THE SPACE APPLICATIONS PROGRAM 1974

APPENDICES

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
OFFICE OF APPLICATIONS

WASHINGTON, D.C.

Appendices for

THE SPACE APPLICATIONS PROGRAM 1974

by

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OFFICE OF APPLICATIONS
WASHINGTON, DC 20546

MAY 1974

CONTENT

I. APPENDIX TO CHAPTER III

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Page

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF TABLES

EARTH OBSERVATORY SATELLITE (EOS)

1. EOS SYSTEMS CONSIDERATIONS

To achieve truly low cost system design with direct evolution for in-orbit Shuttle resupply, a modular "building block" approach has been adopted. The heart of the modular "building block" concept lies in the ability to use a common set of nonoptimized subsystems in such a way that a wide variety of missions can be flown with no detrimental impact on performance. By standardizing the mechanical configurations and electrical interfaces of the subsystem modules, and by designing each of them to be structurally and thermally independent entities, it is possible to cluster these building blocks or modules about an instrument system so as to adequately perform the mission without the need for subsystem redevelopments for each mission. This system concept offers the following capabilities:

a. The ability to launch and orbit the observatory by either the Delta, the Titan, or the Space Shuttle.

b. The ability to completely reconfigure the spacecraft subsystems for different launch vehicles.

c. The ability to perform in-orbit resupply and/or emergency retrieval of the observatory.

Optimization of funding is best achieved by flying groups of instruments with a few large launch vehicles. Furthermore, utilizing the relaxation of physical constraints to reduce costs and to permit in-orbit resupply becomes economically very attractive. However, eventual operational use of EOS components must allow user agencies the flexibility of also optimizing their budgets. Therefore, it is vital to keep a smaller EOS a viable option. The launch vehicle for such a spacecraft would be the present Delta 2910.

Through the use of the Space Shuttle round trip and payload rendezvous capabilities it is possible to reduce overall program costs by:

a. Reducing the number of observatories required through in-orbit changeout of instruments, thereby avoiding instrument obsolescence.

b. Extending the life of observatories through in-orbit replacement of malfunctioning and/or degraded spacecraft modular subsystems.

c. The reuse of retrieved observatories through ground refurbishment.

d. The deletion of the necessity for backup observatories to cover launch vehicle or spacecraft failures, by the use of the Shuttle's inherent abort/retrieval capability.

EOS configuration potential can vary from 2400-pound Delta-launched observatories to Shuttle and Titan-launched observatories, weighing well in excess of 6500 pounds. The multiple configuration capability of EOS provides for observatory earth viewing surfaces ranging from 20 ft^2 to over 200 ft^2, depending on the launch vehicles selected.

2. INSTRUMENT POTENTIALS FOR VARIOUS MISSIONS

The EOS Phase A Report was completed in-house by the Goddard Space Flight Center (GSFC) in August 1971. In the course of the study, a number of instruments were identified which could be available for flight late in the 1970's; others were identified which would require a longer development cycle. Some instruments were found to weigh from 350 to over 500 pounds in contrast to the heaviest single instrument flown in the ERTS/Nimbus program which weighed 204 pounds.

Upon completion of the GSFC Phase A Study, its principal results were presented to the Earth Resources Survey Program Review Committee and to the Meteorological Satellite Program Review Board (MSPRB). At the recommendation of these boards NASA established the EOS Mission Review Group (EOSMRG) "to finalize, based on discipline objectives and user agency requirements the mission objectives and sensor performance specifications for the first two missions (EOS-A and -B) and to formulate requirements for the management of the EOS data".

3. EOS APPLICATIONS

Typical applications which were considered by the EOSMRG are outlined in Table 1. Here, however, the emphasis is placed on the overall EOS requirements regarding information extraction and dissemination to users. In

TABLE 1. TYPICAL EOS APPLICATIONS

	Potential Users	Observables	Information Extraction	Data Dissemination	Models	Ancillary Data Needs
Sea Surface Roughness	Shipping Industry, NOAA, U.S. Navy	Active and, to some degree, passive microwave reflected in ocean wave spectrum.	Derivation from return signal of ocean wave spectrum; allowance for sea foam and temperature and problems.	Prompt relay to ships at sea is necesary for routing; use of TDRSS is indicated.	Sea state/wave radar reflectance models.	Data on surface wind speeds would be helpful. More likely that these will be determined by knowledge of wave spectrum.
Soil Moisture Determinations	U.S.D.A.; conservation services; farmer's cooperatives; flood prediction and control agencies	Passive (and possibly active) microwave emission and response coordinated with visible and thermal infrared.	Quantify degree of soil moisture with parameters such as soil type, elevation, topography and, especially, vegetation cover.	Prompt release of data to farmers (within a week) in the form of maps is required.	Models which take into account those parameters listed under "Information Extraction" are needed.	Base data of soil type and vegetation cover; synoptic data on wind velocity and atmospheric moisture content.
Ice Surveys	Shipping industry; NOAA; U.S. Navy	Microwave (passive) response as a function of type of ice. Active microwave may give some indication of thickness.	Digital level slicing in several microwave bands to extract ice type. Correlation with visible imagery to give open water and location.	Near real-time dissemination to ships underway.	Some additional work needed in correlating response to specific ice types and ice type to navigability. No serious problems.	Wind velocity to help predict ice shifts.
Acreage Estimates of Crops	Food processors; U.S.D.A. Statistical Service; Dept. of Commerce; farmers	Visable and Infrared spectral signatures of crops.	Machine processing past imagery stage and map form to direct numerical readout with statistics and reliability estimates.	Data must be obtained during optimum period of growing season. Dissemination should take place within a month after acquisition	Statistical models required to relate derived parameters to acreage and yield estimates.	Spectral signatures of crops as base data; growth pattern of crops as a function of crop type and geography.
Survey and Monitoring of Water Impoundments	Farmers; agricultural agencies; irrigation cooperatives; water resources agencies	Essentially low emmisivity of water in infrared.	Direct digital interpretation of remotely sensed data – output of total acreage and distribution (if needed) location of impoundments.	In statistical or map form – within a month of acquisition.		None

TABLE 1. (Concluded)

	Potential Users	Observables	Information Extraction	Data Dissemination	Models	Ancillary Data Needs
Identification and Monitoring of Vegetative Stress	Farmers; producers; U.S.D.A. state conservation agencies; flood prediction agencies.	Spectral (visible, infrared, thermal infrared microwave) of stressed vegetation.	Complex. Needs base data on vegetation type and growing patterns; crop planting dates; topography and prompt meteorological data.	Prompt in order to effect alleviation measures. Must be regionally and, at times, locally disseminated in the form of maps.	No specific need for models but need base data no signatures of stressed vegetation.	As indicated under "Information Extraction" and "Models".
Detection of Point Sources of Environmental Pollution	Local environmental agencies; E.P.A.; industry; water quality boards.	Visible and thermal IR signatures of pollutants in water and air (especially particulates).	Need variation of spectral signatures of water as base from which to extract water pollution	Generally within weeks to agencies; occasionally, during alerts and for spastic violators must be prompt.	No particular need.	Meteorological conditions (inversions, etc.) land use patterns would be heldful.
Land-Use Surveys	State and Federal land use agencies; local planners and developers; environmental agencies.	Spectral signatures and distribution of categories of land use.	Complex job of mapping based on ground-truth and pre-existing data base of signatures of land use features. Temporal overlay of data onto existing remotely-acquired base to see changes.	Long lead-time. Data disseminated in the form of maps.	No specific need.	Catalog of spectral signatures; base data of existing land use patterns.
Water Resource Management	NOAA; U.S.D.I.; state and Federal resource managers; farmers; power companies; reservoir managers.	Visible and near infrared signatures of snow cover and melting rates; thermal infrared measure of runoff and microwave signatures of snow type (and depth?)	Complex integration of data of snow extent and depth; type and runoff rate together with soil moisture and vegetation cover including topography and soil/rock type.	Must be prompt; in the case of water availability, to agency heads – in the case of reservoir management, possibly to dam managers.	Strongly needed to relate observable parameters to stream flow and water accumulation.	Those listed under "Information Extraction" together with meteorological data.
Flood Damage Assessment	Disaster relief agencies; state police; Federal insurance agencies.	Visible and near infrared measures of standing water; microwave measure of soil moisture.	Difficult; multilayered signatures on land use base and base of pre-existing remotely sensed data for change detection. Output in the form of reliable (i.e., definitive and positionally precise) maps.	Very prompt – as notifications to disaster relief agencies; in a period of about a month to insurance agencies.	Moderate need for models which incorporate pre-existing land use data and topography data to generate flood impact values.	Land use/topographic information; remotely sensed data base of normal, i.e., non-flooded scene.

considering these applications, it becomes obvious that the extraction of information for a highly diverse user community from a large amount of data that is obtained at very high rates represents a formidable challenge to the EOS missions.

4. TYPICAL INSTRUMENTS

a. Thematic Mapper. The EOSMRG, in their report of November 1971, recommended as the primary instrument a moderate resolution multispectral scanner with an instantaneous field of view (IFOV) no greater than 50 meters. A candidate instrument was under study at that time with an IFOV of 66 meters; subsequent studies indicate an IFOV of 30 meters at 914 -km altitude to be feasible. Significant parameters of the EOS-A Thematic Mapper are tabulated in the report.

b. High Resolution Pointable Imager (HRPI). The HRPI was originally recommended by the EOSMRG as a high-resolution adjunct to a medium-resolution Thematic Mapper; its role was further developed by the December 1972 KSC Conference on Imaging for Earth Resources as an experimental tool for determining the efficiency of long term, high resolution sampled data obtained on a regular programmed basis which could reduce the dependence on aircraft data. In addition to its normal use in this mode, the HRPI can be used for ad-hoc temporary purposes such as floor or hurricane damage assessment. Parameters of the HRPI for the EOS-A are tabulated in the report.

c. Data Collection System (DCS). The primary role envisioned for a DCS on the EOS-A mission is monitoring of hydrological data, for which platforms are located at known fixed sites. Emphasis will be on high traffic capacity of the satellite collection process, and on a design which will permit simplicity (hence, low cost) of the platforms.

d. Synthetic Aperture Radar (SAR). The inclusion of active microwave systems (i.e., radars) for remote sensing in an early EOS payload was specifically recommended by the EOSMRG. As is so often the case, the requirements for a radar addressed to geologic survey, land use monitoring, and water/ice monitoring differ markedly from the requirements imposed on a radar addressed to meteorological and oceanographic problems; so to exploit fully the potential of radar for R&D in the EOS era, 1978-1981, two radars of significantly different characteristics are required. Parameters of an SAR currently being studied for follow-on land-resources management applications are tabulated in the report.

5. EOS COMMUNICATIONS AND DATA HANDLING

Network support for EOS includes three Standard Tracking Data Navigation (STDN) sites for the terrestrial survey mission. The stations are Goldstone, California, Fairbanks, Alaska, and the Network Test and Training Facility (GSFC). A fourth station (Madrid) is required for the ocean/meteorological mission, but could be eliminated with the availability of the Tracking and Data Relay Satellite (TDRS).

Goldstone passes will provide coverage of the western and west-central portions of the continental United States. Fairbanks will provide coverage of Alaska. Support requirements of both sites are identical; to receive and record instrument video data, receive spacecraft housekeeping telemetry data, and transmit OPLE Command Center (OCC) generated commands to the EOS. Video data tapes from both sites will be shipped to GSFC for processing.

The Network Test and Training Facility (NTTF) at GSFC will provide real-time coverage of the central and eastern United States. NTTF will provide real-time instrument video data to the OCC and NASA Data Processing Facility (NDPF). S-band tracking, spacecraft telemetry, and direct real-time command capability will be provided.

An S-band coherent side tone range and range rate (R&RR) system will allow range measurements that are sufficiently accurate to produce knowledge of position along track and across track to within 30 to 50 meters.

Instrument data will be transmitted to STDN and directly to local users at a carrier frequency of 8 GHz (X-band). Two directive antennas on the spacecraft will be used for this purpose. A multi-megabit operation multiplexer system (MOMS) multiplexer, high speed analog-to-digital converter will be capable of generating a composite bit stream of data derived from both the Thematic Mapper (TN) and the High Resolution Pointable Imager. These two sensors will produce a data rate (including overhead) of approximately 240×10^6 bits per second. These data will be transmitted as a quadraphase modulated signal. Another MOMS function will be to selectively produce data of reduced resolution or of reduced swath size and colors which will be available at rates of approximately 20×10^6 bits per second. Data of this type are expected to be most beneficial to local users who can operate with selectable forms of the lower data quantities but cannot afford the processing of 240×10^6 bits per second.

For coverage other than the continental U.S., to accommodate the possible mission requirement of extra continental coverage, one of three approaches will be implemented. These are: (a) direct transmission to foreign user terminals at X-band, (b) addition of an onboard tape recorder capable of recording image data of selected land masses (15-minute capacity), or (c) addition of a KuBand communications system for transmission of data via TDRSS.

6. DATA MANAGEMENT/DISTRIBUTION

Effective utilization of earth observations data depends upon an efficient data management system. Such a system must consider:

a. The transmission of sensor data to both a central processing facility and a network of decentralized, outlying receiving stations.

b. Processing of the acquired data at both the central and decentralized facilities in near real-time, if necessary, to standard analyzable products such as calibrated and geographically referenced images or computer-compatible magnetic tapes.

c. Extraction of information useable in resource management or environmental quality assessments by automatic techniques such as edge enhancements, clustering, or spectral signature correlations employing the necessary analytical and empirical algorithms.

d. Distribution of the extracted information to regional and local resource managers and decision makers.

Direct data transmission to users has an impact on the system design of the spaceborne portion of the system. This capability however, allows the local user, with a modest investment in a ground system, to receive data of local interest directly from the spacecraft. The advantage is one of immediate data availability and the use of a facility responsive to the user's particular needs. Dependence upon a central data recovery processing and extraction facility is useful for more sophisticated applications on a regional or national scale.

7. LOW COST GROUND STATIONS

In addition to transmission of sensor data to NASA ground stations, the EOS will be capable of transmitting data directly to a number of small local user stations. These low cost stations will provide users with a direct data source for information which is of immediate importance to them, eliminating the dependence of the local user upon a central data collection and processing facility.

Low cost ground station equipment would typically include a small antenna, receiver, data synchronization and detection equipment, data processing (mini-computer), and suitable display equipment.

Facilities of these types are seen as being feasible and practical in support of applications such as state, county, and local land resource management.

Universities and colleges with study and research programs in numerous areas including agriculture, forestry, and geology represent another base of users of EOS direct data transmission.

SYNCHRONOUS EARTH OBSERVATORY SATELLITE (SEOS)

1. OBJECTIVES

To make earth observations and to obtain data that cannot be obtained in an effective way from lower orbiting, non-synchronous satellites (repetitive measurements, those made at specific times of day, cloud cover problems, etc.) or from synchronous satellites with less observation capability (i.e., lower resolution). The area of observation is to be the continental and coastal regions of the United States.

SEOS will serve applications in the following fields:

- Earth Resources
- Mesoscale Weather Phenomena
- Timely Warnings and Alerts

SEOS is expected to be launched in 1981.

2. APPLICATIONS

The following is a listing some of the applications considered for SEOS.

a. Earth Resources

- Detection and monitoring of water — suspended solid pollutant.
- Estuarine dynamics and pollutant dispersal.
- Monitoring extent, distribution, and change of snow cover.
- Detecting and monitirong fish location and movement.
- Detection and assessment of disease and insect damage to forest species.

- Flood prediction, survey, and damage assessment.

- Determination of optimum crop planting dates.

- Exploration of geothermal sources.

b. <u>Weather Phenomena</u>

- Detection, monitoring, and prediction of thunderstorms and related tornadoes, hail, and excessive rainfall.

- Detection, monitoring, and prediction of tropical cyclones.

- Predictions and monitoring of frost and freeze conditions.

c. <u>Warnings and Alerts</u>

- Floods

- Storms

- Frost and Freezes

- Fog

Considerations regarding potential users, information extraction and data dissemination are outlined for some typical applications in Table 1.

3. INSTRUMENTATION

The prime payload for SEOS will be the multispectral Large Earth Survey Telescope (LEST). Other instruments are being considered as potential candidates for the SEOS payload:

- Advanced Atmospheric Sounder and Imaging Radiometer (ASSIR)

- Microwave Sounder

- Data Collection System (DCS)

- Framing Camera

TABLE 1. TYPICAL SEOS APPLICATIONS

	Potential Users	Observables	Information Extraction	Data Dissemination	Models	Ancilliary Data Needs
Detection and Monitoring of Water-Suspended Solid Pollutants	Public health service; EPA; NOAA; regional groups (e.g., Delaware River Basin Commission); citizen's groups; industry.	Changes in spectral reflectance of water; correlation with wind and current parameters; bands in .5–.6 and .6–.7 are best	Digital density slicing. 1-day maximum return required for detection of discharge violations. Data must be integrated with meteorological input.	Maps showing source/deposition areas by contours, generated in weeks can be mailed. Alerts of discharge violations can be telephoned/telexed.	Much can be done without models, but optimum use requires models which will accept meteorological/ hydrological parameters.	Background data on level of siltation versus specific band reflectance required.
Esturine Dynamics and Pollutant Dispersal	Bureau of Sport Fisheries and Wildlife; Bureau of Commerical Fisheries; private industry; Corps of Engineers; water pollution control agencies.	Thermal discontinuities in relation to stream flow; upwellings; saline/fresh water interface; dissolved organics and nutrients	Data required over several tidal cycles; must be multispectral digitally processed	Issuances in the forms of charts and maps showing currents and pollutant levels; some requirement for near-real-time acquisition and processing	Hydrologic models relating topography (land and channel) to flow; mixing models of saline/fresh and warm/cold waters.	Chemical analysis – in situ during remote data acquisition.
Monitoring Extent, Distribution and Change of Snow Cover	Users of water resources: agriculture production; domestic and industrial water supply; power utilities; and recreasite managers.	Areal extent of snow cover; thermal data for run-off and melt/must be timed especially with critical snow-melt periods.	Overlay of snow cover maps onto pre-existing maps and data base information (e.g., topography) is important.	Timing is more critical here than elsewhere. Optimum focus of generated information must be identified.	Watershed models required to forecast run-off; these models should accept the ancillary data described below.	Topographic base information; soil composition/moisture; vegetation cover; meteorological data (temperature, wind).
Detecting and Monitoring Fish Location and Movement	National Marine Fisheries Service; fishing industry; Bureau of Commercial Fisheries.	Ocean color (biological content and salinity); temperature +1°C.	Prompt extraction of information from data – generate maps of potential fish nutrients and sea surface temperature.	Must be within a few hours of acquisition; data-faxed to, or remotely acquired and processed by, fishing industry or consultant groups.	No strong need but background research in relating observables to fish location (and quantification of same) is required.	Meteorological and oceanographic parameters. Catalog of data which relate quantities of fish to observables.

TABLE 1. (Continued)

	Potential Users	Observables	Information Extraction	Data Dissemination	Models	Ancillary Data Needs
Detection and Assessment of Disease and Insect Damage to Forest Species	U.S. Forest Service; state departments of natural resources; forestry products industry; recreational resource managers.	Reflectance patterns, especially in the IR region for detection of partial and complete defoliation.	Superposition of data on known vegetation base map; overlay of data during sessions.	Maps outlining areas affected must be generated in a time frame which allows remedial action (week); distribution directly to managers.	Models relating degree of infestation with defoliation and reflectance changes, incorporating background reflectance levels and seasonal variations.	Base vegetation maps; maps of approved, known timber cutting.
Flood Prediction, Survey and Damage Assessment	Local and regional civil defense agencies; state police; disaster relief agencies; Corps of Engineers; USDI.	Snow cover and runoff; soil moisture levels; vegetation levels and type; areal extent of standing water and high moisture levels.	Integration of meteorological data with remotely-sensed data and base data of vegetation type, topography, etc.; land-use base maps also integrated. Complex process.	Variable. Flood prediction, especially flash flood warnings must be disseminated quickly with accuracy. Damage assessment can take somewhat longer, needs to be in fairly accurate map form.	Reliable predictive models for flood warning which take into account met. and other data must be devised. Other statistical models for damage assessment which takes land use into account are needed.	Meteorological data; land use, vegetation, topographic data. Buildup of experience relating parameters and flood level/damage is needed.
Determination of Optimum Crop Planting Dates	Farmer's cooperatives; USDA; state agriculture services; seed and fertilizer industries; statistical reporting service.	Thermal data relative to soil moisture, microwave data for same; visible and IR data relating to foliage flushing.	Correlation of microwave and thermal IR data together with visible and near IR to predict optimum planting dates.	Should take place within a week to farmer's cooperative and state and Federal agencies.	Predictive models of optimum planting dates which take into account the type of commodity, meteorological data, topography, soil type, and remotely-sensed parameters are strongly needed.	Those listed as being required by the models.

TABLE 1. (Concluded)

	Potential Users	Observables	Information Extraction	Data Dissemination	Models	Ancillary Data Needs
Exploration of Geothermal Sources	FEO; USDI; Power companies; land development companies; state geological surveys.	Thermal IR as indicator of warm and hot spots; microwave to take moisture levels into account.	Superposition of data acquired during diurnal cycle, preferentially over several seasons must be performed.	Time frame not crucial; issuance of maps to cognizant agencies.	Models to separate latent and diurnal effects from geothermal effects.	Soil composition and moisture content; topography and vegetation cover; previous cloud cover.
Detection, Monitoring, Prediction and Storm Warning Demonstration of Thunderstorms (with special emphasis on thunderstorms that produce tornadoes, hail and excessive wind and/or rainfall)	All segments of society.	Imaging measurements in the visible and infrared in several wavelength intervals, infared and microwave sounding measurements.	Wind, surface temperature and pressure, cloud top height, cloud movement, cloud type estimates, vertical temperature and moisture profiles, vertical stability, wind shear, convergence and divergence, vertical motion.	NASA and other users through the NASA Data Processing Facility and/or the Space Sciences Data Center.	Insertion of some of the extracted parameters into small scale atmospheric diagnostic and prediction models. Statistical diagnostic and prediction models should also be developed.	Simultaneous aircraft flights and meteorological observations plus special in situ observations on a finer scale than is routinely provided.
Prediction and Monitoring of Frost and Freeze Conditions	All segments of society that have agricultural or horticultural interests that could be adversely affected.	Imaging measurements in the visible and infrared wavelengths in several wavelength intervals, infrared sounding measurements.	Cloud amount, movement, type, thickness, and height, surface temperature, surface windspeed, surface air moisture content, soil moisture and temperature, and temperature and moisture profiles of the lower troposphere.	NASA and other users through the NASA Data Processing Facility and/or the Space Sciences Data Center.	Insertion of some of the extracted parameters into small scale local radiative balance atmospheric models. Statistical diagnostic and prediction models should also be developed.	Simultaneous aircraft flights and conventional meteorological information plus special in situ observations on a given scale than is routinely provided.

The following is a brief description of the SEOS payload.

a. Prime Instrument — LEST. The LEST is a telescope system with an aperture presently specified to be 1.5 meters. It is to be used for imaging in the visible and infrared (IR) regions, and for sounding in the IR. The spectral range will be from 0.2 μm to 15 μm in a series of bands, the specific ranges and bandwidths of which are currently under consideration.

The following subsatellite ground resolutions can be obtained with a 1.5-meter telescope:

Visible	100 meters
Thermal IR	800 meters
Sounding in IR	18 to 30 km

b. Potential Instruments

(1) Microwave Sounder. A sounder is being considered that would cover the region of 50 to 220 GHz in five bands. No antenna size has been determined at this time, but the goal is an aperture of 1.5 meters or larger. Resulting ground resolution would range from 200 km at 50 GHz to 50 km at 220 GHz.

