Highlights
IN
Space

PROGRESS IN SPACE SCIENCE, TECHNOLOGY AND APPLICATIONS, INTERNATIONAL COOPERATION AND SPACE LAW

1996

UNITED NATIONS

A/AC.105/654

Office for Outer Space Affairs
Vienna

Highlights in Space

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United Nations
New York, 1997

INTRODUCTION

This publication has been compiled from two reports prepared for the United Nations Committee on the Peaceful Uses of Outer Space, and covers the period from 1 November 1995 through 31 October 1996. The first part of the report, on space technology, applications, international cooperation and space law, was prepared by the International Astronautical Federation (IAF). The International Institute of Space Law (IISL) provided input for the section on space law. The second part, which focuses on space science, was prepared by the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU). Many of the most prominent international experts from many countries have contributed to this comprehensive and authoritative survey. The information it contains reflects the wide range of space activities currently being conducted in many national and international space programmes. A list of contributors is located at the end of the report. This publication is being circulated only in the language in which the reports were prepared and submitted.

This review of recent developments in space science, technology, applications, international cooperation and space law is intended to provide information on these developments to a broad international audience. First published in 1992 as part of United Nations activities undertaken for International Space Year, the publication seeks to increase the awareness of all countries of the benefit of space activities.

It is hoped that this publication will make a significant contribution to the ongoing United Nations effort to disseminate information on space activities and to highlight the benefits they provide to all countries of the world.

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PART ONE:

1996 HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS

I. OVERVIEW

The major shift of space investment from government to commercial sources continued apace this year. Estimates assembled by Euroconsult in March indicate that spending for space by the world's governments in 1996, including military programmes, totaled about $37 billion, with the U.S. share at $27 billion, western Europe $5.1 billion, Japan $2.2 billion, China $1.3 billion, Russia $465 million, and India $330 million. In contrast, the U.S. magazine *Via Satellite* estimated in July that $54.3 billion would be invested by the private sector in commercial communications satellites (including their launches) between 1996 and 2000. This forecast does not include other commercial space ventures, nor does it include investments in Russian or Chinese satellites. The rapid growth rate projected for private-sector investment was supported by the Commercial Space Transportation Advisory Committee (COMSTAC, USA), whose August report estimated that 460 medium-to-heavy geostationary-orbit communications satellites alone would be developed and launched by 2010.

Moreover, the investment in satellite communications ground stations over the same period is estimated at about $70 billion, exceeding that for the space sector. A study released by Frost and Sullivan (USA) in March projected a doubling in the ground-station market from $10.7 billion annually in 1995 to $22 billion in 2001. The study also identified a major change in market share, with fixed-site stations shrinking from 95 percent of the market in 1995 to 70 percent in 2001, while the markets for mobile stations are expected to grow from 5 percent in 1995 to 30 percent in 2001.

This increase in relative investments in space by the private sector is also reflected in some shifting of the previously reported trend toward the use of smaller satellites. While ever-tighter constraints on government budgets worldwide continue to strengthen the emphasis on shrinking the size and mass, and therefore the cost and risk, of both civil and military spacecraft, the burgeoning market for commercial communications services has driven satellite manufacturers and operators in the opposite direction. Hence this sector of the market shows a steady growth in satellite mass, to accommodate the increased demand most efficiently. COMSTAC's August report projected that more than half of commercial payloads launched to the geostationary orbit in the next 5-10 years will weigh over 4100 kg.

The advanced technology that allows miniaturization of spacecraft components and subsystems with little or no loss in performance or reliability is becoming the dominant factor in the evolution of *both* small and large satellites. These improvements reduce cost and risk reduction and enable the use of smaller, less costly launchers for the small satellites and give the larger ones far greater capability, longer life, higher power, and better reliability.

The great success of the Galileo mission to Jupiter, despite the crippling loss of its main antenna early in the mission and later a host of worrisome but fortunately temporary technical problems, demonstrated an important continuing role for large, complex spacecraft in the new "smaller, faster, cheaper" milieu. The first spectacular data from Europe's Solar and Heliospheric Observatory (SOHO), launched this year, reiterate the key role played by large scientific spacecraft. Moreover, the discovery on Earth of two Martian meteorites that show strong evidence of organic material and possibly fossilized life forms may change the parameters of future Mars missions, with a possible trend toward the necessarily larger and more complex systems needed for subsurface archaeological exploration and sample return capabilities.

1996 saw steady progress toward the goal of completing the international space station. The promise of last year's first joint Shuttle-Mir mission was borne out by three more successful linkings and crew interchanges, and the long-awaited European commitment to the Columbus module was finally implemented.

The planning for deployment and operation of the space station, however, continued to highlight a major concern for all future space missions: the high cost and operational constraints imposed by the use of current launch systems. The programmes initiated by the United States last year to counter this trend by developing new, low-cost reusable vehicles moved ahead in 1996 with the selection of a contractor to develop the X-33 suborbital technology demonstrator and eventually build an orbit-capable commercial reusable vehicle called VentureStar. Perhaps even more important, several nations began pursuing propulsion and other technologies for the next-generation launch system *beyond* VentureStar. This finally begins for space flight the key process behind the success of automotive and air transportation: establishing and maintaining a "pipeline" of progressively more advanced and capable launch systems.

The problems of sustaining a low-cost, reliable space-launch infrastructure using current technology, highlighted by a string of failures last year, continued to plague the space enterprise in 1996. The most serious of these was the loss of Europe's new Ariane-5 on its maiden flight due to improper design of flight-control software. The failures of the U.S. Clipper Graham suborbital technology demonstrator, two more Chinese Long March launchers, and even two eminently reliable Russian Soyuz rockets and a Proton emphasized the need for renewed emphasis on truly operational launch-system development.

Nevertheless, the continuing strong demand for launch services, especially in the fast-growing commercial market, was reflected by a number of advance orders placed this year by satellite builders for multiple launches of both current and new expendable rockets. Such a multiple order last year launched McDonnell Douglas's new Delta-3; several this year placed the new Boeing-Kvaerner-Yushnoye-Energiya Sea Launch system on a firm financial footing, and the prospects for such orders spurred Japan's NASDA to invest heavily in the H-2A and Lockheed Martin to develop the essentially new Atlas IIAR, which features a new Russian engine.

II. SPACE TRANSPORTATION

Current Launch Activities

The Pegasus XL (USA) successfully orbited an experimental U.S. Air Force satellite on 8 March, following failures of the vehicle's first two launch attempts in June 1994 and June 1995 (see last year's report). The mission of the $5-million, 110-kg Rex-2 satellite, placed in an 830-km polar orbit, is to test the effects of atmospheric disturbances on radio transmissions and to demonstrate for the first time the use of Global Positioning System satellites for satellite navigation. The final flight of OSC's smaller Pegasus vehicle occurred on 16 May, with the successful launch of the USAF's MSTI-3 technology satellite. A second successful Pegasus XL launch on 2 July placed NASA's long-delayed Total Ozone Mapping Spectrometer into its polar orbit, and a third-in-a-row success followed on 21 August with the launch of another NASA satellite, the Fast Auroral Snapshot (FAST) mission (see below).

Space Systems/Loral signed an agreement with Arianespace on 1 May for five launches, one firm (1998) and four options, and in July ordered five more firm launches through 2001 from Sea Launch. Loral also has booked five flights with International Launch Services for Proton launches, plus two Atlas IIARs (see below). The new agreement brings Loral's total commitment for spacecraft launches to 17. Loral also committed as many as 10 launches by yet-to-be-developed Evolved Expendable Launch Vehicles, contingent on a contract award by the U.S. Air Force (see below).

On 6 June, the U.S. Secretary of Defense authorized the conversion of up to five surplus Minuteman ballistic missiles to space launchers for small satellites. One such conversion has been approved, to launch the Joint Academy-Weber State Satellite (Jawsat) on a converted Minuteman-2 in 1998, at cost of $11.5 million. Target price for the remaining four, each of which must be approved on a case-by-case basis by the U.S. Defense department, is $9 million each. The Pentagon must report on the actual costs after completion of the five launches.

On 9 April, the first commercial Proton launch of a Western satellite lifted Astra-1F, a European direct-broadcast satellite, from Baikonur Cosmodrome in Kazakhstan. The launch was marketed and contracted by International Launch Services (ILS), a joint venture of Khrunichev (Russia), Energiya (Russia) and Lockheed Martin (USA).

The first commercial contract for a Kosmos launch was signed on 14 December 1995, by the Russian vehicle's manufacturer, AKO Polyot, with the Technical University of Berlin (Germany). The 35-kg payload, DLR-Tubsat, is scheduled to fly as a secondary payload late this year from the Plesetsk Cosmodrome. The Kosmos can lift 1,300 kg into a 400-km polar orbit. Price of the Tubsat launch was approximately $235,000.

The Block DM fourth stage of a Proton launch vehicle exploded on 19 February, leaving a Raduga communications satellite in a useless elliptical orbit along with an estimated 190 pieces of trackable debris. The cause was later traced to a loose fuel pipe to the stage's engine. Two Soyuz-U rockets also failed in attempting to launch military satellites, one on 14 May and another on 20 June, but they were followed on 1 August and 19 August by successful Soyuz launches to Mir.

A new French-Russian joint venture named Starsem was formed on 17 July to market Soyuz and Ariane rockets. Partners are Aerospatiale (France), which holds 35 percent of Starsem, Arianespace (France), with 15 percent, the Russian Space Agency, with 25 percent, and the Soyuz's builder, the Samara Space Center (Russia), with 25 percent. The company's goal is to market about 12 low Earth orbit launches per year for payloads in the range 2.5 to 5 tonnes, complementing Ariane-5 at the low end of the payload scale. A new upper stage called Icare is being developed by Aerospatiale and Samara for some of the projected missions. The first commercial Soyuz vehicles will launch two or three Globalstar satellites into low Earth orbit in 1998 as part of the new venture.

In another international joint venture, announced on 9 October, Akjuit Aerospace (Canada) will launch Start rockets built by STC Complex (Russia) from SpacePort Canada at the Churchill Research Range in Manitoba. Both the four-stage Start-1 and the five-stage Start vehicles are being marketed to launch small satellites into polar, Sun-synchronous, and other high-inclination orbits beginning late in 1998. If successful, the venture will mark the first launching of one nation's vehicles from another's launch site.

The most heavily insured launch in history ($420 million) occurred on 6 December, when an Ariane 44L successfully orbited France's 2280-kg Telecom-2C and India's 2050-kg Insat-2C from Kourou's Guiana Space Centre. Telecom-2C carries a Syracuse-2 military communications payload of five X-band transponders for France's Delegation Generale pour l'Armement (DGA) and a civil payload of 10 C-band and 11 Ku-band transponders for France Telecom. Insat-2C was subsequently co-located with Insat-2B to provide television, business communications, and mobile communication services.

In its first attempt since January 1995 during a failed launch of a Hughes-built ApStar-2 satellite, China Great Wall Industry Corporation's Long March 2E successfully launched on 28 November 1995, AsiaSat-2, a Lockheed Martin Series 7000 spacecraft. Because of the lack of information on the cause of the prior failure (as well as a similar one in December 1992), the insurance premium for the launch was 27 percent, significantly higher than the then-current industry average of 17 percent to 20 percent.

China's new Long March 3B failed on 15 February at Xichang, 25 seconds after its first launch, killing six people, injuring 57, and destroying its payload, an Intelsat 708 satellite built by Hughes. The cause was subsequently reported to be a malfunction of the vehicle's inertial guidance system two seconds after ignition. The launch was the second in a series of 10 Intelsats (the first by a Long March rocket) covered under an insurance premium of $185 million purchased by Intelsat in 1994. Premiums for the three Long March launches covered by this package had been set at 13 percent. The loss cost the insurers $205 million.

The successful liftoff on 3 July of a standard Long March 3, which placed the 1,400-kg Hughes HS-376 Apstar-1A into a geosynchronous transfer orbit for APT Satellite Company (Hong Kong), returned China to its commercial launch programme. However, China suffered another serious setback on 18 August when another Long March 3 failure left the 3,500-kg Hughes-376 ChinaSat-7 stranded in a useless orbit with an apogee of only 22,000 km. The failure occurred when the launcher's liquid oxygen–liquid hydrogen third stage started its second burn 40 seconds too early and then cut off 48 seconds short of the scheduled 328-second burn time. All three of the recent Long March failures were caused by different malfunctions.

The Long March programme suffered another blow on 4 September when Hong Kong's Asia Satellite Telecommunications Co. (Asiasat) filed an insurance claim of $58 million for damage to AsiaSat-2 caused by an alleged "rough ride" during its launch in November 1995 by a Long March 2E (see above). AsiaSat claimed that excessive acceleration caused by the launcher knocked the antenna feed horns of the spacecraft's nine Ku-band transponders out of alignment, reducing effective coverage and transmission power to the company's customers.

On 21 March, India's four-stage Polar Satellite Launch Vehicle (PSLV-D3) successfully lifted the 922-kg remote-sensing satellite IRS-P3 from Sriharikota into a Sun-synchronous 807 x 816-km orbit. It was the second success in a row for the developmental version of PSLV; the first operational launch is scheduled for next year. IRS-P3 carries two remote-sensing payloads, a wide-field sensor, a German modular opto-electronic scanner, and an X-ray astronomy instrument.

Development Activity

On 7 November 1995, Lockheed Martin announced development of the Atlas IIAR, an upgraded commercial Atlas launcher model. Besides increasing the geosynchronous transfer orbit payload capability of the Atlas line from the IIAS's 3,700 kg to about 4,000 kg, the new variant is expected to cut launch costs by over 25 percent, reduce time on pad, and improve operational reliability, all as a result of significantly reduced vehicle complexity. The new Atlas dominates a $300-million launcher-upgrade investment by Lockheed Martin Astronautics. Its key innovations are replacement of the 3-engine stage-and-a-half booster/sustainer by a single-engine, single-stage booster and replacement of the 2-engine Centaur upper stage by a single-engine version. In January Lockheed Martin downselected the developmental Russian Energomash RD-180 over the existing Russian Samara NK-33 for the booster engine. The RD-180, a new half-scale derivative of the Ukrainian Zenit's operational 6-MN RD-170 first-stage booster power plant, offers the new Atlas vehicle significant growth potential to meet the projected forthcoming increase in commercial satellite payload requirements. The engines will be supplied by a joint venture between Energomash (Russia) and Pratt & Whitney (USA). First launch of the Atlas IIAR is scheduled for Space Systems/Loral in December 1998, the first of Loral's firm order for two Atlas IIAR launches.

Work on the cooperative X-34 small launcher development programme (see last year's report) was stopped on 24 January by Orbital Sciences Corporation (OSC), a partner with Rockwell International in American Space Lines (ASL). Citing higher costs than expected and concerns about using a government-owned aircraft (NASA's B-747) as a launch platform, ASL subsequently withdrew its commitment of $100 million to the vehicle's development in February after having spent about $15 million. This decision followed a disagreement among the three partners on which engine to select for the X-34's reusable-stage power plant: the Russian Energomash RD-120M, a modification of the Ukrainian Zenit's upper-stage RD-120, or the U.S. Rocketdyne RS-27, which powers the McDonnell Douglas Delta's first stage. Intervention by the White House was not successful in preserving the programme.

A scaled-down X-34 successor effort, fully funded by NASA with the $62 million remaining of the initial $70-million NASA share, was awarded to OSC on 10 June; the final 30-month contract was signed on 29 August. Unlike the original X-34 concept, it will not reach orbit but will serve as a suborbital testbed for reusable launch technologies to supplement the X-33 programme (see below). The X-34 is expected to be able to fly to an altitude of 75 km and reach speeds up to Mach 8, beginning late in 1998. The new single-stage suborbital design calls for a vehicle 17.4-m long weighing 20,250 kg, about one-third the size of the original two-stage orbit-capable X-34 configuration. It will be launched from OSC's L-1011 airplane flying out of the White Sands Missile Range, New Mexico, or the Kennedy Space Centre, Florida. The agreement includes two powered flight tests of the X-34, with a potential option for 25 more during an additional 12-month period.

On 2 July, NASA downselected Lockheed Martin as the contractor for the suborbital X-33 technology demonstrator programme, based in part on the company's plan to develop a privately financed reusable single-stage orbital launcher, designated VentureStar, upon completion of the X-33 effort (a NASA official had stated on 1 May that NASA may contribute some funding to the development of the orbital vehicle that follows X-33). VentureStar, a scaled-up version of Lockheed Martin's X-33 design, will incorporate a lifting-body configuration and a new Rocketdyne hydrogen-oxygen linear aerospike engine (see below). The contract calls for completing 15 flight tests of the X-33, which will incorporate all the new technologies needed for the operational VentureStar version, by March 1999. NASA committed $941 million to the X-33; Lockheed Martin pledged $220 million, and the state of California will provide $30 million in tax incentives and ground transportation infrastructure.

The DC-XA (later renamed Clipper Graham) was converted from the Department of Defence's DC-X that flew in 1994 to evaluate and flight-demonstrate several technologies for reusable launch vehicles, most notably a Russian-built aluminum-lithium oxygen tank and composite materials for the aeroshell, the hydrogen tank, the intertank, and propellant feedlines. Its first flight, on 18 May, was marred by an external fire during landing after a successful 60-second flight. The fire caused superficial damage to the vehicle's outer shell, but all test objectives of the flight were achieved. Its third flight, on 7 June, demonstrated a 26-hour turnaround time, the shortest for a reusable rocket-powered vehicle since the DC-X's seven-day turnaround in June 1994.

The DC-XA continued its five-flight planned programme on schedule until its fourth flight on 31 July, when failure of one of its landing-gear legs to deploy caused a fire that destroyed the vehicle. The four Clipper Graham flights achieved most of the flight demonstration goals of the DC-XA programme, but left untested the Aerojet hydrogen-oxygen auxiliary propulsion system. That system was to have been a testbed for the X-33 reaction control system, which was contracted to GenCorp Aerojet on 1 August.

On 25 July, NASA announced its intent to award 15 contracts to seven companies, totalling about $10 million, for the agency's Low Cost Boost Technology project. The goal of the programme is to "leverage" commercially available technologies that will enable the development of a new low-cost launch system for small payloads; i.e., about 225 kg to low Earth orbit at a cost of the order of $1 million, or $900 per kg. The winning companies were Campbell Engineering, Dean Applied Technology, Lockheed Martin, Phase IV Systems, Pratt & Whitney, Rocketdyne, and Thiokol.

On 14 December 1995, Hughes Space and Communications (USA) placed an order with Sea Launch Co. (USA) for 10 launches over the five-year period 1998-2002, plus several options. Sea Launch is a joint venture of Boeing (USA), Kvaerner A/S (Norway), NPO Yushnoye (Ukraine), and RSC Energiya (Russia). Boeing is the system integrator; Kvaerner is building the 28,000-tonne oceangoing launch platform and tender; Yushnoye provides the Zenit launch vehicle, and Energiya is to supply the upper stage. The upgraded launcher is claimed to be able to deliver 5500 kg to a geosynchronous transfer orbit.

The 10-launch agreement, which is estimated at $1 billion, further strengthens the role Hughes appears to have assumed as "launch customer" for new vehicle systems, following the 10-launch order Hughes placed last year for the new McDonnell Douglas Delta-3. On 25 October, Hughes added three more Sea Launch and three more Delta-3 launches for a total of 13 each.

An interesting perspective on the U.S. Department of Defense's (DoD's) Evolved Expendable Launch Vehicle (EELV; see last year's report) appeared with the announcement on 22 October that Space Systems/Loral (USA) has committed the purchase of 10 commercial launches from one of the four EELV contractors, Alliant Techsystems (USA), beginning in 2002. The order is, of course, contingent on Alliant's success in winning the award. The other three EELV contractors are also seeking commercial contracts for their vehicles, which have the goal of reducing DoD's launch costs by 25 percent to 50 percent over the next 20 years, starting in 2001. Loral's interest in Alliant's "Low-Cost Launch Vehicle" is based both on lowering launch costs and on the vehicle's capacity to launch the company's big new 4,000-kg FS-1300 satellite bus.

Kistler Aerospace Corporation (USA) filed an application on 16 September with the Federal Aviation Administration's (FAA's) Office of Commercial Space Transportation for approval of six test flights of its two-stage reusable K-1 orbital launch vehicle prototype at the U.S. Department of Energy's Nevada test site. The new vehicle, whose development is being financed wholly with private-sector funds, will use Russian NK-33 engines provided by Aerojet GenCorp (see below). It was the first application filed with the FAA office for a reusable launcher.

On 4 October, Motorola Satcom (USA) announced that it had obtained no-cost options for 10 launches of Iridium satellites aboard a new launch vehicle, the Eclipse E-100 Astroliner, to be developed by Kelly Space and Technology (USA). The new reusable launcher will be towed to altitudes up to 12 km by a Boeing 747 aircraft, after which its three stages will lift payloads up to 1600 kg into low Earth orbit. The first stage of the winged Eclipse vehicle is to be powered by a Russian NK-33 engine; the two upper stages will use solid-propellant Thiokol motors, the Star 48B and the Star 63F. Alternative first-stage engines are Rocketdyne's RS-27 and MA-5, the Russian NK-31, or the Russian RD-180. Launch cost is estimated at $10 million; Motorola's 10-launch contract, signed on 28 October, is priced at $89 million. Kelly plans three stages of development: a suborbital Eclipse Sprint using modified F-106 supersonic fighter aircraft, scheduled to begin flying in mid-1997; a small rocket-powered Eclipse Express, which will ready to carry small payloads (e.g., 80 kg) into low Earth orbit early in 1998; and the E-100 Astroliner, whose first launch is expected late in 1999.

The inaugural flight of ESA's new heavy-lift Ariane-5 launch vehicle ended 40 seconds after launch on 4 June, when the vehicle was destroyed by high aerodynamic loads resulting from an excessively sharp turn. The turn was subsequently traced to improper software design and incomplete testing of software in the alignment platforms of both the main and backup inertial guidance systems, which fed wrong information to the flight-control computer and caused it to order the abrupt turn. The inertial platform had flown successfully for years on Ariane-4, but had not been changed or tested for Ariane-5. Tests subsequent to the failure revealed that the alignment software was unable to process the new vehicle's higher acceleration and different relative position to the ground. The failure occurred when the payload fairing enclosing the four Cluster scientific satellites collapsed at 3.5-km altitude with the vehicle traveling at 857 km/hr., activating the vehicle's onboard self-destruct system. The two solid-rocket boosters operated satisfactorily up to the failure. The failure and the work required to correct it have delayed the next Ariane 5 flight until at least mid-1997 and will add at least $300 million to the $8.5 billion already invested in vehicle development since 1985.

Japan announced in June a number of changes in the H-2A upgrade of the H-2 launcher (see last year's report). These include the use of monolithic carbon-fiber composite casings for the solid-propellant boosters, which will produce 420 tonnes of thrust compared with the H-2's 327 tonnes, carry up to 10 tonnes more propellant, and burn for 100 seconds instead of 88. The liquid-propellant core engine for the first stage will also be upgraded to the LE-7A, which has a higher thrust-to-weight ratio than the H-2's LE-7, and the second-stage's LE-5B (see below) will be a simplified, higher-thrust, lower-cost version of the H-2's LE-5A. Launch preparation time will also be cut from 25 days to 20 days.

The H-2A can also use different boosters for different payload ranges, like the Ariane-4. The basic configuration, with two solid rocket boosters, can place four tonnes into a geosynchronous transfer orbit. Adding a liquid-rocket booster that uses twin LE-7A engines increases payload capability to six tonnes. A third configuration using one more liquid-rocket booster can lift about 7.3 tonnes to a geosynchronous transfer orbit.

In September, Rocket Systems Corporation, which was created to market commercial launches of the H-2 and H-2A, negotiated its first commercial contract with Hughes Space and Communications (USA). The contract calls for 10 H-2A launches at an average price of only $78 million, less than half the current cost of an H-2. The European Space Agency also announced on 10 October that the maiden flight of the H-2A in 200 will launch ESA's 2500-kg experimental data-relay satellite Artemis to its geostationary orbit. Japan's NASDA has agreed to launch Artemis at no cost to ESA, in exchange for using 40 percent of its capacity.

III. UNMANNED EARTH ORBITAL ACTIVITIES

Telecommunications

Fixed-Base Communication Systems

The third U.S. high-power direct broadcast service (DBS) was initiated in February by EchoStar Communications, following the successful launch on 28 December 1995 of the company's EchoStar-1 satellite aboard a Chinese Long March 2E rocket. The Digital Sky Highway (Dish) Network broadcasts 100 television channels to small (46-cm) antennas, following similar services initiated in June 1994 by DirecTV and U.S. Satellite Broadcasting. Another 100 channels were added on 1 November by the launch on 10 September of EchoStar-2, another 16-transponder Lockheed Martin Series 7000 spacecraft, aboard an Ariane 42P. By the end of 1995 DirecTV and USSB had garnered over 1.7 million customers; the medium-power direct-broadcast service supplied by Primestar Partners (USA) to 91-cm antennas had attracted about 500,000 more, for a total at the end of last year of about 2.2 million. The customer base for the three suppliers had increased to over 3.8 million by 30 September and is expected to top 5 million by the end of this year.

The phenomenal growth of the direct-broadcast market became apparent early in the year when U.S. communications company MCI paid over $682 million for the last remaining geostationary orbit slot (at 110 degrees west longitude) able to reach the entire continental U.S. MCI's winning bid came after 18 rounds of an auction held by the U.S. Federal Communications Commission (FCC) in January. On 31 July, the intense competition for this burgeoning new satellite communications market spurred a U.S. price war between EchoStar and AT&T (which in July bought into the DirecTV partnership), bringing the price of the ground equipment needed for DBS programmes down from the $500–$1,000 range to as low as $199. After EchoStar announced the new low prices on 31 July, AT&T immediately followed suit on 1 August. Adding to the competitive scene, MCI Communications applied on 1 August to the FCC for two DBS orbital slots currently held by Intelsat.

On 31 July, NASA and the U.S. Department of Defense endorsed a proposal by the 21-company consortium the Satellite Industry Task Force for a nine-year, $2-billion joint industry-government programme to improve the competitiveness of the U.S. commercial satellite industry by developing advanced high-data-rate communications technologies, including the seamless integration of satellite and ground-based communications systems.

On 7 May, the FCC issued licenses to six companies for domestic U.S. satellite communications services from a total of 11 new spacecraft. In addition to extending the services of the three current licensees, AT&T, GE Americom, and Hughes Communications, the new ruling opened the U.S. fixed-satellite service market to new entrants Loral, Echostar, and Orion. The action was the first since 1988 to license a new operator.

A joint venture agreement was signed on 9 February by Loral Space (USA) and RJSC Gasprom, JSC Gascom, and RKK Energia (Russia) to build, launch, and operate geostationary-orbit and Molniya-orbit communication satellites and other communications projects. The first two 1,350-kg Yamal satellites, scheduled to be launched on a single Proton next year, will link a Gasprom network of very small aperture terminals (VSATs). They are being built by RKK Energia using a Loral communications electronics package of nine 10-W transponders and will be operated by RKK Energia, marking that manufacturing firm's first venture into the marketing and delivery of satellite communication services.

On 28 March, Alcatel Espace (France) announced a new 60-satellite communication system called Sativod to provide broadband data and interactive video service in low-population-density areas around the world beginning in 2001 or 2002. The $3-billion system would use a global constellation of 600-kg satellites in 1,600-km orbits, and would employ the electronic capability developed by Alcatel in building the payloads for Space Systems/Loral's 56-satellite Globalstar system.

On 10 June, Matra Marconi Space (France) announced its new spacecraft series, Eurostar 3000. The big, new spacecraft, designed to compete with Hughes' high-power HS-702 series, will generate 16 kW of electric power, is expected to weigh over 4 tonnes, and carry up to 1 tonne of electronic payload. The company also announced a new $750-million Europe Africa Satellite Telecommunications (EAST) project that will bring telephone service to areas poorly served by ground-based networks.

Israel's 996-kg Amos-1 communication satellite was launched on 15 May by an Ariane 44L, along with Indonesia's Palapa C2, and went into service on 1 July. Amos-1 carries seven active and two backup Ku-band transponders, and has a design lifetime of 11 years. It was built by MBT, a subsidiary of Israel Aircraft Industries, and its services are being marketed by Israel's Spacecom to newsgathering agencies, cable television operators, and for business and educational communications. One-half of a transponder is allocated to Hungary (see last year's report). Amos-1 also provides Internet connections at 40 MB/sec to computer users having personal computer cards and 60-cm dish antennas.

The use of satellites for telemedicine in Africa was demonstrated by the United Nations International Telecommunication Union (ITU) and the European Telemedicine Collaboration Group in a week-long series ending on 10 May. Doctors in Abidjan, Ivory Coast, used a camera and microphones mounted on a computer to transmit images via France Telecom and Telecom Italia ground stations to doctors in France and Italy.

Two middle East satellites were launched by an Ariane 44L on 9 July: Arabsat 2A and Turksat 1C. Both satellites, which together weighed 4,360 kg, were built by Aerospatiale (France), and were sorely needed to fill the burgeoning demand in both the 21-nation Arabsat group and Turk Telecom. A new $700-million system, Al Thuraya, announced in July by Etisalat of the United Arab Emirates, will deliver services to both fixed and mobile receivers via two geostationary-orbit satellites beginning in 2000. In August Aerospatiale and Turk Telecom also created a new organization, Eurasiasat, to cover the area from western Europe to China with multiple steerable spot beams from a satellite to be collocated with Turksat 1C.

Japan's Space Communications Corporation (SCC) initiated in June DirecPC, an experimental direct communication service for personal computers. The service, which is similar to the U.S. service begun last year by Hughes Network Systems, links users in Japan, Korea, and coastal China via the Superbird A and B satellites and 50-cm ground antennas at rates of 12 megabits/sec.

Brazil's Embratel ordered in December 1995 the third Brazilsat, B-3A, from Hughes Space and Communications (USA). The $70-million, 1750-kg satellite will carry 28 C-band transponders for voice, data, business networks, and television on its HS-376W chassis. It will be launched to its slot at 65 degrees west longitude by Ariane early in 1998, joining Brazilsats B-1 and B-2, launched in August 1994 and March 1995, respectively, and is expected to last for 12 years.

India's INSAT-2C was launched by an Ariane rocket on 7 December 1995. The 2050-kg spacecraft carries 12 C-band transponders, 6 extended C-band transponders, and a Ku-band beacon. Collocated with INSAT-2B at 93.5 degrees East longitude, the new satellite offers new services such as business and mobile communications.

On 31 January, the first of Indonesia's third-generation satellites, Palapa C1, was successfully launched from Cape Canaveral aboard a Lockheed Martin Atlas 2AS. The new spacecraft carries 24 C-band, six extended C-band, and four Ku-band transponders.

Pasifik Satelit Nusantara (PSN) of Indonesia announced on 10 September a new fixed-site telephone service, Multimedia Asia (M2A), to complement the mobile-communications Aces system (see last year's report). M2A could involve up to seven geostationary orbit spacecraft, to be built by Space Systems/Loral (USA). The system is designed to service four million southeast-Asia users per satellite (200,000 simultaneous calls) at rates as low as 5 cents per minute via a rural telephony system called the Xpress Connection, which uses 1.2-m dish antennas. The first M2A satellite launch is expected in 1998, but PSN plans to begin service late this year via Palapa C2.

On 11 July, the first Filipino company to own a satellite, Mabuhay Philippines Satellite Corporation (MPSC), acquired Indonesia's Palapa B2B spacecraft from Pasifik Satelit Nusantara. In August, MPSC began using the Palapa satellite, renamed Mabuhay, to deliver communications and broadcast services to customers in the Philippines and neighboring countries in southeast Asia until the company's new satellite, currently being built by Space Systems/Loral (USA), is available. Mabuhay is in an inclined orbit to save onboard propellant, and hence its users will need special tracking antennas to access the satellite's 14 C-band transponders.

A report issued on 9 May by the U.S. Institute of Electrical and Electronic Engineers called for flight experiments to demonstrate laser communications via satellite. The report, titled "Laser Satellite Communications, Programmes, and Applications," estimates that laser communications satellites would need only half the power, weigh one-third less, and require only one-tenth to one-third the volume of conventional communications spacecraft. Moreover, current problems with spectrum crowding would disappear. Preliminary laser communications testing was conducted by the Jet Propulsion Laboratory using Japan's ETS-6 (see last year's report) during a five-month period from December 1995 through May 1996.

Mobile Communication Systems

On 23 October, the International Telecommunication Union's World Telecommunications Policy Forum informally endorsed global mobile telephone satellite communications networks. Over a thousand delegates from 129 nations attended the Forum, whose draft memorandum (as yet unsigned) is expected to be finalized and approved by the participating nations in June 1997.

The first spacecraft in Inmarsat's new Inmarsat-3 series was launched on 3 April by an Ariane rocket and entered service over the Indian Ocean in mid-May. It was the first in-orbit deployment and checkout operated wholly by Inmarsat's London control center; previous Inmarsat deployments had been handled by the French space agency CNES from Toulouse. The second Inmarsat-3 was launched on 6 September by a Russian Proton from the Baikonur Cosmodrome in Kazakhstan and was subsequently moved to its geostationary-orbit slot over the Atlantic Ocean. The Inmarsat-3 series spacecraft allow the use of mini Inmarsat-M telephones, which are about the size of a laptop computer. Japan's NEC manufactures the "Planet-1" phones, which are being marketed by Comsat (USA) at a price of $2,995.

On 8 December 1995, ICO Global Communications, Inmarsat's commercial offspring, signed a $925-million contract with Hughes Space and Communications, supplementing a previous $1.4-billion contract for construction and launch of 12 2,750-kg ICO spacecraft into their 10,344-km orbits between 1998 and 2000. The first launches will be conducted in 1998 by Atlas-2AS and Proton rockets before transitioning to Delta-3s and Sea Launch vehicles in 1999 and 2000 (see above). The ICO spacecraft will have 9 kW of power and are equipped with 163 individual spot beams. Satellite lifetime is projected to be 12 years.

Motorola (USA) filed an application with the FCC on 4 September for a new 72-satellite low-Earth orbit system to complement the service planned by the company's Iridium and Millennium systems (see last year's report). The $6.4-billion M-Star system is being designed to link terrestrial wireless communications customers, especially local-area networks of large corporations, via 66-cm dish antennas. First launch is planned for 1999. The company has asked the FCC for a waiver that would allow it to conduct a $200-million satellite development effort prior to formal FCC license approval. Initial plans call for six 1100-kg satellites in each of 12 orbital planes at 1,350-km altitude. The system will use a region of the spectrum slightly above the Ka-band, with uplinks transmitted at 50 GHz and downlinks at 40 GHz. Motorola predicts revenues of $32 billion from the first decade of system operations.

On 2 July, WorldSpace Inc. (USA) signed a contract with Alcatel Espace (France) to build and operate the control center for its constellation of three radio broadcast satellites, also being built by Alcatel Espace. The first, AfriStar, is scheduled for launch aboard an Ariane-5 in June 1998; AsiaStar is expected to be launched in December 1998, and CaribStar in June 1999. The new control center is being designed to handle five spacecraft to allow for future system growth. Alcatel conducted the first validation testing of the system in June. Current plans call for a first generation of hand-held digital radios to be powered by batteries or solar cells generating 3.3 volts; the second-generation receivers will require only 2 volts.

Canada's MSAT-1 spacecraft was launched successfully on 20 April by an Ariane 42-P to provide mobile telephone service to the 80 percent of Canada which is not served by existing terrestrial communications systems. The HS-601 bus and antennae were built by Hughes (USA); Spar Aerospace (Canada) built the communications payload. The satellite's power system generates 3.3 kW. TMI Communications had been providing service via MSAT-1's twin, AMSC-1, launched in April 1995; that service was transferred to the MSAT-1 on 2 June, when MSAT-1 began commercial operations from its geostationary-orbit slot at 106.5 degrees west longitude. MSAT-1's services to telephones and other mobile radio communications devices are fully interconnected with existing cellular systems and the public telephone network. The satellite's six spot beams cover Canada, its coastal waters, the United States (including Alaska and Hawaii), Mexico, and Central America. MSAT-1 is owned and operated by TMI Communications; in-orbit stationkeeping has been contracted to Telesat Canada.

A new international joint venture to provide mobile communications services in North Africa, the Middle East, and sections of Europe and Asia was announced in January. Partners in Satphone International Ltd. are Lockheed Martin Overseas Corp. (USA), Advanced Technology Fund, Inc. (Saudi Arabia), and M.O.A. Al Aboudi Corp. (Saudi Arabia). The company plans a constellation of three geostationary-orbit satellites costing (with ground stations) about $500 million. Deployment of the first Lockheed Martin-built spacecraft, which will carry 140 to 150 spot beams to accommodate thousands of calls simultaneously, is scheduled for 1998. The system is patterned after Lockheed Martin's Asia Cellular Satellite System (ACES), announced in May

1995 (see last year's report).

On 8 February, Asia Pacific Mobile Telecommunications (APMT) signed a $500-million contract with Hughes (USA) for two satellites and ground facilities. The satellites will provide the Asia-Pacific region with mobile communication services, beginning with China, Singapore, and Thailand in the first quarter of 1998. APMT has contracted with China's Great Wall Industry Corporation for the launches.

