miles) and is not designed to restart its main engines in order to attain escape velocity beyond LEO. Many satellites, such as communications satellites, are in **geosynchronous orbit** 35,786 kilometers (22,300 miles) above Earth and require upper stages to boost them from LEO to their geosynchronous orbit and beyond to begin their operational missions. If a satellite failed to operate at this distance, it would be a total loss for its owners. In the early 1980s, business and government started to look at ways of solving this problem. One concept was a variant of a Martin Marietta Aerospace design of an Orbital Transfer Vehicle for a 1980s U.S. space station concept. This vehicle would be able to take an astronaut to geosynchronous orbit to service satellites already in place.

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

As newer, more powerful geosynchronous satellite systems are built, companies have designed satellites and their upper stages with preventive maintenance in mind. SEE ALSO Accessing Space (volume 1); Long Duration Exposure Facility (LDEF) (volume 2); Robotics Technology (volume 2); Satellite Industry (volume 1); Satellites, Types of (volume 1); Search and Rescue (volume 1); Space Shuttle (volume 3).

Nick Proach

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NASA Goddard Space Flight Center. *The Hubble Project.* <http://hubble.gsfc.nasa.gov/>.

Prime Online NASA Resources for Educators. *Remote Manipulator System.* <http://prime.jsc.nasa.gov/ROV/rms.html>.

Small Satellite Technology

The first satellites built by people were very small. The Soviet Union's Sputnik, which opened the Space Age in 1957, weighed only 84 kilograms (185 pounds). The American response, Explorer-1, weighed 14 kilograms (31 pounds). These early small satellites proved that it was possible to put equipment in orbit and use it, providing the first opportunities for scientific observation outside Earth's atmosphere. Explorer provided the data that led to the identification of the Van Allen **radiation belts** that surround Earth. Bell Labs's Telstar, about the size of a car tire, provided the first transatlantic television link, and Pioneer 10, weighing about 270 kilograms (595

radiation belts two wide bands of charged particles trapped in Earth's magnetic field

Low launching costs and rapid development makes small satellites suitable for new applications that are not possible with larger spacecraft. This small 590-pound satellite, called SAC-A, was ejected from the shuttle STS-88 and carried five technology experiments.

pounds), was launched in 1972, and is the first satellite to leave the solar system. Thirty years after its launch, Pioneer is still functioning and was more than 7 billion miles from Earth.

Almost all satellites are powered by sunlight, and small satellites, which intercept less of this resource, are limited in power as much as they are in size, mass, and budget. However, the modern revolution in digital electronics and portable computing technologies has enabled engineers to build satellites weighing just a few kilograms that have capabilities rivaling those of older, larger satellites. Because launch costs have remained virtually constant since the beginning of the space age, small satellites and their lower costs are receiving renewed attention.

What Is a Small Satellite?

Small satellites are defined as those weighing less than 1,000 kilograms (2,204 pounds). Those below 100 kilograms (220 pounds) are referred to as microsatellites, those with a mass less than 10 kilograms (22 pounds) are known as nanosatellites, and those under 1 kilogram (2.2 pounds) are called picosatellites. However, the major difference between small and large satellites is not their weight but the way they are built. Small satellites are built by small, highly interactive teams that work with the satellite from conception through launch and operation. Large satellites are built in larger, more formally structured organizations. Small satellite teams typically have fewer than twenty members, whereas large satellites may be built by organizations with tens of thousands of people.

The small satellite team has the advantages of speed and efficiency, the ability to evaluate the implications of each design decision for the entire satellite, and the insight into all aspects of the satellite's design and application. The combination of low cost, rapid development, and low launch costs makes small satellites suitable for new applications that are not possible with larger spacecraft.

Students and hobbyists gain hands-on experience in space by building, launching, and operating satellites. Student-built satellites have hosted advanced communications experiments, astronomical and Earth-observing instruments, and video cameras that can be used to look at themselves and the satellites launched with them. Most amateur satellite activity focuses on building novel voice and digital communications links.

A very promising new application of small satellites is the inspection of larger satellites. A low-cost nanosatellite can observe the target spacecraft as it separates from its launch vehicle, deploys solar panels, and begins operations. Any problem during the initialization of operations, or later in the spacecraft's life, can be diagnosed by the escorting nanosatellite, which would have visible and **infrared** cameras as well as radio-based diagnostics.

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

Early exploration of the solar system relied on small spacecraft such as those in the Mariner series (200 kilograms [441 pounds]), the first spacecraft to visit Mars and Venus, and the Ranger (360 kilograms [794 pounds]) lunar missions. Modern interplanetary spacecraft explore their target planets and moons with the aid of robots, and these robots are also becoming very small. The Mars Sojourner, a robotic rover, weighed just 11 kilograms (24 pounds), and its host spacecraft, the Mars Pathfinder, weighed just 570 kilograms (1,257 pounds) plus 320 kilograms (705 pounds) of propellant to guide its flight from Earth to Mars. Although the development teams were large, the small size of these interplanetary spacecraft is remarkable, especially compared with large spacecraft such as the space shuttle that are needed to take human crews a few hundred miles into low Earth orbit.

The Future of Small Satellites

Because small satellites require only a corner of a laboratory, basement, or garage, plus some basic equipment for their construction, there are hundreds of small satellite developers around the world. By contrast, developers of large satellites include a few major corporations and government laboratories in the largest and wealthiest countries. The proliferation of developers and users of small spacecraft has unleashed the same creative forces that propelled the personal computer to its dominant position in the computer market.

The leading commercial developers of small satellites include AeroAstro and Surrey Satellite Technology Limited. University-based developers of small satellites include Stanford's Starlab, Weber State, the Technical University of Berlin, Technion (Israel), the University of Stellenbosch (South Africa), and the University of Mexico. Governments are building small spacecraft in labs in the United States, Canada, the United Kingdom, Israel, Spain, France, Sweden, Finland, Norway, Denmark, Russia, Japan, Australia, Malaysia, and almost 100 other countries.

The future of small satellites, and in large part the future of space exploration and application, will rely on the creativity of this diverse population of developers. SEE ALSO Communications Satellite Industry (volume 1); Satellite Industry (volume 1); Satellites, Future Designs (volume 4); Satellites, Types of (volume 1).

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Space Access *See Accessing Space (Volume 1).*

Space Shuttle, Private Operations

In the early twenty-first century, more than twenty years after the successful maiden voyage of space shuttle Columbia, the National Aeronautics and Space Administration's (NASA) Space Transportation System—commonly known as the space shuttle—remains the only U.S. transit system capable of supporting human spaceflight. The shuttle is also the world's only largely reusable launch vehicle, comprised of an airplane-shaped **orbiter**, which returns to Earth with its human crew for refurbishment and re-flight; two solid rocket boosters, which are recovered for reuse after they separate from the rest of the shuttle system during ascent to orbit; and an irrecoverable fuel tank. (In contrast, the stages of so-called **expendable launch vehicles**—which launch most of the world's satellites as well as passenger-carrying Russian Soyuz capsules—are **jettisoned** to disintegrate in Earth's atmosphere or are left as debris in space.)

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

jettisoned ejected, thrown overboard, or gotten rid of

Capable of sustaining a crew in Earth orbit for several days to weeks, the versatile shuttle has served NASA in such efforts as the deployment, repair, and retrieval of satellites; the conduct of medical, materials, and other scientific research; and the ferrying of astronauts and supplies to and from the former Russian space station Mir. Although NASA is studying options for retiring its aging fleet of four orbiters and developing a new reusable launch vehicle, plans call for continuing shuttle flight at least until the mid-2010s. Shuttle operations will be critical in upcoming years as NASA transfers crews and supplies between Earth and the International Space Station.

The Space Shuttle's Limitations

Despite the shuttle's remarkable achievements and unique capabilities, those familiar with the shuttle program have come to realize that the shuttle has failed to meet many of NASA's original objectives and expectations. At the program's beginning in the early 1980s, NASA expected the shuttle would fly some twenty-four times annually, launching astronauts, satellites, and other **payloads** for the U.S. government as well as for other nations and private companies. By the mid-1990s, however, the shuttle's average annual flight rate was a fraction of the predicted level. Also, fewer government payloads than expected had flown on the shuttle, and as a result of policy made after the 1986 space shuttle Challenger explosion that killed seven astronauts, commercial payloads had been effectively banned from the vehicle. Perhaps the greatest disappointment was that the costs of operating and refurbishing the shuttle were far higher than NASA's original projections.

payloads any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

Outsourcing Shuttle Operations to Reduce Costs

Throughout the shuttle's history, NASA considered placing shuttle operations under private industry's control to reduce costs. That idea was continually rejected on grounds that NASA needed to maintain control of the shuttle for national security reasons. But in 1995, then NASA administrator Daniel Goldin, who had previously spent twenty-five years at a private aerospace firm, asked a team of NASA, other governmental, and industry leaders to study shuttle operations management and propose a new, safe approach to reducing operations costs. The team found that shuttle operations tasks, as then assigned, were **diffused** among many contractors and that no single entity was responsible for streamlining operations and reducing costs. After considering multiple management options, the commission recommended that NASA give a single, private contractor responsibility for shuttle operations. Goldin agreed, and NASA began soliciting bids from companies to take charge of shuttle operations.

diffused spread out; not concentrated

Two companies that then held contracts to manage major elements of shuttle operations, Rockwell International and Lockheed Martin Corporation, recognized that failing to secure the prime contract under NASA's new management scheme would result in a substantial economic loss. As a result, the two companies decided to compete for the contract as a single entity. In August 1995, Rockwell and Lockheed Martin agreed to form a joint venture called United Space Alliance (USA). From the forty companies that responded to NASA's search for a shuttle prime contractor, NASA chose to award USA the contract. USA took over the individual Rockwell and Lockheed Martin contracts and on September 30, 1996, signed the Space Flight Operations Contract (SFOC), by which NASA designated USA as prime contractor for shuttle operations. That December, Rockwell sold its aerospace business to the Boeing Company, which took over Rockwell's share of USA.

A New Way of Doing Business

The SFOC was an unprecedented step for NASA. Never before had the space agency given so much authority and responsibility to a contractor for such a major program. Under the contract, which was set up for six years with options for two, two-year extensions, USA took over operations and maintenance of both ground and flight systems associated with the shuttle at NASA's two primary centers for human spaceflight activity. At Johnson Space Center in Houston, Texas (the control and training center for shuttle missions), USA employees gained responsibility for flight operations, astronaut and flight controller training, mission control center management and operations, mission planning, flight design and analysis, and flight software development. Those at Florida's Kennedy Space Center (the shuttle's

Rockwell International workers prepare the cockpit of space shuttle Endeavour for extended flights.

launch and processing site) took charge of vehicle testing and checkout, launch operations, **procurement** and repair of shuttle hardware and ground support equipment, payload integration, and retrieval of the solid rocket boosters that were jettisoned into the Atlantic Ocean after launches. The SFOC also made USA responsible for training astronauts and planning for operations aboard the International Space Station.

procurement the process of obtaining

NASA emphasized that its expectations for USA under the contract included, in order of importance, maintaining safety of the shuttle system, supporting NASA's planned mission schedule, and reducing shuttle operating costs. In order to ensure that USA would meet these objectives, the SFOC was designed to reward USA on its quality of performance. The $7-billion contract—which could grow to a total of $12 billion with the extensions—was made contingent on the company's ability to meet safety standards, achieve mission and schedule objectives, and find more efficient ways to operate the shuttle program. Failure to meet these objectives could result in financial penalties.