(2) DCS. Data Collection Platforms (DCP's), the SEOS spacecraft, and a Command and Data Acquisition System (CDA) form the fundamental elements of a DCS.

DCP's are small (2 ft^3, 20 pound) automatic radio transmitters that send sensor data at intervals through SEOS back to a central data acquisition facility. These DCP's operate with small (approximately 0.1 watt) average dc power obtained from batteries or solar cells in isolated locations and develop about 5 watts of RF power during transmission. They operate in the 401 to 402 MHz frequency range.

Because of the larger SEOS spacecraft antenna, DCP's would need only one-tenth of the effective radiated power than would be needed for operation through other satellites.

The DCS may be able to operate in either one of the following two modes, or in a mixture of both:

(a) Sequential. A number of platforms will operate on the same frequency, transmitting data on a time-shared basis either through interrogation or self-timing. Data broadcasts may be interrupted during brief interrogation transmissions.

(b) Simultaneous. The spacecraft transponder will have sufficient bandwidth and linearity to permit up to 100 platforms to transmit simultaneously, each on a different frequency within a selected bandwidth (nominally 400 kHz).

(3) Framing Camera. A television-type framing camera with the following characteristics is being considered as a sensor:

- Resolution — Coverage

(a) 216-meter per TV line for 1000 by 1000 km

(b) 45-meter per TV line for 200 by 200 km

- Highlight Range

  Programmable for greater than 1000 times

- Sequential Color Frames

  One color every 15 seconds

- Spectral Ranges from 400 mm to 900 mm

- Limited Radiometric Capability

Such a camera could operate as an individual sensor, or it could become part of the detector complement of the large telescope.

4. SPACECRAFT SYSTEM CONSIDERATIONS

a. Orbit. A synchronous, equatorial orbit has been selected because it provides continuous coverage of the U.S. at near-constant view angles.

b. Spacecraft. The spacecraft is likely to have the following characteristics:

Total weight	1600 to 3000 kg
Average power	600 to 750 watts
Communications capacity	60 megabits per second to ground
Launch Vehicle(s)	Titan, Shuttle

An important consideration is the establishment of spacecraft attitude determination and control (ADC) requirements, based on the proposed method of telescope image formation. Images will be formed by:

- Slew of the spacecraft combined with:

(1) Pushbroom type scan with a large detector array oriented orthogonally to the direction of spacecraft slew.

(2) Image (object) plane scanning with telescope mirrors.

- Spacecraft pointed to fixed ground location combined with image (object) plane scanning.

The spacecraft will be capable of:

- Pointing sensor to ±1 km accuracy at subpoint (28 microradians)
- Holding pointing to ± meters (0.7 microradians)
- Slewing at rates from a few hundred kilometers per minute to 800 km per minute or slewing across the United States (5,000 km) in 5 minutes (0.028 radians/minute, maximum).

5. GROUND DATA HANDLING

It is planned to have all major ground facilities (including ground station, operations control center and data processing facilities) at or near the NASA Goddard Space Flight Center. The data processing facility will produce data both in near real-time and delayed time to meet the following requirements:

<u>Near Real-Time (minutes to hours)</u>

- Warning and Alerts

- Meteorological Forecasting
- All other applications in need of real-time decision making

Delayed (hours to days)

- All experiments nor requiring immediate action

Data products will consist of images, tapes, cards, quick-look displays, computer printouts, etc., and will meet prearranged experimenter requirements.

APPLICATIONS EXPLORER MISSIONS

The Applications Explorer spacecraft (Fig. 1) has been designed to fly in a wide range of Scout-launched orbits from equatorial through polar inclinations. The system flexibility is such that a variety of earth observation instrument requirements can be accommodated without significant subsystem modification. A modularized structure has been designed which separates the instrument (instrument module) and subsystem sections (base module). This provides the ability to first establish a well specified instrument interface and second, to build up and stock pile individual base modules for rapid call up to support an urgently needed mission. The three-axis, earth-oriented attitude control system provides a maximum capability for instruments in the applications disciplines. Random packaging techniques for subsystems will be used, enabling the use of hardware already existing or planned for other programs.

The three-paddle configuration (Fig. 1) will be used for polar, near noon sun-synchronous, and low inclination orbits. A two-paddle configuration will be used for near-twilight, sun-synchronous orbits. Table 1 lists the basic spacecraft parameters and capabilities.

The HCMM will use a version of this small, versatile, low cost spacecraft.

1. HEAT CAPACITY MAPPING MISSION

a. Background

(1) Previous Missions. Remote sensing of temperatures has been carried out from aircraft and satellites using infrared sensors. Spacecraft sensors, devoted to thermal mapping, have been flown mostly in support of the meteorological program. The spatial resolution of the early sensors was too coarse for most earth resources applications. Sensors such as the Nimbus Medium Resolution Infrared Radiometer and Nimbus High Resolution Infrared Radiometer had instantaneous fields of view, at the surface, of 30 by 30 km and 9 by 9 km respectively.

(2) Development. Recent developments in infrared detectors and space cooling techniques have made possible sensors with much finer spatial resolution such as the Nimbus-5 Surface Composition Mapping Radiometer

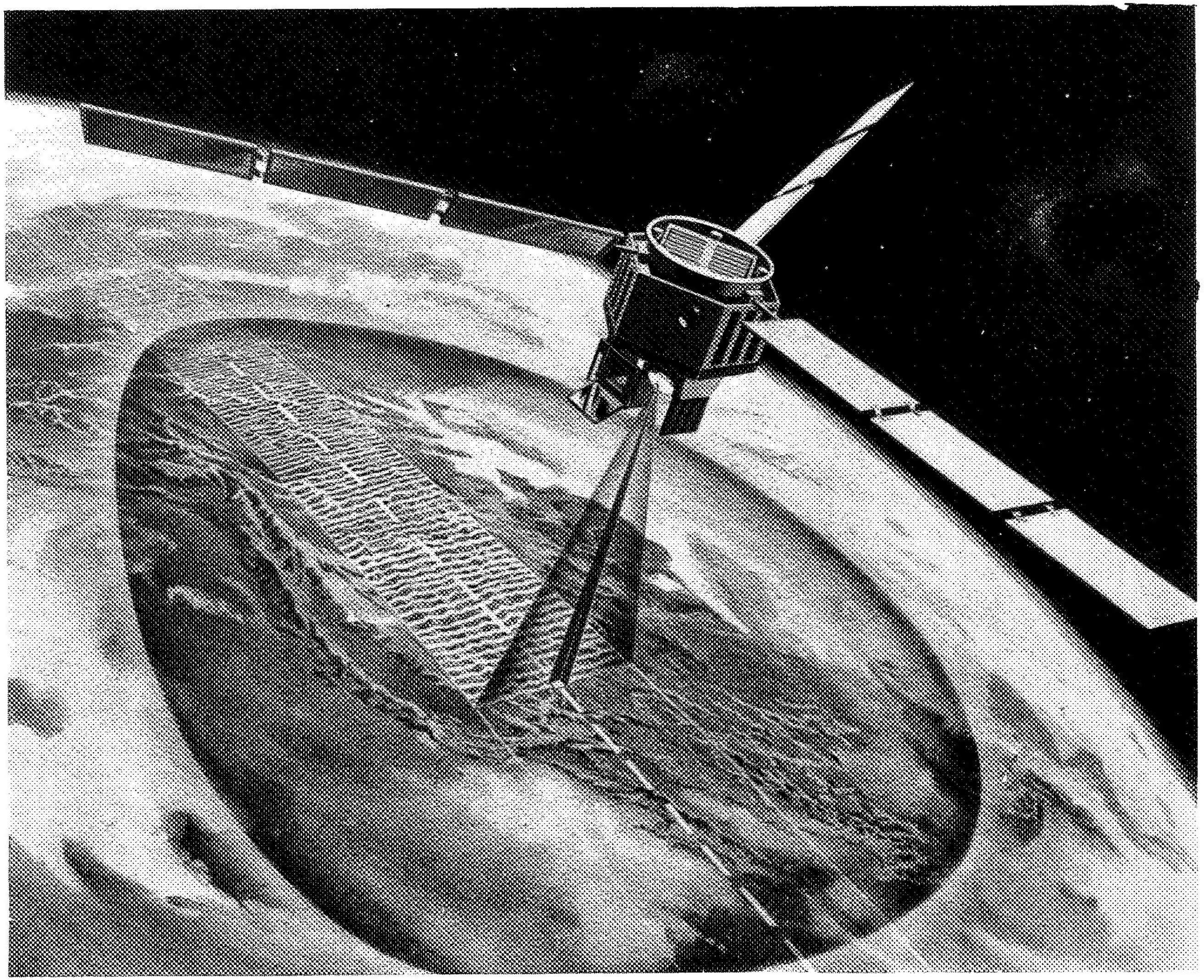


Figure 1. Applications Explorer spacecraft.

TABLE 1. SPACECRAFT PARAMETERS

<u>Power (Orbital Average)</u>, 28 volts ±2 percent regulation
Base Module — 30 watts
Instrument — 30 watts

<u>Data Handling</u>
1 to 40 kilobits/second.
Two switchable bit rates.
Four program formats (two fixed, two reprogrammable).

<u>Data Storage</u>
GSFC standard 10^8 bit tape recorder.

<u>Command</u>
Real time — 1,200 bits per second.
63 individual 37-bit serial digital commands.
64 impulse commands. Delayed execution of any or all commands.

<u>Thermal</u>
Isolation between instrument and base module.
Utilizes active and passive techniques.

<u>Attitude Control</u>
Three-axis earth oriented.
Stability ±1 degree pitch and roll; ±2 degrees yaw.
Maximum body control rate 0.01 degree per second.
Determination ±0.5 degree pitch and roll; ±2 degrees yaw.

<u>Communication</u>
VHF command receivers.
VHF for low data rate instrument and housekeeping data.
S-band for wideband instrument data and tape recorder dump.

<u>Weight</u>
Spacecraft at launch — Up to 165 kg.
Available for instrument — Up to 68 kg.

<u>Volume Available for Instrument</u>
Approximately 196 liters (7 ft^3).

<u>Orbit</u>
Scout launch vehicle. Low altitude, typical inclinations of 0 degree, 38 degrees, 50 degrees, or sun-synchronous at various local times.

with 0.6 by 0.6 km instantaneous field of view and the ITOS Very High Resolution Radiometer (VHRR) with a 1.0 by 1.0 km instantaneous field of view. Resolutions such as this make earth resources sensing feasible using several techniques developed in field research over the past decade.

Measurements by several investigators, principally from the U.S. Geological Survey (USGS), have shown that the temperature variation of surface materials over the diurnal cycle is a function of the solar energy absorbed during the day and the thermal inertia of the material. Measurements from the surface and from aircraft of the surface albedo and the temperature at the peak and minimum of the diurnal cycle have been used to develop a model that can be applied to remotely sensed data to determine surface composition from thermal inertia measurements.

b. Applications

(1) Surface Geology

(a) Potential users. Potential users of remotely sensed thermal inertia data include geologists concerned with mineral exploration in unexplored areas. Measurements from a spacecraft can provide coverage of vast areas of the earth's surface in a short period of time and localize areas of interest.

(b) Observables. The observed quantities from the Heat Capacity Mapping Mission (HCMM) will be the albedo and surface temperature near the peak of temperature during daylight hours and the surface temperature at pre-dawn, the minimum of surface temperature.

Figure 2 shows the temperature variation that would occur for materials of varying thermal inertia and the same albedo on a summer day. The curves show that the maximum of temperature occurs at about 1:30 in the afternoon and the minimum just before sunrise. To achieve maximum discrimination it would be ideal to sense temperature at those times but that would not be possible with a sun synchronous orbit. The HCMM will cross the mid-latitudes in the U.S. at the times shown by the vertical lines in Figure 2, 1330 and 0230, near the optimum.

(c) Information extraction. The registered thermal and albedo data will be processed to calibrated thermal and albedo measurements after digitization of the analog data from the spacecraft. The model, developed by USGS investigators, will be further refined by aircraft data before the flight of the HCMM and used to computer process the albedo and temperature data to produce thermal inertia maps. This will involve registering the day and night data by appropriate scale correction and by rotation of the imagery to provide registration.

(d) Data dissemination. Data will be processed into black and white imagery and magnetic tapes for transmission to a repository from which data dissemination will be carried out.

(2) Soil Moisture Sensing

(a) Potential users. Potential users of soil moisture information are in the agricultural and civil engineering area. Measurements of soil moisture can provide high spatial resolution surveys of moisture content of bare fields and areas around roadways and irrigation facilities.

(b) Observables. The observed quantities will be temperature and albedo from which soil moisture in the upper layers will be derived. Processing will be essentially identical to that used for surface geology.

Water tends to stabilize temperatures and increased soil moisture reduces the temperature excursion during the diurnal cycle. Figure 3 shows the diurnal temperature variations of soils with varying soil moisture from 2 to 19 percent. This type of measurement applied to agricultural areas can provide information on irrigation effects and allow estimates of future irrigation requirements.

(c) Information extraction. Information extraction will follow the same general procedure as used in surface geology with data converted to temperature and registered together with albedo data. A model for soil moisture will be developed from data already collected and studies to be conducted before the launch of the HCMM.

(3) Transient Thermal Effects

(a) Potential users. Potential users of thermal data on transient thermal effects are in virtually all fields of remote sensing investigation. Thermal effluents, either natural or manmade, can be detected at night or in daylight for hydrological studies and thermal pollution detection. Crop temperatures will provide agricultural interests with an indication of growth potential and damage by natural phenomena such as frost.

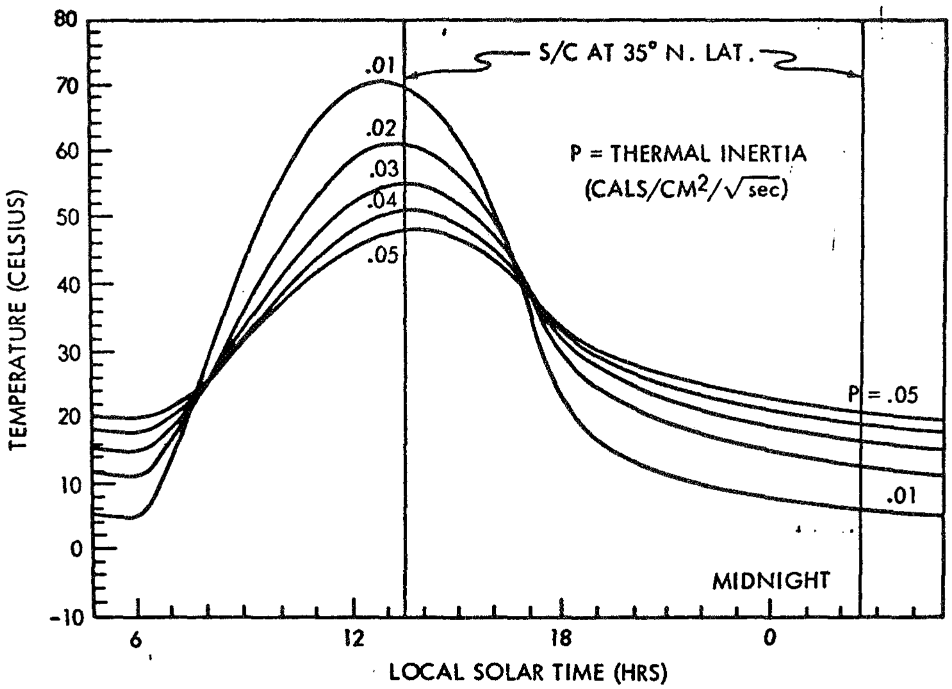


Figure 2. Diurnal surface temperature variation as a function of thermal inertia.

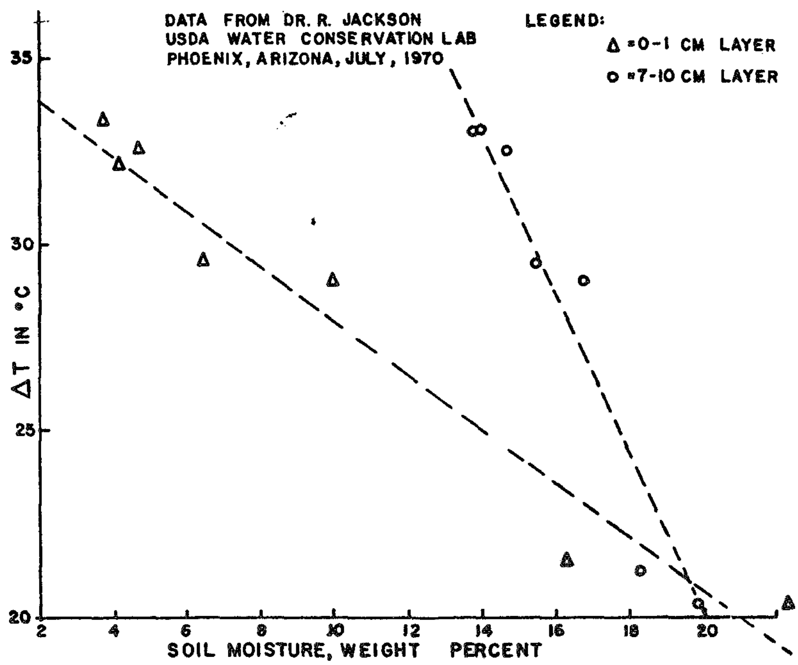


Figure 3. Diurnal temperature variation versus soil moisture.

(b) Observables. The observed quantities will again be albedo and day and night temperature. Processing will be into maps of temperature and albedo but registry of day and night data will not be required.

2. THE APPLICATIONS EXPLORER SYSTEM FOR THE HCMM

a. Spacecraft Description. The spacecraft is designed for earth-viewing instruments. The active attitude control system keeps the instrument module nadir pointing. This is a fundamental spacecraft concept and is reflected in the design parameters of the structure, stabilization and control, and other subsystems.

The spacecraft will weigh approximately 120 kg of which the radiometer instrument is 39 kg. An average of 25 watts of electrical power will be supplied to the radiometer.

b. Orbit. The HCMM will be placed in a nominal 600-km circular sun-synchronous orbit with a 2 p.m. ascending node. Thus temperature measurements will be made over middle-northern latitudes at the peak and minimum of the diurnal cycle. A 6-month operational lifetime is planned.

c. Instrument Module/Heat Capacity Mapping Radiometer (HCMR). The basic radiometer instrument has already been developed in the High Resolution Surface Composition Mapping Radiometer (HRSCMR) for Nimbus-E. The spare flight radiometer, with minor modifications to the basic instrument, will serve as the HCMR. The HCMR will have a small instantaneous geometric field of view, less than 1 by 1 milliradians, high geometric accuracy and a wide enough swath coverage on the ground so that selected areas are covered in a period corresponding to the maximum and minimum of temperature observed. The instrument will operate in two channels, 10.5 to 12.5 μm (IR) and 0.8 to 1.1 μm (visible). The latter is matched to the ERTS MSS band 4.

The instrument utilizes a radiation cooler to cool the two Hg Cd Te detectors to 115° K.

d. Base Module. The base module which houses all the spacecraft subsystems will be hexagonal in shape with dimensions of 75 cm (30 inches) across the flats and 56 cm (22 inches) in height. The subsystems will be mounted in a random manner to facilitate various package configurations.

It will contain all the subsystems necessary to support and control the total spacecraft. In the launch configuration the instrument will be mounted on top of the base module. In orbit, the attitude control system will maintain the instrument module pointed to the center of the earth.

e. Launch Vehicle. The launch vehicle will be the Scout-F, a four-stage solid-fuel rocket system.

f. Data Acquisition. The HCMR utilizes analog telemetry. No spacecraft data storage will be provided. Data will be transmitted in real-time to five especially equipped ground stations. These are in Alaska, California, North Carolina, Spain, and Australia. The data will be put on magnetic tape and mailed to GSFC for processing and dissemination.

SEVERE STORM WEATHER WARNING SATELLITE

Advanced Atmospheric Sounding and Imaging Radiometer

1. OBJECTIVES

The purpose of the Advanced Atmospheric Sounding and Imaging Radiometer (AASIR) is to observe time changes in atmospheric temperature and water vapor structure, surface temperature, and certain cloud properties such as cloud position, height, and horizontal extent. These time changes should allow the detection and study of small scale weather systems; the determination of the large scale, three-dimensional mass distribution and its time variations; the specification of large scale horizontal and vertical motions; small- and large-scale surface temperature variations; and cloud growth and decay. Examples of small scale meteorological phenomena would be thunderstorms, fine structure of tropical cyclones, fog, frost and freeze conditions, dust storms, and squalls in the lee of the Great Lakes.

The AASIR would be the second generation three-axis stabilized meteorological sensor in geosynchronous orbit (the Geosynchronous Very High Resolution Radiometer on ATS-F will be the first) and would be the first sensor on this type of platform to have both sounding and imaging. The successful demonstration of this capability should lead to a second generation operational geosynchronous satellite.

2. BACKGROUND

Meteorological observations from geosynchronous orbit began in 1966 with the launch of a camera on the spinning ATS-1 satellite which could take images of the earth at about half-hour intervals. Wind velocities could be estimated from cloud motions, and cloud growth and decay associated with small scale weather systems could be determined. With this capability it was realistic to consider satellite measurements as an information source to improve short range prediction (0 to 12 hours). Another similar camera was launched on ATS-3 approximately 1 year later.

In the spring of 1974 two radiometers with visible and infrared channels will be launched into geosynchronous orbit. One, the Visible and Infrared Spin Scan Radiometer (VISSR), will be carried on the spinning Synchronous Meteorological Satellite (SMS), and the other, the Geosynchronous Very

High Resolution Radiometer (GVHRR), will be on the three-axis stabilized ATS-F satellite. After the launch of the SMS satellites, a subsequent series, called the Geostationary Operational Environmental Satellite (GOES), will begin. It is planned that future satellites of the GOES series will carry instrumentation that can obtain vertical temperature and moisture profiles.

3. SPECIFIC APPLICATIONS

There are many small scale meteorological phenomena that can be investigated with the AASIR. One that is of great interest to society is the thunderstorm.

A thunderstorm is a small scale, short lived meteorological event that can produce a variety of weather conditions that can have a major economic impact, and when some of the more violent storms occur, human life is threatened.

Before cumulonimbus clouds develop, the successful prediction of thunderstorms involves the measurement of atmospheric conditions that are favorable for their development. Later, as the clouds mature, it is necessary to frequently monitor both cloud and atmospheric structure changes. It is also important to isolate the atmospheric structure and cloud characteristics of the storms that produce tornadoes, hail, and excessive wind and/or rainfall. By using the satellite measurements in conjunction with conventional data it is anticipated that the areas where severe weather from thunderstorms is forecast will be reduced from the current situation and that the successful verifications will be greater within those areas. Besides the economic benefits, achievement of this goal will result in higher public confidence in the forecast which is of great importance even though this benefit cannot be measured directly in dollars.

The meteorological parameters that must be extracted include wind, surface temperature, cloud type, cloud top height, cloud movement, vertical temperature and moisture profiles, vertical stability, wind shear, areas of local convergence and divergence (derived from the wind field), and vertical motion. The changes of these parameters with time is as important as the derivation of the parameters themselves.

Small scale atmospheric numerical diagnostic and prediction models are being developed by the meteorological research community. This type of modeling, which must consider the atmosphere in an unbalanced state, is in the early stages of development. The quantitative measurements of temperature, moisture, and wind from the satellite can be inserted into these models. Even if the spacing and temporal frequency of radiosonde temperature and moisture profiles were the same as the satellite measurements, the nearly instantaneous sampling of the satellite data could make them more suitable for insertion into the models, with short space and time scales, than the radiosonde data. Sounding balloons take several minutes to climb through the troposphere and rarely ascend along a vertical path. In addition to the insertion of the derived parameters into numerical models, statistical models should also he developed. Whenever possible these models should complement diagnostic and prediction methods using conventional measurements.