Delegates from 32 African nations, meeting in Senegal on 18-20 September with representatives of the ITU and six mobile satellite communications providers, endorsed a broad spectrum of mobile satellite communications services and agreed to formulate a coordinated pan-African regulatory policy for their use rather than having each nation set up its own regulations. They also asked the service providers to grant preferential tariff treatment to poorer nations to enable them to realize the multiple benefits associated with mobile telecommunications services, and expressed their concern about potential interference with existing terrestrial communications networks.

Navigation and Position Location

In November 1995, Starsys Global (see last year's report) received its operating license from the FCC. The 24-satellite messaging and position-location system was renamed GE Starsys in June, following last year's acquisition of the company by GE Americom (USA). On 11 July, GE issued a contract to Alcatel Espace (France) to build the first six 70-kg spacecraft, the first two of which are scheduled for delivery in April 1998. GE has committed about $170 million to building and launching the six spacecraft, building two U.S. ground control centers, and operating the system for six years. Decisions on the construction and launch of the remaining 18 satellites, which would probably be done in groups of six, await results of the first group's operations.

Orbcomm (USA) initiated delivery of two-way messaging and position-location services to U.S. customers on 1 February and to the Canadian market on 1 March, using the first two satellites of a planned 36-spacecraft low-orbit constellation. Initial uses of the service include tracking of ground vehicles, pipeline monitoring and corrosion control, and environmental monitoring.

The second Global Positioning System replacement satellite (GPS-2A) was launched on 15 July by a Delta-2, re-establishing full operational status of the system by replacing a satellite that had begun to malfunction. The use of GPS for spacecraft attitude control (see last year's report) was first demonstrated in January by the Spartan-206 spacecraft flown aboard Shuttle Endeavor, followed in March by the 110-kg Pegasus-launched REX-2. Both these demonstrations involved ground processing; eventually onboard processing will provide fully autonomous attitude determination.

On 22 April, Rockwell International (USA) won a $382-million contract for the first six follow-on Global Positioning System satellites, with options for an additional 27 of the new GPS-2F spacecraft by 2012. They will replace the existing Block 2 and Block 2A satellites, also built by Rockwell, and the replacement Block 2R satellites, built by Lockheed Martin and scheduled for initial launch late this year. The Block 2F spacecraft will include a new L-5 signal dedicated specifically to civil use, which will improve the resolution of the current civilian signal from 30 m to about 21 m and provide an additional unencrypted signal for dual-frequency resolution enhancement. Boeing will take over the manufacturing of the new spacecraft following its acquisition of Rockwell's space division (see below).

On 26 April, the U.S. Federal Aviation Administration (FAA) canceled a $475-million contract with Wilcox Electric to build the Wide Area Augmentation System (WAAS) for satellite navigation of aircraft using GPS. The FAA subsequently signed on 1 May an initial $50-million contract with Hughes to continue the process of augmenting GPS for civil navigation use, and in October awarded Hughes the full $483-million WAAS contract. The agency predicts that by 2005 the WAAS will save U.S. airlines over $500 million annually in fuel costs alone.

A new ground-based receiver developed by Ashtec, Inc. (USA), announced on 14 May, is the first to use signals from both the U.S. GPS and the Russian GLONASS constellations without requiring selective action by the user. The new instrument, GG24, employs an algorithm which synchronizes the two systems' satellite clocks and therefore can use signals from all spacecraft in view at any time without distinguishing which constellation they come from. This reduces losses in accuracy due to blocked signals (by increasing the number of available signals), and minimizes the effects of GPS's selective availability imposed by the U.S. Department of Defense. Ashtec claims precision accuracy better than 1 meter for the $10,000 sensor, which was developed by the company's technology center in Moscow.

The first operational use of the Future Air Navigation System (FANS-1) suite of satellite-navigation instruments took place on 16 July, with the direct flight of a United Airlines Boeing 747-400 airliner from Chicago to Hong Kong via Chinese and Siberian airspace. A U.S.-Russian Federation agreement requires FANS-1 equipment in order to use this short-cut route, which saves over an hour of flight time (the Chicago-Hong Kong flight takes 14-15 hours). Cathay Pacific and Qantas aircraft are also equipped with FANS-1 suites, and a number of other airlines are planning the distance-saving installation next year.

Remote Sensing

Earth Observations

Canada's Radarsat-1 was successfully launched on 4 November 1995 from Vandenberg Air Force Base into its 800-km polar orbit by a McDonnell Douglas Delta-2. The launch was Delta's first since the 5 August 1995 failure of one of the vehicle's solid-rocket boosters to separate. Liftoff of the 3,200-kg spacecraft, built by Spar Aerospace for the Canadian Space Agency (CSA), had to be within the unusually tight constraint of a 1-minute launch window. The first data were downlinked on 24 January to the University of Singapore's Center for Remote Imaging, Sensing, and Processing. Radarsat International (RSI) began marketing images from the CSA-operated spacecraft on 1 February, and initiated full commercial service on 28 March. The company is a joint venture of Canada's Spar and COM DEV and Lockheed Martin's (USA) newly acquired MacDonald Dettwiler division. Radarsat-1 provides data on Canada's northern-region ice conditions (RSI's major customer is Canada's Ice Centre), as well as data for use in oil and gas exploration, mining, and forestry. In addition to its commercial operations, RSI has joined with the Canadian Space Agency and NASA in the Applications Development Research

Opportunity programme, which provides about 300 projects in 38 countries with Radarsat-1 data free of charge.

In a unique marriage of radar remote sensing with Global Positioning System (GPS) capabilities, NASA announced on 29 November 1995 a 10-year programme to study the phenomenology of earthquakes and volcanoes in and around Los Angeles and Long Valley, California. Ground-based GPS receivers at strategic points in the neighborhoods of faults measure the motion of those points, and combining these data with radar maps generated by sensors aboard the Shuttle, the European radar satellite ERS-1, Japan's JERS-1, and NASA's DC-8 aircraft provides precise information on key movements along fault lines. Such information is invaluable in understanding the underground stresses and strains that lead to earthquakes and volcanic activity.

On 29 July, NASA announced a much broader activity in monitoring natural hazards: the Solid Earth Sciences and Natural Hazards Research and Applications Programme. The agency expects to fund 35 to 50 researchers, in amounts ranging from $50,000 to $200,000 each, to study geophysical and meteorological outbursts, floods, coastal erosion, volcanoes, earthquakes, and wildfires using combinations of observations and measurements from spacecraft, ground-based instrumentation, and aircraft.

In January, a team led by Boeing Commercial Space Company (USA) filed an application with the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) for a four-satellite agricultural crop-monitoring system called Resource21. The system will assist farmers in a new technique known as "precision farming" by providing detailed, current information that helps determine which cultivated areas need water, seed, pesticides, harvesting, etc. Boeing's partners in the Resource21 Limited Liability Company are GDE Systems, Resource21, Agrium USA, Farmland Industries, and Pioneer Hy-Bred International, all U.S. firms. The satellites' sensors will collect information in five spectral bands having 10-m resolution. The first launch is expected in 1999.

Current efforts in precision farming are being conducted by the J.R. Simplot Company in Idaho (USA), which in May initiated a pilot programme to use a combination of remote-sensing data from Spot and Landsat satellites and precision maps generated by Global Positioning System satellite receivers. Farmers in California and Idaho use special software designed by Erdas, Inc. (USA) to locate and monitor insect infestations, watering-system anomalies, the effects of specific fertilizer applications, etc.

In another example of precision farming techniques, German scientists from the Technical University of Berlin announced on 6 August a new four-year programme to find locust breeding grounds in central China's Lake Qinghai region using satellite imagery. The programme, funded by China, builds on capabilities developed by the German scientists since 1990 in searching out locust breeding sites in Africa under a joint $235,000 grant provided by the United Nations and the German Ministry of International Cooperation. The system uses portable satellite communication receivers powered by automobile batteries to inform local officials of incipient locust plagues via Tubsat, which was launched in July 1991.

On 4 December, the German Space Agency (DARA) signed a joint venture agreement with the Israeli Space Agency for a remote-sensing satellite programme named David. The initial two-year programme, which calls for a mid-1998 launch of a 150-kg satellite having a resolution of about 5 meters, is expected to cost less than $3.5 million, plus $1.7 million in annual operating expenses. OHB-System (Germany) is building the satellite and Israel's El-Op Electro Optics Industries is building the payload. The system will be marketed to commercial customers for information in urban planning, exploring for oil and minerals, agricultural data, and environmental monitoring.

A Russian reconnaissance satellite, SPIN-2, launched on 14 May from Baikonur, was destroyed when its Soyuz-U launcher failed. The film-return satellite had been intended to collect commercial black-and-white imagery at resolutions of 2m and 10m for an international consortium of distributors. The consortium will fill its current orders using archived films from previous reconnaissance satellites. The next SPIN-2 launch is scheduled for 1997.

Japan's 3,500-kg Advanced Earth Observing Satellite (Adeos) was launched on 17 August by an H-2 rocket into an 830 x 800-km polar orbit. Although one of the spacecraft's four 20-N on-board thrusters failed to fire, controllers were able to move Adeos into its circular 800-km Sun-synchronous operating orbit by 8 September using a smaller 1-N thruster. It returned its first images on 1 September, and is expected to operate for three years. The spacecraft's eight sensors make it the first satellite able to conduct an integrated study of the many complex interactions that affect the Earth's climate. Two of the sensors were provided by NASA, two by Japan's Environmental Agency, two by Japan's NASDA, and one each by Japan's Ministry of International Trade and Industry and the French space agency CNES. Total cost of the mission was about $1 billion, including the H-2 launch. The H-2 also carried a secondary payload, the 50-kg Japan Amateur Satellite-2, a solar-powered repeater satellite for ham radio operators.

India's IRS-1C satellite was launched on 28 December 1995 by a Russian Molniya rocket into its 817-km Sun-synchronous orbit. The 1250-kg spacecraft's three cameras were successfully activated on 5 January. The black-and-white panchromatic camera has a resolution of 5.7 m and can swivel 26 degrees, allowing it to take stereo images on successive passes; the linear self-imaging scanner has 23.5-m resolution in the visible and near-infrared and 70.5-m resolution in the far-infrared; and the wide-field sensor has 188-m resolution. Images and data from IRS-1C are marketed globally by Eosat (USA).

Atmosphere and Ocean Observations

Europe's Eumetsat initiated a training programme in February to teach weather services in Africa how to use Meteosat data for rainfall assessment, weather predictions important to air traffic safety, agricultural support, prediction of locust invasions, and other functions. Because Meteosat data have been encrypted since September 1995 to prevent unauthorized use, Eumetsat provides decoding devices to the weather services of all nations having a per capita income below $2,000.

Europe's controversial $2.7-billion Envisat programme took a major step forward on 17 July when after three years of negotiations ESA finally signed a $1.03-billion contract with Dornier Satellitensysteme of Daimler Benz Aerospace, for system engineering and payload development of the 8.2-tonne spacecraft's suite of nine environmental monitoring instruments. Envisat's bus is being built by Matra Marconi Space in the United Kingdom under a $1-billion contract. Launch by an Ariane-5 into Envisat's 98.5-degree, 820 x 780-km orbit is scheduled for mid-1999. Its projected lifetime is five years.

Commercial Developments

On 8 January, Loral Corporation (USA) announced the sale of its defense business to Lockheed Martin for $9.1-billion, retaining its commercial space interest in a new company, Loral Space and Communications Corp. (Loral Space). Loral Space kept 33 percent of satellite manufacturer Space Systems/Loral and 31 percent of Globalstar LP, a 48-satellite low-orbit global mobile communications system scheduled or first launch in 1997. The U.S. Federal Trade Commission approved the transaction on 18 April, but limited Lockheed Martin's ownership of Loral Space to 20 percent. In August, Loral Space increased its holdings of Space Systems/Loral to a controlling 51 percent. The remaining 49 percent continues to be held by four European companies.

After about six months of discussions, Boeing and Rockwell (USA) signed an agreement on 1 August that transferred Rockwell's aerospace and defense divisions to Boeing for $3.1 billion. The transaction is expected to become effective on 6 December 1996. The sale includes Rockwell's Rocketdyne engine company, Shuttle operations (including Rockwell's half interest in United Space Alliance, which is slated to take over Shuttle operations from NASA later this year), the Rockwell/Rocketdyne space-station development effort, and manufacture of the Global Positioning System Block 2F satellites.

On 20 September, Hughes Electronics and PanAmSat created a new satellite service corporation, PanAmSat Corporation. Hughes purchased 71.5 percent of the company's stock for $3 billion, and after regulatory approval of the transaction expects to merge Hughes Communications Galaxy into the new company. PanAmSat Corp's initial assets consist of Hughes Galaxy's 10 domestic (U.S.) satellites carrying 417 transponders and PanAmSat's four international spacecraft having a total of 128 transponders, with a projected fleet growth to 21 spacecraft by 1998.

The following week, on 25 September, Loral Space announced its purchase of Skynet Satellite Services from AT&T (USA) for $712 million. Completion of the sale, which involves four satellites, two ground-control stations, and a research laboratory, is expected early in 1997. The four satellites include two old Telstar-3 and two new Telstar-4 spacecraft, plus another Telstar-4 currently being built. Loral Space plans to use the geosynchronous-orbit Loral Skynet system for international services, with future links to the low-orbit 48-satellite Globalstar network and Loral Space's new 3-satellite Ka-band CyberStar system (see last year's report).

The space insurance industry announced in January that it had received a record $786 million in premiums during 1995 and paid out only $238 million in claims, countering a net loss in 1994 of $208 million ($758 million in claims paid vs only $550 million income from premiums). The industry expects to break its record in 1996, predicting about $1 billion in premiums.

The U.S. government issued its first commercial spaceport license in mid-September, when the FAA approved Space Systems International's application to launch payloads weighing up to 2,700 kg into low Earth orbit from the California Spaceport located at Vandenberg Air Force Base.

On 15 October, the operators of three forthcoming satellite communications networks, Globalstar, Iridium, and Odyssey, took unprecedented action by announcing that they would cooperate instead of competing in seeking global authorization for the electromagnetic spectrum frequencies their systems plan to use.

IV. MANNED EARTH ORBITAL ACTIVITIES

Space Station Development

On 21 January, the United States and Russia revised their previous agreement on international space station programmes by extending the life of the present Russian Mir station to 2000. Mir and the new International Space Station (ISS) will continue as separate projects. The new agreement calls for the United States to deliver 6,000 kg of supplies to Mir on three separate Shuttle flights, and also to replace three Zenit launches by delivering the Russian Science Power Platform to the ISS aboard a Shuttle in 1999. Russia also agreed to redesign the interior of the Soyuz capsule planned for use as a crew rescue vehicle to accommodate taller crew members, and to modify the propellant system so that the rescue vehicle can remain effective for a year instead of the present six months.

On 26 September, the International Space Station Control Board approved a modification to the assembly sequence which reflects the above–mentioned changes in the Russian programme as well as changes to the U.S. programme. The launch date for the first element and the date for completion of the assembly have been maintained in November 1997 and November 2002 respectively. The Japan Experiment Module was delayed until April 2001 due to Shuttle manifest constraints. The Centrifuge Accommodations Module is now scheduled for November 2002 and Europe's Columbus Orbital Facility will be launched in late 2002 or early 2003. The United States and Russia also agreed that the first space station commander will be U.S. astronaut William Shepherd and the station's technical manager will be Russian cosmonaut Anatoly Solovyev. The third member of the initial crew complement will be cosmonaut Sergei Krikalev.

A drop test of NASA's Assured Crew Return Vehicle (ACRV-X) failed on 8 December 1995 when its programmer parachutes, which were to have activated the main parafoil recovery system, separated prematurely about eight seconds after the ACRV-X was dropped from its C-130 carrier aircraft at 4.5-km altitude. The 7,200-kg, 7.2-m long glass-fiber lifting body, also known as the X-35, was based on a military system designed to deliver 19,000 kg to a ground-based target within 150 m.

After nearly 12 years of designing, reviewing, evaluating, and redirecting, the ESA member states finally decided on their ISS participation, and ESA signed an $850-million prime contract with Daimler-Benz Aerospace (Dasa) on 28 March to build the Columbus Orbital Facility, Europe's laboratory for the international space station. It was the largest single fixed-price contract signed by ESA up to that time. The 6.7-m x 4.5-m laboratory will be built by companies from 10 European nations. Mass of the basic system is 9,500 kg, with five International Standard Payload Racks (ISPRs) of European experiment facilities to be added before launch and another five ISPRs to be added by NASA once Columbus is in orbit.

On 25 September, ESA agreed to commit $440 million to the design and development of an expendable Automated Transfer Vehicle (ATV) to carry 9,000 kg of cargo to the space station (the ATV's payload capacity is 14,000 kg). Aerospatiale (France) will lead a team of European contractors (including Russia's RSC Energia) in designing the ATV and building the first flight model, which is scheduled to be launched in 2002 by an Ariane 5. The ATV will also serve as a booster to keep the space station in its 400-km orbit.

NASA pressure tests of the two nodes that will be used to connect the international space station's modules revealed design flaws that were subsequently corrected by adding strengthening structural members. Pressurization of Node Two was halted at 1.3 times its operating pressure when strain gages reached their preset limits, and on 6 May the test of Node One was halted at only 1.12 times operating pressure. After the structural members were added, Node One was successfully pressurized to the full specification (1.5 times operating pressure) on 28 August. The U.S. laboratory module for the station was also successfully pressure-tested on 25 August.

It was decided to decrease early utilization of the ISS facilities during the highly active assembly years 1999 and 2000 due to limitations on power and launch mass available for research payloads. The utilization programme has been rephased accordingly, while maintaining the schedule for complete outfitting of the research payloads.

On 21 May, Boeing (USA) and RSC Energia (Russia) announced a joint venture to deliver commercial payloads to the Mir space station. The Mir Payload Service will use Progress-M cargo vehicles to carry the payloads to the station, whereupon they will be installed by Mir's crew. Nominal price for the service is $7 million for a 100-kg payload. The first demonstration is scheduled for January 1997: a free delivery of NASA's experiment on Measurement of Air Pollution from Satellites. Meanwhile, Shuttle Endeavour was retired from service on 30 July for eight months to modify it for space-station rendezvous and docking capability and a number of weight-saving upgrades.

A U.S. National Research Council report issued on 19 June recommended that NASA should place stronger emphasis on private-sector participation in station operations, and also should implement mechanisms to encourage greater commercial use of the station's facilities. Subsequently, on 1 October, five major space-station contractors announced the formation of an alliance to help manage day-to-day space-station operations. The commercial venture, which is expected to follow the general approach taken by United Space Alliance in managing U.S. Shuttle operations (see below), includes Alenia Spazio (Italy), Boeing (USA), Daimler-Benz Aerospace (Germany), Mitsubishi Heavy Industries (Japan), and Spar Aerospace (Canada). A Russian company is expected to be added later.

On 1 May, Ajax Barros de Melo, director of Brazil's space agency, announced his country's intent to seek a role in the international space station. Preliminary plans call for Brazil to commit about 10 percent of its $250 million annual space budget to this effort, which could involve developing and building an experiment rack for the station to seek commercial or medical products based on Brazilian plant life. Brazil already has space agreements with the United States, China, Argentina, France (see below), Germany and the Netherlands.

Earth-Orbital Flight Operations

On 22 November 1995, Lockheed Martin and Rockwell International created a new joint venture, United Space Alliance (USA), to serve NASA as a single contractor for Space Shuttle operations, ultimately consolidating 85 separate contracts covering this task (see last year's report). The new alliance was approved on 13 December 1995 by the U.S. Federal Trade Commission (FTC), clearing the way for NASA to sign a $7 billion contract with USA on 30 September. The company initiated its operations under the 42-mission, six-year contract on 1 October, consolidating 12 separate former operations contracts. The management transfer will phase in gradually during the next five years and is expected to save NASA over $1 billion annually without compromising safety.

U.S. Space Shuttle Atlantis was launched on 11 November 1995 to evaluate International Space Station Alpha's assembly process by installing a Russian-built 4,500-kg docking module on the Mir space station. Canadian astronaut Chris Hadfield first used the Shuttle's Canadarm to position the module precisely over Atlantis's airlock, and Shuttle Commander Kenneth Cameron then fired Atlantis's maneuvering jets to latch the module to the airlock. Despite extremely close clearances (relative positions of the two spacecraft had to be maintained within 8 cm), he subsequently used a new Canadian advanced space-vision system to maneuver the assembled Shuttle and module, and on 14 November successfully docked with Mir. The vision system, which was being tested on this flight for future use on the international space station, transforms oblique camera views into synthetic boresight views of the target while displaying useful data such as relative position, relative attitude, and their rates of change. The Atlantis astronauts and Mir cosmonauts subsequently transferred food, water, clothing, and experimental apparatus from Atlantis to Mir.

Shuttle Endeavour was launched on 11 January, and subsequently released a 1,200-kg NASA Spartan-class spacecraft (Spartan-206) carrying four technology experiments. The crew, which included Japan's first full-time astronaut, Koichi Wakata, also retrieved Japan's first reusable satellite, the 3,600-kg Space Flyer Unit (SFU), launched in March 1995 by an H-2 rocket. The SFU's experimental deployable two-dimensional solar array was retracted and stowed successfully during the mission, and Japan's first flexible solar paddles also proved successful, although they were intentionally jettisoned before SFU's retrieval. Endeavour's crew tested a number of space-station assembly techniques and components before landing on 20 January.

Shuttle Columbia's primary mission after its launch on 22 February was to repeat the Tethered Satellite System experiment that failed in August 1992. Deployment of the 520-kg satellite on its 2.5-mm tether to a distance of 19.7 km on 25 February was achieved successfully; a 3,500-volt potential at a current of 0.5 amperes was induced in the tether by the Earth's magnetic field; there was no sign of unstable dynamic behavior; and the tether tension was only 70 N, well below its design strength. Unfortunately, however, when the tether still had about 2 km to go to reach the planned length, it broke within its 11.8-m deployment boom. It was later determined that arcing and burning, due to a flaw in its insulation, caused the satellite to be released and destroyed in the atmosphere along, with the broken length of tether. Total cost of the mission, including the failed attempt in 1992, was $404 million. The subsequent failure report indicated no reasons to curtail future tether experiments, although none are currently planned by NASA. Columbia's flight also featured a student experiment on crystal growth (see below).

Shuttle Atlantis was launched on 22 March and docked with Russia's Mir space station on 24 March. U.S. astronaut Shannon Lucid boarded Mir for a projected stay of five months, which was subsequently extended by six weeks when Atlantis's next flight was delayed by concerns about seals on its solid rocket boosters (see below). About 2400 kg of supplies were transferred to Mir during the mission, and 460 kg of experiments and test equipment were returned from Mir to Earth by Atlantis.

The long-awaited launch of the Mir space station's Priroda laboratory module took place on 23 April. The 20-tonne module docked with Mir three days later, adding about 66 cubic meters of volume to the space station. It is the final element in the 116.5-tonne Mir assembly. Priroda carried about 1,000 kg of U.S. laboratory equipment for use by Astronaut Lucid during her stay aboard the Russian space station. A Progress M-31 supply mission brought nearly 3,000 kg of fuel, food, and water to Mir on 7 May; M-32 brought more supplies to the station in June. Included in the M-31's manifest were several large collapsible Pepsi "soda cans," which were displayed on 20 May during a spacewalk by Mir's cosmonauts as part of an advertising campaign Pepsi will launch next year. Russia received over $1 million from the company to stage the demonstration.

Shuttle Endeavour carried an inflatable-antenna experiment into orbit on 16 May, along with 12 major experiments, in the fifth commercial Spacehab module. The $14-million antenna was deployed by a Spartan 207 satellite on 20 May to a distance of about 120 meters. The 20-kg antenna was then inflated with 3 grams of nitrogen to its full diameter of 14 meters via a triangular support structure of three 28-m long inflatable booms. Although premature inflation caused the booms to kink during deployment and a stuck valve prevented full inflation of the antenna, this first orbital demonstration of a new class of large space structures was considered a learning success. The flight also marked the first full use of NASA's new mission control center and the first time all three main engines were equipped with new oxygen feed pumps (see last year's report). Experiments included in the Spacehab module were a commercial Canadian float-zone furnace, which was used to process in space for the first time the commercially important materials bismuth germinate and cadmium germanium arsenide, and the Aquatic Research Facility, which was used to study early birth defects and bone calcium loss.

Shuttle Columbia was launched on 20 June for a record 17-day mission. The flight carried 41 experiments, mostly in the Life and Microgravity Spacelab (LMS-1) manifest, covering life sciences, space biology, microgravity science, fluid physics, metallurgy, protein crystal growth, and the effects of thruster and other forces acting on the Shuttle.

On 12 July, NASA decided to postpone to 12 September the launch of Shuttle Atlantis from 31 July to replace the Shuttle's solid-rocket boosters. The decision was made when after its June flight inspection of Columbia's booster rockets revealed evidence of burning of a new water-based adhesive used in the thermal barriers that protect the rockets' O-rings. The same adhesive had also been installed in Atlantis's boosters as a new measure to accommodate environmental constraints on the old adhesive, which used an ozone-depleting chemical. Astronaut Shannon Lucid therefore spent an additional six weeks aboard Mir, since Atlantis is the only Shuttle orbiter currently equipped with the necessary docking equipment for Mir. That gave her the space endurance record for women, formerly held by Russian cosmonaut Helena Kondakava for her 169-day flight ending in 1995. Lucid departed Mir on 23 September to board Atlantis, which had finally been launched on 16 September after further delays caused by hurricanes near the launch site, and returned to Earth on 26 September after her record stay of 188 days and five hours in space. U.S. Astronaut John Blaha replaced her aboard Mir for a projected stay of four months.

Two Canadian astronauts, Steve McLean and Julie Payette, began their mission-specialist training at NASA's Johnson Space Center on 12 August. McLean had operated the Canadian Advanced Space Vision System (see above) as a payload specialist aboard Shuttle Columbia in October 1992, and will operate the vision system in forthcoming Shuttle missions. Payette, an electrical engineer, is being trained to operate the space station's Mobile Servicing System and other operations systems.

The longest flight experienced by a European cosmonaut ended on 29 February when a Soyuz TM-22 capsule returned ESA's Thomas Reiter to Earth with Russian colleagues Yuri Ghidzenko and Sergei Avdeyev, after having spent 180 days aboard the Mir space station. Reiter's tour, which was part of the joint Euro-Mir programme, included two space walks.

A progress M-32 transport carried about two tonnes of supplies to Mir in preparation for the 17 August Soyuz launch which brought French cosmonaut Claudie Andre-Deshays and two Russian cosmonauts to Mir on 19 August. The Russian crew was the backup for the primary crewmen, one of whom had been grounded a week prior to the mission for medical reasons. Andre-Deshays returned to Earth on 2 September after working with U.S. astronaut Shannon Lucid and four Russian cosmonauts on a series of cardiovascular and neurosensory experiments. France paid Russia $16 million for the flight.

V. SPACE EXPLORATION

Astronomy and Astrophysics

On 30 December 1995, the U.S. orbited its first X-ray satellite since Einstein, which had been launched in 1980. The 3,000-kg X-Ray Timing Explorer (XTE), lifted to its 580-km orbit by a Delta-2 from Cape Canaveral, joins Germany's RoSat and Japan's Advanced Satellite for Cosmology and Astrophysics (ASCA), launched in 1990 and 1993, respectively. One of XTE's three sensors, the All-Sky Monitor, scans the sky searching for bursts of X-rays. Upon spotting one, XTE maneuvers to train its other two sensors (the Proportional Counter Array and the High-Energy X-Ray Timing Experiment) on the burst to take measurements. The $195-million spacecraft is unique in its ability to detect emissions as brief as 10- to 100-microseconds and measure time-variable phenomena with a resolution of about a millisecond.

NASA embarked on a new approach on 8 November 1995 for building scientific spacecraft when it authorized Johns Hopkins University to start construction of the Far Ultraviolet Spectroscopic Explorer (FUSE), scheduled for launch on a MedLite vehicle in October 1998. The decision to proceed with FUSE was based on a reduction of projected cost to $108 million (plus launch) from $253 million, mainly by using commercially available or previously developed components and abbreviating the development schedule by two years. About 30 percent of the raw data obtainable from the spacecraft was sacrificed by the choice of a MedLite launcher, which reduced the orbit from that which could have been attained using the original launcher selection, a more costly Delta.

From 25 October through 21 November 1995, NASA launched a series of six Black Brandt sounding rockets from Australia's Woomera range to study the ultraviolet and X-ray spectra of interstellar space and the Larger Magellanic Cloud from a point in the Southern Hemisphere of Earth. This phase of NASA's Mobile Sounding Programme involved research teams from the University of Colorado, Johns Hopkins University, Pennsylvania State University, and the University of Wisconsin, all in the United States.

The European Space Agency's 2,400-kg Infrared Space Observatory (ISO) was successfully launched on 16 November 1995 into its highly elliptical 1,000 x 71,000-km orbit by an Ariane 44P. The $1.3-billion satellite, designed and built by prime contractor Aerospatiale (France), is ESA's costliest scientific spacecraft to date. The 5.3-m long spacecraft is equipped with a 60-cm telescope along with four different instrument packages to analyze the collected light's spectra and its polarization and to focus it into images: a short-wave spectrometer, a long-wavelength spectrometer, a camera and polarimeter, and an imaging photo polarimeter. The spacecraft's sensors are enclosed in a large cryostat, cooled to 1.8 K by 2,140 liters of liquid helium, designed and built by Daimler-Benz (Germany). During its expected 18- to 22-month lifetime, ISO will give astronomers a new perspective on the Universe's birthplaces: the clouds of gas and dust that spawn stars and galaxies and the dusty regions around stars that coalesce into planets. ISO is over a thousand times more sensitive than its predecessor, the U.S.-Dutch-UK Infrared Astronomical Satellite (IRAS), and unlike IRAS it can track stars and other regions of interest for hours at a time.

The European Space Agency selected Cobras-Samba on 26 April for the agency's third Medium-class scientific mission. The $460-million satellite, which was chosen over four competing mission proposals, will be launched in 2004 to search for radiation generated during and shortly after the birth of the Universe.

On 30 April, a Lockheed Martin Atlas-1 launched the 1400-kg joint Italian-Dutch high-energy X-ray "Satellite per Astronomia a raggi X" (Sax) into a 600-km orbit. The $360-million satellite, built by Alenia Spazio (Italy), began making observations on 1 May. The Italian space agency plans to operate the satellite's six instruments for three years.

After 20 years of preliminary efforts, NASA finally implemented the Space Infrared Telescope Facility (SIRTF) this year by issuing initial development contracts for the spacecraft and the 85-cm infrared telescope to Lockheed Martin and Ball Aerospace. SIRTF is the last of the four "Great Observatories" (the others are the Hubble Space Telescope, the Compton Gamma Ray Observatory, both currently in orbit, and the Advanced X-Ray Astrophysical Facility, scheduled for launch next year). SIRTF's mass has been reduced from the 5,700 kg estimated in 1990 to 750 kg, and its estimated cost from well over $1 billion to $443 million, plus launch (on a Delta rocket) and operations. Launch could be as early as 2001. SIRTF's lifetime is limited to about 2.5 years by its 250-liter liquid helium capacity.

NASA also announced on 25 September that the agency and several industry partners were exploring several Next-Generation Space Telescope (NGST) concepts as potential follow-ons to the Hubble Space Telescope (HST). The NGST might use synthetic apertures, as well as advanced technologies such as deployable structures and advanced actuators, sensors, and controls derived from military spacecraft, to collect 10 times as much light as the HST with only 20 percent of the HST's mass. Typical NGST diameters range from 6 to 8 m compared with HST's 2.4 m. Its earliest launch date would be 2005.

Plasma Physics

On 24 February, NASA launched its much-delayed Polar spacecraft aboard a Delta-2 rocket from Vandenberg Air Force Base, joining Wind (launched in November 1994) to study the effects of the solar wind on the Earth's atmosphere. Both spacecraft are part of the International Solar Terrestrial Physics programme. The $238-million, 1300-kg Polar carries eleven instruments to measure electric and magnetic fields in space and the density and energy distributions of solar-wind particles. It is in an elliptical orbit having a perigee of 5100 km over the Earth's South Pole and an apogee of 51,200 km over the North pole.

NASA's 192-kg Fast Auroral Snapshot (FAST) mission was launched on 21 August into an elliptical (350 x 4200 km) orbit at 83 degrees inclination by a Pegasus XL. The $72-million Small-Class Explorer spacecraft's five instruments are monitoring the flow of electrons into the Earth's auroras with millisecond response times, and are also photographing auroral phenomena with 5-m resolution, in contrast to the 1-km resolution of previous auroral studies. Charged-particle distributions are being measured by FAST at altitudes from 1,920 km to 4,160 km and at latitudes within 30 degrees of both magnetic poles.

Japan's Tail spacecraft was launched on 3 August as part of the International Solar-Terrestrial Physics (ISTP) programme, to study solar-terrestrial physical phenomena in the tail of the region where the solar wind interacts with the Earth's magnetosphere. On 29 August, the Interball-2 Auroral Probe was launched by a Molniya rocket from Plesetsk into its 20,000-km orbit to complement Tail's data. Interball is a Russian-led international programme operated by the Russian Space Agency, ESA, NASA, and Japan's ISAS in conjunction with other ISTP missions such as Polar, FAST, SOHO, and Tail. The Molniya launch also orbited the Czech Republic's Magio-5 satellite, which is working in tandem with Interball-2, and a Mu-sat spacecraft for Argentina.

ESA's $1-billion, 1,850-kg Solar and Heliospheric Observatory (SOHO) was launched successfully on 2 December 1995 by an Atlas 2AS rocket, and on 14 March reached its 1.6-million km operating orbit at the L-1 Lagrangian location between the Earth and the Sun where their gravitational forces are in balance. The accurate launch and a trajectory-refinement maneuver conducted on 4 January left enough propellant onboard for about 20 years of operation. Ireland's Low Energy Ion Detector (LION) instrument, designed and built by Space Technology Ireland Ltd, began measuring solar wind particles on 7 December 1995. The three French instruments are GOLF, which will study the internal structure of the Sun; EIT, an extreme ultraviolet imaging telescope for examining coronal structure; and SWAN, a Lyman-alpha sensor which will study the anisotropy of the solar wind. Financing of the mission included $442 million by ESA, $132 million by ESA member nations, and $510 million by NASA for onboard equipment, the launch, and two years of spacecraft operations.

Among SOHO's first findings, reported by ESA on 2 May, was the unexpected nonstop violent upheaval of the solar surface during a relatively quiet period (one prominence alone was estimated to have ejected over a million tonnes of gas into space). SOHO also discovered that the sound waves that had formerly been believed to originate from the Sun's surface (and therefore might occlude SOHO's observations) are generated in the Earth's atmosphere and hence will not degrade SOHO's planned studies of the Sun's interior. Another interesting SOHO finding was the detection of 100-million-degree oxygen ions in the solar atmosphere, 100 times hotter than the electrons in the corona and tens of times higher than previous ion temperatures measured there.

The 4 June failure of Ariane-5 (see above) destroyed its payload, the four 1,200-kg Cluster satellites that were intended to study the Earth's magnetic field and its relationship to solar phenomena in three dimensions as part of the joint NASA/ESA Solar Terrestrial Science Programme (see last year's report). ESA subsequently decided in July to build a fifth Cluster spacecraft, renamed Phoenix, from Cluster spares and launch it in the spring of 1997, probably as an auxiliary payload and possibly on Ariane-5. Projected cost of the satellite and testing is $38 million.

Solar System Exploration

On 7 December 1995, the Galileo spacecraft was successfully inserted into Jupiter orbit, and the probe released five months earlier entered and descended into Jupiter's atmosphere as planned. The parachute opened 53 seconds late, so that measurements began to be made at a point 26 km below the altitude originally planned, and the probe's internal temperatures exceeded the specified -20C to +50C by -20C at the low end and +50C at the high end. Nevertheless, all six instruments collected data for 35 minutes after deployment of the parachute, and the acceleration, pressure, and temperature sensors continued operating for over 58 minutes, after which the probe was presumed to have been destroyed by heat and pressure. Final conditions measured by these instruments, at the 159-km descent point, were 425K and 22 bar.

Probe data released by the Jet Propulsion Laboratory on 22 January revealed unexpected dryness of the upper atmosphere, with only about one-tenth of the expected water and oxygen; a clearer-than expected atmosphere, lacking the predicted three distinct cloud layers; half the amount of helium expected, as well as much less neon, krypton, xenon, carbon, and sulfur; only about one-tenth the expected lightning activity; much stronger winds than anticipated; and increasing wind strength with depth (up to 525 km/hr), suggesting an internal heat source rather than solar energy as the wind's driving force.

A 23-minute burn of the main spacecraft's engine on 14 March moved Galileo into a higher orbit, reducing its instruments' exposure to harmful radiation and setting it on a course for its first of its four encounters with Ganymede, which occurred on 27 June. The flyby, which brought the spacecraft within 835 km of the 5,120-km-diameter moon, revealed unexpected surface detail that included ridges, fissures, faults, and meteor craters in the water ice that covers much of Ganymede. Processed data released in October showed Ganymede surface details to an unprecedented resolution of about 10 meters. Galileo's magnetometers also detected a magnetic field surrounding Ganymede (about one-thousandth the strength of Earth's), the first ever observed on a planetary satellite, suggesting an unexpected molten core (Galileo's observations had previously indicated that another Jupiter moon, Io, had an iron core, suggesting that it too has a magnetic field). Ganymede was also found to have an ionosphere and therefore probably an atmosphere. Galileo also photographed the moons Io and Europa in June, as well as the Great Red Spot on Jupiter itself, revealing much greater detail than the previous photos taken in 1979 by Voyagers 1 and 2.

