Chapter 5

U.S. CIVILIAN SPACE PROGRAM

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OUR DEPENDENCE ON SPACE

The extent to which the modern world in general and the United States in particular have become dependent on space technology is not generally appreciated. If the United States were to cease using space systems, day-to-day life and business activities throughout society would be disrupted. National security would be jeopardized as well. This section outlines the effects of doing without space, first in the civilian sector, then in the military sector. Tables 3 and 4 list the major U.S. space systems.

In the civilian sector, long-distance ***communications*** would be perhaps hardest hit. Already over two-thirds of all overseas telephone traffic is carried over satellite links provided by the International Telecommunications Satellite Organization (INTELSAT) system. Not only would private citizens be unable to complete many of their calls, but the rates for those calls completed would have to rise in order to provide enough capital to lay additional transatlantic cable to replace the capacity lost from satellite circuits.

News reporting all over the world would be severely restricted and delayed. Global television reporting would be out of the question, so that news from the international wire services would be restricted to stories and photographs that could be taped or transmitted as they were before the space age, through uncertain and congested ground links or via private courier. Newspaper editors in the United States would be left in the same quandary as their television counterparts, especially in receiving news from remoter regions such as the Middle East, South Africa, and Southeast Asia.

Domestic television service of the major networks would be severely curtailed, not only to relatively remote locations such as Alaska and Hawaii, but even within the continental United States, About two-thirds of all cable television service would be shut down, for much of both the basic-service national programing as well as premium pay-television programing is transmitted to cable television systems across the Nation via

Table 3.—U.S. Government Civilian Satellite Systems

Program	Orbit	Purpose
GOES *(2)*	Geosynchronous	**Meteorological**
NOAA (3)	Geosynchronous	**Meteorological**
TDRSS (first launch early 1983)	Geosynchronous	**Communications relay from other satellites to ground**
HEAO (High Energy Astronomy Observatory)	LEO	**Scientific**
NIMBUS	Polar	**Meteorological**
TIROS	Polar	**Meteorological**
Landsat-3	Polar	**Earth observation**
Landsat-D (mid 1982)	Polar	
DE (2)	(1) Elliptical	**Electromagnetic field observation,** space science
(Dynamics Explorer)	(1) LEO	Scientific
SBS (3)	Geosynchronous	Communication data, voice, video
RCA (4)	Geosynchronous	Communication data, voice, video
Comstar (4)	Geosynchronous	Communication (COMSAT) data, voice, video
Westar (3)	Geosynchronous	Communication (Western Union) data, voice, video
AT&T (2)	Geosynchronous	Communication data, voice, video
Marisat (3)	Geosynchronous	Marine Communication (COMSAT) data & voice

SOURCE: Office of Technology Assessment.

Table 4.—U.S. Military Satellite Systems

Program	Satellites	Functions
Defense Satellite Communications System II (DSCS 11)	**4 active** **2 dormant spares**	**High capacity super high frequency communications. Part of Worldwide Military Command** and Control System (WWMCCS).
Satellite Data System (SDS)	3	Carries AFSATCOM transponders.
Air Force Satellite Communications System (A FSATCOM)	Radio transponders carrod on SDS, FLTSATCOM (other satellites?)	UHF communications among National Command Authority, Joint Chiefs. Military Commanders in Chief, and nuclear capable forces.
Fleet Satellite Communications (FLTSATCOM)	3	UHF and separate SHF uplink. Naval Communications System operates over U.S. Atlantic Ocean, Indian Ocean, Contains some jam-resistant 5-KHz channels for AFSATCOM, 1,500-KHz channel for Presidential support for network of regional commands.
Defense Support Program (DSP)	3	Early warning of ICBM, SLBM launches by infrared detection of rocket plumes. Also carries visible light detectors and radiation sensors for detecting nuclear explosions. Provides surveillance of missile test launches.
Photographic Reconnaissance	2 types	Area-search and close-look remote sensing.
Electronic (Signals) Intelligence	At least 5 launches since 1973	
Geodetic Satellite	6	Photographic mapping in three dimensions. Radar altimeter for topographical mapping of land and seacoasts.
Defense Meteorological	2 block 5D spacecraft	Visual and infrared images satellite programs (most recent launch weather conditions, global failed) coverage four times a day.
Navy Navigation Satellite System	TRANSIT (5 operating?) NOVA	Measurement in Doppler shift of radio emissions from satellites permits ship and aircraft navigators to find position.
Global Positioning System (GPS)	6 NAVSTAR (18 now planned)	Precisely timed radio beacons will allow users to determine position in three dimensions to within 10 m velocity to O.lm/sec.
Integrated Operational Nuclear Detection System (IONDS)	Aboard GPS, beginning with NAVSTAR 5	Detect and monitor nuclear explosions worldwide using bhangmeter sensors and GPS location data.
Space Detection and Tracking System	Ground-based cameras, radar, and radio receivers	Data funneled into Aerospace Defense Command Space Defense Operations Center, Colorado Springs, Colo. Identification and tracking of objects in space.

SOURCE: Office of Technology Assessment.

communications satellite transponders, Future plans for a variety of direct broadcast satellite television and information programs to private homes and businesses would be canceled.

Several less obvious services would no longer be possible. ***Weather reporting*** would be severely hampered; no synoptic view of large portions of the Earth from either polar orbits or from geosynchronous orbit would be available. These services are especially necessary for viewing the development of large weather patterns over the ocean several hundred miles off shore. Meteorologists would have to rely once again on piecing together fragments of weather observations from observation ships, radiosonde balloons, buoys, and light aircraft. Furthermore, observations of long-term changes in the ocean, atmosphere and polar ice would no longer be readily available. Without them, we could not predict long-term trends as well as we do now.

Navigation services would be significantly curtailed. Already more than 1,000 ships rely on satellite transmissions to ascertain their positions with great accuracy. Similar services soon to be made available for use in remote land regions would no longer be possible. Ship-to-shore and ship-to-ship communications via the global maritime satellite communications system (MARISAT) would be dangerously reduced; the task of the Navy, Coast Guard, and commercial ships on search-and-rescue missions would therefore be even more difficult. The International Maritime Satellite Organization (I NMARSAT) would have no raison d'être.

Satellite ***remote-sensing services,*** which have been important for the Departments of Agriculture, Commerce, and Interior, would be eliminated. No longer would satellite sensors be available to improve the management of the Nation's agriculture, forest, range, land and water resources—or to monitor large-scale catastrophic events such as the eruption of Mount St. Helens. Worldwide crop forecasting, an essential service for the U.S. agricultural sector, would be made much more difficult, nor would the United States be able to help developing countries to inventory and manage their own resources.

No longer would satellites be available for gathering data for studying the movement of air masses and the transformation of pollutants in the lower atmosphere. Similarly, of longer term concern, it would no longer be possible to monitor the chemistry, radiation exchange, and dynamics of the upper atmosphere in order to predict the long-term effects of human activities on these regions. Therefore, it might not be possible to know until too late whether man-made chemicals will continue to reduce the amount of ozone in the ozone layer, and what ill effects such a reduction might have on human life in this generation and the next.

The NIMBUS weather satellites of the National Oceanographic and Atmospheric Administration (NOAA) with their coastal-zone color scanners, would no longer observe the colors of the oceans over vast areas—revealing the murky green regions rich in plankton that are feeding grounds for schools of fish. Without this information, fishing fleets would expend 10 to 20 percent more marine fuel to locate their catches, and would pass along that increase in cost to the consumer as a higher price for seafood.

The search for new sources of minerals and energy resources would be curtailed; sensors under development, such as improved magnetometers or the multilineal array would not be sent into orbit. Without the data they promise to return, the ability to search for resources of long-range strategic importance, such as cobalt, titanium, and petroleum would be hindered.

Not only would all these applications become impossible, but many parts of ***space science*** would cease. No longer would spacecraft be launched into orbit to study the activity of the Sun or to observe the atmosphere and surface of the planets. In the absence of orbiting sensors and telescopes above the atmosphere to investigate radiation at wavelengths unattainable on Earth, ultraviolet, X-rays, gamma rays, cosmic rays, future understanding of the structure and evolution of the universe would be severely limited.

Meanwhile, in the ***military*** sector, many systems on which we rely for national security and for which adequate substitutes do not exist would be lost. Perhaps the most dangerous loss would be the capability to monitor the military activities of potential enemies. Surveillance satellites, which monitor the ground with high resolution at visible and infrared wavelengths, with synthetic-aperature radar, and by electronic "ferret" listening devices, are essential to ensure that foreign countries observe the terms of arms control treaties and to provide early warning of a nuclear attack. Military and diplomatic communications abroad and at sea would be slower, less reliable and less secure. There would be less ready access to high-speed instant communications between ground stations, field commanders, ships, submarines and long-range strategic bombers. Navigation and global positioning for military units would be deprived of the high degree of precision available through the use of positional satellite systems.

The way in which our society does business would be seriously affected by the loss of space. Not only would the availability of space services be cut off, but the revenue from those services would cease to flow. Perhaps hardest hit would be corporations in the communications business. Many of the major cable television operators would suffer, since their principal revenue flows from satellite-carried pay-television programmers such as Home Box Office, Showtime, and a dozen others. Furthermore, the loss of commercially sponsored "basic" cable programing beamed from satellite transponders would cause advertisers to cancel their commercials and withdraw their support-resulting in the bankruptcy of a number of programing sources. Western Union with its WESTAR satellites, RCA with its SATCOM satellites, would feel similar blows, although the impact would be somewhat lessened since the parent companies are diversified. Still, those employees directly connected with those companies' space segments—plus companies such as the Communications Satellite Corporation (COMSAT) whose entire business was related to space—would find themselves either idled or in desperate straits.

A final but important result of the dependence on space systems is that a large number of jobs and business opportunities would be lost if space activities ceased. Not only would future entrepreneurial activities in such areas as materials processing be cut off at the outset, the disappearance of space science as an existing discipline would wash up into the halls of major contracting centers such as the Jet Propulsion Laboratory in Pasadena, Calif., and in major universities heavily committed to space investigation (some 10 to 20). With the dissolution of the civilian space activities of the National Aeronautics and Space Administration (NASA), agreements with some 100 prime contractors would be canceled–forcing those contractors to cancel orders from subcontractors for specialized components. Since approximately two-thirds of the U.S. civilian space budget is awarded each year to private contractors, as those commitments disappeared some 50,000 jobs with contractors related to space would also disappear—undoubtedly adding a bit more burden to the unemployment rolls. Furthermore, those companies affected would probably retrench a bit on corporate advertising in various trade and lay publications. That loss in advertising revenue would cause a number of the heavily space-oriented publications to reduce the number of editorial pages in each issue and to perhaps contract their staffs.

Although many workers connected with space activities would probably find other employment (a good number in military and civilian high technology), an important infrastructure of expertise and experience would be lost. The future U.S. position in many areas of advanced technology would also be jeopardized—e.g., sensors, data analysis, precision control systems. in addition, through losing the extension of our society's collective eyes and ears throughout the solar system, and losing the heartpounding excitement of sharing an astronaut's launch and experiments in orbit, the United States would lose an important aspect of its shared national experience—the sense of adventure, confidence, self-esteem and world leadership provided by pursuing and ***succeeding*** at space activities over the past 25 years.

The conclusion of imagining what life in the United States would be like without space systerns is that it would certainly be very different and in many respects poorer. The extent of our present uses of space systems and the increasing promise of future uses of space technology argue that our dependence on space is great and will increase.

CURRENT STATUS AND PLANNED FUTURE ACTIVITIES

This section reviews the civilian space activities of the United States in Government, industry, and academia, and the direction those activities are likely to take in the near future (through 1990). Department of Defense (DOD) space activities are not treated in detail in this report except as they directly relate to the civilian program. Table 5 offers a glimpse of the generic space flight activities and spacecraft that have comprised the U.S. civilian program. Table 6 shows NASA's flight programs for the future.

Applications

Communications

Broadly speaking, satellite communications comprises point-to-point message, data, and video transmissions. It includes broadcasting from one point to many, distributed over relatively large areas; position-location activities such as navigation, traffic control, and search and rescue; and transmissions to, from, and among mobile transmitters and receivers (e.g., aircraft, ships, motor vehicles).

In the civilian sector, point-to-point satellite communications has been a commercial activity since the Communications Satellite Act of 1962 established COMSAT and designated it to represent U.S. interests in international, commercial satellite communication. The Federal Communications Commission (FCC) "Open Skies" decision in 1970 opened domestic satellite communications services to competition among commercial entities. Today (early 1982) there are four

Table 5.—Selected Groups of Civilian Spacecraft Launched by NASA From 1950 to 1980

Purpose	Spacecraft names	Sponsor (if not NASA)	Launches Number successful/total	Years
Astrophysics	Explorer, Orbiting Observatories		*60/74*	1961-80
Planetary	Pioneer, Mariner, Viking, Voyager		*20/24*	1962-78
Communicaions—R&D	Echo, Relay, Syncom, ATS,		**13/16**	**1960-74**
operational	Intelsat, Westar, etc.	Commercial	**39/43**	**1962-80**
Meteorology—R&D	**TIROS, Nimbus, SMS (1)**		*22/24*	1959-78
operational	**ITOS, GOES, NOAA(2)**	**NOAA**	*19/22*	1966-80
Geodesy	**Explorer, PAGEOS, GEOS, LAGEOS (3)**		*717*	1964-76
Terrestrial	**ERTS, Landsat**		*3/3*	1972-78
Oceanography	**Seasat (4)**		1/1	1978

(l), (2), (3) **Also benefit oceanography:**

Spacecraft	Sensor
(1) TIROS-N	DCS, IR
NIMBUS-5	MR
NIMBUS-6	DCS, MR
NIMBUS-7	CS, MR
SMS	DCS

(2)	**GOES series**	**DCS**
	NOAA series	**DCS, IR**
(3)	GEOS-3	ALT

(4) Seasat sensor complement:
ALT, IR, MR, SAR, SCAT

Sensor key:
ALT . . . . Altimeter
Cs . . . . **Color scanner**
DCS. . . . . . . Data collection system
IR . . . . Infrared radiometer
MR. . . . . Microwave radiometer
SAR. . . . . . . Synthetic aperture radar
SCAT. . . . . . Scatterometer

SOURCE: National Aeronautics and Space Administration.

Table 6.—Selected Groups of Potential Future NASA Spacecraft

Purpose	Spacecraft names	Acronym	Earliest launch
Astrophysics	● 8 explorer-class satellites		1981-87
	● Space telescope		1985
	Origin of plasmas in Earth's neighborhood	OPEN	1987
	Gamma Ray Observatory	GRO	1988
	Advanced X-ray Astrophysics Facility	AXAF	1989
Planetary	● Galileo (Jupiter)		1985
	Halley Comet Flyby		1985
	Venus orbiting imaging radar	VOIR	1988
Communications–R&D	30/20 GHZ		1987
Meteorology—R&D	● Earth radiation budget experiment	ERBE	1984
	Upper atmospheric research satellite	UARS	1988
	NOAA next and GOES next		1989, 1990
Geodesy	Gravity Satellite (1)	GRAVSAT	1987
Terrestrial	● Landsat D & D'		1982, 1983
Oceanography	Topography experiment	TOPEX	1987
	Free-flying imaging radar experiment (2)	FIREX	1988

● These are the only spacecraft currently under development.