Besides the satellite observations the AASIR analysis program will require the use of conventional meteorological data including radar. In addition, concurrent aircraft flights will be able to verify inferences and improve the interpretations made with the AASIR measurements.

4. TECHNOLOGY DISCUSSION

The AASIR nominally will be a cylinder 5 to 6 feet long by 2.5 feet in diameter. It will weigh 200 pounds and consume an average power of 60 watts.

The sensor will be capable of sounding either the entire earth's disk or smaller areas. The smaller areas can be of any size and may be located wherever desired on the disk. When sounding small areas, the effective sounding resolution is improved and the time required is decreased.

The sensor, which operates from a three-axis stabilized spacecraft, contains a two-axis mirror to accomplish the necessary scanning. The channels are as follows:

Spectral Interval (μm)	IFOV (km)	Use
0.75	1.5	Visible Imagery
3.7	13.5	Sounding
4.3	13.5	Sounding
6.7	13.5	Thermal Imagery and Sounding
7.2	13.5	Sounding
11.1	4.5	Thermal Imagery
6 bands 12 to 15	13.5	Sounding

The following table shows the effective sounding resolutions and measurement times:

Frame Size	Effective Sounding Resolution	Measurement Time in Minutes
Full Earth	$(54\ km)^2$	20
$(2500\ km)^2$	$(27\ km)^2$	4
$(750\ km)^2$	$(13.5\ km)^2$	1.2
$(250\ km)^2$	$(13.5\ km)^2$	0.4

The above table assumes that the minimum accuracy for satisfactory sounding is 0.25 ergs/sec cm^2 ster cm^{-1}. This requirement is met at $(750\ km)^2$. As the frame size decreases from this, the effective resolution remains constant and the accuracy improves. As the frame size becomes larger, the effective sounding resolution increases since spatial averaging is necessary to achieve 0.25 ergs/sec cm^2 ster cm^{-1}.

METEOROLOGICAL SATELLITE FLIGHTS

TABLE 1. SUMMARY OF METEOROLOGICAL SATELLITE FLIGHTS, 1960 THROUGH 1969

Satellite	Purpose	Launch Date	Operations Ceased Date
TIROS-1	Research	4/1/60	6/15/60
TIROS-2	Research	11/23/60	2/7/61
TIROS-3	Research	7/12/61	10/30/61
TIROS-4	Research	2/8/62	6/12/62
TIROS-5	Research	6/19/62	5/5/63
TIROS-6	Research	9/18/62	10/11/63
TIROS-7	Research	6/19/63	2/3/66
TIROS-8	Research	12/21/63	1/22/66
Nimbus-1	Research	8/28/64	9/23/64
TIROS-9	Research	1/22/65	2/15/67
TIROS-10	Research	7/1/65	7/31/66
ESSA-1	Operational	2/3/66	5/8/67
ESSA-2	Operational	2/28/66	10/16/70
Nimbus-2	Research	5/15/66	11/15/66
ESSA-3	Operational	10/2/66	10/19/68
ATS-1	Research	12/6/66	--
ESSA-4	Operational	1/26/67	6/19/67
ATS-2	Research	4/5/67	(a)
ESSA-5	Operational	4/20/67	2/20/70
ATS-3	Research	11/5/67	--
ESSA-6	Operational	11/10/67	11/4/69
ESSA-7	Operational	8/16/68	7/19/69
ESSA-8	Operational	12/15/68	--
ESSA-9	Operational	2/26/69	11/15/73
Nimbus-3	Research	4/14/69	9/25/70

a. Unstable attitude; data not useful.

TABLE 2. METEOROLOGICAL SATELLITE FLIGHTS AND FUNCTIONS, 1970 THROUGH 1974

Satellite	Purpose[a]	Launch Date	Orbit	Instruments and Functions[b]	Remarks
ITOS-1	R/O	1/23/70	Sun Synch. 1420 km	2 AVCS, 2 APT, 2 SR, FPR, SPM	Ceased operations June 1971.
Nimbus-4	R	4/8/70	Sun Synch. 1100 km	IDCS, THIR, IRIS, SIRS, SCR, FWS, IRLS, BUV, MUSE	THIR, FWS, and IRIS not operable.
NOAA-1	O	12/11/70	Sun Synch. 1420 km	2 AVCS, 2 APT, 2 SR, FPR, SPM	Ceased operations August 1971.
ITOS-B	O	10/21/71	Sun Synch.	2 AVCS, 2 APT, 2 SR, FPR, SPM	Failed to orbit.
ITOS-C[c]	O		Sun Synch. 1420 km	2 AVCS, 2 APT, 2 SR, FPR, SPM	Stored.
NOAA-2	O	10/15/72	Sun Synch. 1450 km	2 SR, 2 VHRR, 2 VTPR, SPM	
Nimbus-5	R	12/12/72	Sun Synch. 1100 km	THIR, ESMR, ITPR, SCR, MWS, SCMR	
ITOS-E	O	7/16/73	Sun Synch.	2 SR, 2 VHRR, 2 VTPR, SPM	Failed to orbit.
NOAA-3	O	11/6/73	Sun Synch. 1450 km	2 SR, 2 VHRR, 2 VTPR, SPM	
SMS-A	R/O	5/74	Geostationary 35,790 km	VISSR, DCDR, SEM	
SMS-B	R/O	7/74	Geostationary 35,790 km	VISSR, DCDR, SEM	
Nimbus-F	R	6/74	Sun Synch. 1100 km	THIR, ESMR, TWERLE, HIRS, SCAMS, LRIR, PMR, ERB, TDRE	
ITOS-G	O	7/74	Sun Sunch. 1450 km	2 SR, 2 VHRR, 2 VTPR, SPM	

a. R: Research
O: Operational
R/O: Operational prototype

b. APT – Automatic Picture Transmission
AVCS – Advanced Vidicon Camera System (weather satellite)
BUV – Backscatter Ultraviolet Spectrometer
DCDR – Data Collection and Data Relay
ERB – Earth Radiation Budget
ESMR – Electrically Scanning Microwave Radiometer
FPR – – Flat Plate Radiometer
FWS – Filter Wedge Spectrometer
HIRS – High Resolution Infrared Sounder
IDCS – Image Dissector Camera System
IRIS – Infrared Interferometer Spectrometer
IRLS – Interrogation, Recording, and Location System
ITPR – Infrared Temperature Profile (multi-channel) Radiometer
LRIR – Limb Radiance Inversion Radiometer
MUSE – Monitor of Ultraviolet Solar Energy
MSW – Microwave Spectrometer
PMR – Pressure Modulated (Carbon Dioxide) Radiometer
SCAMS – Scanning Microwave Spectrometer
SCMR – Surface Composition Mapping Radiometer
SCR – Selective Chopper Radiometer
SEM – Solar Environment Monitor
SIRS – Satellite Infrared Spectrometer
SPM – Solar Proton Monitor
SR – Scanning Radiometer
TDRE – Tracking and Data Relay Experiment
THIR – Temperature-Humidity Infrared Radiometer
TWERLE – Tropical Wind, Energy Conversion, and Reference Level Experiment
VHRR – Very High Resolution Radiometer
VISSR – Visual and Infrared Spin-Scan Radiometer
VTPR – Vertical Temperature Profile Radiometer

c. ITOS-C to become ITOS-E2 and modified to NOAA-2 configuration.

BASIC AGREEMENT BETWEEN U.S. DEPARTMENT OF COMMERCE AND THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION CONCERNING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEMS OF THE DEPARTMENT OF COMMERCE

SECTION I. AUTHORITY AND PURPOSE

Recognizing the success of the National Aeronautics and Space Administration (NASA) research and development (R&D) satellite programs and the utilization by the Department of Commerce (DOC) of satellite data in a variety of environmental programs; and

Taking note that Congress, also recognizing this success, initially in meteorology, provided in the Supplemental Appropriation Act of 1962, and thereafter, funds authorizing DOC "...to establish and operate a system to observe environmental conditions from space satellites and for the reporting and processing of the data obtained for use in environmental forecasting... and

Recognizing the broad responsibilities of NASA under the Space Act for continuing a research and development program for the developemnt of spacecraft technology and satellite systems for (1) application to operational systems and (2) research activity in the environmental sciences; and

Taking note that Congress appropriated separate funds to NASA for the purpose of supporting such an R&D program of spacecraft technology and satellite systems;

It is, therefore, the purpose of this agreement to define the relationship between, and the functions to be performed by, the DOC and NASA (1) in the conduct of operational environmental satellite programs of the DOC, and (2) in the development of supporting technology required for these operational satellite programs.

SECTION II. ESTABLISHMENT AND OPERATION OF THE SYSTEM

A. Objective

The primary objective of the Department of Commerce operational satellite systems is to provide information for prompt and effective use in environmental services and warnings, and for analysis and prediction within the scope of its mission, or by agreement with other agencies. The system will be based on technology produced in the NASA R&D Program as well as other related developments, and will satisfy the requirements of user agencies, subject to limitations of budget, resources or law. The DOC may modify the system, as appropriate and in accordance with the terms of this agreement, to accommodate changes in requirements and developments in technology.

B. <u>Basic Responsibility and Functions</u>

1. The DOC by law has the basic responsibility for the establishment and operation of its operational satellite systems, which includes obtaining necessary funds.

2. NASA by law has the basic responsibility for the development of new and advanced technology, and operational prototype spacecraft as required, in support of operational satellite systems, which includes obtaining necessary funds.

3. NASA and DOC agree to perform the functions and follow the management duties and procedures set forth in paragraphs D and E of this section.

C. <u>Funding</u>

1. <u>Operational Satellite Systems</u>

The DOC will submit and defend requests for annual appropriations to establish and operate the operational satellite systems. The DOC will develop the plans and budget estimates for the justification thereof, with the assistance and support of NASA and other agencies, as appropriate. At the beginning of each fiscal year, or as soon thereafter as funds are appropriated, or as program changes require, the DOC will issue a reimbursement order to NASA for the full amount of funds required for the execution of the NASA portion of the program during that fiscal year, in accordance with the approved Project Plan or Operations Plan prepared under this agreement. NASA will provide appropriate budget estimates and account to DOC for the funds so transferred in accordance with a reporting procedure to be agreed upon in a memorandum of understanding. NASA also will provide necessary reports to the DOC regarding the proposed and actual commitments, obligations, and expenditures of these funds, so that DOC may meet its fiscal responsibilities with respect to the funds appropriated to it or otherwise received.

2. Research and Development

NASA with the assistance of NOAA and other agencies, as appropriate, will submit and defend requests for annual appropriations for the development of supporting technology and for operational prototype spacecraft in support of the operational satellite system.

D. Functional Responsibilities

The functions of the DOC and NASA in the conduct of the operational satellite program are as follows:

1. The Department of Commerce shall:

   a. Determine overall program requirements (including cost and schedule).

   b. Specify quantities to be measured by satellite instruments.

   c. Approve the basic plan of approach and concur in the Project Plan[1] prepared by NASA and changes involving schedules, resources, interfaces, and performance.

   d. Approve Project Operating Plans[2] prepared by NASA for the operational systems.

   e. Monitor the performance of the systems for meeting user requirements.

   f. Determine the need for replacing a spacecraft that has experienced marginal failure.

   g. Operate the DOC Command and Data Acquisition Stations, including control of the operational satellites after NASA has determined that the satellites are ready for operational use.

   h. Operate remote DOC satellite ground terminals, including data collection and position location facilities.

---

[1] Project Plan - as defined in NASA Management Instruction -NMI 7120.1 dated May 4, 1970

[2] Project Operating Plan - Semi-annual time phased funding requirements submitted by each project

i. Communicate operational data from CDA stations to NOAA, NASA, and others, as appropriate.

j. Process data for use.

k. Disseminate data, analyses, forecasts, etc.

l. Archive data (processing, storage, retrieval).

m. Use the data for the purposes of research and environmental applications.

n. Conduct system studies as required to meet its responsibilities.

o. Establish ground facilities as appropriate.

2. The National Aeronautics and Space Administration shall:

a. Prepare the Basic Plan of Approach, the Project Plan, and the Project Operating Plans for spacecraft and launching.

b. Design, engineer, procure, and qualify flight spacecraft.

c. Select and procure launch vehicles.

d. Maintain and operate launch sites.

e. Design, construct, and insure initial operational status of Command and Data Acquisition stations, and other ground equipment, as may be requested by and agreed with DOC.

f. Prepare the pre-launch plans for the spacecraft and launch vehicles.

g. Conduct launch operations.

h. Track and determine basic orbital parameters during the useful life of the satellite.

i. Monitor the engineering status of the satellite and command the satellite during initial time in orbit and as required by the Project MOU, using the DOC Command and Data Acquisition Stations, Control Center, and Data Processing facilities as appropriate.

j. Consult, as appropriate, on technical matters.

E. Management Responsibilities and Procedures

1. The management of the functions of the Department of Commerce portion of this agreement is a responsibility of the National Oceanic and Atmospheric Administration (NOAA) under authority delegated by the Secretary of Commerce under Departmental Order 25-5B as amended. The NOAA shall provide or obtain the necessary DOC resources and shall serve as the official DOC contact for this program.

2. The management of the NASA portion of this agreement is the responsibility of Headquarters, Office of Applications. It shall provide the necessary NASA resources and shall serve as the official NASA contact for this program.

3. The following specific management functions and procedures are agreed upon:

a. The DOC will forward mission requirements to NASA and acceptance.

b. NASA will forward the basic plan of approach to the DOC-NOAA for review and approval.

c. NASA will forward the Project Plan to the DOC-NOAA for review and concurrence.

d. NASA will forward Project Operating Plans pertinent to the DOC operational systems to the DOC-NOAA for review and approval.

e. NASA will forward Requests for Proposals to the DOC-NOAA for review and comment.

f. Appropriate representation of the DOC will be assigned by the NOAA to the NASA and will participate in project planning and project implementation including definition of statements of work and specifications; source evaluation; and project financial, managerial, and technical status reviews. DOC Observers may be present during contract negotiations and fee determination meetings, and may participate, as appropriate, in award fee determination during the contract period.

g. NASA will make the final source selection, and will negotiate with and be the single official interface with the spacecraft and launch vehicle and launch support contractor.

h. NASA will submit to DOC-NOAA for review and concurrence the definitized contract work statement, schedules, and cost.

i. NASA will forward the final project plan to the DOC-NOAA for review and concurrence.

j. Major changes involving schedules, costs, and system performance will be forwarded by NASA to the DOC-NOAA for review and approval.

k. All changes affecting the interface between NASA-provided equipment and DOC-NOAA equipment will be forwarded to the DOC-NOAA for review and approval.

F. Interagency Relationships

The DOC-NOAA will furnish a statement of mission requirements to NASA, and will ensure that such requirements and the resulting project plans meet the needs of DOD and other user agencies, as appropriate.

SECTION III. THE DEVELOPMENT OF SUPPORTING TECHNOLOGY FOR OPERATIONAL SATELLITES

A. Scope

This section deals only with the development of space technology which is specifically identified as applying to operational satellite systems of the DOC.

B. Basic Responsibility and Functions

1. NASA has the basic responsibility for supporting the advancement of civilian satellite technology.

2. The DOC-NOAA will submit to NASA estimates of future satellite requirements and the DOC-NOAA estimates of present technological limitations to meeting them. NASA will draw up its R&D plans with due consideration of the stated NOAA requirements, the requirements of the scientific community, and the available technology, and will keep DOC fully informed on relevant R&D program plans and developments.

3. The DOC may conduct sensor development, but will coordinate with NASA to ensure compatibility with NASA's R&D program.

C. Funding

NASA will fund for and manage the supporting technology effort for relevant operational satellite development programs.

D. Management Procedures

1. Supporting technology under this agreement is the responsibility of the Office of Applications in NASA Headquarters.

2. The NASA, after consultation with the DOC-NOAA, and in accord with established payload selection procedures, will choose and allocate space in its R&D satellites for flight tests of experimental sensors pertinent to the DOC operational satellite systems. NASA will fund for these tests, including the costs of flight hardware beyond the preprototype stage.

E. Data

1. Data from proven sensors flown in NASA research and development satellites, such as Nimbus scanning radiometer data, will be made available at the request of the DOC/NOAA for operational use.

2. Data from experimental sensors flown in NASA R&D satellites, such as the Nimbus SIRS, ATS SSCC, and other new sensor developments of potential operational use, will be made available to the NOAA as soon as practicable, on a non-interference basis to NASA missions, for the conduct of operational experiments. In the case of these data, the experimenting agency may retain exclusive publication rights for a negotiated period of time, but the

DOC may conduct operational experiments during this period with the proviso that dissemination of these data is restricted to such purposes, and that scientific publication will not result without the concurrence of the experimenter.

3. NASA will be reimbursed for all additional costs incurred in making such data available to the NOAA.

SECTION IV. DOC-NASA SATELLITE PROGRAM REVIEW BOARD

A DOC-NASA Satellite Program Review Board (SPRB) is hereby established. The Board is composed of two members each from NASA and DOC-NOAA, with the Associate Administrator for Applications of NASA and the Associate Administrator of NOAA serving as co-chairmen. The Board will meet quarterly or at the request of either co-chairmen to review the program and consider any substantive issues which may arise. It may make recommendations to the DOC and/or the NASA on the resolution of issues concerning the operational programs and their supporting R&D activity. Either chairman may refer any issue to the Deputy Administrator of NASA and to the Administrator of NOAA for resolution.

SECTION V. MEMORANDA OF UNDERSTANDING

A. A specific and separate memorandum of understanding, including reporting procedures, shall be negotiated and agreed for each major project. Examples of major projects are ITOS, TIROS N, SMS/GOES, etc. Memoranda will be co-signed by the co-chairmen of the Satellite Program Review Board established under the terms of Section IV above.

B. Memoranda of understanding for major projects shall include, as a minimum:

1. Commitment of NASA and NOAA staff to be assigned directly to the project for planning, technical, and administrative monitoring, including resident representation at contractor facilities;

2. Definition of authority

3. Reporting requirements

4. Schedule

5. Commitment of resources (funds, facilities, etc.)

C. Memoranda of understanding may be revised at the request of either co-chairman of the Satellite Program Review Board.

D. Supplementary memoranda of understanding, within the terms of the above, may be negotiated at the working level as appropriate.

SECTION VI. RELEASE OF PUBLIC INFORMATION

Release of public information on the operational and directly related R&D programs may be initiated by either the DOC-NOAA or by NASA. Before any release is issued to the public, however, clearance and final approval must be given by the agency having the assigned function listed in Section IID or Section IIIB. Coordinated or joint releases should be issued where appropriate.

SECTION VII. INTERNATIONAL RELATIONS

A. International negotiations may be carried out by either agency according to its basic responsibilities and functions as defined in this agreement, with due regard to the provisions B and C below and subject to normal State Department policy guidance.

B. Where such negotiations imply obligations or place commitments upon the other agency, that agency will be consulted in advance of international agreement or commitment.

C. The design of the operational satellite systems covered by this agreement will give due consideration to the commitments already expressed or implied by the United States.

SECTION VIII. DURATION AND AMENDMENT OF AGREEMENT

A. This agreement supersedes the DOC/NASA agreement dated January 30, 1964, entitled "Basic Agreement Between U.S. Department of

Commerce and the National Aeronautics and Space Administration Concerning Operational Meteorological Satellite Systems," and shall remain in effect indefinitely. The Meteorological Satellite Program Review Board and the Advisory Committee established by Section IV and Section III Paragraph D2 of the January 30, 1964 agreement cease to exist upon the date of affixing signatures of both agencies to this agreement.

B. DOC or NASA can recommend termination or modification of this agreement at any time. The agreement will be reviewed formally at the request of either Agency.

Signed by Administrator Fletcher	Signed by Secretary Dent
Administrator, NASA	Secretary of Commerce

Memorandum of Understanding Between the Department of Commerce (DOC)
National Oceanic and Atmospheric Administration (NOAA)
and the
National Aeronautics and Space Administration (NASA)

PROGRAM PLANNING/BUDGETING AND COST ANALYSIS

I. Scope of Memorandum of Understanding

Taking note of the Basic Agreement between the DOC and NASA concerning Operational Environmental Satellite Systems, this memorandum establishes the procedures for the conduct of program planning/budgeting and cost analysis activities by NASA and NOAA, as these relate to work performed by NASA for NOAA under reimbursable arrangements.

II. Program Planning and Budgeting

A. Introduction

Recognizing the roles of NASA and NOAA in the conduct of the National Environmental Satellite program, NOAA will receive budgetary estimates and financial reports from NASA at stated intervals to enable NOAA to prepare its budget requests and to control its available resources. NASA inputs will be provided for the following NOAA events:

1. The Annual NOAA Program Review — February
2. Preparation of budget estimates for OMB — May
3. Preparation of the Congressional budget — November
4. Preparation of NOAA financial plans — June/July

B. Procedures

1. NOAA will submit to NASA Headquarters (with copy to GSFC) a description of satellite program objectives and satellite system requirements (e.g., planning launch schedules, number and types of spacecraft as specified in separate Project Memorandum of Understanding, etc.) for a period extending from the current year through a planning period of five (5) years, or other period designated by OMB. A reasonable number of program alternatives may be included. Program objectives and satellite system requirements will be provided by NOAA on December 1 and June 1.

2. NASA will prepare accrued cost budget estimates, including programs to attain NOAA objectives. NESS liaison personnel at GSFC may assist in the preparation of budget estimates and may review the completed estimates with the cognizant GSFC personnel.

a. NASA will provide its response to the NOAA December 1 program objectives by the following February 1.

b. NASA will provide its response to the NOAA June 1 program objectives by the following August 1.

3. During the period of the NOAA program budget review with the DOC and the OMB, it may be necessary for NOAA to request additional information from NASA. Both parties to this agreement recognize that such requests may be in the form of program alternatives not previously defined nor provided by NOAA in the original program objective submission. NASA will provide rapid response to such requests, and NESS liaison personnel will provide maximum assistance possible to the cognizant GSFC personnel (in this activity).

4. NOAA will provide timely advice to NASA of any program changes which may occur during the various stages of the NOAA budget cycle.

5. Not later than May 15, NOAA will provide purchase orders, effective July 1, to NASA Headquarters, covering the estimated accrued cost for the next fiscal year for continuing and approved new-start NOAA programs, up to the level allowed by law. At the option of NOAA, these purchase orders will provide either for first quarter or for full year funding. The status of Congressional action on the NOAA budget request will determine the option that NOAA will exercise. In the event that NOAA elects to provide quarterly funding, additional purchase orders will be provided at least six weeks prior to the start of each quarter.

III. Cost Analysis

A. Introduction

It is recognized that cost analysis is the responsibility of both NASA and NOAA. To exercise this responsibility, NOAA staff will interface through the Project Office with those directorates of GSFC which contribute to the operational program. The objective is the continuing analysis and reporting of actual program schedule and cost versus budgeted schedule and cost.

B. Procedures

1. GSFC project personnel and NESS representatives will jointly review the NOAA programs being undertaken by GSFC on a monthly or quarterly basis as designated below. A detailed review of accrued cost projections will be included. In general, flight projects will be reviewed monthly, while other projects such as Maintenance and Operation ground support to the Gilmore Creek command and Data Acquisition Station will be reviewed quarterly. Reviews will evaluate cost performance and cost outlook against the established budgetary target in order to facilitate management decisions and actions.

2. GSFC and NESS representatives will prepare jointly a monthly financial analysis and outlook for submission to NASA Headquarters and NOAA. The analysis will be by each major project (e.g., ITOS, GOES, TIROS-N, Delta) and by sub-projects as agreed on by GSFC and NESS representatives. The monthly report will contain:

a. Cost to date.

b. Cost projections for the current FY as compared to NOAA budget levels.

c. The April and October reports will additionally provide cost projections for the next fiscal year, and

d. Cost to completion, where appropriate.

e. A narrative summarizing the results of the monthly project review.

