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SATELLITE SYSTEMS FOR CARTOGRAPHY

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Worldwide experience by many individuals and organizations with remote sensing data acquired from space, primarily Landsat-1, -2, and -3, has demonstrated the utility for land-use classification, agricultural assessment, energy and resource exploration, and many other applications. There has been some reluctance to adopt these procedures in operational programs because of a lack of assured continuity of data collection, continuing changes in the systems, and some dissatisfaction with the types of data made available to users. Nevertheless there is sufficient conviction of the value of satellite remote sensing so that new systems will be developed by several countries in the decade of the 1980's.

Major Developments in the United States

In the United States there are several fundamental technological developments which will impact remote sensing in the future. The first and by far the largest of these is the development of the Space Shuttle. The major advantage of the Shuttle is that its principal component, the orbiter vehicle, can be returned to Earth and be reused on successive missions. The first flight of the Shuttle, April 12-14, 1981, was a complete success. The orbiter vehicle is about the size of a DC-9 aircraft. As shown in figure 1, the back of the vehicle opens up to a cargo bay which is 18.3 meters long, and 4.6 meters in diameter. Manned modules and instrument pallets can be installed in this cargo bay and operated while the Shuttle is on sortie missions in space. Initial launches of the Shuttle will be due east from Cape Canaveral permitting coverage from latitudes 30° north to latitudes 30° south. Due to range safety conditions, the maximum orbit inclination available from Cape Canaveral is 57° which provides coverage of most of the world's populated areas. Polar orbits for the Shuttle will not be available until

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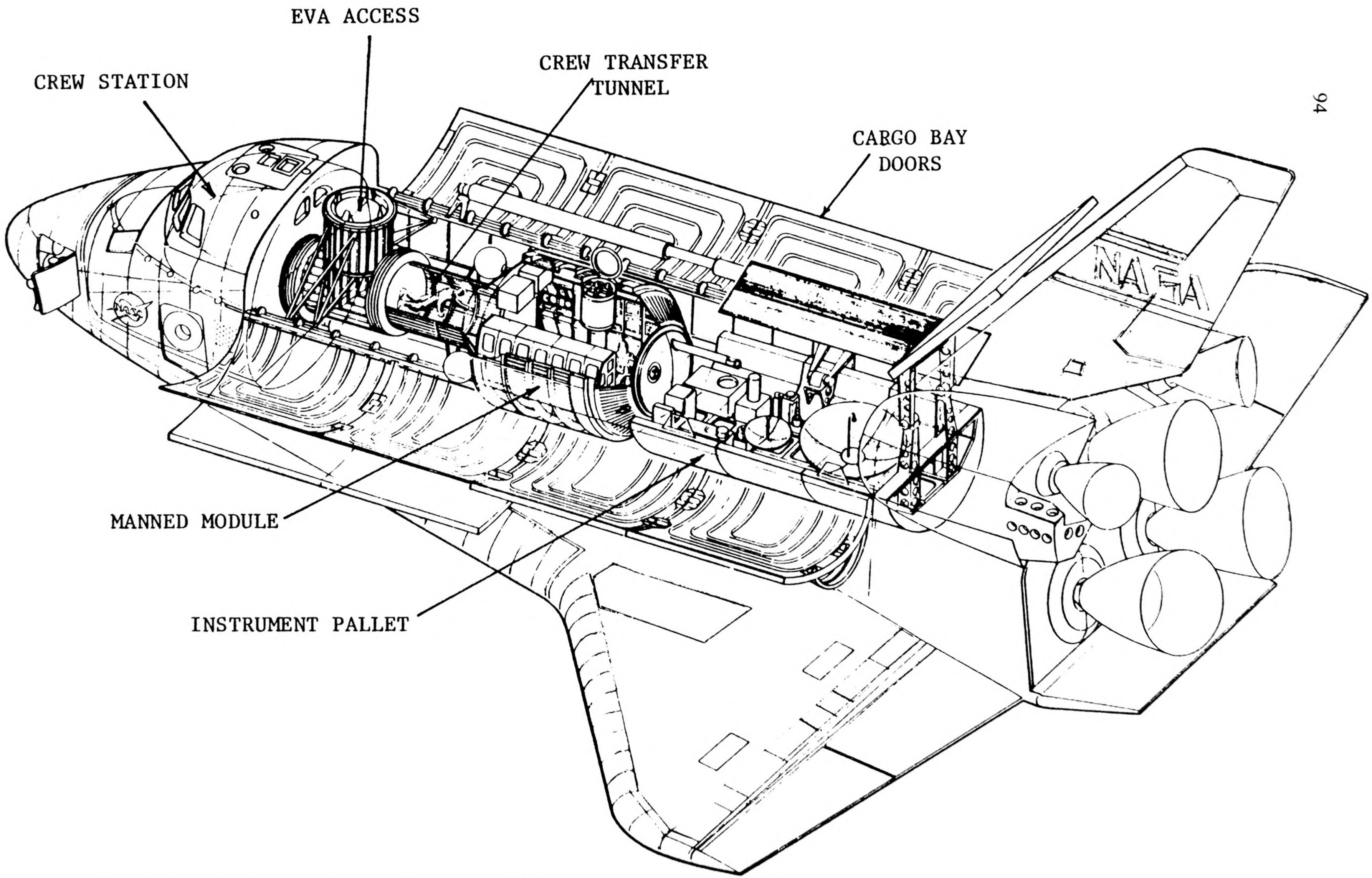

FIG. 1. – The cargo bay of the Space Shuttle Orbiter can be equipped with manned laboratory modules and pallets for mounting instruments in the open space environment.

after 1984 when the Western Test Range should become operational. Shuttle missions will be designated as STS (Space Transportation System) followed by the sequential flight number.