The SFOC has presented USA with many challenges. As the first and only company in the world to be fully responsible for maintaining and operating a reusable launch system, USA has had to develop, from scratch, methods of fulfilling the basic contract requirements while finding ways to make operations less costly and more efficient. With accountability and quality of performance dominating the contract, USA has been forced to accept a new way of earning a profit. Nonetheless, USA has proven its ability to

NASA's Space Transportation System, commonly known as the space shuttle, is the only American transit system that is capable of supporting human spaceflight.

manage successfully the new type of contract and the responsibilities it has brought. Since managing its first shuttle mission in November 1996, USA has kept safety and reliability as top priorities: The shuttle has had no major operational problems under USA's oversight. Both NASA and USA have recognized that cost savings have been realized through the SFOC, with USA reporting a reduction in operations costs of nearly $400 million between the fiscal years 1996 and 1998. NASA has also pointed to more on-time launches and smoother prelaunch operations as indicators of USA's success in managing the shuttle program. USA keeps building on that success as it continues to absorb contracts for NASA's human spaceflight needs.

Prospects for the Future

While USA takes increasing responsibility for day-to-day shuttle operations, the SFOC made no provisions for ever giving USA ownership of the shuttle fleet. NASA still maintains ownership and ultimate control of the shuttle program. With the government still in charge, NASA determines the nature of each shuttle mission and flies only government payloads. USA would like that to change. The company's vision is to pioneer human spaceflight as an affordable, viable business. USA would like to see the shuttle fully privatized—that is, given to the private sector to own, control, and fund—and commercialized, which would open the shuttle for use by paying customers from outside the U.S. government. USA also wishes to become increasingly involved in operations of the International Space Station as well as any new space vehicles NASA develops.

Many people—including NASA as well as USA officials—believe that privatization and commercialization of the shuttle would bring numerous benefits to NASA, private industry, and taxpayers alike. By either turning over this asset to private hands or opening its use to commercial customers—or both—NASA could cut costs, which in turn could translate into savings for taxpayers. These measures could also allow NASA to focus more attention on and apply some of the funds saved to activities such as exploring the solar system and universe. By fully owning, managing, and commercializing the shuttle fleet, a private company potentially could realize revenues that far exceed NASA's current budget for operating the shuttle. As a result, the managing company could afford to conduct more shuttle missions and other space activities, in turn stimulating the growth of businesses whose satellites, experiments, or other hardware it launches.

Whether or not USA's vision of complete shuttle privatization becomes reality will depend on NASA's willingness to relinquish control of its assets and functions. NASA has been reluctant to give up control of the shuttle for reasons of national security and public safety. The agency is also aware that giving a single company full control of the shuttle could be viewed by companies that manufacture, develop, and market other launch vehicles as a transfer to one company of government assets that were already paid for with public funds, which creates unfair competition. NASA, nonetheless, recognizes the benefits of privatization and thus intends, at the very least, to increase the private role in shuttle management and operations in upcoming years. It is likely that, in any privatization scenario, the space agency will continue to maintain ownership and management of some launch infrastructure, play an active role in assuring safety of the program, and financially back the private company in the case of catastrophic disaster involving the shuttle.

NASA also believes that increasing the private role in shuttle management will enable future commercialization opportunities. By 2001, NASA had begun to explore opportunities for commercializing its various programs and assets, allowing USA to solicit payloads of private customers for two shuttle missions. Regardless of who owns the shuttle, however, commercialization will succeed only if potential customers find the shuttle's capabilities and prices attractive compared to other launching options. Moreover, the shuttle must be made available for commercial use: NASA's goal of completing work on the International Space Station now dominates the shuttle's schedule.

It is almost certain that NASA will, to some extent, privatize and commercialize the space shuttle. As the space agency will be looking for the most competent and efficient company to assume the job, USA must continue to perform at its best if it wishes to fulfill its vision of opening up the human spaceflight business. SEE ALSO Challenger (Volume 3); Commercialization (Volume 1); Launch Vehicles, Expendable (Volume 1); Launch Vehicles, Reusable (Volume 1); NASA (Volume 3); Reusable Launch Vehicles (Volume 4); Solid Rocket Boosters (Volume 3); Space Shuttle (Volume 3).

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Spaceports

Spaceports are facilities used to launch, and in some cases land, spacecraft. Spaceports are similar to airports and seaports but have some unique features and requirements. They have to be able to support the assembly and launch of large, powerful rockets and the satellites or other cargoes that they carry. There are only a handful of spaceports around the world, although more may be built as the demand for launches grow and the types of launch vehicles evolve.

Spaceport Components

The most familiar element of a spaceport is the launch pad. Originally just a patch of ground where rockets were hastily set up and launched, launch pads have evolved considerably as rockets became larger and more complex. Most launch pads have a tower, known as a gantry, which stands next to the rocket. Through the gantry, technicians have access to various levels of the rocket so they can check and repair systems, add propellant, and in the case of piloted rockets, provide a way for crews to get in and out.

Below the pad itself are pathways called flame trenches, which allow the hot exhaust from the rocket to move away from the pad at the time of the launch, so that it does not damage portions of the pad or the rocket itself. Some launch pads, such as the ones used by the U.S. space shuttle, have water towers nearby that spray water onto the pad at launch. The water is designed to suppress the noise and vibration of the launch, which otherwise could reflect off the pad and damage the shuttle.

The launch pad itself, though, is only a small part of a spaceport. Other facilities at spaceports include hangars on which sections of rockets are put together before moving them to the launch pad. The Vehicle Assembly Building at the Kennedy Space Center, built for the **Apollo** program and

Apollo American program to land men on the Moon. Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

Space shuttle STS-1 is illuminated by Launch Pad A, Complex 39, at one of the best-known spaceports in the world, NASA's Kennedy Space Center, at Cape Canaveral, Florida.

used by shuttles today, is one of the largest buildings in the world when measured by volume.✶ The shuttle and some other rockets are transported vertically from the assembly building to the launch site using large, slow-moving flatbed transporters. In Russia, launch vehicles are carried out to the pad horizontally on conventional rail lines. In some cases rockets are assembled, stage by stage, at the launch site itself.

Spaceports also operate control centers where the progress of a countdown and launch is monitored. Nearby is **radar** that keeps tracks of both the rocket in flight as well as any planes or boats that may venture too close to the launch site. Spaceports usually notify pilots and ship captains of the regions of the ocean that will be off-limits during a launch because rocket stages or debris could fall there.

✶The Vehicle Assembly Building is the first visible landmark at NASA's John F. Kennedy Space Center. It can be seen from at least ten miles in every direction.

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

Spaceports of the World

One of the best-known spaceports in the world, the National Aeronautics and Space Administration's (NASA) John F. Kennedy Space Center, is located at Cape Canaveral, Florida. There are actually two separate spaceports there: NASA's Kennedy Space Center (KSC) and the U.S. Air Force's Cape Canaveral Air Force Station (CCAFS). NASA uses KSC exclusively for launches of the space shuttle, from two launch complexes: 39A and 39B. The same pads were used to launch the Saturn 5 rockets for the Apollo Moon missions. CCAFS is home to a number of launch facilities for unmanned military and commercial rockets, including the Atlas, Delta, and Titan.

There are several other spaceports in the United States. Vandenberg Air Force Base in southern California is used for launches of several types of unmanned rockets, including Delta and Titan boosters, for NASA, the military, and private companies. Vandenberg is used for launches into polar orbit because the only clear path for launches is south, over the Pacific Ocean.

The Kodiak Launch Complex, located on Kodiak Island in Alaska, was used for the first time for an unmanned orbital launch in 2001. Wallops Island, Virginia, has a launching pad for an expendable rocket, as well as runways for aircraft carrying the Pegasus small-winged rocket.

Outside of the United States there are several very active spaceports. Europe established a spaceport near Kourou, French Guiana, on the northeast coast of South America in the late 1960s for European launches. The European Space Agency and the commercial firm Arianespace use Kourou for launches of the Ariane 4 and 5 boosters.

Russia's primary launch site is at Baikonur, in Kazakhstan, formerly part of the Soviet Union. Baikonur is used by a number of Russian rockets, including manned Soyuz missions. Unlike other spaceports, Baikonur is located in the middle of a continent, far from the ocean; spent rocket stages are dropped on desolate regions of Kazakhstan and Siberia rather than in the ocean. Russia also operates spaceports in Plesetsk, in northern Russia, and Svobodny, which it uses for some unmanned flights and military missions.

The Future

Like the rockets that use them, spaceports are evolving. As reusable launch vehicles, which launch and return, become more common, spaceports will have to support pre-launch preparations and post-landing operations. KSC handles both because most shuttle missions end with a landing back at the center. Spaceports will also have to develop facilities to maintain these vehicles and prepare them for their next flights, much like at airports.

Currently even the busiest spaceports, such as Kourou and Cape Canaveral, handle only a couple dozen launches a year, which is near the maximum supportable with current technology. In the late 1990s a study by NASA found that new technologies and an improved infrastructure would be needed to support higher flight rates.

Greater demand for spaceflight should also lead to the creation of new spaceports. The development of single-stage reusable launch vehicles—which travel from the ground to space without dropping any stages along the way—would make it possible for spaceports to be located in many areas, not just near oceans. In the United States alone over a dozen states, including inland states such as Idaho and Oklahoma, have expressed an interest in developing spaceports for future reusable launch vehicles. The creation of these new spaceports could be a major step toward making space travel as routine as air travel. SEE ALSO Launch Services (volume 1); Launch Sites (volume 3); Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Reusable Launch Vehicles (volume 4); Rocket Engines (volume 1); Vehicle Assembly Building (volume 3).