In the event that an agreed-on analysis cannot be achieved, the representatives of each agency will summarize the areas of difference for submission as part of the narrative in 2e, above.

IV. Amendments

This memorandum of understanding may be amended at any time by mutual consent of the signatories.

Signed by Associate Administrator Townsend	Signed by Associate Administrator Mathews
John W. Townsend, Jr. Associate Administrator, NOAA	Charles W. Mathews Associate Administrator for Applications NASA

REVISED AGREEMENT BETWEEN
THE DEPARTMENT OF DEFENSE
And The
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Concerning
THE AERONAUTICS AND ASTRONAUTICS COORDINATING BOARD

(This Agreement supersedes and replaces the Agreement of similar title dated September 13, 1960.)

I. Policies and Purposes.

(a) It is essential that the aeronautical and space activities of the National Aeronautics and Space Administration and the Department of Defense be coordinated at all management and technical levels. Where policy issues and management decisions are not involved, it is important that liaison be achieved in the most direct manner possible, and that it continue to be accomplished as in the past between project-level personnel on a day-to-day basis.

(b) It is essential that close working relationships between decision-making officials within the National Aeronautics and Space Administration and the Department of Defense be developed at all management levels. Where policy issues and management decisions are involved, it is important that the planning and coordination of activities, the identification of problems, and the exchange of information be facilitated between officials having the authority and responsibility for decisions within their respective offices.

(c) To implement the foregoing policies it is the purpose of this Agreement to establish the Aeronautics and Astronautics Coordinating Board.

II. Establishment of the Board.

There is hereby established the Aeronautics and Astronautics Coordinating Board, which shall be responsible for facilitating —

(1) the planning of activities by the National Aeronautics and Space Administration and the Department of Defense to avoid undersirable duplication and to achieve efficient utilization of available resources;

(2) the coordination of activities in areas of common interest to the National Aeronautics and Space Administration and the Department of Defense;

(3) the identification of problems requiring solution by either the National Aeronautics and Space Administration or the Department of Defense; and

(4) the exchange of information between the National Aeronautics and Space Administration and the Department of Defense.

III. Composition of the Board.

(a) The Board shall be headed by the Deputy Administrator of the National Aeronautics and Space Administration and the Director of Defense Research and Engineering as Co-Chairmen.

(b) The other Board members shall consist of Co-Chairmen of panels as hereinafter established, and a minimum number of additional members as may be required to insure that each military department is represented and that the National Aeronautics and Space Administration and Department of Defense have an equal number of members.

(c) The members of the Board shall be appointed by the Co-Chairmen, jointly.

IV. Principles of Operation.

(a) Panels of the Board shall be established by the Co-Chairmen and shall include the following:

(1) Manned Space Flight and Launch Vehicles Panel
(2) Unmanned Spacecraft Panel
(3) Space Flight Ground Environment Panel
(4) Supporting Space Research and Technology Panel
(5) Aeronautics Panel

(b) Terms of reference shall be prescribed for each panel by the Co-Chairmen of the Board. The Co-Chairmen and members of each panel shall be designated by the Co-Chairmen of the Board.

(c) The Board shall meet at the call of the Co-Chairmen, at least quarterly, and the Co-Chairmen shall alternately preside over the meetings. Only Board members, and such other as the Co-Chairmen specifically approve, may attend meetings.

(d) The Co-Chairmen shall establish a small secretariat to maintain records of the meetings of the Board and of its panels and to perform such other duties as the Co-Chairmen may direct.

(e) The Board, its panels, and the secretariat shall make full use of available facilities within the National Aeronautics and Space Administration and the Department of Defense, and all elements of the Administration and the Department of Defense shall cooperate fully with the Board, its panels, and the secretariat.

(f) Actions based on consideration of matters by the Board may be taken by individual members utilizing the authority vested in them by their respective agencies.

FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION:

Signed by
Acting Administrator Low

George M. Low
Acting Administrator

Date: Signed on Jan. 7, 1971

FOR THE DEPARTMENT OF DEFENSE:

Signed by
Secretary Laird

Melvin R. Laird
Secretary of Defense

Date: Signed on Jan. 20, 1971

CHARTER

Interagency Coordination Committee: Earth Resources Survey Program

1. Purpose: This charter establishes the Interagency Coordination Committee, herein called the Committee, for the Earth Resources Survey Program (ERSP) of the Federal Government. The Committee shall be the primary Executive Branch mechanism to coordinate and integrate Federal plans, policies, and programs of aerospace remote sensing of the earth's resources.

2. Scope: This charter applies to all Executive Departments and Establishments with substantial roles in the experimental ERSP or related programs as defined below. The following policy guidelines shall apply to the ERSP:

   2.1. The primary objective of the experimental effort is to evaluate both the feasibility, benefits and costs of a long term ERSP.

   2.2. Each user agency is responsible for developing applications and test programs and for evaluating and justifying the usefulness of Earth Resources Survey activities to the community it serves. The user agencies, together with the lead development agency, are responsible for appropriate data dissemination to the citizens of the United States and abroad.

   2.3. The National Aeronautics and Space Administration, as the satellite technology development agency for the experimental ERSP, is charged with insuring that the development effort is responsive to the requirements of the participating Federal Agencies as determined by the Committee.

   2.4. The technology development role of the National Aeronautics and Space Administration does not preclude other Federal agencies from ground-based development activities. However, all earth resources research should be coordinated and integrated so that individual activities will be mutually supporting to the maximum extent possible. It is the primary function of the Committee to facilitate this coordination between user agencies as well as between user and development agencies.

3. Definitions:

3.1. Earth Resources Survey Program (ERSP). This program is comprised of activities within the Federal Government related to experimental remote sensing of earth resources from aircraft and spacecraft and associated data handling and analysis activities. These include the following:

- Experimental earth resources satellite programs, including the Skylab Earth Resources Experiment Package.
- Experimental earth resources aircraft programs.
- Data acquisition, processing, analysis, distribution and archiving facilities, and resources associated with experimental satellite and aircraft programs.
- Supporting research and development programs related to the foregoing.

3.2. Related Agency Programs. These are agency programs which may beneficially use outputs from the experimental ERSP for activities that produce data or information which may be useful to Earth Resources Survey research, but which are not primary elements of the experimental ERSP defined in 3.1. These programs would include related aspects of the following:

- National Environmental Satellite Service programs.
- Federal civil aircraft observation and survey programs.
- Related surface sensor programs.
- Data analysis, interpretation and dissemination activities associated with agency programs.
- Development of appropriate environmental and resource models.
- Research and development in support of the foregoing where not otherwise covered in the experimental Earth Resources Survey program.

3.3. User Agencies. Those agencies which may potentially use ERSP data or information either to improve internal operations or as part of their direct services to the public in accordance with their established mission.

4. Responsibilities and Authority of the Committee: In conjunction with the authority of the participating Departments and Establishments, the Committee is responsible for the conduct of the following activities:

4.1. Coordination and Integration of the Experimental National Earth Resources Survey Program.

— The Committee will provide a focus for the conceptualization and implementation of general and specific experiment ERSP activities.

— The Committee will establish procedures to obtain information from agencies and other users in order to validate requirements for data on a continuing basis.

— Based on validated data requirements, the Committee will perform a systematic and continuing review of agency and other user requirements to assess the potential value of current and proposed remote sensing systems and facilities, the optimum composition and characteristics of such systems and facilities, and the need for future improvements.

— Based on agency inputs, including those from lead agencies for certain components of the program, the Committee will coordinate the plans and programs which comprise the national program and review and comment, on a timely basis, on budgets for the various elements of the program.

— It will develop and disseminate guidelines and priorities for planning and operating interagency facilities in support of the ERSP.

— The Committee will examine the long-term inpact of the location, equipping, and staffing of facilities intended predominantly to support ERSP.

— The Committee will undertake studies, as may be required, to determine (1) the overall program priorities and direction, (2) the benefits from existing and proposed program activities, and (3) an appropriate balance between research, development, and operationally-oriented activities.

4.2. Coordination of Related Agency Program. The Committee will review appropriate related agency plans, programs, and budgets to ensure compatability between the ERSP and appropriate elements of the related agency programs. This review is to ensure that maximum benefits are being derived from program data and to ascertain that a balanced program is maintained within available funding. The Committee will make such recommendations on related programs to agency management as it deems appropriate following such review.

4.3. Coordination outside the Federal Government. The Committee will provide a focal point to coordinate National ERSP activities with related activities, agencies and institutions outside the Federal government. The Committee will not supersede other coordinating mechanisms dealing primarily with existing operational programs.

4.4. Preparation of Annual Federal Report and Plan. The Committee will each year prepare and submit by August 31 to the Office of Management and Budget a report of all Federal activities in Earth Resources Surveys, including the national program and appropriate elements of related agency programs. The report will be a Federal Plan for Earth Resources Surveys which will assess the progress of the experimental national program, its relationship to the related agency programs, and plans and resource requirements for the next fiscal year and succeeding four years.

5. Membership: The primary members of the Committee will be policy-level officials, nominally at the Assistant Secretary level. In addition, each agency will designate an alternate authorized to commit the agency, who will attend Committee meetings in the absence of the primary member. The Committee will be chaired during the experimental phase of the program by the National Aeronautics and Space Administration. The Committee will select a Vice-Chairman from the primary members of the user agencies, who will chair meetings in the absence of the Chairman. The Committee will be composed of members from the following agencies:

National Aeronautics and Space Administration
Department of Agriculture
Department of Commerce
Department of Defense
Department of Interior
Department of State
Corps of Engineers (Civil Works)
Environmental Protection Agency
Office of Science and Technology

Other Federal agencies with developing interest in Earth Resources Surveys will be invited to participate by the Committee and to become members when appropriate.

Official observers to the Committee's activities will be provided by the following agencies within the Executive Office of the President:

Council on Environmental Quality
National Aeronautics and Space Council
Office of Management and Budget
National Security Council

Other observers may be invited as appropriate.

6. Procedures:

6.1. Meetings. Meetings will be held at the call of the Chairman. The Chairman will honor a request by any member to call a meeting and to place items on the agenda. Any member may initiate committee action items.

6.2. Committees and Advisers. The Committee shall establish those standing and ad hoc subcommittees or panels necessary for the conduct of committee business. Members may be assisted by advisers during meetings, and upon request of the Committee, the advisers may make reports and presentations.

6.3. Supporting Services. The Committee will select, direct, and be supported by two full-time executive coordinators, at least one of which shall be provided by a user agency. They shall provide timely notice of meetings, advanced agenda, background information, and follow-up reports on action items, as well as prepare the Federal Plan outlined in paragraph 4.4. Agencies will supply additional Committee support when required. In preparation for a meeting, or between meetings, any member may request assistance from the coordinators. Other supporting services for the Committee, including the retention of all official records, reports, and files, will be provided by the Office of Science and Technology.

7. Duration: This charter will remain in effect for three years subsequent to establishment unless terminated sooner by the Office of Management and Budget.

BIBLIOGRAPHY

1. NASA Meteorology Long Range Plan. 5-Year Plan.

2. NASA FY-75 Congressional Testimony (Weather and Climate).

3. NASA FY-74 Congressional Testimony (Weather and Climate).

4. Final Report of the Space Shuttle Payload Planning Working Groups. NASA-GSFC, May 1973.

5. Meteorological Uses of the Synchronous Earth Observatory Satellite. Space Science and Engineering Center, University of Wisconsin, July 31, 1973.

6. Earth Resources Applications of the Synchronous Earth Observation Satellite (SEOS). Environmental Research Institute of Michigan, October 1973.

7. EOS Payload Discussion Group — Final Report. EOS-410-09, October 1973.

8. A Plan for the Observation, Study, and Amelioration of Transient Environmental Phenomena (SEOS) NASA, August 18, 1971.

9. Advanced Scanners and Imaging Systems for Earth Observations. NASA SP-335.

10. Drummond, Robert R.: Digest of NASA Earth Observation Sensors. GSFC X-733-72-464, December 1972.

11. Earth Observatory Satellite (EOS) Definition Phase Report. GSFC X-401-72-332, August 1971.

12. Earth Observatory Satellite Mission Review Group (EOSMRG) — Final Report. GSFC X-401-72-333, November 1971.

13. Federal Plan for Meteorological Data from Satellites. Federal Coordinator for Meteorological Services and Supporting Research, FCM 71-5, May 1971.

14. GARP Project Data Systems Test Plan. August 1973.

15. Synchronous Meteorological Satellite System Description Document. Vols. 1-4, GSFC.

16. The Federal Plan for Meteorological Services and Supporting Research FY 1974. Federal Coordinator for Meteorological Services and Supporting Research, June 1973.

17. The First GARP Global Experiment — Objectives and Plans. GARP Publication No. 11, WMO, March 1973.

18. TIROS N Phase A Report. Vols. 1-3, GSFC, 1973.

19. Final Report of the Space Shuttle Payload Planning Working Groups. Volume 7, Earth Observations Working Group, NASA/GSFC, 1973.

20. National Atmospheric Sciences Program, FY 1974. Federal Council for Science and Technology, Interdepartmental Committee for Atmospheric Sciences (ICAS), 1973.

21. Useful Applications of Earth-Oriented Satellites — Meteorology. Vol. 4, National Academy of Sciences, 1969.

22. Plan for U.S. Participation in the Global Atmospheric Research Program. National Academy of Sciences, 1969.

23. The Atmospheric Sciences and Man's Needs — Priorities for the Future. National Academy of Sciences, 1971.

24. Remote Measurement of Pollution (RMOP). Report of a working group meeting at Norfolk, Va., August 16-20 1971. NASA SP-285, prepared by the Langley Research Center, 1971.

25. Multidisciplinary Studies of the Social, Economic, and Political Impact Resulting from Recent Advances in Satellite Meteorology. An Interim Report in four volumes (I and II, June 71; III and IV, August 72) Grant NGL 50-002-114, Space Science and Engineering Center, University of Wisconsin.

26. Study of Critical Environmental Problems (SCEP), 1970: Man's Impact on the Global Environment. MIT Press.

27. Study of Man's Impact on Climate (SMIC), 1971: Inadvertent Climatic Modification. MIT Press.

28. World Weather Program, Plan for Fiscal Year 1974. Annual Report to the Congress, The White House, 1973.

29. Thompson, J. C.: The Potential Economic Benefits of Improvements in Weather Forecasting. Final Report, Grant NGR 05-046-005, California State University, San Jose, California, 1972.

30. COSPAR Report on the Application of Space Techniques to Some Environmental Problems — Preliminary Observing System Considerations for Monitoring Important Climate Parameters. Prepared by COSPAR Working Group 6 for the United Nations and Scientific Committee on Problems of the Environment (SCOPE), 1972.

31. Federal Plan for Meteorological Services and Supporting Research. Department of Commerce, NOAA, FY-1973.

32. National Severe Local Storms Operations Plan. Department of Commerce, NOAA/FCM 74-3, February 1974.

33. A Federal Plan for Natural Disaster Warning and Preparedness. Department of Commerce, NOAA, June 1973.

34. Federal Plan for National Climatic Services. Department of Commerce, NOAA, FCM 74-1, January 1974.

35. Atmospheric Exploration by Remote Probes. Vol. 1, National Academy of Sciences, 1969.

36. Goddard Institute for Space Studies Program Plan for Meteorological Research (1974-79).

37. Zero-Gravity Cloud Physics Laboratory, Experiment Program Definition and Preliminary Laboratory Concept Studies. NASA-MSFC CR-129013, September 1973.

38. Plan for U.S. Data Management in the Global Atmospheric Research Program. National Academy of Sciences, Washington, D.C., 1971.

39. The Global Atmospheric Research Programme. World Meteorological Organization, International Council of Scientific Unions, 1971.

40. An Introduction to GARP. GARP Publication Series No. 1, World Meteorological Organization, International Council of Scientific Unions, October 1969.

41. Plan for U.S. Participation in the GARP Atlantic Tropical Experiment. National Academy of Sciences, Washington, D.C., 1971.

42. The Planning of the First GARP Global Experiment. GARP Publication Series No. 3, World Meteorological Organization, International Council of Scientific Unions, October 1969.

43. The Planning of GARP Tropical Experiments. GARP Publication Series No. 4, Meteorological Organization International Council of Scientific Unions, January 1970.

44. Report of the Planning Conference on the First GARP Global Experiment. GARP Special Report No. 8, World Meteorological Organization, International Council of Scientific Unions, October 1972.

45. Report of the Interagency Ad Hoc Study Group on the Earth Resources Survey Program. Prepared by National Aeronautics and Space Council, 1971.

46. Annual Federal Report on Earth Resources Survey Programs. Prepared by the Interagency Coordination Committee for the Earth Resources Survey Program, 1972.

47. Office of Applications Earth Resources Program Summary. Prepared by the Earth Resources Program Office, Johnson Space Center, 1974.

48. Earth Resources Program, Results and Projected Applications, ERTS-1 Applications Investigations. Prepared by the Earth Resources Program Office, Johnson Space Center, 1973.

49. Synthesis and Analysis of ERTS Program, Midterm Report, Water Resources, Significance, User Requirements, Remote Sensing Applications. Contract NASW-2488, Ecosystems International, Inc., Gambrills, Maryland, November 15, 1973.

50. Photography from Space to Help Solve Problems on Earth. NASA Pamphlet.

51. Nimbus Earth Resources Observations. Report No. 9G90-8, Allied Research Associates, Inc., Concord, Mass., November 1971.

52. FY 1975 Congressional Testimony, Earth Resources Survey Program. C. W. Mathews, NASA.

53. The Federal Ocean Program. U.S. Government Printing Office, Stock No. 3800-00149, April 1973.

54. Earth Resources Program, Results and Projected Applications, ERTS-1, Applications Investigations. NASA-JSC, November 1973.

55. Earth Photographs from Gemini III, IV, and V. NASA SP-129, Library of Congress Catalog Card No. 66-62098, 1967.

56. Earth Photographs from Gemini VI through XII. NASA SP-171, Library of Congress Catalog Card No. 68-61301, 1968.

57. Ninth International Symposium on Remote Sensing of Environment Summaries. Environmental Research Institute of Michigan, Ann Arbor, Michigan.

58. A Report to: The President and Congress. National Advisory Committee on Oceans and Atmosphere, Second Annual Report, June 29, 1973.

59. A Report to: The President and Congress. National Advisory Committee on Oceans and Atmosphere, First Annual Report, June 30, 1972.

60. Federal Plan for Marine Environmental Prediction. Fiscal Year 1973, U.S. Department of Commerce, NOAA, Washington, D.C., March 1972.

61. Remote Sensing with Special Reference to Agriculture and Forestry. National Academy of Sciences, 1970.

62. 1972 Annual Federal Report on Earth Resources Survey Programs. Interagency Coordination Committee for the Earth Resources Survey Program, August 1973.

63. Fourth Annual Earth Resources Program Review. MSC-05937, January 1972.

64. Lowman, Paul D., Jr.: Space Panorama. Weltflugbild, Zurich, Switzerland, Library of Congress Catalog Card No. 68-19817, 1968

65. Report of the Interagency Ad Hoc Study Group on the Earth Resources Survey Program. National Academy of Engineers, March 10, 1971.

66. Symposium of Significant Results Obtained from the Earth Resources Technology Satellite — 1. NASA SP-327, 1973.

67. Environmental Quality. The annual report of the Council on Environmental Quality to the Congress for the years 1970 through 1973.

68. Proceedings of the Interagency Conference on the Environment. Held October 17-19, 1972, Livermore California, Sponsored by EPA and ADC, Hosted by Lawrence Livermore Laboratory, University of California, CONF 721002, Available from National Technical Information Service.

69. Ludwig, C. B.; Griggs, M.; Malkmus, W.; and Bartle, E.R.: Air Pollution Measurements from Satellites. NASA CR-2324, November 1973.

THE SPACELAB SORTIE MISSION

1. INTRODUCTION

This mission description provides a typical layout of how the Spacelab can be used to accomplish experiments in the earth observations area as well as experiments from the other applications disciplines. The Spacelab will be used primarily as a test bed for the development of observational techniques and sensors, equipment, and procedures for the Earth Observation Program.

2. PRELIMINARY LAYOUT

A preliminary layout of a complement of application experiment equipment and sensors including that for earth observation has been made. The task was performed to ascertain the requirements and problems that are associated with the integration of several application disciplines within Spacelab. Included in this configuration are experiment equipment from space processing, earth and ocean physics, communications, and earth observation experiment areas. A sketch of the layout is presented in Figure 1. The complement of instrumentation does not represent an approved configuration or mission, but is presented to give the reader the basic concept of a mission configuration.

The earth observation equipment included in the layout will be taken into space to check out, calibrate, test, and evaluate the equipment and operations but primarily to determine its utility to make significant physical measurements. This item of equipment might then be included in a long term automated satellite for synoptic data gathering.

The zero-g cloud physics experiments will be flown for the purpose of increasing the understanding of numerous microphysical processes and their relation to such aspects as the growth of cloud particles and its role in cloud dynamics required in weather modification development. In laboratory research, the particles extend from millimeter rain drops and ice crystals down to submicrometer condensation nuclei. Their study involves problems of drop dynamics, growth, collision, and electrical properties. The laboratory provides for long duration observation of the behavior of suspended particles and for the elimination of artificial supports and the attendant thermal, electrical, and mechanical contamination of the droplets.

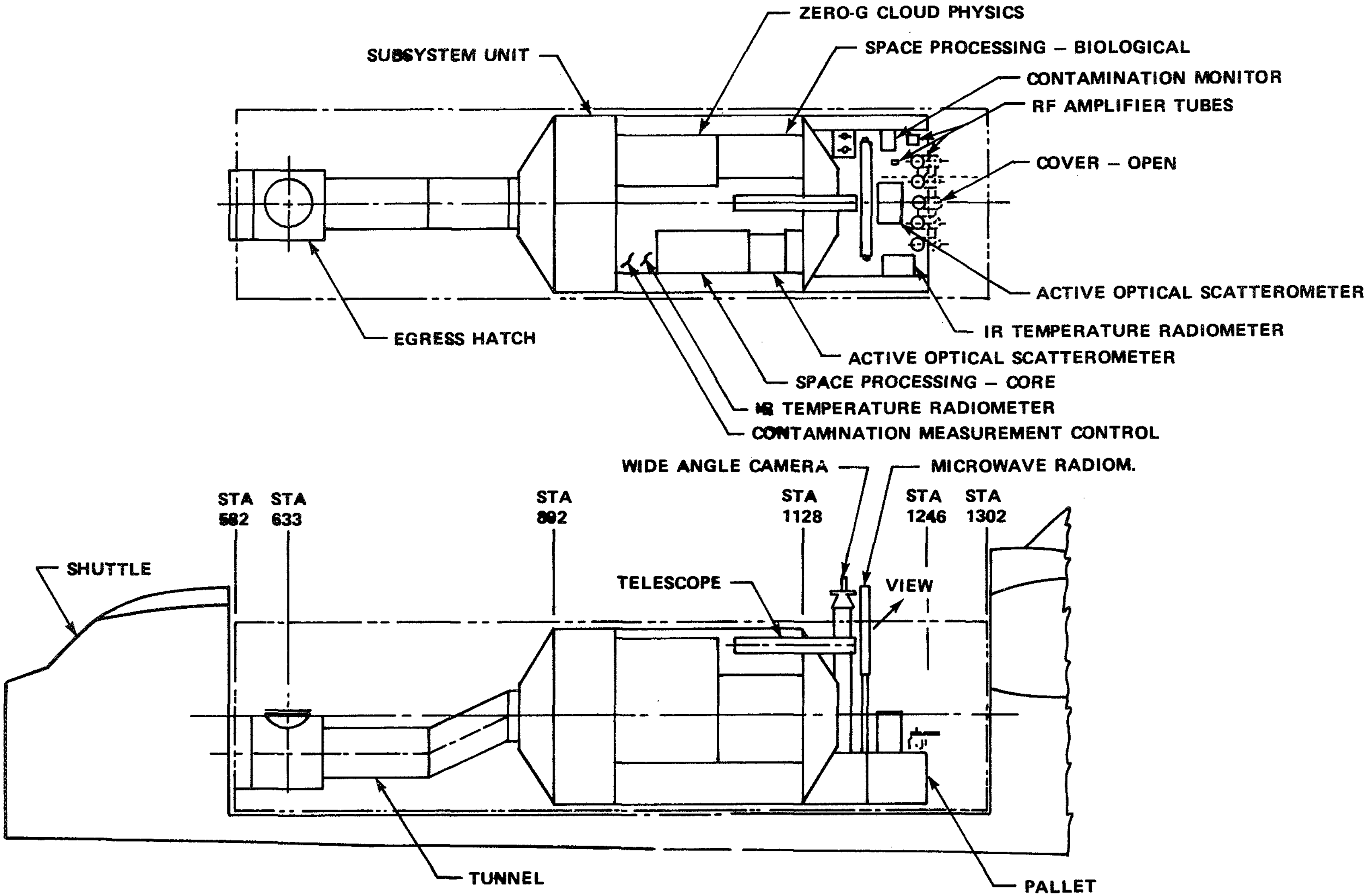


Figure 1. Office of Applications dedicated sortie concept.