The Near Earth Asteroid Rendezvous (NEAR) mission (see last year's report) was launched on 17 February by a Delta-2 rocket. The first spacecraft built under NASA's new Discovery series guidelines (see below), NEAR's development cost only $122 million ($3 million below initial estimates) and took less than two years. According to Johns Hopkins Applied Physics Lab engineers, NEAR's low cost was achieved by using a simplified design concept, not by cutting corners or reducing redundancies that could increase risk of failure. The 805-kg spacecraft's multi-spectral imager was tested successfully following the launch, and the spacecraft is now on its 3-year journey to fly past asteroid Mathilde on 27 June 1997 and to rendezvous with asteroid 433 Eros on 6 February 1999, after which it will orbit the 45-km long asteroid for a year at an altitude of about 30 km and collect images with an estimated 3-5m resolution.

NASA selected a cometary sample-return in November 1995 for the agency's fourth "smaller, faster, cheaper, better" Discovery mission (see last year's report). Lockheed Martin's Stardust mission will be launched by a Med-Lite rocket in 1999 to pass within 100 km of Comet Wild-2 in 2004. It will photograph the comet's nucleus and collect particles from its coma and tail using an aerogel collector, returning them to Earth for analysis in 2006 via a low-cost reentry capsule. The mission will cost only $200 million.

In March, NASA announced the first New Millennium spacecraft, Deep Space-1, a $112-million mission to fly by asteroid McAuliffe and comet West-Kohoutek-Ikemura following its launch in mid-1998 aboard a Med-Lite vehicle. The main goal of the New Millennium programme is to develop and demonstrate radically new space hardware and software (see last year's report). Deep Space-1 will use a solar-electric propulsion engine having a 30-cm xenon thruster, ground testing of which began in April at the Jet Propulsion Laboratory (see below), and will be equipped with a miniature camera, a mini-spectrometer, advanced-technology solar arrays and a highly sophisticated miniaturized computer.

The second New Millennium mission, also announced in March, consists of two 2.5-kg penetrators that will search for subsurface water on Mars following their deployment as a secondary payload aboard the U.S. Mars Surveyor-2 lander, currently scheduled for launch in January 1999. The probes will be dropped from the orbiting mother spacecraft at an altitude of 110 km above the Mars surface. The 10-cm-long penetrator portion of each probe is expected to penetrate up to 2 m into the soil. A cable will connect it to the 7.5 x 12.5 cm aftbody left on the surface, which will transmit the subsurface data back to the orbiter.

The third New Millennium mission, tentatively designated Earth Orbiting 1, is expected to be an Advanced Land Imager, scheduled for launch in 1999. It will demonstrate an advanced hyperspectral imaging spectrometer that could expand the usefulness of Landsat data at low cost.

Several other New Millennium missions are under consideration for 2000–2004. Deep Space 3, 4 and 5 would demonstrate technologies for space interferometry using separated spacecraft, sample acquisition and return from small, airless celestial bodies such as asteroids and comets, and long-life microprobe seismic stations for Mars or the far side of the Moon. Earth Orbiting 2 would demonstrate technologies for integrated multispectral atmospheric sounders. Earth Orbiting 3 would demonstrate tropospheric and stratospheric chemistry technologies and high-response monitoring of atmospheric measurements from the geostationary orbit.

The Deep Space 4 mission may be built around the Champollion lander, originally planned for inclusion along with a German-built lander in ESA's Rosetta mission to Comet Wirtanen, which is tentatively scheduled for launch in January 2003. By mutual agreement, NASA and ESA withdrew Champollion from Rosetta on 2 October due to a number of complicating factors affecting its integration into the ESA mission.

On 8 May, NASA also announced preliminary results of its Second-Generation Microspacecraft technology programme, which is derived from both NASA's New Millennium effort and the U.S. Department of Defense's Ballistic Missile Defense Organization's technology development activities. The Jet Propulsion Laboratory has assembled a functional 75-kg engineering model of a modular spacecraft based on the use of four common building blocks: an information processing and control subsystem, optics and focal-plane arrays, a power subsystem and a telecommunications subsystem. Miniature cold-gas thrusters are included for attitude control.

Three Mars spacecraft—Mars 96 (Russia), Mars Global Surveyor (USA) and Mars Pathfinder (USA)—are all on track for late 1996 launches (see last year's report). Mars 96 is scheduled for launch by a Proton rocket from Baikonur on 16 November. Its 800-kg orbiter will carry the German/French ARGUS complex (camera and infrared spectrometer), the Irish SLED-II (energetic particle sensor), the Irish Mariprobe (cold plasma sensor for Mars' nightside ionosphere), the British Fonema (ion composition analyzer) and the U.S. Mars Oxidant Instrument (Mars surface chemistry). The spacecraft also carries two 65-kg Russian subsurface probes and two 50-kg Russian-built landers equipped with imagers and meteorological instruments.

In addition to its U.S. suite of instruments (see last year's report), Mars Global Surveyor, launched successfully on 6 November aboard a Delta-2 rocket, also carries the French Martian relay instrumentation that will relay information from Mars 96 to Earth. Surveyor's instruments had been tested successfully for five weeks under simulated mission conditions in June. The spacecraft is to be injected into Mars orbit on 11 September 1997.

Mars Pathfinder, scheduled for launch aboard a Delta-2 on 12 December, was the second mission designed under the Discovery programme guidelines (see above). Its primary goal is to demonstrate advanced technologies for future Mars missions (see last year's report). The U.S.-Russian 2001 Mars Together mission (see last year's report) underwent yet another descoping in October. Plans now call for a Russian rover to be carried by a U.S. spacecraft in a Russian Mars descent module, launched by a Russian Molniya rocket and employing the U.S. Deep Space

Network for communications with Earth.

The world's Mars exploration programmes were given added impetus on 6 August with the revelation that analysis of a 2-kg meteorite found in Antarctica twelve years ago showed strong evidence of fossilized 4- to 4.5-billion-year-old microbial life. Meteorite ALH84001 is believed to have been spalled from Mars by an asteroid collision an estimated 16 million years earlier, reaching Earth about 13,000 years ago. The discovery has prompted NASA to consider possible plans for changing the parameters of a Mars sample return mission tentatively scheduled for 2005.

The ALH84001 discovery was bolstered by the announcement on 31 October that researchers from the United Kingdom's Open University had found traces of organic matter in a 175-million-year-old, 7.9-kg meteorite that they estimated had left Mars about 600,000 years ago. The meteorite, designated EETA-79001, had also been found in Antarctica, in December 1979. This find, if verified, would imply that Martian life had existed in relatively recent times, from 600,000 to 175 million years ago.

Search for Extraterrestrial Intelligence (SETI)

On 16 January, the privately funded SETI Institute announced results of the first phase of its five-year Phoenix programme, during which star sweeps conducted last year by Australia's 64-m Parkes radiotelescope examined over 200 stars using special SETI detection equipment. Phoenix has targeted about 1,000 sunlike stars for examination, including the three recently found to have planetary systems.

VI. TECHNOLOGY ADVANCEMENT

Propulsion

The engine that will power Lockheed Martin's suborbital X-33 technology demonstrator and subsequently the company's operational reusable VentureStar (see above) will be a linear aerospike, first demonstrated during ground testing by Rocketdyne (USA) in the late 1960s as a candidate for the Space Shuttle's main engines. NASA's selection of Lockheed Martin on 2 July as the X-33 developer was based in good part on the company's novel engine proposal. Because the aerospike's exhaust is unconstrained by the bell-shaped nozzle used in conventional rocket engines, it expands to adjust itself automatically to the decreasing atmospheric pressure experienced as the vehicle climbs during launch, thereby offering significant theoretical performance improvement potential over conventional rockets. However, since no aerospike engine has ever demonstrated this performance potential in flight, Lockheed Martin plans to flight-test a small-scale linear aerospike aboard a supersonic SR-71 "Blackbird" airplane late in 1996 or early in 1997.

On 11 July, NASA announced awards for the first phase of an effort to develop an advanced rocket-based combined-cycle (RBCC) engine for future reusable launch vehicles to follow the current X-33/VentureStar launcher. The four-phase programme, supervised by NASA's Marshall Space Flight Center, is expected to last eight years. Phase 1 contracts totalling

$20 million went to five organizations, which will conduct ground demonstrations of their RBCC designs. The five Phase-1 contractors are Aerojet GenCorp, Kaiser Marquardt, Pennsylvania State University, Pratt & Whitney and Rocketdyne. The second phase will test key propulsion technologies; the third phase calls for flight-testing a small-scale integrated vehicle-plus-propulsion system, and the fourth phase will be flight-testing of a large-scale vehicle. A single contractor will be downselected for Phases 3 and 4. The RBCC effort is part of NASA's Advanced Space Transportation Technology Programme (ASTP).

The U.S. Air Force's Phillips Laboratory announced in July the initiation of an Integrated Powerhead Demonstration (IPD) programme aimed at developing the technologies needed for lightweight, low-cost, reliable rocket engines, focusing strongly on the oxygen-rich cycles commonly employed in Russian rockets. Technologies of interest include oxygen-rich preburners, hot-oxygen turbopumps, oxygen-cooled nozzles, and hydrostatic bearings. Programme goals for a typical reusable engine (100 missions) are a 30 percent increase in thrust/weight ratio, a 15 percent reduction in hardware cost, a 25 percent reduction in failure rate, and a 1 percent increase in specific impulse.

Included in the Advanced Space Transportation Programme (ASTP) this year is a new study by a 19-person team to explore and evaluate potential breakthroughs in physics that could spawn radically new space propulsion concepts. The team will consider such extreme possibilities as faster-than-light drives, manipulation of gravity fields, distortion of the space-time continuum (e.g., "worm holes" in space), and new approaches to onboard energy generation.

NASA's Langley Research Center also issued on 9 October a request for proposals to design, build, and flight-test four research vehicles for the Hyper-X hypersonic research programme. The vehicles would fly in the range Mach 5 to Mach 10 using dual-mode supersonic-combustion ramjets (scramjets). They are to be boosted to the test-flight Mach numbers by Pegasus boosters, which will release them at an altitude of about 30 km to fly under their own power.

NASA's Jet Propulsion Laboratory initiated a one-year programme in July to ground-test a prototype 30-cm, 2-kW xenon ion thruster for the first New Millennium mission, Deep Space 1 (see above). The effective exhaust velocity of the singly ionized xenon propellant from the prototype is 31 km/sec.

On 31 July, Lockheed Martin announced that the upper-stage engine for the small-payload range of its new Evolved Expendable Launch Vehicle (EELV) will be an upgrade of the 35-year-old liquid-propellant Agena. The engine was originally developed by Bell Aerospace as the workhorse for 362 early U.S. space missions from the 1960s through the 1980s. It was bought by Atlantic Research in 1987, and will now be upgraded to the "Agena 2000" by Atlantic Research and Aerojet GenCorp for the EELV. Lockheed Martin is still in competition with three other companies for the EELV (see last year's report), and company officials stated that development of the Agena 2000 would probably not be pursued by Lockheed Martin unless they are selected as the EELV developer by the U.S. Air Force in April 1998. The company would continue to use the Centaur upper stage for the larger payload range.

Boeing tested its EELV propulsion-module recovery system on 24 June by dropping it into the Gulf of Mexico from a helicopter flying at an altitude of 1800 meters. The module, which contained an inert Space Shuttle Main Engine (SSME), was decelerated by three parachutes and was successfully protected from salt-water encroachment by deployment of an inflatable shield during splashdown. On 27 August, Boeing and Rocketdyne engineers successfully test-fired a "live" SSME engine after a splashdown in inland waters to demonstrate the effectiveness of the recovery system, throttling the engine over the range 65 percent to 100 percent of rated thrust.

Aerojet GenCorp (USA) received on 29 August 12 Russian NK-33 engines for use in the first and second stages of the K-1 launcher being developed with private-sector funding by Kistler Aerospace Corporation. The NK-33 was originally developed in the 1960s by the Samara Scientific-Technical Complex.

Mitsubishi Heavy Industries completed 950 seconds of testing in June on the improved second-stage LE-5B engine for Japan's uprated H-2A launcher (see above). The 2-month test series demonstrated the specified thrust increase from the LE-5A's 12,500 kg (122 kN) to 14,000 kg (137 kN). Another LE-5B prototype engine will be tested next year to demonstrate conformance with environmental and high-altitude specifications.

Following the release on 19 September of President Clinton's new space policy, which reaffirmed the need for nuclear propulsion and power technologies to support long-duration deep-space missions (see below), NASA's Marshall Space Flight Center announced on 9 October its support of research on two nuclear propulsion concepts by the Department of Energy's Los Alamos National Laboratory. One involves studies of a small bimodal nuclear thermal rocket engine utilizing heat pipes to extract energy for long-term electric power generation, a concept conceived in the late 1960s and studied extensively in the 1970s. The other is a three-year programme begun on 1 October to conduct hydrodynamic studies in support of a modern version of the gas-core nuclear rocket, which was conceived in the late 1950s and subjected to intensive investigation in the 1960s and 1970s.

Power

Significant advancements in static power conversion device efficiency occurred in 1996. Cascade (multilayer) photovoltaic converters in France achieved 42 percent conversion efficiency. In Japan, the use of functional-gradient materials allowed thermionic conversion efficiencies up to 15 percent and thermoelectric conversion efficiencies in the 30 percent to 35 percent range. Combining these devices into a hybrid direct electric conversion system (HYDECS) demonstrated overall efficiencies up to 40 percent. In the U.S. thermophotovoltaic converters using gallium antimonide photovoltaic cells covered with spectrally selective infrared filters demonstrated efficiencies up to 15 percent—nearly three times that of conventional thermoelectric converters—with prospects of attaining 30 percent at high power fluxes (e.g., 3 W/sq. cm).

A cyclotron wave converter (CWC) was demonstrated by Russia at the Wireless Power Transmission Conference on 16-19 October 1995, in Kobe, Japan. By using transverse grouping of a homogeneous electron beam instead of traditional electron beam bunching, the CWC ameliorates the dispersion effects of space-charge fields and allows the achievement of high conversion efficiency. At the same conference Japan conducted an "energy transmission to a high-altitude long-endurance airship" experiment (ETHER), driving a small blimp from an altitude of 35m to 45m, and also providing power that enabled the airship to hover for over four minutes, using microwave power transmitted from the ground to a rectenna aboard the airship.

A 16-month, $750,000 NASA study of solar power satellite (SPS) systems was released in September. It focused on a number of new design concepts and technologies that were not feasible when the previous NASA-Department of Energy study was undertaken in 1978, as well as updated environmental considerations, current economics, and new market opportunities. The report concluded that investment costs were still too high for major power-grid applications, but that the SPS might make sense in certain niche markets; for example, in developing countries having little or no existing power-supply infrastructure.

In a report issued on 26 June, "Assessment of the Topaz International Programme," the U.S. National Research Council (NRC) recommended terminating work unless the funding agencies (currently the U.S. Department of Defense and the Defense Special Weapons Agency) combine present nuclear space power technology efforts to commit at least twice the present annual budget to Topaz. The NRC cited the funding agencies' lack of commitment to firm missions requiring Topaz-level power as the main reason for its recommendation. The programme was subsequently cancelled in September. Topaz was started in 1991 with the shipment of two—and in 1994, four more—unfueled Topaz-2 space power reactors from Russia to the University of New Mexico for testing and thermionic power system technology development.

The new space policy released by Clinton motivated a reassessment of the United States' virtual abandonment of space nuclear power research (see below). On 18 October, the Defense Special Weapons Agency issued a solicitation for research and development of advanced thermionic technologies to support long-duration space missions using nuclear-electric propulsion for five-year missions at power levels of 40 to 100 kW.

A thermal experiment flown aboard Shuttle Endeavour in May (see above) achieved the highest heat-pipe temperatures ever experienced in space. The 80-kg experiment package, designed and developed by the U.S. Air Force Phillips Laboratory, included three potassium heat pipes, a flight computer, controls, and a power distribution system. The heat pipes are being developed for future high-performance space power systems such as thermionic converters and advanced photovoltaic arrays.

Materials and Structures

Pressure testing of NASA's new aluminum-lithium lightweight Shuttle propellant tank test article was successfully completed on 5 September. Testing of the 12-m long, full-diameter (8.25-m) tank verified all critical design parameters for the full-length (46-m) tank. The new flight article, scheduled to begin undergoing tests in November, is lighter than the current Shuttle tank by 3,400 kg, allowing an equal increase in Shuttle payload. The increase is needed for Shuttle launches to the high-inclination (51.6-degree) orbit of the international space station.

On 6 November 1995, a suborbital tether experiment was conducted on the Canadian Oedipus-C system to explore system dynamics and tether stability. The 1200-m tether also provided information on electromagnetic wave propagation during its 15-minute parabolic flight, along with tether dynamics as defined by a Bristol Aerospace sensor that measured the direction and magnitude of the tether tension vector in three axes. Tether behavior was similar to that of the much longer tether subsequently deployed from Shuttle Columbia in February (see above). Another tether experiment, Tether Physics and Survivability, was successfully deployed in orbit from a U.S. military satellite on 20 June to a length of 4 km. The purpose of the test, designed and conducted by the National Reconnaissance Office and the Naval Research Laboratory, was to test the 2-mm-thick cable for its susceptibility to space-debris damage.

Analytical methods developed by Aerospatiale (France) to determine the life of large composite propellant tanks through chaos theory were verified by test measurements in November 1995. In June 1996, the company also demonstrated the use of advanced carbon-carbon manufacturing technologies for highly stable 3-m structural elements of satellite optical benches.

The feasibility of a low-noise magnetic-bearing momentum wheel which can swivel to reduce the number of wheels required for satellite attitude control was successfully demonstrated in March by TELDIX.

Tests at various descent angles conducted in May by Daimler Benz Space (Germany) successfully demonstrated the stability upon impact of a novel toroidal airbag system for planetary landings and Earth-returning capsules. The airbag is inflated before impact to reduce shock loads to the landing vehicle or capsule.

Automation and Robotics

On 26 September, ESA committed $10 million to the design, development, launch, and operations of the agency's first minisatellite programme, the 90-kg Proba spacecraft, which will test and demonstrate technologies for achieving high levels of spacecraft autonomy. It is expected to be launched into a high-inclination 1200-km circular orbit as a secondary payload in 1999, possibly aboard a Russian Kosmos.

Space Research Facilities

The European Space Agency launched on 28 November 1995 a 12,000-kg Maxus sounding rocket from Sweden's Esrange site to an altitude of 706 km. The 500-kg payload of eight biology and physics microgravity experiments helped researchers from France, Germany, Belgium, and Switzerland gain experience for similar studies to be conducted on the international space station. The $11.7-million flight gave the experimenters about 12.5 minutes of microgravity conditions.

On 2 March, the 34th Texus sounding rocket, built and integrated by Daimler-Benz Aerospace and Kayser-Threde (Germany), was launched from Sweden's Esrange launch complex carrying six experiments on low-gravity fluid behavior for German and other European scientists. Sweden's Maser sounding rocket subsequently carried 265 kg of ESA experiments from the Esrange site to a height of 252 km on 3 May, providing six minutes of microgravity time and recovery of the instrument package by helicopter an hour later.

NASDA's TR-1A sounding rocket, built by Nissan (Japan), concluded its fifth successful suborbital flight from the Tanegashima Space Center on 25 September, carrying six microgravity experiments weighing 634 kg.

On 12 February, Japan launched the 1050-kg Hypersonic Flight Experiment (Hyflex) aboard the new J-1 vehicle, beginning flight testing of new thermal protection systems slated for use on the H-2 Orbiting Plane (HOPE), evaluating attitude controls for reentry, and verifying performance during hypersonic flight. The $45-million mission accomplished 12 of the planned 14 experiments, including 15 minutes of hypersonic flight, but after a successful splashdown in the ocean the vehicle broke loose from its flotation system and was lost. The last two experiments, which required recovery and inspection of the thermal protection system, therefore could not be completed.

Japan's Automatic Landing Flight Experiment (Alflex) was also tested at the Woomera range in Australia during a series of drop tests beginning on 6 July, completing the three-phase initial test programme for HOPE. The tests verified automated guidance and landing behavior of the 6-m long, 780-kg test vehicle during 2.7-km flights from an altitude of 1.5 km after being dropped from a helicopter. All 13 tests of the one-third-scale proto-shuttle were completed successfully by 15 August.

NASA's Johnson Space Center successfully completed on 12 July a one-month test of the Early Human Test Initiative. The test was to demonstrate recycling of air, water, and urine to demonstrate regenerative life support capability that will eventually be needed for long-term stays on the Moon and for exploration of Mars by humans. The crew of four were able to remain in the 6m x 8m vacuum chamber three weeks beyond the originally planned seven-day stay, recycling all fluids for a full month.

On 1 May, NASA created a new Center for Commercial Development of Space (CCDS) at the Colorado School of Mines. The new center, called the Center for Commercial Applications of Combustion in Space (CCACS), was initiated with a $5-million, 5-year NASA grant. Among the research tasks to be pursued in seeking commercial applications of the effects of space microgravity on combustion processes are studies of more porous ceramics for bone replacements, evaluations of new fire-fighting chemicals to replace ozone-depleting halons, development of metal-matrix composite materials, and studies of flame behavior to help minimize the production of pollutants by commercial combustion processes.

Environmental Effects of Space Flight

The explosion of a Proton Block DM fourth-stage engine on 19 February (see above) released an estimated 200 pieces of debris, some of which passed through the orbits of the Mir space station and the Shuttle Columbia, which was in the midst of a mission. It was the first time a Block DM stage had suffered an explosion of any type. The orbital debris inventory was further boosted on 3 June, when a Pegasus upper stage launched in 1994 shattered into 577 measurable pieces.

On 28 February, the Office of Science and Technology Policy (USA) released "The Interagency Report on Orbital Debris 1995." Citing the expected increase in debris that will result from the deployment of several low Earth orbit communication constellations during the next few years, the report recommends a series of actions to mitigate the growing orbital debris problem.

On 1 May, NASA revealed that the peaking of the 33-year Leonid meteor cycle in 1998-1999 will pose a significant risk to large satellites. If the meteor storm develops as predicted, the probability that a 10-sq. meter spacecraft will be struck by a particle bigger than 10 micrograms traveling at 72 km/sec (the average speed of Leonid meteors) grows to 1 in 1,000. Because of its size, the international space station would experience a 100 percent probability of being struck by one or more of the high-speed particles.

On 24 July, the 50-kg French Cerise military intelligence technology microsatellite launched as a secondary payload with Helios-1A on 7 July 1995, was damaged by collision with a piece of old Ariane debris from the 22 February 1986, launch of the French Spot-1 satellite. Both objects had been documented by tracking systems; this was the first recorded collusion of two catalogued objects.

VII. EDUCATION

Teaching Programmes

The first graduating class of the International Space University at Strasbourg, France, received their Master's degrees in space studies on 26 July. During their nine-month course of study, the 30 students from 14 nations completed a study of deforestation using a satellite network and prepared a detailed proposal for the system. The Space-Assisted Network Against Desertification (SAND) was estimated by the class to cost about $26 million. The students suggested that it start in Morocco, which not only has problems with desertification but also operates Africa's center for Earth observations, the Royal Remote Sensing Center.

The Regional Centre for Space Science and Technology Education for the Asia-Pacific region was established on 1 November 1995. The Centre, which is affiliated with the United Nations, is located in India at the India Institute of Remote Sensing in Dehra Dun and the Space Applications Centre in Ahmedabad. Its areas of academic activity include remote sensing, geographic information systems, satellite communications, space science, and research on global climate change.

The student-built Summer Undergraduate Research Fellowship (Surfsat-1) satellite was launched by a Delta-2 from Vandenberg Air Force Base as a secondary payload on the 4 November 1995 launch of Canada's Radarsat-1 (see above). The 55-kg Surfsat-1, which cost NASA and the California Institute of Technology about $3 million, was designed, developed, and built during the past eight years by 60 students from the United States and the United Kingdom. Its mission is to test new communications hardware and software for NASA's Deep Space Network and to help train new tracking engineers.

Students at the U.S. Air Force Academy initiated the Blue Moon project in November 1995 to launch a microsatellite in October 1997 that will fly into orbit around the Moon. Total cost of the mission is estimated at $1 million or less. The spacecraft weighs 50 kg and uses several new technologies; for example, hybrid (solid-liquid) rocket propulsion and a ballistic capture trajectory which is estimated to reduce the propellant consumption needed for a lunar orbit insertion by 10 percent. Blue Moon will be launched as a secondary payload on a geosynchronous transfer orbit mission. It will carry a magnetometer to study the solar wind and an optical imager similar to the one used on Clementine (see last year's report).

On 4 March, students at Rensselaer Polytechnic Institute (USA) took over data collection from a crystal-growth experiment aboard Space Shuttle Columbia (see above). NASA controllers at RPI sent commands to the Isothermal Dendritic Experiment, which involved computer-aided tomography (CAT) scanning of the growth of crystals of succinonitrile.

The Delft University of Technology (Netherlands) began offering in September an international Master's degree in space systems engineering. The one-year course, whose motive is to improve Europe's competitiveness in commercial space endeavours, emphasizes methods for cost reduction and management of satellite communications and remote sensing systems.

On 10 October, the United Kingdom's National Science Centre committed $6 million in national lottery proceeds to develop, launch, and operate a small astronomy satellite, called the Humble Space Telescope, to deliver astronomy data to students' desktop computers via the Internet. Satellites International and Surrey Satellite Technology, both British companies, are expected to compete for the satellite contract.

Canadian high-school students submitted proposals to the Canadian Space Agency (CSA) on 8 November for experiments to be flown on the Russian Mir space station in May 1997. The Canadian Protein Crystallization Experiment calls for 800 protein samples to be flown in small sample "wells" on Mir for five months; 40 of the wells have been set aside for student experiments. The programme is sponsored by the CSA and 12 Canadian universities.

Public Awareness

A multi-year public outreach programme jointly sponsored by the National Space Society (USA), the U.S. Space Foundation, and 16 corporations began on 22 March with ceremonies at the National Air and Space Museum in Washington DC. The campaign, called Harvesting Opportunities for Mother Earth (HOME), is designed to promote civil, commercial, and military uses of space.

The X-Prize Foundation offered a $10 million prize to the first company or person who designs, builds, and flies a spaceship to an altitude of 100 km twice within two weeks using only private-sector funds. The ship must be able to carry three people, although only one needs to be aboard to win the prize. Participating in the award announcement ceremony, held in May in St. Louis, Mo. (USA), were Charles Lindbergh's grandsons, astronauts from the Apollo and Shuttle missions, and the NASA Administrator.

VIII. INTERNATIONAL COOPERATION AND SPACE LAW

On 2 October 1995, in Oslo, Norway, Peter Korobenkov, head of the Space Systems Coordination Division of the International Telecommunication Union (ITU), said that the ITU is receiving numerous applications for satellite systems that may never be built. Korobenkov said the ITU has no procedures to dismiss coordination applications for satellite systems that are clearly not ready for development. The matter is becoming a major administrative problem at the ITU in Geneva.

From 2-6 October 1995, the 46th International Astronautical Congress was held in Oslo, Norway on the theme "Benefits of Space for Humanity." The Congress was attended by 900 participants, accompanying persons and students from more than 40 countries, with member agencies or organisations participating in the International Astronautical Federation. In discussing the IAF's role in a changing world, the General Assembly of the Federation indicated its desire to continue and to strengthen its cooperation with the United Nations and its specialized agencies.

From 18-20 October, the Council of the European Space Agency (ESA) met in Toulouse, France. Senior representatives of the 14 member countries and Canada (Cooperating State) reached major decisions on ESA's future programmes. Observers from the Commission of the European Union, Eumetsat and Eutelsat attended. The Council approved funding for development of the Columbus Orbital Facility and the Automated Transfer Vehicle, which will serve the International Space Station when launched on an Ariane-5 vehicle. The Council also approved definition studies of a Crew Transfer Vehicle.

The Council unanimously decided to introduce the European Currency Unit (ECU) as ESA's currency unit to provide greater stability in financial operations. The Council approved a proposed evolution programme to keep Ariane in step with user needs; an improved Ariane infrastructure programme, to strengthen Ariane competitiveness; and an Ariane Research and Technology Accompaniment Programme to maintain Ariane's reliability. The Council established a five-year stable funding plan for the mandatory Science Programme. An Industrial Policy Working Group was formed to review and strengthen ESA's industrial policy and to make more effective execution of ESA programmes.

On 12 November 1995, Mission STS-74 was launched from the United States to the Russian space station Mir for the primary purpose of delivering the Orbital Docking System and the Russian Docking Module to the Mir. RSC Energiya and the Rockwell Aerospace Group did development work on the module. This was the second successful Mir docking mission involving a U.S. Shuttle Orbiter.

On 16 November 1995, an Ariane 44P successfully placed the European Infrared Space Observatory (ISO) into a planned, highly elliptical orbit. ISO is designed to search for cosmic objects visible only to infrared sensors. The estimated $1.3 billion total cost of the ISO programme makes it Europe's most expensive scientific satellite programme to date. The programme control centre is located near Madrid, Spain.

On 28 November, a British company contracted with a Thai company in Bangkok to assist in the construction and launch of the first national Thai microsatellite. The £3 million contract includes a state-of-the-art satellite, construction of a ground station and an 18-month technology transfer training programme.

Also on 28 November, a Chinese Long March booster successfully launched the AsiaSat 2 communications satellite for its Hong Kong owners. The launch was covered by an expensive insurance contract costing the owners a 27 percent premium to insure a $180 million risk. The launch was important to the Chinese for confidence restoration following earlier Long March failures.

In November, the National Space Development Agency of Japan signed an agreement with Eosat, of Lanham, Maryland, USA, to retrieve remote sensing imagery from Indian sensing satellites. Eosat markets the images under an agreement with Antrix, the commercial agent of the Indian Space Research Organization (ISRO). Eosat seeks to establish a network of 15 ground stations around the world to collect data from the Indian satellites.

Also during November, the American corporation PanAm Sat signed an agreement with an international partnership of entities in Australia, Brazil, Mexico and the United States. The agreement provides 48 transponders on three satellites for the use of the partnership in broadcasting direct satellite television in the Latin American region and in the Caribbean basin. One of the partners, News Corp. of Sydney, Australia, owns the United Kingdom's BSkyB, Asia's Star TV satellite television services, 20th Century Fox film studio, and the Fox television network. Services in Latin America and Caribbean were to begin in early 1996.

On 1 December, the European Meteorological Satellite Organization (Eumetsat) assumed operational control of European Meteosat spacecraft. Formerly managed through the ESA European Space Operations Centre (ESOC) in Damstadt, Germany, the three operational Meteosats will now be managed at expected lower cost and with rapid turnaround of imagery access. Satellite data will pass through a Fucino, Italy, earth station to the Eumetsat headquarters, also in Damstadt, be processed there, and returned rapidly to the satellite through the same path for rebroadcast to user earth stations. Data up-links also exist at Bracknell, United Kingdom; Toulouse, France; and Rome, Italy.

On 2 December, the Solar and Heliosphere Observatory (SOHO) was launched from Cape Canaveral, Florida, on an Atlas HAS rocket. In April 1997, the satellite is to arrive at, and be parked in, an orbit around the First Lagrange Point, where the gravitational forces of the Earth, Sun and Moon are in balance about 1.5 million kilometres from Earth on the Earth/Sun axis. SOHO carries 12 sophisticated telescopes and other instruments developed by 12 international consortia composed of scientific institutes in 15 countries. SOHO is part of ESA's Solar-Terrestrial Science Programme, a cornerstone of ESA's long-term science programme "Horizon 2000."

On 14 December 1995, the United States and Ukraine signed an agreement for up to 20 geostationary-orbit launches of U.S.-built payloads on Ukrainian launchers through 2001, following similar agreements signed in previous years with China and Russia. Five of the launches are unrestricted; another 11 are set aside for joint U.S.–Ukrainian ventures such as Sea Launch (see above), and four more will be added should market growth warrant them.

On 28 December, a Russian Molniya rocket placed India's most advanced remote sensing satellite (IRS-1 C) in an 817 kilometre polar orbit from Baikonur. The IRS-1C can produce black and white images with 6 metres resolution, which is the sharpest commercially available imagery in the world.

During the Pacific Telecommunications Conference, 14-18 January 1996, the issue of orbital crowding and consequent inter-satellite system radio interference received considerable attention. Several industry spokespersons and consultants suggested possible future actions by the ITU to address the problems. Suggestions included: (1) streamlining coordination procedures and reducing the backlog of pending applications; (2) establishing due diligence requirements to select out applications for systems not being timely pursued; (3) allocating new bandwidth for satellite services, possibly in the X-band range of the spectrum; (4) encouraging implementation of new technologies to overcome interference problems; (5) requiring signal identification by broadcasters to permit prompt contact with offending signal sources; and (6) finding ways to account for satellites in inclined orbits that can contribute to interference problems.

In mid-January, the 44-nation Eutelsat Organization announced a modified membership policy to permit private broadcasters and telecommunication entities to become co-members with national telecommunication agencies. The policy will permit multiple members from a single country. Private entity members will be permitted direct access to the organization's satellites. The policy will come into effect in mid- 1997 and could eventually result in lower user costs for Eutelsat satellites.

On 14 January 1996, Koreasat 2 was launched from Cape Canaveral Florida aboard a Delta II booster. On the same day, Ariane launched two communication satellites on a single booster from Kourou, French Guiana. Ariane launched the PanAm Sat 3R for the U.S. PanAm Sat Corp., and the Measat-1 satellite. The Measat-1 is Malaysia's first privately-owned satellite and will provide direct broadcasting satellite service and domestic and regional communication services.

U.S. Vice President Al Gore and Russian Prime Minister Viktor Chernomyrdin signed an agreement on 30 January 1996, increasing to 20 from nine the allowable number of Russian launches of U.S.-built geosynchronous-orbit commercial spacecraft through the end of the century.

On 31 January, the Palapa C1 satellite, the first of Indonesia's third-generation comsats, added new capabilities to meet satellite communication service needs in the Asia Pacific Region. Palapa C1 was launched on an Atlas 2AS booster from Cape Canaveral, Florida.

In January, the U.K. Defence Research Agency announced the signing of a licensing agreement with the Canadian Radarsat programme to receive and process Radarsat data using an earth station at West Freugh, Scotland, for distribution in the United Kingdom, Ireland and Denmark. An earlier agreement had been reached between The Centre for Remote Sensing and Processing (CRISP) of the National University of Singapore, Radarsat International and the Canadian Space Agency for similar purposes in the Pacific basin. CRISP's Singapore ground station can acquire imagery of Indonesia, parts of Australia, Sri Lanka, Bangladesh, Indochina, Myanmar, southern China, Brunei; and the Philippines. Images collected by CRISP can significantly help in ocean monitoring. CRISP received its first imagery from space on 22 January.

During January, Lockheed-Martin entered into an international partnership with two Saudi Arabian-owned firms to create Satphone International Ltd. Satphone plans to bring radio mobile communications to the Middle East, using a 3 geostationary satellite constellation planned to be established near the end of this decade.

In early February Arianespace ordered 10 additional Ariane 4 launch vehicles from Europe's space industry at a cost of about 5 billion French Francs. With these launchers Arianespace can offer launch capacity for nearly 70 satellites through 1999.

On 8 February a group of Russian space companies and two American companies signed a strategic accord. The agreement provides for cooperation in manufacturing arid use of satellite communications and television, environmental monitoring and other advanced technology projects.

On 15 February, an attempted launch of an Intelsat communication satellite on a Chinese Long March booster failed. The failure occurred early in the flight and the booster and satellite debris came to earth inside China.

On 23 February, Tajikistan became the 137th member of the International Telecommunications Satellite Organization (Intelsat) with a 0.05 percent ownership share.

On 27 February, the British Particle Physics and Astronomy Research Council announced formation of an eight-member consortium to set up a future data processing centre for Europe's planned X-Ray Multi-Mirror (XYLEM) spacecraft, now scheduled for launch in 1999. The consortium will include Leicester University in the United Kingdom and five cooperating institutes from France and Germany. The consortium will design software programs to analyse XMM data for science users in Europe and the United States.

On 29 February, one European and two Russian cosmonauts departed the Mir space station, landing on Earth in northern Kazakhstan after about 3 hours and 20 minutes. Thomas Reiter, an ESA astronaut, had spent 180 days in space with his Russian colleagues. Reiter's mission was the longest ever undertaken by an astronaut outside the former Soviet Union. Reiter also engaged in two spacewalks.

In early March, Intelsat notified Chinese authorities of Intelsat's decision to cancel contracts for future launches of Intelsat satellites from China. The cancellations, made pursuant to a decision during Intelsat's Board of Governors meeting in Bangalore, India, raise the possibility of the China Great Wall Industries Corp. seeking legal redress for the contract cancellations.