The second major development in the United States is the Multimission Modular Spacecraft (MMS), shown in figure 2. The MMS consists of a central core to which can be attached modules for power supply, attitude control, and command and data handling. There is a propulsion module to provide in-orbit maneuvering, and an adapter between the spacecraft and its payload. The assembled spacecraft may be fitted with solar panels and various antennas for communications. The MMS is specifically designed for launch and retrieval by the Shuttle using a long articulated arm referred to as the Remote Manipulator System (RMS). Insofar as possible, the MMS will be used as the basic vehicle for all future unmanned missions in low Earth orbit.

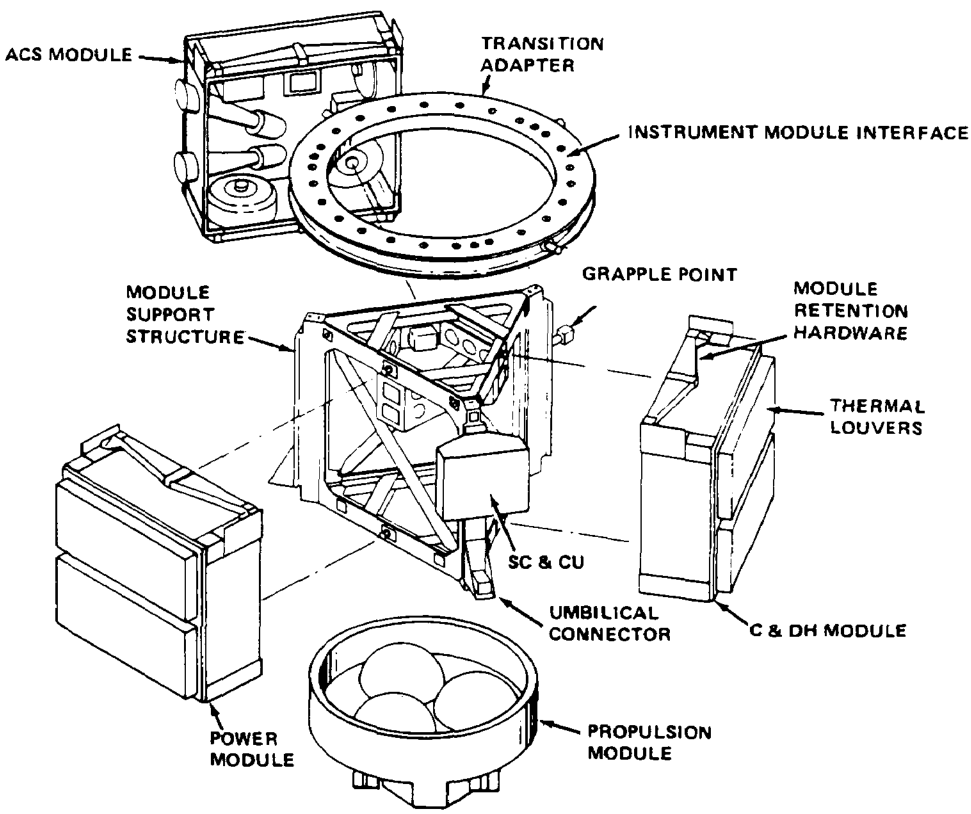

FIG. 2. – The Multi-mission Modular Spacecraft (MMS) contains modules for attitude control system (ACS), command and data handling (C and DH), spacecraft power supply, and orbit propulsion.

The third major development is the Tracking and Data Relay Satellite System (TDRSS). As shown in figure 3, TDRSS will consist of two communication satellites and a single ground station located in White Sands, New Mexico. Commands from the ground to manned and unmanned spacecraft will be sent first to the TDRSS and then to the spacecraft. Similarly, data collected by spacecraft in low Earth orbit will go to the TDRSS and be retransmitted to the ground station. The two TDRSS satellites will be located in geosynchronous orbit at 41° west longitude and 171° west longitude. From these positions they provide nearly complete coverage of the Earth. There is however a zone of exclusion over the Indian Ocean and extending up into the U.S.S.R. The size of this zone depends upon the altitude of the spacecraft being serviced by the TDRSS. The TDRSS spacecraft will be launched by the Shuttle, and full operation with two spacecraft is expected by mid-1983.

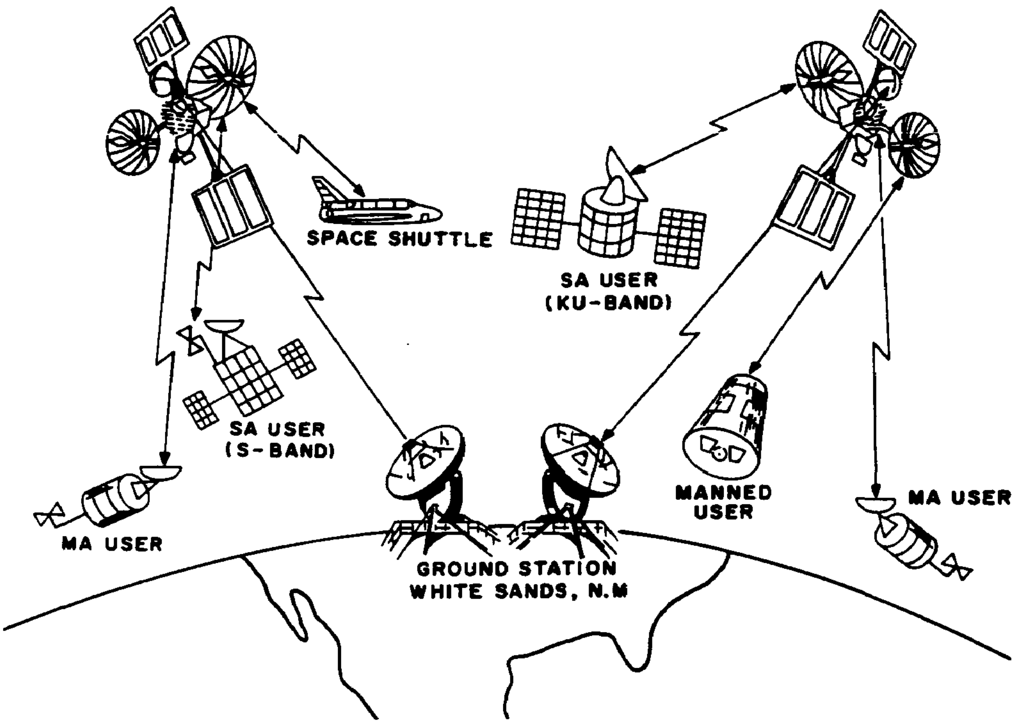

FIG. 3. – The two geosynchronous spacecraft of the Tracking and Data Relay Satellite System (TDRSS) will provide multiple access (MA) data links for low volume and single access (SA) data links for high volume user spacecraft in low Earth orbit.