It would be a flexible multiexperiment facility in which the experiments would vary from the simple observation of cloud chamber actions to complex measurements of physical processes. Some experiments would be for the examination of the nucleation properties of soluble, insoluble, and hydropholic nuclei; growth and optical properties of ice crystals; ice multiplication processes within clouds; scavenging processes of precipitation particles; and diffusional growth of sodium chloride nuclei.

II. APPENDIX TO CHAPTER IV

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF TABLES

THE SEASAT-A MISSION

SEASAT-A is the first spacecraft dedicated to meeting, at least partially, the Earth and Ocean Physics Applications Program objectives in ocean dynamics. It is an outgrowth of a scientific and technical work conducted by NASA, the Department of Defense, the Department of Commerce, and several other institutions in both the measurements of the physical phenomena and the implementation of the appropriate sensors on the spacecraft and on the ground.

During the feasibility study phase of SEASAT-A, which took place in early 1973, NASA sought the involvement of the "user" community, the agencies and institutions that are the intended users of SEASAT-A data, to help ensure that the needs of the organizations and the types and quantity of data to flow from the spacecraft are as satisfactory as possible. The list of active users is contained in Section 6 of Chapter IV.

SEASAT-A is a research-oriented program consisting of spacecraft, precision ground tracking systems, and data processing and modeling capabilities that will address both scientific and applications problems in ocean surface dynamics. Its strong suit is in an array of active radar and passive microwave and infrared instruments that give it the capability to observe the ocean on a day/night, near-all-weather basis. It is this group of sensors that allows SEASAT-A to make quantitative measurements of oceanic, atmospheric, and geodetic parameters not only in clear weather but under wind and wave conditions, perhaps approaching hurricane force, as well as over regions lying under persistent cloud cover.

The mission profile for SEASAT-A is tentatively as follows: lifetime, 1 year minimum; orbit, approximately 800-km altitude at an inclination of 108 degrees (retrograde); eccentricity, less than 0.006, for a nearly circular orbit; period, 100 minutes, resulting in 14.5 orbits per day. This orbit is non-sun-synchronous and will precess through a day/night cycle in approximately 4.5 months. Its ground track for 1 day is shown in Figure 1; as can be seen, it spans almost all of the unfrozen oceans of the world, from the Antarctic to the Alaskan North Slope and the Canadian archipelago. The orbit is also optimum for fine-grained mapping of the geoid over the open ocean.

1. INSTRUMENTS AND SENSORS

Each of the sensors proposed for SEASAT-A has predecessors which have been successfully flown on both aircraft and spacecraft. These five instruments are described in the following paragraphs.

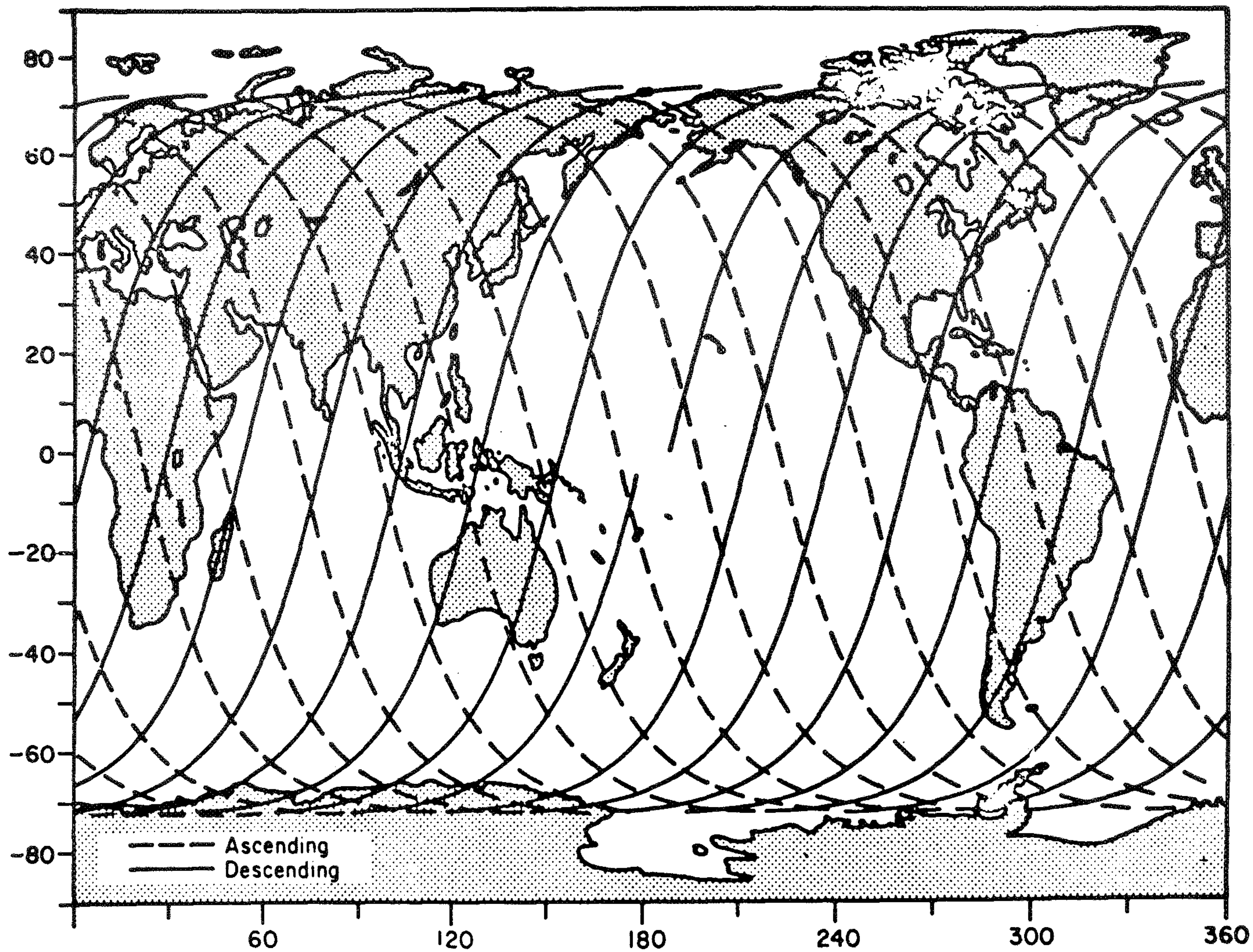


Figure 1. SEASAT-A orbital ground track during 1 day.

a. Compressed Pulse Radar Altimeter (CPRA). The CPRA has two distinct functions: (1) to measure the altitude between the spacecraft and the ocean surface to a root-mean-square precision near ± 10 cm, and (2) to determine average wave heights along the subsatellite path. The altitude, when blended together with accurate orbit determinations, may be used to decipher the topography of the sea surface including spatial variations in the geoid in the Western Atlantic where precise tracking is available, and to begin to sense time variations resulting from ocean dynamics.

b. Coherent Imaging Radar (CIR). The required extension of wave information will be made by using a coherent imaging radar to obtain images of the ocean on a sampled basis. Such a radar can function through clouds and moderate rain to yield wave patterns near shorelines and in storms, and can see waves whose length is greater than about 50 meters. It can also provide high resolution pictures of ice, oil spills, current patterns, and similar features. Computations can be performed on the radar data to yield a quantity called the wave directional spectrum which gives the relative distribution of wave energy among different wavelengths traveling in various directions; this, together with the surface wind velocity, is the fundamental information needed in forecasting wave conditions on the ocean.

Figure 2 illustrates two trains of waves off Kayak Island, Alaska, one of 150-meters and the other of 60-meter wavelength, taken from the NASA Convair 990 aircraft with the Jet Propulsion Laboratory imaging radar; the waves are being refracted and shortened by shoal water as they approach the island visible on the left side. Also on the lower left and center of the figure is a directional spectrum computed for the relatively uniform part of the wave train to the right of the image. Distance from the center of the spectrum corresponds to increasing wave frequency, angle to direction of propagation, and intensity to wave energy.

c. Microwave Wind Scatterometer (MWS). The third radar system is a microwave scatterometer, intended to measure surface wind speed and direction by sensing the small capillary waves induced by the wind over the ocean. Previous aircraft experience and recent Skylab data taken over the Pacific hurricane Ava in June 1973 indicate this sensor is useful in winds approaching 25 meters/second, yielding speeds with an error of ± 5 meters/second.

In the SEASAT-A configuration, the output of the scatterometer will be measurements of lower wind speeds and directions taken over two 450-km wide swaths equally displaced about nadir by 300 km. In 12 hours, these swaths map

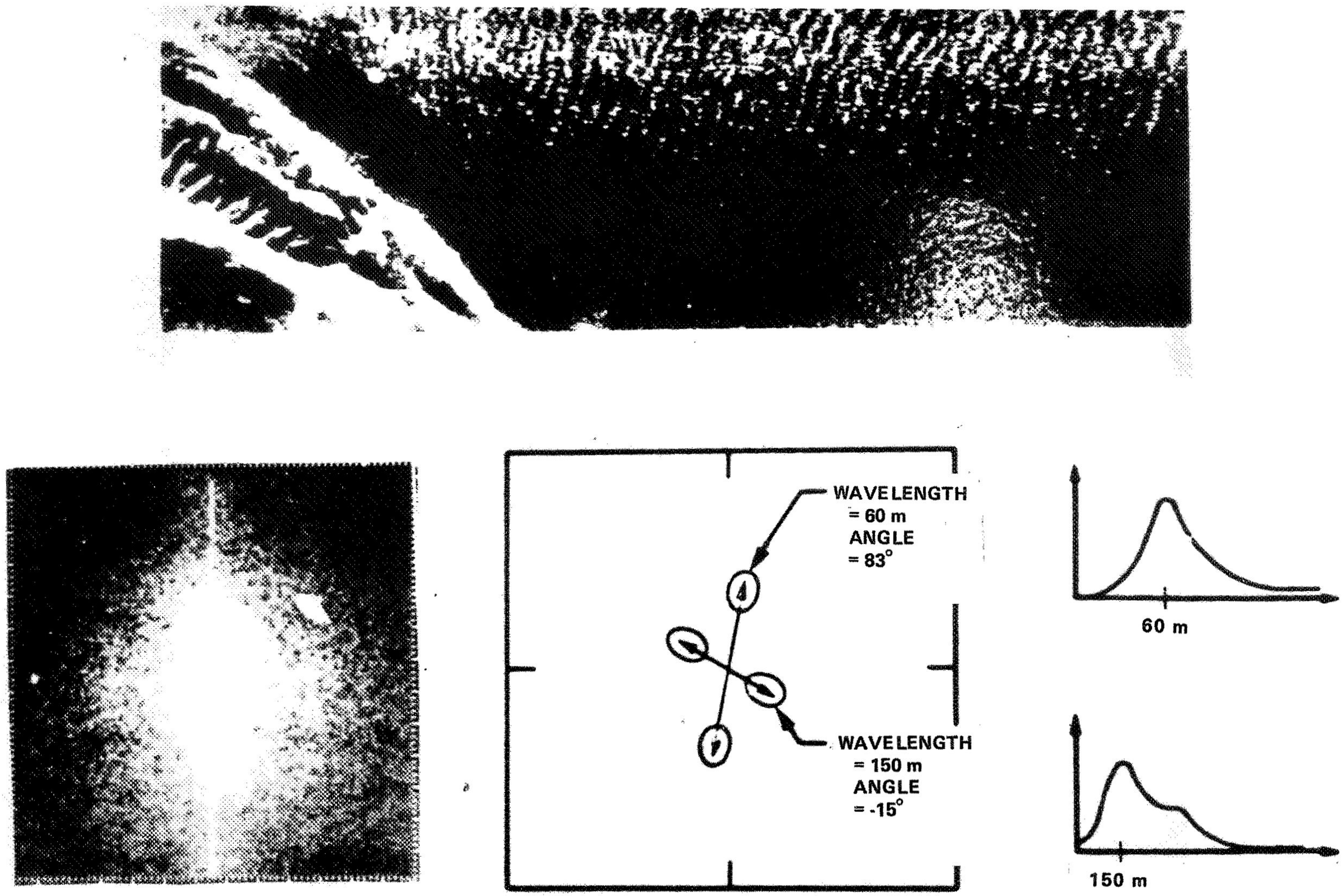


Figure 2. Section of ocean wave pattern south of Alaska.

out a quilt-like pattern of areas over the portion of the oceans between 72 degrees north and south latitude with enough density of observations so that an essentially complete chart of surface winds will be obtained.

d. Scanning Multifrequency Microwave Radiometer (SMMR). The SMMR is a passive, nonradiating microwave device, in contrast to the three previous sensors. It simultaneously senses the microwave energy emitted by and reflected from the ocean, ice, and atmosphere. To separate the various contributions to the signal from these sources, several microwave frequencies are used with each chosen for maximum sensitivity to one of those geophysical parameters.

Figure 3 is one such low-resolution image made at a microwave frequency of 35 GHz using the Nimbus-5 Electronically Scanning Microwave Radiometer (ESMR). While this instrument was adjusted primarily for viewing ice, it nevertheless shows rainfall and the near-permanent cloud cover over the intertropical convergence zone (ITCZ) just north of the equator.

The SEASAT-A instrument will be a device considerably improved over the ESMR now on Nimbus-5. It will be optimized for viewing the sea by scanning at the proper angles over a swath width of about 900 km about nadir.

The SMMR has several functions. It is first a wind speed instrument that senses the increase in emitted microwave energy due to roughness, foam, and streaks on the ocean caused when higher wind speeds create wave breaking and whitecaps. The estimated observable range of speeds is from about 10 to perhaps 50 meters/second (20 to 100 knots), but the upper limit has yet to be firmly established. Thus, the range of speeds measurable from SEASAT-A should be extended by SMMR from the 25-meters/second limit of the scatterometer up toward hurricane force winds. Secondly, the SMMR appears capable of measuring sea surface temperature with an accuracy of 1.5 to 2° C, even through light clouds where present infrared devices are useless, such as over the ITCZ. Third, the other frequencies are used for determining atmospheric liquid water and water vapor content, quantities that are needed in models of oceanic and atmospheric boundary layer processes as well as for important corrections to the precision altimeter measurements. Ice fields and cover will also be observed with low resolution from SMMR.

Maps of higher ocean surface winds, temperatures, and overlying atmospheric water content will be the output of the SMMR. These maps will, of course, be blended with the wind data from the Microwave Wind Scatterometer to yield a global, quantitative chart of wind speed wherever it is below

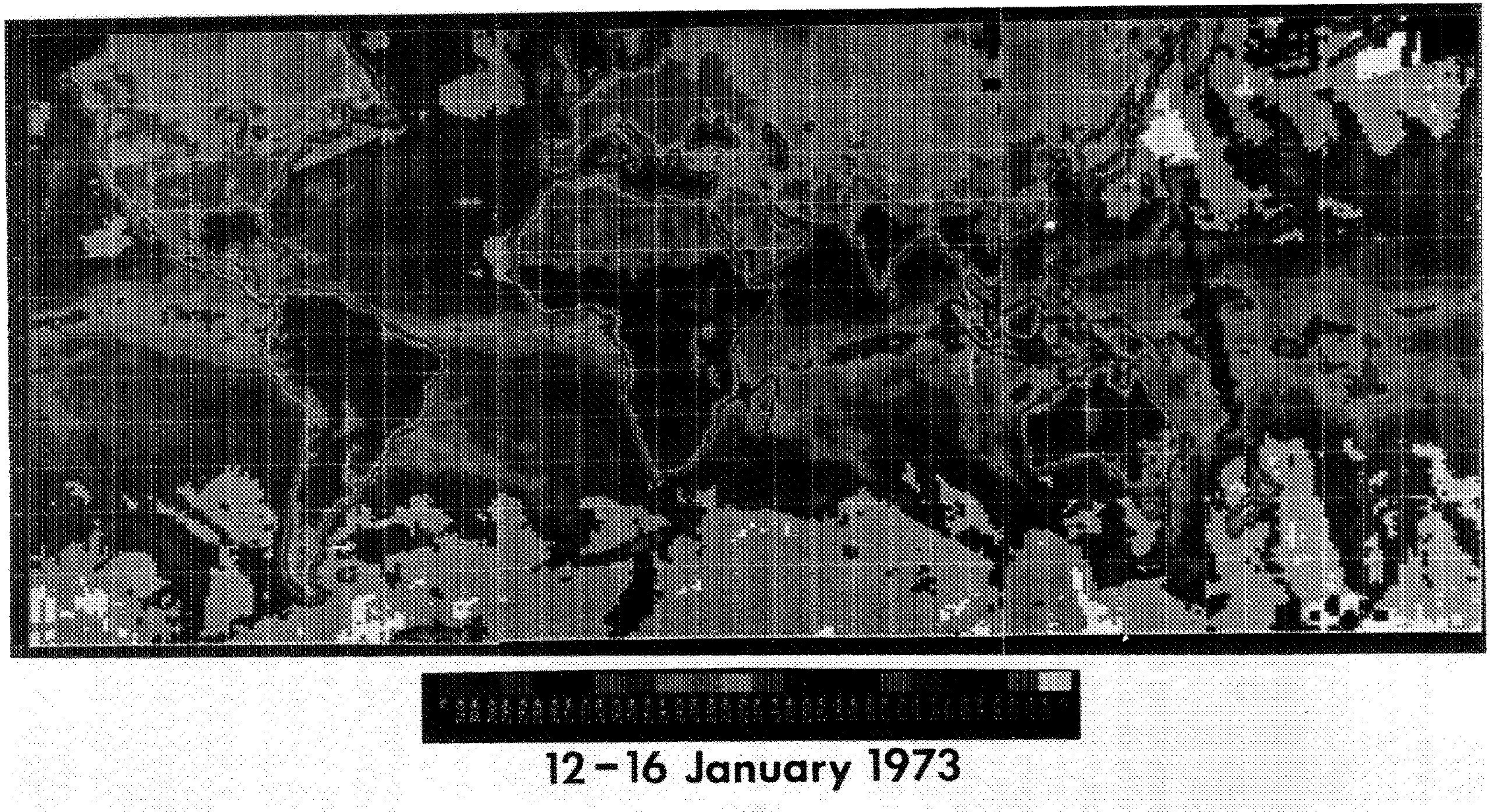


Figure 3. Radiometric brightness of the world at 1.55 cm.

essentially hurricane force. The measurements will be equivalent to some 20,000 ship reports a day. When combined with available ship and buoy surface information on wind and pressure, it becomes possible to compute the atmospheric pressure field over the entire ocean, except perhaps near severe storms; this will also be true in the data-sparce Southern Hemisphere. Such results should help to improve the 24-hour weather forecasts substantially, perhaps making them extensible to 2 or 3 days. This improved predictive capability for winds implies an approximately equal improvement in forecasting waves, especially when assisted by the data on the initial state of the sea obtained from the radar altimeter and image.

e. Infrared Radiometer (IRR). The purpose of this sensor is to provide images of thermal infrared emission from ocean, coastal, atmospheric features, which will aid in interpreting the measurements from the other four microwave instruments. The device will be similar to scanning radiometers flown on Nimbus and ITOS/NOAA. Figure 4 is an example of imagery taken from the NOAA-2 Very High Resolution Radiometer over the Southeastern United States and clearly shows the Gulf Stream off the coast as a dark band of water, as well as the Gulf of Mexico Loop Current, a time-varying feature that apparently profoundly affects the fishing and weather in the area.

A word on the measurement of sea surface temperature is in order here. This seemingly inconsequential parameter is actually of considerable importance in oceanic and atmospheric processes, since it results from the absorption of that prime mover, solar energy, by the sea. For instance, the difference between active and inactive hurricane seasons may be due to just 2 to 3° lower water temperature in hurricane gestation areas. Ocean temperature is a major factor determining the tone of weather and climate in many coastal regions of the world. Maps of sea surface temperature are very useful for tracing current systems such as the Gulf Stream, especially in the winter months. Furthermore, open-ocean fish such as tuna tend to swim along lines of constant temperature at certain times during their excursions, and a knowledge of temperature can assist in their location.

2. THE TOTAL SYSTEM

As as has been suggested above, these sensors separately provide data which, when used jointly, enhance the interpretation of the total. Figure 5 shows the ocean coverage provided by the devices. The output of the instrument complement will fall into three classes. The first will be measurements of wave height, wave directional spectrum, and surface wind speed and

Figure 4. Infrared radiometer image of Southeastern United States.

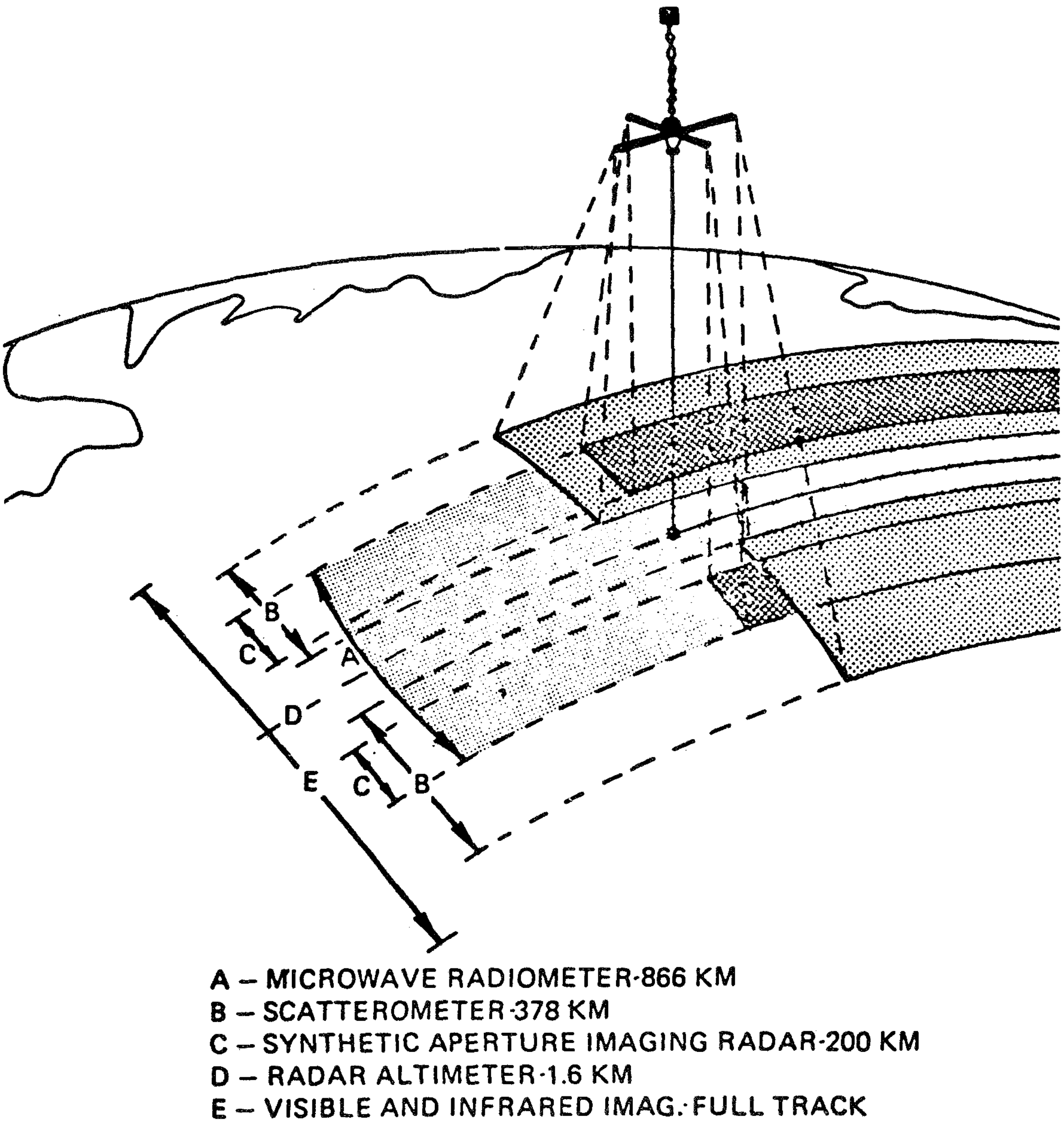


Figure 5. SEASAT-A sensor swath coverage of the ocean.

direction over the global ocean with a repeat time of 12 to 36 hours, on a somewhat uneven grid that is at least as fine as 250 km in most parts of the world. The second class will be sea surface topography from which currents, setup, tides, and other similar features may be deduced in selected regions over a time scale of days or weeks. The third class is high resolution imagery, both radar and infrared, made over selected areas at specified times, on selected time and space scales.