Jeff Foust

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Spinoffs *See Made with Space Technology (Volume 1).*

Sputnik

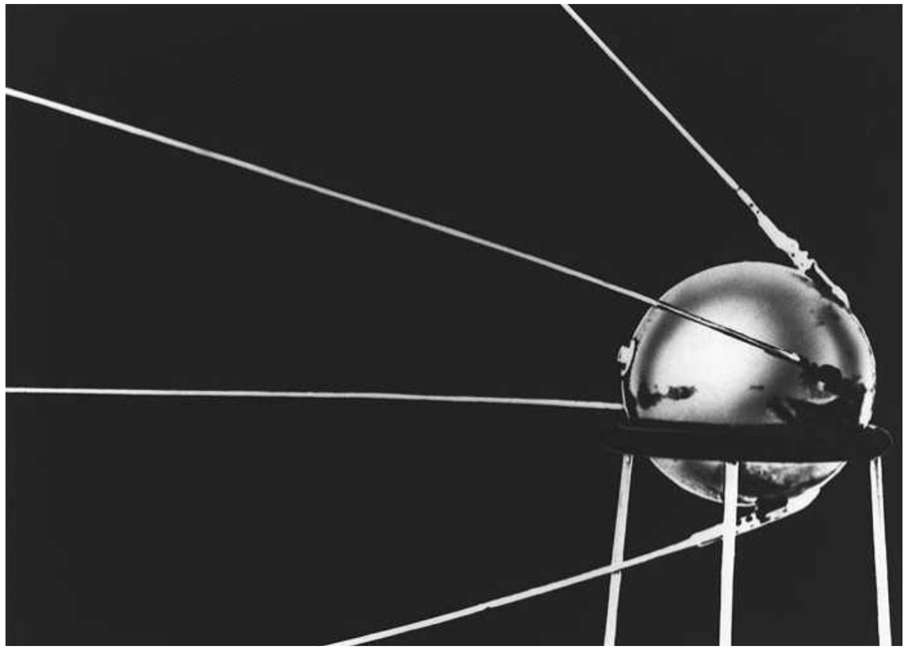
Sputnik is the name given to a series of scientific research satellites launched by the Soviet Union during the period from 1957 to 1961. The satellites ranged in size and capability from the 83.6-kilogram (184.3-pound) Sputnik 1, which served only as a limited radio transmitter, to Sputnik 10, which weighed 4,695 kilograms (10,350 pounds). Together the Sputnik flights ushered in the space age and began the exploration of space by orbital satellites and humans. Sputnik 1 is the most famous in the series.

In August 1957 the Soviet Union conducted a successful test flight of a stage-and-a-half liquid-fueled intercontinental **ballistic** missile called the R-7. Shortly thereafter Soviet scientists were quoted in the news media inside the Soviet Union saying that they were planning for the launch of an Earth satellite using a newly developed missile. Western observers scoffed at the accounts. In the late summer of 1957 Soviet scientists told a planning session of the International Geophysical Year celebrations that a scientific satellite was going to be placed into orbit, and they released to the press the radio frequency that the satellite would use to transmit signals. Again, the statements were widely dismissed inside the United States as Soviet propaganda.

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

Late in the evening in the United States (Eastern Standard Time) on Friday, October 4, 1957, Radio Moscow announced that a small satellite designated Sputnik 1 had been launched and had successfully achieved orbital flight around Earth. The U.S. Defense Department confirmed the fact shortly after the reports reached the West.

Sputnik 1 was the first artificial satellite to reach orbit. Launched from a secret rocket base in the Ural Mountains in Soviet central Asia, it weighed 83.6 kilograms (184.3 pounds), was 0.58 meter (1.9 feet) wide, and carried four whip-style radio antennas that measured 1.5 to 2.9 meters (4.9 to 9.5 feet) in length. Aboard the tiny satellite were instruments capable of



The Sputnik 1 satellite carried four whip-style radio antennas that measured 4.9 to 9.5 feet long, and can be seen in this 1957 photograph.

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

measuring the thickness and temperature of the high upper atmosphere and the composition of the **ionosphere**, and the satellite was also capable of transmitting radio signals. The Soviet news agency Tass released the final radio frequency of the Sputnik and the timetables of its broadcasts, which were widely disseminated by news media worldwide. Sputnik 1 transmitted for twenty-one days after reaching orbit and remained in orbit for ninety-six days. It burned up in the atmosphere on its 1,400th orbit of Earth.

Sputnik 2 was launched into orbit a month later on November 3, 1957. It was a much larger satellite, weighing 508 kilograms (1,120 pounds), and contained the first living creature to be orbited, a dog named Laika. The dog, its capsule, and the upper part of the rocket that launched it remained attached in space for 103 days before burning up after making 2,370 orbits. However, there was only enough oxygen, food, and water to keep Laika alive for a week. There were no provisions to either save the dog or return its capsule to Earth.

Sputniks 3 through 10 were research craft aimed at obtaining design data for the construction of a human-carrying spacecraft. Sputnik 3 was launched on May 15, 1958, Sputnik 4 on May 15, 1960, Sputnik 5 on August 19, 1960, Sputnik 6 on December 1, 1960, Sputnik 7 on February 4, 1961, Sputnik 8 on February 12, 1961, Sputnik 9 on March 9, 1961, and Sputnik 10 on March 25, 1961. Sputnik 10 was a full test version of the Vostok human-carrying space capsule, which carried the first human into space two weeks later on April 12, 1961. Sputniks 5, 6, 9, and 10 carried dogs. Sputnik 10's canine passenger, Zvezdochka, was successfully recovered. Sputnik designations were briefly given to a series of interplanetary probes but these were renamed as part of the Luna series in 1962 and 1963. SEE ALSO ANIMALS (VOLUME 3); INTERNATIONAL SPACE STATION (VOLUME 1 AND VOLUME 3); SATELLITES, TYPES OF (VOLUME 1); SPACE SHUTTLE (VOLUME 3).

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American Aeronautics Company Executive
1954–

David W. Thompson is the chairman and chief executive officer (CEO) of Orbital Sciences Corporation (OSC), a space technology and satellite services company he cofounded in 1982. Before starting OSC, Thompson was a project manager and engineer who worked on advanced rocket engines at the National Aeronautic and Space Administration's (NASA) Marshall Space Flight Center.

David Thompson, CEO of Orbital Sciences Corporation, cofounded his company with the vision of commercial companies forming the driving force in the space industry, instead of government agencies.

As a graduate student, Thompson worked on the first Mars landing missions at the Jet Propulsion Laboratory. Thompson and his cofounders of OSC met at Harvard Business School, where they shared an interest in the commercial uses of space. OSC was founded on the concept of commercial companies, not government agencies, being the driving force in the space industry. Whereas most established space companies' commercial businesses have evolved from government- or military-funded programs, OSC is devoted exclusively to the commercial aspects of the space industry.

OSC is one of the world's ten largest space-related companies, with over 5,000 employees. The company has its headquarters in Dulles, Virginia, and maintains major facilities in the United States, Canada, and several locations overseas. OSC's business activities involve satellites, the Pegasus and Taurus launch vehicles, space robotics, and software. In addition, OSC provides mobile data and messaging services (ORBCOMM) and satellite imaging of Earth. SEE ALSO Launch Vehicles, Expendable (volume 1); Launch Vehicles, Reusable (volume 1); Remote Sensing Systems (volume 1); Reusable Launch Vehicles (volume 4); Satellites, Types of (volume 1).

John F. Kross

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Tourism

It is highly likely that the general public will be traveling, touring, and living in space at some time in the twenty-first century. If history is to be followed, the human expansion into space, on a large scale, is a foreseeable prospect for humankind. One possible scenario begins with 30-minute suborbital flights by the year 2005, followed by orbital flights of two to three revolutions (three to four-and-a-half hours) by about 2010. Surveys have shown that people would like to have a specific destination in space. That desire suggests a destination such as a resort hotel that can provide several days of accommodation in **low Earth orbit**, and a hotel like this may be available in about 2020. Beyond that, space hotels could be followed by or-

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

The space travel and tourism market must attract investors and businesspeople in order to become economical and efficient. American millionaire Dennis Tito (center), the first "space tourist," and Russian cosmonaut Talgat Musabayev (right) are welcomed aboard the International Space Station by commander Yury Usachev (left).

biting sports stadiums and lunar cruises with excursions to the Moon's surface by 2040. After suborbital rides become commonplace, a new **aeroballistic** cargo and human transportation system could begin operation, leaving no major transportation hub on Earth more than an hour's flight time away.

aeroballistic term used to describe the combined aerodynamics and ballistics of an object, such as a spacecraft, in flight

Just exactly how and when these new modes of transportation and resorts will materialize is difficult to predict. However, there is an organized effort underway between the private and public sectors to assure that the right ingredients and the proper **catalysts** are brought together. This effort is multifaceted and includes the government, business, and the general public.

catalysts chemical compounds that accelerate a chemical reaction without itself being used up; any process that acts to accelerate change in a system

Human space activity to date has been the exclusive domain of the Russian and U.S. governments. But this situation has changed, at least to a small degree. The Russian Aviation and Space Agency has made available one to three seats per year on its Soyuz taxi flights to the International Space Station to anyone who can mentally and physically qualify and pay the ticket price of $20 million. In April 2001 American Dennis Tito became the world's first space tourist by qualifying and paying the required fee for transportation and a week's stay at the station. Mark Shuttleworth, a South African, became the second space tourist to the station in April 2002. The exact size of this market remains to be seen. At the stated price, an extremely small proportion of the population will be able to experience space in this new international facility. However, this is a start and this activity will likely encourage others to act.

Barriers and Obstacles to Space Travel and Tourism

Before space travel and tourism can be made economical, reliable, efficient, and safe for everybody, several obstacles must be overcome and many barriers will have to be removed, as detailed next.

Market Research and Development. The space travel and tourism market must attract investors and businesspeople. Although there have been a number of space travel and tourism market surveys and analytic studies, a carefully thought-out market survey should be designed and conducted by professionals in the market research field. In addition, ways to enhance the credibility of space tourism by piquing the interest of nontraditional space businesses, which stand to profit from its development, must be realized.

Legislative Measures. Several legislative measures have been discussed, including three bills that have already been introduced in Congress, that could create favorable conditions for investors and entrepreneurs to join in new commercial space ventures. U.S. Senator John Breaux (D-LA) introduced a bill to make Federal Government insured loans available to space transportation companies; Congressman Nick Lampson (D-TX) introduced a bill to make Federal Government insured loans available to space tourism companies; and Congressman Ken Calvert (R-CA), et al., introduced a bill to provide tax credits to purchasers of space transportation vehicle provider stock. These bills are being evaluated along with other initiatives to be studied including relief from taxes on company-expended space research and development funds, and tax breaks for profits earned during a venture's start-up years.

Technology and Operations. There is a need to go far beyond space shuttle technology and operational capabilities. The shuttle's costs, depending on the annual budget and flight rate, are between $500 million and $750 million per flight, and it takes approximately six months to process **orbiters** between flights. From these baseline parameters, it is essential to lower the unit cost and decrease the turnaround time between flights. Furthermore, reliability must be increased before space travel and tourism can become safe and affordable for the vast majority of the general public.

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

Medical Science. There are volumes of recorded data about how a nearly physically perfect human specimen reacts to the space environment but no information about people with common physical limitations and treatable maladies. For example, how would the medicines taken by a large percentage of the general public act on the human body in a state of weightlessness? Astronauts and cosmonauts are physiologically screened for their ability to react quickly and correctly under extreme pressure in emergency situations, but early living in space will be characterized by cramped living conditions, common hygienic and eating facilities, and semiprivate sleeping quarters. Such conditions are conducive to unrest and conflict among certain individuals, making screening of early space tourists for temperament and tolerance a must.

Regulatory Factors. Methods must be devised through public and private sector efforts that will allow an orderly, safe, and reliable progression of certification and approval of a venture's equipment without the imposition of potentially crippling costs. Initially it will not be possible to match the safety and reliability levels of conventional aircraft that have evolved over time. Instead, a system is needed that will allow voluntary personal risk to be taken in excess of that involved in flying on modern aircraft while fully protecting the safety of third parties (people and property not affiliated with the operator and/or customer).