The fourth major development is a second generation multispectral scanner called the Thematic Mapper (TM). It will have six spectral bands in the visible and short wavelength infrared with a 30 meter IFOV, and one band in the thermal infrared with 120 meter IFOV. It is designed for an operating altitude of about 700 km and will provide a swath width of 185 km, the same as Landsat-1, -2, and -3. It has data rate of 85 megabits per second.

The final major development is the Global Positioning System (GPS) which will eventually consist of an array of 18 separate satellites arranged in three different orbital planes. From any place on Earth or in low Earth orbit, a minimum of four spacecraft will always be visible. By real-time processing of the signals from the GPS it will be possible to establish the position of a vehicle on the ground or in space with a precision of a few meters in all three coordinates.

Policy Decisions

In the last several years the United States has conducted inter-agency studies which resulted in major policy decisions with regard to satellite remote sensing. These decisions are:

a) The Space Shuttle will replace all expendable launch vehicles.

b) All spacecraft data transmission will use the TDRS System, and the existing NASA ground receiving station network will be phased out.

c) Responsibility for operational Earth observation satellites is assigned to the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce.

d) The prices for satellite data to users will assure maximum recovery of the total system cost, rather than simply the cost of data reproduction and distribution as at present.

e) Commercial ownership and operation of Earth observation satellite systems is the eventual goal.

These decisions have been reviewed by the Reagan Administration. The major emphasis has been to move more rapidly towards cost recovery and commercial ownership and operation. These policies will obviously have major impact on the future of U.S. space remote sensing systems.

Landsat-D

These technical developments and policy decisions come together in the plans for Landsat-D. The Multi-mission Modular Spacecraft will be launched by the Delta 3920 expendable vehicle into a 705 km, near-polar, sun-synchronous orbit. As shown in figure 4, the payload will be the TM, and a Multispectral Scanner (MSS) which is nearly the same as that on Landsat-1, -2, and -3. The spacecraft will have solar arrays for power, an antenna for use with the Global Positioning System, and a large steerable antenna for communication with the Tracking and Data Relay Satellites. No on-board tape recorders are provided for either the MSS or the TM. In operation the two sensors will record simultaneously – the MSS with an 80 meter pixel and the TM with a 30 meter pixel. When within range of a ground station equipped to receive it, data can be transmitted directly – MSS data on S-band at 15 Mbits/s and TM data on X-band at 85 Mbits/s. At all other times data will be relayed to the TDRSS and from there back to the ground station at White Sands. After some preliminary processing it will then be relayed by domestic communication satellite to Goddard Space Flight Center for product generation.

The currently operating Landsat-2 and -3 are beginning to show signs of failure. In order to assure data continuity, the current plan (May 1981) is to launch Landsat-D from Cape Canaveral in the third quarter of 1982. It will carry both the MSS and the TM, but NASA retains the option to launch Landsat-D without the TM if there should be further problems with the instrument.

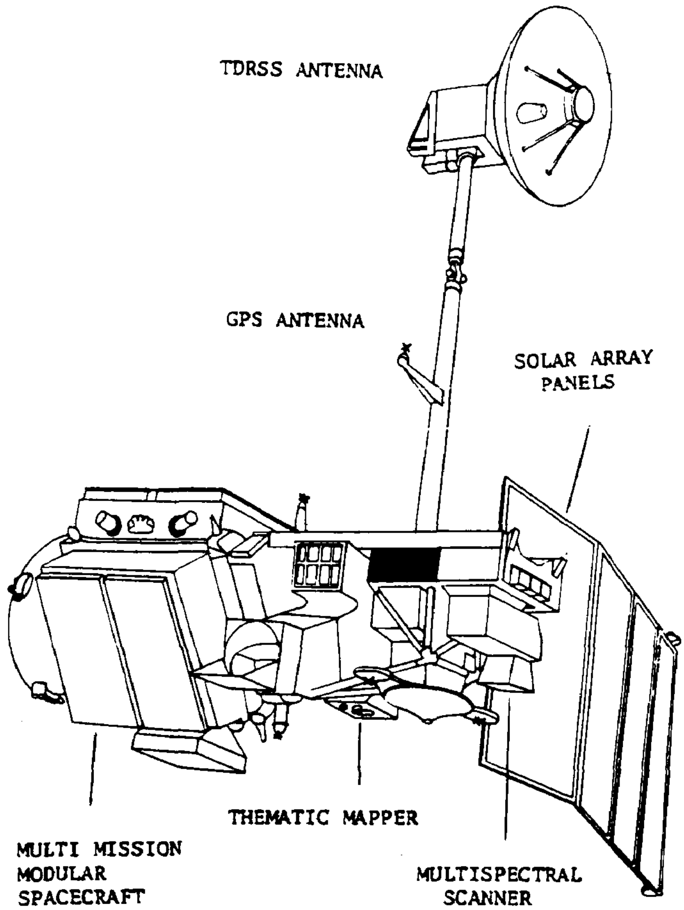

FIG. 4. – Landsat-D will use the Multi-mission Modular Spacecraft to carry the Multi Spectral Scanner (MSS) and the Thematic Mapper (TM) with antennas for communication with Tracking and Data Relay Satellite System (TDRSS) and the Global Positioning System (GPS).