The interrelationships between these several classes of data are suggested in Figure 6, which illustrates the complex nature of the contribution that each sensor makes to the geophysical parameters being measured.

SEASAT-A is thus an integrated observatory addressing the objectives discussed at the beginning of this paper. Table 1 outlines the capabilities of the spacecraft system in meeting the requirements set forth by the users at the start of the program. Not all of the desiderata have been met; in particular, the operationally determined requirements demand more than one spacecraft. These data will nevertheless be highly valuable for both research purposes and for demonstrations of near operational uses in marine and weather forecasting.

An important element in interpreting the SEASAT-A data and extending its utility will be in fleshing out the information obtained from this spacecraft with the considerable data on oceans and atmosphere available from other sources. The environmental/meteorological satellites are one such obvious source for marine and weather data, as are ships, buoys, and transoceanic aircraft. In the case of ocean wave forecasts, a land-based high frequency skywave radar that is intended for operational, detailed monitoring of wave spectra near the continental United States is expected to be in service; its fine-grained data nicely complements the necessarily coarser-space open ocean wave spectral data from SEASAT-A. Similarly, research data on currents, tides, the geoid, and the other parameters of interest will be amalgamated with the SEASAT-A data by individual researchers interested in specific problems.

3. APPLICATIONS PROBLEMS

The SEASAT-A program will yield data whose application to problems in several sectors of public and private concern will yield sizable benefits. These can be grouped under two headings: (a) protection of life and property, and (b) economic benefits. In almost all of these cases, the spacecraft data are only a part, albeit usually an important part, of the total information needed to solve the applications problem.

a. Protection of Life and Property. Improvements in navigation and safety at sea may be achieved by the better forecasts of high seas and adverse currents obtained from SEASAT-A global-scale wind, wave, and current data. Navigation through ice in passages can be demonstrated on an experimental basis using radar images of limited areas. Knowledge of current systems in the northwestern Atlantic will aid in forecasting movement of icebergs across

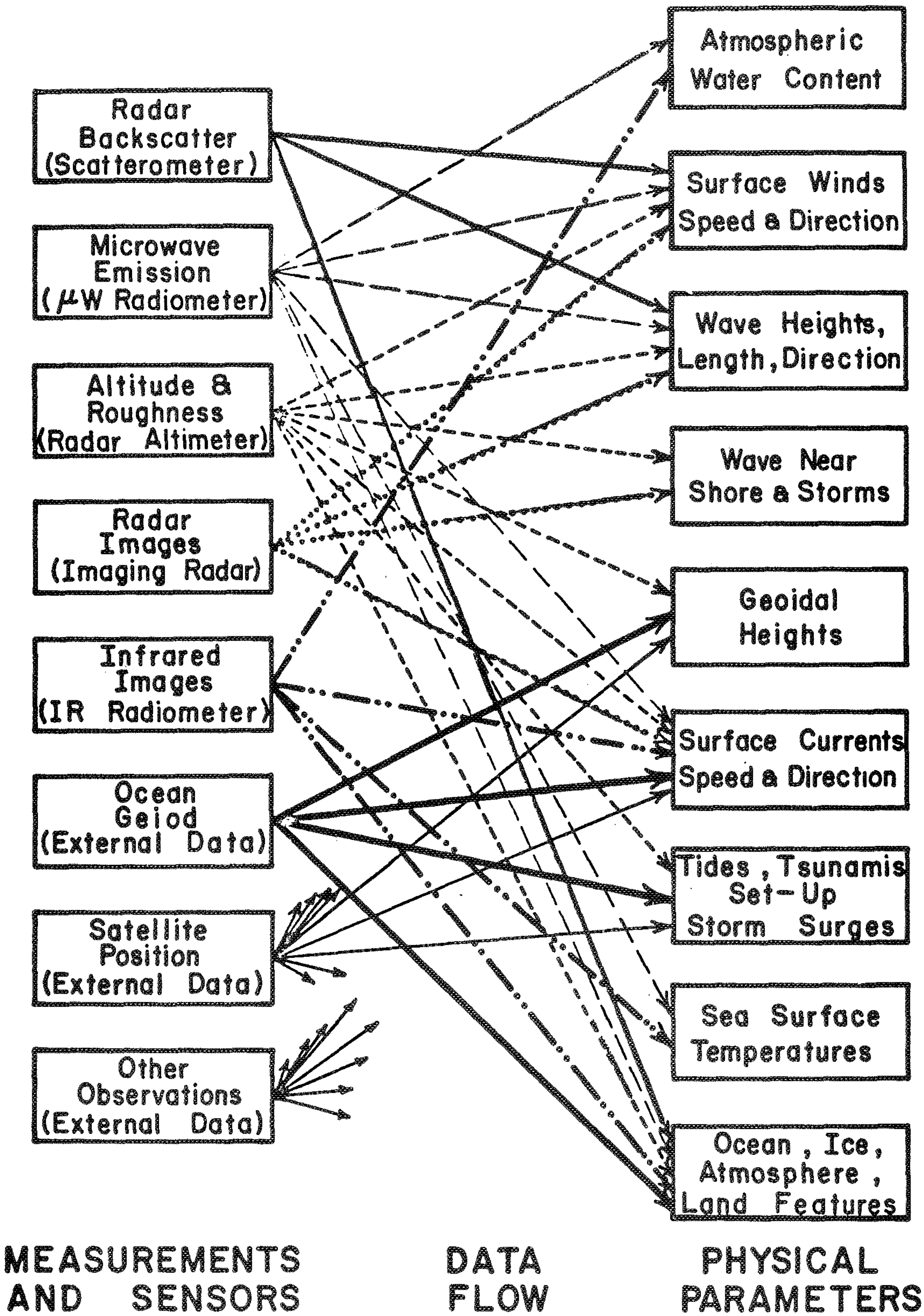


Figure 6. SEASAT-A program measurement logic.

TABLE 1. CAPABILITY OF SEASAT-A IN MEETING USER REQUIREMENTS

Physical Parameter	Instruments	Range	Precision	Resolution or IFOV	Total FOV	Comments
Wave Height, $H_{1/3}$ (x,y)	Pulse Altimeter Coherent Alt.	1.0 - 20 m	±0.5 m or ± 10%	2X7 km spot	2-km swath	Along subsatellite track only
Directional Wave Spectrum S (λ,θ,x,y)	Imaging Radar (2-D transform)	S: unknown λ: 50-1000 m θ: 0-360°	S: --- λ: ±10% θ: ±10°	50-m resolution	20X20 km squares	Global samples at 250-km intervals
	2-f Wave Spectrometer	S: unknown λ: 6-500 m θ: 90° sector	S: --- λ: ±10% θ: ±90°	8X25 km spot	300-km swath about nadir	Global samples at 150-km intervals
Surface Wind Field, $\vec{U}$(x,y)	Scatterometer	U: 3-25 m/s θ: 0-360°	±2 m/s, ±10% ±20°	⩽ 50-km spot	Two 450-km swaths	Global, 36 hrs (low speeds)
	μW Radiometer	U: 10-50 m/s θ: unknown	±2 m/s, ±10% ---	⩽ 100-km spot	900-km swath about nadir	Global, 36 hrs (high speeds)
Surface Temperature Field, T(x,y)	IR Radiometer	-2° to +35°C	±¼° - 1°C	1-7 km IFOV	1500-km swath about nadir	Global, 36 hrs (clear air only)
	μW Radiometer	0° to 35°C	±1.5°C	100-km spot	900-km swath about nadir	Global, 36 hrs (clouds & light rain)
Geoidal Heights, h(x,y) (above reference ellipsoid)	Pulse Altimeter Coherent Alt.	7 cm - 200 m	±7 cm	2X7 km spot	18-km spacing along equator	sampled throughout 1 year
Sea Surface Topography, j(x,y) (departures from geoid)	Pulse Altimeter Coherent Alt.	7 cm - 10 m	±7 cm	2X7 km spot	2-km swath	Along subsatellite track only
Oceanic, Coastal, and Atmospheric Features (patterns of waves, temperature, currents, ice, oil, land clouds, atmospheric water content)	Imaging Radar	High Resolution	All Weather	25 or 100 m	100 or 200 km	Sampled direct or stored images
	IR Radiometer	High Resolution	Clear Air	1-7 km	1500-km swath	Broadly sampled images
	μW Radiometer	Low Resolution	All Weather	15-100 km	900-km swath	Global images

shipping lanes. Such information will undoubtedly lead to decreases in the loss rate of men, ships and cargo, although not on the scale possible with an ultimate, operational ocean monitoring system.

Warning of hazards due to weather and earthquakes can be made more accurate and timely through the same general body of data. Quantitative measures of winds up to near-hurricane force will lead to more accurate predictions of storm landfall and storm surge forecasts. These measurements, when merged with other meteorlogical data, will aid in extending the 1-day general weather forecast toward a scale of several days.

b. Economic Benefits. In principle, large economies are possible for activities utilizing SEASAT-A derived information directly or indirectly. These are discussed further elsewhere. The areas in which benefits are sought are listed in Table 2.

4. SCIENTIFIC PROBLEMS

In addition to being an applications satellite, SEASAT-A will be an important research tool in several areas of geophysics. These are indicated in Table 3.

TABLE 2. BENEFITS DERIVED FROM SEASAT-A DATA

General	Specific
A. Advancement of Knowledge	. Oceanographic, Meteorological, Geodetic, and Engineering Science
B. Protection of Life and Property	
1. Navigation and Safety at Sea	. Prediction of High Seas, Adverse Currents . Navigation through Ice Fields . More Precise Iceberg Warnings . Decreased Loss of Men and Ships
2. Warning of Natural Hazards	. More Accurate, Longer-Term Weather Forecasts . Improved Warnings of Storms and Surges . Decreased Tsunami False Alarm Rate
C. Economic Benefits to the Nation	
1. Maritime Operations	. Optimum Ship Routing and Scheduling . Reduced Loss of Oil Drilling Rigs . Improved Design of Offshore Structures . Improved Ship Design . Improved Mapping, Charting, and Geodesy
2. Utilization of Ocean Resources	. Assessment of Biological Productivity . Location of Potential Fisheries . Enhanced Extraction of Oil, Sand, Minerals
3. Environmental Impact	. Dispersal of Pollutants and Foreign Substances . Improvement in Shoreline Protection
D. National Defense Posture	. Improved Environmental Forecasts . More Precise Geoidal Model . Enhancement of Other DOD Missions

TABLE 3. SCIENTIFIC BENEFITS

Physical Oceanography
  Dynamic Behavior of Currents and Tides
  Thermal Dynamics and their Effects
  Air Sea Interface Dynamics (Winds, Heat Transfer, Mechanisms, etc.)
 	
Ocean Geoid Fine Structure
 	
Interdisciplinary Research in Oceanography/Meteorology and Climatology

OTHER EOPAP MISSION DESCRIPTIONS

1. GEOPAUSE MISSION DESCRIPTION

The requirement for a 10-cm satellite tracking accuracy is necessary for a number of other earth- and ocean-dynamics investigations. These include a set of earthquake-related studies of fault motions and the earth's tidal, polar, and rotational motions, as well as investigations of the gravity field and the sea-surface topography, which should furnish basic information about flow of mass and heat in the oceans.

The state of orbit analysis is currently at about the 10-meter level, or about two orders of magnitude away from the 10-cm accuracy capability expected in the next several years. The realization of a 10-cm orbit analysis capability awaits the solution of four kinds of problems:

a. Orbit determination

b. Tracking system biases

c. Gravity field uncertainties

d. Station location uncertainties

The GEOPAUSE satellite system concept offers promising approaches in connection with all these areas (Fig. 1).

a. Orbit Determination. The suggested GEOPAUSE orbit has a period of 14 hours and a mean distance of about 4.6 earth radii; it is nearly circular, polar, and normal to the ecliptic. The tracking geometry is such that the GEOPAUSE satellite's radial distance can be determined with an accuracy that is close to the instrumental accuracy of the range tracking system (Fig. 1). Knowledge of the GEOPAUSE orbital radial position will be sufficient to permit solution of the remaining three types of problems indicated above.

b. Gravity-Field Uncertainties. The height of GEOPAUSE is such that only a relatively few gravity terms have uncertainties corresponding to orbital perturbations above the decimeter level; e.g., six compared to over a thousand for Geodynamic Experimental Ocean Satellites (GEOS). The

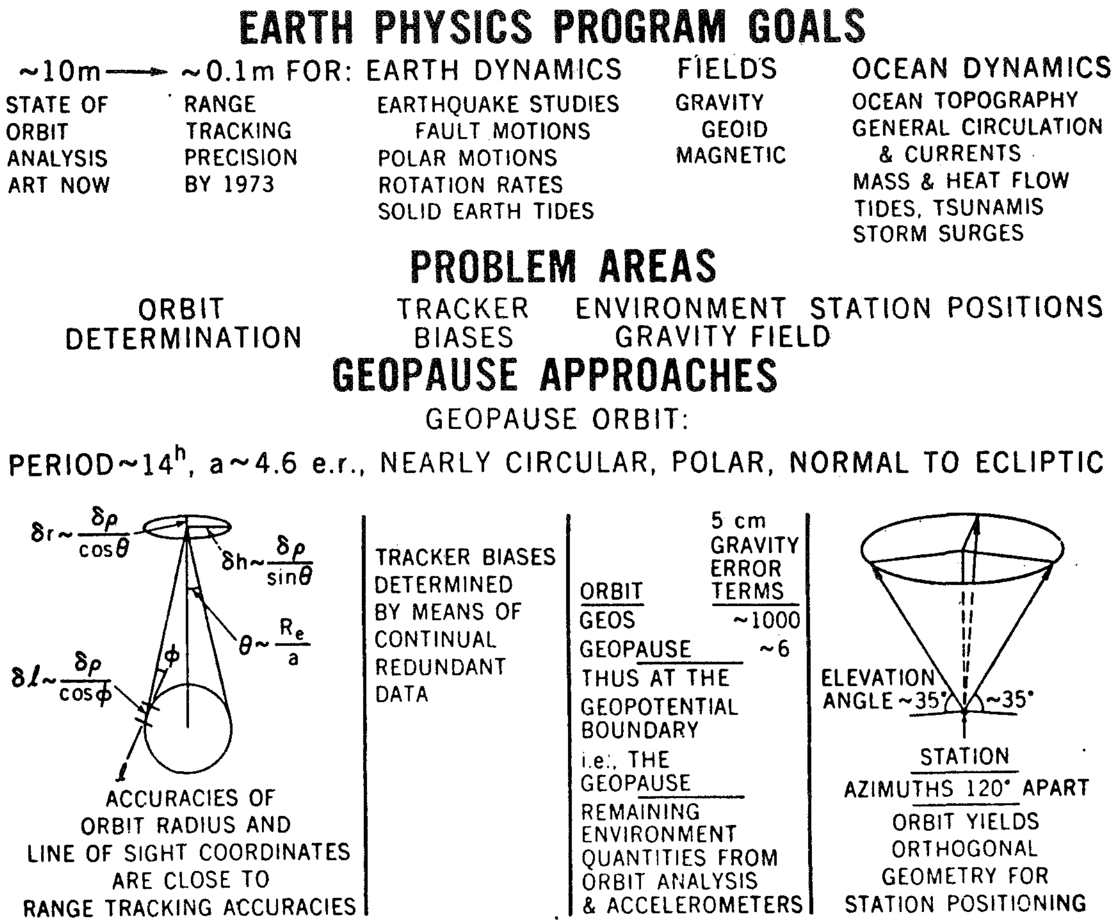


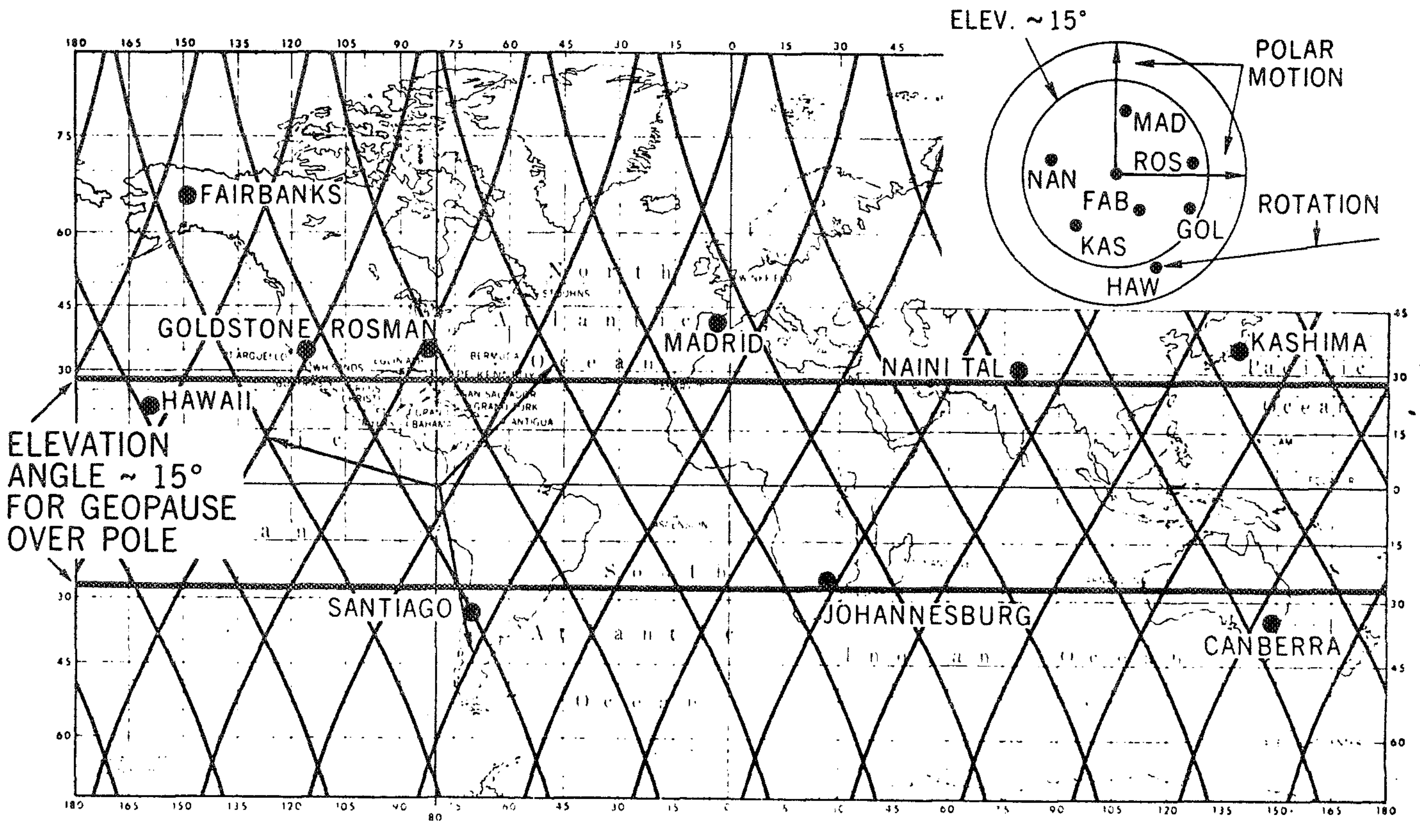
Figure 1. Earth physics program goals, problem areas, and GEOPAUSE approaches.

orbit is, in this sense, at the geopotential boundary; i.e., the geopause. The few remaining environmental quantities that may be significant can be determined by means of orbit analyses and accelerometers.

c. Station-Location Uncertainties. The GEOPAUSE satellite system also provides the tracking geometry and coverage needed for determining the orbit and the tracking-station locations (Figs. 1 and 2). Studies indicate that the GEOPAUSE satellite, tracked with a 2-cm ranging system from nine NASA-affiliated sites, can yield decimeter station-location accuracies.

d. Tracking-System Biases. The GEOPAUSE orbit is ideal from the standpoint of the coverage of the NASA network stations that NASA provides for use in the continual monitoring and determining of tracking-system biases.

GEOPAUSE ORBIT YIELDS THE GEOMETRY
FOR DETERMINATION OF
ORBIT, TRACKER BIASES, GM, STATION LOCATIONS,
FAULT MOTIONS, POLAR MOTIONS, ROTATION RATES, TIDES



GEOPAUSE SUBSATELLITE TRACKS DURING ONE WEEK
● TYPICAL FUNDAMENTAL STATIONS
GEOPAUSE WITH 2cm RANGE TRACKING DATA YIELDS DECIMETER STATION LOCATIONS
AND FAULT MOTIONS

Figure 2. GEOPAUSE orbit.

For example, as can be seen from Figure 2, GEOPAUSE can be tracked simultaneously from up to six sites when it is over the North Pole. Similar redundant coverage occurs elsewhere in the orbit. Tracking of the satellite from four or more stations is sufficient to permit the determination of tracking-system biases.

The geodetic orbit-determination program has relied largely on optical data up to now. Biases have been removed from them through astronomical data. As we advance from optical orbit accuracies of the order of a dekameter to the decimeter laser tracking realm, we must provide solutions of our own for the problem of tracking-system bias. The GEOPAUSE satellite system provides a practical means for continual determination of tracking-system biases.

e. Earth Dynamics

(1) Polar Motion. The GEOPAUSE satellite can be viewed simultaneously from six sites that are well separated in longitude when it is over the North Pole. It thus provides an excellent platform for observing two components of the polar motion directly. A similar, somewhat less redundant, capability exists over the South Pole. Suitable geometry occurs whenever GEOPAUSE is within 15 degrees of the pole. GEOPAUSE thus provides the capability for observing both components of the polar motion with a time resolution of one-fourth of a day. The in-plane component can, in fact, be observed nearly continually.

(2) UT-1. When GEOPAUSE is near the equator, it provides a fine platform for observing variations in the earth's rotation rate. The discussion is analogous to the one for GEOPAUSE over the poles.