(1) Also benefits oceanography.
(2) Also benefits terrestrial.

separate domestic systems in orbit, with a total of 10 satellites, providing voice, data, video, and networking distribution services to a variety of clients: 1) the Comstar system of COMSAT General provides services to the American Telephone and Telegraph Co. (AT&T) and the General Telephone and Electronics Corp.; 2) the RCA American Communications system furnishes point-to-point and video network distribution services to private customers as well as to cable and terrestrial broadcasting systems; 3) Western Union's WESTAR supplies point-to-point services to private customers and video and radio network distribution services to the Public Broadcasting Service and National Public Radio; and 4) Satellite Business Systems (SBS) provides data transmission services to industrial organizations. In addition, several other firms, among them Fairchild Industries' American Satellite Co., Southern Pacific Communications, and Xerox Corp. 's XTEN, supply specialized communication services through transponders leased from satellite-owning corporations. Other firms, not in the business of transmission, lease satellite data or voice channels directly from members of other sets of carriers.

In addition, COMSAT General owns and operates the MARISAT system, providing message and data transmission services to ships at sea. Until 1973, COMSAT also managed the INTELSAT system, a global, commercial satellite communications system providing voice, data, and video transmission services to 103 countries. As manager for INTELSAT, COMSAT specified, procured, arranged for launch, and controlled satellites in the INTELSAT system. Under the definitive arrangements, entered into force in 1973, most of these functions have been taken over by the Director General of INTELSAT, assisted by an international staff, though COMSAT retains some responsibilities. Domestic carriers perform these functions themselves for their own satellites. NASA provides launches and launch services for all corporations under reimbursable contract arrangements.

Technology

Most communications satellites are placed in geostationary satellite orbit (GSO), a circular orbit the center of which coincides with the Earth's center, and which lies in the plane of the Earth's Equator. It has a radius of some 42,200 km, which corresponds to an altitude of some 35,800 km above the Equator. On the GSO, a satellite moves around the polar axis with the same period and in the same sense as does the Earth: as a result, the satellite, if visible, would appear from the Earth to be stationed at a fixed point in the sky.

Because its celestial latitude is fixed at 0°, a GSO satellite's position is defined by its longitude.

The definition of the GSO given above is theoretical because several natural forces perturb the orbit of the spacecraft. A satellite placed in GSO and then left unattended will suffer changes both in its longitude and in its latitude, Seen from the ground, these changes become alterations in the elevation and azimuth angle of the satellite. In order to keep the satellite in GSO, it is necessary to resort to artificial, "stationkeeping devices. " At present, stationkeeping is considered adequately accurate if the satellite is maintained within a range of &/–O. 10 in both longitude and latitude. Because of the remaining motions of the satellite, GSO is not actually a circle, but rather a narrow torus with dimensions corresponding to some 150 km of north-south variation and 30 km of altitude variation.

GSO belongs to a broader family of orbits called geosynchronous; these orbits are generally inclined with respect to the equatorial plane, they may be circular or elliptical, but satellites move on them with the same period, and with the same sense of rotation, as the Earth. Geosynchronous satellites are seen from the ground to describe figures of 24-hour periods and varying shapes.[1]

Commercial communications satellites (except for some early U.S. experiments and some developed by the U .S. S. R.) lie in GSO. The reason for this choice is that advantages of GSO far outweigh its disadvantages. The advantages are as follows:[2]

- The satellite remains essentially stationary relative to look angle of the Earth station antennas; the cost of computer-controlled tracking of the satellite can be avoided. A fixed antenna (with provision for manual adjustment) will suffice.
- There is no need to switch from one satellite to another as one disappears over the horizon.
- Because the radius of GSO is so large, a GSO satellite is in line-of-sight from 42.4 percent of the Earth's surface (or 38 percent, if angles of elevation below 50 are not used). A large number of Earth stations may thus intercommunicate.
- Three communications satellites can provide coverage of 90 percent of the globe; only the polar regions cannot be reached.

The disadvantages of GSO satellites are:[3]

- Latitudes greater than 81 .25° north and south (or 77o, if angles of elevation below 5° are excluded) are not covered.
- Because of the distance of the satellite, the received signal power, which diminishes inversely as the square of the distance, is weak, and the signal propagation delay is 270 milliseconds. To minimize the effects of this time delay and the associated effects of echo, which are problems both in voice conversations and in error correction equipment used with high-speed data circuits, echo suppressors and echo chancellors have been developed.

For a given position of GSO, there is a definite area on the surface of the Earth within which all points can effectively intercommunicate with a satellite in that given position, the so-called service zone. In order to cover a maximal service zone, positions for the satellite are severely limited. Satellites intended for intercontinental, or generally, global service must by necessity have priority for certain orbital longitude slots, once the service zone has been defined. (This comment applies not only to telecommunication services, but also to the observation zone in cases of meteorological or Earth observation missions.) On the other hand, satellites that service or observe a relatively small area of the Earth's surface can generally be positioned with greater flexibility, the more so the lower the mean latitude of the served areas. However, small service areas that extend to higher latitudes will also be limited in their satellite positions because of the limited visibility of the GSO from high latitudes.

As a result of these various constraints imposed on the positions of GSO satellites, with radiofrequency constraints not yet considered, the GSO is not, and probably will never be, populated with

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[1] International Aeronautical Federation, ' 'On the Efficient Use of the Geostationary Orbit, " 1980, p. 8.

[2] James Martin, *Communications Satellites,* p. 45.

Ibid., p. 45.

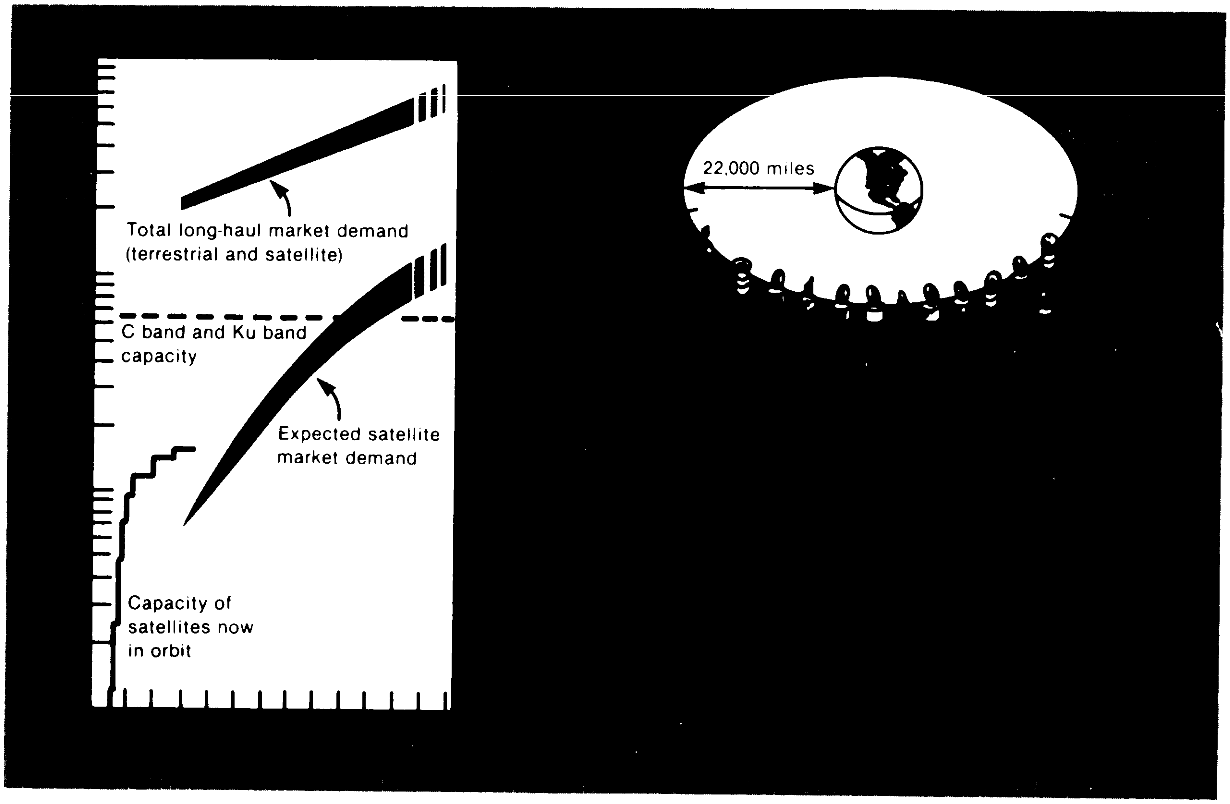
a uniform density of satellites. It follows that congestion in desirable arcs of the GSO will proceed more rapidly as demand for service grows than was initially envisioned by the regulatory agencies (fig. 1).

Radiofrequency allocations and GSO positions are controlled by the International Telecommunications Union (ITU). ITU is responsible for the maintenance of international cooperation in communications and it assigns operating frequencies and GSO slots to satellite communications systems.

With the early satellites, the enormous distances involved, the limited channel capacity, and the limited power available to the transponders–transmitter-and-receiver pairs on the spacecraft-dictated that Earth stations use powerful transmitters, very large antennas, and sensitive receivers. Those requirements generally still hold true, but contemporary commercial communications satellites carry a dozen or more transponders, each capable of relaying as many as 600 voice channels. Wide-band signals are beamed to the satellite from an Earth station on an assigned up-link (Earth-to-space) frequency; the satellite receives the signals and retransmits them on a down-link (space-to-Earth) frequency to an Earth station that may be thousands of kilometers away from the transmitting Earth station. By convention, to describe the band used by a particular satellite, the up-link frequency is given, followed by the down-link frequency (e.g., 6/4 GHz).

Satellites must be sufficiently separated to avoid radio interference. The required separation between satellites depends on several factors, including the beamwidths of satellite and Earth-station antennas, the side-lobe performance of Earth-station antennas, the modulation technique employed, and the carrier frequency of the trans-

figure 1 .—The Communications Problem



SOURCE: National Aeronautics and Space Administration.

missions. Currently, a 30 separation of spacecraft operating in the 6/4 GHz band is required. In any case, only a limited number of spacecraft can be accommodated in a given arc of geostationary orbit.

Current commercial communications satellites operate primarily in two bands of the microwave region of the radio spectrum, the 6/4 and the 14/1 2 GHz bands (or, the C and the Ku bands, respectively), well above the band used for ultra high frequency (UHF) television broadcasting. At these frequencies, signals are propagated in straight lines, requiring the satellite to be within line-of-sight of Earth stations. The very narrow beam widths require that the ground and satellite antennas be alined precisely, within a fraction of a minute of arc.

As use of the 14/12 band is still in its early stages, nearly all commercially operated communications satellites operate in the 6/4 band. Because this band is shared with heavily congested microwave relay systems, collocating an Earth station poses the problem of finding an interference-free location. There are few such locations around large population centers, which have the greatest need for communications services. Moreover, relatively large antennas and costly Earth stations are required to provide high-density telephone-type traffic. Once the allocated band is filled, further increases in satellite capacity can be achieved only by reuse of the available frequency spectrum. Reuse is possible both by reducing the down-link beam width and by increasing the satellite antenna gain so that different beams cover different service areas.

Capacity can be further increased by polarization diversity. A vertically polarized beam can be transmitted along with a horizontally polarized beam of the same frequency, and the two can be detected and received separately. Polarization diversity occurs when two beams with identical or overlapping frequency bands are orthogonally polarized. Receivers are designed to respond to only one polarization, so that the same frequency band can be used twice within the same coverage area—i.e., using two polarized beams in the same frequency range doubles the amount of information that can be sent with that bandwidth.

From 1980 to 1990, increasing demand for North American satellite circuits will outstrip the available capacity of the geostationary orbit for 6/4 GHz systems, even with the application of frequency reuse techniques. In addition, the difficulty of locating Earth stations in and near the communication sources in population centers will accelerate the use of the higher frequency bands. To meet these projected demands, additional satellites will become operational in the 14/1 2 GHz bands. Because there is no sharing of these frequencies in the United States with the terrestrial radio relay service, Earth stations could be located directly in cities. Recent research (the CTS experiment) has indicated that 3-m ground antennas are adequate for J 4/12 reception. Techniques such as increased satellite transmitter power, higher antenna gain, and spot beam spacecraft antennas must compensate for this use of smaller ground antennas and the occasional rain attenuation in the higher frequency bands (discussed below). A disadvantage of spot beam antennas is that the area they can serve is reduced. Thus, multiple spot beams must be provided, and satellite transmitter power increased to cover the same total area as before.

A constraint on operations in the 14/12 GHz band is that signals transmitted from the satellite to Earth can suffer significant attenuation during periods of intense rainfall (a problem that will be worse at 30/20 GHz, the Ka band). Measurements and analysis.have been made of the effects of this attenuation on satellite signal propagation. Satellite systems using this band must have high power levels (a factor that increases their cost), rely on paired Earth stations geographically separated ("diversity"), or have some other form of backup, if all ground locations require that service be available nearly 100 percent of the time. However, for many commercial applications, rain outages can be tolerated.

An important factor in satellite communication in the 1980's will be the use of the space shuttle for many launches. The shuttle will facilitate the introduction of physically larger, more powerful satellites with increased capabilities. However, to achieve synchronous orbit, expendable rockets to boost payloads from low-Earth orbit (LEO) will also be needed. In addition, so-called large plat-

forms may be assembled in LEO, where their components have been transported on two or more shuttle flights, and then raised to GSO with an expendable upper stage. Frequency reuse techniques will be common on next generation satellites, providing a further significant increase in total available capacity. Future satellites will also have increased sensitivity in up-link reception, increased effective down-link power, and reduced susceptibility to interference from signals associated with adjacent satellites in geostationary orbit.

Except for AT&T's LEO TELSTAR, flown in 1962, the basic research, development, and demonstration (RD&D) establishing the practicality of satellite communications was done by NASA, with substantial industrial involvement. RD&D for direct broadcast satellites, including early attempts to develop market constituencies, was also done by NASA. From 1973, when its satellite communications research and development (R&D) activities were curtailed on the assumption that the private sector would continue the R&D, until 1980, NASA did not pursue such activities vigorously except for completing the direct broadcast satellite programs of ATS-6 and, in conjunction with the Canadians, CTS.