Legal Factors. Just as there are laws for operating on Earth's land surface and oceans, there will be a need for laws for operating in space and on and around other celestial bodies. The United Nations treaty governing the use of space must be improved and expanded to take into account eventual space operations involving people and accommodating **infrastructure**. From the navigational rules of space lanes to real estate claims for settlement or mining purposes, laws will have to be created by international legal bodies to provide order and justice on the final frontier.

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

Finance and Insurance. Perhaps the most prominent obstacle that must be overcome is the lack of financing available for private space ventures, particularly those involving new **reusable launch vehicles** (RLVs). Several RLV development programs have been stalled because of an inability to find investors. Persuading investors to accept some front-end risk in return for the large rewards that will be realized in the years ahead is the main challenge. Legislation to ease the risk is one potential solution. Innovative methods for raising capital (e.g., tax-exempt bonds) and other ways to lower the risks to acceptable levels will have to come from the investment and insurance communities.

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

Space should be seen as another medium that will be developed for business and recreational purposes, contributing to the welfare and enjoyment of all the world's people. Before long space will become an extension of Earth itself. SEE ALSO HOTELS (VOLUME 4); LIVING IN SPACE (VOLUME 3); SPACE TOURISM, EVOLUTION OF (VOLUME 4).

Robert L. Haltermann

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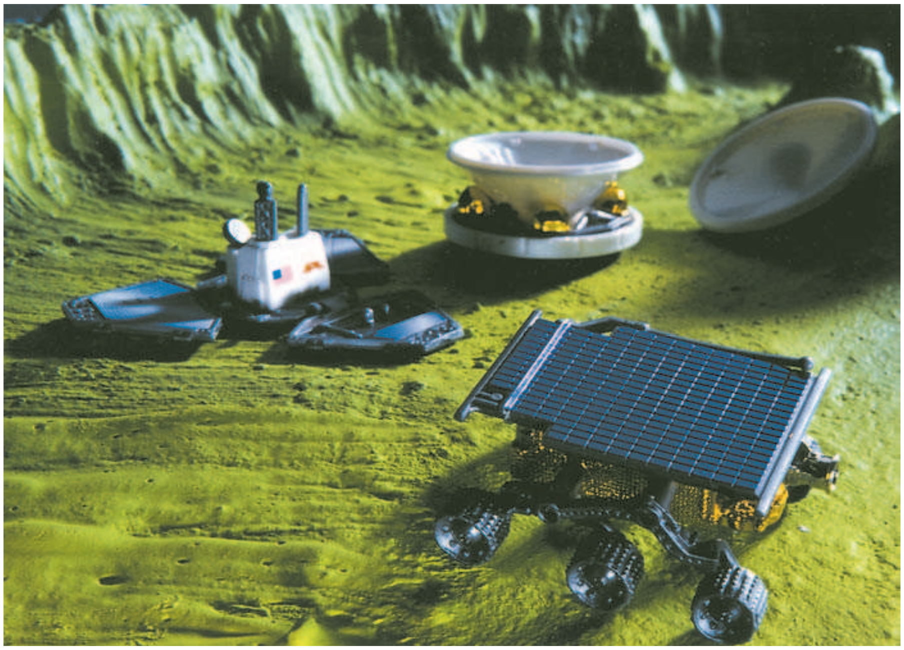
Toys

The term "toy" generally applies to any object used by children in play. However, there is a huge business in creating objects, usually in miniature, designed specifically for children's play. These toys generally model adult culture and society, frequently with great accuracy. In the last half of the twentieth century, model National Aeronautics and Space Administration (NASA) spacecraft, toy ray guns with light and sound action, and spaceships and action figures related to popular films reflected the recent growth of interest in science fiction and space exploration.

There are a wide range of space toys available in the market today. Children have access to transparent model Saturn V rockets, models of the International Space Station, models of the Apollo 15 Lunar Lander with the Lunar Rover, and a complete Cape Canaveral launch pad. The toy manufacturer Brio has a Space Discovery Set suitable for very young children that includes an astronaut, a launch vehicle, and a launch control center with a ground crew member. Lego has three toys in its Life on Mars series: the



Space-related toys, such as this Mattel Hot Wheels JPL Sojourner Mars Rover Action Pack set, can generate profits for toy manufacturers and publicize advancing space technology.

Excavation Searcher, the Mars Solar Explorer, and the Red Planet Protector. Action Products sells the Complete Space Explorer with models of the space shuttle, Apollo Lunar Lander, Skylab, and dozens of small action figures representing astronauts and ground crews.

The Mars Pathfinder mission, one of a series of robotic explorations of other planets, created many business opportunities for toy manufacturers. The Jet Propulsion Laboratory (JPL) and NASA have signed thirty-seven licensing agreements for products related to this mission, including T-shirts, caps, and toys. One of the most interesting and ambitious toys was the Mattel Hot Wheels JPL Sojourner Mars Rover Action Pack set. This set includes toy models of Sojourner, the Pathfinder spacecraft, and a lander. Many of the Sojourner rover's unique attributes are included, such as its six-wheel independent suspension that allows it to navigate rough terrain. According to Joan Horvath, a business alliance manager with JPL's Technology Affiliates Program, these toy models helped educate both kids and parents alike about the Mars Pathfinder mission in the most user-friendly manner possible. Moreover, it made the business community aware of the many different aspects of the JPL's technology transfer programs.

The success of the Mattel Mars Pathfinder set led to another license agreement. JPL and Mattel teamed up for a toy version of NASA's Galileo spacecraft. The Hot Wheels Jupiter/**Europa** Encounter Action Pack includes a highly detailed reproduction of the Galileo spacecraft, the Galileo descent probe, and of one of the ground-based antenna dishes.

Europa one of the large satellites of Jupiter

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

Toys in Space

Toys have also ventured into space. Carolyn Sumners of the Houston Museum of Natural Science in Houston, Texas, assembled a small group of toys to be flown on space shuttle mission 51-D in April 1985. During the flight, crew members experimented with the toys, demonstrating the behavior of objects under conditions of apparent weightlessness. The first "Toys in Space" mission was so successful, a second group of toys was flown on the STS-54 mission in January 1993. During the second Toys in Space mission, astronauts John Casper and Susan Helms demonstrated how the behavior of several simple toys was quite different under **microgravity** conditions.

In June 2001, The Lego company teamed up with Space Media, Inc.™ and RSC Energia to conduct the first experiment on the International Space Station using toys. The Life on Mars: Red Planet Protector was used to measure the mass of an object under zero-gravity conditions. Cosmonauts Talgat Musabayev and Yuri Baturin demonstrated how an object's mass can be determined from oscillation frequency in a weightless environment.

Educational toys related to space exploration can serve the dual roles of providing a good return on investment for toy manufacturers while at the same time providing a rich learning opportunity for children. The vision of Lego, sparking an interest in science and space, can provide a sound basis for socially conscious free enterprise. The cooperative model developed by Mattel and JPL has been mutually beneficial, serving as a strong profit center for Mattel while effectively publicizing NASA and JPL's commitment to technology transfer. SEE ALSO EDUCATION (VOLUME 1); MARS (VOLUME 2); MICROGRAVITY (VOLUME 2); ROBOTIC EXPLORATION OF SPACE (VOLUME 2).

Elliot Richmond

SOME BUSINESS FACTS ABOUT TOYS

- In the United States, toy sales amounted to $25 billion dollars in 2001.
- Wal-Mart was the largest retailer, with toy sales of $7,300 million ($7.3 billion).
- Toys 'R Us was a close second with sales of $6,933 million ($6.9 billion).
- Science-related toys were the fastest growing segment of the toy market in the years 1996 through 1999.
- Science-related toy sales amounted to $90 million in 1999.
- Science-related toy sales continue to grow at a rate of 12% a year.
- The Mars Pathfinder Action Pack continues to sell out whenever a shipment is received.
- In contrast to the $90 million science-related toy market, sales of *Star Wars* action figures alone amounted to $500 million in 1999.

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V

Verne, Jules

French Science Fiction Novelist
1828–1905

Jules Gabriel Verne, one of the founding fathers of science fiction, was born in Nantes, France, in 1828. He was the eldest son of a successful provincial lawyer. At twelve years of age, Verne ran off to be a cabin boy on a merchant ship, thinking he was going to have an adventure. But his father caught up with the ship before it got very far and took Verne home to punish him. Verne promised in the future he would travel only in his imagination.

In 1847 Verne was sent to study law in Paris, and from 1848 until 1863 wrote opera librettos and plays as a hobby. He read incessantly and studied astronomy, geology, and engineering for many hours in Paris libraries. His first play was published in 1850, prompting his decision to discontinue his law studies. Displeased upon hearing this news, his father stopped paying his son's expenses in Paris. This forced Verne to earn money by selling his stories.

Jules Verne, author of *20,000 Leagues under the Sea* (1870), predicted many scientific advancements of the twentieth century and is considered one of the founding fathers of science fiction.

In 1862, at the age of thirty-four, Verne sent a series of works called Voyages Extraordinaire to Pierre-Jules Hetzel, a writer and publisher of literature for children and young adults. Verne attained enough success with the first in the series, *Five Weeks in a Balloon*, published in 1863, for the Verne/Hetzel collaboration to continue throughout his entire career. Hetzel published Verne's stories in his periodical, *Magasin d'Education et de Recreation*, and later released them in book form.

Due to nineteenth-century interest in science and invention, Verne's work was received with enormous popular favor. He forecast with remarkable accuracy many scientific achievements of the twentieth century. He anticipated flights into outer space, automobiles, submarines, helicopters, atomic power, telephones, air conditioning, guided missiles, and motion pictures long before they were developed. In his novels, however, science and technology are not the heroes. Instead, his heroes are admirable men who master science and technology. His object was to write books from which the young could learn.

Among his most popular books are *Journey to the Center of the Earth* (1864), *From the Earth to the Moon* (1865), *20,000 Leagues under the Sea* (1870), *Mysterious Island* (1870), and *Around the World in Eighty Days* (1873). These five novels have remained in almost continuous print for over a century. Verne also produced an illustrated geography of France, and his works have been the source of many films.

Because of the popularity of these and other novels, Verne became a wealthy man. In 1857 he married Honorine de Viane. In 1876 he bought a large yacht and sailed around Europe. This was the extent of his real-life adventuring, leaving the rest for his novels. He maintained a regular writing schedule of at least two volumes a year. Verne published sixty-five novels, thirty plays, librettos, geographies, occasional short stories, and essays.

The last novel he wrote before his death was *The Invasion of the Sea*. He died in the city of Amiens, France, in 1905. SEE ALSO Careers in Writing, Photography, and Filmmaking (volume 1); Literature (volume 1).

Vickie Elaine Caffey

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X

X PRIZE

In the early twenty-first century, millions of people fly on airplanes between cities around the world. At any one time, an astounding 10 million people are airborne. But it was not always this way. Only 100 years ago, during the birth of aviation, flying in an airplane was a very expensive, risky, and infrequent activity, much the way spaceflight is in the early twenty-first century.