(3) Continental-Drift Studies. The capability provided by GEOPAUSE for determining locations of the 10 fundamental NASA sites in Figure 2 with decimeter accuracy includes as a corollary a built-in capability for monitoring continential drift at these sites.

(4) Fault Motions. Observation of fault motions as well as gross tectonic plate motions at other sites can be accomplished by means of GEOPAUSE through the use of portable lasers, portable turnaround radio-tracking-system transponders, or portable VLBI terminals.

f. Global Surveys

(1) Gravity-Field Surveys. GEOPAUSE provides the basic capability for satellite-to-satellite tracking of drag-free satellites for mapping the gravity field. GEOPAUSE tracking a coplanar, drag-free gravity satellite for

2 months to 0.03-mm/second accuracy can yield the geoid over the entire earth to decimeter accuracy with spatial resolution of several hundred kilometers. Both the along-track and the radial components of the velocity perturbations are observed in this survey.

(2) Magnetic-Field Surveys. GEOPAUSE can provide the data for determining the orbit of the MAGSAT spacecraft with the necessary accuracy.

g. The Twin Geopause Space Reference Coordinate System. Tracking from two GEOPAUSE spacecraft to a coplanar altimeter spacecraft when the altimeter is between the twin GEOPAUSE satellites gives the two in-plane components of the altimeter satellite's position in the Twin GEOPAUSE Space Reference Coordinate System and hence relative to the earth's center of mass and the geoid (Fig. 3). Any other in-plane component, specifically the radial one, can then be derived in the same system.

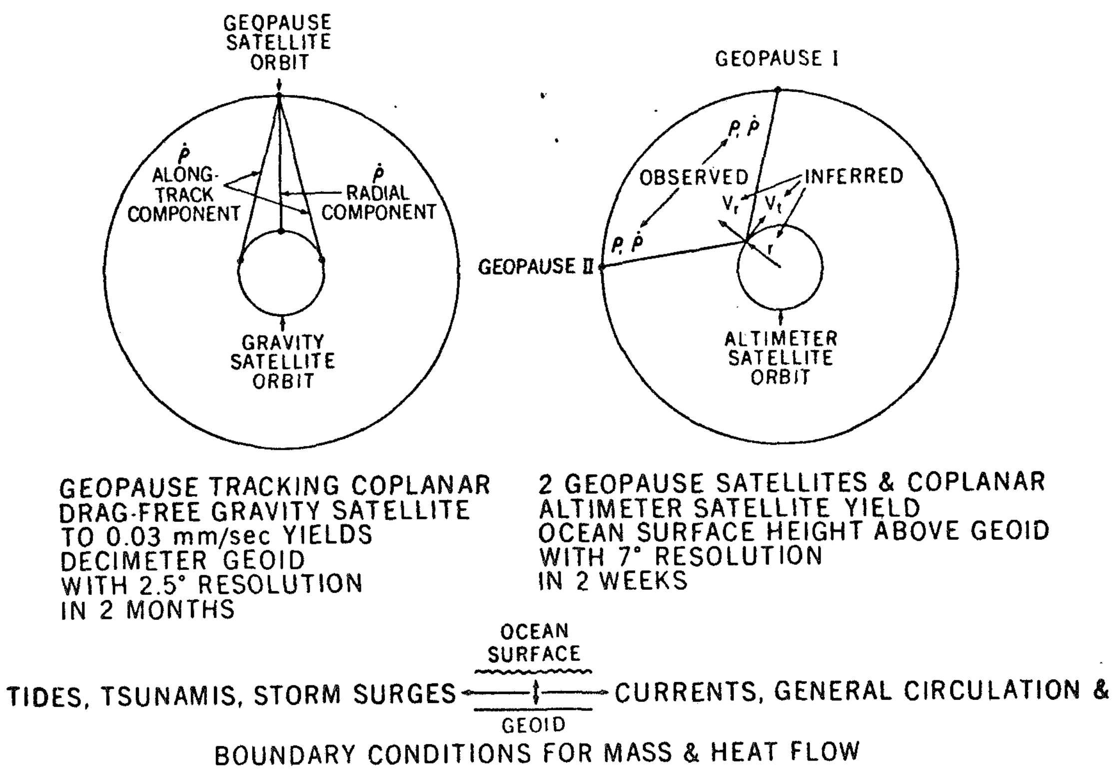


Figure 3. GEOPAUSE for global surveys and reference coordinate systems.

2. GRAVITY MISSION

The definition of the gravity mission is an important milestone that must be achieved in 1975. The most significant issue to be studied and resolved by that time is the optimum spacecraft configuration to measure geoid features with wavelengths ranging from global dimensions to the shortest detectable from orbit.

Improvements in the present gravity-field representations can be made by more than one type of satellite technique, such as: (a) the "classical" method of orbit-perturbation analysis using ground-based observations of satellites, (b) high-low satellite-to-satellite tracking, (c) low-low satellite-to-satellite tracking, (d) gravity gradiometry, and (e) radar altimetry. These techniques must be evaluated in terms of resolution, accuracy, and cost, and the role for each in the program must be determined.

Each of the above techniques has particular characteristic advantages. All but the first are relatively recent concepts that are now undergoing analysis, refinement, and instrumental improvement. The first, relying on radio and optical tracking techniques, has been very successful in the determination of the large scale gravity-field terms, and there is every expectation that a modest number of high precision lasers at suitable locations will be adequate to refine the large scale features in the gravity field to an accuracy of better than 10 cm. The satellite-to-satellite tracking methods involve at least two spacecraft, which, in the low-low configuration, may be capable of being launched with a single launch vehicle. The satellite-to-satellite tracking technique and the gravity gradiometer are most sensitive to the intermediate gravity-field terms (250 to 1500 km). The altimeter will be sensitive to the shorter scale terms in the gravity field (20 to 1000 km). The dynamic features in the ocean-surface topography must be accounted for in order to determine the geoid to accuracies in the decimeter region. It appears that geoid determination from nonaltimeter techniques will be required to interpret properly the oceanography topography for terms of intermediate and large scales.

By FY-1976, we expect to be in a position to determine the exact role that each of these techniques will play in the program. By that time, the high-low satellite-to-satellite technique will have been tested by the GEOS-C/ATS-F and the Nimbus/ATS-F experiments, further numerical analyses will have been performed for low-low tracking, the gravity-gradiometer instrumentation and associated data handling and analytic techniques that are under development in AAFE and other programs will have been demonstrated on the ground, and the GEOS-C altimetry data for the ocean geoid will be available for analysis to show the feasibility of geoid mapping by altimetry systems alone and in combination with other tracking techniques.

3. GRAVSAT, THE HIGH-LOW SATELLITE APPROACH

The gravity-field experiment can be conducted effectively by satellite-to-satellite tracking between a low altitude satellite that is strongly perturbed by the gravitational features of interest and a high altitude satellite that is virtually unaffected by them. With an orbital radius of about 30,000 km or more for the high altitude satellite, only about six geopotential terms are significant at the 5-cm level; hence, errors caused by imperfections in geopotential models should be minimal. At the GEOS height, more than a thousand terms are significant at an accuracy level of 5 cm. This basic separation of the variables is an important distinction between the high-low and the low-low approach.

The high-low satellite technique includes a built-in redundancy in that it provides two nearly orthogonal sets of tracking data that are equivalent to the radial and nearly along-track components of the perturbed velocity (Fig. 4). The radial component has been used with striking success to discover the lunar mascons and can be used in the same way around the earth.

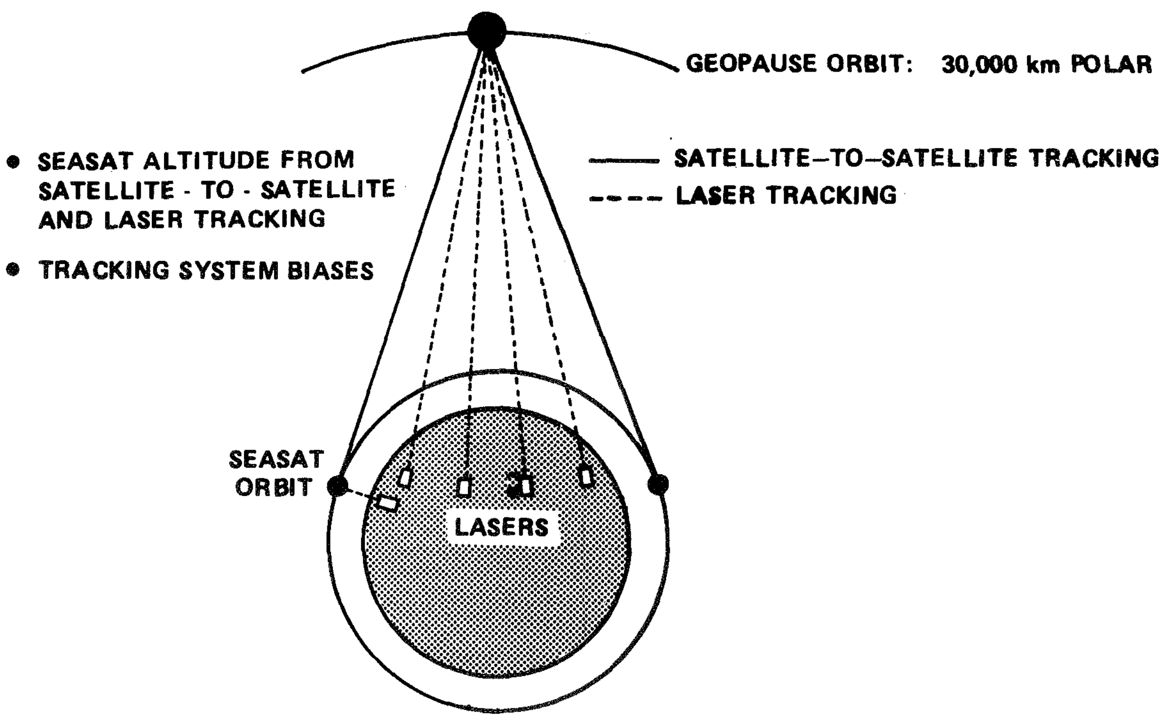


Figure 4. Satellite-to-satellite range-rate tracking geometry for various relative positions of the geopause and a coplanar low altitude spacecraft.

The tracking of a low altitude satellite from a high altitude satellite will be analogous in many ways to the tracking of lunar satellites from stations on the earth. The data from lunar orbiters were originally analyzed in conventional ways in terms of spherical-harmonic coefficients. It was realized after a time that many of the residual anomalies of the lunar satellite range-rate tracking data could be correlated analytically with calculated anomalous surface-density distributions. This interpretive approach is perhaps one of the most striking features of recent research relating to planetary gravitational fields. A typical doppler residual pattern and the correlation with a surface feature are indicated in Figure 5.

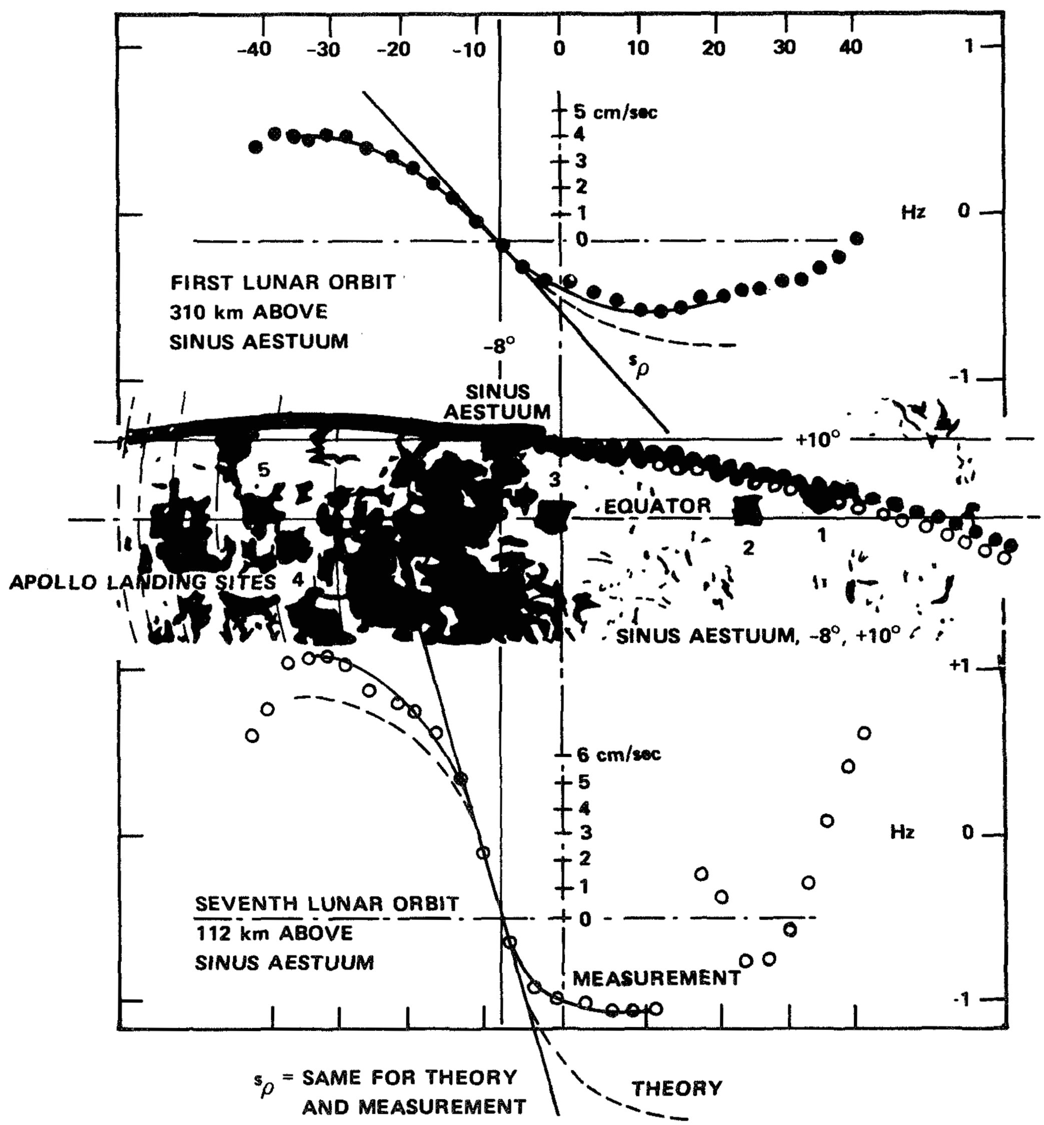


Figure 5. Velocity Variations ΔV_ρ as a function of θ; a comparison using Apollo 8 flight data.

The tracking of a low altitude satellite such as GEOS-C from ATS-F is expected to yield information about the gravitational field that is more detailed in terms of spatial resolution than that obtainable from the existing sets of satellite data. Velocity variations of the type expected are seen in Figure 6. The degree to which mean gravity anomalies in adjacent squares on the earth's surface can be separated on the basis of satellite-to-satellite tracking data of the ATS/GEOS-C type is a function of the altitude of the low satellite. The nature of this relationship is exhibited in Figure 7.[1]

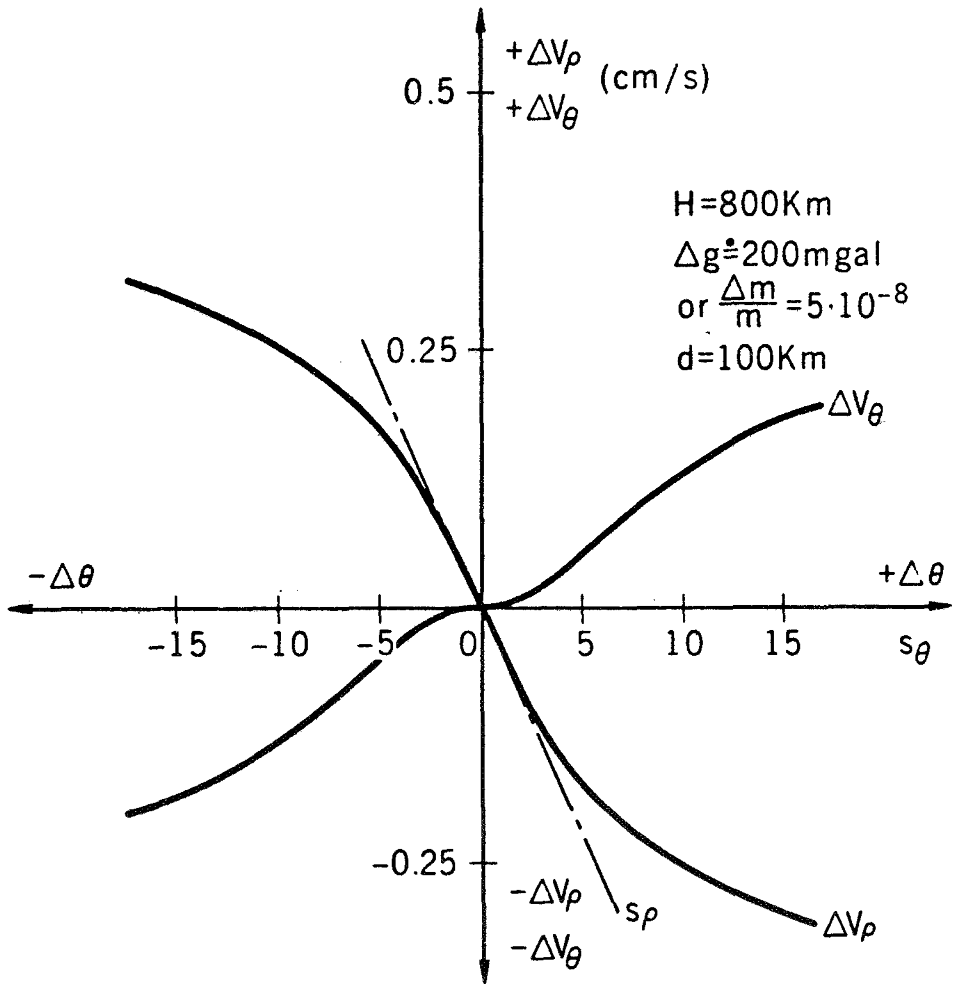


Figure 6. Velocity variations ΔV_ρ and ΔV_θ as a function of $\Delta\theta$.

1. From Ph. D. dissertation by C. R. Schwarz, Ohio State University, 1970.

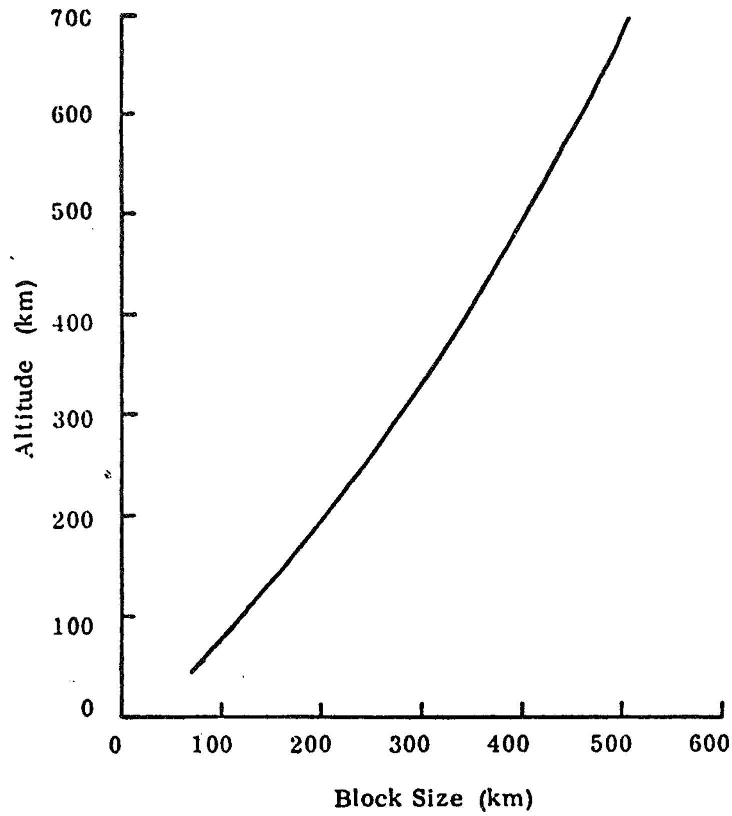


Figure 7. Approximate maximum altitude from which the gravity field can be successfully resolved, as a function of block size.

Reduction of ionospheric errors in the high-low satellite-to-satellite technique can be achieved by the use of either a sufficiently high (above 20 GHz) single radio frequency or two lower frequencies (e.g., 1000 and 2000 MHz). The latter would be preferred because it would result in larger antenna apertures on the low altitude tracked satellities without resorting to steered antennas.

A crucial experiment for the EOPAP will be the ATS-F/Nimbus-E tracking and data-relay experiment. A range-rate sum resolution of 0.035 mm/second for 10-second averages is expected for the ATS-F/Nimbus-E doppler sum measurements. Range-sum measurements to a precision of 2 meters or better are predicted.

The ATS-F/Nimbus-E experiment will, for the first time, establish the extent to which the orbit of a satellite can be determined by means of a "synchronous tracking" station. It will also demonstrate the feasibility of data and command relay between an earth-orbiting spacecraft and the earth via a synchronous satellite. In this experiment, the synchronous station consists of ATS-F, and the earth-orbiting vehicle is Nimbus-E. The experiment logically separates into two phases: first, the development and demonstration of the critical aspects of the technology required to obtain the basic tracking data that form the input to any orbit-computation scheme, and second, the postflight orbit computations, which use as input various combinations of data types as well as tracking geometries. The latter would lead to a determination of optimum orbit-computation techniques as well as to the establishment of orbit-computation accuracies associated with a synchronous tracking data relay. The goals of this experiment are to:

a. Establish the accuracy to which an earth-orbiting satellite can be tracked by a synchronous spacecraft.

b. Compare the orbits of ATS-F and Nimbus-E thus computed with orbits based on conventional ground tracking techniques.

c. Link the results to the practical problems of future Tracking Data Relay Satellite Systems (TDRSS).

d. Determine to what extent gravitational model uncertainties and system errors can be separated.

e. Attempt to detect gravity anomalies through analysis of the satellite-to-satellite tracking data.

f. Provide a basis for tradeoff studies by using combinations of synchronous-satellite and conventional ground tracking.

g. Evaluate the effect of multipath and atmospheric distortions on the relay of tracking data and telemetry as function of Nimbus-E geometry.

The primary purpose is a twofold satellite applications experiment. First, the results will lay the foundation of the tracking and orbit-determination capability for a future tracking and data relay satellite system and thus will influence the design or determine the desirability to build such a system. Once it has been shown that trajectory determination from an orbiting station is feasible and advantageous, a final system such as the

TDRSS can be considered. Second, this experiment will show what tradeoff can be achieved between tracking and orbit determination by means of a ground network and an orbiting network. This, in turn, will indicate under what conditions ground stations can be eliminated. At this time, only theoretical studies unsupported by experimental evidence have been performed to determine the trajectory errors to be expected for a near-earth satellite when tracked by a synchronous orbiting station. These published studies reflect a rather conservative view since their original purpose was to serve as a guideline for the design of a future orbiting tracking system.

In contrast, the proposed experiment will show what actually can be done with the most advanced approaches currently available for precision orbit determination. We will learn how best to handle metric information for orbit determination. The EOPAP will need improvements in orbit determination of up to two orders of magnitude. We should be able to determine orbits to much greater precision than we can today for two reasons. First, current orbital development programs will have been completed, providing a much better capability for precise orbit determination by using more sophisticated gravity terms, drag terms, solar radiation pressure, earth-tide effects, and lunar and solar gravitational perturbations. Second, there will exist for the first time the option to "select" tracking data along the orbit in an optimum fashion, permitting better orbit and tracking data geometry which in itself reduces trajectory errors.