New Programs

In 1980, because of growing concern over the perceived loss of a technological lead in communications satellites, NASA reactivated its R&D program at 30/20 GHz. This work is directed toward wideband transponder capability intended to explore the allocated but unoccupied bands at 30/20 GHz. Technologies under development include onboard switching, solid state transmitters, switched, multiple-beam antennas, and low-noise receivers for satellite use. NASA hopes to demonstrate the new band technologies in orbit on a new satellite, to be developed for a 1986 launch. The system concept is based on traffic projections developed for NASA by two

Photo credit: *National Aeronautics and Space Administration*

Satellite frequencies

satellite communications carriers, COMSAT and American Satellite Co. NASA is also developing adaptive, multibeam antenna technology at L-band, the band in use for maritime (and aeronautical) satellite communications use.

While NASA pursues a program currently dominated by R&D at 30/20 GHz, commercial entities are expanding their channel capacities in lower frequency bands at 6/4 GHz and 14/12 GHz. SBS'S launch in the fall of 1980 marks the first U.S. commercial satellite use of the 14/12 GHz band (Ku band). Canada's ANIK-B and-C were the first domestic satellites to exploit that band, predating SBS by 2 years or more. INTELSAT-V, launched in late-l 980, is carrying traffic at both 6/4 and 14/12 GHz. Commercial carriers' plans for future satellites through the 199o's continue to concentrate on these bands, using multiple-beam antenna technologies and the frequency reuse technologies first developed in the late 1970's and continuing in development today. Multiple-beam antenna technologies refer to the use of a single antenna to send and receive more than one frequency signal. Frequency reuse technologies refer to the ability to handle the same frequency in different modes, thereby increasing capacity without increasing spectrum use.

Continuing advances in technology, many of them by industry in the late **1970's** as markets for 12 GHz Earth stations became viable, have made it possible for commercial carriers to provide many of the services initially demonstrated on ATS-6 by NASA under the classification "community broadcasting. " Cable program distribution, interactive services such as multipoint teleconferencing, educational broadcasting, and remote health-care services are now being provided by the commercial carriers. These services, together with the traditional point-to-point services, are carried on first generation satellites operating at 6/4 GHz.

Advances in bandwidth compression and frequency reuse technologies appear, for perhaps the next decade, to allow first generation satellites to keep pace with traffic projections. Second generation satellites such an INTELSAT-V and Advanced WESTAR, which will start flying in the nexts years, include increased capacity sufficient to accommodate traffic projections by using new technologies such as switchable, multiple-beam antennas, onboard switching and signal processing, and frequency reuse capabilities at frequencies of 6/4, 14/1 1, and 14/12 GHz. These will require developing large, possibly deployable space structures, distributed, solid state transmitters and low-noise receivers, precise and possibly adaptive phase control, and attitude stabilization in the presence of solar-array or antenna-structure motions.

Except for the 9-m deployable antenna of NASA's ATS-6, DOD (on the Defense Satellite Communications System, Phase Ill) and the commercial sector (I NTELSAT-V, Advanced WESTAR) have the lead in multiple, switched-beam antennas and in somewhat larger, deployable antenna structures. ATS-6 included, these spacecraft types are the first so-called orbiting antenna farms, carrying capability for multiband, multibeam communications services. As future traffic projections indicate a limitation of capacity, plans for the first satellite generation of the 1990's could be expected to include 30/20 GHz frequencies in addition to 6/4, 14/1 1, and 14/12 GHz. The trend will be toward fewer, larger satellites carrying more bands, more beams, and more diverse services. These satellites will incorporate some of the space construction techniques developed during the 1980's.

Commercial sector hardware is provided by industrial firms, many of them Japanese, French, German, and Italian. As part of its reactivated program, NASA will conduct R&D in advanced technologies for low-cost Earth stations. The results of this R&D, which also involves industrial firms, are intended for transfer to the private sector. NASA's customary applications experiment-demonstration activities with its ATS satellite series have been transferred to the National Telecommunications and Information Administration (NTIA) in the Department of Commerce, together with responsibility for stimulating new applications experiments and demonstrations and for aggregating future markets.

Tracking and Data Relay Satellite System

Advanced WESTAR is a variation of the Tracking and Data Relay Satellite System (TDRSS) being leased by NASA from Space Communications Co. TDRSS comprises two satellites in synchronous orbit, controlled from a master station at White Sands, N. Mex., and used to track and relay data from LEO satellites to the ground. it will replace much of NASA's terrestrial Space Tracking and Data Network (STDN) and will increase the potential for continuous coverage of other, LEO satellites. For the lowest-altitude orbits, coverage will increase from about 15 to 85 percent, providing a great improvement in timely data acquisition for NASA experimental and NOAA operations. This capability will greatly reduce the need for costly and unreliable satellite data recorders. While Advanced WESTAR carries 6/4, 14/11, and 14/1 2 GHz capability, TDRSS also carries capability in the space research bands at 1.7/1 .8, and 2.0/2.3 GHz. Both spacecraft use the same basic structure, including deployable antennas for some of the three or four bands they carry. The first TDRSS launch is planned for the shuttle in early 1983, the second 6 months later. Two Advanced WESTARs will be launched in 1984; one will be dedicated to commercial service and the other will serve as a shared spare between NASA and Space Communications Co.

Navigation

Most of the U.S. work on navigation has been done by DOD. The Navy navigation satellite system transmissions have been made available to the public for the cost of the receiver and position-fixing computer equipment. Position can be fixed to an accuracy of 50 ft if processing time is long enough (up to 12 hours). Such performance is suitable for ships but not for aircraft, whose positions change too rapidly.

Work by NASA and the European Space Research Organization in 1969-70 had defined a system (Aerosat) that could work for aircraft. Capable of handling 500 aircraft simultaneously, it was also of interest for air traffic control. Responsibility for Aerosat was transferred to the Federal Aviation Administration (FAA) early in 1971. in 1973, work on it was terminated.

NASA has continued to pursue studies in search and rescue, but not in navigation or traffic control, based on special receivers attached to NOAA meteorological satellites to detect signals of distress beacons carried by aircraft and ships. NASA is pursuing this experimental work cooperatively with DOD, the Department of Transportation, and with Canada, France, and the U.S.S.R. The United States is providing the spacecraft, launch vehicles, and the U.S. ground stations; Canada is providing the space telecommunications equipment and ground station in their country; and, France is providing an onboard processor and receiver. The Soviet Union will launch and maintain in orbit two spacecraft operationally compatible with the U. S., Canadian, and French system and will operate their own ground station. in addition to NASA, DOD, and the Department of Transportation are expected to purchase and operate ground stations and participate in the program test and evaluation phase while NOAA is providing the spacecraft for modification.

Satellite Remote Sensing

Remote sensing from satellites is one important component of the general field of detecting, recognizing, and evaluating objects from a distance by means of advanced electro-optical instruments with cybernetic interpretation. Radar, sonar, astronomical and aerial photography are all forms of remote sensing. Satellite remote sensing is used in conjunction with aerial photography and aerial radar scanning to assess and help to control the productivity of the surface of the Earth, to help locate subsurface resources, and to understand, forecast, and, eventually, help control the environment.

Satellite remote sensing will be discussed in this section under the following three categories: 1) ocean sensing; 2) Earth resources sensing; and 3) environmental sensing. Listed in this order, they lead from an area with no current operational systems to an area that has had operational space systems for 14 years.

Ocean Sensing

This is the newest, least developed of satellite remote-sensing efforts. NASA, NOAA, DOD and the oceanographic science community all recognize the tremendous potential that satellites have for the study of the world's oceans. Gathering ocean data from satellites may be the only reasonable way to observe ocean processes routinely and continuously. Currently, there are no existing or planned U.S. civilian operational ocean-sensing satellite systems.

NASA's SEASAT, which was flown in 1978 and failed prematurely after 6 months, was a satellite demonstration to show what an operational ocean-sensing system could do. Each of SEASAT's complement of sensors had been flown before but never together on a civilian, ocean-oriented spacecraft.

Along with SEASAT, NIMBUS, and the Geodynamic Experimental Ocean Satellite (GEOS) data have been used in ocean studies. NIMBUS is classed as an experimental weather/climate spacecraft; GEOS was primarily to study ocean waves. The data these satellites supply consist primarily of global wind fields, sea states, surface temperature, ice coverage, and ocean color.

SEASAT data have demonstrated that scatterometer observations enable space mapping of the detailed structure of the ocean surface wind fields, including atmospheric fronts and typhoons. Altimeter observations enable mapping of surface waves and circulation features such as the Gulf Stream and mesoscale eddies. Microwave radiometer observations enable mapping of the characteristics of sea ice. Color scanner observations enable mapping of chlorophyll concentration. Taken collectively, these observations will help enable the determination of the general circulation of the ocean—both the wind-driven and geostrophic components—along with sea ice coverage and primary biological productivity in the oceans.

Applications of ocean sensing divide into two classes—operational and scientific. NOAA uses the data from the experiments to support its operational responsibilities that include: the management and conservation of marine resources; the preservation, conservation, and development of U.S. coastal resources; the prediction of weather; and, the provision of maps, charts, surveys, and other specialized data for navigation. Ocean sensing from space is expected to contribute to safety, to improve the efficiency of weather forecasting, and to reduce the cost of shipping operations, air transportation, offshore oil and gas exploration and drilling, platform operations, marine construction, commercial fishing, pollution monitoring, ice monitoring, and marine search and rescue.

NASA, in conjunction with academia, will use the data primarily for R&D in weather and climate. NASA also will increase its participation with the oceanographic community by supporting university scientists and encouraging further commercial participation in carrying out a number of advanced studies for future research missions in applying satellite remote sensing to oceanography.

NASA's ocean research programs will include processing SEASAT data records into final geophysical units and their subsequent analysis; evaluation of the performance of X/L/C-band aircraft synthetic aperture radar (SAR) in conjunction with experiments undertaken by the National Science Foundation (NSF) on warm Gulf Stream rings and coastal ocean dynamics; characterization of sea ice properties by various remote-sensing techniques; definition of altimetry dependence on sea state; investigation of photoplankton productivity associated with physical and chemical ocean properties near the Nantucket Shoals, in cooperation with the National Marine Fisheries Service; refinement of techniques for assimilation of wind data from the scatterometer into numerical models; and development of a shipborne lidar system for basic studies of optical oceanography. The ocean processes program will develop techniques for assimilating satellite data–especially scatterometer wind data—into numerical models, and demonstrate a remote-sensing system that will supply specific global oceanographic data on a routine and repetitive basis to meet specific user needs.

Earth Resources Sensing

The U.S. program addresses the needs for gathering the vital information required for managing the world's limited food, water, energy supplies, and mineral resources, and for identifying potential geodetic (primarily earthquake) hazards. Its objective is to develop and demonstrate the use of space technology for providing the United States with a global capability for monitoring and forecasting major agricultural commodities, managing water resources, assessing land use, improving the exploration for mineral and energy resources, and understanding the dynamic characteristics of the Earth's crust. Many, if not most, Federal agencies use space data in the day-to-day conduct of their missions (see fig. 2).

Numerous State and local governments, many in conjunction with academia, use satellite data for a whole range of projects, including land cover classification, wetland development, and water management (see tables 7 and 8). The universities are studying ways to manipulate the data and apply them to a variety of problems. Industry has made some use of space-generated data, especially in its search for nonrenewable resources. Several companies that are characterized as "value-added" firms take the raw satellite data, manipulate it, integrate it with other data and sell the information products to a variety of users.

Currently there are no plans for a Federal operational Earth resources-sensing satellite system. NOAA will shortly (1983) assume operation of NASA's experimental Landsat system, but there are no plans for the Government to continue to operate a satellite land remote-sensing system once Landsat fails. NASA's principal activities include pursuing the R&D necessary for developing and improving space remote-sensing capabilities and the related information extraction techniques, providing for the acquisition of space data, and joint research, development, and test projects with users. Its goal is to establish the routine use of global data collection systems. American industry has been the dominant source of equipment, provided largely under Government funding, for the U.S. remote-sensing effort. It has supplied spacecraft, sensing instruments, Earth stations, data processing equipment, and information extraction devices.

Landsat Technology

Space Segment

The return beam vidicon (RBV), a kind of television camera, was initally promoted for use in Landsat by the Department of the Interior. The RBV uses a shutter to expose a light-sensitive plate and then scans the plate with an electron beam to capture the image on videotape or to radio it to the ground. Although Landsat 3 carries only two RBVS, three of these devices would allow the reconstruction of color pictures. Each RBV image from Landsat 3 covers an area 90 km on a side (180 km total swath) and has an equivalent instantaneous field of view (IFOV) of 40 m. The low distortion of the RBV makes its especially useful for mapmaking.

The multispectral scanner (MSS) uses a mirror to scan the scene on the ground one line at a time, reflecting the light onto a series of detectors (photoelectric cells) sensitive to four different spectral regions. MSS scans a swath 185 km wide and has an IFOV of 80 m, which for many scenes is approximately equivalent to a photographic resolution of about 160 m. MSS provides better spectral resolution, but higher distortion, than does RBV. It was therefore championed by the Department of Agriculture (USDA) as particularly useful for monitoring crops.

The thematic mapper (TM) is a remote sensor with seven spectral bands covering the visible, near-infrared, and thermal infrared regions of the spectrum (see fig. 3). It is now scheduled for launch in the third quarter of 1982 aboard Landsat D, from which it will achieve complete coverage of the Earth's surface every 16 days.

The TM is designed to satisfy more demanding performance specifications than have previously been applied to an instrument of its type. In response to these requirements, the design incorporates advanced state-of-the-technology materials, structures, control techniques, calibration mechanisms, data handling, and electronics. De-

Figure 2.— Earth Resources Sensing

The top photograph shows upper Delaware, Maryland, and the Virgina peninsula taken from the Landsat 1 satellite at an altitude of 568 miles. The photo at bottom left shows a technician performing a quality control assessment of the Landsat 1 photo while on the bottom right, a technician prepared a negative of the Landsat 1 photo for printing in the Goddard Space Flight Center processing facility.