At the turn of the last century (1904–1930), one of the major activities that made aviation very popular, exciting, and affordable was a series of prizes or competitions. History has shown the amazing power of prizes to accelerate technological development. For example, in 1714, in response to a series of tragic maritime disasters, the British Parliament passed the Longitude Act, which provided a large financial prize for the demonstration of a marine clock that was sufficiently accurate to permit precise determination of a ship's longitude. Within twenty years of the announcement of the Longitude prize, a practical clock was demonstrated and marine navigation was revolutionized.

In the twentieth century the history of aviation contains hundreds of prizes that greatly advanced aircraft technology. One of the most significant prizes in the history of aviation (and the one from which the X PRIZE is modeled) was the Orteig Prize, an award for the first nonstop flight between New York and Paris, which was sponsored by Raymond Orteig, a wealthy hotel owner. Nine teams cumulatively spent $400,000, sixteen times the $25,000 purse, in pursuit of this prize. By offering a prize instead of backing one particular team or technology, Orteig automatically backed the winner. Had Orteig elected to back teams in order of their probability of success, as judged by the conventional wisdom of the day, he would have backed Charles Lindbergh last. Lindbergh achieved success, taking an unconventional single pilot/single engine approach. On May 20, 1927, Lindbergh flew his airplane, the Spirit of St. Louis, nonstop for thirty-three and a half hours across the Atlantic Ocean from New York to Paris, and won the $25,000 Orteig prize.

The X PRIZE is a competition that was created to inspire rocket scientists to build a new generation of spaceships designed to carry the average person into space on a suborbital flight to an altitude of 100 kilometers (62 miles). This flight is very similar to the flight made by astronaut Alan Shepard on May 5, 1961, on the Mercury Redstone rocket from Cape Canaveral, Florida. Shepard, who was the first American in space, did not actually go into orbit, as the space shuttle does, but instead flew a **suborbital trajectory** that lasted about twenty minutes.

suborbital trajectory the trajectory of a rocket or ballistic missile that has insufficient energy to reach orbit

The X PRIZE Foundation, headquartered in St. Louis, Missouri, is offering a $10 million cash prize. To win the prize, vehicles must be privately financed and constructed, and competitors must demonstrate their ability to fly to an altitude of 100 kilometers with three passengers. Furthermore, competitors must prove that their vehicle is reusable by flying it twice within a two-week period. Since the announcement of the X PRIZE, twenty-one teams from five countries have registered to compete.

The suborbital flights of the X PRIZE are just the first step. The competition's goals are to bring about the creation of new generation of spaceships that will serve new markets such as space tourism and point-to-point package delivery (rocket mail). As X PRIZE teams gain experience and improve their technology, their ships will evolve from suborbital to orbital ships in the same fashion that one can draw the lineage from the Wright brothers' Flyer to the DC-3 and eventually to today's 747 aircraft.

The mission of the X PRIZE Foundation is to change the way that people think about space. Rather than viewing spaceflight as the exclusive province of governments, the foundation's goal is to transform spaceflight into an enterprise in which the general public can directly participate, much in the way that people can fly on airplanes today. SEE ALSO LAUNCH VEHICLES, REUSABLE (VOLUME 1); REUSABLE LAUNCH VEHICLES (VOLUME 4); SHEPARD, ALAN (VOLUME 3); SPACE TOURISM, EVOLUTION OF (VOLUME 4); TOURISM (VOLUME 1).

Peter H. Diamandis

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Glossary

ablation removal of the outer layers of an object by erosion, melting, or vaporization

abort-to-orbit emergency procedure planned for the space shuttle and other spacecraft if the spacecraft reaches a lower than planned orbit

accretion the growth of a star or planet through the accumulation of material from a companion star or the surrounding interstellar matter

adaptive optics the use of computers to adjust the shape of a telescope's optical system to compensate for gravity or temperature variations

aeroballistic describes the combined aerodynamics and ballistics of an object, such as a spacecraft, in flight

aerobraking the technique of using a planet's atmosphere to slow down an incoming spacecraft; its use requires the spacecraft to have a heat shield, because the friction that slows the craft is turned into intense heat

aerodynamic heating heating of the exterior skin of a spacecraft, aircraft, or other object moving at high speed through the atmosphere

Agena a multipurpose rocket designed to perform ascent, precision orbit injection, and missions from low Earth orbit to interplanetary space; also served as a docking target for the Gemini spacecraft

algae simple photosynthetic organisms, often aquatic

alpha proton X-ray analytical instrument that bombards a sample with alpha particles (consisting of two protons and two neutrons); the X rays are generated through the interaction of the alpha particles and the sample

altimeter an instrument designed to measure altitude above sea level

amplitude the height of a wave or other oscillation; the range or extent of a process or phenomenon

angular momentum the angular equivalent of linear momentum; the product of angular velocity and moment of inertia (moment of inertia = mass $\times$ radius^2)

angular velocity the rotational speed of an object, usually measured in radians per second

anisotropy a quantity that is different when measured in different directions or along different axes

annular ring-like

anomalies phenomena that are different from what is expected

anorthosite a light-colored rock composed mainly of the mineral feldspar (an aluminum silicate); commonly occurs in the crusts of Earth and the Moon

anthropocentrism valuing humans above all else

antimatter matter composed of antiparticles, such as positrons and antiprotons

antipodal at the opposite pole; two points on a planet that are diametrically opposite

aperture an opening, door, or hatch

aphelion the point in an object's orbit that is farthest from the Sun

Apollo American program to land men on the Moon; Apollo 11, 12, 14, 15, 16, and 17 delivered twelve men to the lunar surface between 1969 and 1972 and returned them safely back to Earth

asthenosphere the weaker portion of a planet's interior just below the rocky crust

astrometry the measurement of the positions of stars on the sky

astronomical unit the average distance between Earth and the Sun (152 million kilometers [93 million miles])

atmospheric probe a separate piece of a spacecraft that is launched from it and separately enters the atmosphere of a planet on a one-way trip, making measurements until it hits a surface, burns up, or otherwise ends its mission

atmospheric refraction the bending of sunlight or other light caused by the varying optical density of the atmosphere

atomic nucleus the protons and neutrons that make up the core of an atom

atrophy condition that involves withering, shrinking, or wasting away

auroras atmospheric phenomena consisting of glowing bands or sheets of light in the sky caused by high-speed charged particles striking atoms in Earth's upper atmosphere

avionics electronic equipment designed for use on aircraft, spacecraft, and missiles

azimuth horizontal angular distance from true north measured clockwise from true north (e.g., if North = 0 degrees; East = 90 degrees; South = 180 degrees; West = 270 degrees)

ballast heavy substance used to increase the stability of a vehicle

ballistic the path of an object in unpowered flight; the path of a spacecraft after the engines have shut down

basalt a dark, volcanic rock with abundant iron and magnesium and relatively low silica common on all of the terrestrial planets

base load the minimum amount of energy needed for a power grid

beacon signal generator a radio transmitter emitting signals for guidance or for showing location

berth space the human accommodations needed by a space station, cargo ship, or other vessel

Big Bang name given by astronomers to the event marking the beginning of the universe when all matter and energy came into being

biocentric notion that all living organisms have intrinsic value

biogenic resulting from the actions of living organisms; or, necessary for life

bioregenerative referring to a life support system in which biological processes are used; physiochemical and/or nonregenerative processes may also be used

biosignatures the unique traces left in the geological record by living organisms

biosphere the interaction of living organisms on a global scale

bipolar outflow jets of material (gas and dust) flowing away from a central object (e.g., a protostar) in opposite directions

bitumen a thick, almost solid form of hydrocarbons, often mixed with other minerals

black holes objects so massive for their size that their gravitational pull prevents everything, even light, from escaping

bone mineral density the mass of minerals, mostly calcium, in a given volume of bone

breccia mixed rock composed of fragments of different rock types; formed by the shock and heat of meteorite impacts

bright rays lines of lighter material visible on the surface of a body and caused by relatively recent impacts

brown dwarf star-like object less massive than 0.08 times the mass of the Sun, which cannot undergo thermonuclear process to generate its own luminosity

calderas the bowl-shaped crater at the top of a volcano caused by the collapse of the central part of the volcano

Callisto one of the four large moons of Jupiter; named for one of the Greek nymphs

Caloris basin the largest (1,300 kilometers [806 miles] in diameter) well-preserved impact basin on Mercury viewed by Mariner 10

capsule a closed compartment designed to hold and protect humans, instruments, and/or equipment, as in a spacecraft

carbon-fiber composites combinations of carbon fibers with other materials such as resins or ceramics; carbon fiber composites are strong and lightweight

carbonaceous meteorites the rarest kind of meteorites, they contain a high percentage of carbon and carbon-rich compounds

carbonate a class of minerals, such as chalk and limestone, formed by carbon dioxide reacting in water

cartographic relating to the making of maps

Cassini mission a robotic spacecraft mission to the planet Saturn scheduled to arrive in July 2004 when the Huygens probe will be dropped into Titan's atmosphere while the Cassini spacecraft studies the planet

catalyst a chemical compound that accelerates a chemical reaction without itself being used up; any process that acts to accelerate change in a system

catalyze to change by the use of a catalyst

cell culture a means of growing mammalian (including human) cells in the research laboratory under defined experimental conditions

cellular array the three-dimensional placement of cells within a tissue

centrifugal directed away from the center through spinning

centrifuge a device that uses centrifugal force caused by spinning to simulate gravity

Cepheid variables a class of variable stars whose luminosity is related to their period. Their periods can range from a few hours to about 100 days and the longer the period, the brighter the star

Čerenkov light light emitted by a charged particle moving through a medium, such as air or water, at a velocity greater than the phase velocity of light in that medium; usually a faint, eerie, bluish, optical glow

chassis frame on which a vehicle is constructed

chondrite meteorites a type of meteorite that contains spherical clumps of loosely consolidated minerals

cinder field an area dominated by volcanic rock, especially the cinders ejected from explosive volcanoes

circadian rhythm activities and bodily functions that recur every twenty-four hours, such as sleeping and eating