On 4 March, the U.K. Government announced that it had committed £2.8 million to the Ariane 5 programme up to the year 2000.

On 6 March, the Republic of Bosnia and Herzegovina joined Intelsat as its 138th member with a 0.05 percent share.

During early March the Japanese National Space Development Agency completed negotiation of an agreement with the Russian Space Agency to perform microgravity and radiation experiments on microflora aboard the Russian space station Mir. Russia will be paid $1 million by Japan to assist in the experiments. The Japanese experiments were tentatively scheduled for launch from Baikonur on a Russian Cargo Supply Craft in mid-October; to be returned to Earth in December.

On 22 March, the Space Shuttle Atlantis was launched to conduct the third Shuttle-Mir docking mission. This mission successfully delivered several logistics support packages and U.S. astronaut Shannon Lucid for an extended visit aboard the space station.

On March 26, the Mitsubishi Corp. of Tokyo and LunaCorp. of Arlington, Virginia, formed a partnership to undertake a commercial mission to the Moon in 1999. Two intelligent robotic vehicles are being designed for the mission by the Robotics Institute of Carnegie Mellon University in Pittsburgh, Pennsylvania.

In March, a Dutch and a Russian company agreed to undertake joint development of solar panels for a forthcoming Dutch satellite called Sloshsat. Participants in the joint programme believe that the two companies might eventually market their jointly developed solar panels to space programmes in Russia and in the West.

In late March, the U.S. PanAm Sat Corp. announced a joint satellite broadcasting venture including the United Kingdom's Carlton Communications, TVB of Hong Kong, the Hindustan Times of Delhi, and Schroder Capital Partners of Hong Kong. The venture will distribute a new Hindi language TV channel to India and other parts of south Asia, using the PAS-4 satellite. Uplinked from Hong Kong, the channel will be distributed in C-band for redistribution on the ground by cable systems.

In April, Brazil and Argentina signed an agreement on space and technology development. One of the articles of the accord will allow Argentina to use Brazil's Alcantara launch facility for development and launch of space payloads.

On 3 April, Inmarsat launched its Inmarsat-3 IF from Cape Canaveral. This first of five next generation satellites, built by an Anglo-French-U.S. team of lead contractors, improves provision of global commercial mobile satellite telephone services to users in the air, at sea or on the ground. It is the first Inmarsat spacecraft for which all ground control and check-out was done by Inmarsat. The satellite completed check-out and entered service on 13 May.

On 9 April, the first commercial Russian Proton rocket was launched from Baikonur carrying the Astra IF satellite for Hughes and SES (Societe Europeene des Satellites). This is the sixth satellite in the Astra series providing pan-European television broadcasts.

On 30 April, the Italian-Dutch SAX (Satellite per Astronomia in raggi X) was launched from Cape Canaveral by an Atlas-Centaur booster. This launch is the climax of a cooperative programme on which the feasibility study began in 1984. Actual development began in 1989 With its highly accurate pointing system, SAX will observe high-energy, cosmic X-ray sources with far greater resolution than previous astronomical satellites.

In early May it was announced that the People's Republic of China reached agreement with the Canadian Space Agency and Radarsat International to receive, process and distribute imagery from the Radarsat satellite system. Received at the Remote Sensing Satellite Ground Station in Beijing, the satellite data will be processed in China's National Remote Sensing Centre. The Beijing station can acquire imagery of China, Japan, Korea and Taiwan. The data distributor, Tradeglobe Import and Export, will work with the National Remote Sensing Centre and the Radarsat Resource Centre, scheduled to open later in 1996. Also in May, it was announced that similar agreements were made by the Canadians for national collection, processing and distribution of imagery with agencies in Austria, France and the Phillippines. Other national distributors were added as the year progressed.

On 6 May, the FCC granted Columbia Communications special temporary authority to operate its commercial C-band communications capacity on the NASA TDRS-4 satellite from the geostationary-orbit slot at 41 degrees west longitude beginning in 1998. In 1991, Columbia had agreed to turn that slot over to Intelsat in six years, but then asked Intelsat for a four-year extension until it can afford to buy and launch a new satellite to Columbia's slot at 47 degrees west. When Intelsat refused, Columbia sought redress from the FCC, which decided in favor of the small company in order to ensure its ability to compete with a "large intergovernmental organization born of privilege...and nurtured by years of regulatory policies designed...to insure its commercial viability." Columbia also began marketing commercial services from NASA's TDRS-6, a 12 C-band transponder spacecraft located at 74 degrees west, under an agreement reached in May with NASA.

On 9 May, the FCC issue a proposed ruling enabling non-U.S. communication satellite operators to market their services in the U.S. provided their countries allow U.S. operators to do the same. This ruling responded to a U.S.-Mexican bilateral agreement signed in April.

TRW (USA) filed a U.S. patent infringement suit against ICO Global Communications on 10 May, following months of unsuccessful negotiations with the commercial Inmarsat spin-off company. The claim is based on TRW's two patents based on TRW's Odyssey system, issued in July and August 1995 following applications filed in 1991, for directed coverage by a global cellular telephone system using a constellation of satellites in medium-altitude Earth orbits. ICO's plans call for a $2.6-billion system using 10 satellites plus two spares in 10,355-km orbits; Odyssey's $3-billion network will have 12 satellites in 10,354-km orbits.

On 14 May, meeting in Berlin, The German Space Agency (DARA) and the National Space Development Agency (NASDA) of Japan agreed on a range of potential cooperative space activities, including cooperation on a Japanese rendezvous and docking mission planned for 1997. The agreement calls for DARA to contribute a ground station in Japan to provide control of a complex separation and rendezvous in space of parts of Japan's Engineering Test Satellite-7. Other aspects of the agreement address ways in which Germany may use Japan's laboratory module and exposed platform on the International Space Station, and possible future collaboration in an international global observing system.

In late May it was announced that the 21-nation Arabsat organization expects to name a manufacturer later in the year to build a large direct-broadcasting satellite. The satellite, to be known as Arabsat 2C. would provide regional television broadcasting for the Arab states after its planned launch in 1999.

Brazil and France signed on 28 May the first contracts that implement a June 1995 agreement to pursue cooperative space ventures. The Brazilian Space Agency (AEB) and the French space agency (CNES) agreed to design and build a joint scientific satellite weighing 80 kg to study the space environment from low Earth orbit. Launch is scheduled for 1998. Contracts were also signed with French companies for a rocket ground-test facility in Brazil, technical studies for optical instruments to be used on the China-Brazil Earth Resources Satellite, and expansion of Brazil's satellite test center.

On 4 June, the cooperative European Ariane programme suffered a major setback when the first flight of the Ariane 5 booster went out of control early in the flight and broke up just 39 seconds after lift-off. The failure destroyed four Cluster spacecraft, each containing 11 scientific instruments developed by many institutes in Europe for solar studies and examination of the Sun–Earth relationship. No backup spacecraft exist.

On 15 June, an Ariane 44P rocket successfully placed the Intelsat 709 satellite in geostationary orbit above the Atlantic Ocean. The satellite adds 36 Ku-band and C-band transponders for service in the Atlantic Region.

In early July the China Great Wall Industry Corp. successfully launched on a Long March 3 booster the Apstar IA telecommunication satellite, owned by API Satellite Co., Ltd., of Hong Kong, into a geostationary orbit. This launch returned the Chinese launch program to operational status. The Apstar 1A, a Hughes-built HS 376 telecommunication satellite, will make possible voice, data and television services for southern and eastern Asia.

On 24 July, ESA and the Government of the Portuguese Republic signed in Paris an Agreement of Space Cooperation for peaceful purposes. The agreement will strengthen Portuguese/ESA cooperation in areas including space science, remote sensing, telecommunications and microgravity research.

After months of heated and often acrimonious debate, U.S. President Clinton adopted a policy on 1 August that restricts future U.S. commercial remote-sensing satellites from imaging Israeli territory at resolutions better than those commercially available today. The wording of the policy, however, is such that it is expected to have little or no real effect on high-resolution commercial systems planned for the foreseeable future. These will use digital imaging at resolutions down to 1 meter, which are considered comparable in resolution to the 2-meter photographic images currently available commercially from Russian military reconnaissance satellites.

On 24 August, Asia Satellite Telecommunications Company (AsiaSat) of Hong Kong completed arrangements for a $250 million line of credit involving 12 international banks. The money will be used to refinance existing debt of AsiaSat and as working capital. The 7½ year arrangement involves six Asian banks, four European and two North American financial institutions. AsiaSat currently provides regional telecommunication services with two satellites and plans to establish a third satellite in late 1997.

In late August an agreement was reached in Beijing between China and Thailand to locate their communication satellites in space at least 2 degrees apart in geostationary orbit to avoid mutual harmful radio interference.

The United States' long-awaited space policy document was finally released on 19 September after a 10-month delay. It reaffirms the strong U.S. science and exploration programme, but puts off any decisions on human missions to Mars until the lessons learned from space station research and a sustained robotic presence on Mars through 2000 have been analyzed. It also states the U.S. intent not to renew the present bilateral launch agreements with Russia, China, and Ukraine, but to replace them with free and fair trade in launch services. The policy further instructs the U.S. Department of Energy to maintain the capability to produce and test the nuclear isotope power sources needed for far-planet exploration missions, and instructs both NASA and the Department of Defense to purchase commercial components wherever possible and practical, rather than develop dedicated ones, up to and including entire spacecraft.

India and Hungary signed a space cooperation agreement on 27 October 1995 embracing the fields of Earth observations, space physics, astronomy, and solar-terrestrial physics. Signatories were the Chairman of the Indian Space Research Organization (ISRO) and the Director of the Hungarian Space Office.

ISRO also signed a joint agreement for space cooperation with Canada on 15 October 1996. The two countries will exchange technical personnel to explore cooperation, primarily in Earth observations and joint commercial ventures involving Canada's Radarsat and India's IRS satellite series, but the agreement also covers satellite communications, space research, and space exploration.

On 7 November, the Czech Republic and the European Space Agency (ESA) signed a five-year agreement establishing a framework for cooperation on space science, Earth observation research and applications, satellite communications, microgravity research and ground segment engineering and utilisation.

In 1996, the International Institute of Space Law (IISL) continued both to develop the substantive law of outer space and to disseminate knowledge about space law. The major formal framework of the Institute's work is its annual Colloquium at which papers on space law matters are presented and discussed. The 39th Colloquium was held, as usual, in conjunction with the annual Congress of the International Astronautical Federation, which took place in Beijing, China. The subjects covered at the Colloquium included the legal status of property rights on the moon and other celestial bodies, cases and methods of dispute settlement in space law and the legal aspects of sharing benefits from the conduct of space activities.

The Moot Law Competition held on 10 October at the IAF Congress was won by two Finnish law students from the University of Helsinki, Anna Markkanen and Satu Heikkila. They bested two students from the University of Wyoming (USA), Joe Richer and Bastiaan Coebergh, in debating the liability issues raised when a satellite is destroyed by its own launch-vehicle's upper stage.

In cooperation with the United Nations Office for Outer Space Affairs, the IISL published a bibliography on space law, consisting of a cumulative subject/author index of the proceedings of IISL Colloquia from 1958-1994.

In cooperation with the European Centre for Space Law (ECSL), the IISL organized a Symposium for the benefit of delegates to the 1996 session of the Legal Subcommittee of COPUOS, on "Protection of the Space Environment."

At the special Colloquium to celebrate the 50th anniversary of the International Court of Justice, held at The Hague in April 1996, space law was one of the two subjects chosen for consideration to equip the Court to deal with developing areas of international law. Several other important conferences dealing with various aspects of space law were also held in 1996. These included the conference to celebrate the 40th anniversary of McGill University's Institute of Air and Space Law and the conference on the regulation of Global Navigation Satellite Systems (GNSS), held at ESTEC, in the Netherlands. The ECSL's annual summer course on space law and policy was held this year at Leiden, The Netherlands.

PART TWO:

PROGRESS OF SPACE RESEARCH 1996

I. SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

Satellite Programs

On 4 November 1995, NASA launched the Canadian Radarsat-1 spacecraft into a 794 km x 788 km orbit, inclined at 98.59 degrees, opening new avenues of radar exploration of the Antarctic ice sheet and other surface features. The Synthetic Aperture Radar on-board is a C-band radar with several operation modes: precise measurement, wide area coverage and others. As Radarsat flies at 6 o'clock equator crossing time in a Sun-synchronous orbit, it can observe the Earth 24 hours a day.

The Indian Remote Sensing Satellite (IRS-IC) was launched as scheduled on 20 December 1995, with improved sensor and coverage capabilities to meet the growing application needs. It has put into orbit a Panchromatic camera (PAN) with 5.6 m resolution and stereo viewing capability, a multispectral Linear Imaging Self-Scanner (LISS-III) with a resolution of 23.6 m and 70.8 m in VNIR and SWIR bands, respectively, and a Wide Field Sensor (WiFS) with 189 m coarse resolution. PAN caters for cartography-related applications, LISS-III caters for agricultural, hydrological, forestry and land-use mapping applications, and WiFS caters for agricultural/vegetation mapping applications.

The successful launch of IRS-P3 on 21 March 1996, has given a further boost to the Indian remote sensing program. IRS-P3 has the novelty of providing both remote sensing data and astronomical data. The Modular Opto-electronic Scanner (MOS) has been optimized for oceanographic application, the WiFS for vegetation dynamics and the Indian X-ray Astronomy Payload (IXAP) for study of cosmic activities.

The Total Ozone Monitoring Spectrometer (TOMS EP-1) was launched successfully from VAFB in July 1996. It is now producing ozone mapping data on a daily basis. Further TOMS instruments are being developed, including one which is complete and in storage, which is planned for a launch on the Russian Meteor 3 mission in FY 2000.

On 17 August 17 1996, NASDA successfully launched the Advanced Earth Observing Satellite (ADEOS), on the fourth flight of the H-II launch vehicle from Tanegashima Space Centre, into an orbit 804.6 km x 789.0 km, inclined at 98.625 deg. ADEOS is the largest satellite Japan has ever developed, with a total mass of approximately 3.5 tons and dimensions of 11 x 7 x 29 m at deployment of the NASA Scatterometer (NSCAT) and Solar Array Paddle Subsystem (PDL). ADEOS carries two core sensors (OCTS and AVNIR) and six Announcement of Opportunity (AO) sensors. These are the NSCAT, a TOMS instrument, the Polarization and Directionality of the Earth's Reflectances instrument (POLDER), the Interferometric Monitor for Greenhouse Gases (IMG) experiment, the Improved Limb Atmospheric Spectrometer (ILAS) and the Retroreflector In Space instrument (RIS). ADEOS was placed into final orbit on 8 September, and the function of the bus system and the mission instruments are now being checked. The initial mission checkout of ADEOS will continue for about 90 days until the middle of November. The Ocean Color and Temperature Scanner (OCTS) is an optical radiometer to achieve highly sensitive spectral measurement with 12 bands covering the visible and thermal infrared region. This is the first ocean color sensor since the Coastal Zone Color Scanner (CZCS) aboard the Nimbus-7 satellite was launched 18 years ago. The Advanced Visible and Near-infrared Radiometer (AVNIR) is a high spatial resolution optical sensor and its data will be useful for environmental awareness and monitoring of such phenomena as desertification, destruction of tropical forests, and pollution of coastal zones as well as for resource exploration, land use and other things. The TOMS and POLDER experiments are also optical instruments. The principal mission of TOMS is to monitor global ozone trends during the period when CFC-related depletion is predicted to be near its maximum. POLDER is a French instrument that can acquire nine bands and two bands x three polarization with a wide area camera. POLDER is expected to detect the Earth radiation budget, vegetation and ocean color. These instruments are expected to lead to a better understanding of radiation transfer in the atmosphere, specifically aerosols that are considered parameters of large uncertainty in a recent IPCC report. NSCAT, a microwave scatterometer, will measure near-surface wind vectors (both speed and direction) over the global oceans. This information is critical in determining regional weather patterns and global climate. The two infra-red instruments, IMG and ILAS, are from the Japanese Agencies MITI and EA, and they will make spectral measurements of the atmosphere. Long durational and global measurements of trace gas concentration, temperature and water vapour soundings will come from these instruments. Onboard ADEOS a corner cube reflecting mirror, RIS, is installed to measure the atmospheric concentration with the absorption of lidar light transmitted from the ground. ADEOS has a comprehensive observing capability for global change with eight instruments from the ultraviolet to microwave spectral regions.

Meteosat 3 and Meteosat 4 were moved out of geostationary orbit on 15 and 23 November 1995, respectively, and, on 25 April 1996, the Japanese MOS-1b satellite operation was terminated after six years.

At present, Meteosat 5 serves as EUMETSAT's operational satellite whereas Meteosat 6 is kept in backup orbit. Meteosat missions have been operated directly by EUMETSAT's ground segment since 15 November 1995. As far as other geostationary satellites are concerned, GMS-5 is operational at 140 degrees east, GOES WEST is at 135 degrees west and GOES EAST is at 76 degrees west. The latter two are operational over the American Continent. GOMS is operated in experimental mode at 76 degrees east. Due to the malfunctions in onboard optical systems in the visible channel, not more than 15% of visible images may be utilized from this satellite.

The launch of SPOT-3 in September 1993, resulted in a significant increase in the capacity and availability of the SPOT constellation now composed of three satellites in orbit. SPOT-2 is operated in direct acquisition mode only in order to increase the coverage and revisit capacity of SPOT-3, which is used as the prime operational spacecraft with its full recording capacity available. SPOT-1 continues to provide high-quality imagery and can be activated as a back up or as an additional service. SPOT-3 carries also DORIS and POAM-2, a UV/visible spectrometer procured by the Naval Research Laboratory and used in solar occultation mode to sound the polar stratosphere.

Both the European Remote Sensing 1 and 2 (ERS-1 and 2) systems are continuing to perform their missions with an availability of mission products averaging 98-99 %. The Japanese Remote Sensing satellite, JERS-1, is still operating four years after launch, collecting an extremely large volume of data for the Global Rain Forest Mapping project.

The Shuttle Solar Backscatter Ultraviolet (SSBUV) instrument was flown in early FY 1996 in support of the continuing mission to monitor the ozone layer. The first flight of the Shuttle Laser Altimeter took place in January 1996, aboard STS-72. Work will begin on a second mission which is currently planned for FY 1998.

The Optical Transient Detector (OTD) completed its first year on orbit after uncovering tantalizing links between space-based lightning measurements and the intensity of severe storms. Launched on a private satellite, the orbiting detector has produced the first high-quality images of lightning on a global scale, enabling researchers to potentially use lightning flash rates as an aid in predictions of tornado formation. OTD is a precursor for the Lightning Imaging Sensor (LIS), which will fly on TRMM (see below).

The Upper Atmospheric Research Satellite (UARS) completed its fifth year in orbit and is continuing to provide data to support improvement in monitoring the processes that control upper atmospheric structure and variability, the response of the upper atmosphere to natural and human-induced changes, and the role of the upper atmosphere in climate variability.

TOPEX/Poseidon has completed its fourth year of providing definitive data on the principal tidal components of the world's oceans. Understanding tidal patterns is critical in accurately assessing the effects of the oceans on global and regional climate patterns. Data from the same satellite has led to major improvements in satellite orbit determination and in our knowledge of the geopotential.

Future Satellites

Launches in the near future include the US Seastar mission, which will be launched in January 1997, and the European Meteosat-7, which is planned for launch in mid-1997.

The EOS portion of the MTPE program will begin with the AM-1 mission, to be launched in June 1998. AM-1 focuses on the physical and radiative properties of clouds, trace gases, and air-land and air-sea exchanges of carbon and water. All five AM-1 instruments have shown very good progress. These are the Moderate-resolution Imaging Spectro-radiometer (MODIS), the Multi-angle Imaging Spectro-Radiometer (MISR), the Clouds and Earth Radiant Energy System instrument (CERES), the Japanese Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer and the Canadian Measurements of Pollution in the Troposphere (MOPITT).

The LEWIS satellite was originally scheduled for launch in July 1996. However, due to failure of the Lockheed Launch Vehicle (LLV), the launch schedule is under review. LEWIS will carry 25 new technologies plus three advanced sensors to meet the needs of the commercial remote sensing and Earth science communities.

Funding received from the U.S. Defence Mapping Agency (DMA) will allow work to begin on a joint NASA/DoD/DMA Space Shuttle mission scheduled to be flown in May 2000, carrying a specially modified radar system that will produce the most accurate and complete topographic map of the Earth's surface ever assembled. The planned 11-day Shuttle Radar Topography Mission (SRTM), a follow-on to SRL, is designed to collect three-dimensional measurements of nearly 80 percent of the Earth's land surface, except near the poles, with an accuracy of better than 53 feet.

The United States and France have agreed to pursue the Altimetry-Radar mission (JASON-1), as a modified follow-on to the TOPEX/Poseidon mission. CNES will provide the spacecraft and altimeter, NASA will provide the radiometer, ground system, and launch.

The EOS PM-1 mission will provide information on cloud formation, precipitation, and radiative properties and on air-sea fluxes of energy, carbon and moisture—which will contribute to short term weather prediction improvements. The Atmospheric Infrared Sounder (AIRS), Advanced Microwave Sounding Unit (AMSU), CERES, MODIS, Microwave Humidity Sounder (MHS), the Humidity Sounder from Brazil (HSB) and the Japanese Advanced Microwave Scanning Radiometer (AMSR) instruments, will fly on EOS PM-1.

The Chemistry-1 mission, focusing on the atmospheric chemical processes of trace gases and their impact on global climate, is proceeding on schedule toward a 2002 launch. Chemistry-1 instruments, including the High Resolution Dynamics Limb Sounder (HIRDLS), Microwave Limb Sounder (MLS), Tropospheric Emission Spectrometer (TES), and the Japanese provided Ozone Dynamics Ultraviolet Spectrometer (ODUS) instrument, are currently in extended phase B.

The TRMM observatory is on schedule for a November 1997 launch on the Japanese H-II launch vehicle from Tanegashima Space Centre. All five instruments, including the Japanese Precipitation Radar (PR), have been delivered to GSFC and installed on the observatory. This has completed the integration phase and baseline performance testing.

Landsat-7, with a new generation instrument to capture Landsat data, is on schedule for a launch date of May 1998.

The EOS Laser Altimetry Mission (LAM), focusing on ice topography and mass balance, has continued its phase A technology development for the Geoscience Laser Altimeter System (GLAS) instrument.

The Stratospheric Aerosol and Gas Experiment (SAGE-III) instrument, which will focus on measuring aerosol and gas constituents of the atmosphere, will fly in a polar orbit on a Russian Meteor-3M(1) spacecraft in August 1998. A second SAGE-III instrument is planned also to fly in an inclined orbit on the International Space Station in 2001.

The Active Cavity Radiometer Irradiance Monitor (ACRIM) instrument, which will record changes in the total solar irradiance, is expected to proceed for a late 1998 launch.

NASA has started a new program for technology infusion—the New Millennium Program (NMP). NMP focuses on identifying and demonstrating, in flight, advanced technologies that reduce cost or improve performance of spacecraft and/or instruments. The first MTPE NMP mission (EO-1) was selected earlier this Spring, with a launch planned for May 1998. The EO-1 mission is for an advanced land imager incorporating several innovative design features.

SPOT-4 is under development and slated for launch in 1998. Its primary high resolution imagery mission will benefit from an upgraded imager, the HRVIR, equipped with an additional 1.7 micrometer channel and from the doubling of the recording capacity. SPOT-4 will also carry DORIS, POAM-3 a follow-up to POAM-2, and the VEGETATION payload, a wide-field-of-view, medium-resolution push broom imager providing co-registered measurements in the same bands as HRVIR. VEGETATION is a cooperative program of the European Commission, France, Belgium, Sweden and Italy.

The continuity of the SPOT service will be ensured with SPOT-5 scheduled for launch in 2002. Just like SPOT-1, 2, 3 and 4, SPOT-5 is a cooperation between France, Sweden and Belgium. It will represent an improvement over SPOT-4 with an increased resolution (10 m multispectral and 5 m panchromatic).

In a move to develop operational oceanography, a series of small satellites dedicated to altimetry will be implemented through a CNES/NASA cooperation. It will ensure continuity of the TOPEX/Poseidon measurements, at the same level of performance. As mentioned above, the first one called JASON-1 is scheduled for launch in 1999.

The Meteosat Second Generation (MSG) is in Phase C/D development. The MSG program of EUMETSAT foresees three satellites to be designed and built under ESA responsibility according to EUMETSAT user requirements, whereas operations will be carried out by EUMETSAT. The first satellite, MSG-1, is scheduled for launch in 2000.

EUMETSAT's Microwave Humidity Sounder (MHS) is in its Phase C/D development stage, with the first instrument to be delivered in 1998. MHS will fly on the NOAA-N, N' satellites, with further flight models foreseen to fly on the METOP series of spacecraft. The METOP satellites will form the space segment of the EUMETSAT Polar System (EPS) program, which is currently in the approval process. The METOP Phase B study is currently ongoing under ESA responsibility.

As a continuation to IRS-IA/IB, IRS-IC and IRS-P2/P3 Missions, the Department of Space (DOS), of the Government of India is in the process of defining continuation missions mainly addressing the gap in application areas not covered by the present IRS satellites. Suitable sensors for applications such as cartography, crop and vegetation monitoring, oceanography and atmospheric studies are being designed as described below:

The IRS-ID, which is slated for launch in 1997 by the indigenous Polar Satellite Launch Vehicle (PSLV), will be a follow-on to IRS-1C and will carry the same payloads, viz., PAN, LISS-III and WiFS.

IRS-P4 (OCEANSAT-1) will have payloads, specifically tailored for the measurements of physical and biological oceanography parameters. An Ocean Color Monitor (OCM) with eight spectral bands, Multi-frequency Scanning Microwave Radiometer (MSMR) operating in four frequencies will provide valuable Ocean-Surface related observation capability. The OCEANSAT-1 is slated for launch by PSLV in early 1998.

IRS-P5 (CARTOSAT-1) will have a cutting edge technology in terms of sensor systems and will provide a state-of-the-art PAN camera with about 2.5 m resolution with fore-aft stereo capability. This mission will cater for the needs of cartographers and terrain modelling applications. The satellite will provide cadastral level information up to 1:5,000 scale and will be useful for making 2-5 m contour maps. The CARTOSAT-1 is slated for launch by PSLV, in early 1999.

IRS-P6 (RESOURCESAT-1) will be a state-of-art satellite mainly for agriculture applications and will have a 3-band multispectral LISS-IV camera with a spatial resolution better than 6 m and a swath of around 25 km with across track steerability for selected area monitoring. An improved version of LISS-III with four bands (red, green, near IR and SWIR), all at 23 m resolution and 140 km swath will provide the essential continuity to LISS-III. These sensors will provide data which will be useful for vegetation related applications and will allow multiple crop discrimination and species level discrimination. Together with an advanced Wide Field Sensor (WiFS) with 80 m resolution and 1400 km swath, the payloads will greatly aid crop/vegetation and integrated land and water resources related applications. The IRS-P6 is slated for launch by PSLV by end of 2000.

The IRS-2 series (OCEANSAT-2/CLIMATSAT-1/ATMOS-1) will be an integrated mission that will cater to global observations of climate, ocean and atmosphere. Microwave instruments to cater for oceanographic applications will be mainly a Ku band Altimeter, Ku band Scatterometer, Microwave Radiometer and Thermal Infrared Radiometer for observing oceanographic parameters like winds, sea surface temperature, waves, bathometry and internal waves. Instruments for atmospheric chemistry applications include spectrometers, sounders and radiometers for studying the atmospheric constituents, pollution and for monitoring ozone and greenhouse effect. Instruments to observe climate and meteorological parameters will include microwave sounders, radiometers and rain radars.

IRS-3, beyond 2002, will have all weather capabilities with multi-frequency and multi polarisation microwave payloads and other passive instruments.

Several Japanese missions are in development. TRMM is the joint US-Japan project referred to above. Another Japanese mission, the Advanced Earth Observing Satellite-II (ADEOS-II), which is the successor to the ADEOS mission, will take an active part in research of the global climate changes, practical utilization for weather phenomena and fishery.

The Advanced Land Observing Satellite (ALOS), another Japanese satellite, is mainly aimed at cartography. It will be equipped with the AVNIR-2, which is a 2.5 m-capable triplet optical radiometer, and the VSAR, which is an L-band Synthetic Aperture Radar. ALOS will be launched in 2002 by a Japanese H-IIA rocket.

Developments in China of the geostationary meteorological satellite, FY-2, and polar-orbiting meteorological satellite, the modified FY-1, are underway. In addition, a resource remote sensing satellite with Chinese and Brazilian cooperation is making significant progress.

New kinds of space-born sensors, such as moderate resolution imaging spectrometers, Multi-mode (scatterometer, altimeter, radiometer) MW sensors, SAR, as well as Solar/Atmospheric Backscattering UV Spectrometer, Earth Radiation Budget Sensors, are being developed in China. Key techniques are being developed for other advanced sensors, such as a space-borne lidar. The Multimode Microwave Remote Sensor is a new sensor in which active and passive modes are working simultaneously. The Main application of this sensor system is ocean research, atmospheric research and land soil moisture monitoring. The altimeter mode can provide geoid, significant wave height and wind speed measurements with precision, satisfying user requirements. The scatterometer mode will provide ocean wind field data and the radiometer can provide atmospheric data and ocean surface temperatures. The Multimode Microwave Remote Sensor consists of three operation modes. The specific mode combination can be selected in order to meet user requirements. The Altimeter (ALT), Scatterometer (SCAT) and Radiometer (RAD1) work at the same K-band frequency and use a common antenna. The active mode (ALT and SCAT) and passive mode (RAD1) will work time-sequentially to avoid power release to the RAD1 receiver. Radiometers (RAD2-RAD6) work at frequencies covering from 6.6 GHz to 90 GHz and use two separate antennae. The Altimeter will operate in a pulse limited mode and use de-ramped technology with LFM. In the Scatterometer mode a pencil beam conical scanning antenna has been used, unlike the usual scatterometer in which several fan-beam antennae are used. In radiometers a multi frequency system has been selected to meet the user's requirements. The radiometers are of three types. The first group is the scanning image radiometer which uses a pencil beam antenna sharing which the scatterometer a separate feeder at a frequency 13.9 GHz. The second group is the multi frequency along track radiometer using a common parabolic antenna with separate feeders. Finally a 90 GHz radiometer working with an independent special model antenna to protect a high measuring accuracy. All radiometers work in all-power type with an indirect calibration technique.

Highlights of Scientific Results

NOAA studies of the upper atmosphere using Global Positioning System (GPS) data reveal the flow of blobs of concentrations of ionization in the low latitude ionosphere. Analysis of the GPS signals from several satellites infer the total electron content of the atmosphere between the ground and the satellites. Measurements from a variety of ground stations and satellites show that the movement of these blobs is controlled by the low latitude electric fields, a critical parameter for space weather models. This is a new and exciting technique to monitor ionospheric parameters in a region of the globe that is very difficult to observe.

Major progress has been made in atmospheric ozone science, an important example of science in support of national and international policy. Analysis of global data from the Upper Atmosphere Research Satellite (UARS) has confirmed that ozone-depleting chemicals reaching the stratosphere are primarily of industrial origin. The results reconfirmed the sound scientific basis for the Montreal Protocol.

The ozone data-set generated from NOAA and NASA Solar Backscatter Ultraviolet (SBUV) instruments on NOAA operational satellites and the NASA Nimbus-7 continues to be extended with the launch of the NOAA-14 satellite in late 1995. These data are being used by an increasing number of researchers internationally especially for ozone depletion analyses.

New results on several other important aspects of atmospheric ozone have provided new data on ozone levels as well as information relevant to possible health effects studies. New analysis techniques developed for the Total Ozone Mapping Spectrometer (TOMS) provided the first global data set on surface ultraviolet (UV) radiation. These results provide the first confirmation of global trends in increasing UV radiation related to stratospheric ozone depletion, and provide the basis for improved health effects assessments. A recently launched TOMS will provide the data for continued ozone and UV trend determinations with improved resolution and precision.

Atmospheric ozone studies have also been able to show an environmental response to policy actions such as the Montreal Protocol. Ground-based measurements documented a continued decrease in the growth of ozone-depleting industrial chemicals in the lower atmosphere, confirming the industrial response to the Montreal Protocol. From these results, stratospheric ozone is expected to reach a minimum within the next decade and then begin to recover.

The improved resolution and dynamic range of the United States' new Geostationary Operational Environmental Satellite (GOES) has allowed for the development of advanced image products and now-casting techniques. With the new generation of GOES, imagery is taken over the continental United States and coastal waters, Hawaii and Alaska once every 15 minutes under normal operational modes, and at approximately 7½ minute intervals when severe weather threatens. In special cases, imagery has been obtained over hurricanes at one minute intervals, and over tornadic thunderstorms once every 30 seconds. This super rapid scan imaging is allowing for a number of exciting quantitative measurements and qualitative observations to be made. A demonstration, evaluation and training program that allows for the receipt and analysis of digital GOES imagery and products is in place at more than 50 National Weather Service field offices. The capabilities for using digital GOES imagery has significantly improved the utility of satellite imagery for now-casting at those offices.

Real time experimental satellite products for Quantitative Precipitation Forecast (QPF) and flash flood prediction have been developed at NOAA. The family of experimental products include: (1) precipitation estimates that cover the entire GOES image data derived from the GOES 8 Automatic Flash Flood Precipitation Algorithm, (2) precipitable water and precipitation efficiency analyses for detecting precipitable water plumes—a key ingredient for extreme precipitation events, and (3) soil wetness for detecting flooded areas and antecedent ground conditions prior to flash floods. These experimental products are still undergoing development and validation. All of these products are available on the NESDIS Flash Flood World Wide Web Home Page at ftp://orbit-net.nesdis.noaa.gov/pub/ff/ff.htm.

Blended precipitable water (PW) products for detecting areas and plumes of moisture are available for the continental United States. This blended product, is composed of SSM/I, GOES 8/9, and ETA model derived PWs. A Precipitation Efficiency Factor that is computed by multiplying the blended PW times the blended relative humidity (1000-500 mb) is also available.

The Soil Wetness Index (SWI) is available for the continental United States and global scale raw SWIs (daily and pentad) and SWI anomalies (pentad). It uses the differences between the 85 GHz and 19 GHz horizontally polarized radiation from the SSM/I instrument. These differences are selectively scaled to enhance the extremely wet to flooded soil conditions. The anomalies are used to remove the pixel climatology in order to better interpret the pentad product. SWI has an archive back to 1987.

Climatological data sets of monthly mean hydrological cycle parameters (e.g., rainfall, cloud liquid water, TPW, snow cover, and sea-ice cover) derived from the SSM/I continue to be produced by NOAA scientists and archived at NOAA's National Climatic Data Centre, and are now nine years in length. The mean fields and monthly anomalies from the nine-year base period have proven to be useful in a number of applications throughout the scientific community.

NOAA's operational single channel AVHRR optical thickness product has been produced with an improved second generation retrieval algorithm since March 1995 from NOAA-14. The algorithm was revised based on a careful analysis of match-ups between AVHRR and surface Sun-photometers. The new algorithm appears to be working well and is undergoing validation with surface Sun photometer data.

NOAA development of CLAVR Phase II has proceeded to a one-month (September 1989) demonstration of global cloud amount by cloud type. Four generic cloud types: liquid water, mixed phase, thick glaciated and thin cirrus are identified, and the fractional amount of each type (explicitly accounting for partially cloud-filled pixels), together with clear and cloudy radiance statistics in all five channels of AVHRR are given in a 110 km resolution equal area grid.

Pixel effective cloud amount, pressure and temperature from the TOVS cloud remote sensing program are being mapped, and daily and monthly averaged into cells of polar stereoscopic and lat./long. projections. These products are being produced routinely by NOAA from its polar orbiting satellites on a rotating file of ten days for evaluation purposes. They are expected to become operational in 1997.

All afternoon AVHRR data sets from 1981 to 1995 (five channel instruments) are being reprocessed with atmospheric parameter retrieval algorithms. A benchmark period of 18 months in 1987-88 were processed to yield: cloud/clear radiances, total cloud amount, Earth radiation budget parameters, and aerosol optical thickness over oceans. The entire 14-year data set is expected to be completed in 1997 using a cloud algorithm that classifies observations as clear, cloudy, or mixed. A second processing of the 14-year dataset is being planned for 1998, but this time with a subsequent version of the processing system which provides layered cloud statistics, including cloud optical properties, and in addition, surface radiation budget parameters, precipitation indices, and aerosol optical thickness over land.

A fast model for simulation of radiative transfer in the atmosphere, called the Radiance Sampling Method (RSM), has been developed by EUMETSAT in order to support operational calibration monitoring and product generation from future EUMETSAT satellites, MSG and METOP.

EUMETSAT hosted the Third International Winds workshop in Switzerland in May 1996, dedicated to wind extraction from operational meteorological satellites.

Research work into improved methods for the extraction of wind from METEOSAT water vapour channel is ongoing in EUMETSAT, and a special study focused on wind extraction in the middle troposphere was completed in 1996.

Resulting from studies aimed at improving seasonal-to-interannual climate prediction, significant scientific progress was made on El Nino forecasting. An improved characterization of air-sea interaction increased the forecasting skill for El Ninos for the 1980s, compared with previous forecasting procedures. These results suggest that El Nino is more predictable than previously estimated.