Table 7.—Overview of Landsat Applications in the 50 States

State	Water resources	Forestry/ rangeland	Wildlife management	Land resources management	Environmental management	Agriculture	Geologic mapping
Alabama	X	X		x	x		X
Alaska	X		x	x	x		X
Arizona	X	X	X	x	x	x	X
Arkansas				X		X	X
California	X	X	X	X	X	X	X
Colorado	X		X	x	x	X	
Connecticut							
Delaware	X				X		X
Florida	X	X	X	X	X	X	
Georgia	X	X	X	X	X	X	X
Hawaii		X		X	X		
Idaho	X	X	X	X		X	
Illinois	X	X		X	X	X	
Indiana		X	X	X	x	x	x
Iowa	X			x	x	x	X
Kansas	X		X	X		X	X
Kentucky	x	X	X	X	X	X	X
Louisiana	X	X		X	X	X	
Maine	X	X		X	X	X	
Maryland				X	X	X	X
Massachusetts					X		
Michigan				X	X		
Minnesota	X	X	X	X	X	X	X
Mississippi	X	X	X	X	X	X	
Missouri	X	X	X	X	X	X	X
Montana	X	X		X		X	
Nebraska	x	X	X	x	x	x	x
Nevada	X						
New Hampshire		X		X			
New Jersey		X		X	X		
New Mexico		X	X	X	X	X	
New York	X	X	X		X	X	X
North Carolina	X	X	X	x	X	X	
North Dakota	x		X	X	X	X	
Ohio				X			X
Oklahoma	X	X		X	X	X	X
Oregon	X	X	X	X	X	X	
Pennsylvania		X		X	X		X
Rhode Island							
South Carolina	x	x	x	X	x		
South Dakota	x	X	x	x	x	X	x
Tennessee			x	x	x		X
Texas	x	X	X	X	X	X	x
Utah		X	X		X		X
Vermont		X			X		
Virginia	x	X		X	X	X	X
Washington	x	X	X	X	X		
West Virginia		X			X		X
Wisconsin	x	X		X	X	X	
Wyoming	X		X	X	X	X	x

SOURCE: National Governors Conference,

Table 8.—Summary of Operational Landsat Applications in the States[a]

A. **Water Resources Management**

- Surface water inventory (7)
- Flood control mapping and damage assessment (7)
- Snow cover mapping (3)
- Water resources planning and management (2)
- Irrigation demand estimation (2)
- Determination of runoff from cropland (2)
- Watershed or basin studies
- Water circulation
- Lake eutrophication survey
- Irrigation/saline soil
- Geothermal potential analysis
- Ground water location
- Offshore ice studies

B. **Forestry and Rangeland Management**

- Forest inventory (6)
- Forest productivity assessment (3)
- Clear cut assessment (2)
- Forest habitat assessment (2)
- Wildlife range assessment (2)
- Fire fuel potential
- Fire damage assessment and recovery

C. **Fish and Wildlife Management**

- Wildlife habitat inventory (9)
- Wetlands location and analysis (3)
- Vegetation classification
- Snow pack mapping
- Salt exposure

D, **Land Resources Management**

- Land cover inventory (18)
- Comprehensive planning (4)
- Corridor analysis (2)
- Facility siting (2)
- Flood plain delineation
- Solid waste management
- Lake shore management

E. **Environmental Management**

- Water quality assessment and planning (16)
- Environmental analysis or impact assessment *(4)*
- Coastal zone management (3)
- Surface mine inventory and monitoring (2)
- Wetlands mapping
- Lake water quality
- Shoreline delineation
- Oil and gas lease sales
- Resource inventory
- Dredge and fill permits
- Marsh salinization

F. **Agriculture**

- Crop inventory (7)
- Irrigated crop inventory (5)
- Noxious weeds assessment
- Crop yield prediction
- Grove surveys
- Assessment of flood damage
- Disease monitoring

G. **Geological Mapping**

- Lineament mapping (9)
- Geological mapping (6)
- Mineral surveys (4)
- Powerplant siting
- Radioactive waste storage

[a] The number in ( ) indicates the number of States for each application, where greater than 1.

SOURCE: National Governors Conference

velopment and fabrication of the TM are proceeding on schedule. Most of the subsystem parameters which have been tested so far have met or exceeded specifications.

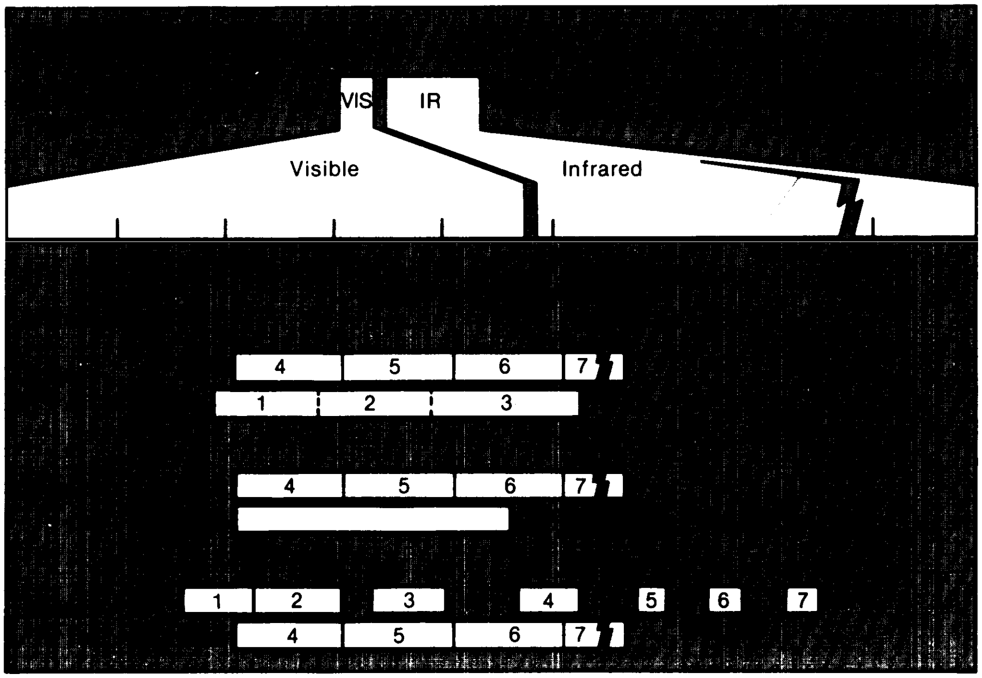
Ground Segment

Data can be transmitted to Earth when the satellite is within view of one of the receiving stations (fig. 4)—the NASA stations in Alaska, California, and Maryland, and nine foreign-owned and -operated stations that function under agreements with NASA. Data acquired while the spacecraft is beyond the range of a ground station are stored by an onboard, wide-band video tape recorder until it is within range of a U.S. station. The rate of data transmission from satellite to ground station is on the order of megabits/second.

A control center at the Goddard Space Flight Center (Goddard) monitors and commands the satellite to acquire and transmit data directly to U.S. or foreign ground stations.

The master recordings (station tapes) received at U.S. ground stations of Landsat 3 are sent to Goddard for preprocessing. This initial step in data reduction consists of segregating data from each of the spectral bands and applying two sorts of corrections: a) radiometric corrections to account for the difference in response of the detectors in the various spectral bands, and b) geomet-

Figure 3.—Landsat Bands and Electromagnetic Spectrum Comparison



[a] Thematic mapper.

SOURCE: U.S. Geological Survey,

ric corrections that account for distortions in the satellite viewing process and relate the received data to the exact position on the ground that was observed by the satellite. The results of this preprocessing are recorded in the form of high-density digital tape (H DDT), either as fully corrected data, or with the required geometric corrections only noted on the tape. Foreign ground stations perform an equivalent function, although not all of them apply a full set of corrections.

HDDTs are provided to the Department of the Interior's EROS Data Center in Sioux Falls, S. Dak., and the USDA facility in Houston, Tex. At the EROS Data Center, the data in HDDT form are put through additional computer processes to convert them into standard data products suitable for sale to public or private sector customers. They, in turn, may use these products in that form or further process them for their own use or for resale to additional customers.

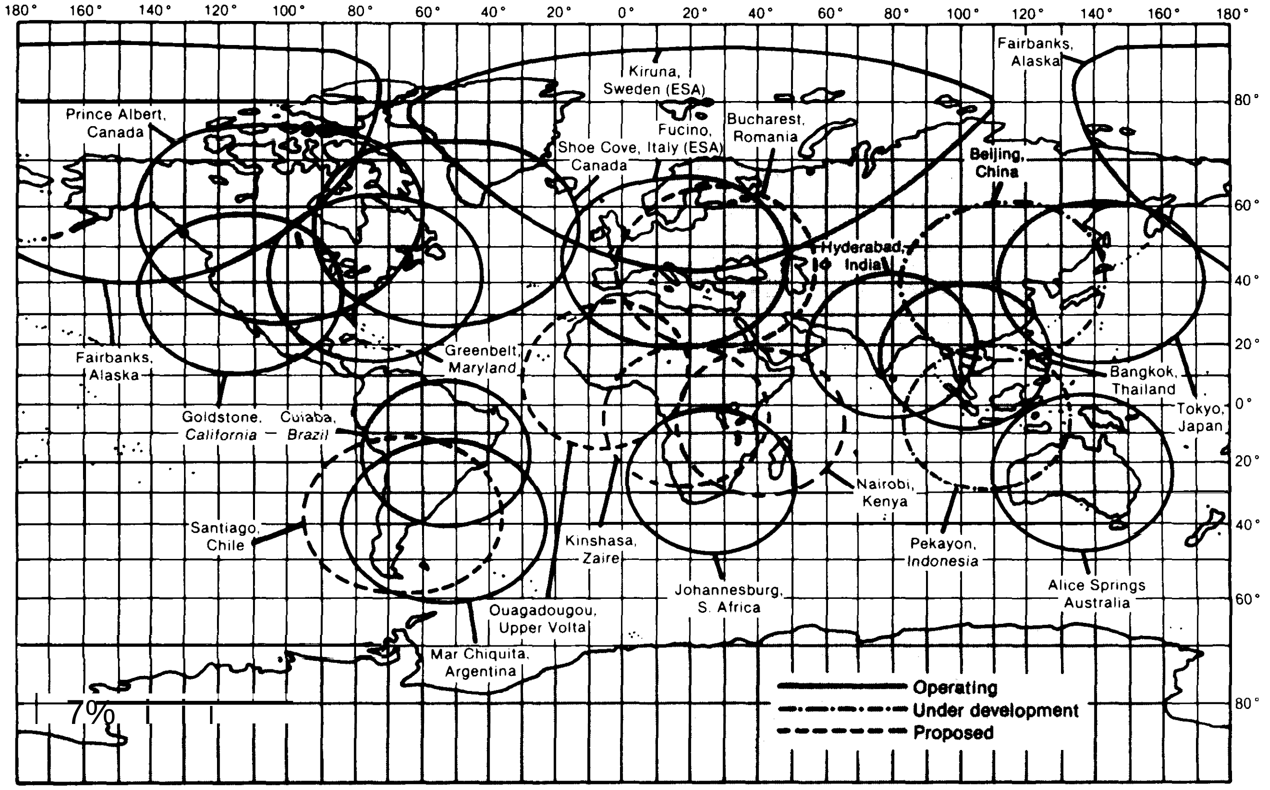
Two classes of standard data products are available: film imagery, which is convenient for those accustomed to working with maps and photographs, and computer compatible tapes (CCTS). The tape form is suitable for input to standard computers and lends itself to automated or specialized data handling and analysis. The digital form of CCTS makes them especially appropriate for integration with other digital data.

For most uses, the data as they emerge from preprocessing at Goddard and processing at EROS are still in raw form. It is at this point that firms in the private sector step in to process Landsat data further. Such firms constitute the value-added industry. Value-added firms are found both in the United States and abroad; most of them are small. The kinds of work they perform are: image processing, image enhancement, image interpretation, and integration of Landsat data with data from other sources.

Other Remote-Sensing Programs

Currently Federal experimental or scientific flight programs include the Landsat series, Magsat, and the Heat Capacity Mapping Mission (HCMM). Landsat 3 is aging but continues to be

Figure 4.—Current and Probable Landsat Ground Stations



NOTE: Coverage circles based on Landsat-3 reception (altitude: 917 km)

SOURCE: National Aeronautics and Space Administration.

the **primary** source of Earth resources data. **Landsat** D will soon be launched, and if plans to launch the follow-on satellite, Landsat D', come to fruition, both are expected to operate until the mid- to late-1980's. New sensor capabilities on Landsats D and D' are expected to be especially useful for nonrenewable resources observations. Magsat, launched in 1979, has charted the Earth's magnetic fields to aid in navigation and to provide a better understanding of the solid Earth for geophysical and geologic studies; and, the HCMM has made global measurements of Earth surface temperature variation to aid in locating mineral resources and in measuring water runoff from snowmelt. NASA is also planning to fly experiments on early space shuttle missions designed to test the applicability of active microwave measurements, and of high-resolution imagery for mapping investigations. IT is also studying how to define the appropriate space systems for gravity measurements for solid Earth studies, for global stereoscopic imagery for resource exploration, and for improved remote sensors for multiple applications.

NASA has also entered into joint R&D activities with other Federal agencies (USDA, USDC, USAID) to advance the understanding of how to apply multiple data sources in improving agricultural early warning and crop commodity forecasting (AgRISTARS). The AgRISTARS program has been somewhat restructured by lengthening the schedules and changing the program scope in several areas. This restructuring has been caused by constraints on the fiscal year 1982 budgets of the involved agencies and the delay in the availability of Landsat D. Other joint research activities are planned with additional Federal agencies and with international organizations for advancing the scientific knowledge of the solid Earth.

ENVIRONMENTAL SENSING

understanding the dynamics and limitations of our environment is essential to our long-term survival and important to many day-to-day activities. The global interrelationships between the atmosphere, ocean, land, and space environments can be studied only from space. These programs are aided by data from the ocean and Earth resources sensing systems.

The operational meteorological satellite systems of NOAA (GOES and TIROS) form the backbone of the environmental program. Prediction of the weather, monitoring and control of pollution, ship routing, storm warning, and modeling of long-term trends in climate and the stratosphere are all areas of study.

NOAA's operational responsibility regarding weather and climate is to monitor the weather and prepare weather forecasts for a myriad of users. NOAA, therefore, has the responsibility for the ground-based observation systems, the operational meteorological satellite system, and the related receiving , analyzing, and disseminating systems that turn the space and ground data into weather forecasts. For the space segment, NOAA coordinates with NASA for the improvement of the space and space-tied systems and for the procurement of spacecraft and launch arrangements. NOAA is also charged with conducting R&D in the analysis and application of satellite data.

The primary and routine use of the satellite data from the NOAA system is, of course, weather predicting. NOAA transforms them into a broad variety of weather projections and distributes them throughout the world. In addition to being used in real-time weather predicting operations, they are also placed in archives for future theoretical research and case studies. These data are widely used by meteorologists and environmental scientists in Government and academia in routine operations throughout the world and are considered indispensable for conducting atmospheric analyses and preparing short-range weather forecasts.

Users of weather data vary in their involvement with determining the standard weather forecasting services provided by NOAA. Aviators in well-established working groups provide regular data on their needs through FAA. However, only about one-third of the farming sector is well-served by standard NOAA products. Private weather services provide specialized forecasting to many users whose requirements are not met by those products.

NASA studies and flight missions are directed at all characteristics of the atmosphere, including upper atmospheric and tropospheric air quality, global weather, severe storms, oceanic processes, and general climate.