MSS data will be transmitted on S-band directly to GSFC and to foreign stations. Because of the lack of on-board tape recorders, NASA will provide tape recorders at selected foreign receiving stations from whence the data can be transmitted to GSFC for processing. GSFC will transmit high density digital tape data (HDDT) via domestic communication satellite (DOMSAT) to the EROS Data Center at Sioux Falls, South Dakota. EDC will produce both film and computer compatible tapes (CCT's) for distribution to users. The MSS ground processing system at GSFC should have the capability to process 200 scenes/day by the first quarter 1983. At that time NOAA will assume responsibility for command and control of the spacecraft and distribution of MSS data.

Initially TM data will be transmitted on X-band directly to the ground station at GSFC. No foreign ground stations are currently configured to receive and process the 85 Mbit/sec X-band data, though several have indicated their intention to do so. The separate TM processing system at GSFC will be operated by NASA, initially on an experimental basis producing 1 or 2 scenes/day by first quarter 1983. It should reach 12 scenes/day by first quarter 1984, and full capacity of 50 scenes/day by 1985. GSFC will produce both film and CCT products. EDC will receive film from GSFC and will supply photographic products to users, but CCTs will be supplied directly by GSFC. NOAA will assume operational responsibility for TM data when full capacity of the ground processing system has been adequately demonstrated.

An identical spacecraft, Landsat-D prime, will be ready for launch about one year after Landsat D. It is hoped to add wide band video tape recorders for the MSS on this spacecraft, but funds have not yet been provided for this modification. According to present plans the spacecraft will not be launched until Landsat-D begins to fail. Since the specification lifetime for the TM is two years and for the MMS is three years, this plan should provide data through 1986 to 1988. By that time NOAA is expected to have reached an agreement for commercial operation of the Earth observation satellite system. Both Landsat-D and -D prime are equipped for recovery and possible relaunch by the Shuttle, but at the moment there are no plans to do this, because of the prospect of commercial operation using a different system configuration. NOAA has proposed that they be authorized to operate the system if an acceptable contract cannot be reached with a commercial venture, but this has not yet been approved, and no Federal funding is anticipated after Landsat-D and -D prime.

Space Transportation System, Mission 2

The second Shuttle mission STS-2, now scheduled for September or October 1981, will carry an Earth observation payload package called OSTA-1, developed by the NASA Office of Space and Terrestrial Applications. As shown in Figure 5, the major components will be mounted on a pallet carried in the cargo bay. The instruments are:

SMIRR – Shuttle Multispectral Infra-Red Radiometer

A telescope, rotating filter wheel, and detector will record surface reflectivity in 10 spectral bands between 0.5 and 2.5 μm with 100 m IFOV to evaluate their effectiveness for geologic classification. Two 16 mm film cameras, black/white and color, will record the scene, and the data will be correlated post-flight with field spectrometer data.

MAPS – Measurement of Air Pollution from Satellites

This is a gas filter correlation radiometer for measurement of carbon monoxide concentration in the troposphere.

OCE – Ocean Color Experiment

A rotating mirror imaging scanner with a 3 km IFOV, 550 km swath, and 8 spectral bands between 0.49 and 0.79 μm will be used to determine chlorophyll concentration as a measure of ocean bioproductivity.

FILE – Feature Identification and Location Experiment

The objective of this experiment is to develop the eventual capability of on-board classification of terrain features. The output of 2 TV cameras – one in the visible red and the other in the near infrared – will be