New science results demonstrated the importance of the El Nino effects on climate and vegetation. Meteorological satellite data from 1982-1990 were used to document, for the first time, the link between El Nino rainfall perturbations and vegetation stress for Africa, Australia, and South America. The unique technique for identifying stressed vegetation is used by the U.S. Aid Famine Early Warning System as an early warning indicator of potential food supply problems in Africa.

In the area of understanding long-term climate variability, improved climate prediction skills have been developed through studies of natural variability. For example, global observations by the Stratospheric Gas and Aerosol Experiment (SAGE) and the Earth Radiation Budget Experiment (ERBE) provided a unique understanding of the climate effects of the Mount Pinatubo volcanic eruption. In addition, the climate model produced a prediction of the effects of Mount Pinatubo aerosols on surface temperatures which showed excellent agreement with subsequent observations.

This verification of skill in modeling the effects of aerosols on climate is a major accomplishment in global climate research.

Maps of high resolution gravity fields that cover the world's oceans have been constructed by NOAA from a combination of Geosat and ERS-1 satellite altimeter data. A comparison with ship tracks shows these fields can resolve gravity anomalies down to wavelengths of about 25 km. Since ship track coverage of the oceans is sparse, these gravity fields show fine tectonic details of the sea floor that were previously undetected. Plate tectonic reconstructions constrained by fracture zones and plate boundaries visualized in these gravity maps reveal details of past plate motions. This gravity field was subsequently used to predict sea floor topography by determining the gravity topography transfer function in local areas via calibration to archival shipboard bathometric surveys. The predicted sea floor topography is computed on the same two-minute grid and is thought to have resolution better than 100 m in depth in most areas. Efforts are now under way to include depths from this grid in ocean circulation models.

Data from TOPEX/Poseidon has challenged a fundamental oceanographic theory about the speed of large-scale ocean waves—a finding that could ultimately revise science textbooks and improve global weather forecasting. The large-scale ocean waves, with wavelengths of hundreds of miles from one wave crest to the next, are called Rossby waves. Using data gathered by the satellite, scientists tracked the waves as they moved through the open ocean and have determined that, at mid-latitudes, the Rossby waves are moving two to three times faster than previously thought. Rossby waves can alter currents and their corresponding sea surface temperatures, which influences the way the oceans release heat to the atmosphere and thus are able to affect weather patterns. This more precise information about how fast the waves are travelling may help forecasters improve their ability to predict the effects of El Nino events on weather patterns years in advance.

The First ISLSCP (International Satellite Land Surface Climatology Project) Field Experiment (FIFE) Project collected intensive remote sensing and field data on a prairie site in Kansas, USA. The objectives of FIFE were to understand the biophysical processes controlling the fluxes of radiation, moisture and carbon dioxide between the land surface and the atmosphere, and to develop remote sensing methodologies for observing these processes. Data from FIFE has been published on five CD-ROMs which contain surface observations, non-image datasets, satellite imagery, aircraft imagery and processed images (approximately 3 gigabytes) and is available through the Internet.

Major scientific progress was made on how land cover characterization improves weather prediction. During the joint NASA/Canadian study of northern forests, the Boreal Ecosystem-Atmosphere Study (BOREAS) project, an important advance was made in characterizing the role of the northern forests as a control on water, heat and momentum transfers between the surface of the Earth and the lower atmosphere. BOREAS data from ground-based, airborne and satellite sources introduced into experimental weather prediction models significantly improved the ability to predict regional weather. In addition, BOREAS accomplished the accurate measurement of the rate of growth of northern forests for the first time, demonstrating that the slow growth of boreal forests results in low transpiration of water to the atmosphere; also, that the strong control of forests on water fluxes to the atmosphere is a primary reflection of the strong link between biology and weather.

Recent research has demonstrated the power of Synthetic Aperture Radar (SAR) for natural hazard science and applications. Examples of new science results showing the utility of SAR to natural hazards problems through precisely documenting changes in topographic features of the Earth's surface are (1) measuring the spatial effects of post-seismic deformation (ground motion) associated with recent Californian earthquakes, (2) quantifying regional subsidence due to groundwater extraction in the Los Angeles Basin, and (3) measurements of volcanic eruption rates at the Kilauea volcano in Hawaii.

The M7.6 earthquake called the "Hannshinn-Awaji dai-shinnsai" occurred on 5:46 (JST) on 17 January 1994 centred 10 km below the Akashi channel near Kobe. It resulted in the death of 5502 people. The differential interferometry technique using the JERS-1 L-band SAR data pair, one acquired on 9 September 1992 and the other on 6 February 1995, could detect the two-dimensional surface deformation pattern caused by the earthquake in this area. From the image, two major features were confirmed: 1) the Nojima fault, northwest of Awaji island, caused a half-egg type deformation pattern; 2) its accumulated deformation was around a metre, which agreed well with the ground truth data; and 3) the other faults (the Egeyama-fault and Kobe-Nishinomiya fault) also generated the half-egg pattern with around 20 cm deformation. It was also recognized that L-band wavelength is adequate for interferometry because of less temporal decorrelation.

To improve the measurement of surface deformation (ground motion) produced by underlying geological faults in southern California, NASA is implementing a high density global GPS geodetic array in collaboration with the US Geological Survey and the National Science Foundation. In addition to providing better data for analysing this important natural hazard, the GPS array provides a test bed for evaluating the accuracy of new methods of SAR remote sensing techniques.

Population and energy consumption by cities and towns that can be inferred from lights at night are seen in meteorological satellite imagery analysed by NOAA scientists. DMSP satellites record nighttime emissions in the visible and near infrared emission bands at very low levels of radiance, i.e. 10^{-9} Watts/cm^2. Stable emission sources as faint as towns, squid fishermen, the aurora, and moon lit clouds are captured in the images. Several studies have demonstrated the technique and its application to population dynamics and economic vitality.

A global monthly climatology of a quantity called Vegetation Fraction was developed by NOAA as part of the GEWEX Continental-scale International Project (GCIP). Vegetation fraction is the fractional area of the surface covered with active green vegetation. This quantity was derived from AVHRR data and provided at 0.15 degree lat/long resolution for each month. The vegetation fraction is used in numerical weather forecast models and general circulation models to help specify the energy and water budgets at the surface.

Satellite tracking has been used by NOAA's National Marine Mammal Laboratory for the past decade to monitor the movements of several species of marine mammals around the world.

Near real-time AVHRR sea surface temperature satellite images were used to direct the NOAA Ship David Starr Jordan while sampling for larval Dungeness crab (Cancer magister) and juvenile rockfish (Sebastes spp.) off the central California coast near Point Reyes in June 1994, 1995 and 1996.

Some new areas of natural hazard research and application are being developed. For example, in China research on disaster reduction with Earth observation data is broadly being conducted in different areas, including drought, flood, and forest fire warning and monitoring with AVHRR images, soil erosion, forest classification, vegetation damage, forest disaster, with TM data, earthquake warning with GPS.

For drought monitoring, the Anomaly Vegetation Index has been used, since it can identify the anomaly of vegetation growing from normal precipitation and shows good correlation with monthly precipitation anomaly. On the other hand, for dynamic flood monitoring, a new ratio index of AVHRR Channel 1 and 2 has been suggested as a way of detecting water area in cloud-contaminated AVHRR images. Different technical systems are being developed and partly put into operation in which Earth observation plays an important role.

Composite Dataset Programs

Twelve French teams are actively involved in the use of ERS and TOPEX/Poseidon satellite altimeter data. In the field of geophysics, 10 km resolution global maps of the marine geoid and related gravimetric and bathometric fields have been constructed using merged data sets and are widely distributed. Glaciologists have produced a 10 km topographic map of Antarctica, after complete reprocessing of one full 35-day cycle of ERS-1 data. Ice flow lines and surface slopes derived are distributed to modellers of the polar cap dynamics. In Oceanography, reprocessed, merged data sets are analysed to extract ocean signals, including accurate ocean and load tides, seasonal change of the ocean height, mean sea level drift patterns, propagating Kelvin and Rossby waves in the tropics and subtropics, and their relation with western boundary currents. Assimilation into dynamical models is developed in the tropical oceans, the Mediterranean sea and the North Atlantic. In the latter case, high resolution quasi-geostrophic models are adjusted in near real time and prediction for mesoscale circulation in the Azores current area is routinely made available.

Three years of highly accurate DORIS measurements from SPOT and TOPEX/Poseidon have allowed the computation of the movements of beacons installed on all tectonic plates. The three-year displacements are in agreement with those estimated on geological time scales, except near plate boundaries. DORIS instruments will be also launched on the ENVISAT and JASON spacecraft.

The Global Rain Forest Mapping project (GRFM) is an effort by NASDA to acquire contiguous SAR coverages of the major rain forest areas on the Earth by the L-band SAR on the JERS-1 satellite. The project is led by NASDA, but relies on extensive cooperation with other agencies and organizations, most notably NASA (via the Jet Propulsion Laboratory and the Alaska SAR Facility), the Joint Research Centre of the EC, the National Institute for Space Research (INPE, Brazil), and the Ministry of International Trade and Industry (MITI), via the Earth Remote Sensing Data Analysis Centre, ERSDAC (Japan). The entire Amazon Basin, from the Atlantic to the Pacific, was acquired once in one sweep during the low water season in September-December 1995 and once again in May-August 1996, during the peak of flooding in the Amazon river. The second acquisition was extended to cover also the northern part of the South American continent as well as Central America. Central and west Africa, from the eastern coast of Kenya to Guinea in the west, were acquired in the same fashion between January and March 1996, during the low water season of the Congo river. The Congo River Basin will also be covered during the high water period in October and November 1996. Southeast Asia and the South Pacific is the third major region covered in the project. The islands of New Guinea, Borneo/Kalimantan, Sumatra, Java and Sulawesi have been covered since August 1996 and the Philippine Islands, the Indochina Peninsular and northern Australia will be covered in late 1996 and early 1997. The three regions sum up to some 11,000 SAR scenes, covering an area of approximately 45 million square km. The output of this project will be SAR mosaics at 100 metre resolution (regional coverage -about 5500 x 5500 km/mosaic), and SAR mosaics at 400 metre resolution (semi continental coverage) and coarse classifications (5-6 classes) over certain areas. Mosaics and classifications will be made available to the international science community (for research purposes only) on CD-ROMs and/or 8 mm tapes. An Internet homepage is currently under construction, where non-mosaic scenes at 100 metre resolution will be made available for browsing and possibly for downloading.

A European Development group has been set up to design and develop a software package for the processing and utilization of Advanced TOVS (ATOVS) data that will be provided through direct readout of HRPT data from the forthcoming NOAA K, L, and M satellite series. The group is coordinated by EUMETSAT. The complete package is planned to be ready in 1997.

International Cooperation

The Committee on Earth Observation Satellites (CEOS) and the Intergovernmental Oceanographic Commission (IOC) have established the International Ocean Color Coordination Group (IOCCG) to promote the wide use of ocean color data from space for scientific, operational and commercial purposes. IOCCG comprises representatives from research institutes, space agencies and others. Ocean color data is now coming from many satellites including MOS/IRS, OCTS/ADEOS, SeaWiFS/Seastar, MODIS/EOS-PM and MERIS/ENVISAT.

The Intergovernmental Panel on Climate Change (IPCC) released their Second Assessment Report (SAR) to the public in December 1995. One of major conclusions in the scientific part of the report is: "Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate." The IPCC prepared also, based on SAR, the "IPCC Second Assessment Synthesis of Scientific-Technical Information Relevant to Interpreting Article 2 of the UN Framework Convention on Climate Change." The "IPCC Third Assessment Report" is to begin in about 1998 and completed in approximately 2000. IPCC decided to produce a set of Technical Papers to assist the FCCC in its work. Technical Papers would be based on the material presented in IPCC reports and relevant portions of references cited and relied upon therein. Currently, the following papers are being prepared; "Simple Climate Models," "Stabilization of greenhouse gas concentrations in the atmosphere" and "Technologies, policies and measures." The IPCC guidelines for National Greenhouse Gas Inventories are revised at the 12th session of the IPCC (September 1996), particularly concerning the reporting of (1) industrial emissions, (2) emissions from forests, forest soils and forest products, the ultimate fate of which may be important to consider, and (3) methane emissions from rice fields.

The collaboration between space agencies and the World Climate Research Program (WCRP) has been extensively enhanced through the reporting period. NASDA has started to support the Global Energy and Water Cycle Experiment (GEWEX) Asian Monsoon Experiment (GAME) researches through EORC activities. The first GAME International Science Panel (GISP) supported by NASDA was held 3-7 November 1995, at EORC. NASDA is now conducting intensive rawin/radio-sonde observation in collaboration with TMD (Thai Meteorological Department) through the National Research Council of Thailand (NRCT) to investigate a diurnal cycle in the monsoon area, and preparing an intensive radar observation in the Tibetan Plateau region to investigate a behaviour of convective system there. In addition, ADEOS products will contribute to the GEWEX, Climate Variation and Predictability (CLIVAR), Stratospheric Processes and their Roles in the Climate (SPARC) and Arctic Climate System Study (ACSYS) programs.

Monthly mean precipitation on a 2.5 x 2.5 degree grid has been produced by the GEWEX Global Precipitation Climatology Project (GPCP) for the period July 1987- December 1995. It consists of a blend of satellite infrared and microwave estimates of precipitation with rain gauge analyses. A total of 19 products, including the single source input fields, combination products and error estimates for the rainfall products are available. It is an international effort with contributions from EUMETSAT, Germany, Japan and the USA. The data are available electronically from World Data Centre A at the NOAA/National Climatic Data Centre.

Public Education and Awareness

EUMETSAT has, in close cooperation with WMO, established a User Forum for Developing Countries that will be open to all registered users of EUMETSAT data, products and services in developing countries. Its second meeting to be held in Harare, Zimbabwe, in mid-December 1996, will be focused on training issues and preparation for the use of new generation satellites.

NOAA scientists have made available to the international user community, through the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV), user-friendly formulae for the calculation of near-real time calibration updates for the visible and near-infrared channels of the Advanced Very High Resolution Radiometer (AVHRR) onboard the NOAA-14 spacecraft. The formulae, which can be accessed on World Wide Web, are presently being used by researchers in national space agencies, remote sensing laboratories, weather services, and academia.

NOAA's National Climatic Data Centre is planning a conference on Satellite Applications to be held in March 1997 in Asheville, North Carolina, USA. The focus of this conference will be to educate users of satellite data (and potential users) on new applications and techniques for satellite data processing, and the available tools for these applications. For further information, see the NCDC home page.

COSPAR Scientific Commission Resolution

In view of the importance of studies of the Earth and other objects based on analysis of natural electromagnetic emissions, the COSPAR Council, at the behest of its Scientific Commission A, adopted the following resolution.

COSPAR, noting that,

the requirements for increased telecommunications systems (fixed, mobile, and intersatellite) will be addressed at the World Radio Conference in 1997; and

Taking into account that,

electromagnetic emissions, particularly in the centimetre and millimetre wave range, can be used to obtain information on the state and composition of the atmosphere and other objects of interest, that measurements both from the ground and from space are of the utmost importance in determining the amount of water vapour, molecular oxygen and trace gases present, and hence for weather forecasting and long-range climate monitoring, Reaffirms that,

it is vitally important to preserve an adequate spectrum range for astronomical radio science and atmospheric environmental science and its application; and

Requests,

the support of other ICSU bodies, such as URSI and IAU, in upholding this stand.

II. SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS AND SMALL BODIES OF THE SOLAR SYSTEM

Terrestrial Planets

Mercury

ESA has initiated a study of a Mercury Orbiter as part of its post-2000 program of space missions. Preliminary results of this study were presented at COSPAR meetings in July 1996 in Birmingham, England. The nominal launch year is 2007. The mission will include science observations of Venus en route to Mercury, where it will complete the mapping of the surface begun by Mariner 10 (which only viewed half of the planet) adding geochemical information and improved characterization of the magnetic field.

Venus

With the completion of the Magellan radar mapping mission in 1994, no new missions to Venus have been initiated.

Moon

Lunar Prospector is a NASA Discovery-class spacecraft being built by Lockheed -Martin. It is scheduled for launch on 24 September 1997 and will go into a polar orbit with an altitude of 63 miles for one year of geochemical mapping of the lunar surface. It will carry six instruments that are designed to map the Moon's surface composition, gravity and magnetic fields, and to search for the possible release of volatiles from the lunar interior. If fuel is available at the end of the one-year nominal mission, lunar mapping may be extended to lower altitudes over areas of special interest.

Mars

A new age of Mars investigations is opening in 1996. Three spacecraft will be launched in November and December, to arrive in the summer of 1997. The Russian Mars96 mission consists of an orbiter with a comprehensive payload of science instruments that is also equipped with two penetrators and two landers to be deployed on the Martian Surface. NASA's Global Surveyor is an orbiter carrying several of the experiments from the failed Mars Observer Mission, including a high resolution camera and a thermal mapper. The NASA Pathfinder is a small rover, to be soft-landed on a set of air bags, equipped with a camera and a device to measure elemental composition by means of alpha backscatter.

A Martian mission called PLANET-B is being developed by Japan for launch in 1998. It is designed to study Martian aeronomy and the interaction of Mars with the solar wind (including studies of the planet's magnetic field).

A Discovery-class mission to land on or near the northern Mars polar cap was approved by NASA and is being prepared for launch in 1998. It will be joined by an orbiter that will carry the rest of the Mars Observer payload except for the gamma-ray spectrometer, which will be sent in 2001.

Plans for Mars network missions were put on hold as ESA elected not to go forward with MARSNET and NASA and the Russian Space Agency similarly backed away from complementary multi-station missions originally planned for the 2001 or 2003 launch opportunities.

Mars was the subject of a major discovery this year with a proposal by D.S. McKay et al. (Science 273, 924 [1996]) that one of the meteorites known to come from Mars might contain signs of ancient Martian life. This suggestion has added considerable interest to the field of Martian studies.

Asteroids

The NEAR mission, designed to study asteroids Matilda (27 June 1997) and Eros (January 1999) was successfully launched on 17 February 1996. As of October 1996, all systems are performing normally. The Eros encounter in 1999 will be a rendezvous lasting for one year, during which the spacecraft will reach an altitude of 12 miles from the asteroid's surface, obtaining images and geophysical and geochemical data.

Comets

One of ESA's cornerstone missions is the cometary mission called Rosetta to Comet P/Wirtanen. The spacecraft is scheduled for launch in January 2003 and will rendezvous with the comet in 2011. The project consists of an Orbiter and a Lander. The orbiter will stay with the nucleus for three years, a period that will include the comet's perihelion passage, studying the nucleus with remote sensing instruments while simultaneously investigating the coma with mass spectrometers, dust detectors and a plasma package. The Lander will be deployed by the orbiter after the first year of operation and will make in situ studies of the nucleus for a period of one to several months. The exact payload, configuration and lifetime of the Lander are still under discussion.

The Discovery-class Stardust mission also received a new start from NASA. It is designed to fly out to comet Wildt-2 in January 2004 and then return to Earth in January 2006 with a sample of comet dust to Earth. The nominal launch date is 6 February 1999.

The big science news in this field in the current year was the discovery of two comets that reached naked eye visibility—C/ Hyakutake and C/ Hale-Bopp. While a large amount of new information has been (and is being) obtained by ground-based observations, neither of these comets will be visited by spacecraft.

The Outer Solar System

Jupiter

The Galileo spacecraft released its atmospheric probe in July 1995 and the probe entered Jupiter's atmosphere on 7 December 1995. The entry and descent were a complete success; preliminary reports on the results are collected in several papers in Science (272, 837-860 [1996]). Highlights include a definitive determination of the value of He/H = 0.8 solar, detection of Ne, Ar, Kr, Xe and H_2S for the first time, discovery of a new radiation belt close to the planet (1.5 Rj), and the measurement of high speed (200 m/s) winds that continued to the lowest point in the atmosphere measured by the probe (22 bars). The Galileo spacecraft itself successfully achieved its intended orbit around the planet and is steadily returning new information about Jupiter, its satellites, magnetosphere and rings. Among the discoveries already reported are the presence of an iron core in Io, a magnetic field from the satellite Ganymede, an aurora in the tenuous atmosphere of Io, and huge "thunderstorms" in the vicinity of Jupiter's Great Red Spot.

The orbiter mission is scheduled to continue through 31 December 1997, after which time an extended mission must be initiated by NASA if the enterprise is to continue.

Saturn

The joint ESA-NASA mission Cassini-Huygens is being prepared for launch in October 1997. This mission consists of a spacecraft that will go into orbit around Saturn in July 2004, sending the Huygens probe into the atmosphere of Titan in November of that same year. Prospects for an outstanding mission continue to look excellent.

Uranus, Neptune and Pluto

NASA continues to study a possible flyby of Pluto that, if approved, would occur in the early years of the next century.

III. SPACE STUDIES OF THE UPPER ATMOSPHERES OF THE EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES

The Earth's Middle Atmosphere and Lower Ionosphere

The middle atmosphere and lower ionosphere, the region between 20 and 110 km in altitude, is the focus of extremely active research involving all the major nations of the world who engage in solar terrestrial physics research. Understanding this region is critical for a comprehensive appreciation of the interactions between the Sun and Earth, and essential for studies of climate change and of anthropogenic influences upon composition and dynamics. Much of the research is coordinated with, or consistent with, the 1990-1997 Solar Terrestrial Energy Program (STEP), and with the Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) Program being conducted in the United States. Both of these efforts contain major working groups focusing upon this area and both of these communities held significant meetings during 1996 (see below).

The Upper Atmosphere Research Satellite (UARS) continued to provide unique data on constituents, temperatures and winds during 1995-1996, providing opportunities for collaborations with many ground-based observing systems. Considerable efforts continued to be made on the analysis and interpretation of data from campaigns held during 1993-1996 and from UARS. For example, ANLC/ALOHA-93 provided opportunities to study the dynamics and structure of the mesopause regions at mid to high latitudes (Canada) and also at the equator (Hawaii to Tahiti). There have been many published studies on dynamics this year involving UARS (WINDII and HRDI instruments), in collaboration with ground-based systems. UARS is now confirming and expanding the view of wave and wind interactions developed from radars since 1980. In particular, tidal and mean wind global climatologies and model comparisons have been most impressive. A second "Winds Measurement" workshop was held in May 1996 in Toronto to focus again on the various methods of wind measurements available, and their advantages and disadvantages. The comparisons between the major systems (UARS, radars, optical, rocket) are largely satisfactory (e.g. wind and tidal phases), but some biases are evident (radars often provide smaller magnitudes). There is some evidence of greater gravity wave influences and contamination in UARS data. Work continues on this topic, and collaborations that benefit from the combination of global/temporally-intensive soundings.

Highlights of UARS-HRDI/WINDII scientific results have been multitudinous: MLT tides show semi-annual, annual, QBO and inter-annual variations consistent with wave-wind coupling (the QBO has been followed from the stratosphere into the MLT region); large perturbations in the oxygen airglow emission (WINDII) has been related to the large observed equinoctial diurnal tide in the wind field, and compared with TIME-GCM results; global tidal influences on the three emissions (O('s), O2, OH) and hence atomic oxygen (HRDI) have been demonstrated; longitudinal modulation of the airglow emission rate (WINDII) has been related to planetary scale disturbances. Now that a global view of such processes is emerging, the collaborations with ground-based systems, which have high temporal resolution, will allow synergistic studies of wave processes and their detailed interactions. The post-STEP PSMOS program (below) will involve such collaborations.

There have been several missions or campaigns conducted over the past year. Data analysis for the NASA Shuttle experiments CRISTA/MAHRSI (Germany) started in the spring of 1995, and showed that the instrument worked very well, and that the data are of high quality. Preliminary temperatures, and Ozone, CFC11, $ClONO_2$ mixing ratios (out of a total of 16 gases measured) are available. Very interesting small-scale structures are seen in these data in the stratosphere (as streamers or tongues, filaments, etc.). At mesospheric altitudes analysis has begun for CO_2 and Ozone. In the lower thermosphere atomic oxygen fine structure emission at 63 mm has been measured, and mixing ratios are presently being evaluated. Other global campaigns included those of the Mesosphere Lower Thermosphere Coupling Study (MLTCS of STEP, LTCS of CEDAR), involving about 30 radars (MF, Meteor, MST, Incoherent Scatter), and focusing on mean winds, tides, planetary waves and gravity waves and their mutual interactions:

December 1995-February 1996, July-August 1996 for PW studies; and October 23-27, 1995, 19-22 March and 8-12 October, 1996 with the IS Radars. Papers on an earlier 10-day interval (January 1993) will soon be published; and a CEDAR-LTCS planning/analysis workshop was held at Boulder in June, 1996.

Perhaps the most significant Middle Atmosphere satellite presently being developed is the Swedish ODIN, which is being developed in cooperation with Canada, Finland and France. The CSA (Canada) system OSIRIS comprises an optical spectrograph and IR imager; and there is also a radiometer (sub-mm/mm) on ODIN. The satellite, scheduled for launch in 1998, will provide global data on aeronomy/minor constituents and structures, allowing for study of the ozone "holes," PMCs and stratospheric warming influences. Collaborations with ground-based systems capable of validating the ODIN data, and of providing necessary wind and waves measurements for global modelling, are now being planned.

As first reported in 1994, the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) has been established near Andenes (69N, 16E) on Andoya, Norway. The observatory has investigated the physics, chemistry and meteorology of the Lower and Middle Atmospheric regions during 1995-96. The instruments have included a Rayleigh/Mie/Raman lidar (10-80 km altitude; now with full summer-time / daytime operations and with a wind-measuring capability), an Ozone lidar which has operated throughout the 1995-96 winter, the upgraded SOUSY VHF/MST radar, and an IR scanning radiometer. An MF wind radar has now also been installed. Other systems at Ramfjordmoen (EISCAT, MF radar) were also used. The polar mesospheric summer echo (PMSE) event, as studied during the ECHO-94 campaign of 1994, was very intense, and has been explored in unprecedented detail, using rocket-data as well as the ALOMAR systems. The echoes were observed at UHF, VHF and MF for the first time, and PMSE-NLC relationships dependent on temperatures and winds-waves were demonstrated. Very vigorous research on PMSE, NLC, turbulence, gravity waves, ozone and the polar vortex continue involving systems and scientists at ALOMAR, EISCAT (Ramfjordmoen) and Kiruna. The scientific involvement is international. A new VHF-MST radar has been installed at Kiruna, and a rocket/ground bases program (MIDAS) is being developed for the region.

There are also extensive equatorial research programs, involving CADRE (STEP and CEDAR). This coupling and dynamics activity involves an increasing array of radars (ST, MFR, Meteor, MST) and optical systems which are global, but mostly concentrated in the Pacific region. This work will be focused in a Post STEP activity: EPIC, Equatorial Processes including Coupling, 1998-2002. Much of the existing work e.g. on the SAO, QBO in winds and tides, is being linked with UARS-HRDI/WINDII global views, and TIME-GCM modelling.

The major 1996 meeting on Solar Terrestrial Physics was the July COSPAR General Assembly in Birmingham, UK. There were symposia on many topics important to C2: Influence of Tides on species concentrations; Coupling and Energetics in the Stratosphere-Mesosphere-Thermosphere-Ionosphere System; Horizontal and Vertical Small Scale Structures in the MA; Advances in Optical Remote Sensing of the Upper Atmosphere; Permanent changes in the Ionosphere and Middle Atmosphere; the Polar Cap Thermosphere/Ionosphere; Electrodynamics of the MA; Planetary Atmospheres and Ionospheres; E- and D- Region Physics and Modelling.

Well balanced studies featuring observations, modelling and theory are ensuring that significant progress on the objectives of STEP and CEDAR are being made. There was also a three-day SCOSTEP meeting before COSPAR (Foxbury, UK). While STEP is flourishing, plans for post-STEP activities are also well advanced.

The Steering Committee of S-RAMP, the Results, Applications, Modelling Phase (1998-2002), met and planning for the program is well in hand. An informal preparatory meeting of PSMOS (Planetary Scale Mesopause Observing System) also occurred during COSPAR; an extensive network of optical systems at several latitude circles will supplement radar systems which have been active in STEP.

There will be an STP Symposium, featuring the observational and modelling results from STEP, at the IAGA/ICMA meeting in Uppsala, Sweden (1997).

The Earth's Upper Atmosphere and Ionosphere

An Inter-Agency Working Group was established in the USA to develop a National Space Weather Service (NSWS). The NSWS effort is devoted to improve predictive services for the Near-Earth Environment. The work is related to identifying, assessing and predicting the risks to ground-based and space-based technological systems—as diverse as the risk of damage due to space-craft charging, to the possibility of disruption to electricity distribution systems and damage to extended oil distribution pipe-lines. It is expected that this effort will move from initial assessment into prediction followed by prompt circulation of near-term hazards within the next 12-24 months.

The Mid-course Space Experiment (MSX) satellite was launched on 24 April 1996, from Vandenberg AFB, California. The instruments include a Visible-UV Imager/Spectrometer System (UVVISI) and a cryogenically cooled I.R. Sensor (SPIRIT III). Full-scale operations of the spacecraft were started in June 1996. The science program includes an extensive space-ground program of coordinated observations of the night-glow, twilight-glow and aurora using a number of well-distributed ground-based stations.

The Polar Cap Initiative of the U.S. National Science Foundation has established the Early Polar Cap Observatory (EPCO) at Resolute Bay, Northwest Territories, Canada. A combination of optical and H-F radio instruments have been commissioned by USA and Canada research groups. The facility will be used to investigate the mesosphere, thermosphere and ionosphere in the central portion of the geomagnetic polar cap. Plans for the deployment of an advanced Incoherent-Scatter Radar at EPCO by the end of the decade have been adopted.

The new EISCAT-Svalbard Radar (500 MHz, incoherent scatter radar) was commissioned, using a single antenna, in early 1996, and was officially opened in a ceremony in August 1996. Japan has joined the EISCAT Consortium, and as the result, the equipment for a second antennae is now in preparation. The ESR Facility will observe the polar ionosphere and magnetosphere in the vicinity of the Polar Cusp as well as the Polar Cap. Considerable Facilities for Optical Observations of the aurora, thermosphere and ionosphere, already existing at Longyearbyn (Kjell Henriksen Auroral Observatory, formerly the Nordlysstasjonen), will be used for joint studies with the ESR.

The Norwegian Space Centre has approved and implemented plans for launches of sounding rockets from Nye-Aylsund, Svalbard, with initial flights of NASA payloads planned for 1997-98 exploring the regions of the Polar Cusp and central Polar Cap.

The Upper Atmosphere Research Satellite continues to provide important new measurements of upper atmosphere data, the most relevant being the upper atmosphere dynamics data sets obtained from the WINDII and HRDI wind-measuring instruments. A recent Winds Workshop, held in Canada, presented important new findings from the Inter-comparison Campaigns (Ground-based Radar and Optical comparisons with UARS).

The UARS descriptions of diurnal and seasonal variations of winds, airglow intensities, and the altitude variations of airglow layers, are unique and provide a particularly exciting view of the variable upward propagation of tides and other waves through the atmosphere.

The NASA Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) mission is being prepared for launch with a complement of four-instruments—UV Imaging Spectrometer, Fabry-Perot Interferometer, I.R. limb-Scanning Instrument and a Solar extreme UV Spectrophotometer—in 1999. The mission will study the physical and dynamical processes of the Thermosphere-Ionosphere-Mesosphere regions, and the important interactions which occur throughout these regions.

In view of the relatively small number of new satellite missions in operation or currently being planned, NASA's National Space Science Data Center (NSSDC) has made a major effort to make unique space data sets available via the Internet. In particular, the Automated Retrieval Mail System (ARMS) is being used for direct user retrieval via the Internet of much of its recent space data set holdings. Satellite Missions already included on ARMS are: IMP-8, DE-1, DE-2, Hawkeye and ISEE. Other important data sets are being added from time to time. An additional activity related to the recovery of older data sets originally stored on Magnetic Tape is under way at NASA Goddard Space Flight Center.

The 1996 COSPAR Assembly in Birmingham included six meetings of particular interest to research in the Earth's Upper Atmosphere and Ionosphere: Coupling and Energetics in the Stratosphere, Mesosphere, Thermosphere and Ionosphere System; Advances in Remote Sensing of the Upper Atmosphere; Permanent Changes in the Ionosphere and Middle Atmosphere; The Polar Cap Thermosphere-Ionosphere and its role in Solar-Terrestrial Physics.

Planetary Atmospheres and Aeronomy

The Galileo spacecraft arrived at Jupiter on 7 December 1995. The probe was successfully deployed and made measurements during its descent into the atmosphere. All instruments worked well and the resulting data is providing new insights into Jupiter's atmosphere (e.g. very strong winds of about 200 m/s, persistent deep into the atmosphere). The orbiter is also working well and has begun to provide exciting new information (e.g. possible intrinsic magnetic fields for Io and Ganymede).

The NEAR (Near Earth Asteroid Rendezvous) spacecraft was successfully launched on 17 February 1996. All instruments are operating and the first encounter with the asteroid 253

Mathilde is scheduled for June 1997. The aim of this mission is to make measurements of bulk (e.g. size, shape, volume, spin rate), surface (e.g. elemental and mineral composition, geology, structure) and internal properties (e.g. magnetic field mass distribution) of asteroids.

A number of spacecraft are set to be launched in late 1996 to study Mars. The Russian Federation Mars-96 spacecraft is scheduled to be launched in November. The mission consists of an orbiter and four small landers. Two of the landers are scheduled for hard landings and the other two are penetrators. The landers carry a number of instruments to study the surface and interior as well as meteorological sensors. The orbiter will carry an extensive instrument complement, directed at observations of the surface, atmosphere and plasma environment. International cooperation involving about 20 countries is a key feature of this program.

The two U.S. Mars spacecraft, also scheduled to be launched late in 1996, are the Mars Global Surveyor and Mars Pathfinder spacecraft. The first of these will carry the same instrument complement as the ill-fated Mars Observer, except for the pressure modulator infrared radiometer and gamma-ray spectrometer. The Pathfinder will carry an imager, an atmospheric structure cluster and an alpha-proton X-ray spectrometer, which will be deployed by a mini-rover.

In Japan, the ISAS Planet-B mission to Mars is on schedule for a 1998 launch. The main scientific aim of this program is to study the upper atmosphere-ionosphere system of Mars and its interaction with the solar wind. It has a very extensive scientific payload and some of the instruments are being developed in collaboration with Canada, Germany, Sweden and the United States.

The NASA/ESA Cassini/Huygens mission to Saturn/Titan is also on schedule for an October 1997 launch. The Huygens Probe, built by ESA, will make measurements of the atmosphere of Titan. The Cassini Orbiter is instrumented to make comprehensive measurements of the surfaces, atmospheres and plasma environments of Saturn and its moons and rings.

Instrument selections for the joint ESA/NASA Rosetta cometary mission have been completed. The plans call for the Rosetta spacecraft to rendezvous with comet Wirtanen and make close, but remote, measurements, as well as to deploy two landers which will make in-situ measurements on the surface of the comet.

The next two U.S. Shuttle Discovery missions were recently selected. The Lunar Prospector will orbit the moon and provide global information on the physical and chemical properties of the moon. The other mission is called Stardust and is to fly through a cometary coma and collect and return cometary dust samples.

Recent planetary observations by the Hubble Space Telescope include: (i) near-UV images and the identification of SO_2 and SO absorption in the atmosphere of Venus, (ii) colder temperatures in the Martian atmosphere and an increasing extent of ozone absorption, and (iii) the highest resolution images to date of the surface of Pluto. Earlier studies of the atmospheric dynamics of Jupiter and Saturn have now been extended to Uranus and Neptune. Jupiter's UV aurora have been imaged with the highest sensitivity and angular resolution to date, including the detection of the Io footprint aurora and spectra revealing the temperature of the auroral atmosphere. Follow-up images and spectra of the Shoemaker/Levy 9 impact sites on Jupiter have been used to track the evolution of the "smoke" left from the impacts. Observations of Jupiter's satellites have shown a transient oxygen atmosphere on Europa, and possibly O_3 on Ganymede. Saturn's rings were imaged edge-on to the Earth in 1995, revealing new satellites and OH gas around the rings.

A vigorous program of theoretical studies of planetary atmospheres and plasma environments is continuing. Some of these activities are associated with the interpretation of observations, as well as predictive studies associated with planned future missions. There is also an ongoing program of laboratory studies, whose aim is to lead to a better understanding of numerous important and relevant processes.

Task Groups for Trace Species and the International Reference Ionosphere

The COSPAR International Reference Atmosphere for Trace Constituents (CIRA Part III) was published in 1996. This was immediately followed by a successful meeting at the Birmingham COSPAR Assembly at which the new results on trace and minor constituents of the atmosphere obtained from the UARS and other recent space missions and investigations were presented and discussed. This meeting also started the planning for a new empirical modelling activity, incorporating all these new results, with the intention of producing an updated (1990's) CIRA for trace constituents before the COSPAR Assembly in 2000.

The "Prediction and Retrospective Ionosphere Modelling over Europe" (PRIME) project—a new computerised product for ionospheric research and applications—has been implemented. The goals of one of its activities—Ionospheric Telecommunications Systems Planning and Operating (IITS)—include improvements and validation of the ionospheric models for Earth-Space Systems, short and long-term ionospheric variability and forecasting.