NASA launched three atmospheric research/demonstration satellites in the late 1970's, SEASAT, NIMBUS-7, and Stratospheric Aerosol and Gas Experiment (SAGE). As noted above, SEASAT has ceased to function, but returned significant ocean data, which are being studied. NIMBUS-7 and SAGE are performing satisfactorily. SAGE primarily measures atmospheric concentrations of ozone and aerosols in an attempt to show how pollutants might be transported globally. NASA has planned to launch the Halogen Occultation Experiment (HALOE) and the Earth Radiation Budget Experiments (ERBE) spacecraft in the mid-l 980's. HALOE will measure global atmospheric profiles of key species involved in the depletion of stratospheric ozone. ERBE is to measure the radiation balance over the globe to gain basic insights into the reasons for climatic fluctuations. NASA's advanced planning includes the uses of satellites for the simultaneous global study of the radiative, chemical, and dynamic processes occurring in the upper atmosphere.

It is apparent that air pollution problems must be solved on a regional basis, and that global chemical budgets (e.g., carbon dioxide) act both as tracers of transport processes and as a background for regional events. NASA, the Environmental Protection Agency (EPA), and NSF are focusing on these areas with field analytical and laboratory studies to quantify the global carbon-nitrogen-ozone and sulfur-ammonia-aerosol chemical systems. Data derived from spacecraft are essential to these efforts.

Severe storms, tornados, damaging downdrafts, and destructive lightning are being studied by NOAA and NASA to improve observation and forecasting of such events. Remotely sensed data from NASA's severe environmental storms and mesoscale experiment, and ongoing mesoscale modeling efforts for forecast improvement with computer interactive systems will lead to a joint NASA/NOAA project at NOAA's National Severe Storm Forecast Center, similar to the recently successful frost-freeze warning demonstration in Florida. Improved airborne wind measurement tools and temperature and moisture sounders on the GOES-D spacecraft are being evaluated.

International Weather Activities

WORLD METEOROLOGICAL ORGANIZATION (WMO)

The United States participates in international meteorological programs through WMO, a specialized agency of the United Nations that was established in 1951. It was formed in order to establish, coordinate, and improve meteorological services throughout the world, U.S. operational and experimental meteorological satellites contribute to this effort. WMO members obtain access to meteorological information from U.S. weather satellites indirectly through a WMO network of international, regional, and national meteorological centers, and directly from automatic picture transmission (APT) receiving sets.

GLOBAL ATMOSPHERIC RESEARCH PROGRAM (GARP)

As part of the U.S. worldwide weather R&D activities, NOAA, NSF, and NASA participate through the National Research Council in GARP. GARP's goal is to conduct studies to understand the atmosphere, It is sponsored by WMO and the International Council of Scientific Unions, with participation and funding provided by all member nations. Current U.S. activities for GARP are directed at analyzing parts of the data from the recently successful GARP global weather experiment, assessing the requirements for improved operational forecasting and defining future remote measurement requirements. This experiment, conducted in 1979, provided a unique set of data that did not exist before. As a result, atmospheric numerical forecast models have been improved and space research is being directed to improved temperature sounders, surface pressure instruments, passive and active microwave moisture sensors, wind sensors, and rainfall measurements technique.

Materials Processing in Space (MPS)

MPS is both a set of new technologies designed to exploit the unique environment of space and a developing program to implement these technologies. The unique properties that make space an ideal environment for processing certain kinds of materials are: 1) the availability of unlimited, unfiltered solar radiation; 2) the existence of a near-perfect vacuum; 3) a range of temperatures, from –200° to +200"F; and, most important, 4) microgravity–an almost complete absence of gravitational force. VVith the exception of long-term microgravity, these properties can be well enough approximated on Earth to allow their extended effects on materials processing to be investigated. The factor of microgravity, however, is what makes MPS so attractive.

Process variables such as temperature, composition, and fluid flow may be controlled far better in an environment of microgravity. As a result, some materials may be manufactured in space with greater precision and fewer defects; others, which cannot be made at all on Earth, may become possible for the first time. MPS looks particularly promising for pharmaceuticals, electronic components, optical equipment, and metal alloys.

Already, a U.S. program to implement these technologies is taking shape. NASA has established an MPS program to pursue the basic science and the applied R&D of microgravity environments. Within NASA's MPS program, a Commercial Applications Office has been set up to encourage the private sector to participate.

EARLY WORK IN SPACE

During the earlier years of the Apollo Program, several unusual phenomena, peculiar to microgravity, were first observed. First considered only as posing problems in the engineering of spacecraft systems, these phenomena were later recognized as clues for inventing processes to manufacture products in space for use on Earth. To broaden the discussion, NASA organized symposia in 1968 and 1969 for industry representatives to discuss the possibilities of MPS. NASA also established in 1969 a new program, “Materials Science and Manufacturing in Space.”

Through the early 1970’s, in-space research was conducted on Apollo, Skylab, and Apollo-Soyuz missions. Aboard Apollo 14, 16, and 17, several necessarily brief, but important experiments were performed to investigate certain basic processes (i.e., heat flow and convection, electrophoresis, and composite casting). Skylab, the orbiting space laboratory station, allowed for much more extensive experimentation. Altogether, three teams of astronauts conducted 15 MPS experiments. Skylab’s materials processing facility, including a multipurpose electric furnace, provided the means of studying more complex processes: crystal growth, metal alloying, eutectics, welding and brazing, fluid effects, and combustion, Again, the 1975 flight of the Apollo-Soyuz test project continued the research conducted on the Apollo and Skylab missions. The processes investigated included: electrophoresis, crystal growth of semiconductors, processing of magnets, convection induced by surface tension, density separation during solidification of two alloys, and halide eutectic growth. Throughout these missions, the experiments performed in space were essentially repetitions of techniques used in terrestrial materials processing.

CONCURRENT WORK ON EARTH

NASA has perfected three terrestrial facilities for attaining microgravity for short periods: drop tubes and drop towers, aircraft flying high-altitude parabolic trajectories, and sounding rockets. These facilities allow relatively low-cost experimentation for MPS investigators to establish and set experimental parameters, to establish proof of concept, and to provide specimens for laboratory research.

Drop tubes and towers allow spacelike microgravity conditions to be achieved for some 2 to 4 seconds. In drop tubes, molten droplets are released into a vertical evacuated tube (either 100 or 300 ft long) and are solidified during free fall. in drop towers, small rockets (used to overcome friction) thrust canisters containing experiment packages down vertical guide rails. These apparatus provide useful opportunities, however fleeting, to study both high-temperature calorimetry and changes in density, surface tension, and volume as liquids solidify.

Although longer in duration by an order of magnitude (1 O to 60 seconds), the microgravity attained by NASA aircraft (KC-132s and F-104Bs) is much less steady than that of drop tubes and towers. The aircraft, therefore, do not provide a suitable environment for precise experimentation, but are useful for training crews and for developing and verifying tests of experiment hardware.

Since introducing the Space Processing Application Rocket (SPAR) Program in 1975, NASA has flown nine sounding rocket missions. These flights provide 4 to 7 minutes of microgravity. However, severe stresses during launch significantly constrain the design of experiments. The SPAR program has resulted in an inventory of low-cost hardware suitable for longer duration experiments during shuttle operations.

FUTURE PLANS

From the foregoing discussion of work already done in space and on Earth, one can see that significant future evolution of MPS experimentation lies in the direction of providing an extended microgravity environment along with more complex hardware. The space shuttle transportation system holds the key to MPS development. Major shuttle facilities for MPS experimentation (small self-contained payloads, the materials experiment assembly, and Spacelab) can be used on shuttle flights lasting up to 1 month,

Small self-contained payloads are packages flown in containers rented by NASA to companies, universities, or private individuals. The payloads, designed by the users, operate under their own power and carry their own recording systems. Some of them may also be used as test-beds for broader experimentation aboard Spacelab.

The materials experiment assembly (MEA), the first article of new materials processing hardware to be flown in the shuttle, is also designed to operate under its own power in its preliminary version. Later models will draw power from the shuttle. Accommodating as many as four experiments

in separately sealed subenclosures, MEA contains a control computer, a heat rejection system, and data recorders.

Spacelab, the centerpiece of NASA's new MPS system, has two **major components, the module and the pallets.** The module provides a habitable laboratory for scientists and engineers to work comfortably in space. The pallets form an open porch in the cargo bay of the orbiter, where instruments may be exposed to space and various experimental apparatus may be accommodated.

Four MPS instruments are currently under development for deployment on Space lab. The fluid experiment system uses Schlieren photography and holography to study fluid behavior under microgravity. In the vapor crystal growth system, crystals are to be grown from fluids, vapors, or melts of solid materials; the results are recorded by video and holography. The pallet-mounted, acoustic, containerless, positioning module is used to control the position and rotation of a sample to be raised to a temperature of 1,600 degrees by radiant heat. The solidification experiment system employs a modular furnace in which up to 16 samples per flight may be processed. Solidification may be achieved, either under uniform heating and cooling, or directionally, by means of a temperature gradient.

There are several other MPS activities planned for development if funds are approved. There are also important long-term prospects for more advanced activities. These and the various foreign efforts, current or planned, are discussed elsewhere in this assessment.

Space Transportation

Currently the U.S. Government has the sole capability in the United States to launch both manned and unmanned payloads from Earth, Each capability presents different opportunities and different constraints.

MANNED SPACE SYSTEMS

The space transportation system (STS) that has been developed by NASA, with extensive industrial involvement under Government funding, is the sole U.S. system planned to carry humans and objects into space in the 1980's and 1990's. Expendable launch vehicles (ELVS) will continue to provide launch services through the early transition period.

The major components of the STS initially include the reusable space shuttle, upper stages, the remote manipulator system, and the workshop Spacelab. The shuttle will be launched from both the east and west coasts of the United States with a nominal payload capability of 65,000 pounds (29,500 kg) into LEO (1 85-1,110 km). It can carry a crew of three to seven persons for mission durations up to 30 days.

The space shuttle orbiter, an aircraft-like, reusable spacecraft, will be used to carry payloads to Earth orbit and deploy them from its cargo bay. The remote manipulator system can be attached to the orbiter bay to aid the crew in deploying or retrieving payloads in space, Upper stages will be included with those payloads that must go farther than LEO, i.e., on missions to the planets or to geosynchronous orbit. Spacelab is a complete orbital laboratory that fits into the cargo bay and connects with the crew compartment of the orbiter. It will make possible a variety of human-directed experiments in the space environment. Planned utilization of STS may be seen in table 9 and figure 5.

NASA is conducting numerous studies to provide advanced capabilities for STS:

- Thrust augmentation—a study to supplement the existing shuttle capability with strap-on assist rockets;
- ***Solar electric propulsion systems–solar-*** powered ion-engine upper stages for varying orbit and payload requirements;
- ***Orbita/ transfer*** vehic/es–manned and unmanned vehicles capable of moving payloads from the LEO attainable by the shuttle, either to a different LEO or to higher orbits;
- ***Teleoperator maneuvering system–a*** remotely controlled payload maneuvering unit;
- ***Deployable antenna***—an experiment to test the feasibility of deploying very large antennas;
- ***Space*** p/atforms–shuttle-deployable platforms to perform as test beds for experiments

Table 9.–STS Operations Traffic Model (34 **flights through 1985)**

	Fiscal year														
	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Total
Kennedy Space Center:															
NASA	—	3	3	5	7	8	11	12	15	13	15	14	13	12	131
Other civil government	—	—	—	—	1	—	1	—	1	—	1	—	1	—	5
U.S. commercial	—	1	—	1	2	3	5	6	6	7	7	7	7	5	57
Foreign	1	1	2	—	1	3	4	5	5	6	7	6	7	4	52
DOD (preliminary rev. 10)	—	1	2	5	5	7	8	11	11	12	8	11	10	8	99
Subtotal	1	6	7	11	16	21	29	34	38	38	38	38	38	29	344
Refights	–	–	1	1	1	2	2	2	2	2	2	2	2	2	21
Total	1	6	8	12	17	23	31	36	40	40	40	40	40	31	365
Vandenberg Air Force Base:															
NASA	—	—	—	—	1	—	2	2	3	3	5	4	5	3	28
Other civil government	—	—	—	—	1	—	1	1	2	2	2	2	2	2	15
U.S. commercial	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Foreign	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
DOD (preliminary rev. 10)	—	—	—	3	3	7	5	8	9	9	7	8	7	5	71
Subtotal	—	—	—	3	5	7	8	11	14	14	14	14	14	10	114
Reflights	—	—	—	—	—	—	1	1	1	1	1	1	1	1	8
Total	—	—	—	3	5	7	9	12	15	15	15	15	15	11	122
Traffic model total	1	6	8	15	22	30	40	48	55	55	55	55	55	42	487

SOURCE: National Aeronautics and Space Administration

in space construction for space science and applications;

- ***Large space structure*** experiments—to test the ability to construct large structures in space;
- ***Liquid-fueled*** upper stage—an upper stage for use with the shuttle, that will be powered by a liquid fuel rather than solid propellant, thereby providing greater controllability and payload capacity.

EXPENDABLE LAUNCH VEHICLES

The existing Government expendable launch vehicles used for routine civilian launches now (Scout, Delta, Atlas, and Centaur) are scheduled to be phased out by about 1985 or 1986. Should the Centaur be selected for the liquid-fueled shuttle upper stage, its production will continue, but not as an Earth to Earth-orbit launch vehicle. Figure 6 illustrates the normal payload capacity for these ELVS.