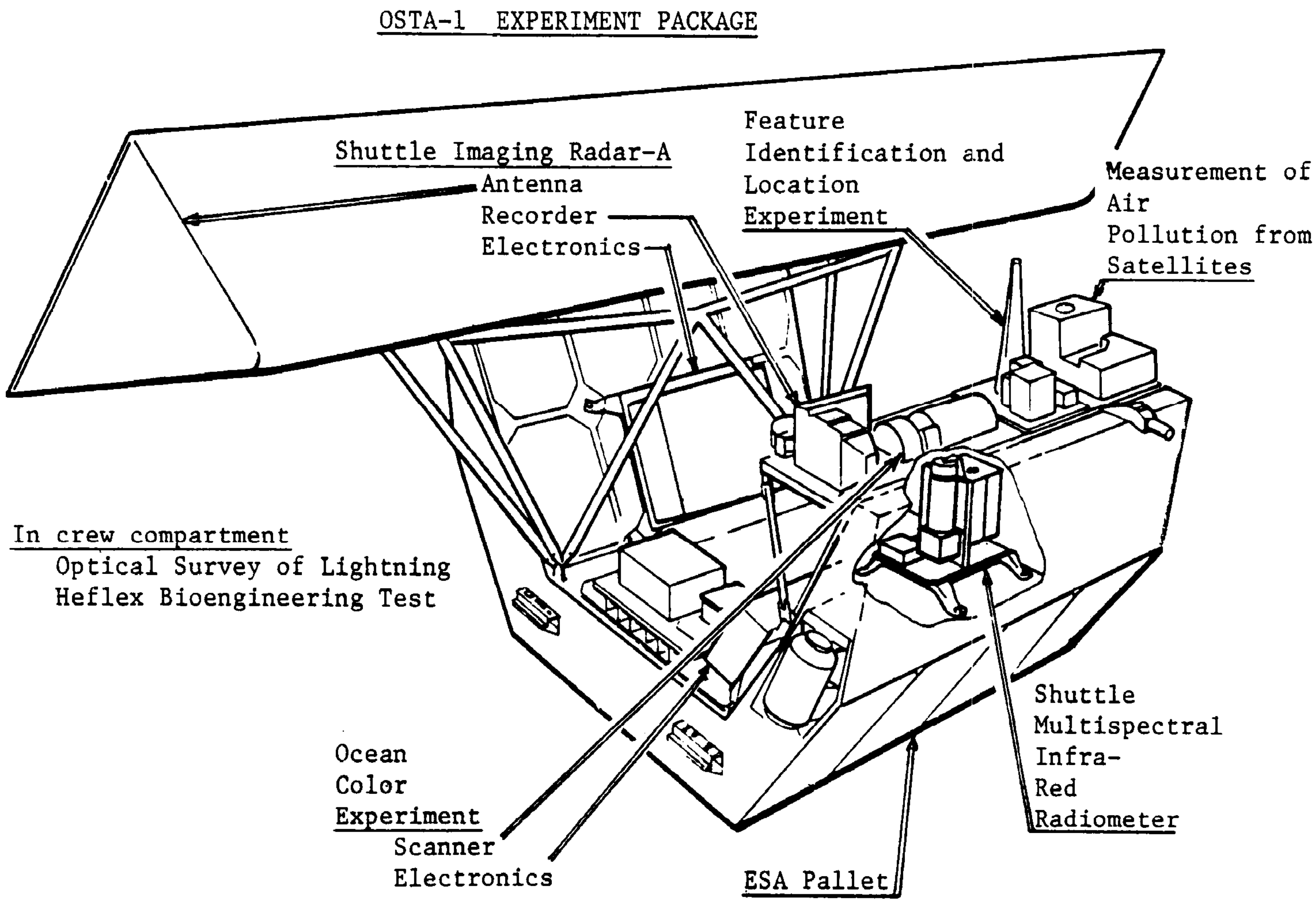

FIG. 5. – The Office of Space and Terrestrial Applications (OSTA-1) remote sensing experiment package will be mounted on a pallet to be carried in the cargo bay of the second Shuttle mission (STS-2) in September-October 1981.

ratioed to determine scene classes. A 70 mm film camera will take a color photograph for post-flight comparison with each TV frame.

SIR-A – Shuttle Imaging Radar

A modification of the Seasat synthetic aperture radar will provide a 47° look angle, 56 km swath, and 40 m resolution. The data will be optically recorded on film. The primary application will be interpretation of geologic structures.

Operated from the crew compartment will be another experiment called NOSL-Night/Day Optical Survey of Lightning. It consists of a hand-held 16 mm motion picture camera and a photocell for recording lightning flashes associated with severe thunderstorms.

The STS-2 mission will be 4 days duration in a 275 km orbit at 40.3° inclination.

NASA is also studying another radar for the Shuttle. It will employ a folded antenna mounted on a pallet at the rear of the cargo bay. The system would be designed to investigate the effect of various radar parameters – look angle, wave length, and polarization. It would produce a data rate of 150 megabits per second and major study items have to do with how this data should be handled – by TDRSS, onboard tape recorders, or onboard film. No flight mission has yet been designated for this sensor.

Experimental Electro-Optical Sensors

One of the most promising imaging sensors is the linear array of detectors. These arrays consist of several thousand elements, and they can be butt-joined to provide more than 10,000 detectors per line. An optical system images a line from the ground scene to the line of detectors. Ground resolution in the cross track direction depends upon the ratio of optical system focal length to flight altitude, and in the along-track direction it depends on the time in which the signals can be recorded as the vehicle moves along the orbit.

NASA has undertaken several studies of possible sensor instruments using this concept. Currently under way (March 1981) is the MLA (Multispectral Linear Array) Instrument Definition Study in support of an eventual Operational Land Observing System (OLOS). The study proposes use of the MMS launched by Shuttle into a Landsat-D orbit. The sensor instrument would provide six spectral bands in the visible and short wave infrared. Five of these would have 30 m IFOV and one in the red would have 15 m IFOV for recording cultural features. The optical system would provide ±26° fore-and-aft stereo viewing, and ±30° across track pointing for missed scene recovery. The data rate would be 200 M bits/sec with onboard storage and data compression, transmission direct to ground and via TDRSS. NASA hopes to have an experimental demonstration instrument available for flight on the Shuttle or an independent spacecraft by about 1988, with operational capability about 1990.

Other Proposed U.S. Systems

Some users of satellite remote sensing data, concerned about the technical or economic viability of systems as complex as Landsat-D, or with foreseen requirements for specialized data types, have undertaken studies of other proposed systems. The U.S. Geological Survey has completed a study contract for a system called Mapsat which would provide data adequate for compilation of 1:50,000-scale maps with 20 meter contour interval. The orbit would be the same as Landsat-1, -2, and -3. Three Multispectral Linear Arrays would look in the vertical and ± 26° fore and aft to provide stereo data. Each array would have three spectral bands and have a minimum 10 meter IFOV, but the information could be clustered by on-board processing to provide lower resolution at multiples of the 10 meter IFOV. On-board compression and selected acquisition would reduce the average data rate to 15 megabits per second which is compatible with the existing worldwide network of Landsat ground receiving stations. A highly stable spacecraft would permit a simple algorithm to be employed in the ground data reduction for correlating the stereo records in order to produce digital elevation data. Mapsat is not an approved program, and has no funding beyond the feasibility study.

A somewhat similar concept called Stereosat had its origin in the requirements of the geologic community for stereo data. The vertical, fore, and aft looking linear arrays would be panchromatic with multispectral data to come from the Landsat series. Stereosat would use the Multimission Modular Spacecraft and be launched from the Western Test Range by the Shuttle into the same orbit as Landsat-D. It would have a 15-meter IFOV and a 61.4 km swath. Like Mapsat, Stereosat has not been approved or funded beyond the study phase.

With the successful operation of Seasat unfortunately terminated by spacecraft failure after only three months, there was considerable interest in a follow-on system for ocean surveillance. NASA, NOAA and the Department of Defense cooperated in preliminary studies of a National Oceanic Satellite System (NOSS). The proposed system would have used the Multi-mission Modular Spacecraft, launched by the Shuttle, to carry an array of scatterometers, altimeters, and radiometers for recording ocean surface and wind conditions. Notable by its absence was a synthetic aperture radar, such as was carried on Seasat.