An Ionospheric Database on CD-ROM has been created at WDC-A for STP at Boulder, Colorado, in collaboration with other WDCs and many individual contributors. CDs containing these data sets and appropriate software for display and use of the data have been widely circulated to the International Research Community.

Effort continues, with URSI and COSPAR participation, into the further development of the International Reference Ionosphere. A special session on "The High Latitudes in IRI" was held during the 1994 COSPAR (Hamburg) Assembly, and a "Low-Latitude IRI" Workshop was organized in 1995 in NPL, New Delhi, India. There was a successful scientific meeting during the 1996 COSPAR assembly at Birmingham, followed by a business meeting to review current initiatives and developments.

In 1994, a new style of activity, IRI Task Force Activity (TFA), was initiated to focus effort onto specific modelling problems. The first three of these TFAs concentrated on "The F1 Region," the "Bottom-side F2 Region," and the "Topside Electron Density Profile." Several important updates and improvements to IRI have arisen from these early TFAs. Further such activities are planned.

A series of meetings during 1997 and 1990 will be co-sponsored by COSPAR through the joint COSPAR/URSI Task Group on IRI, and coordinated with the U.S. CEDAR Group -

Problems Remaining in Ionospheric Modelling (PRIMO). During the SCOSTEP Meetings in London in July 1996, one of the future SCOSTEP Projects approved under S-RAMP (STEP - Results and Modelling Phase) was the improved coordination between the empirical modelling activities, IRI, and the physical (or numerical) modelling activities. The Activities of the joint task groups will be presented and discussed during the IAGA and SCOSTEP meetings to be held in Uppsala in August 1997, and during the 1998 COSPAR Assembly in Nagoya, Japan.

A feature which is already widely used internationally, is real-time access to the IRI and MSIS empirical models (and other models of wide-spread use) via the World Wide Web, through the efforts of scientists and staff at the National Space Science Data Center.

IV. SPACE PLASMAS IN THE SOLAR SYSTEM, INCLUDING PLANETARY MAGNETOSPHERES

COSPAR Commission D is responsible for the study of plasmas in the solar system, from the Sun's corona and solar wind to the magnetosphere and ionized atmosphere of each of the planets, including also the extended plasma environments of comets. Our knowledge of the physics of plasmas in space comes mainly from in-situ and remote sensing measurements made by space probes, but important information has also come from balloons, rocket probes, and ground based facilities.

The joint ESA/NASA heliospheric mission Ulysses successfully continued its exploration of high solar latitudes, with all instruments fully operational. Some important discoveries have been firmly established. There are indications that the cosmic ray intensity at the north pole may be slightly higher than at the south, and that the "symmetry" equator for cosmic radiation in the 1994-95 time frame may have been around 10 degrees south solar latitude. In October 1995 Ulysses embarked on a second six-year orbit of the sun, which will make possible an examination of the solar poles at a time of maximum solar activity, when the solar atmosphere will differ greatly from its 1994-95 quiet configuration.

The ICE spacecraft started life as ISEE 3 (International Sun Earth Explorer) in 1978. In recent times the radio signal from the spacecraft has been used to probe the content of the interplanetary medium, and especially in the period when the spacecraft-Earth line was passing close to the Sun.

The Pioneer 10 and 11 and the Voyager 1 and 2 spacecraft were launched by NASA in the 1970's, and after passing by the planets are all now at large distances from the Sun. Pioneer 11 ran out of power in 1995 and Pioneer 10 is nearing its end of life, with one scientific instrument only in operation. All Pioneer/Voyager instruments are on the look-out for the boundary of the heliosphere. In June 1996, Pioneer 10 was at 65 AU from the Sun, Voyager 1 at 64 AU, and Voyager 2 at 49 AU.

The SAMPEX spacecraft, the first of NASA's small explorers, launched in 1992 into a near-Earth polar orbit, has studied the arrival and storage of anomalous cosmic rays in the Earth's radiation belts. It was believed that all anomalous cosmic rays were singly charged, and indeed this feature helped separate them from the real cosmic rays which have been stripped of all available electrons. Recent observations, using the Earth's magnetic field as an analyser, indicate that the higher energy anomalous cosmic rays may carry several electronic charges. This complicates the picture, but helps explain why the charged particles are accelerated to such high energies in the heliosphere.

The Solar and Heliospheric Observatory (SOHO) was launched on 2 December 1995. SOHO is part of the first "cornerstone" of ESA's Horizon 2000 program, and is carried out jointly with NASA. On 14 February 1996, it was inserted into its halo orbit around the sunward Lagrangian point and on 2 May it began its fully commissioned operational mission. With its mix of remote-sensing and in-situ measurements, SOHO investigates solar and interplanetary processes, many of which are closely related to those pursued by the IASTP missions. All instruments are working well and already excellent results are being obtained. For example, the "background noise" in the global solar surface velocity is much lower than expected and as a result helioseismology measurements are extremely sensitive. Flows under the photosphere, in the convection zone, have been measured for the first time. The Sun, now at minimum activity, maintains an unexpectedly high level of activity when observed in extreme ultraviolet light. Polar plumes, which connect to the polar solar wind, have been observed over a very wide temperature and spatial ranges, together with the photospheric magnetic field.

After a long cruise, NASA's Galileo mission has finally begun its study of the giant planet Jupiter's magnetosphere, moons and atmosphere. After the atmospheric probe was released in July 1995, orbiter and probe reached Jupiter separately in December 1995. The orbiter flew close by the moon Io and made its closest approach to Jupiter, to record the probe signals as the latter descended through Jupiter's atmosphere. The orbiter then used its main engine to go into orbit around Jupiter to study its magnetosphere. Among the surprising results is the finding that the moon Ganymede seems to have a tiny magnetosphere of it own.

The ambitious program to study solar-terrestrial physics, referred to as the Inter-Agency Solar-Terrestrial Physics Program (IASTP), is now in its main phase. IASTP comprises a globally distributed fleet of satellites and ground-based instruments, all directed at studying the chain of plasma processes that govern the transfer of mass, momentum and energy from the Sun's atmosphere to the Geospace environment.

The Japanese contribution to IASTP, the Geotail spacecraft, is the oldest member of the satellite fleet and has been providing exciting data since its launch in 1992. Geotail's first goal was to explore the Earth's magnetotail, up to distances of 220 Earth radii, and has shown a richness in structure and dynamics which have changed our views of this region. After this part of the mission, Geotail started descending to its present 10 Earth radii times 30 Earth radii orbit. Geotail is skimming the Earth's magnetopause and bow shock and is ideally suited to study those boundaries. This orbit also traverses the source regions of the magnetic substorms.

NASA has contributed two satellites to the IASTP program, Wind and Polar, that were launched in November 1994 and February 1996, respectively. Wind's main goal is to study phenomena in the solar wind and to monitor conditions upstream of the magnetospheric system. For this purpose, Wind will in early 1997 be placed in a halo orbit around the L1 libration point between the Earth and the Sun. So far it has used periodic encounters with the Moon to maintain a variable size orbit around the Earth which allowed for studies of the Earth's magnetopause, bow shock and foreshock regions, in addition to those of the solar wind. Polar was placed in a 90 degree inclination elliptical orbit with a 9 Earth radii apogee initially located over the north pole. It is carrying out in-situ studies of the distant polar magnetosphere, but with its set of imaging instruments also investigates the auroral region.

Also part of IASTP, the program called Interball is led by the Russian Space Agency, but involves a large international community of Russia, Austria, Bulgaria, Canada, the Czech Republic, ESA, Finland, France, Germany, Hungary, Italy, Kirgizia, Poland, Romania, Slovakia, Sweden, the United Kingdom and Ukraine. Interball-Aurora was launched in August 1996 into an orbit with an inclination of 63 degrees and a 20,000 km apogee. The configuration is particularly well suited to study the cause-and-effect relationships between the plasma processes in the geomagnetic tail and in the auroral acceleration region.

Related to IASTP is Fast Auroral Snapshot (FAST) satellite, the second in NASA's small explorer program. FAST was delayed for two years because of launcher development problems, but was finally launched in August 1996. FAST will study the auroral acceleration region at altitudes of several thousand km with unprecedented time resolution, thus complementing the lower altitude measurements obtained earlier with the Swedish-German FREJA mission.

A major set-back for space plasma physics occurred on 4 June 1996, when the catastrophic failure of the first Ariane 5 flight destroyed the four satellites of the Cluster mission. Cluster, the second element of ESA's first cornerstone, was to be an element of IASTP and widely awaited as a major step for space plasma physics. Its four identically instrumented spacecraft would have flown in close formation through the Earth's magnetosphere, particularly its polar part, and into the solar wind, to clarify the small-scale structure and temporal evolution of the key plasma processes occurring in these regions.

As is apparent from the list of active or recently launched missions, the next few years should provide a great advance in our understanding of space plasmas, in spite of the loss of Cluster. Ground based observations of various kinds are planned in conjunction with those missions and will contribute significantly to our understanding, particularly with regard to global questions, as will instruments carried on balloons and sub-orbital rocket flights.

V. RESEARCH IN ASTROPHYSICS FROM SPACE

Astronomy

The needs of the astronomy community can only be met by access to the entire electromagnetic spectrum from the radio to the gamma-ray range. Large parts of the spectrum do not penetrate the Earth's atmosphere so observations are literally impossible unless the relevant instruments are placed in space above the Earth's atmosphere. In addition, even for wavelengths that can reach Earth, the distorting effects of the atmosphere mean that substantial performance gains can be achieved with space-based instruments, as is now being demonstrated with missions such as the Hubble Space Telescope (HST). A considerable degree of complementarity is thus implied between ground-based and space-based astronomy. However, given the current high cost and extreme shortage of finance for space instrumentation, it is increasingly important to establish that access to space is absolutely essential and that the proposed observations cannot be pursued with ground-based facilities. In addition, due to the budgetary pressures mentioned above, there is increasing emphasis on the possibility of using small spacecraft with reduced launch and operations costs. Present difficulties with newly developed small launch vehicles are in the process of being overcome. It is clear that in the future, consideration will increasingly be given to more modest scale missions.

As in previous reports, an updated overview of world-wide space programs in astronomy and astrophysics is summarized in Tables 1 and 2.

The tables list the missions that are operating in space and those which are approved and are either awaiting a start or are already under construction. Tables 1 and 2 include: the main responsible agency or nation; launch dates (actual or scheduled), and, a brief description of the main characteristics of the mission.

A large number of projects and proposals have been submitted to the various agencies. ESA has selected the Cobras-Samba microwave background mission for the M3 (ESA's third medium-sized mission) opportunity while an advanced astrometry mission will form part of the extended Horizon 2000-Plus program. Several interesting mission proposals in all areas of astronomy were submitted for the NASA Medium Explorer (MIDEX) program. This now includes the Microwave Anisotropy Project (MAP) mission.

Comments on the content of the tables and on the situation in each of the principal spectral regions are given below.

Gamma-ray

With the continued success of the Compton Gamma Ray Observatory (GRO), the importance of the gamma-ray spectral domain is strikingly emphasized. Thus the start of the ESA Integral program, which includes high energy imaging and spectroscopy instruments along with context instruments for X-ray and optical monitoring, is particularly timely in enabling a strong and complementary follow-up mission.

X-ray/EUV

Rosat and ASCA continue to produce important results that are having a significant impact throughout the subject while EUVE continues operation in an observatory mode. The Rossi-XTE and Beppo-SAX missions have begun a program of temporal, imaging and broad-band spectral studies of X-ray sources. Both spacecraft are operating as expected. The major missions, AXAF and XMM, which are due for launch before the end of the century, will produce the next substantial advances in this important field. The FUSE mission will have a significant impact in the areas of cosmic abundance studies and interstellar physics.

Visible/UV

HST is fully operational and will have two new instruments fitted in 1997. The ESA Hipparcos mission has completed its astrometry task with major findings while an advanced interferometry mission has been chosen for study as a cornerstone in the ESA Horizon 2000-plus program. Very large ground-based projects are underway in several countries. The International Ultraviolet Explorer (IUE) operations will finally cease altogether in February 1997 and end an extremely productive mission that will have operated for more than 17 years. No successor to this enormously successful UV observatory is foreseen at present. Continued weakness in this area will prove detrimental to astronomy.

Infrared

The Infrared Space Observatory (ISO) is operating extremely successfully in the 2.4 to 240.0 micron band with several important findings emerging. Following commissioning, a two-year operational lifetime is anticipated. The U.S. SIRTF mission is still being pursued. The Japanese IRIS mission will conduct an all-sky survey and be flown in 2002 or 2003. Taking into account the impressive developments of ground based near-IR telescopes, the field seems reasonably well covered.

Table 1: Missions in Operation

Year	Radio Sub-mm	IR	Visible/UV	EUV/X-ray	Hard X/Gamma-ray
1978		Kuiper	IUE		
1987					MIR/KVANT
1989					GRANAT
1990			HST	ROSAT	Ulysses
1991					GRO
1993				EUVE ASCA	
1994					
1995		ISO			
1996					Rossi-XTE, Beppo-SAX

Kuiper (NASA) Airborne IR Observatory with 91 cm telescope.

IUE (NASA/ESA/UK) International UV Explorer. 45 cm telescope for medium-high resolution spectroscopy.

HST (NASA/ESA) Hubble Space Telescope. 2.4 m telescope for imaging and spectroscopy of galactic and extragalactic sources. Observatory mission.

EUVE	(NASA) Extreme UV Explorer. Sky survey for broad band spectroscopy of bright sources in the range 8-50 nm. EUV spectroscopy. Now in observatory phase.
ISO	(ESA) Infrared Space Observatory. 60 cm cooled Cassegrain telescope for spectrophotometry and imaging of IR sources. Observatory mission with contributions from NASA and ISAS.
ROSAT	(D/NASA/UK) Roentgen Satellite. Imaging Soft X-ray/EUV telescopes for surveys and pointed observations (0.03-2.5 keV). Guest observer program will continue to 1998.
ASCA	(Japan/NASA) Advanced Satellite for Cosmology and Astrophysics. High sensitivity imaging and spectroscopy of X-ray sources.
XTE	(NASA) Temporal studies and broadband spectroscopy of compact X-ray sources (1-200 keV).
SAX	(I/NL) Imaging broadband spectra and long-term monitoring of X-ray sources (0.1-200 keV). PI mission with contribution from ESA.
MIR/KVANT	(Russia) Imaging, spectroscopy and timing studies in the band 2-200 keV. PI mission with guest observer program.
GRANAT	(Russia/F) Monitoring and localization of X-ray sources and low energy gamma ray imaging. PI mission with French guest observer program for the gamma-ray telescope SIGMA.
GRO	(NASA/D) Compton Gamma Ray Observatory. Imaging and broad band spectroscopy (0.1 MeV-30 GeV).
Ulysses	(ESA/NASA) French gamma-ray burst experiment HGS-OGRE.

Table 2: Approved Projects

Year	Radio	Sub-mm	IR	Visible/UV	EUV/X-Ray	HardX/Gamma-Ray
1996	VSOP	SWAS			<-----------------HETE------------>	
					SAC-B	MARS 96
1997		ODIN RELICT-2		HST Refurbishment	EURD LEGRI	
1998					<------Spectrum X-GAMMA------>	
					AXAF	
1999	Radio Astron				XMM Astro-E	
2000				Spectrum-UV		
2001	MAP					Integral
2003			IRIS			
2004	COBRAS/ SAMBA					
2006	FIRST					

Projects are listed in order of waveband, starting from radio and ending with Gamma-Rays.

VSOP — (Japan) VLBI Space Observatory Program. 10 m antenna for orbiting VLBI imaging at 1.3, 6 and 18 cm. Observatory in phase C/D development.

Radio-Astron — (Russia/Eur/USA) 10 m antenna for orbiting VLBI at 1.3, 6, 18 and 92 cm. Observatory in phase C development.

RELICT-2 — (Russia) Study of large scale anisotropy and spectrum of 2.7 K cosmic background radiation.

MAP — (NASA) Microwave Anisotropy Project. Study of anisotropy of 2.7K microwave background. Medium Explorer mission.

COBRAS/SAMBA — (ESA) Study of anisotropy of 2.7K microwave background. ESA medium mission (M3) in Horizon 2000-plus program.

SWAS — (NASA) Sub-mm Wave Astronomy Satellite. 55 cm off-axis Cassegrain warm telescope for spectroscopic survey of the galactic plane in lines of H_2O, O_2, CI, CO (480-550 GHz). PI mission awaiting launch.

ODIN — (S/F/Canada/SF) 1.1 m telescope for mm (119 GHz) and sub-mm (420-580 GHz). Interstellar chemistry and atmospheric ozone.

FIRST	(ESA) Far IR Sub-mm Telescope. 3 m warm Cassegrain telescope for high throughput heterodyne and far IR spectroscopy and imaging. Observatory.
IRIS	(Japan/ISAS) 70 cm Ritchy-Chretian telescope for spectrophotometry and imaging of IR sources. 2-200 micron with 50-200 micron sky survey.
HST	(NASA) Hubble Space Telescope. NICMOS (IR) and STIS (Optical/UV) instruments to be installed.
Spectrum-UV	(Russia/I) Optical/UV telescope-1.7 m, 90-900 nm, for spectroscopy and wide field imaging.
Spectrum-X	(Russia/NASA/EUR) Spectroscopy, imaging, monitoring and polarimetry of X-ray sources. PI mission in phase C/D
SAC B	(Argentina/NASA) CCD detector to study the diffuse X-ray background and X-rays from Solar Flares. Primarily an engineering test.
EURD	(E) UV spectrometer on Minisat-1 (E) to monitor the diffuse background from 30 to 100 nm.
HETE	(NASA) Primarily aimed at gamma ray burst and X-ray transients but also has a UV CCD camera and a French experiment.
AXAF	(NASA) Advanced X-ray Astrophysics Facility. High resolution imaging and spectroscopy of the X-ray sky. Observatory facility.
XMM	(ESA) X-ray Multi-Mirror mission. High throughput spectroscopy and imaging in the soft X-ray range. Observatory, in phase B.
Astro-E	(Japan/NASA). High throughput imaging X-ray spectroscopy facility including a microcalorimeter and CCDs, for the range 0.1-10 keV
LEGRI	(E/UK) Low Energy Gamma-Ray Instrument on MINISAT-1 (E) to cover the range 15-150 KeV.
Mars 96	(Russia) French Gamma-Ray burst experiment LILAS-2.
Integral	(ESA) Imaging and spectroscopy from about 5 keV to 10 MeV. Phase B.

Sub-millimetre

Approved missions in this range are the Russian RELICT-2 and the U.S. SWAS, a small Explorer. ODIN is in a phase B study. FIRST, the largest mission approved in this frequency band, is the fourth of the ESA cornerstones. COBRAS/SAMBA (ESA) and MAP (NASA) have both been selected for the important field of microwave background anisotropy studies.

Radio

The Japanese VSOP and the multinational Radio-Astron missions are the first approved VLBI missions and will open up a new frontier and will be used in collaboration with ground-based VLBI arrays. Lower frequencies and longer baselines should be considered in the future.

Complementary Research

The missions mentioned above involve the detection of photons and, thus, analysis of information from electro-magnetic emissions. Astronomers are seriously considering the possibility of using other particles such as neutrinos, gravitons, and charged species (cosmic rays). Neutrino detection, for the time being at least, appears to be an exclusively ground-based activity. Gravitational wave astronomy from space may have considerable potential. A space-based interferometer system (LISA) is being considered as a future cornerstone mission in the ESA Horizon 2000-plus program while the exciting OMEGA project is being studied as a possible future Medium Explorer in the NASA program. At present no missions are approved for cosmic ray studies. However Astromag, which includes a large superconducting magnet, is being considered by NASA as an attached payload for the space station.

From the tables and from the above comments, the following conclusions may be drawn:

(I) The state of astrophysical research in general and of the ever increasing part of it performed with space-based instruments continues to be healthy.

(ii) Nevertheless increasingly severe budgetary pressures rather than scientific or technical reasons are leading to reductions in scope and eliminations of missions.

(iii) Most of the wavelength bands require further investigation from space. The electromagnetic spectrum from UV to Gamma Ray cannot be explored other than with space borne observatories. Thus continued access to space is essential for astronomy.

(iv) New missions tend to be bigger and more costly. Hence international collaboration and cooperation continue to increase in importance—both to contain costs for individual funding agencies and to avoid duplication in the implementation of large facilities.

(v) Increasing consideration is being given to the role of small missions. While much of space astronomy requires intrinsically large facilities, technical advances—particularly in on-board data processing and storage, now allow modest scale missions to play an increasing role.

Solar Physics

The Sun, because of its proximity, is our most important and interesting star and can therefore be studied in detail. Operation of solar physics instruments in space eliminates the distorting and absorbing effects of the atmosphere thus allowing imaging of fine structures and observations of the electromagnetic spectrum beyond the ultraviolet cutoff. Because of the high temperatures reached in the upper chromosphere and corona, the solar atmosphere is best observed at shorter wavelengths—ultraviolet (UV), extreme ultraviolet (EUV) and X-ray. Work at these wavelengths must be undertaken from space.

The main problems addressed remain those related to the transfer of the mechanical energy from below the photosphere and the conversion of this energy to forms that are responsible for the heating and activity of the corona and the acceleration of the solar wind. Both problems require observations of the solar atmosphere on the smallest possible scale since it is clear that some of the crucial physical processes are very localized. It is also necessary to detect simultaneously the entire solar spectrum in order to encompass all the possible temperature and height regimes of the Sun.

The past major solar space missions have made significant contributions by allowing coordinated studies over a wide range of wavelengths including visible, UV, X and Gamma-ray photons. This emphasis on coordination is one of the key elements in most of the major programs for solar physics. Furthermore from lengthy experience in solar observing and the need for collaboration with colleagues in many nations, the solar physics community has a long and successful history of international collaboration which is fully exploited in planning space missions.

Currently operating solar programs are reported below. Projects in development are described and future planning efforts for solar physics outlined.

The current solar programs cover two major areas of interest. These are: (I) the study of solar activity and the drive to understand solar flare phenomena, and (ii) the study of the 'quiet' Sun with instruments that address a broad range of scientific questions. For the former, in addition to the important fundamental aspects, this work has the ultimate goal of enabling us to forecast flares, mass ejections and other coronal activity which can strongly influence the interplanetary and terrestrial environment. For the latter, studies include investigations of the nature of the inner and extended corona, coronal mass ejections and the acceleration of the solar wind. The high temperature of the solar corona remains unexplained while the investigation of the sources of the solar wind is crucial for the understanding of mass loss from the sun and ultimately for clarifying important features of stellar evolution. Mass ejections have impact throughout the interplanetary medium and have an especially important role on the magnetic configuration of the earth.

SOHO

ESA and NASA launched the Solar and Heliospheric Observatory (SOHO) on 2 December 1995. The spacecraft arrived at the Lagrangian (L1) point between Earth and the Sun on 14 February 1996, and has since observed the Sun continuously. At this location 1.5 million km in front of the Earth, the spacecraft can operate free from the effects of orbital velocity present for near-earth missions and of the geocoronal UV background. This ambitious mission includes 11 instruments, six built in collaboration with groups from the United States. These instruments are now observing the Sun from centre by means of helioseismology to outer atmosphere by remote sensing in the visible and UV. Simultaneously, the solar wind is being probed at 1 AU by in situ studies. A twelfth instrument observes Hydrogen Lyman alpha emission from the interplanetary medium to monitor the solar wind mass flow. The ESA–NASA cooperation in SOHO includes the staffing of a common operations centre at the NASA/Goddard Space Flight Centre for day-to-day operational decisions and collaborative research. Following the start of scientific operations in April 1996, a wealth of new data has already been acquired. The UV imager, two ultraviolet spectrometers and a UV coronagraph are investigating the processes which heat the solar atmosphere and accelerate the solar wind.

Although the Sun is presently at its minimum activity level, highly dynamic phenomena are continuously observed by SOHO. The UV imager is detecting very thin jets of strong emission which may be responsible for heating the outer atmosphere to more than two million degrees. Also visible in the ultraviolet images are the polar plumes from the regions where the fast solar wind originates. Observations of the extended corona obtained with the ultraviolet coronagraph map for the first time the fast and slow solar wind flows in the outer solar atmosphere thus enabling us to relate the flows to the topology of the solar magnetic fields. It is possible to trace the solar wind acceleration up to a few kilometres per second through the solar corona.

Even for a quiet Sun, the visible light coronagraph shows the release of large amounts of hot material into the solar system in global coronal mass ejections. Such events disturb the whole solar system and can affect the Earth's own space environment. Continued observations by SOHO should lead to a major advance in our knowledge of these enigmatic events.

It is clear from the H Lyman-alpha sky maps obtained in these months that the solar wind blowing from the poles is less strong than that from lower latitudes. The Earth is also visible in the maps produced with this instrument, because a cloud of hydrogen gas called the geocorona envelopes it and glows in the ultraviolet. As SOHO sees the geocorona from the outside, it will be able to monitor the effects of solar activity on the Earth's outer atmosphere.

SOHO is successfully probing the interior of the Sun. It does so with several instruments that observe the solar surface oscillations that can be detected almost completely free of noise. They measure periodic variations in intensity of the light emission or in surface velocity. The detection of short-range oscillations due to sound waves has already allowed us to observe the complex gas motions occurring just below the solar surface.

Yohkoh

In August 1991, the Japanese Institute for Astronomical Science and Aeronautics (ISAS) launched Yohkoh, the only long-duration mission totally devoted to solar observations during the current cycle. The four-instruments on Yohkoh were designed to study high energy solar flare activity, the global coronal structure and the irradiance variations of the Sun. Yohkoh is carrying: the Soft X-Ray Telescope, a collaborative US-Japanese experiment, which is imaging the soft X-ray corona and a Bragg crystal spectrometer developed jointly by experimenters in the UK, USA and Japan. The Japanese instruments include an advanced Fourier-synthesis hard X-ray telescope providing much better sensitivity and resolution than the imaging detectors previously flown on the Hinotori and Solar Maximum Mission satellites. Higher energy X-rays and gamma rays are also monitored by the Yohkoh instruments provided by Japanese groups.

Yohkoh has produced many new results. Its excellent spatial and temporal resolution have revealed the highly dynamic nature of the solar corona with changes of the coronal magnetic structures taking place very suddenly. With Yohkoh the process of magnetic reconnection was for the first time actually observed to occur in solar flares and active regions. Yohkoh has discovered active region brightenings with a frequency of occurrence as a function of their energy which is a continuous extension of the similar distribution for flares. This implies that small events ("microflares") are not over-abundant. This result is important in relation to the problem of heating of the solar atmosphere since it rules out microflares as the source of coronal heating. With the decline of the current solar cycle, much new information has been obtained on the evolution of coronal streamers, the related occurrence of Coronal Mass Ejections (CMEs) and on the nature and evolution of Coronal Holes—the sources of the high speed Solar Wind streams. Novel observational techniques for the detection of CMEs are proving particularly successful. This work is continuing with combined analysis of Yohkoh and Ulysses data. Following the successful launching of SOHO, important joint observations by Yohkoh and SOHO are now being carried out.

In addition to work with SOHO, simultaneous observations of the Sun that include Yohkoh and US sounding rockets and several ground-based observatories are continuing. Support for Yohkoh operations is planned at least through 2000.

Spartan

The NASA solar physics program continues to use flight opportunities from the space shuttle to conduct investigations of the corona with Spartan—a retrievable, autonomous satellite that permits up to two days of solar observing time. A white light coronagraph and an ultraviolet coronal spectrometer study bulk flow patterns and acceleration mechanisms of the inner solar wind. The instruments undertake UV spectroscopy and white light polarimetry of the extended solar corona from 1.5 to 6 solar radii from Sun centre, thus allowing measurement of temperature, densities and bulk outflow velocities of electrons, protons and several minor ions. The resulting description of the extended corona can be used together with theoretical studies to identify and understand the physical processes involved in solar wind acceleration.

Three Spartan missions have been flown. The second and third of these took place when the ESA/NASA Ulysses spacecraft reached its maximum latitude over the Sun's south and north poles respectively. While Ulysses undertook in-situ sampling of the solar wind high in the heliosphere above the Sun, Spartan performed remote sensing of the source regions for the same solar wind observed with Ulysses—the first such simultaneous observations. Finally, following the successful operation in orbit of SOHO, the Spartan 201 will underfly the ESA/NASA spacecraft in a calibration mission.

Coronas

Coronas is a series of Russian satellites designed to observe the solar atmosphere from near-Earth orbit, and to observe solar activity and magnetospheric solar effects. They will carry a number of instruments developed by groups from Russia, in collaboration with groups from many other countries. The instruments include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as detectors for helioseismology, dedicated to the indirect investigation of the solar interior.

The Solar Station Coronas-I was launched on March 1994. The 11 instruments of the scientific payload covered a wide region of the electromagnetic spectrum from radio to gamma rays. Particles were also detected. The main instruments are an imaging X-ray telescope and spectroheliograph (6 intervals in 2-304 Angstrom spectral range) having spatial resolution a few arcseconds, an optical photometer for measuring solar oscillations, a radiospectrometer and a set of hard X-ray and gamma-ray spectrometers from 1-2 MeV.

While there is no hardware collaboration between the US and the Russian Space Agency for the Coronas program, a Participating Scientist Program is being supported for the encouragement of Russian-U.S cooperation in operations and data analysis for this mission.

Other missions related to solar physics

Currently operating missions of special importance for solar studies, but not primarily dedicated to solar physics, are Ulysses and the Gamma Ray Observatory.

Ulysses was launched in October 1990 and is an exploratory mission carried out jointly by ESA and NASA. Its primary objective is the study of the interplanetary medium and solar wind as a function of heliolatitude. The solar physics objectives of Ulysses encompass the study of the structure of the interface between the Sun and the solar wind/interplanetary magnetic field, solar radio bursts, solar X-rays and solar cosmic rays out of the ecliptic plane. In September 1994 after a journey of almost four years Ulysses reached its maximum latitude during the first-ever pass over the south pole of the Sun. Ulysses spent a total of 234 days above 70 degrees latitude during its first polar pass. The second polar pass, over the north pole, occurred on July 31, 1995. Ulysses has already sent back a wealth of extremely valuable information from the polar regions on the properties of the high-latitude solar wind and interplanetary magnetic field. The acceleration of energetic particles, at large radial distances and high latitudes in regions where co-rotating solar magnetic fields interact, has been studied in detail. In view of the unique importance of this mission, it is vital that the agencies involved should support mission operations for a second complete orbit.

The Compton Gamma-Ray Observatory (GRO), launched in 1991, is well-suited for observations of the solar X and gamma radiation which are the most energetic phenomena taking place during solar flares. Flare emission is observed in the energy range 50 to 1000 keV and above 20 MeV. GRO data allow extremely accurate measurement of the spectrum of the Sun's non-thermal radiation. Many important results have emerged including the direct demonstration by timing that non-thermal electrons move from the coronal flare release site to impact the Chromosphere.

Missions Currently in Development

Coronas-F

Coronas-F is under development in Russia and is scheduled for launch in 1998. The payload will include improved versions of the instruments of Coronas-I. Coronas-F will also observe spectral lines in region 3-7 Angstrom. The third solar mission in the Coronas program is Foton which will include a large solar gamma-ray telescope.

TRACE

Development of the TRACE mission continues. It is a NASA small Explorer mission, to be launched in late 1997 into a Sun-synchronous orbit to allow eight months of continuous solar observation. It will be operated in coordination with Yohkoh and SOHO. The objective of the TRACE mission is to observe directly the connections between the small-scale features that characterize the photospheric magnetic field and the larger scale structures that are seen in the solar corona thus pursuing the discovery by Yohkoh that the corona is a continuously dynamic atmosphere which is responding to impulses from the photosphere. TRACE will survey this connection from the photosphere into the corona, with unsurpassed temporal and spatial resolution (about 400 kilometres on the solar surface). For this reason, TRACE is expected to make major contributions to our understanding of the mechanism of coronal heating. The TRACE instrument is designed to isolate narrow UV and EUV spectral bands containing emission lines formed in the chromosphere, transition region and corona.

SAC-B

The Satellite de Aplicaciones Cientificas-B (SAC-B), is the first satellite mission of Argentina. It is in collaboration with NASA and with the participation of the Brazilian and Italian space agencies. SAC-B will study the X-ray emission from solar flares in the 2 to 300 keV energy range with spectral resolution of up to 1 keV at low energies and a temporal resolution of few tens of milliseconds. The instruments were built by the Argentine space agency and NASA's Goddard Space Flight Centre.

Future Solar Programmes in Planning

As reported in recent years, future solar space missions continue to focus on understanding the problem of chromospheric and coronal heating, namely the coupling of sources of energy in coronal activity with structures and changes of magnetic fields and plasma motions in the solar outer atmosphere. Significant advances in this field require major improvement in the resolution of the instruments and the use of stereoscopic techniques to define the geometry of the magnetic confinement of the plasma in the solar atmosphere.

SMEI

The U.S. Air Force is studying an instrument called the Solar Mass Ejection Imager (SMEI). Its goal would be to provide advance warning of the arrival at earth of solar transient disturbances. It would also be able to map the mass ejection in three dimensions. This mission is now expected to fly in the Yohkoh and SOHO time frames for complimentary studies of the extended solar corona.

Solar-B

Following the highly successful solar missions Hinotori and Yohkoh, launched by the Japanese ISAS, the Japanese solar physics community is evaluating a further Sun-observing satellite. The mission, Solar-B, would be launched by ISAS in 2003/4 and could involve teaming between the Japanese, U.S. and U.K. solar physics communities. The model payload includes an optical telescope capable of making photospheric images with a spatial resolution of 200 kilometres on the solar surface and of measuring magnetic and velocity fields in the photosphere, a X-ray imager for the diagnosis of coronal plasmas having temperature of 0.5 to 10 million K. Line broadening in transition region and coronal emission lines, which may be manifestations of energy input into the corona, can be observed with an XUV imaging spectrometer. A Sun-synchronous orbit will be chosen to minimize the effects of observing time gaps and of line shifts due to the spacecraft motion.

Space Solar Telescope

The Space Solar Telescope was proposed in 1992 in China. The telescope system will consist of a diffraction limited optical telescope with 1 metre aperture size, spectrographs, and attached telescopes for the UV, soft and hard X-rays. The satellite carrying the telescope will be placed in a circular polar orbit of 500 km. Launch is planned in the years 2001-2002, around the maximum of the next solar cycle. The major scientific targets are to achieve a breakthrough in solar physics by coordinated high-resolution observations of the magnetohydrodynamic processes in the solar atmosphere. The telescope will obtain two-dimensional spectra, magnetic vector fields, velocity fields and images in the visible, UV and X-ray spectral ranges.

SIMURIS

The Solar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy (SIMURIS) was studied by ESA in the framework of the Space Station Attached Payloads and recommended for a second phase of study in 1992. Uncertainties on the Space Station Program have delayed the work though studies were undertaken for accommodation of a reduced version on the External Viewing Platform of the Columbus Module. SIMURIS will provide ultra-high spectral, temporal and spatial resolution to investigate the very fine structure of the Sun. Thus it would be a unique mission capable of observations at scales smaller than 0.1 arcsec or 70 km which are appropriate for many of the processes occurring in the solar atmosphere. Besides its temporal and spectral coverage, the SIMURIS Mission also proposes a UV imaging interferometer from 1175 A to 2800 Å with ultrahigh spatial (~ 20 km), spectral and temporal (50 ms) resolutions.

Solar Probes

Cooperation between the United States, Russia, Europe and Japan is proceeding toward the approval of a heliospheric probe mission consisting of two spacecraft, the Solar Probe and Plamya, to graze the Sun's corona at about 4 and 10 radii. These spacecraft would carry a variety of miniaturized in situ instruments and imagers for testing all of our current beliefs concerning the Sun's outer atmosphere some time after 2000.

Solar Stereo Mission

Studies are beginning in Europe, the United States and Russia for a program that would place two or more spacecraft in orbit around the Sun so as to view it from additional directions represented by the Earth-Sun line. Methods for placing one spacecraft in a solar-polar orbit with a plane at 90 degrees to the Earth-Sun line are also being discussed. Such a mission would provide a tomographic view of solar atmospheric structures and of the surface magnetic fields. It would produce a major advance in the understanding and forecasting of Coronal Mass Ejections.

International Space Station Alpha (ISSA)

ESA is studying the possibility of flying several solar instruments, some of which have been developed for the Eureca platform, on the ISSA. They include systems devoted to the study of solar variability at UV wavelengths which is of particular importance for Earth's atmosphere.

Conclusions

Solar physics activities in space include extensive international cooperation and a rich variety of research goals over the next decade. These involve both the continued operation of existing spacecraft and preparation and planning for future missions. With the advent of new communications technology, the long-standing tradition of such cooperation in solar research will be strengthened still further as the millennium changes.

VI. LIFE SCIENCES AS RELATED TO SPACE

In 1996, the space life sciences research community has taken advantage of a number of opportunities that were prepared over the last decade or more, and are preparing for several missions that follow-on to missions last flown nearly two decades ago. A series of U.S. and European missions and the Russian Mir station have provided new capabilities in biological and biomedical research, lending further promise to the developing international space station as a microgravity research laboratory. Further missions with the Bion spacecraft and the planned launch of three robotic spacecraft to Mars in 1996 have required extensive preparation, while results from the Galileo mission to the Jupiter system and an obscure meteorite collected from Antarctica have captured the imagination of exobiologists.