Clarke orbit geostationary orbit; named after science fiction writer Arthur C. Clarke, who first realized the usefulness of this type of orbit for communication and weather satellites

coagulate to cause to come together into a coherent mass

comet matrix material the substances that form the nucleus of a comet; dust grains embedded in frozen methane, ammonia, carbon dioxide, and water

cometary outgassing vaporization of the frozen gases that form a comet nucleus as the comet approaches the Sun and warms

communications infrastructure the physical structures that support a network of telephone, Internet, mobile phones, and other communication systems

convection the movement of heated fluid caused by a variation in density; hot fluid rises while cool fluid sinks

convection currents mechanism by which thermal energy moves because its density differs from that of surrounding material. Convection current is the movement pattern of thermal energy transferring within a medium

convective processes processes that are driven by the movement of heated fluids resulting from a variation in density

coronal holes large, dark holes seen when the Sun is viewed in X-ray or ultraviolet wavelengths; solar wind emanates from the coronal holes

coronal mass ejections large quantities of solar plasma and magnetic field launched from the Sun into space

cosmic microwave background ubiquitous, diffuse, uniform, thermal radiation created during the earliest hot phases of the universe

cosmic radiation high energy particles that enter Earth's atmosphere from outer space causing cascades of mesons and other particles

cosmocentric ethic an ethical position that establishes the universe as the priority in a value system or appeals to something characteristic of the universe that provides justification of value

cover glass a sheet of glass used to cover the solid state device in a solar cell

crash-landers or hard-lander; a spacecraft that collides with the planet, making no—or little—attempt to slow down; after collision, the spacecraft ceases to function because of the (intentional) catastrophic failure

crawler transporter large, tracked vehicles used to move the assembled Apollo/Saturn from the VAB to the launch pad

cryogenic related to extremely low temperatures; the temperature of liquid nitrogen or lower

cryptocometary another name for carbonaceous asteroids—asteroids that contain a high percentage of carbon compounds mixed with frozen gases

cryptoendolithic microbial microbial ecosystems that live inside sandstone in extreme environments such as Antarctica

crystal lattice the arrangement of atoms inside a crystal

crystallography the study of the internal structure of crystals

dark matter matter that interacts with ordinary matter by gravity but does not emit electromagnetic radiation; its composition is unknown

density-separation jigs a form of gravity separation of materials with different densities that uses a pulsating fluid

desiccation the process of drying up

detruents microorganisms that act as decomposers in a controlled environmental life support system

diffuse spread out; not concentrated

DNA deoxyribonucleic acid; the molecule used by all living things on Earth to transmit genetic information

docking system mechanical and electronic devices that work jointly to bring together and physically link two spacecraft in space

doped semiconductor such as silicon with an addition of small amounts of an impurity such as phosphorous to generate more charge carriers (such as electrons)

dormant comet a comet whose volatile gases have all been vaporized, leaving behind only the heavy materials

downlink the radio dish and receiver through which a satellite or spacecraft transmits information back to Earth

drag a force that opposes the motion of an aircraft or spacecraft through the atmosphere

dunites rock type composed almost entirely of the mineral olivine, crystallized from magma beneath the Moon's surface

dynamic isotope power the decay of isotopes such as plutonium-238, and polonium-210 produces heat, which can be transformed into electricity by radioisotopic thermoelectric generators

Earth-Moon LaGrange five points in space relative to Earth and the Moon where the gravitational forces on an object balance; two points, 60 degrees from the Moon in orbit, are candidate points for a permanent space settlement due to their gravitational stability

eccentric the term that describes how oval the orbit of a planet is

ecliptic the plane of Earth's orbit

EH condrites a rare form of meteorite containing a high concentration of the mineral enstatite (a type of pyroxene) and over 30 percent iron

ejecta the pieces of material thrown off by a star when it explodes; or, material thrown out of an impact crater during its formation

ejector ramjet engine design that uses a small rocket mounted in front of the ramjet to provide a flow of heated air, allowing the ramjet to provide thrust when stationary

electrodynamic pertaining to the interaction of moving electric charges with magnetic and electric fields

electrolytes a substance that when dissolved in water creates an electrically conducting solution

electromagnetic spectrum the entire range of wavelengths of electromagnetic radiation

electron a negatively charged subatomic particle

electron volts units of energy equal to the energy gained by an electron when it passes through a potential difference of 1 volt in a vacuum

electrostatic separation separation of substances by the use of electrically charged plates

elliptical having an oval shape

encapsulation enclosing within a capsule

endocrine system in the body that creates and secretes substances called hormones into the blood

equatorial orbit an orbit parallel to a body's geographic equator

equilibruim point the point where forces are in balance

Europa one of the large satellites of Jupiter

eV an electron volt is the energy gained by an electron when moved across a potential of one volt. Ordinary molecules, such as air, have an energy of about $3x10^{-2}$ eV

event horizon the imaginary spherical shell surrounding a black hole that marks the boundary where no light or any other information can escape

excavation a hole formed by mining or digging

expendable launch vehicles launch vehicles, such as a rocket, not intended to be reused

extrasolar planets planets orbiting stars other than the Sun

extravehicular activity a space walk conducted outside a spacecraft cabin, with the crew member protected from the environment by a pressurized space suit

extremophiles microorganisms that can survive in extreme environments such as high salinity or near boiling water

extruded forced through an opening

failsafe a system designed to be failure resistant through robust construction and redundant functions

fairing a structure designed to provide low aerodynamic drag for an aircraft or spacecraft in flight

fault a fracture in rock in the upper crust of a planet along which there has been movement

feedstock the raw materials introduced into an industrial process from which a finished product is made

feldspathic rock containing a high proportion of the mineral feldspar

fiber-optic cable a thin strand of ultrapure glass that carries information in the form of light, with the light turned on and off rapidly to represent the information sent

fission act of splitting a heavy atomic nucleus into two lighter ones, releasing tremendous energy

flares intense, sudden releases of energy

flybys flight path that takes the spacecraft close enough to a planet to obtain good observations; the spacecraft then continues on a path away from the planet but may make multiple passes

fracture any break in rock, from small "joints" that divide rocks into planar blocks (such as that seen in road cuts) to vast breaks in the crusts of unspecified movement

freefall the motion of a body acted on by no forces other than gravity, usually in orbit around Earth or another celestial body

free radical a molecule with a high degree of chemical reactivity due to the presence of an unpaired electron

frequencies the number of oscillations or vibrations per second of an electromagnetic wave or any wave

fuel cells cells that react a fuel (such as hydrogen) and an oxidizer (such as oxygen) together; the chemical energy of the initial reactants is released by the fuel cell in the form of electricity

fusion the act of releasing nuclear energy by combining lighter elements such as hydrogen into heavier elements

fusion fuel fuel suitable for use in a nuclear fusion reactor

G force the force an astronaut or pilot experiences when undergoing large accelerations

galaxy a system of as many as hundreds of billions of stars that have a common gravitational attraction

Galilean satellite one of the four large moons of Jupiter first discovered by Galileo

Galileo mission succesful robot exploration of the outer solar system; this mission used gravity assists from Venus and Earth to reach Jupiter, where it dropped a probe into the atmosphere and studied the planet for nearly seven years

gamma rays a form of radiation with a shorter wavelength and more energy than X rays

Ganymede one of the four large moons of Jupiter; the largest moon in the solar system

Gemini the second series of American-piloted spacecraft, crewed by two astronauts; the Gemini missions were rehearsals of the spaceflight techniques needed to go to the Moon

general relativity a branch of science first described by Albert Einstein showing the relationship between gravity and acceleration

geocentric a model that places Earth at the center of the universe

geodetic survey determination of the exact position of points on Earth's surface and measurement of the size and shape of Earth and of Earth's gravitational and magnetic fields

geomagnetic field Earth's magnetic field; under the influence of solar wind, the magnetic field is compressed in the Sunward direction and stretched out in the downwind direction, creating the magnetosphere, a complex, teardrop-shaped cavity around Earth

geospatial relating to measurement of Earth's surface as well as positions on its surface

geostationary remaining above a fixed point above Earth's equator

geostationary orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

geosynchronous remaining fixed in an orbit 35,786 kilometers (22,300 miles) above Earth's surface

geosynchronous orbit a specific altitude of an equatorial orbit where the time required to circle the planet matches the time it takes the planet to rotate on its axis. An object in geostationary orbit will always remain over the same geographic location on the equator of the planet it orbits

gimbal motors motors that direct the nozzle of a rocket engine to provide steering

global change a change, such as average ocean temperature, affecting the entire planet

global positioning systems a system of satellites and receivers that provide direct determination of the geographical location of the receiver

globular clusters roughly spherical collections of hundreds of thousands of old stars found in galactic haloes

grand unified theory (GUT) states that, at a high enough energy level (about 10^{25} eV), the electromagnetic force, strong force, and weak force all merge into a single force

gravitational assist the technique of flying by a planet to use its energy to "catapult" a spacecraft on its way—this saves fuel and thus mass and cost of a mission; gravitational assists typically make the total mission duration longer, but they also make things possible that otherwise would not be possible

gravitational contraction the collapse of a cloud of gas and dust due to the mutual gravitational attraction of the parts of the cloud; a possible source of excess heat radiated by some Jovian planets

gravitational lenses two or more images of a distant object formed by the bending of light around an intervening massive object

gravity assist using the gravity of a planet during a close encounter to add energy to the motion of a spacecraft

gravity gradient the difference in the acceleration of gravity at different points on Earth and at different distances from Earth

gravity waves waves that propagate through space and are caused by the movement of large massive bodies, such as black holes and exploding stars

greenhouse effect process by which short wavelength energy (e.g., visible light) penetrates an object's atmosphere and is absorbed by the surface, which reradiates this energy as longer wavelength infrared (thermal) energy; this energy is blocked from escaping to space by molecules (e.g., H_2O and CO_2) in the atmosphere; and as a result, the surface warms

gyroscope a spinning disk mounted so that its axis can turn freely and maintain a constant orientation in space

hard-lander spacecraft that collides with the planet or satellite, making no attempt to slow its descent; also called crash-landers

heliosphere the volume of space extending outward from the Sun that is dominated by solar wind; it ends where the solar wind transitions into the interstellar medium, somewhere between 40 and 100 astronomical units from the Sun

helium-3 a stable isotope of helium whose nucleus contains two protons and one neutron

hertz unit of frequency equal to one cycle per second

high-power klystron tubes a type of electron tube used to generate high frequency electromagnetic waves

hilly and lineated terrain the broken-up surface of Mercury at the antipode of the Caloris impact basin

hydrazine a dangerous and corrosive compound of nitrogen and hydrogen commonly used in high powered rockets and jet engines

hydroponics growing plants using water and nutrients in solution instead of soil as the root medium

hydrothermal relating to high temperature water

hyperbaric chamber compartment where air pressure can be carefully controlled; used to gradually acclimate divers, astronauts, and others to changes in pressure and air composition

hypergolic fuels and oxidizers that ignite on contact with each other and need no ignition source

hypersonic capable of speeds over five times the speed of sound

hyperspectral imaging technique in remote sensing that uses at least sixteen contiguous bands of high spectral resolution over a region of the electromagnetic spectrum; used in NASA spacecraft Lewis' payload

ilmenite an important ore of titanium

Imbrium Basin impact largest and latest of the giant impact events that formed the mare-filled basins on the lunar near side

impact craters bowl-shaped depressions on the surfaces of planets or satellites that result from the impact of space debris moving at high speeds

impact winter the period following a large asteroidal or cometary impact when the Sun is dimmed by stratospheric dust and the climate becomes cold worldwide

impact-melt molten material produced by the shock and heat transfer from an impacting asteroid or meteorite

in situ in the natural or original location

incandescence glowing due to high temperature

indurated rocks rocks that have been hardened by natural processes

information age the era of our time when many businesses and persons are involved in creating, transmitting, sharing, using, and selling information, particularly through the use of computers

infrared portion of the electromagnetic spectrum with waves slightly longer than visible light

infrared radiation radiation whose wavelength is slightly longer than the wavelength of light

infrastructure the physical structures, such as roads and bridges, necessary to the functioning of a complex system

intercrater plains the oldest plains on Mercury that occur in the highlands and that formed during the period of heavy meteoroid bombardment

interferometers devices that use two or more telescopes to observe the same object at the same time in the same wavelength to increase angular resolution

interplanetary trajectories the solar orbits followed by spacecraft moving from one planet in the solar system to another

interstellar between the stars

interstellar medium the gas and dust found in the space between the stars

ion propulsion a propulsion system that uses charged particles accelerated by electric fields to provide thrust

ionization removing one or more electrons from an atom or molecule

ionosphere a charged particle region of several layers in the upper atmosphere created by radiation interacting with upper atmospheric gases

isotopic ratios the naturally occurring ratios between different isotopes of an element

jettison to eject, throw overboard, or get rid of

Jovian relating to the planet Jupiter

Kevlar® a tough aramid fiber resistant to penetration

kinetic energy the energy an object has due to its motion

KREEP acronym for material rich in potassium (K), rare earth elements (REE), and phosphorus (P)