Another interagency study group sponsored by NASA was concerned with the problems of monitoring snow and ice conditions in the polar regions. They proposed an Ice and Climate Experiment (ICEX) satellite with a payload similar to NOSS, but in addition it would carry an X-band synthetic aperture radar capable of 100 m resolution over a 360 km swath. In the current climate of budget austerity, both NOSS and ICEX have been dropped from further consideration.

The Large Format Camera

One Shuttle payload sensor system which has already been built is the Large Format Camera (LFC). The essential parameters of the camera are a

30.5 cm focal length with a 23 × 46 cm format. The camera has automatic exposure sensor and forward motion compensation, permitting use of high resolution fine grain film. The magazine has capacity for 2,400 frames. A ground resolution of 10 to 15 m can be obtained from nominal Shuttle altitudes. The LFC is presently scheduled for flight on STS-26 in mid-1984. The primary role of this mission is to launch three communications satellites, which forces the Shuttle into a 28.5° inclination at 296 km altitude. After that objective has been accomplished the Shuttle will remain in orbit for about six days to exercise the OSTA-3 payload, shown in figure 6. This will consist of the MPE (Mission Peculiar Equipment) support structure, which, in addition to the LFC will carry the FILE, SMIRR, and MAPS experiments from OSTA-1.

Short duration, low inclination, manned missions are not optimum for photography or other forms of remote sensing since U.S. coverage can be obtained only for southern Florida and Texas. For this reason negotiations are under

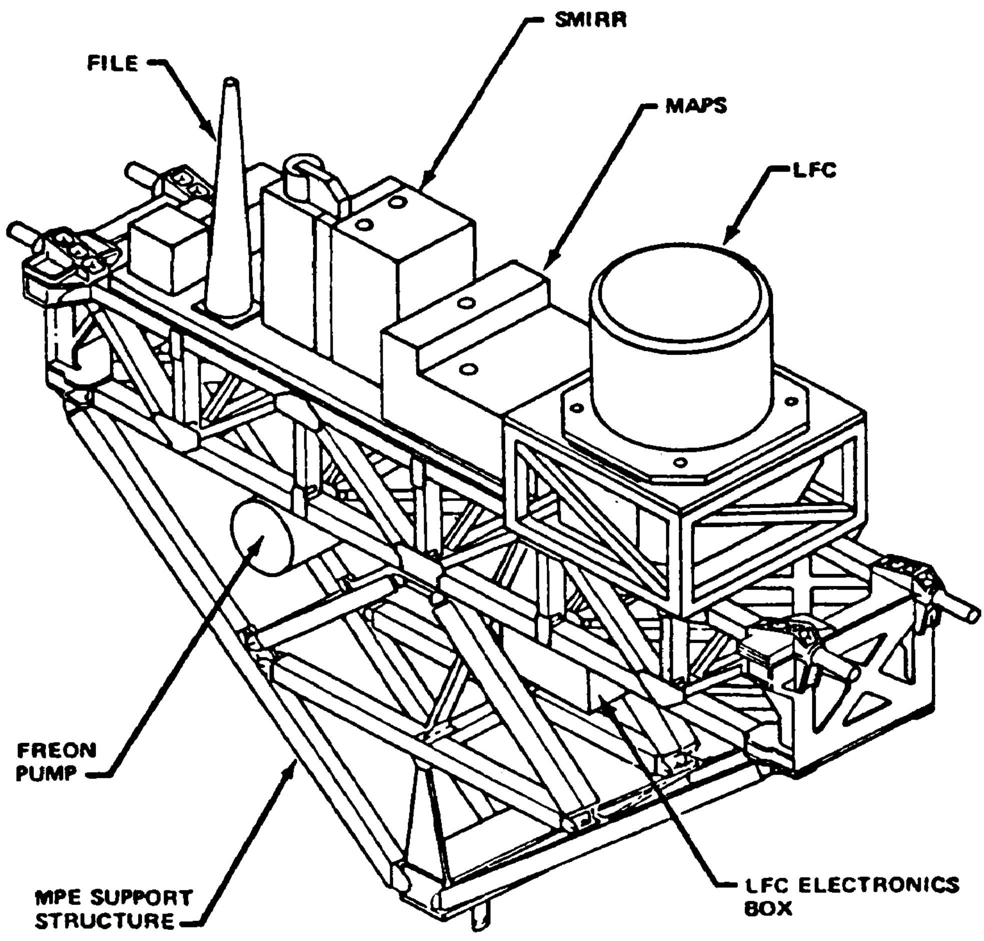

FIG. 6. – The principal sensor on the OSTA-3 payload for STS-26 will be the Large Format Camera (LFC) mounted on the Mission Peculiar Equipment (MPE) support structure in the Shuttle cargo bay.

way to get an earlier mission with a higher inclination more suitable for extended coverage. There has also been some discussion with an industrial consortium about lease-back of the camera and paying for reflights on additional Shuttle missions to develop a worldwide data base of high resolution stereo photography.

The MKF-6 Camera System

The Russian manned spacecraft, Salyut 6, has been in a 260 km 65° inclination orbit for more than three years. Among the other instruments aboard is the MKF-6 Multispectral Camera System. Exposed film is recovered and new supplies are brought to Salyut by the Soyuz and Progress spacecraft. The system is comprised of six separate cameras of 125 mm focal length and 55 × 81 mm format, equipped with appropriate filters. It provides ground resolution up to 20 meters. The configuration is roughly comparable to the S-190A system carried on the American Skylab. Higher resolution imagery is acquired because of the lower orbital altitude. An additive color viewer and printer has been designed for use with the MKF-6 camera. Excellent results can be produced in black and white, conventional color, and color infrared response. The U.S.S.R will acquire photography for other nations under bilateral agreements.