Gravitational Biology

Space studies on the influence of weightlessness to living systems encompass a wide range of scientific disciplines, from human behavioural studies to the control of genes in single cells. Having been of an exploratory nature in the Skylab, Salyut and early Spacelab period, they now focus on increasingly more detailed questions using elaborate instrumentation and, especially, applying techniques and scenarios based on growing experience in spaceflight experimentation. Compared to the pace of ground-based research, the opportunities for the performance in space of individual experiments are very scarce, and the experience obtained takes a relatively long time. Therefore, it is of vital importance to the space life science community that this know-how can be instilled in new generations of scientists. Continuity of flight opportunities and progressively increasing opportunities for space-related ground-based studies are essential.

Osteoporosis, the weakening of bone due to calcium loss, is a serious disease occurring particularly in older people, but its symptoms can also be observed in healthy persons in weightlessness. The mechanisms operable in living bone that react to changing forces on the bone are poorly understood. With the help of the "weightless" conditions in a free orbit, studies have been conducted on bone dynamics in humans, animals, isolated embryonic bone, and isolated bone cells. Strikingly, even isolated cells already appear to be sensitive to microgravity. This fact, and the other influences observed, now allow space life scientists to ask more precise questions about the mechanisms involved.

Many of these question can, and should, be studied on the ground, utilizing facilities that impose or simulate different "weight" levels on bone tissues. Such studies, in turn, generate the questions that can only be answered fully in spaceflight, or define the precise verification needed in spaceflight. Only within a firmly ground-based research program will optimum use be made of the precious tool that space microgravity is, and with the help of that tool unprecedented progress can be made in this field.

A similar case can be made for studies of cardio-pulmonary function. Here too, microgravity provides a new perspective toward the understanding of the underlying regulatory mechanisms and dysfunctions leading to disease. To further advance these insights, continuous ground-based studies and regular access to space are required.

On the cellular level, it has now been firmly established that some signalling pathways of cells, essential for their proper communication and function in tissue, are strongly disturbed in microgravity. The consequence of this finding may have preformed implications, both for the understanding of human health issues in space, as well as for the possible biotechnological and research applications of this phenomenon. The immediate questions generated might have to wait another 10 years before they can be answered, if only spaceflight opportunities were required to perform the appropriate experiments. Luckily, this is not so, and many relevant studies can be done on the ground, enabling researchers to derive the maximum benefit from spaceflight opportunities. Because of this complementarity, it is necessary to establish and maintain a framework in which these complementary research activities can be funded, recognizing that unique ground facilities may need to be developed and maintained for some of these studies.

In the life sciences, the "weightless" condition offered by the International Space Station will be a great tool for the advancement of our knowledge in many disciplines. Many results were developed in 1996 from spaceflight because of the mutually supportive relationship between ground-based studies and experimental platforms of much less capability than the planned International Space Station, and the prospects for the productive use of that facility are extremely bright if that mutual support can continue in the space life sciences. Because of the inherent complexity of performing an experiment in space, and not in the least because of the costs of such experiments, it is of vital importance for gravitational biology that the possibilities for space-related ground-based research be progressively developed by the nations and agencies involved.

Radiation Biology

The last few years has seen an encouraging increase in collaboration in the area of space radiation dosimetry between Western scientists and those of the former Soviet Union and Eastern bloc nations. There is presently a close collaboration on an upcoming unmanned Russian mission to Mars. An ongoing collaboration on the Mir spacestation is continuing and becoming stronger. Japanese scientists are becoming involved in dosimetry measurements on the U.S. Space Shuttle. In addition, collaborations between scientists of various countries are developing in radiation environment measurement and definition.

In the area of radiation biology and health, progress is being made on determining effects of the components of space radiation on biological systems of various sorts. The closure of an important accelerator in the United States (the Bevalac in California) for the study of high-energy heavy-ion effects has been somewhat ameliorated by the availability of another accelerator (the AGS in New York). An active experimental program is presently being carried out there. Other high-energy heavy-ion accelerators that have been used in such studies are at GSI in Germany and the HIMAC in Japan. A medium energy (200 MeV) therapeutic proton accelerator is also being used to study biological effects by the space radiation biology community.

Finally, radiation effects in the Central Nervous System and possible synergistic effects with microgravity are emerging as a potentially important area of study. Long-term build-up of deleterious effects in the brain from galactic cosmic rays over mission times of several years has been suggested as possibly modifying brain function and perhaps crew performance. This appears to be a promising area of new research.

In sum, there is a continuing active community of researchers from around the world interested in determining the effects of space radiation on space travellers engaging in prolonged missions, either earth-orbiting or outside the geomagnetosphere.

Planetary Biology and Origins of Life

1996 has seen a marked increase in public awareness of the possibility that life may exist outside our own planet. In August, scientists announced their findings of strong circumstantial evidence of possible early Martian life. The team found the first organic molecules thought to be of Martian origin; several mineral features characteristic of biological activity; and possible microscopic fossils of primitive, bacteria-like organisms inside of an ancient Martian rock that fell to Earth as a meteorite.

The announcement, from indirect measurements, of planets around other stars has now become nearly a monthly activity. The family of planetary systems thus discovered has invigorated the planetary modeling community to explain measured distribution of planets, and has increased interest in the possibility of detecting extrasolar planets that may have liquid water, a quintessential ingredient for life.

Although not a product of space research, scientists found microbial communities living 2,500 metres below the Earth's surface, living autotrophically on basalt using only CO_2 and H_2. This raises the possibility that there may be sub-surface habitats on other planets that are not dependent on the planet's surficial environment, including solar radiation.

Discovered in January by a Japanese amateur comet hunter, Comet Hyakutake became the "comet of the century" with its illuminating close pass of Earth. Astronomers observing the close approach of Comet Hyakutake in March discovered large quantities of the gases ethane and methane in the comet. This is the first time these or other molecules classified as "saturated hydrocarbons" have been found in a comet, strongly suggesting that at least two basic types of comets inhabit the Solar System.

Trapped helium isotopes in fullerenes from the Sudbury impact structure in Canada show that organics can survive delivery to Earth. The implication is that impactors could be significant sources of prebiotic compounds important for the origin of life on early Earth.

ESA's Biopan platform was flown aboard the BION satellite, a Russian recoverable satellite. Biopan provided a platform to test the response of biological systems to space vacuum and solar UV-radiation. In one experiment, osmophilic bacteria exposed to space solar radiation and space vacuum showed a remarkable resiliency to what heretofore has been considered a lethal circumstance for all but bacterial spores. These organisms' ability to survive the rigours of the space environment has implications for the possible interplanetary spread of microbes via spacecraft, meteors, and dust particles.

Interstellar and interplanetary dust may have played a significant role in the prebiotic chemistry of early solar system planets. The Russian station Mir has enabled deployment of several devices from ESA and NASA designed to capture cosmic dust particle for earth return and analysis.

NASA's Galileo probe has made the first quantitative measurements of the Jovian atmosphere below its outer clouds, reaching a region below that where heat from the Sun can penetrate. Scientists did not detect the three-tiered cloud structure that most researchers had postulated, and the amount of helium measured was about one-half of what was expected. The new concepts arose from the probe's successful parachute-borne descent into Jupiter on 7 December 1995.

Tantalizing new images of Jupiter's moon Europa from the Galileo spacecraft indicate that "warm ice" or even liquid water may have existed, and perhaps still exist today beneath Europa's cracked icy crust. Scientists believe Europa's cracked cue-ball appearance is dramatic evidence of geologic activity that has caused melting and reshaping of the surface of Europa, a frozen world largely made of water ice. Europa has long been considered by scientists, and celebrated in science fiction, as one of the few places in the Solar System that may possess an environment where primitive forms of life could exist.

Natural and Artificial Ecosystems

A principal goal of COSPAR sub-commission F.4. (Natural and Artificial Ecosystems) is to understand how ecological systems (ecosystems) function. While it is difficult to strictly define an ecosystem, a useful operational definition is that the term "ecosystem" includes and describes the dynamic interactions among all (or a selected group) of the organisms in a chosen volume of space, as well as all (or a selected set) of their interactions with the physical environment.

Historically, the discipline of ecology has conducted observational studies of natural ecosystems, and has developed sets of precepts that in some cases include causal sequences. For example, an early theory of higher plant "succession" was developed in this way.

It has seldom (if ever) been possible to examine all of the organisms within an "ecological volume," and most frequently a practical rule is adopted to restrict observation to a specific set of organisms. Thus, in most studies, it has been inconvenient (or downright impossible) to study the interaction of the underground microbiological community with the above ground mammalian populations.

Because of the desire to understand the workings of real, "natural" systems, most ecologists have preferred not to manipulate the system's components, but rather to observe the changes in the systems under study. As a consequence, very few "ecological experiments" have been conducted that would pinpoint, as an example, the communication mechanisms that must exist between species that interact.

The study of scientifically constructed ecosystems could very well aid in identifying such phenomena as "communication chemicals," if they exist. In any case, the study of artificial ecosystems may ultimately contribute to our understanding of the terrestrial environment, our home on Earth. Such studies will also aid in the assembly of artificial ecological systems that will be used in space. Such systems are likely to be useful during extended missions within the solar system, and on planetary surfaces. Thus, COSPAR fosters investigations that have both academic and practical rationales, and discusses research applicable to space and to the Earth.

Artificial ecosystems constructed for specific purposes, such as for research or for human life support, are technological tools that have only been available for the last two decades. While several countries have made major investments in the construction of artificial ecosystems that are large enough to contain and support humans for extended periods, it is unlikely that such systems will ever be freely available for general research purposes.

Such facilities should be considered as important and significant national research laboratories, and have been (or are being) constructed in Russia at the Institute for Biological and Medical Problems (IBMP), in Moscow, and at the Biophysics Institute, in Krasnoyarsk; in the United States in Oracle, Arizona at Biosphere II, and at the Johnson Space Centre, in Houston; and in Japan at the Institute for Environmental Sciences at Rokkasho-mura, Aomori prefecture.

Smaller facilities, designed to study interactions among organisms by isolating them from the external environment have been constructed in Russia, France, the United States, the Netherlands and Canada, among other countries. Such tools also permit studies of the mechanisms of ecological control. With that knowledge comes an increased ability to identify the factors that contribute to the stability of natural systems.

It is anticipated that studies of both natural and artificial ecological systems will contribute to our understanding of the "laws" of ecology and that application of such "laws" will permit us to interact more intelligently with our environment, as well as to carry efficient and reliable ecosystems with us into space.

VII. MATERIALS SCIENCES IN SPACE

Microgravity research is scientific investigation conducted in a gravitational field that is a small fraction of the gravitational acceleration on Earth. Gravity is certainly a weak force compared, for example, to atomic binding forces. Therefore, the role of gravity in physical phenomena is important only when stronger forces are in equilibrium or when special circumstances arise. The goal of materials science research in space is to use the unique experimental environment to study fundamental phenomena during solidification of melts, crystal growth and combustion, and to determine thermophysical properties of fluids.

Materials Science Research

The particular interest in this field is the understanding of the roles of buoyancy-driven convection, sedimentation, and hydrostatic pressure in the processing of alloys, composites, ceramics, and polymers. NASA, ESA, DARA, CSA and NASDA have continued to support vigorous programs involving solidification and materials property measurement in ground-based experimental programs and short duration microgravity experiments carried out in drop tubes and rockets.

On the STS-63 Shuttle mission (SPACEHAB) the Gas Permeable Polymer Materials (GPPM) hardware was reflown (its first flight was in July 1993). The purpose of these flights is to determine if certain types of polymers made in low gravity while the Space Shuttle is in orbit, differ greatly from the same polymers made at the same time on the ground. The current flight will evaluate new materials based on results from the first GPPM flight.

The STS-75 (USMP-3) Mission had three major materials science experiments. The Advanced Automated Directional Solidification Furnace (AADSF) was used to grow a crystal of lead-tin-telluride (PbSnTe) by directional solidification. Also included was the Isothermal Dendritic Growth Experiment (IDGE). These experiments build upon the solid results obtained on USMP-2. Finally the Materials for the Study of Interesting Phenomena of Solidification on Earth and in Orbit (MEPHISTO) is a cooperative program between NASA, the French Space Agency and the French Atomic Energy Commission, with the goal of understanding how gravity-driven convection affects the production of metals, alloys and electronic materials.

MEPHISTO flew on both previous USMP missions. On MEPHISTO electrical measurements are employed to gauge the temperature variations in the solidification front. These temperature variations are indicative of the stability of the interface which is very important in controlling the properties of the material in its solid state. The shape of the front is marked in the growing crystal by subjecting the sample to electric-current pulses.

The STS-76 (SPACEHAB module) included two experiments that were transferred to the MIR Space Station for long duration microgravity studies. First, the Queen's University Experiment in Liquid Diffusion (QUELD), and second, the High Temperature Liquid Phase Sintering (LPS) hardware. The LPS utilized the Optizon furnace aboard the Mir space station.

Additional experiments performed in SPACEHAB used the Commercial Float Zone Furnace (CFZF). Three international agencies are cooperating on the project: NASA Marshall Space Flight Centre, Huntsville, Alabama; the Canadian Space Agency (CSA) and the German Space Agency (DARA). The US samples of gallium arsenide (GaAs) and gallium antinomide (GaSb) have been prepared by the University of Florida in cooperation with industrial participant, Atramet Inc. This technique was investigated on the first SPACEHAB mission in 1993. The parabolic-ellipsoid mirror type furnace is provided by the CSA and DARA. The furnace flew on the D-2 Spacelab mission in 1993.

The Space Experiment Facility (SEF), was flown in SPACEHAB4 on the STS-77 mission. This crystal growth experiment, using the SEF's transparent furnace, focused on mercurous chloride a valuable electro-optic material of commercial interest.

Biotechnology Research

Application of biotechnology research results range from the design of new drugs, to protein engineering, synthetic vaccines, and biochip technology for the electronics industry. Biotechnology under microgravity conditions has focused on the study of isolated biomacromolecules, such as proteins and the study of cells in controlled fluid and chemical environments. In particular, protein crystal growth has been the subject of many space experiments. Proteins are complex molecules responsible for many biochemical functions essential to life on Earth. Scientists use protein crystals to determine the structure and function of proteins. The pharmaceutical industry uses such information for the design of drugs that bind to a specific protein which can block chemically active sites. Such drugs are able to "turn off" the protein's activity, thus regulating metabolic processes.

The three-dimensional structures of proteins are determined by X-ray analysis of protein crystals. However, many proteins that interest medical researchers have not produced crystals of adequate size and quality to allow X-ray data to be collected. Crystals grown in space, where they are virtually free from the distortions of gravity, often provide better structural information than their counterparts grown on Earth.

Biotechnology continues to be an a major part of STS microgravity missions. STS-63 (SPACEHAB) experiments utilized four different hardware designs for protein crystal growth; the Vapour Diffusion Apparatus (VDA), the Protein Crystallization Facility (PCF), the Handheld Diffusion Test Cell (HH-DTC), and the Protein Crystallization Apparatus for Microgravity (PCAM), to be carried in the Shuttle middeck.

The Handheld Diffusion Test Cell (HH-DTC) apparatus evaluated experiment chambers designed for the new Observable Protein Crystal Growth Apparatus (OPCGA), which uses sophisticated optical techniques to analyse the growth of individual crystals in orbit. HH-DTC experiment units were reflown on STS-77.

The PCAM will grow crystals using the vapour diffusion method, which has been highly effective in previous Shuttle experiments. In vapour diffusion, liquid evaporates from a protein solution and is absorbed by a reservoir solution contained in a wicking material.

During the STS-67 mission biotechnology studies included experiments on the Microencapsulation of Drugs (flown again on STS-70) and crystallization studies using the Protein Crystallization Apparatus for Microgravity (housed in a Single-locker Thermal Enclosure System) and the Vapour Diffusion Apparatus. The Protein Crystallization Apparatus for Microgravity (PCAM) is the second test of a new design for growing large quantities of protein crystals in orbit. It first flew aboard STS-63 in February 1995.

The Commercial Protein Crystal Growth (CPCG) experiment, sponsored by the Centre for Macromolecular Crystallography (CMC) based at the University of Alabama at Birmingham, initially flown on STS-63, was reflown aboard STS-70, STS-75 and again on STS-77 (SPACEHAB-4). One of the proteins grown on STS-77 was a new form of recombinant human insulin provided by Eli Lilly.

Fluid Physics

Fluid and interfacial transport processes are common to both materials and biological systems. Under terrestrial conditions, the effect of gravity on inhomogenous fluids generally results in internal phenomena such as buoyancy-driven convection, particle sedimentation as well as the distortion of fluid interfaces. These effects can add complexity to fluid systems. For example, the effects of other contributing processes (such as diffusion) can be masked or substantially modified. Thus, the microgravity environment affords the opportunity to study these other processes without the complicating influence of gravity.

The Zeno investigation, on USMP-3, explored an unusual state of matter by measuring the density of the element xenon at its critical point. The orbital environment permitted measurements to be made within a few millionths of a degree of the critical temperature.

The USML-2 mission included the Geophysical Fluid Flow Cell (GFFC) experiment, which studies how fluids move in microgravity. It was first flown on Spacelab 3 in 1985, and was extensively refurbished for this mission.

On the STS-77 mission, a Get-Away Special (GAS) experiment, G-741, involved a study of the fundamentals of nucleate pool boiling heat transfer under the microgravity conditions of space. An improved understanding of the basic processes that constitute boiling is sought by removing the buoyancy effects which mask other phenomena. The canister consisted of two reflight experiments which propose to broaden the range of experimental parameters beyond those covered previously in order to study an element involved in the boiling process which, as a result of the experimental work in microgravity conducted to date, appears to play a significant role in pool boiling—that of dryout and its reverse, wetting.

Combustion Research

The availability of improved low gravity facilities such as drop tubes and towers, parabolic flights and manned space missions offers unique opportunities and challenges to combustion science and technology. The reduced gravity levels afforded by these low gravity environments enable the study of combustion phenomena that, under terrestrial conditions, are obscure or substantially modified by gravitational effects. These research opportunities facilitate work toward the challenging task of developing strategies for the prevention and control of fire and explosion hazards for spacecraft, as well as improved fire detection, prevention and extinguishing methods on Earth.

Microgravity conditions for experimentation in combustion offer a variety of simplifications compared to terrestrial experimental conditions. These include a reduction in dimensionality, the inhibition of settling effects for multiphase phenomena, and a substantial reduction of buoyancy forces. Studies focus on the processes of ignition, flame spreading, flame extinction, flamefront instabilities, smoldering, flammability limits of gaseous pre-mixed flames, and soot processes in nonpre-mixed flames. In addition, materials synthesis in heterogeneous pre-mixed flames has also been considered. In many cases these experiments are of short duration.

Short duration combustion experiments have been performed during 1995-96 in microgravity facilities such as the drop shafts at the NASA Lewis Research Centre in Cleveland, USA, at Kamisunagawa in Japan, the drop tower in Bremen, as well as on parabolic flights.

The STS-63 mission SPACEHAB Solid Surface Combustion Experiment (SSCE) is a major study of how flames spread in a microgravity environment. In the SSCE test on STS-63, scientists investigated flame spread along a sample of Plexiglas in an environment of 50 percent oxygen and 50 percent nitrogen at 1 atmosphere pressure.

Investigations on the STS-75 United States Microgravity Payload-3 (USMP-3) involved experiments on Forced-Flow Flamespreading Test (FFFT), Radiative Ignition and Transition to Spread Investigation (RITSI) and Comparative Soot Diagnostics (CSD). The objective of FFFT was to identify the effect of low-speed flows and bulk fuel temperature on the flammability, ignition, flame growth and flame spreading behaviour of solid fuels in a microgravity environment. RITSI studied of the radiative ignition and subsequent transition to flame spread in low gravity in the presence of very low-speed air flows in 2-D and 3-D configurations. While the Comparative Soot Diagnostics (CSD) examined particulate formation from a variety of sources and quantified the performance of several diagnostic techniques.

Investigators on STS-77 included the Microgravity Smoldering Combustion (MSC) experiment for studying the smolder characteristics of porous combustible materials in a microgravity environment. Smoldering is a non-flaming form of combustion that takes place in the interior of porous combustible materials. The propagation of the smolder reaction is controlled by complex thermos-chemical mechanisms, which are not well understood.

VIII. FUNDAMENTAL PHYSICS IN SPACE

Projects under Development

Gravity Probe B (GP-B) is a NASA Project aimed at testing two predictions of Einstein's theory of General Relativity to an unprecedented high precision. According to this theory a gyroscope in a polar orbit at 650 km altitude will experience two relativistic precession effects. First, in the orbital plane it will experience a geodetic precession of 6.6 arcsec per year. Second, at right angles to the orbital plane a frame-dragging precession (or Lense-Thirring precession) of

0.042 arcsec per year will be experienced due to the Earth's rotation.

GP-B aims at testing these predictions to better than 0.01 percent and 1 percent, respectively. Besides directly seeing these precession effects, the design accuracy of the experiment will permit improvement in determining the PPN space-curvature coefficient by two orders of magnitude, down to 1 part in one-hundred-thousand.

The principle of the experiment is to accurately measure the precession of a gyroscope relative to fixed stars with one star whose proper motion is accurately known as the guide star. A gyroscope is placed in a drag-free satellite in a polar orbit with an ascending node so that the line of sight of the guide star lies in the orbital plane. The gyroscope is spun up so that its axis is pointed toward the guide star.

The GP-B scientific payload comprises four gyroscopes, a drag-free proof mass, and a star tracking telescope all held together with a fused-quartz block and four DC SQUID packages for the gyro readout. Each gyroscope independently measures the geodetic and frame-dragging precessions, thus giving both measurement and failure redundancy. The payload is accommodated in a superfluid helium dewar which maintains a temperature of about 2.5 K during the mission lifetime of 17 months. GP-B has a launch mass of 3000 kg; it will be launched by a Delta 2 rocket from WTR at Vandenberg, California in the year 2000.

CRONOS is an experiment to test Einstein's "clock gravitational frequency shift" to a precision of 1 part in one million, an improvement by 2 orders of magnitude over the most precise experiment up to now (the suborbital flight of the GP-A rocket in 1976). CRONOS is a hydrogen maser clock in space (weighing only 35 kg) which is under development in Switzerland and intended for flight on the Radioastron mission, an international space VLBI mission led by the Astro Space Centre in Moscow. On Radioastron, CRONOS is mainly used as a high precision local oscillator of the space radio telescope receiver. The redshift experiment is possible by comparing two identical hydrogen maser clocks, one on the ground, the other on Radioastron whose apogee is 80,000 km, thereby exploiting the large gravitational potential difference available in space.

Projects Under Study

The LISA Project is a Laser Interferometer Space Antenna for the detection and observation of gravitational waves in the frequency range 10^{-4} to 10^{-1} Hz, which are inaccessible to ground-based detectors. It is included as the third cornerstone project in ESA's long-term space science program "Horizon 2000 Plus." LISA consists of six identical spacecraft, forming an equilateral triangle in interplanetary space with two closely spaced (200 km) 'near' spacecraft at each vertex. In principle, one spacecraft at each vertex would be sufficient, but the optical system and attitude-control requirements would be more complicated. The distance to the 'far' spacecraft is 5 million km, which defines the interferometer arm length. Each spacecraft sends out a 1 W laser beam (at 1 m wavelength) to its corresponding far spacecraft, and a 10 mW laser beam to its neighbouring near spacecraft. The lasers at each pair of near spacecraft are phase-locked together, thus behaving effectively as a single laser. Each spacecraft receives the laser light through a f/1 Cassegrain telescope with a 30 cm aperture and sends out a beam of its own through the telescope. For the two main arms of the interferometer, the far spacecraft transmits back beams that are phase-locked with a small frequency offset from the incoming beam. When a gravity wave passes through the system, it causes a strain distortion of space, which is detected by measuring the fluctuations in distance between proof masses that are floating freely inside the spacecraft. The incoming light from the telescope is reflected off the proof mass and superimposed with the local laser on a phase-measuring diode. The distance fluctuations are measured to sub-Angstrom precision. Each proof mass is shielded from external disturbances (e.g. solar radiation pressure) by the spacecraft in which it is accommodated. The position signals from capacitative sensors are used in a feedback loop for drag compensation using FEEP (Field Emission Electric Propulsion) thrusters to enable the spacecraft to follow its proof mass precisely. LISA is designed to detect gravitational-wave strains with a signal-to-noise ratio of 5 down to a level of order 10^{-23} in one year of observation.

The six spacecraft, including three propulsion modules for the transfer from Earth orbit to the final position in interplanetary space, can be launched by a single Ariane 5. The three pairs of spacecraft are positioned in individual heliocentric orbits at 1 AU from the Sun; their orbits have a specific inclination and eccentricity such that the three spacecraft pairs move relative to each other on a circular orbit inclined at 60° to the ecliptic. This keeps the distances between them (the interferometer arm lengths of 5 million km) constant. To ensure that the gravitational perturbations stay small enough for this, the system is placed at least 20° behind the Earth. As this configuration orbits the Sun in the course of one year, the observed gravitational waves get Doppler-shifted. For periodic waves with sufficient signal-to-noise, this allows the direction of the source to be determined. The three arms give two almost independent interferometers and also provide redundancy in case of the failure of up to two spacecraft (not at the same vertex).

The STEP (Satellite Test of the Equivalence Principle) Project was studied as an ESA/NASA collaborative project at Phase A level as a candidate for M2 and as a European-only project again at Phase A level as a candidate for M3 (M2 and M3 are ESA's second and third medium-size projects, respectively). Although STEP was in both cases not selected, it stirred up quite some interest in the scientific community and there are now three low-cost projects under study, all aimed at testing the Equivalence Principle in space: MiniSTEP, GEOSTEP and GG.

NASA is studying a "minimal-cost" version of STEP, called MiniSTEP which aims at testing the Equivalence Principle to 1 part in 10^{18}, six orders of magnitude better than has been achieved on the ground. A large number of European institutes have been invited and have accepted to participate in the payload and the data analysis; ESA is actively involved in the study and would provide the mission operations and a few other elements. MiniSTEP carries a cryogenic payload consisting of four differential accelerometers accommodated in a superfluid helium dewar. Much of the MiniSTEP technology can be inherited from GP-B.

Like GP-B, MiniSTEP is a drag-free spacecraft using the boil-off from the helium dewar to feed a number of proportional thrusters on the spacecraft to compensate for the drag from the residual atmosphere at orbital altitude and from solar radiation pressure. Like GP-B, position sensing is done with ultra-sensitive SQUID magnetometer circuits. The launch of the 400 kg MiniSTEP spacecraft into a Sun-synchronous circular orbit at 400 km altitude is planned for 2002 or later; mission lifetime is four to six months.

The French space agency CNES is studying the GEOSTEP Project, which is similar in concept to MiniSTEP (both are derived from the original STEP studies) but employs electrostatic suspension, capacitative position sensing and a supercritical helium dewar as baseline. The GEOSTEP payload includes four differential accelerometers aimed at testing the Equivalence Principle to 1 part in 10^{17}. Like MiniSTEP, GEOSTEP is drag-free, 3-axis stabilised and would also be placed in a Sun-synchronous circular orbit although at slightly higher altitude (600-900 km). GEOSTEP would use the French PROTEUS platform, which is under development for a variety of missions in low-Earth orbit.

A very different concept is pursued by the Italian space agency, ASI, which has studied the Galileo Galilei (GG) Project since 1994. GG is a room-temperature experiment with a somewhat lower precision than MiniSTEP or GEOSTEP. GG is built on the idea that the dynamic properties of elastically connected bodies co-rotating with an angular velocity in excess of the passive natural frequencies of the system (i.e. 'supercritical rotation') can be beneficial to the measurement of ultra-low accelerations between the test masses. The proposed system consists of six cylindrically-symmetric bodies connected by a nested arrangement of springs and gimbals. The outer body is the spacecraft bus. Inside, suspended by weak springs, is the experiment chamber ("pico-gravity box" or PGB). The two test masses are suspended inside the PGB by weak springs attached to the ends of two rods, which, themselves, are connected to the PGB by weak gimbal springs affording two degrees of freedom angular motion for each rod. The entire system spins at 5 Hz around the symmetry axis. Ideally, there is no relative rotational motion between the bodies. The putative Equivalence Principle signal is to be detected by measuring the relative translational displacements between the two test masses using capacitative sensors. Drag-free control using FEEP (Field Effect Electric Propulsion) thrusters is proposed to attenuate the drag forces acting on the outer spacecraft body.

IX. SATELLITE DYNAMICS

The COSPAR Panel on Satellite Dynamics is concerned with the orbital and attitude motion of artificial satellites and space probes and with techniques for the determination of these motions. Topics in satellite dynamics in which progress has been made in the current year include the further exploitation of the Earth observation spacecraft ERS-1, ERS-2 and TOPEX/Poseidon, with their payloads including advanced tracking systems and altimeters; continuing development of the International GPS Service for Geodynamics (IGS); advances in gravity field modelling and intensified efforts in the analysis of potential future missions for gravity field improvement; refined modelling of non-gravitational forces and preparation of space missions with sensors able to accurately measure such forces.

Earth Observation Missions

With the launch of the ERS-2 in April 1995, the way was prepared for a very successful tandem mission with the ERS-1 spacecraft. Between September 1995 and June 1996, in order to support interferometric SAR measurements, both spacecraft were maintained in very similar orbits, with ERS-1 leading by 36 minutes in the orbital plane in such a way that the same ground points were being overflown with a time difference of exactly 1 day. The constraint on the accuracy of the repeat track was specified in the range 50 to 150 m during the major part of this tandem phase: this was the first time that such a tight constraint has been realised (the usual constraint of 1 km at equator crossing was maintained for the individual tracks). On average one manoeuvre every 7 days was needed (low solar activity).

With the gradual deployment of the ground segment of the PRARE (Precise Range and Range Rate Equipment) during 1995 and 1996, and the completion of the commissioning of the on-board hardware and the preprocessing of the data, an important new contribution to the precise tracking of ERS-2 has become available. Single range measurements show a noise level of about 3 cm and range rate (30 s) 0.2 mm/s (resulting in about 1 cm and 0.01 mm/s, respectively, for the operationally used compressed measurements), allowing computation of the orbit with an accuracy similar to that using laser measurements. Residual fits of the PRARE data after orbit determination are typically 3-5 cm and 0.4 mm/s respectively. The radial orbit accuracy for the ERS satellites is now at the level of 5-8 cm, providing an excellent basis for exploitation of the altimeter data provided by those spacecraft. The possibility of further improvement, in particular with better force models derived from combining all the available tracking data, is under investigation.

A major activity was undertaken by a number of European groups to calibrate the ERS-2 altimeter relative to that of ERS-1. The results of a number of different methods, mostly involving orbital dynamic approaches, showed that measurements of both altimeters are agreeing to within 1 cm.

The TOPEX/Poseidon mission continues to provide a rich flow of data from its altimeter, DORIS (Doppler), on-board GPS, and laser instrumentation. The radial orbit accuracy of 2-3 cm provided by the various tracking systems remains unparalleled. One major area of research has been concerned with improved ocean tide models, on the basis of the accurate orbits together with altimeter data. These in turn, though their contribution to the time-varying part of the Earth's gravity field, feed back into improved models of satellite orbital motion. In particular, the University of Texas developed a new model (CSR3.0) using several years of TOPEX altimetry to adjust the Grenoble hydrodynamical model FES94.1, while a new version of the latter also became available (FES95.2). Further advances were made on Mean Sea Surface models, using data from the TOPEX/Poseidon altimeters and from the ERS-1 geodetic phase (168 d repeat cycle).

The parallel computation of the TOPEX/Poseidon orbit by NASA and CNES, as well as by a number of other groups with more limited scope, continues, using the JGM-3 gravity model. CNES are now using a reduced dynamics approach to process the DORIS Doppler data, estimating the amplitude of a Gauss-Markov process modelling unknown accelerations.

The ensemble of tracking systems onboard TOPEX/Poseidon includes an S-band antenna enabling communication with and tracking by the US Tracking and Data Relay Satellite System (TDRSS). This has enabled the computation of very precise orbits of the geostationary TDRSS satellites. These orbits could be used to compute high-precision orbits of an array of user satellites of TDRSS flying at relatively low altitudes and inclinations not well represented in gravity field models.

Global Positioning Systems

The activities of the International GPS Service for Geodynamics (IGS) extended during the past year to include a rapid orbit product, a new approach to combining station coordinate and other products of the service, and detailed studies of the use of the data generated by the IGS network as a contribution to monitoring the troposphere and ionosphere.

The IGS "Final Orbits and Clocks" for the complete GPS constellation are now available with a delay of 11 days, while the new "Rapid Orbits," based on all data available within some hours of the end of each day, are disseminated to the Global Data Centres each day within 24 hours of the last measurements. The accuracy of the final orbit combination is currently 5-10 cm per coordinate, while the corrections to the GPS satellite clocks are in the sub-nanosecond range. The rapid orbits are accurate to 10-20 cm. Experimental solutions are being made with a predicted orbit, which should be continuous with the rapid orbit.

As a contribution to the maintenance of the terrestrial reference frame (see below), the IGS analysis centres are now supplying weekly solutions for the positions of the stations of the global tracking network and other parameters. Combinations of these are preparing the way for handling the processing of very dense regional and global networks comprising hundreds, or even thousands, of stations.

The analysis of data sets from the GPS-MET mission provided an encouraging vision of the potential of orbiting GPS receivers for extracting vertical temperature profiles and 3-dimensional views of the water content of the troposphere (with important implications for weather forecasting and climatology), and of the electron content of the ionosphere.

The Russian GLONASS system reached the complete configuration of the space segment during 1996 with 24 active satellites in orbit.

Significant advances towards the application of these systems for air, maritime and land navigation were made with extensive studies in the United States (Wide Area Augmentation System–WAAS), Europe (European Geostationary Navigation Overlay System–EGNOS), and in Japan.

Gravity Models and Non-gravitational Forces

The most accurate determinations of Earth satellite motion are currently based on use of the JGM-3 gravity model. Proliferation of GPS receivers in the surveying and cadastre user communities created a need for a geoid model of global nature with far better accuracy than the currently used WGS-84 model. Furthermore, the abundance of highly accurate altimetric datasets has forced scientists to develop a better geoid model in order to extract more accurately the oceanographic signals from these measurements. These two requirements led to a combined effort by NASA Goddard Space Flight Centre and the U.S. Defence Mapping Agency to produce a model, called EGM96, based on space tracking data as well as surface gravimetry, complete to a degree and order 360. In contrast to previous Goddard Earth Models (GEMs), which were based on older data and contemporary laser tracking data from only a few satellites (e.g. Lageos, Starlette, Ajisai), more than 50 percent of the tracking data used in developing EGM96 come from new technologies (such as GPS, DORIS, TDRSS and laser tracking)and from several new targets (e.g. Lageos 2, TOPEX, Explorer Platform, GPS/MET, Stella, GFZ-1, ERS-1, RADCAL and HILAT). The resulting geoid has a root mean square commission error of less than 50 cm at degree 360.

In Europe, the Earth Gravity Models (EGM series) are being developed for ERS by GFZ. An important new data source now being introduced into the models is from the laser tracking of the GFZ-1 spacecraft, flying in a relatively low orbit (400 km).

Among the new projects being considered in the ESA Earth Explorer series (launch from 2004 onwards) is the Gravity Field and Ocean Circulation Explorer (GOCE), selected as a high-priority candidate for further study in late Spring 1996. This would carry a payload consisting of an ultra-sensitive gravity gradient gradiometer and a combined GPS/GLONASS dual-frequency receiver. Such a mission to determine a high resolution gravity field is considered essential to advances in ocean circulation studies (using radar altimetry) and the analysis of various geophysical processes. The drag-free system needed for the gradiometer would also provide unique input to the development of new air density models, another essential component of satellite orbital models. Significant advances were made by a consortium of institutes during the year in understanding the processing capabilities needed to handle such a mission.

In the United States, NASA is studying similar scenarios for a gravity mapping mission. At present the candidates include: the GRACE mission, a pair of low orbit GPS-equipped spacecraft with a radio (or possibly laser) link to measure highly accurately the range between the two; and a constellation of GPS-carrying low orbit spacecraft, the Hummingbird Constellation (or Colibri mission).

The German CHAMP mission was approved (expected launch 1999). While the main objectives of this mission relate to gravity field improvement, its three-axis electrostatically compensated accelerometer will directly measure the non-gravitational forces acting on the spacecraft (air drag and lift, direct and albedo and infrared radiation pressure, and thermal forces).

Analysis of Lageos-type satellite orbits over long time intervals has proved to be a unique source for detecting long-term phenomena in the Earth's gravity field. Satellite laser ranging observations of Lageos-1 and Starlette have allowed the derivation of new results for the secular and 18.6 year tidal variations in the zonal harmonics of the geopotential.