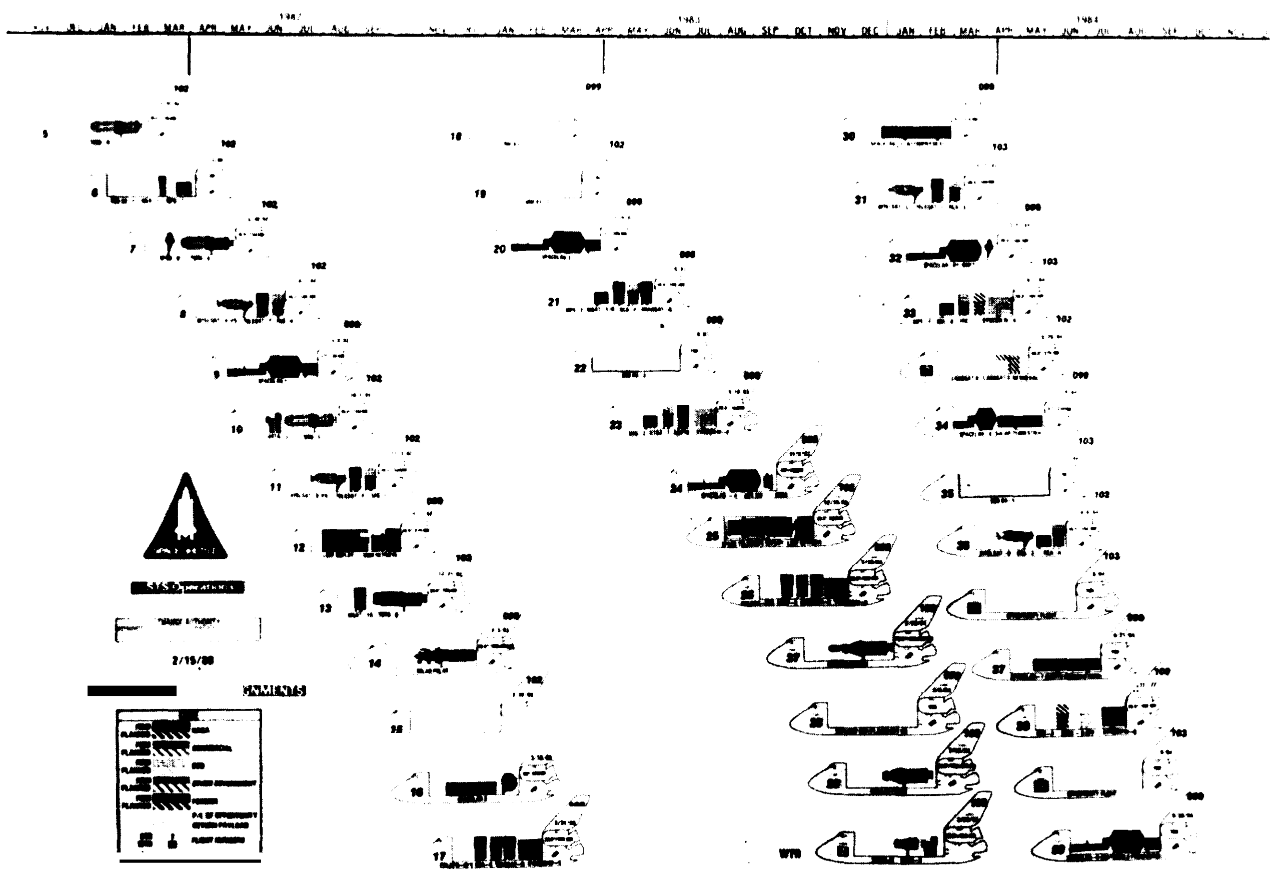
As previously mentioned, the U.S. Government is the only entity in the United States currently launching payloads into space. However, at least one privately owned U.S. company, Space Services, Inc., has indicated that its Percheron launcher will be ready in the near future (1 to 2 years). Maximum payloads for the Percheron are planned to be 700 kg into LEO by 1982, and 200 kg into geosynchronous orbit by 1983.

Space Construction

NASA is planning numerous experiments to test and demonstrate the ability and utility of constructing objects in space. It is clear that space platforms for operational or experimental work will need to be constructed in space because their size will likely preclude launching them in one piece from Earth. Component (beam) builders have been tested on Earth and await testing in space. Should a permanent orbiting space station be included in the space program, its construction will of necessity be carried out in space. In addition, if solar power satellites are deployed, they will have to be constructed in space.

Design requirements are being established for both manned and unmanned permanent platforms that will incorporate evolutionary power systems. NASA is analyzing the feasibility and benefits of low-Earth orbital science and applications space platforms, which would aggregate

Figure 5.—Shuttle Manifest Through 1984



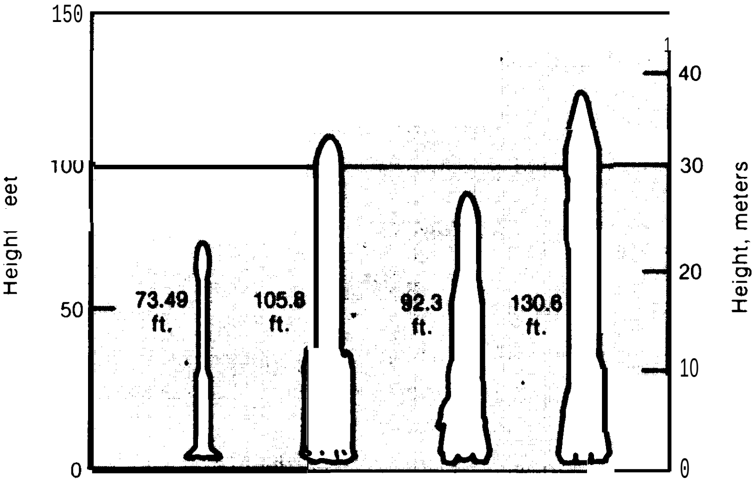
SOURCE National Aeronautics and Space Administration

many long-duration space experiments on unmanned, shuttle-tended platforms. The postulated initial system could accommodate science and applications payloads, demonstrate on-orbit servicing and payload exchange, conduct multidisciplinary investigations, and provide an evolutionary space power system. It could **grow to include** a capability for materials processing experiments, and eventually a habitat for life science and human research (fig. 7).

NASA is also studying a large communications platform that could alleviate the potential saturation of orbit arc and frequency spectrum by aggregating most communications payloads on a common support bus. This platform would be serviced and upgraded remotely by a teleoperator (also under study). For the longer range, NASA is studying a permanent, manned Space Operations Center to establish, service, upgrade, and operate both the low- and high-altitude platforms. Its future potential uses could be to tend and refurbish a reusable orbital transfer vehicle orbiting between low and geostationary orbits and ***to*** construct and assemble large orbiting structures.

In order to plan for support of future possible permanent platforms and facilities, NASA intends to extend its research into a series of developmental test flights and space demonstrations in large space structures, satellite services near to and remote from shuttle, including satellite placement, retrieval and repair, and proof test of a satellite tethered from the orbiter.

Figure 6.—Current NASA Expendable Launch Vehicles



a) Payload values are for east launch from ESMC for Delta and Atlas Centaur
b) Scout values are for launch from Wallops
c) Atlas E/F values are for launch from WSMC and use of a TE 364-4 AKM

SOURCE: National Aeronautics and Space Administration

Figure 7.—initial Space Station Conception

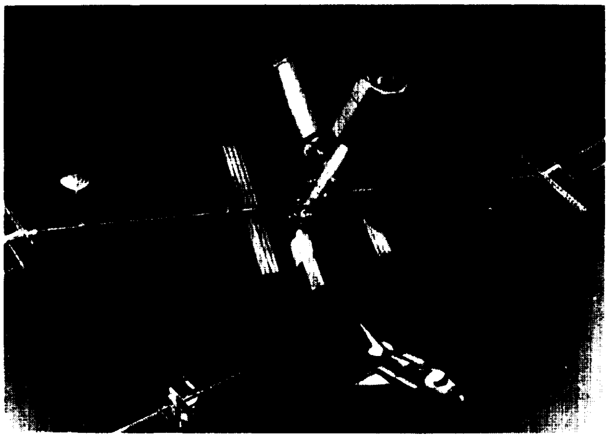


Illustration credit: National Aeronautics and Space Administration

Solar Power in Space

The constancy and strength of sunlight in Sun synchronous or geosynchronous orbits makes the conversion of sunlight to electrical power especially attractive either for use in space or for transmission to terrestrial receivers. Currently, the only active program in the United States is NASA's program to provide an orbiting photovoltaic power supply that could be used by a spacecraft, including the shuttle, to supplement its normal power supply. A 25 kW module can supply power for a spacelab or construction mission of 60 days or more. After 60 days the flight would be limited by such factors as food and drinking water. The module could also supply plug-in power for free-flying payloads that would dock with it, and it could be detached and parked in orbit between shuttle missions. One version could itself fly free of the orbiter with instruments for, say, studying the Sun or Earth. Another could be attached to a free-flying spacelab for long-duration missions like observing the Sun continuously through two or more 28-day solar cycles or studying plants or animal specimens through several generations.

The solar power satellite (SPS), originally proposed in 1968, was the subject of major studies by NASA, the Department of Energy, the National Academy of Sciences, and OTA[4] (fig. 8). The latter two studies concluded that, although SPS was technically feasible, its high initial cost, environmental and health uncertainties, and lower estimates for the future demand for electricity preclude a major research effort at this time. OTA identified possible research funding levels that range from $0 to $30 million. There are no specific research funds for SPS in the 1982 Federal budget.

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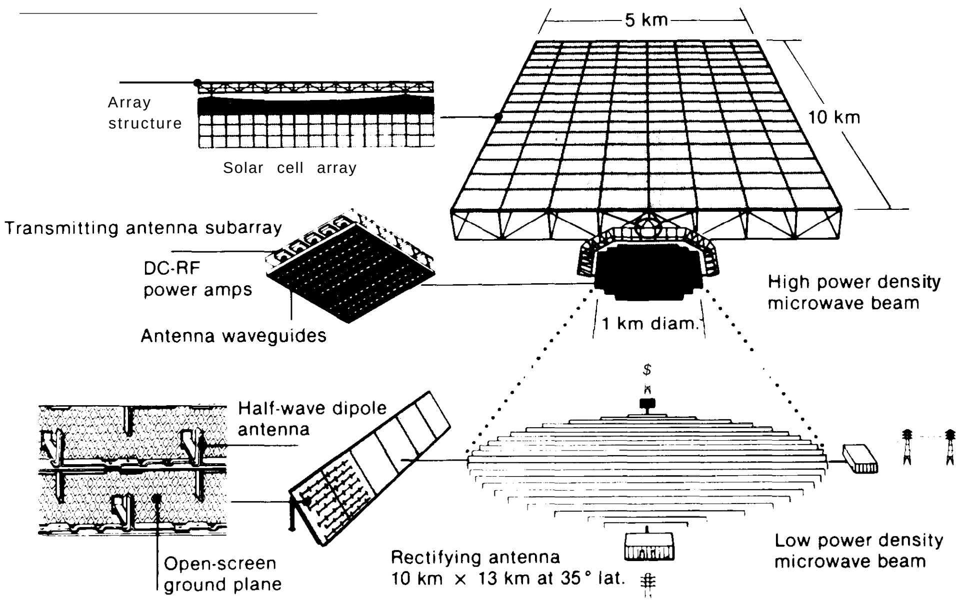
[4] U.S. Department of Energy, Program *Assessment Report Statement of Findings,* NASA/DOE, Satellite Power Systems Concept Development and Evaluation Program, November 1980; National Academy of Science, Electric Power *From Orbit:* A *Critique* of a *Satellite Power System,* 1981; Office of Technology Assessment, Solar *Power Satellites,* OTA-E-144 (Washington, D. C.: U.S. Government Printing Office, August 1981.

Figure 8.—Solar Power Satellite Reference System



SOURCE National Aeronautics and Space Administration.

Space Science

Although OTA was not asked to assess space science, we felt it necessary, as a point of information, to describe the current U.S. space science programs. Parts of the life sciences program do have implications for the application of space technology for human benefit. This area is centered in NASA and utilizes space systems, supported by ground-based and airborne observations, to conduct scientific investigations to advance our knowledge of the Earth and interstellar space, the other stars of our galaxy, and the universe as a whole. NASA also conducts a life sciences program to further the exploration and use of space by studying space biology and medicine and the origin and evolution of life. Near-term activities focus on investigations of human physiology and of the effects of the space environment on man.

The Office of Space Science and Applications at NASA funds the following science programs, though the funding levels of some may be reduced.

PHYSICS AND ASTRONOMY PROGRAM

The major objective of the physics and astronomy program is to increase our knowledge and understanding of the solar terrestrial space environment and the origin, evolution, structure, and composition of the universe, including the Sun, the stars, and the other celestial bodies. Space-based research is being conducted to investigate the physics, chemistry, and transport processes occurring in the Earth's magnetosphere, ionosphere, and atmosphere, and the responses of the transport processes to solar phenomena and variability; the structure and dynamics of the Sun and its long- and short-term variations; cosmic ray, X-ray, gamma ray, ultraviolet, optical, infrared, and radio emissions from stars, interstellar gas and dust, pulsars, neutron stars, quasars, black holes, and other celestial sources; and the law governing the interactions and processes occurring in the universe. Many of the phenomena being investigated in the physics and astronomy program are not detectable from ground-based observatories because of the obscuring or distorting effects of the Earth's atmosphere.

HIGH ENERGY ASTRONOMY OBSERVATORIES (HEAO) DEVELOPMENT

A major scientific objective of the HEAO program is to observe and investigate not only those)(-ray sources that are already known, but also a much larger number which, because of their distance or their low intensity, remained undetected prior to HEAO. This work has detected classes of intrinsically weak X-ray sources within our own galaxy, as well as stronger sources outside our galaxy. Other equally important objectives include the observation of rare species of cosmic rays, which are crucial to our understanding of heavy element formation, and the search for nuclear gamma ray lines, which are important in understanding the origin of the elements. This program promises to advance our understanding of newly discovered processes that release extraordinary amounts of energy. It will also enhance our understanding of the creation of matter, and deepen our knowledge of observed phenomena such as quasars, pulsars, novae, and supernovae.

SPACE TELESCOPE (ST) DEVELOPMENT

The space telescope is expected to make a major contribution to understanding the stars and galaxies, the nature and behavior of the gas and dust between them, and the broad question of the origin and scale of the universe.

It will enhance the ability of astronomers to study radiation in the visible and ultraviolet regions of the spectrum. Because of its location above the atmosphere, it will be more sensitive than ground-based telescopes of comparable diameter and will record greater detail about the objects under study. It will make it possible to look far into the distant past of our universe.

The telescope should also contribute significantly to the study of the early stages of stars and the formation of solar systems and to the observation of such highly evolved objects as supernova remnants and white dwarf stars. With it we may be able to determine the nature of quasars, and the processes by which they emit such enormous amounts of energy. It will also be possible to study nearby individual stars and perhaps determine if they have planetary systems.

No budget cuts are foreseen for the space telescope.

GAMMA RAY OBSERVATORY (GRO) DEVELOPMENT

The objective of the GRO program is to measure gamma ray radiation from the universe in order to explore the fundamental physical processes powering it: Certain celestial phenomena can be studied only at gamma ray energies. These include direct evidence of the synthesis of the chemical elements; high-energy astrophysical processes occurring in supernovae, neutron stars, and black holes; gamma ray burst sources; diffuse gamma ray radiation and unique gamma ray-emitting objects that may exist. Gamma rays represent one of the last frontiers of the electromagnetic spectrum to be explored, because the required detector technology has only recently been developed. The low flux levels of gamma ray quanta, and the high background they produce through their interaction with the Earth's atmosphere, coupled with the demand for better spectral, spatial, and temporal resolution of source features, combine to require that large gamma ray instruments be flown in space for a prolonged period. Observations of gamma rays are likely to provide unique information on the most astronomically intriguing objects yet discovered: quasars, neutron stars, and black holes.