Spacelab

A major approved Shuttle payload is Spacelab, which is a joint venture between the European Space Agency (ESA) and NASA. It is presently scheduled for launch on STS-10 in May 1983. The payload will consist of both manned experiment modules and pallets for other instruments. Operating through a window in the manned module will be the Metric Camera experiment, which is essentially a standard Zeiss aerial camera with 30 centimeter focal length and 23 × 23 centimeter format. From the anticipated 250 km altitude these pictures will cover an area of 190 × 190 km, with a ground resolution of approximately 20 meters.

This camera is Phase A of the ATLAS camera development program conducted by the West German Research Agency (Deutsche Forschungs-und Versuchsanstalt für Luft und Raumfahrt - DFVLR). Under Phase B consideration is being given to:

1°) Adding image motion compensation to this camera and mounting it on the exterior pallet;

2°) Using a similar camera but with 60 cm focal length and image motion compensation;

3°) Developing a new high resolution camera with image motion compensation for mounting in the manned module.

Under Phase C consideration is being given to mounting the camera system on free-flying satellites which will operate independent of the Spacelab.

Also being built by DFVLR for Spacelab is the Microwave Remote Sensing Experiment (MRSE). This consists essentially of a parabolic reflector, a subreflector, and a feed horn. The instrument can operate as a two-frequency scatterometer to measure ocean wave spectrum, as a passive thermal radiometer to measure surface temperature with sensitivity of ± 1° k, or as a synthetic aperture radar providing 25 meter resolution over a 9 km swath.

There will be subsequent Spacelab missions with various objectives such as life sciences and materials processing. One of these has been designated for Earth and atmospheric observations and a tentative selection of payload instruments has been made. The Earth observation instruments would include the Metric Camera and Microwave Remote Sensing experiments from Spacelab-1, a multispectral linear array camera operating in the visible wavelengths, an optical-mechanical scanner operating in the near and thermal infrared wavelengths, and a synthetic aperture radar. This instrument selection may be changed before the launch date presently planned for 1984-85.

The SPOT Program

The Centre National d'Etudes Spatiales (CNES) in France is developing the Systeme Probatoire d'Observation de la Terre (SPOT). This spacecraft, shown in figure 7, will be launched in 1984-85 by the ESA Ariane expendable launch vehicle into a sun-synchronous orbit at 822 km altitude. Mission control and data processing will be at Toulouse, France. The payload will consist of two high-resolution optical systems (HRV) with linear array detectors. It can operate in a three-band multispectral mode with 20 meter IFOV, or in the panchromatic mode with 10 meter IFOV. A rotating mirror will permit the scene to be acquired from areas up to 400 km left or right of the spacecraft as well as in the vertical, thus permitting side-to-side stereodata acquisition and more frequent looks at high priority scenes. CNES is considering a commercial contractor for dissemination of products. CNES also plans to configure the Toulouse ground station to receive TM data from Landsat-D.

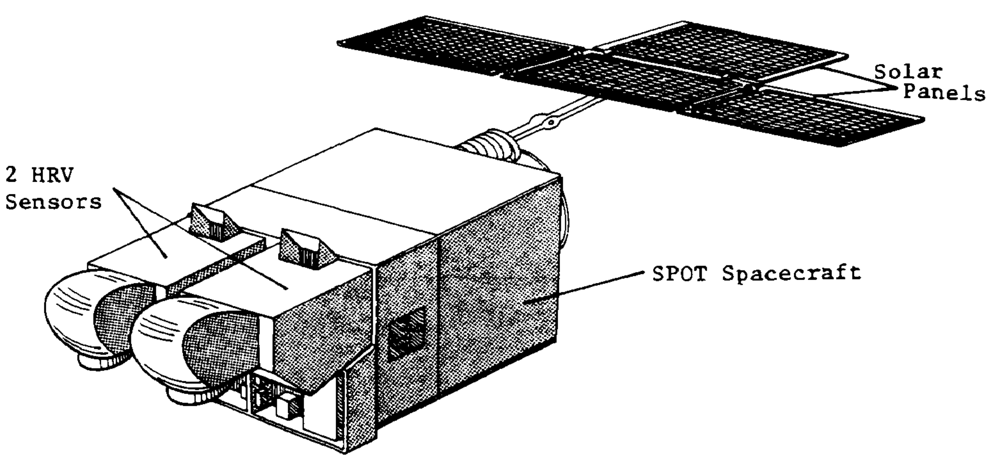

FIG. 7. – The Système Probatoire d'Observation de la Terre (SPOT) being developed by the Centre National d'Etudes Spatiales in France will use a standard spacecraft and two Haute Résolution Visible (HRV) sensors.

Other ESA Programs

A principal concern of ESA has been the development of the Ariane expendable launch vehicle. The first launch in December 1979 was an outstanding success. The second launch in May 1980 failed because of an engine misfire, but the vehicle is expected to be available for operational use by 1982.

ESA has also received several proposals for a standard spacecraft somewhat comparable to the NASA Multimission Modular Spacecraft. The current plan is to adopt the SPOT spacecraft being developed by the French CNES.

ESA has committed to the development and launch of a European remote sensing satellite. After extensive consultation with potential data users, an advisory Remote Sensing Work Group was formed, and contracts were given to industry to establish requirements and propose spacecraft and sensor configurations. Two concepts emerged: a Coastal Ocean Monitoring Satellite System (COMSS), and a Land Applications Satellite System (LASS). The objective of COMSS would be to provide fundamental data for oceanography, glaciology, and climatology. The objective of LASS would be to provide data for crop inventory and yield prediction, monitoring of forest productivity, land use classification, water resources inventory and monitoring, and mineral and energy resources exploration.

Contemporary with these system studies, industrial organizations have undertaken design or development of several candidate sensor systems. Among these are a Modular Opto-electrical Multispectral Scanner (MOMS), using linear arrays of detectors which will operate in the visible, near infrared, and eventually thermal infrared wavelengths, an Imaging Microwave Radiometer (IMR), a multichannel Ocean Color Monitor (OCM), and several versions of Synthetic Aperture Radar (SAR). The MOMS, and perhaps some of the other instruments, will be carried on test flights aboard the Shuttle, before being incorporated in the free-flying spacecraft.