In order to fully profit from the very precise data a number of non-gravitational perturbations have to be modelled and eliminated. Although several important steps forward have been achieved over last few years (e.g. a qualitative understanding of the Lageos spin axis evolution, and a new generation of thermal models) there remain important problems to be solved. Among the most urgent is understanding of the anomalous signal in the Lageos eccentricity excitation, which has been conjectured to be of non-gravitational origin. If those problems are better understood, orbits of Lageos satellites can also serve as precise probes for fundamental physics, e.g. constraining possible anisotropies of the gravitational constant.

X. SCIENTIFIC BALLOONING

In the past year three major international meetings on balloon technologies and observations have taken place: the AIAA meeting in the United States in January 1996; the International Symposium on Space Technology and Science (ISTS) in Japan in May 1996; and the COSPAR meeting in the United Kingdom in July 1996. Considerable progress from various countries has been highlighted in these meetings.

The United States balloon program, managed by NASA, reports continued success in supporting the scientific research community. During the past year, flights were conducted from six sites including Palestine, Texas; Ft. Sumner, New Mexico; Lynn Lake, Manitoba, Canada; Alice Springs, Australia; Fairbanks, Alaska; and McMurdo Station, Antarctica. Five successful flights were conducted from Alice Springs and two successful long duration flights were conducted from McMurdo Station, which has been the annual site of long duration flights since 1990.

A successful test launch was conducted this year to prove operational procedures for launching top-mounted payloads up to 193 kg (425 pounds). This test was in preparation for the Top-Hat payload, a top-mounted infrared telescope. Another successful test conducted this year was the flight of a superpressure balloon. This was a reliability and quality assurance test conducted to ensure a transfer of technology after the purchase of one balloon manufacturer by the other.

The NASA balloon research and development has continued to make progress in several technical and operational areas. Work is being done toward extra-long duration missions and missions on Mars. Working meetings have begun to establish criteria and technology status for a 100-day balloon mission. If these super pressure balloons of 28 MCF (~800,000 m^3), which can carry moderate size payloads of 1 ton, are realised, the role of balloons as a space vehicle may change completely because of its cost performance and its capabilities to detect rare events together with more precise observations. Thus this system undoubtedly opens a new era of scientific ballooning. Many efforts have been devoted to developing a new, stable material which meets the requirements of super-pressure balloons. They almost succeeded to provide composite materials including polyester, woven or non-woven high density polyethylene fabric, and at present there are efforts for a stable long line seaming of these materials for large size balloons.

Efforts on long duration flights of balloons were not only made in the United States. Some studies have focused on establishing systems to save the ballast consumption as well as on providing long telemetry range and wide recovery area for trans-oceanic and trans-continental flights. In this context, satellite links with Argos, GPS, and Inmar-C are widely used, and TDRSS is being considered for use in the near future. Mobile communication systems such as Iridium and other systems will be available and become useful for long range flights within a few years.

Other programs for super-pressure balloons have already been noted in the report for 1995. The French group is implementing a campaign with about 200 small super-pressure balloons in the Antarctic area around the year 2000, in order to study the global motions of the atmosphere in stratospheric heights in this polar region.

Over-pressurized balloons are less pressurized than super-pressure balloons. They have a great capability to save the ballast particularly in the polar region where the effect of the day-night cycle is small in summer. U.S. researchers have already conducted several test flights with over-pressurized zero-pressure, shaped balloons. They confirmed that the burst pressure of the balloon just coincides with the value calculated by structural analysis. One of the major difficulties of pressurized balloons is the large stress acting on the balloon films. Over-pressurized balloons are now at the stage of practical applications, and the key point is to develop the most suitable and reliable system to maintain the desired over-pressure during the flight. The United States has developed an automatic gas pressure control system, combining the newly developed large exhaust valves with differential pressure sensors. On the other hand, Japanese groups have proposed more simple and passive systems with normal horse-tail ducts, closed by small permanent magnets. The duct is open when the force due to over-pressure becomes larger than the magnet force to close the duct. They show in laboratory tests that the performance is satisfactory.

Another approach to save the ballast is to reduce the change of gas temperature inside the balloon during the day and night excursion. A French group has been continuing the project of MIR (Montgolfière Infrarouge), which is a hot air balloon heated by the Infra-red radiation from the ground. A new valve to exhaust the hot air was prepared to control the change of the gas temperature inside the balloon, in order to keep the same balloon altitude. The test flights were successful. The system will be applied to study the details of the global motion of the air in the polar stratosphere.

A Japanese group proposed balloons manufactured from the new balloon film EVAL (Ethylene-Vinyl-Alcohol). This film absorbs preferentially the infra-red from the ground at balloon altitudes, and they note the possibility of saving the ballast consumption of the balloons in long duration flights. A test flight was performed in the fall of 1995. The performance was satisfactory, and further test flights are scheduled later in 1996 to prove the application of EVAL balloons for long duration flights.

In the past several years, two campaigns for long duration flights have been operated at Antarctica, taking advantage of the absence of sunsets, and thus no or minor ballasting, in the summer season. One is the program conducted by a Japanese group in collaboration with the National Polar Institute and ISAS. The balloons were launched from Syowa Station. The flights lasted 15 to 20 days with circum-polar trajectories. NASA performed some flights also in 1996 to observe the extremely high energy cosmic ray spectrum (JACEE program) and other scientific subjects with zero pressure balloons. In the beginning of 1996, the United States performed a flight of JACEE-13, achieving 13 days, and successfully recovering the balloon near the McMurdo Station. A Japanese group has scheduled flights for the recovery of payloads near the launching site, based on the test experiments of 1995. In this Antarctic flight, the efficiency is one order of magnitude higher than in balloon observations at mid-latitude. Thus one flight exposure at Antarctica almost corresponds to the total exposure during the past 10 years. Because of the high cost performance of this program compared to other space programs it is hoped to extend this program further into the coming years. The Antarctica flights will undoubtedly open a new era of scientific ballooning for space exploration.

There were several reports at the COSPAR Assembly in 1996 on possible future trans-oceanic and trans-continental flights. Among those, an Indian group has been pursuing a feasibility study of trans-oceanic flights from Andaman Island to mainland India, as well as from mainland India to South Africa.

The advanced material studies for long duration missions and the Mars mission have continued at NASA. Several candidate materials have met the minimum strength requirements established by the study. Seaming studies have been initiated, with scale tests planned for the Fall of 1996.

New power systems for long duration missions have undergone significant progress at NASA this year. A phase-one definition study for a Sterling Cycle engine has been completed with the objective being a one to two kilowatt power system. In addition to this system, a 200 watt prototype "proof-of-concept" fuel cell is being built in cooperation with NASA Lewis Research Centre.

Because of the nature of scientific ballooning, international collaboration in this field is indispensable. For example, a new Russian-Japanese collaboration started in 1996. Also, in a U.S.-Japanese collaboration, a balloon experiment of a super-conductive magnetic spectrometer was also performed in 1995 in Lynn Lake, Canada, as a continuation of the successful flights of 1993 and 1994. Because of the large size of the super-conducting magnet (1 m diameter, 1.3 m length) in this collaborative experiment, almost 50 anti-protons have been detected. More flights are planned for the next few years together with improvements of the detectors towards the higher energy region.

Many countries have taken efforts to develop new balloon systems and facilities to meet the requirements of long duration flights and sophisticated observations. The Chinese launching site has been Xiang He, located between Beijing and Tianjin. Many flights were conducted from there, including long duration flights of several days in a Chinese-Russian collaboration for the past 15 years. Because of the surrounding big cities, previous long duration flights and landing of the payloads for recovery had been prevented. This year, China constructed a new balloon facility at Gu Chang (37 47'N, 116 08'E), located a few hundred kilometres south of Beijing. The new facility is convenient for long duration flights and the recovery of payloads, and it is hoped for a further development of scientific ballooning based from this area.

India also has long experience and has realised many scientific achievements. The improvement of their facilities was reported at the COSPAR Assembly as well as the development of an exhaust valve which is capable of controlling the balloon altitude during the flight.

In the COSPAR Assembly, Australia, China and India reported on their recent developments in scientific ballooning. They have developed capable balloon-borne detectors, performed balloon flights for scientific observations, and report progress of technology. The instruments developed include large area X-ray and gamma-ray telescopes and a coded-mask telescope.

For several years the subject of balloons floating on other planets has become one of the exciting items in scientific ballooning. Balloons on other planets have continuously been studied by groups in Russia, France, Japan, and the United States. The French have studied using balloons of 4000 m^3 on the planet Mars, to float in the years 2001 to 2003, in collaboration with groups from the United States and Russia.

A test of the capsule to land on Titan in the Cassini/Huygens mission was successfully performed from Leon (Spain) in 1996. This flight was performed by a group with Austrian, French, Spanish, Dutch and Italian contributions, following an earlier test from Esrange in 1995. Thereby the important role of balloons as the test-bench for expensive programs for planetary missions was proven.

The Jet Propulsion Laboratory has been performing studies for planetary balloons and feasibility studies of balloons floating in the atmosphere of Titan to observe its atmosphere. The balloon altitude is stabilized by using the phase change from gaseous to liquid state with temperature, and is planned to float in 2008, after the Cassini/Huygens mission to be performed in 2004.

In the area of scientific ballooning for magnetospheric physics, the balloon campaign INTERBOA was conducted in August 1996 in cooperation between CESR Toulouse (France), the University of Washington (USA), and the Polar Geophysical Institute, Apatity (Russia). Three balloons were successfully launched from Kiruna, Sweden, to measure parameters supporting studies of the magnetosphere, mainly X-rays, magnetic pulsations, and electric fields. The data analysis will involve measurements onboard the satellites Interball (Tail Probe), Polar and Wind, as well as ground-based observations from Scandinavia.

A NASA suborbital program review, including the balloon program, again confirmed the importance of balloon scientific investigations and their value for developing technology for future space missions. A follow-on study looked into restructuring the entire suborbital program, in order to find more efficient and effective ways of doing business. These studies were a result of the adverse effect of NASA's declining budgets and work force constraints on all aspects of space research. The challenge is to accomplish more with less. The balloon program began stepping up to this challenge several years ago with the advent of 10- to 20-day long duration flights in Antarctica. It is continuing with a push for enhanced flight capabilities and new science instrument technologies to take advantage of the potential offered by sealed superpressure balloons.

Scientific ballooning is active and we see steady progress in the technology required for long-duration flights. In addition, multi-national balloon programs continue to be attractive for scientists in many fields including astronomy, astrophysics, magnetospheric and atmospheric sciences. Plans for balloon campaigns not only on Earth, but also on other planets, extend well beyond the year 2000.

XI. SPACE RESEARCH IN DEVELOPING COUNTRIES

A meeting of the COSPAR Panel on Space Research in Developing Countries (PSRDC) was held on 19-20 July 1996 as part of the deliberations of the 31st COSPAR Scientific Assembly in Birmingham to discuss "Problems of space science education and the role of the teacher." The meeting was cosponsored by COSPAR Commissions A&F, the United Nations Committee on

Peaceful Uses of Outer Space (UN-COPUOS), the Committee on Science & Technology in Developing Countries (COSTED) and the Third World Academy of Sciences (TWAS). The main scientific objective of the meeting was to identify and understand typical problems experienced in introducing and implementing space science education at various academic and professional levels, particularly in developing countries, and to improve public awareness about the excitement and benefits of space research. In his welcome to the participants, Dr. K. Kasturirangan, the main scientific organizer of this COSPAR event, outlined the efforts of PSRDC during the past few years to energize and promote space research activities in developing countries and mentioned that the goal of the present meeting was to address issues and strategies related to introducing space science education in academic curricula. Professor G. Haerendel, President of COSPAR, mentioned that COSPAR is committed to providing the necessary support for the promotion of space research and space science education in developing countries. He highlighted the need to utilise the global resource of information and data related to space science and applications. Professor Sir Hermann Bondi emphasized in his keynote address the inspiration derived from space research which is a unique venture of human cooperation.

Other speakers emphasized the need for training of teachers, establishment of UN sponsored centres for space science and technology education at the regional level (the first of which has been recently initiated in India), use of computer and communication networks in aid of space science education, weather/remote sensing data reception, processing and analysis.

The status of current efforts, and future plans, in the area of space science education by different countries, namely China, India, Brazil, Argentina and in Africa, were presented. Various problems while introducing/implementing such education in academic curricula were also discussed to explore better approaches. Some of the recommendations made during the meeting include: (a) space science elements to be adequately incorporated in academic curricula and professional courses, primarily to enhance literacy in space science and technology; (b) vast global resource of space based data and information to be utilised particularly by the scientists from developing countries to augment the in-house education/training programs; © innovative audio-visual tools, models and kits to be used along with effective electronic communication facilities to impart space science education in schools, colleges and universities; and (d) space science education programs to be organized and strengthened with international cooperation for access to information and data, availability of text books and teaching aids.

The proceedings of the meeting on "The role of developing countries in ground based experiments in support of space observations for global and regional change studies," organized by PSRDC during the 30th COSPAR meeting in Hamburg, on 16-19 July 1994 have been published by COSPAR as an independent issue of Advances in Space Research (Ref: Vol.17, No.8, 1996, editors: Dr. K. Kasturirangan and R.R. Daniel) and distributed to the representatives of a large number of developing countries. As another follow-up activity a compendium on information on ground based experiments, space data, international programs, contact addresses etc. is being prepared as a reference handbook particularly for scientists in developing countries.

After the approval in 1995 of its 11-year National Space Plan, Argentina, through its civilian space agency CONAE (Comision Nacional de Investigaciones Espaciales), has embarked in an ambitious program of space research and applications, with the aim of developing the necessary infrastructure to bring the benefits of space information to the country's public sector and the scientific community. The highlight for 1996 is the launch of SAC-B (Satellite de Aplicaciones Cientificas-B) in October. Under a cooperative agreement with NASA, the spacecraft will be placed into orbit by a Pegasus XL launch vehicle from the Wallops Flight Facility, Virginia, USA. SAC-B will carry four scientific instruments. A Hard X-ray Spectrometer to measure hard X-ray emission from solar flares (HXRS) designed and built in Argentina will also be able to detect cosmic gamma ray bursts. The Goddard X-ray experiment (GXRE), provided by NASA, will test new detector technologies to observe soft X-rays from solar flares and hard X-rays from gamma ray bursts. The Cosmic Unresolved X-ray Background Instrument using CCDs, designed and built at Penn State University (CUBIC), will investigate the origin of the diffuse X-ray background emission and produce an all-sky X-ray map. The Imaging Spectrometer for Energetic Neutral Atoms (ISENA), provided by the Institutio di Fisica dello Spazio Interplanetario of Frascati, Italy, through an agreement between CONAE and the Italian Space Agency (ASI), will investigate the origin and role of high energy neutrals in the terrestrial magnetosphere and ionosphere. SAC-B is a truly international project. Besides the two main partners, CONAE and NASA, ASI also provided the GaAs solar panels in exchange for flying the ISENA instrument, and the Brazilian National Space Research Institute (INPE) provided its facilities at Sao Jose dos Campos, where SAC-B underwent environmental tests in 1995. CONAE is also in the process of completing Argentina's ground segment. A TTC station was installed last year in the city of San Miguel, near the capital city of Buenos Aires, and it is expected that a ground station to collect remote sensing satellite data will begin its operations before the end of 1996 near the city of Cordoba. The second spacecraft of the SAC series, SAC-C has completed its preliminary design phase and is expected to be launched and become operational, as Argentina's first Earth-observing mission, in 1999.

Under a cooperation on the CLUSTER mission between the Chinese Academy of Sciences (CAS) and ESA, some research related to the CLUSTER mission have been carried out by Chinese Cluster Data Research Centre (CCDRC), including magnetic field reconnection plasma instability, acceleration and waves. CCDRC has sent scientists to Europe to learn about the computer net and related softwares. (Although the Cluster spacecraft were lost in the first Ariane V flight, a replacement mission is being discussed by ESA member states).

A cooperative experiment between CAS and German industry on a balloon microgravity drop capsule is under preparation. The balloons will be provided by CAS and the drop capsule by a German company. The joint payload is planned to be launched from the Chinese balloon launching facility during 1996.

In pursuance of the recommendations of the Conference on Space Applications for Development in Asia and the Pacific, and the Beijing declaration on environmentally sound and sustainable development, various departments of the Chinese Government led by the State Science and Technology Commission participated in the implementation of the cooperative projects and the action plan organized by the Economic and Social Commission for Asia and the Pacific of the United Nations (UN-ESCAP). Four regional working groups on remote sensing application, satellite communication, satellite meteorological application and space science and technology application have been organized by ESCAP. The first meeting of the satellite meteorological application Working Group was held 26-28 March 1996, at the Satellite Meteorological Centre of the State Meteorological Administration in Beijing. There are a number of other collaborative efforts of CAS which include the Max Planck Institute for Aeronomy, Germany, an academic exchange program with Portugal, and active space physics experiments with IZMIRAN (Russia).

The COSPAR Colloquium on Magnetospheric Research with Advanced Techniques was held 15-19 April 1996 in Beijing. There were 53 scientists from various countries and more than 20 Chinese scientists who participated and actively exchanged scientific results. The meeting was cosponsored by PSRDC and COSPAR.

The third operational Indian remote sensing satellite, IRS-1C, was successfully launched on 28 December 1995 by the Russian launch vehicle Molinya-M into a polar sun-synchronous orbit. The 1250 kg satellite, developed indigenously, carries three instruments: PAN (Panchromatic Camera of 6m resolution), multispectral LISS-3 (Linear Imaging Self Scanner), and WIFS (Wide Field Sensor). The third developmental flight of the Indian Polar Satellite Launch Vehicle (PSLV) successfully launched the IRS-P3 satellite into a polar Sun-synchronous orbit on 21 May 1996. The satellite carries a unique combination of Earth and sky viewing sensors, including a German payload Modular Opto-electronic Scanner (MOS) for oceanography, a 3-band WIFS for global vegetation dynamics and an X-ray astronomy experiment to study spectral and temporal characteristics of cosmic x-ray sources developed by the Tata Institute of Fundamental Research (TIFR) in Mumbai, and the Technical Physics Division of the ISRO Satellite Centre (ISAC) in Bangalore. The X-ray payload consists of four collimated multi-layer, multi-wire Argon filled proportional cameras with an effective area of 1200 cm^2 in the energy range 2-20 keV and two wide Field Of View (FOV) sky monitors using an X-ray pinhole camera technique. The experiment can be operated in a pointed mode with a pointing accuracy of about 1 arc minute and also in a sky survey mode for observing bright and transient sources.

Under a collaborative agreement between TIFR, in Mumbai, India; the P.N. Lebedev Institute, in Moscow; the Moscow Physical Engineering Institute, in Moscow and several other institutes in the Commonwealth of Independent States (CIS); a Gamma Ray Astronomy Satellite Experiment NATALYA II is planned to be launched. The payload consisting of low and high energy gamma-ray telescopes is undergoing qualifying tests for a possible launch by 1996 in a Photon satellite mission of CIS. The LEG payload developed by the scientists of TIFR consists of three detector modules that are identical except for their FOV and the onboard electronics information processing and interfacing system. The basic detection unit is a NaI (Tl)/CSI(Na) phoswich scintillator viewed by a specially selected photomultiplier tube. The main objective of the combined experiment is to conduct high sensitivity and high time resolution spectral studies of the Sun and selected gamma-ray sources. The SROSS-C2 satellite launched on 4 May 1994 from the Sriharikota launch complex in India carried two experiments, one for studying the cosmic gamma-ray bursts in the energy range 20 keV-3 MeV with 2 ms temporal resolution and a Retarding Potential Analyser (RPA) experiment to study the energetics of the ionospheric region over the low and middle latitude regions. A number of gamma ray burst events have been detected and confirmed by ULYSSES, GRO and WIND space observatories.

Since the initiation of space science research in 1951 in Taiwan, extensive ionospheric observations have been carried out using ground based ionosonde and radars. Theoretical research on magnetospheric physics and upper atmospheric phenomena started about 10 years ago at the National Central University when the Chung-Li VHF radar first became operational. Experimental work has also been initiated for solar physics in conjunction with theoretical investigations of the solar atmosphere and flare energetics. On the application side, there is a major effort in space remote sensing for the purpose of environmental monitoring, civil engineering and other areas of social service. A major milestone was reached in 1994 when the 13-m antenna and the associated facilities at the Centre for Space and Remote Sensing Research were finally installed and began to receive data from different Earth observations satellites (e.g. SPOT, ERS-1). With the gradual buildup of the research facilities and faculty members at different institutions, a national space program was established in 1991 under the auspices of the National Science Council with its first science and applications satellite ROCSAT 1, scheduled to be launched in 1998. Three payload experiments selected for this satellite are: Ionospheric Plasma and Electrodynamics Instrument (IPEI), an Ocean Color Imager (OCI), and an Experimental Communication Payload (ECP) in the Ka band.

CONTRIBUTORS

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ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

AADSF	Advanced Automated Directional Solidification Furnace
ADEOS	Advanced Earth Observing Satellite
AGS	Alternating Gradient Synchrotron
AIAA	American Institute of Aeronautics and Astronautics
AIRS	Atmospheric Infrared Sounder
ALOHA	Airborne Lidar and Observations of Hawaiian Airglow
ALOMAR	Arctic Lidar Observatory for Middle Atmosphere Research
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
ANLC	Arctic Noctilucent Cloud
ARGOS	French DCLS on NOAA operational satellites
ARMS	Automated Retrieval Mail System
ASCA	Advanced Satellite for Cosmology and Astrophysics
ASI	Italian Space Agency
ASOS	Automated Surface Observing Stations
ASTRO-E	High throughput imaging x-ray spectroscopy facility
ASTROMAG	A large superconducting magnet
ATOVS	Advanced TIROS-N Operational Vertical Sounder
ATSR	Along Track Scanning Radiometer
AU	Astronomical Unit
AVHRR	Advanced Very High Resolution Radiometer
AVNIR	Advanced Visible and Near Infrared Radiometer
AXAF	Advanced X-ray Astrophysics Facility
BATSE	Burst and Transient Source Experiment
BION	A Russian recoverable satellite
BOREAS	Boreal Ecosystem Atmospheric Study
CADRE	Coupling and Dynamics in Regions Equatorial
CAS	Chinese Academy of Sciences
CCD	Charged Coupled Device
CCDRC	Chinese CLUSTER Data Research Centre
CEDAR	Coupling, Energetics and Dynamics of Atmospheric Regions
CEOS	Committee on Earth Observations Satellites
CERES	Cloud and Earth's Radiant Energy System
CESR	Centre d'Etude Spatiale des Rayonnements (France)
CFZF	Commercial Float Zone Furnace
CHAMP	A challenging micro-satellite payload for geophysical application and research
CIRA	COSPAR International Reference Atmosphere for Trace Constituents
CIS	Commonwealth of Independent States
CLAVR	Clouds from AVHRR
CLUSTERS	A S/C squadron to study Earth's magnetosphere
CMC	Centre for Macromolecular Crystallography
CMEs	Coronal Mass Ejections
CNES	Centre National d'Etudes Spatiales (France)

COBRAS/SAMBA	ESA medium mission to study anisotropy of 2.7K microwave background
CONAE	Comision Nacional de Actividades Espaciales (Argentina)
COSPAR	Committee on Space Research
COSTED	Committee on Science and Technology in Developing Countries
CPCG	Commercial Protein Crystal Growth
CRISTA	Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere
CRONOS	Clock Relativity Observations of the Nature of Spacetime
CSA	Canadian Space Agency
CSD	Comparative Soot Diagnostics
CUBIC	Cosmic Unresolved X-ray Background Instrument using CCDs
DARA	Deutsche Agentur für Raumfahrtangelegenheiten (Germany)
DC	(SC H)
DCLS	Data Collection and Location System
DE 1 & 2	NASA Dynamics Explorer Satellites 1 & 2
DMA	Defence Mapping Agency (USA)
DMSP	Defence Meteorological Satellite Program
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
DOS	Department of Space (India)
EA	Environment Agency
ECP	Experimental Communication Payload
EGM	Earth Gravity Models
EGNOS	European Geostationary Navigation Overlay System
EISCAT	European Incoherent Scatter Facility
ENVISAT	Environmental Satellite
EPCO	Early Polar Cap Observatory
EPIC	Equatorial Processes Including Coupling
EPS	EUMETSAT Polar System
ERS	ESA Remote Sensing Satellite
ESA	European Space Agency
ESOC	European Space Operational Centre
ESR	EISCAT-Svalbard Radar
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EURD	European UV spectrometer on MINISAT-1
EUV	Extreme Ultraviolet
EUVE	Extreme Ultraviolet Explorer
EVAL	Ethylene-Vinyl-Alcohol
FAST	Fast Auroral Snapshot explorer
FEEP	Field Emission Electric Propulsion
FFFT	Forced-Flow Flamespreading Test
FIRE	First ISCCP Field Experiment
FIRST	Far Infrared Sub-mm Telescope
FOV	Field of View
FUSE	Far Ultraviolet Explorer

GAC	Global Area Coverage
GALILEO	NASA's Jupiter orbiter
GAS	Get-Away Special
GCIP	GEWEX Continental Scale International Project
GCM	General Circulation Model
GDR	Geophysical Data Record
GEMs	Goddard Earth Models
Geosat	Geodesy Satellite
GEOSTEP	Gravity Experiment in Orbit Satellite Test of the Equivalence Principle
GEOTAIL	Satellite to study the Earth's magnetotail
GEWEX	Global Energy and Water-cycle Experiment
GFFC	Geophysical Fluid Flow Cell
GFZ-1	First satellite of the GeoForschungs Zentrum
GG	Galileo Galilei
GLI	Global Imager
GLOBAL SURVEYOR	A NASA orbiter carrying several experiments from the failed Mars Observer Mission
GLONASS	(Russian) Global Navigation Satellite System
GMS	Geostationary Satellite
GNSS	Global Navigation Satellite System
GOCE	Gravity Field and Ocean Circulation Explorer
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Equipment
GOMS	Geostationary Operational Meteorological Satellite
GP	Gravity Probe
GPCP	Global Precipitation Climatology Project
GPPM	Gas Permeable Polymer Materials
GPS	Global Positioning System
GRACE	A NASA gravity mapping mission
GRO	(Compton) Gamma-Ray Observatory
GSI	Gesellschaft für Schwerionenforschung
GXRE	Goddard X-ray Experiment
HETE	(SC E)
HF	High Frequency
HGS-OGRE	(SC E)
HH-DTC	Handheld Diffusion Test Cell
HIMAC	Heavy Ion Medical Accelerator
HIRS	High Resolution Sounder
HRDI	High Resolution Doppler Imager
HST	Hubble Space Telescope
HXRS	Hard X-ray Spectrometer
IAGA	International Association of Geomagnetism and Aeronomy (IUGG)
IASTP	Inter-Agency Solar-Terrestrial Physics Program
IBMP	Institute for Biological and Medical Problems (Russia)
ICE	International Cometary Explorer

ICMA	International Commission on the Middle Atmosphere
IDGE	Isothermal Dendritic Growth Experiment
IGS	International GPS Service for Geodynamics
IITS	Ionospheric Telecommunications Systems Planning and Operating
ILAS	Improved Limb Atmospheric Spectrometer
IMG	Interferometric Monitor for Greenhouse Gases
IMP	Interplanetary Monitoring Platform
INPE	Instituto Nacional de Pesquisas Espaciais (Brazil)
INTEGRAL	ESA imaging and spectroscopy program
INTERBALL	InterCosmos Fireball
INTERBOA	INTERBALL Balloon Observations of Aurora
IPEI	Ionospheric Plasma and Electrodynamics Instrument
IR	Infrared
IRI	International Reference Ionosphere
IRIS	International Radio Interferometric Surveying
IRS	Indian Remote Sensing Satellite
IS	Incoherent Scatter
ISAC	ISRO Satellite Centre
ISAS	Institute of Space and Astronautical Science (Japan)
ISCCP	International Satellite Cloud Climatology Project
ISEE	International Sun Earth Explorer
ISENA	Imaging Spectrometer for Energetic Neutral Atoms
ISO	Infrared Space Observatory
ISRO	Indian Space Research Organization
ISSA	International Space Station Alpha
ISTS	International Symposium on Space Technology and Science
IUE	International Ultraviolet Explorer
IXAP	Indian X-ray Astronomy Payload
IZMIRAN	Russian Federation Institute for Geomagnetism and Radio Wave Propagation
JACEE	A NASA program designed to observe the extremely high energy cosmic ray spectrum
JPL	Jet Propulsion Laboratory
KUIPER	NASA airborne IR observatory with 91 cm telescope
LAGEOS	Laser Geodynamic Satellite
LANDSAT	Land Remote-Sensing Satellite
LEG	Low Energy Gamma ray
LEGRI	Low Energy Gamma-ray Instrument
LILAS-2	(SC E)
LIS	Lightning Imaging Sensor
LISA	Laser Interferometer Space Antenna
LISS	Linear Imaging Self-scanning Sensor
LMA	Lockheed Martin Aeronautics
LPS	(High temperature) Liquid Phase Sintering
LTCS	Lower Thermosphere Coupling Study
LUNAR PROSPECTOR	A Discovery-class spacecraft being built for NASA
MA	Middle Atmosphere

MABS	Mars Aerobot/Balloon System
MAHRSI	Middle Atmosphere High Resolution Spectrograph Investigation
MAP	Microwave Anisotropy Project
MARSNET	Mars Network
MEPHISTO	Materials for the Study of Interesting Phenomena of Solidification on Earth and in Orbit
Meteosat	European Geostationary Meteorological Satellite
METOP	Meteorological Operational Satellite
MF	Medium Frequency
MFR	Medium Frequency Radar
MHS	Microwave Humidity Sounder
MIDAS	A mid-sized satellite program of NASA
MIDEX	NASA Medium Explorer
MINISAT-1	(SC E)
MiniSTEP	A minimal-cost version of STEP
MIR	Mongolfière Infrarouge
MIR/KVANT	Russian imaging, spectroscopy and timing studies mission
MITI	Ministry of International Trade and Industries
MLT	Mesosphere and Lower Thermosphere
MLTCS	Mesosphere and Lower Thermosphere Coupling Study
MOS	Modular Opto-electronic Scanner
MSC	Microgravity Smoldering Combustion
MSG	Meteosat Second Generation
MSIS	Mass Spectrometer Incoherent Scatter
MSMR	Multi-frequency Scanning Microwave Radiometer
MST	Mesosphere/Stratosphere/Troposphere
MSX	Mid-course Space Experiment
MTP	Meteosat Transition Program
NASA	National Aeronautics and Space Administration
NASA/ARC	NASA Ames Research Centre
NASA/GSFC	NASA Goddard Space Flight Centre
NASA/WFF	NASA Wallops Flight Facility
NASDA	National Space Development Agency of Japan
NATALYA	A Gamma ray astronomy satellite experiment
NCDC	National Climatic Data Centre
NEAR	Near Earth Asteroid Rendezvous
NESDIS	National Environmental Satellite, Data, and Information Service
NICMOS	(SC E)
NLC	Noctilucent Clouds
NOAA	National Oceanic and Atmospheric Administration
NPL	National Physical Laboratory (India)
NSCAT	NASA Scatterometer
NSSDC	National Space Science Data Centre
NSWS	National Space Weather Service
OCI	Ocean Color Imager
OCM	Ocean Color Monitor
OCTS	Ocean Color and Temperature Sensor

ODIN	Swedish Middle Atmosphere Satellite
OMEGA	(SC E)
OPCGA	Observable Protein Crystal Growth Apparatus
OSIRIS	Optical Spectrograph and Infrared Imaging System
PAN	Panchromatic camera of 6m resolution
PAR	Photosynthetically Active Radiation
PATHFINDER	A small rover to measure elemental composition on Mars by means of alpha backscatter
PATMOS	Pathfinder Atmosphere Project
PCAM	Protein Crystallization Apparatus for Microgravity
PCF	Protein Crystallization Facility
PGB	Pico Gravity Box
PI	Principal Investigator
PLANET-B	ISAS program aimed at clarifying the structure and dynamics of the Martian upper atmosphere and its interaction with the solar wind
PMC	Polar Mesospheric Clouds
PMSE	Polar Mesospheric Summer Echo
POAM	Polar Ozone and Aerosols Measurements
POES	Polar-orbiting Operational Environmental Satellites
POLAR	NASA spacecraft to study polar magnetosphere
POLDER	Polarization and Directionality of Earth's Reflectance
PPN	(SC H)
PRARE	Precise Range and Range-rate Equipment
PRIME	Prediction and Retrospective Ionosphere Modelling over Europe
PRIMO	Problems Remaining in Ionospheric Modelling
PROTEUS	Plateforme Reconfigurable pour l'Observation, les Télécommunications et les Utilisations Scientifiques
PSLV	Polar Satellite Launch Vehicle
PSMOS	Planetary Scale Mesopause Observing System
PSRDC	Panel on Space Research in Developing Countries
PW	Precipitable Water
QBO	Quasi-biennial Oscillation
QPF	Quantitative Precipitation Forecast
QUELD	Queen's University Experiment in Liquid Diffusion
RADARSAT	Radar Satellite
RADIO ASTRON	Observatory with antenna for orbiting VLBI
RIS	Retroreflector in Space
RITSI	Radiative Ignition and Transition to Spread Investigation
ROSAT	Röntgen Satellite (German X-ray satellite)
ROSETTA	Re-scoped version of the original ESA-NASA Comet Sample Return Mission
RPA	Retarding Potential Analyser
S-RAMP	STEP Results and Modelling Phase
SAA	Satellite Active Archive
SAC	Satellite de Aplicaciones Cientificas (Argentina)
SAGE	Stratospheric Aerosol and Gas Experiment

SAMPEX	Solar, Anomalous, Magnetospheric Particle Explorer
SAO	Semi-annual Oscillation
SAR	Synthetic Aperture Radar
SAX	X-ray Astronomy Satellite
SBUV	Solar Backscattered Ultraviolet
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SDL	Space Dynamics Laboratory
SEF	Space Experiment Facility
SESAME	Second European Stratospheric Arctic and Mid-latitude Experiment
SIGMA	Gamma-ray telescope
SIMURIS	Solar Interferometric Mission for Ultrahigh Resolution Imaging and Spectroscopy
SIRTF	Space Infrared Telescope Facility
SMEI	Solar Mass Ejection Imager
SOHO	Solar and Heliospheric Observatory
SOUSY	Sounding System
SPECTRUM X-GAMMA	PI mission for spectroscopy, imaging monitoring and polimetry of X-ray sources
SPECTRUM-UV	Optical/UV telescope for spectroscopy and wide field imaging
SPIRIT III	A cryogenically cooled infrared sensor
SPOT	Satellite Probatoire d'Observation de la Terre
SQUID	Superconducting Quantum Interference Device
SROSS	Stretched Rohini Satellite System
SSCE	Solid Surface Combustion Experiment
SSIES	Ionospheric Plasma Orbit/Scintillation Monitor
SSM/I	Special Sensor Microwave Imager
SSM/T	Special Sensor Microwave Temperature
SST	Sea Surface Temperature
ST	Stratosphere-Troposphere
STEP	Solar Terrestrial Energy Program
STEP	Satellite Test of the Equivalence Principle
STIS	(SC E)
STP	Solar-Terrestrial Physics
STS	Space Transportation System
SWAS	Submillimeter Wave Astronomy Satellite
SWIR	Short Wave Infrared Radiometer
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment
TDRSS	Telemetry and Data Relay Satellite System
TFA	Task Force Activity
TIFR	Tata Institute of Fundamental Research (India)
TIME	Thermosphere-Ionosphere-Mesosphere Explorer
TIMED	Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics
TIROS	Television and Infrared Operational Satellite
TMI	TRMM Microwave Imager
TOMS	Total Ozone Monitoring Scanner

TOPEX/POSEIDON	Oceanic Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TPW	Total Precipitable Water
TRACE	Transition Region and Coronal Explorer
TRMM	Tropical Rainfall Measurement Mission
TTC	Tracking, Telemetry and Command
TWAS	Third World Academy of Sciences
UARS	Upper Atmosphere Research Satellite
UHF	Ultra High Frequency
ULYSSES	A joint ESA/NASA heliospheric mission
UN	United Nations
UN-COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UN-ESCAP	UN Economic and Social Commission for Asia and the Pacific
URSI	International Union of Radio Science
USAF	United States Air Force
USML	United States Microgravity Laboratory
USMP	United States Microgravity Payload
UTC	Universal Time Conversion
UV	Ultraviolet
UVVISI	Visible UV Imager/Spectrometer System
VDA	Vapour Diffusion Apparatus
VHF	Very High Frequency
VIRS	Visible Infrared Scanner
VIS	Visible
VISSR	Visible and Infrared Spin Scan Radiometer
VLBI	Very Long Base Interferometry
VNIR	Visible and Near-Infrared Radiometer
VSOP	VLBI Space Observatory Program
WAAS	Wide Area Augmentation System
WDC	World Data Centre
WEFAX	Weather Encoded Facsimile Transmission
WGCV	Working Group on Calibration and Validation
WiFS	Wide Field Sensor
WIM	Windows Image Manager
WIND II	Wind Imaging Interferometer
WIND	NASA spacecraft to study solar wind and terrestrial plasma
WMO	World Meteorological Organization
WTR	Western Test Range
WWW	World Wide Web
XMM	X-ray Multi-Mirror
XTE	X-ray Timing Explorer
XUV	X-ray and far Ultraviolet