L-4 the gravitationally stable Lagrange point 60 degrees ahead of the orbiting planet

L-5 the gravitationally stable Lagrange point 60 degrees behind the orbiting planet

Lagrangian point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

laser-pulsing firing periodic pulses from a powerful laser at a surface and measuring the length of time for return in order to determine topography

libration point one of five gravitationally stable points related to two orbiting masses; three points are metastable, but L4 and L5 are stable

lichen fungus that grows symbiotically with algae

light year the distance that light in a vacuum would travel in one year, or about 9.5 trillion kilometers (5.9 trillion miles)

lithosphere the rocky outer crust of a body

littoral the region along a coast or beach between high and low tides

lobate scarps a long sinuous cliff

low Earth orbit an orbit between 300 and 800 kilometers above Earth's surface

lunar maria the large, dark, lava-filled impact basins on the Moon thought by early astronomers to resemble seas

Lunar Orbiter a series of five unmanned missions in 1966 and 1967 that photographed much of the Moon at medium to high resolution from orbit

macromolecules large molecules such as proteins or DNA containing thousands or millions of individual atoms

magnetohydrodynamic waves a low frequency oscillation in a plasma in the presence of a magnetic field

magnetometer an instrument used to measure the strength and direction of a magnetic field

magnetosphere the magnetic cavity that surrounds Earth or any other planet with a magnetic field. It is formed by the interaction of the solar wind with the planet's magnetic field

majority carriers the more abundant charge carriers in semiconductors; the less abundant are called minority carriers; for n-type semiconductors, electrons are the majority carriers

malady a disorder or disease of the body

many-bodied problem in celestial mechanics, the problem of finding solutions to the equations for more than two orbiting bodies

mare dark-colored plains of solidified lava that mainly fill the large impact basins and other low-lying regions on the Moon

Mercury the first American piloted spacecraft, which carried a single astronaut into space; six Mercury missions took place between 1961 and 1963

mesons any of a family of subatomic particle that have masses between electrons and protons and that respond to the strong nuclear force; produced in the upper atmosphere by cosmic rays

meteor the physical manifestation of a meteoroid interacting with Earth's atmosphere; this includes visible light and radio frequency generation, and an ionized trail from which radar signals can be reflected. Also called a "shooting star"

meteorites any part of a meteoroid that survives passage through Earth's atmosphere

meteoroid a piece of interplanetary material smaller than an asteroid or comet

meteorology the study of atmospheric phenomena or weather

meteorology satellites satellites designed to take measurements of the atmosphere for determining weather and climate change

microgravity the condition experienced in freefall as a spacecraft orbits Earth or another body; commonly called weightlessness; only very small forces are perceived in freefall, on the order of one-millionth the force of gravity on Earth's surface

micrometeoroid flux the total mass of micrometeoroids falling into an atmosphere or on a surface per unit of time

micrometeoroid any meteoroid ranging in size from a speck of dust to a pebble

microwave link a connection between two radio towers that each transmit and receive microwave (radio) signals as a method of carrying information (similar to radio communications)

minerals crystalline arrangements of atoms and molecules of specified proportions that make up rocks

missing matter the mass of the universe that cannot be accounted for but is necessary to produce a universe whose overall curvature is "flat"

monolithic massive, solid, and uniform; an asteroid that is formed of one kind of material fused or melted into a single mass

multi-bandgap photovoltaic photovoltaic cells designed to respond to several different wavelengths of electromagnetic radiation

multispectral referring to several different parts of the electromagnetic spectrum, such as visible, infrared, and radar

muons the decay product of the mesons produced by cosmic rays; muons are about 100 times more massive than electrons but are still considered leptons that do not respond to the strong nuclear force

near-Earth asteroids asteroids whose orbits cross the orbit of Earth; collisions between Earth and near Earth asteroids happen a few times every million years

nebulae clouds of interstellar gas and/or dust

neutron a subatomic particle with no electrical charge

neutron star the dense core of matter composed almost entirely of neutrons that remain after a supernova explosion has ended the life of a massive star

New Millennium a NASA program to identify, develop and validate key instrument and spacecraft technologies that can lower cost and increase performance of science missions in the twenty-first century

Next Generation Space Telescope the telescope scheduled to be launched in 2009 that will replace the Hubble Space Telescope

nuclear black holes black holes that are in the centers of galaxies; they range in mass from a thousand to a billion times the mass of the Sun

nuclear fusion the combining of low-mass atoms to create heavier ones; the heavier atom's mass is slightly less than the sum of the mass of its constituents, with the remaining mass converted to energy

nucleon a proton or a neutron; one of the two particles found in a nucleus

occultations a phenomena that occurs when one astronomical object passes in front of another

optical interferometry a branch of optical physics that uses the wavelength of visible light to measure very small changes within the environment

optical-interferometry based the use of two or more telescopes observing the same object at the same time at the same visible wavelength to increase angular resolution

optical radar a method of determining the speed of moving bodies by sending a pulse of light and measuring how long it takes for the reflected light to return to the sender

orbit the circular or elliptical path of an object around a much larger object, governed by the gravitational field of the larger object

orbital dynamics the mathematical study of the nature of the forces governing the movement of one object in the gravitational field of another object

orbital velocity velocity at which an object needs to travel so that its flight path matches the curve of the planet it is circling; approximately 8 kilometers (5 miles) per second for low-altitude orbit around Earth

orbiter spacecraft that uses engines and/or aerobraking, and is captured into circling a planet indefinitely

orthogonal composed of right angles or relating to right angles

oscillation energy that varies between alternate extremes with a definable period

osteoporosis the loss of bone density; can occur after extended stays in space

oxidizer a substance mixed with fuel to provide the oxygen needed for combustion

paleolake depression that shows geologic evidence of having contained a lake at some previous time

Paleozoic relating to the first appearance of animal life on Earth

parabolic trajectory trajectory followed by an object with velocity equal to escape velocity

parking orbit placing a spacecraft temporarily into Earth orbit, with the engines shut down, until it has been checked out or is in the correct location for the main burn that sends it away from Earth

payload any cargo launched aboard a rocket that is destined for space, including communications satellites or modules, supplies, equipment, and astronauts; does not include the vehicle used to move the cargo or the propellant that powers the vehicle

payload bay the area in the shuttle or other spacecraft designed to carry cargo

payload fairing structure surrounding a payload; it is designed to reduce drag

payload operations experiments or procedures involving cargo or "payload" carried into orbit

payload specialists scientists or engineers selected by a company or a government employer for their expertise in conducting a specific experiment or commercial venture on a space shuttle mission

perihelion the point in an object's orbit that is closest to the Sun

period of heavy meteoroid the earliest period in solar system history (more than 3.8 billion years ago) when the rate of meteoroid impact was very high compared to the present

perturbations term used in orbital mechanics to refer to changes in orbits due to "perturbing" forces, such as gravity

phased array a radar antenna design that allows rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

phased-array antennas radar antenna designs that allow rapid scanning of an area without the need to move the antenna; a computer controls the phase of each dipole in the antenna array

photolithography printing that uses a photographic process to create the printing plates

photometer instrument to measure intensity of light

photosynthesis a process performed by plants and algae whereby light is transformed into energy and sugars

photovoltaic pertaining to the direct generation of electricity from electromagnetic radiation (light)

photovoltaic arrays sets of solar panels grouped together in big sheets; these arrays collect light from the Sun and use it to make electricity to power the equipment and machines

photovoltaic cells cells consisting of a thin wafer of a semiconductor material that incorporates a p-n junction, which converts incident light into electrical power; a number of photovoltaic cells connected in series makes a solar array

plagioclase most common mineral of the light-colored lunar highlands

planetesimals objects in the early solar system that were the size of large asteroids or small moons, large enough to begin to gravitationally influence each other

pn single junction in a transistor or other solid state device, the boundary between the two different kinds of semiconductor material

point of presence an access point to the Internet with a unique Internet Protocol (IP) address; Internet service providers (ISP) like AOL generally have multiple POPs on the Internet

polar orbits orbits that carry a satellite over the poles of a planet

polarization state degree to which a beam of electromagnetic radiation has all of the vibrations in the same plane or direction

porous allowing the passage of a fluid or gas through holes or passages in the substance

power law energy spectrum spectrum in which the distribution of energies appears to follow a power law

primary the body (planet) about which a satellite orbits

primordial swamp warm, wet conditions postulated to have occurred early in Earth's history as life was beginning to develop

procurement the process of obtaining

progenitor star the star that existed before a dramatic change, such as a supernova, occurred

prograde having the same general sense of motion or rotation as the rest of the solar system, that is, counterclockwise as seen from above Earth's north pole

prominences inactive "clouds" of solar material held above the solar surface by magnetic fields

propagate to cause to move, to multiply, or to extend to a broader area

proton a positively charged subatomic particle

pseudoscience a system of theories that assumes the form of science but fails to give reproducible results under conditions of controlled experiments

pyroclastic pertaining to clastic (broken) rock material expelled from a volcanic vent

pyrotechnics fireworks display; the art of building fireworks

quantum foam the notion that there is a smallest distance scale at which space itself is not a continuous medium, but breaks up into a seething foam of wormholes and tiny black holes far smaller than a proton

quantum gravity an attempt to replace the inherently incompatible theories of quantum physics and Einstein gravity with some deeper theory that would have features of both, but be identical to neither

quantum physics branch of physics that uses quantum mechanics to explain physical systems

quantum vacuum consistent with the Heisenberg uncertainty principle, vacuum is not empty but is filled with zero-point energy and particle-antiparticle pairs constantly being created and then mutually annihilating each other

quasars luminous objects that appear star-like but are highly redshifted and radiate more energy than an entire ordinary galaxy; likely powered by black holes in the centers of distant galaxies

quiescent inactive

radar a technique for detecting distant objects by emitting a pulse of radio-wavelength radiation and then recording echoes of the pulse off the distant objects

radar altimetry using radar signals bounced off the surface of a planet to map its variations in elevation

radar images images made with radar illumination instead of visible light that show differences in radar brightness of the surface material or differences in brightness associated with surface slopes

radiation belts two wide bands of charged particles trapped in a planet's magnetic field

radio lobes active galaxies show two regions of radio emission above and below the plane of the galaxy, and are thought to originate from powerful jets being emitted from the accretion disk surrounding the massive black hole at the center of active galaxies

radiogenic isotope techniques use of the ratio between various isotopes produced by radioactive decay to determine age or place of origin of an object in geology, archaeology, and other areas

radioisotope a naturally or artificially produced radioactive isotope of an element

radioisotope thermoelectric device using solid state electronics and the heat produced by radioactive decay to generate electricity

range safety destruct systems system of procedures and equipment designed to safely abort a mission when a spacecraft malfunctions, and destroy the rocket in such a way as to create no risk of injury or property damage