The objectives of COMSS and LASS have been combined into a single spacecraft called ERS-1 (Earth Resources Satellite-1). It will use the SPOT spacecraft launched by Ariane about 1984-85 into a 650 km near-polar, sun-synchronous orbit. The sensors will be:

- SAR with 30 m resolution and 100 km swath;
- OCM with 10 spectral bands between 0.4 and 11.5 μm;
- IMR operating in 6 frequencies;
- Scatterometer (2 frequency) for wind direction and velocity;
- Radar altimeter for sea state determination.

The total data rate will be 117 Mbit/sec to the ESA Earthnet receiving stations.

Other National Systems

In Japan the Science and Techology Agency has undertaken an extensive study program for Marine Observation Satellites (MOS) and Land Observation

Satellites (LOS). The first spacecraft, MOS-1, would carry a Multispectral Electronic Self-Scanning Radiometer (MESSR) to measure sea surface color with a 50 meter IFOV for a 100 km swath in four spectral bands between 0.51 and 1.10 μm. A Visible and Thermal Infrared Radiometer (VTIR) would measure sea surface temperature over a 500 km swath with one band in the visible providing 0.9 km IFOV, and three bands in the infrared between 6.0 and 12.5 μm providing 2.6 km IFOV. The third instrument would be a 2 frequency Microwave Scanning Radiometer (MSR) to measure atmospheric water content. The spacecraft would be launched from Tanegashima about 1984-85 into a 909 km, 99.1° inclination orbit.

The second spacecraft, LOS-1, would have a payload consisting of: two linear array panchromatic cameras with 25 m IFOV to provide stereo coverage over a 50 km swath; a Visible and Near Infrared Radiometer (VNIR) using linear arrays in four spectral bands from 0.45 to 1.10 μm with 25 m IFOV and 200 km swath for land cover classification; a Visible and Infrared Radiometer (VIR) mechanical scanner with 50 m IFOV and 200 km swath for five bands in the visible and shortwave infrared and one band with 150 m IFOV in the thermal infrared for vegetation and geology; an 8-channel Infrared Sounder with 25 km IFOV and 750 km swath to provide atmospheric correction. This spacecraft would be launched from Tanegashima about 1987 into a 700 km sun-synchronous orbit.

The Japanese Ministry of International Trade and Industry (MITI) prepared a separate study for a Mineral and Energy Resources Exploration Satellite (MERES). Its sensor payload would include: a linear array stereo camera with 30 m IFOV in five spectral bands between 0.51 and 1.10 μm; a mechanical scanner Infrared Radiometer with two bands of 50 m IFOV between 1.3 and 2.5 μm, and two thermal bands of 130 m IFOV between 10.5 et 12.5 μm; an L-band synthetic aperture radar with 25 m resolution.

The National Space Development Agency (NASDA) is evaluating these studies and will decide upon the actual configurations to be built.

The Indian Space Research Organization (ISRO) developed an Earth observation spacecraft "Bhaskara" which was launched by the U.S.S.R. in June 1979 into a 550 km, 51° inclination orbit. It carried 2 TV cameras providing 1 km resolution in two spectral bands for land observation, and three microwave radiometers for ocean survey. One TV camera and two radiometers are still operating (November 1980). A second Bhaskara is planned for launch in 1981. ISRO has also annouced its intention to develop a second generation Satellite for Earth Observation (SEO) and is negotiating with both NASA and the U.S.S.R. for launch service.

The Netherlands Agency for Aerospace Programs (NIRV) has initiated a study of a remote sensing satellite which would carry a Dutch built multispectral linear array sensor in a near equatorial orbit. The project is being planned in cooperation with Indonesia where the ground data reception station will probably be located. The sensor parameters will be specifically selected for the weather conditions and vegetation types in equatorial areas.

The Canadian Centre for Remote Sensing (CCRS) conducted a study program to determine the applicability of the data from the NASA Seasat to the monitoring of ice conditions in the polar seas. The study concluded that the essential sensor is a synthetic aperture radar (SAR) capable of producing 25 to 30 m resolution for a swath width of approximately 100 km. Beginning in 1980, CCRS has undertaken a two-year study program to develop the operational parameters for a C-band radar which would meet these requirements. The study will include the mission and orbit parameters and the ground processing capabilities. The program might entail two or three satellites in orbit simultaneously to provide the necessary coverage for adequate monitoring of the arctic seas and coastlines. At the moment Canada does not envision its own launch program, but is negotiating with NASA and ESA on the terms of a cooperative agreement to fly the radar.

The Space Research Institute (INPE) in Brazil has published its intention to develop a national remote sensing satellite which might be launched in 1985 or 1986. The sensors would include a multi-spectral linear array and a high resolution panchromatic camera, but no details have been released.

The People's Republic of China has announced its intention to develop a comprehensive space program including Earth Observation Satellites. No detailed information is currently available on this program.

CONCLUSION

It is evident that there is a great deal of near duplication in the various proposals for future Earth observation satellites. Minor differences in orbit parameters, number and limits of spectral bands, resolution, and swath widths result from the perceptions of research scientists and engineers in the various agencies. There are differing views on how difficult it will be to implement an effective synthetic aperture radar for operation in space. Finally there are different priorities placed upon use of space sensors for agriculture, mineral and energy exploration, environmental monitoring, and marine sciences. But it is inordinately expensive to build and operate space systems, and equally if not more expensive to process, disseminate, and apply the data which can be acquired. Scientists and managers from all countries involved in space activities realize that satellites are inherently international in operation, and have begun to talk to one another about making their systems complementary rather than competitive.

There can be little doubt that the world is faced with global problems as the pressures of population and pollution press against available resources and energy. Many of us believe that remote sensing from space is the most important approach to providing the information required for solving these global problems. Developing the technical, managerial, and political ability to operate such systems is the biggest challenge before us in the next decade.