EXPLORER DEVELOPMENT

The Explorer program provides the principal means of conducting astronomical studies and long-term investigations of solar physics and of the near-Earth interplanetary environment that have limited, specific objectives and do not require major satellite observatories. Included in the present program are missions to study atmospheric and magnetospheric physics; magnetospheric boundaries; interplanetary phenomena; and X-ray, ultraviolet, and infrared astronomy.

SUBORBITAL PROGRAMS

The sounding rocket program provides versatile, relatively low cost research tools that complement the capabilities of balloons, aircraft, free-flying spacecraft and the space shuttle in all the space science disciplines, including the study of the Earth's ionosphere and magnetosphere, space plasma physics, stellar astronomy, solar astronomy, and high-energy astrophysics. Activities are conducted on both a domestic and an international cooperative basis. The current level of activity is about 60 rocket flights per year.

THE PLANETARY PROGRAM

This program includes the scientific exploration of our solar system; the planets, their satellites, the comets and asteroids, and the interplanetary medium. The program objectives are to understand the origin and evolution of the solar system, to understand the Earth through comparative studies with the other planets, and to understand how the appearance of life in the solar system is related to the chemical history of the system.

The strategy that has been adopted calls for equal study of the terrestrial-like inner planets, the giant gaseous outer planets, and the small bodies (comets and asteroids). Missions to these planetary bodies start at the level of reconnaissance and exploration, to achieve the most fundamental characterization of the bodies, and proceed to a level of detailed study, The reconnaissance phase of inner planet exploration began in the 1960's, and has now been completed.

Mars has provided a program focus because of its potential as a site of biological activity, and the Viking landings in 1976 carried out the exploration of this planet forward to a new, high level of scientific and technological achievement, setting the stage for the next step of detailed study. Analyses of the Moon rock samples returned by Apollo continue to be highly productive, as new insights into the early history of the inner solar system are achieved and as our theoretical concepts are revised accordingly. The continuing Pioneer Venus mission is taking the study of our nearest neighbor, and closest planetary analog, beyond the reconnaissance stage to the point where we have made a basic characterization of the massive cloud-covered atmosphere of Venus.

The Galileo mission will conduct direct and long-duration studies of Jupiter. The objectives of this program are to conduct a comprehensive exploration of Jupiter, its atmosphere, magnetosphere, and satellites, utilizing a new deep spacecraft concept that combines both remote sensing and direct measurements on an orbiter spacecraft with separate atmospheric probe. Galileo is the only planetary program still under development and is scheduled for launch in 1984.

MISSION OPERATIONS AND DATA ANALYSIS

The mission operations and data analysis program funds the operations phase of planetary missions after development, launch, and initial inflight checkout are complete. IT also provides for multi mission flight support. Currently, active planetary missions being supported within mission operations and data analysis are Voyager, Pioneer Venus, Pioneer 6-II, Helios, and Viking.

The objective of the Voyager mission to the outer planets is to conduct scientific studies of the Jupiter and Saturn planetary systems, including their numerous satellites and the rings of Saturn. While the two spacecraft are cruising to the outer planets, they are also performing continuing investigations of the interplanetary medium. Since their launches in 1977, the two Voyager spacecraft have encountered both Jupiter and Saturn and returned spectacular data and pictures.

Subsequent to the Saturn encounters, the spacecraft will continue to provide data on the interplanetary medium. Voyager 1 will investigate the outer limits of our solar system and Voyager 2 will go on to Uranus and Neptune.

LIFE SCIENCES PROGRAM

The objective of the life sciences program is to conduct studies in the areas of space biology and medicine, and thereby to expand scientific knowledge of the origin and evolution of life, The realization of this objective, which is intimately linked to our understanding of the basic mechanisms of biological and medical processes, is achieved through a program of research conducted both on Earth and in space. The near-term activities will help us to discover and investigate the effects of the space environment on humans to facilitate their safe, useful participation in space activities. The life sciences program utilizes a composite of disciplines addressing all space-related problems in biology and medicine.

The life sciences program is composed of three major programs. The first consists of flight and ground-based experiments, whereby the physiological effects of the space environment on humans are explored. The unique properties of space (e.g., microgravity, radiation, etc.) provide, for the first time in our history, an opportunity to explore significant problems in biology under a controlled set of conditions that cannot be adequately duplicated in laboratories on Earth. The second is the continuous inflight observation of crews venturing in space and the testing and refining of countermeasures and establishing requirements in human space exploration. The third is the studies in exobiology, with special emphasis on a problem of profound philosophical and scientific significance: origins and the distribution of life in the universe.

The life sciences operational medicine program is the catalyst responsible for bringing the science, technology, and practice of medicine to bear on solving the problems of sustaining, supporting, and protecting individuals working in the space environment. This includes assurances that physical welfare and performance are preserved and that adequate treatment of inflight illnesses or injuries is provided.

The biomedical research program objective is to develop the basic medical knowledge needed to enable men and women to operate more effectively in space, The program is organized into discrete elements with each designed primarily to rectify a particular physiological problem expected to affect the human organism in prolonged or repetitive space flight. Thus, motion sickness, bone loss, and hormonal disturbances are the subjects of a continued search for mechanisms and countermeasures. The program is largely dependent upon the use of ground-based analogs of space flight.

The space biology activity will explore the role of gravity in life processes and use gravity as an environmental tool to investigate fundamental biological questions. Specific objectives are to: 1) investigate and identify the role of gravity in plant and animal cellular processes, embryonic development, morphology and physiology; 2) identify the mechanisms of gravity sensing and transmission of gravity-perception information within both plants and animals; 3) identify the interactive effects of gravity and other stimuli (e.g., light) and stresses (e.g., vibration) on the development of metabolism of organisms; 4) use gravity to study the normal nature and properties of living organisms; and 5) extend the limits of knowledge about plant and animal growth and metabolism to provide for long-term survival and multigeneration reproduction of life in space. This program provides basic ground-based information in support of future space flight experiments and life support systems environment. This includes assurances that physical welfare and performance is preserved and that adequate treatment of inflight illness or injuries is provided.

Exobiology is the study of the origin, evolution, and distribution of life and life-related molecules on Earth and beyond. Sophisticated analyses of life as we know it, its chemical precursors and its origin, coupled with extrapolation to extraterrestrial environments, affords a unique opportunity to address a most fundamental question regarding the existence of such processes beyond the Earth. Theories about chemical evolution and the origin of life are being refined to reflect results from the most recent planetary and astronomical explorations. The current research program also is uncovering an intimate association between the origin and evolution of life on Earth and the processes that shaped the evolution of the solar system itself. These discoveries have highlighted gaps in our knowledge which, when completed as the program expands, will ultimately allow tests of the concept of universality of biological processes.

It may be useful to describe one additional space science program that has now been sig**nificantly cut back, because this cutback has ramifications for future international cooperation in space applications.**

The international solar polar mission (ISPM) was a joint NASA and European Space Agency mission designed to obtain the first view of the solar system from a new perspective—a view from far above and far below the plane in which the planets orbit the Sun's equator, i.e., over the poles of the Sun. The two spacecraft would have aided in the study of the relationship between the Sun and its magnetic field and particle emissions (solar wind and cosmic rays) as a function of solar latitude, and hence might have allowed us to gain insight into the possible effects of solar activity on the Earth's weather and climate. The objective of the international solar polar mission was to conduct an exploration of those regions of the heliosphere above and below the equatorial plane of the Sun. Observations in the extreme, high-latitude regions of the sun have not been made before, and evidence indicates that this region of space is greatly different from the region in which the Earth is located.

The U.S. spacecraft for ISPM was canceled on account of budget constraints. The issues raised by its cancellation are discussed in chapter 7.

PUBLIC ATTITUDES ON SPACE

Democratic government is based on the premise that there should be some linkage between public attitudes and political choice, not only in general but also with respect to specific issues on the public agenda. This linkage is not a one-way path, of course; public officials are leaders, teachers, and molders of public attitudes and opinion as well as representatives of the public in the political process. Thus, the following account of public attitudes about the space program needs to be interpreted with the understanding that general public opinion is only one determinant of public policy, and that its influence is rarely direct. Public opinion more frequently acts as a general constraint, setting boundaries within which political leaders are free to chose, or as an indirect shaping influence on the attitudes of elites inside and outside of government; most often, it is these attitudes that are closely correlated with specific policy choices.

From this analysis it follows that:

1. During the early years of the U.S. space program, the general public was willing to accept the interpretation of society's leaders as to the significance of space activities. This made it possible for the United States to first adopt a moderate response to Soviet space achievement, then to reverse policy and to enter into competition with the Soviets, even though public attitudes seemed to be opposed to such competition.
2. More recently, public understanding of the space program, and a supportive public attitude toward that program, have increased to the point where they may have political impact. Although an official's position on space-related issues may not be a crucial determinant of electoral success, prospace attitudes, and particularly, groups organized to reflect them, appear to be having some impact in influencing public policy with respect to the U.S. space program.

It is important, however, even if the second of these propositions is accepted, to recognize that "while it has considerable intellectual interest and entertainment value, space exploration is not a daily concern of the general public. . . . The levels of interest and information in this area are especially low."[5] Thus it is likely that public attitudes will provide the background, but not much more, against which national space policy will continue to be formulated.

Public Opinion and Space Policy: 1965-80

A striking example of a leadership decision not being constrained by apparent public opinion is the U.S. commitment to a manned lunar landing. In the very month that President John F. Kennedy announced that he was setting as a national goal a lunar expedition before 1970, the Gallup Poll reported that the public was opposed by a 58 to 33 percent margin to spending the up to $40 billion such an enterprise would require, Until very recently, only once since 1965 has the percentage of U.S. adults calling for the United States to do more in space exceeded the portion believing that the Government should do less. Figure 9 compares this division of opinion for the period

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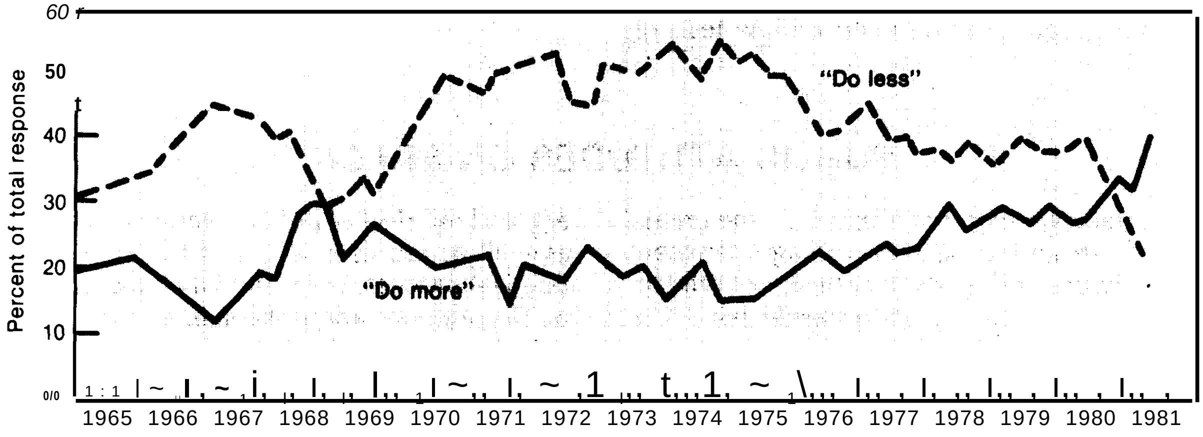
[5] National Science Board, Science *Indicators, /980,* p. 169.

Figure 9.–Long-Term Trend Polling Results of U.S. Public Opinion on the Federal Space Effort



NOTE: Responses to question of whether government should "do more" or "do less" In support of space exploration, 1985-1981.

SOURCE: For 1965-1975, Herbert Krugman, "Public Attitudes toward the Apollo Program, " Journal of Comrnurr/cations, vol. 27, No. 4 (1977), More recent data are derived from Trendex Polls taken for the General Electric Co.

from 1965 to 1981; the recent shift toward a markedly more prospace position is clear from this chart.

Table 10, which reports opinions for the 1973-**80 period,** is even more revealing, both in terms of the longer term trends and in terms of the current uprising in prospace opinion. Only in recent years have space "antagonists" comprised less than an absolute majority, and the explicitly prospace group grew only slowly, from **7.4** percent in 1973 to 11.6 percent in 1978. Most recently, however, the figure for those believing the United States is spending too little on space has jumped to 18 percent, and space antagonists are now only 39 percent of the total. The size of the "space neutral" segment has stayed constant, and thus the gain in support for expanded space spending appears to reflect a real shift in opinion. In 1980, for the first time, those of the opinion that space spending should not be lowered outnumbered those holding the opposite view, 53 percent to 39 percent.[6]

While prospace opinion appears ***to*** be increasing, the priority assigned to the space program has historically remained low. Tables 11 and 12 demonstrate this both for Government priorities in general (table 11) and for priorities within science and technology (table 12). What is most relevant in table 11 is that only the "military, armaments, and defense" category showed a greater increase in percentage in favor between 1977 and 1980 than did the "space exploration program," although this increase only moved space one rank up the priority scale. According to one analyst, "the increasing approval of space activities among Americans over the past several years is

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[6] Robert D. McWilliams, **"The Improving Socio-Political Situation of the American Space Program in the Early 1980' s," paper prepared for Fifth Princeton/AIAA Conference** *on* **Space Manufacturing, May 1981, p. 2.**

Table IO.—Distribution of Opinion Toward Federal Spending on the Space Program: 1973 Through 1980 (percentages)

	1973	1974	1975	1976	1977	1978	1980
Too little	7.4	7.7	7.4	9.1	10.1	11.6	18.0
About right	29.3	27.5	30.1	28.0	34.4	35.0	34.6
Too much	58.4	61.0	58.1	60.2	49.6	47.2	39.1
Don't know	4.7	3.6	4.4	2.5	5.9	6.5	8.3
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

SOURCE National Opinion Research Center Polls as reported in Robert D. McWilliams, "The Improving Socio-Political Situation of the American Space Program in the Early 1980s, " paper prepared for Fifth Princeton/AIAA Conference on Space Manufacturing, May 1981

Table 11.—Percentages of Americans Favoring Increased Funding, and Relative Priority Rankings, for 11 Areas of Federal Government Spending, 1977 and 1980

	1977 percent	1977 rank	1980 percent	1980 rank	Percent increase
Halting the rising crime rate	70.0	1	72.0	1	2.0
Dealing with drug addiction	**59.5**	2	**64.5**	**2**	**5.0**
Improving-protecting Nation's health	**58.5**	3	**57.1**	**4**	**– 1.4**
Improving-protecting the environment	**51.2**	**4**	**50.8**	**6**	**– 0,4**
Improving Nation's education system.	**49.5**	**5**	**54.9**	**5**	**5.4**
Solving problems of the big cities	**46.9**	**6**	**45.8**	**7**	**-1.1**
Improving conditions for blacks.	**27.3**	7	**26.2**	**8**	**– 1.1**
Military, armaments and defense	**25.7**	8	**60.2**	**3**	**34.5**
Welfare	**13.0**	9	14.0	10	1.0
Space exploration program	**10.7**	**10**	**19.6**	**9**	**8.9**
Foreign aid.	**3.7**	**11**	**5.4**	**11**	**1.7**