Ranger series of spacecraft sent to the Moon to investigate lunar landing sites; designed to hard-land on the lunar surface after sending back television pictures of the lunar surface; Rangers 7, 8, and 9 (1964–1965) returned data

rarefaction decreased pressure and density in a material caused by the passage of a sound wave

reconnaissance a survey or preliminary exploration of a region of interest

reflex motion the orbital motion of one body, such as a star, in reaction to the gravitational tug of a second orbiting body, such as a planet

regolith upper few meters of a body's surface, composed of inorganic matter, such as unconsolidated rocks and fine soil

relative zero velocity two objects having the same speed and direction of movement, usually so that spacecraft can rendezvous

relativistic time dilation effect predicted by the theory of relativity that causes clocks on objects in strong gravitational fields or moving near the speed of light to run slower when viewed by a stationary observer

remote manipulator system a system, such as the external Canada2 arm on the International Space Station, designed to be operated from a remote location inside the space station

remote sensing the act of observing from orbit what may be seen or sensed below on Earth

retrograde having the opposite general sense of motion or rotation as the rest of the solar system, clockwise as seen from above Earth's north pole

reusable launch vehicles launch vehicles, such as the space shuttle, designed to be recovered and reused many times

reusables launches that can be used many times before discarding

rift valley a linear depression in the surface, several hundred to thousand kilometers long, along which part of the surface has been stretched, faulted, and dropped down along many normal faults

rille lava channels in regions of maria, typically beginning at a volcanic vent and extending downslope into a smooth mare surface

rocket vehicle or device that is especially designed to travel through space, and is propelled by one or more engines

"rocky" planets nickname given to inner or solid-surface planets of the solar system, including Mercury, Venus, Mars, and Earth

rover vehicle used to move about on a surface

rutile a red, brown, or black mineral, primarily titanium dioxide, used as a gemstone and also a commercially important ore of titanium

satellite any object launched by a rocket for the purpose of orbiting the Earth or another celestial body

scoria fragments of lava resembling cinders

secondary crater crater formed by the impact of blocks of rock blasted out of the initial crater formed by an asteroid or large meteorite

sedentary lifestyle a lifestyle characterized by little movement or exercise

sedimentation process of depositing sediments, which result in a thick accumulation of rock debris eroded from high areas and deposited in low areas

semiconductor one of the groups of elements with properties intermediate between the metals and nonmetals

semimajor axis one half of the major axis of an ellipse, equal to the average distance of a planet from the Sun

shepherding small satellites exerting their gravitational influence to cause or maintain structure in the rings of the outer planets

shield volcanoes volcanoes that form broad, low-relief cones, characterized by lava that flows freely

shielding providing protection for humans and electronic equipment from cosmic rays, energetic particles from the Sun, and other radioactive materials

sine wave a wave whose amplitude smoothly varies with time; a wave form that can be mathematically described by a sine function

smooth plains the youngest plains on Mercury with a relatively low impact crater abundance

soft-landers spacecraft that uses braking by engines or other techniques (e.g., parachutes, airbags) such that its landing is gentle enough that the spacecraft and its instruments are not damaged, and observations at the surface can be made

solar arrays groups of solar cells or other solar power collectors arranged to capture energy from the Sun and use it to generate electrical power

solar corona the thin outer atmosphere of the Sun that gradually transitions into the solar wind

solar flares explosions on the Sun that release bursts of electromagnetic radiation, such as light, ultraviolet waves, and X rays, along with high speed protons and other particles

solar nebula the cloud of gas and dust out of which the solar system formed

solar prominence cool material with temperatures typical of the solar photosphere or chromosphere suspended in the corona above the visible surface layers

solar radiation total energy of any wavelength and all charged particles emitted by the Sun

solar wind a continuous, but varying, stream of charged particles (mostly electrons and protons) generated by the Sun; it establishes and affects the interplanetary magnetic field; it also deforms the magnetic field about Earth and sends particles streaming toward Earth at its poles

sounding rocket a vehicle designed to fly straight up and then parachute back to Earth, usually designed to take measurements of the upper atmosphere

space station large orbital outpost equipped to support a human crew and designed to remain in orbit for an extended period; to date, only Earth-orbiting space stations have been launched

space-time in relativity, the four-dimensional space through which objects move and in which events happen

spacecraft bus the primary structure and subsystems of a spacecraft

spacewalking moving around outside a spaceship or space station, also known as extravehicular activity

special theory of relativity the fundamental idea of Einstein's theories, which demonstrated that measurements of certain physical quantities such as mass, length, and time depended on the relative motion of the object and observer

specific power amount of electric power generated by a solar cell per unit mass; for example watts per kilogram

spectra representations of the brightness of objects as a function of the wavelength of the emitted radiation

spectral lines the unique pattern of radiation at discrete wavelengths that many materials produce

spectrograph an instrument that can permanently record a spectra

spectrographic studies studies of the nature of matter and composition of substances by examining the light they emit

spectrometers an instrument with a scale for measuring the wavelength of light

spherules tiny glass spheres found in and among lunar rocks

spot beam technology narrow, pencil-like satellite beam that focuses highly radiated energy on a limited area of Earth's surface (about 100 to 500 miles in diameter) using steerable or directed antennas

stratigraphy the study of rock layers known as strata, especially the age and distribution of various kinds of sedimentary rocks

stratosphere a middle portion of a planet's atmosphere above the tropopause (the highest place where convection and "weather" occurs)

subduction the process by which one edge of a crustal plate is forced to move under another plate

sublimate to pass directly from a solid phase to a gas phase

suborbital trajectory the trajectory of a rocket or ballistic missile that has insufficient energy to reach orbit

subsolar point the point on a planet that receives direct rays from the Sun

substrate the surface, such as glass, metallic foil, or plastic sheet, on which a thin film of photovoltaic material is deposited

sunspots dark, cooler areas on the solar surface consisting of transient, concentrated magnetic fields

supercarbonaceous term given to P- and D-type meteorites that are richer in carbon than any other meteorites and are thought to come from the primitive asteroids in the outer part of the asteroid belt

supernova an explosion ending the life of a massive star

supernovae ejecta the mix of gas enriched by heavy metals that is launched into space by a supernova explosion

superstring theory the best candidate for a "theory of everything" unifying quantum mechanics and gravity, proposes that all particles are oscillations in tiny loops of matter only 10^{-35} meters long and moving in a space of ten dimensions

superstrings supersymmetric strings are tiny, one dimensional objects that are about 10^{-33} cm long, in a 10-dimensional spacetime. Their different vibration modes and shapes account for the elementary particles we see in our 4-dimensional spacetime

Surveyor a series of spacecraft designed to soft-land robotic laboratories to analyze and photograph the lunar surface; Surveyors 1, 3, and 5–7 landed between May 1966 and January 1968

synchrotron radiation the radiation from electrons moving at almost the speed of light inside giant magnetic accelerators of particles, called synchrotrons, either on Earth or in space

synthesis the act of combining different things so as to form new and different products or ideas

technology transfer the acquisition by one country or firm of the capability to develop a particular technology through its interactions with the existing technological capability of another country or firm, rather than through its own research efforts

tectonism process of deformation in a planetary surface as a result of geological forces acting on the crust; includes faulting, folding, uplift, and downwarping of the surface and crust

telescience the act of operation and monitoring of research equipment located in space by a scientist or engineer from their offices or laboratories on Earth

terrestrial planet a small rocky planet with high density orbiting close to the Sun; Mercury, Venus, Earth, and Mars

thermodynamically referring to the behavior of energy

thermostabilized designed to maintain a constant temperature

thrust fault a fault where the block on one side of the fault plane has been thrust up and over the opposite block by horizontal compressive forces

toxicological related to the study of the nature and effects on humans of poisons and the treatment of victims of poisoning

trajectories paths followed through space by missiles and spacecraft moving under the influence of gravity

transonic barrier the aerodynamic behavior of an aircraft moving near the speed of sound changes dramatically and, for early pioneers of transonic flight, dangerously, leading some to hypothesize there was a “sound barrier” where drag became infinite

transpiration process whereby water evaporates from the surface of leaves, allowing the plant to lose heat and to draw water up through the roots

transponder bandwidth-specific transmitter-receiver units

troctolite rock type composed of the minerals plagioclase and olivine, crystallized from magma

tunnelborer a mining machine designed to dig a tunnel using rotating cutting disks

Tycho event the impact of a large meteoroid into the lunar surface as recently as 100 million years ago, leaving a distinct set of bright rays across the lunar surface including a ray through the Apollo 17 landing site

ultramafic lavas dark, heavy lavas with a high percentage of magnesium and iron; usually found as boulders mixed in other lava rocks

ultraviolet the portion of the electromagnetic spectrum just beyond (having shorter wavelengths than) violet

ultraviolet radiation electromagnetic radiation with a shorter wavelength and higher energy than light

uncompressed density the lower density a planet would have if it did not have the force of gravity compressing it

Universal time current time in Greenwich, England, which is recognized as the standard time that Earth’s time zones are based

vacuum an environment where air and all other molecules and atoms of matter have been removed

vacuum conditions the almost complete lack of atmosphere found on the surface of the Moon and in space

Van Allen radiation belts two belts of high energy charged particles captured from the solar wind by Earth’s magnetic field

variable star a star whose light output varies over time

vector sum sum of two vector quantities taking both size and direction into consideration

velocity speed and direction of a moving object; a vector quantity

virtual-reality simulations a simulation used in training by pilots and astronauts to safely reproduce various conditions that can occur on board a real aircraft or spacecraft

visible spectrum the part of the electromagnetic spectrum with wavelengths between 400 nanometers and 700 nanometers; the part of the electromagnetic spectrum to which human eyes are sensitive

volatile ices (e.g., H_2O and CO_2) that are solids inside a comet nucleus but turn into gases when heated by sunlight

volatile materials materials that easily pass into the vapor phase when heated

wavelength the distance from crest to crest on a wave at an instant in time

X ray form of high-energy radiation just beyond the ultraviolet portion of the spectrum

X-ray diffraction analysis a method to determine the three-dimensional structure of molecules

Volume 1 Index

Page numbers in **boldface type** *indicate article titles; those in italic type indicate illustrations. A cumulative index, which combines the terms in all volumes of* Space Sciences, *can be found in volume 4 of this series.*

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