SOURCE' Robert D. McWilliams, "The Improving Socio-Political Situation of the American Space Program in the Early 1980s," paper prepared for Fifth Princeton/AIAA Conference on Space Manufacturing, May 1981

Table 12.—Public Priorities for Federal R&D Spending

Funding objective	Most preferred		Least preferred	
	Response	Rank	Response	Rank
Improving health care	815	1	60	12
Developing energy sources and conserving energy	754	2	40	14
Improving education	630	3	55	13
Reducing crime	587	4	82	11
Developing or improving methods for producing food	368	5	253	8
Reducing and controlling pollution	358	6	113	10
Developing or improving weapons for outer space	266	7	403	6
Preventing and treating drug addiction	259	8	195	9
Developing faster and safer public transportation	210	9	430	5
Improving the safety of automobiles	155	10	284	7
Finding better birth control methods	139	11	705	1,5
Discovering new basic knowledge about man and nature	135	12	577	4
Exploring outer space	99	13	705	1.5
Predicting and controlling the weather	60	14	592	3

SOURCE: Institute for Survey Research, Temple University, *National Survey of the Attitudes of the U.S. Public Toward Science and Technology*, submitted to National Science Foundation, May 1980, pp. 178-180. (This was a survey of 1,635 people over 18. Respondents were asked: "Which 3 areas . . . would you *most* like to receive science and technology funding from your tax money?" and "Which 3 areas . . . would you *least* like to have science and technology funding from your tax money?"

not a trend that is riding mainly on the coattails of militarism or growing faith **in science and technology. Rather, it seems that Americans may be coming to view the space program as being conducive to the achievement of other types of goals of which they are in favor. ”**[7]

One indication of what the public expects from space exploration is presented in table 13. A national survey taken for NSF asked adults to identify benefits they believed would result from exploring **outer space. Listed in table 13 are those benefits mentioned either first or second by respondents. What is striking about the results is the high ranking given to an indirect benefit of the program (“improve other technologies”) and the low rankings given to direct economic** benefits (“find industrial use,“ “create jobs and other economic benefits”). Compared with other technology-related issues such as nuclear power or chemical food additives, a greater proportion of Americans see space exploration as producing substantially more benefits than potential harm.[8]

It is possible to construct a profile of those who most “support” and those who most “oppose” the U.S. space program, if “support” and “oppose” are defined as deviations of more than 10 percent from the average of all Americans. Table **14** contains such a profile, Those who support the space program tend to have one or more of the following characteristics: male, between 25 and 34, college-educated, professional or technical employment, working for government, income over $25,000/year, and living in the West. Opponents of the space program tend to be: female, over 65, black, less than a high school degree, laborers and service workers, and under **$5,000** income. One more relevant characteristic that emerges from another opinion study is that those who support increased space spending are significantly more likely to vote than those who believe that too much is spent on space; over 72 percent of those who supported an increase in space budgets in 1980 voted in the 1976 Presidential election, while only 56 percent of those calling for reduced spending voted that year.[9]

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[7] **1 bid., p. 8**

‘National Science Board, op. cit., p. 170.

[9] McWilliams, **op. cit., p.** 16.

Table 13.—Perceived Benefits From Space Exploration

Benefits	First or second mention
Improve other technologies (e.g., computers)	272
Find mineral or other wealth, other resources, sources of energy	**200**
Increase knowledge of universe and/or of man's origins	190
Find new areas for future habitation	134
Contact other civilizations, other forms of life	107
Improve rocketry and missile (military) technology.	43
Find industrial use for space	27
Find new kinds of food/places to raise more food products	26
Create jobs and other economic benefits.	16
Learn about weather and how to control it.	13

SOURCE: Institute of Survey Research, p. 164

Table 14.—Profile of Public Attitudes of Space Exploration: "In General, Do You Favor or Oppose the Exploration of Outer Space?"

Group characteristics	Percent favor	Percent oppose
All	60	31
Men.	71	22
Women	49	38
Age 25 t0 34	70	23
Age over 65	34	**50**
Black	38	49
O to 8 years of schooling	32	50
9 to 11 years of schooling	40	50
Some college, no degree	74	19
Bachelor' s degree	79	15
Graduate degree	85	10
Professional or technical job.	78	16
Operatives and laborers	43	43
Service workers	47	41
Work for government	76	17
Under $5,000 income	31	55
$25,000 to $49,999 income	76	17
Over $50,000 income	74	15
Live in West	74	20

[a] Only those characteristics that differ by more than 10 Percent ‘rem overall opinion are included.

SOURCE: Institute for Survey Research, Vo/ *II, Detailed Findings*, p 170.

The demographic makeup of the "prospace" group appears to be undergoing some changes in recent years, although its general characteristics as profiled in table 11 have remained stable. Among those changes:

- recent increases in prospace attitude are much more marked among the most highly educated;
- formerly, "lower" and "working" classes were more antispace than were **"middle" and "upper" classes. Recently, however, the "middle" and "working" have become** more space positive than either "upper" or "lower" class respondents;
- prospace attitudes have increased substantially among whites and only negligibly among blacks; and
- support for space is increasing faster for divorcees than for any other marital class.[10]

There has been a suggestion that the shifts in space-positive attitudes with respect to variables of social class and education "provide a classic example of how social change tends to begin and develop in society. Innovations generally find their beginnings in the ideas and efforts of the more highly educated members of the upper-middle class and, if they survive and grow more prevalent in the upper strata, they then tend to catch on at the lower socioeconomic levels." The same analyst argues that "the resurgence of space-positivism in America since 1975 was spawned by the upper and middle social classes. The trend then began to spread throughout the general public with the classic pattern that has characterized other prominent American social movements such as the feminist and civil rights crusaders.'" [11]

One of the most striking recent developments in the space policy field is the emergence of a number of organized prospace groups. As the quotation just cited suggests, the aggregation of individual opinions into more-or-less broadly based interest groups with middle and working class roots is part of the traditional pattern by

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[10] McWilliams, op. cit., pp. 10-15.

[11] **Ibid., p. 14.**

which issues are given increased attention on the public agenda. perhaps this is what is happening with respect to space. The following section describes the recent emergence of a space interest group network.

Interest Groups and Space Policy

During the 1970's, interest groups organized around one or a few issues and claiming to represent broad sectors of the general population—so-called "public" interest groups—became an increasingly important influence on public policy. In part, the increased influence came at the expense of political parties as vehicles for articulating, influencing, and implementing the public's policy preferences.[12] Thus the rapid increase in space interest groups in recent years may be a development of political significance. A May 1980 survey of space interest groups identified 39 organizations with nationwide activities.[13] In the past 2 years, and particularly with the transition in administrations, there have been a number of one-time efforts organized ad hoc to mobilize opinion on space policy; these groups have provided a base for such mobilization efforts.

There is an active "Coordinating Committee on Space" that attempts to identify areas of agreement and disagreement among the major pro-space groups; its membership includes 11 of the most active organizations. There are two general types of prospace groups: 1) traditional professional groups, and 2) citizen support groups. Most prominent among the former are:

- ***American Institute of Aeronautics and Astronautics,*** the professional society for people in the aeronautics and astronautics field, with almost 30,000 members.
- ***American Astronautical Society,*** a group of individuals with professional interest in space. Current membership is about 1,000.
- ***Aerospace Industries Association,*** a consortium of major aerospace firms that functions as a trade association.
- ***National Space Club,*** a Washington-based group of business and government leaders in the space field.
- ***University Space Research Association,*** a consortium of universities active in space research that operates several facilities under NASA contract.

Among the most active and/or largest of the public interest or citizen support space groups are:

- ***Delta-Vee,*** a citizen-supported, nonprofit corporation that channels public contributions into the support of specific space activities, such as the continued operation of the Viking spacecraft on Mars and a U.S. Halley's Comet Mission.
- ***High Frontier,*** a group formulating a national strategy to make maximum use of space technology to counter the threat of Soviet military power, to replace current nuclear strategy with one based on space defense, and to promote the industrial and commercial potentials of space.
- ***Institute for the Social Science Study of Space,*** which sponsors research and publications related to the social science aspects of space exploration and development.
- ***L-5 Society,*** which emphasizes human settlement in space as a long-term goal. Founded in 1975 by Gerard K. O'Neill, it has broadened its scope to most aspects of space policy. Its membership is between 3,000 and 4,000 individuals.
- ***National Space Institute,*** the largest of the broadly based space groups, with over 10,000 members. Founded in 1975 by Wernher von Braun, its emphasis is on communication with general audiences.
- ***Planetary Society,*** which promotes awareness of and public involvement in planetary exploration and search for extraterrestrial life. Publishes newsletter, supports research, organizes meetings. Has grown to over 100,000 members in just over a year.

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[12] Charles Chafer, "The Role of Public Interest Groups in Space Policy, " Jerry Grey and Christine Krop (eds.), *Space Manufacturing III,* Proceedings of the Fourth Princeton/AIAA Conference (New York: American Institute of Aeronautics and Astronautics, 1979), pp. 185-189.

[13] Trudy Bell, "Space Activists on the Rise, " *Insight,* August-September 1980, pp. 1, 3, 10, 13-15.

- Space **Foundation,** a private foundation for support of space industrialization.
- ***Space Studies Institute,*** a research performing and supporting group with focus on use of nonterrestrial resources.
- ***World Space Foundation,*** a group supporting research projects to accelerate space exploration (e.g., solar sail).

The purposes of these and other space groups fall into three general categories:

1. educating and informing the public;
2. conducting research themselves; and
3. funding external research.

Recently added to the list are groups explicitly engaging in political activities. There were attempts to organize prospace Political Action Committees (PACS) for the 1980 election, and at least one prospace PAC remains in existence.

The influence of these various organizations and groups on space policy is difficult to estimate. Certainly, as the Reagan administration took office in january 1981 and as the proposed NASA budget was cut several times in the following year, there have been a number of attempts by one or a coalition of these groups to mobilize opinion in support of specific projects (e.g., a mission to Halley's Comet) or for the civilian space program in general. Whether the reductions in the NASA budget would have been even more severe, had not these groups been active, is a question difficult or impossible to answer.

Finally, note should be taken of the emergence of a Congressional Space Caucus, and a supporting Congressional Staff Space Group. This caucus is initially limited to the House of Representatives; its goal is to increase the awareness of Members and staff of the benefits of the Nation's space effort.

Space Achievement and Public Opinion: 1981

With two successful flights of the shuttle *Columbia* and the encounter of Voyager 2 with Saturn, 1981 was a year of spectacular space achievement for the United States. Several public opinion polls have confirmed that the citizens of the United States were quite supportive of these achievements.

- A May 1981 Harris survey, taken less than 1 month after the initial shuttle flight, found 76 percent of Americans calling the shuttle "a major breakthrough for U.S. technology and know-how' and a 63 to 33 percent majority favoring the expenditure of several billions of dollars over the next decade to develop the full potential of the shuttle. The Harris poll noted that "after the 1969 Moon landing, a 64 to 30 percent majority did not feel it was worthwhile to spend an additional $4 billion on the Apollo space program" and commented that "current support for spending on the space program is even more significant in view of the current overwhelming preference for cutting Federal spending. "
- An August 1981 Associated Press-NBC survey found that 60 percent of U.S. adults thought that the United States was not spending enough or was spending about the right amount on the space program, and 66 percent believed that the shuttle was a good investment for the United States.
- An October 1981 Associated Press-NBC poll confirmed the results of the earlier survey, finding that 60 percent of respondents think the shuttle program is a good investment, 30 percent do not, and 10 percent aren't sure.

A further examination of the results of the May Harris poll suggests both that support for the space program is not evenly distributed across all strata of U.S. society and that the reasons for the support differ substantially among respondents (see tables 15 and 16). The August poll found that 49 percent of respondents believed that the emphasis of the Nation's space program should be primarily on national defense, 32 percent cited scientific exploration, 10 percent cited both, and 9 percent were not sure. By October, these responses had shifted, with 43 percent in support of a defense emphasis and 40 percent favoring an emphasis on scientific exploration. In this latter poll, 46 percent of respondents believed that the United States should keep its space program

Table 15.—How Would You Rank the Importance of Various Uses of the Space Shuttle?

	Very important	Only somewhat important	Not very important at all	Not sure
	Percent	*Percent*	*Percent*	*Percent*
Doing experiments with new pharmaceutical products that can help cure disease	82	11	5	2
Developing a military capability in space beyond what the Russians are doing.	**68**	**20**	**10**	**2**
Putting new communications satellites in space at a much lower cost	64	25	9	2
Doing scientific research on metals, chemicals, and living cells in space .	55	27	16	2
Picking up other U.S. space satellites and repairing them in space.	47	32	19	2

SOURCE: May 1981 Harris Survey.

Table 16.— "IS the Space Shuttle Program Worth Spending Severai Billion Dollars Over the Next 10 Years to Develop its Full Potential?"

	Worth it	Not worth it	Not sure
	Percent	*Percent*	*Percent*
Total	***63***	33	**4**
College educated	**71**	26	**3**
Men	76	21	
Women	52	43	**3**
Blacks	45	53	**2**
Republicans	71	***26***	**3**
Democrats	57	***39***	**4**
Conservatives.	66	**30**	4
Liberals	57	**41**	2

SOURCE: May 1981 Harris Survey.

separate from the programs of other nations, 32 percent favored a joint space program between the United States and the U. S. S. R., and 15 percent favored joint ventures with other countries, but not with the Soviet Union.

Opinion polls, taken singly, do not reveal fundamental views underlying the shifting tides of opinion. Thus, the facts that by 1981 the success of the shuttle and of the Voyager missions spurred public interest in the U.S. space program and that a clear majority of the public was found to favor the program do not in themselves prove that there is deep public support for space. But, viewed in the context of a quarter century of space activities, the recent upswing in opinion in favor of the space program appears significant.

First of all, current support is part of a long-term trend of increasing support. It cannot, therefore, be explained as the result only of shuttle and Voyager successes. Second, the trend of increasing support coincides with the proliferation and growth of citizens' support groups. As public education about space is perhaps the major overall goal of these groups, their efforts have been the effect, if not the cause, of continued rising interest in space. Third, the Space Caucus, arising as a "back bench" movement within Congress, rather than in response to the leadership, is evidence for a genuine space constituency, i.e., one whose real interests, economic, political, or scientific, are at stake. These three conditions suggest that public awareness of space issues is increasing and that official space policy may begin to receive more constant scrutiny among at least the attentive public. This would seem to bode well for those who believe that increased understanding of the benefits of U.S. activity in space will lead to continued and firmer public support for that activity.