Instrumentation installed on GEOS-C will enable it to be tracked by the ATS-F and ATS-G satellites via a link with an ATS ground station. The measurements will be in the form of range and range-rate sums, with the initial signal transmitted by the ground station to the spacecraft, which in turn coherently changes the carrier frequency of the interrogation signal for transmission to GEOS-C. The GEOS-C satellite then retransmits the signal to the ATS spacecraft and then back to the ATS ground station.

The objectives of such tracking are the following:

a. To determine the gravity field that influences the GEOS-C orbit directly from satellite-to-satellite observations and to look for evidence of gravity anomalies.

b. To compare GEOS-C and ATS orbits as determined by satellite-to-satellite tracking with orbits determined by conventional ground-based systems.

c. To determine the utility of satellite-to-satellite tracking for precision orbit determination.

d. To assess the value of satellite-to-satellite tracking to oceanographic studies by means of the GEOS-C radar altimeter.

GEOS-C is planned to be in a relatively circular orbit at a height of about 1000 km with an inclination to the earth's equator of approximately 65 degrees, while the ATS-F and ATS-G satellites will be in a geosynchronous equatorial orbit. Each ATS satellite will have the capability to provide continuous tracking coverage over about 170 degrees of the GEOS-C orbit. This will provide an opportunity to evaluate range-rate variations for gravity anomalies over a large portion of the earth's surface. For an integration interval of 10 seconds, range-rate variations on the order of 0.035 cm/second should be detectable with this tracking system; this should provide solutions for gravity anomalies equivalent to a (20,20) degree and order gravity field, in terms of spherical harmonics.

Experimental studies have indicated that the position uncertainties in ATS orbits that use satellite-to-satellite tracking would be on the order of a few tens of meters, while the positon uncertainties for GEOS-C orbits would be about 5 to 10 meters.

When the actual tracking data become available, the determined orbits will be compared with those obtained from conventional ground-based tracking data. The ATS spacecraft will be tracked by the ATS ground stations and lasers, while GEOS-C will be tracked by USB, C-band radar, lasers, cameras, and radio doppler beacons. Additionally, the GEOS-C/ATS-F and GEOS-C/ATS-G links may be of benefit in evaluating the GEOS-C radar altimetry data themselves.

4. GRAVSAT, THE LOW-LOW SATELLITE APPROACH

The tracking of one satellite following another in low orbit about the earth can yield doppler data that can be processed to yield gravimetry. Such systems have been proposed informally from time to time, and it is the purpose here to explain in modest detail the basic considerations in such systems.

a. Technique. NASA spacecraft in earth orbit and interplanetary flight are tracked via the S-band doppler tracking system of the Deep Space Network (DSN). The data consist of the difference between the transmitted and the received S-band radio signal frequencies as controlled by a precision atomic clock. These data are extremely precise range-rate measurements. The error in range-rate change over a time T in seconds for the DSN observations can be expressed as

$$V_{error} = 3.0/T \text{ mm/second}$$

for times up to about 10 minutes, where correlated noise effects begin to dominate. Since tracking measurements for gravity analysis might be taken with about 1-minute averaging times, the velocity variations are determined to approximately 0.05-mm/second accuracy, each minute of data constituting a separate and independent measurement.

In the case of low-low tracking, at least one spacecraft has the equivalent of the ground station's transmitting-receiving hardware (at low power) and the other has the ordinary spacecraft transponder.

The transmitter-receiver spacecraft contains a frequency standard of moderate precision, a transmitter, a receiver, and a signal multiplying and differencing electronics. In addition, it can have a ground-access communications channel.

The tracked spacecraft can have the normal S-band (or X-band) spacecraft navigation transponder system. As with the usual spacecraft systems, telemetry could be returned along this system without effects detrimental to the doppler gravity measurements.

A simplified system could consist of two identical spacecraft, each capable of tracking the other, each capable of transponding, and each able to communicate telemetry to the ground. In either case, a memory is required to store the data, but the quantity of data is modest.

The spacecraft would be launched into following orbits, with the beginning separation about the same as the spacecraft altitude (250 to 300 km). This configuration will have maximum sensitivity at the shortest wavelengths of gravimetric variations that can be observed from orbital altitude. It will have lesser sensitivity to some of the other wavelengths, however, and gradually increasing separations might be adopted in the mission profile and data reductions to produce an integrated mapping adequately measuring all pertinent wavelengths. This is the only major difference in the data analysis between this system and the high-low satellite system.

First, the orbital motions caused by the earth and its long wavelength gravity variations, the effects of solar pressure and atmospheric drag, and the other normal parameters in the orbit-determination process are modeled and the data are filtered. Then, the remaining range-rate difference signatures are directly converted into gravimetry through differentiation and suitable coordinate transformations, following which the mappings can be built up orbit by orbit. A near-polar orbit is desirable in order to map the entire earth.

b. The Gravimetry. The resulting observations constitute satellite gravimetry of high resolution; this is limited to wavelengths (resolutions) longer than the spacecraft altitude and may be more typically 1.5 to 2.0 times this distance in practice. Precisions equivalent to 0.1 to 1.0 mgal at the earth's surface appear achievable with the above-noted doppler-system tracking accuracies, which currently are a matter of daily practice with earth spacecraft tracking.

Satellite-to-satellite tracking and gravity gradiometry constitute the only known ways of globally mapping the earth gravimetrically from orbiting spacecraft down to resolutions of several hundred kilometers. Satellite altimetry, for example, is limited to ocean areas and by restrictions imposed by modeling requirements on spacecraft trajectory and ocean currents. The extremely precise orbit determination needed for altimetry is not required by the satellite-to-satellite systems.

c. Current Capabilities and Ongoing Development. The necessary tracking hardware is well understood and in daily use throughout NASA. The spacecraft will have to be designed from scratch, however. On the other hand, the instrumentation required is relatively simple and well proved and should have long life and high reliability as compared with many earth satellite measurement systems designed and flown in the past.

5. GRAVSAT, GRAVITY-GRADIOMETER SATELLITE

The objective of a gravity-gradiometer satellite mission is to obtain an improved map of the earth's entire gravity field. The horizontal resolution of satellite-determined gravity models currently available is of the order of 1500 km. A gravity gradiometer offers the potential to improve resolution over the entire earth to a few hundred kilometers.

Gravity gradiometers provide an alternative gravity-mapping technique when compared to more conventional satellite techniques. Perturbation analysis of satellite trajectories is based on position measurment, which is obtained by integrating the acceleration twice, and thus is relatively insensitive to high frequencies. Proposed doppler radar techniques measure a relative velocity, which is a single integral of acceleration and again is less sensitive to high frequencies than is the gradiometer. A gravity gradiometer measures the second derivative of the gravity field. This means that the higher frequency effects of the gravity field can be seen by a gradiometer, and it would be possible to calculate high order (up to 75th) terms of the harmonic expansion for the gravity field.

An enhanced gravity map could be used to improve orbit-determination accuracies for future earth-satellite missions, and because the gravity gradiometer measures a derivative, density changes in the earth's mantle will be accentuated instead of smoothed by the integration techniques of other spacecraft gravity-mapping methods.

Currently, there are at least four gravity-gradiometer instruments under various stages of development. They are listed below by institution and key personnel and described briefly in the paragraphs that follow. A more complete description of these instruments can be obtained from the following:

Institution	Personnel
Hughes Research Labs	R. L. Forward C. C. Bell
MIT	M. Traegesis
Bell Aerospace	D. Allen E. Frey E. H. Metzger
A. D. Little	I. Simon

The Hughes approach uses a rotating cruciform with end masses. As the cruciform rotates in a gravity field, its end masses are differentially accelerated and the differential torque is sensed by piezoelectric strain transducers tuned to twice the spin frequency.

The MIT instrument uses a dc method that senses the torquing of a single dumbbell floated in "fluorolube." This approach has the disadvantage of requiring the removal of any background signal from the true signal.

The Bell Aerospace approach uses a rotating cruciform scheme with four miniature electrostatic accelerometers at the end points to sense the gravity gradient at twice the spin frequency.

The A. D. Little instrument is in two parts. The first measures the vertical component by a doppler technique on two differentially dropped items. (It should be noted that this scheme is currently limited to operation in a gravity field and is not applicable to orbiting spacecraft.) The second part measures the other components of the gradient field by using a rotating cruciform with end masses similar to the Hughes instrument, but spins the instrument with the dumbbells skewed out of the plane of rotation. Thus, the information comes out at the spin frequency.

The Hughes instrument is currently under an AAFE contract to produce a flight instrument capable of measuring to 0.1 E.U.[2] Previous laboratory tests of this instrument have demonstrated 1.0 E.U. Hughes is aiming, however, to produce an instrument capable of measuring to the 0.01 level. The Bell Aerospace instrument, being developed with "in-house" funds, is attempting to attain the 0.01-E. U. level.

Several problems must be considered, however, before a gravity-gradiometer mission design can be completed:

a. In the case of the Hughes instrument, temperature-control requirements are not yet clearly know, but they are severe.

b. At the 0.01-E. U. level, the need for a 19-bit analog-to-digital converter as a part of the data encoding system is beyond the present state of the art, which is 17-bit conversion.

c. The accuracy to which the satellite center of mass must be aligned with the elastic center of the instrument poses a difficult but solvable problem.

A gravity-gradiometer phase A mission study conducted at the Jet Propulsion Laboratory (JPL) yielded the following general mission characteristics for a rotating gradiometer instrument. Spacecraft weight would be 135 pounds, and a Scout launch vehicle could be used. The orbit would be circular, polar, and at about 300-km altitude. Orbit-determination requirements are within the current state of the art. The complete spacecraft would

2. 1 E. U. = 1 Eötvös unit = a gradient of 10^{-12} g/cm, where g is the gravitational acceleration at the earth's surface ($\sim$ 980 cm/sec^2).

be spin-stabilized at 4 rps with the spin axis normal to the plane containing the orbit. The spin would provide spacecraft stabilization as well as rotation for the gradiometer. The mission lifetime would be 40 to 50 days at about 16 orbits per day and would yield at least two complete earth mappings. Complete results are contained in JPL Report 700-70, "Gravity Gradiometer Satellite," May 1972.

A gradiometer satellite is constrained in a variety of ways by the applications objectives and by the gradiometer operating requirements. Some conclusions can be drawn without considering a particular gradiometer.

The applications objectives require a low, polar, circular orbit. The orbit must be polar in order to obtain global gravitational data, low in order to achieve the maximum accuracy possible at a fixed signal resolution, and circular in order to obtain uniformly accurate data.

The desirability of a circular orbit is dictated by the rate at which the second derivatives of the field fall off with respect to increasing altitude. The radial second derivative of the spherical-harmonic expansion for the earth's gravitational field is expressed by

$$\frac{\partial^2 V}{\partial r^2} = \frac{GM}{R^2} \sum_{n=0}^{\infty} \left(\frac{R}{r}\right)^{n+3} \sum_{m=0}^{n} (n+2)(n+1) P_{nm} (\cos\theta) (C_{nm} \cos m\lambda + S_{nm} \sin m\lambda) \quad , \tag{1}$$

where V is the gravitational potential; R is the equatorial radius of the earth; GM is the product of the gravitational constant and the earth's mass; P_{nm} is the associated Legendre polynomial of degree n and order m; r is the radial distance to the point in question; θ, λ are the colatitude and longitude, respectively, of the point in question; and C_{nm}, S_{nm} are the spherical-harmonic coefficients of degree n and order m.

Note that in equation (1) the higher degree terms fall off not as the cube of the distance but as the degree plus three. This is true for terms like $\partial^2 V/\partial x\, \partial y$ or $\partial^2 V/\partial z^2$, which must exhibit this behavior regardless of the definition of x, y, and z as long as orthogonal Cartesian coordinates are used. In other words, for degree 75, the amplitude falls off inversely as the radius to the 78th power.

Let us suppose we are trying to reduce data to degree 75. If the satellite apogee is 330 km and perigee 270 km, the 75th-degree terms contribute only half as much at apogee as at perigee. That contribution would be extremely small and of unknown amplitude and phase. The 75th-degree terms have a fundamental wavelength of 550 km and an amplitude of less than 0.01 E. U. They cannot be corrected by adjusting these data on the basis of the known coefficients. A least-squares-curve fit could overcome this problem, but the accuracy would uniformly be no better than that at apogee. Thus, while a noncircular orbit does not invalidate these data, it would be preferable to have a circular orbit.

Orbit-determination requirements are difficult but not severe. The mean signal from the gradiometers in question is $3GM/r^3$. Let us call the sensitivity of the gradiometer X. We can calculate the change in position equivalent to the gradiometer sensitivity by setting the signal ratio equal to

$$\frac{\text{signal } (r)}{\text{signal } (r + \Delta r)} = \frac{3GM/r^3}{(3GM/r^3) - X} , \qquad (2)$$

where r is the radius to the satellite. For a gradiometer sensitivity of 0.01 E. U., this is a distance of 5.5 m.

The desirability of a low orbit is dictated by considering the amplitude of gradients of the earth's gravitational field as a function of altitude. As expressed in equation (1), the second derivatives of the earth's gravitational field fall off inversely at the degree plus three. Thus, the orbit must be low in order to obtain the highest accuracy at a fixed signal resolution.

The requirement that the orbit be as low as possible creates problems with satellite drag. Satellite drag is difficult to predict, and available data are sparse. Clearly, the satellite must be high enough to guarantee a lifetime long enough to obtain a complete set of data, but it must also be low enough so that these data are as accurate as possible. The situation is further complicated by the fact that drag will create torques on the satellite that will cause the gradiometer to register erroneous signals.

Satellite drag at the altitudes in question is expected to be all-profile drag as opposed to viscous drag. It is important to keep the torque created by satellite drag from having frequency components at one and three times spin speed. This suggests the satellite will have to be circular in cross section to an unusually fine tolerance. A slightly elliptical cross section would tend to create drag-torque components at three times the spin speed. These torques would act on a small misalignment in the location of the instrument with respect to the center of mass, thereby creating signals completely undistinquishable from the gradient signal.

The components of a tensor change their magnitudes under rotation of the coordinate system. Thus, by definition, a gravity gradiometer is sensitive to instrument orientation. This necessitates the stabilization of a satellite containing a gradiometer.

Two candidate types of stabilization commonly used in satellites are inertial guidance and spin stabilization. The more attractive of these for gradiometer satellite applications seems to be spin stabilization. Both the Bell Aerospace and the Hughes proposals call for the instrument to be spun. This is done in part to overcome the instrument's sensitivity to orientation and, for the Hughes instrument, also to increase the signal-to-noise ratio. An inertially stabilized satellite would become more complicated by having a large rotating system inside it.

Spin stabilization causes the spin axis to be permanently oriented in inertial space. If the spin vector is perpendicular to the plane of rotation of the satellite about the earth, these data will be taken in the same plane with respect to the earth at all times. This is the orientation considered superior from the JPL study. When the spin vector is not perpendicular to the plane of rotation of the satellite about the earth, the spin vector will rotate with respect to earth-centered coordinates with a period equal to the time between orbits.

The difference is pervasive. Having the spin vector at 90 degrees to the proposed orientation would affect the location of photoelectric cells on the satellite, the antenna locations, the locations of horizon sensors and sun sensors, the data rates and magnitudes, the phase references, the output equation for rotating cruciform gradiometers, and the data storage mode. Thus, if data from more than one orientation were required to determine the gravitational field of the earth, at least one other satellite configured differently would be necessary.

Studies to date, however, strongly suggest that data from only one satellite orientation will be required to fit the spherical-harmonic coefficients. Further, it appears that the orientation proposed is the one that comes closest to giving an output that is linear with respect to the spherical-harmonic coefficients.

It is possible to calculate the effect of satellite altitude on measuring resolution. Hughes has performed computer simulations based on the flight of a satellite over large disk-shaped mass distributions on the ground. This simulation is based only on the radial second derivative, so some uncertainty is introduced into the Hughes conclusions because they have not actually performed a simulation of their instrument's output. One conclusion drawn from this simulation is that a gradiometer is able to separated two masses into two local maxima when the masses are separated by a distance equal to or greater than the altitude at which the gradiometer is flown over the masses.

6. MAGNETIC FIELD MONITORING SATELLITES

The magnetic field monitoring satellites are expected to be of three types. They are envisioned as having the following general characteristics:

- Vector-Magnetometer Satellites — Weight, 150 kg; diameter, 1 meter folded, 4 meters deployed; orbits, 400 km circular; three satellites separated by 4 hours local time, operating simultaneously for 6 months.

- Tethered Vector Magnetometer Satellite — Weight, 150 kg; diameter, 1 meter folded, 4 meters deployed; trailing Shuttle by 2 miles.

- Magnetic-Field Monitor Satellite — Weight, 200 kg; diameter, 1 meter folded, 4 meters deployed; orbit, 1000 to 2000 km circular; inclinations, 0 to 28 degrees.

III. APPENDIX TO CHAPTER VII

TABLE OF CONTENTS

FUTURE APPLICATIONS

1. PROJECTS IN ENERGY RESEARCH AND DEVELOPMENT

This portion of the report deals with those research and development projects which pertain directly to current and potential energy needs on earth. Some projects are funded through NASA appropriations and have been initiated in response to the recommendations of Congress as in the case of the $2 million authorized in FY-74 for energy-related work [Section 1(a)(7) of NASA Authorization Act, 1974] in the Office of Applications. Other projects have been initiated in response to requests by other agencies and in most cases involve the transfer of funds to NASA to support contracted studies and development activities.

a. <u>Solar-Electric Power Systems</u>. The United States demand for electrical energy is expected to increase by a factor of more than four from 1971 to 2000. The demand is expected to be met primarily by large increases in the use of both coal and nuclear energy [1]. Substantial research and development have been proposed [2] in order to make available the needed supplies of coal and nuclear energy while conforming to environmental standards and safety requirements.

With an aim toward satisfying environmental quality and safety criteria, studies of powerplant sites remote from user load centers and advanced energy transmission techniques are among the projects receiving consideration. These include studies of space-based power conversion and power relay satellites, cryogenically-cooled transmission lines, and energy transport.

In the long term, beyond the year 2000, it is anticipated that clean, safe, essentially inexhaustible solar energy (and possibly fusion energy) will help replace fossil and fission sources. In order to examine the large scale conversion of solar energy into electricity, research and development on space-based and earth-based solar energy conversion systems are in progress. Projects encompassing this work are summarized below.

<u>Project Title:</u> Space-Based Solar Power Conversion and Power Relay Systems Study

General Need and Approach:

Space-based solar power systems have been suggested as means to meet future demands for electrical power with a nonpolluting, inexhaustible energy source. Two space-based systems being considered are the satellite solar power station, in which an orbiting solar-cell array converts sunlight to electricity for transmission to earth, and the passive power relay satellite, which relays energy transmitted from earth-based power plants to distant load centers on earth. The advantages of space-based solar array systems are detailed in Reference 3a. A solar array in synchronous orbit would receive from 6 to 11 times as much solar energy as a terrestrial array, because in space the solar flux is not diminished by atmospheric absorption or by weather conditions and is available 24 hours a day. The full-time availability of the sun's energy would minimize the need for energy storage. Satellite solar power stations, if shown to be technically and economically feasible, could produce from 2 to 20 times the nominal 100 kW of electrical power of a representative nuclear reactor [3a].

The advantage of orbiting power relay satellites are stated in Reference 3b. Such satellites permit power transmission from one point to another on earth, over long distances and complex terrain. They permit dispersion of nuclear power sources and the use of remotely located natural sources, especially solar energy sources such as the deserts of the world.

Project Objectives:

A major problem with space-based solar power and relay stations is the lack of definitive engineering and economic data for reasonable trade-off studies. The initial objectives of the project are to provide a basis for technical and cost reduction efforts on space-based solar power conversion and delivery systems and to compare such space systems with possible terrestrial systems for the production and transmission of electrical power. A particularly important objective is to identify near-term technological activities on which to proceed if warranted.

Project Plan:

Technical and economic studies will be made of the Satellite Solar Power Station, which uses solar cells to convert sunlight to electricity, and of the satellite solar thermal system, which converts solar heat to electricity by means of turbines. In both systems it is assumed that the electricity will be delivered to earth by microwave beams. In the future, solar power plants will be compared with other forms of power generating systems. Studies will also be made of the orbiting passive power relay satellite, which collects microwave energy from suitably sited, earth-based nuclear or solar powerplants and relays the energy to load centers located far from the powerplants [3b].

Space-based systems such as these require continuing cost studies, as well as analysis and innovative design in the areas of photovoltaic systems, structures, assembly methods, transportation to orbit, maintenance, stabilization and control, radio interference, microwave energy transmission and reception, and environmental impacts [3, 4].

The FY-74 studies in these areas will identify technical targets, cost targets, and appropriate follow-on work. Subsequent efforts would involve the initiation of critical technology development and performance of key experiments.

NASA Centers and Relation to Other NASA Work:

The work will be done at the Marshall Space Flight Center (MSFC) and at the Jet Propulsion Laboratory (JPL). The work is related to the NASA shuttle development program, to NASA's advanced technology programs on solar cells and microwave energy transmission systems, and to NASA studies of solar thermal power conversion and delivery systems.

FY-74 Resources:

Total R&D Funding	$275K[1]
NASA Direct Man-Years	10.5

Project Title: Earth-Based Solar-Thermal Power Conversion and Delivery Systems Study

General Need and Approach:

The low population, desert areas of the U.S. have a great deal of available solar energy. Ten percent of this available energy converted to electricity could supply approximately $2\frac{1}{2}$ times the present electrical needs of the United States. There are at least three alternative collector system concepts that are possible. The real question is whether any of these collectors can be made sufficiently inexpensive to complete with modern coal, geothermal, or nuclear fueled power generation methods. As a first step toward assessing the practicality of solar thermal electrical power systems, the many trade-offs between systems and components within a system important to achieving low cost must be identified. In addition, technological advances need to be defined and justified.

1. Funded under authorization for energy-related work in Section 1(a)(7) of NASA Authorization Act, 1974.

Project Objective:

The objective of this project is to define the most promising solar thermal electrical power system concepts and to identify and justify needed technology improvements.

Project Plan:

A 1-year study is currently underway to explore system trade-offs and siting requirements, as well as to define limiting technology factors. A reference system concept and a typical site will be selected and limiting problems identified. This study was discussed with the National Science Foundation (NSF) prior to its initiation and is complementary to the NSF program.

NASA Center and Relation to Other NASA Work:

The work will be performed at MSFC and the Lewis Research Center (LeRC). The work is related to the residential solar heating and cooling project in progress at MSFC, to the solar collector technology in progress at LeRC and to past and on-going NASA technology in turbomachinery and dynamic power conversion systems.

FY-74 Resources:

Total R&D Funding	$175K[2]
NASA Direct Man-Years	2.8, increasing to 9.4 in FY-75

b. Solar Heating and Cooling. The United States consumes about one-fourth of its total energy in space heating and cooling and in the heating of water [5a]. Solar energy could be applied for the performance of these functions. Solar water heaters are made commercially and are widely used, several types of solar heating systems have been successfully tested in residences and small buildings, and a few experiments have shown that solar energy can be used as a heat supply for thermally operated absorption-type air conditioners [5b].

2. Funded under authorization for energy-related work in Section 1(a)(7) of NASA Authorization Act, 1974. In addition, a total of $360K of FY-73 Supporting Research and Technology (SRT) Funds have been applied to other studies related to solar-thermal power systems.

Up to the present time the most significant factor in delaying the widespread application of solar energy for buildings has been the high cost of solar heating and cooling, as compared to the cost with conventional fossil-fueled and electric heaters. The "pacing" component has been the solar collector, the cost of which must be reduced from current prices ($\$4$-$\$20/ft^2$) to perhaps $\$1$-$\$2/ft^2$ and the efficiency of which must be increased and perhaps doubled [6].

NASA is conducting three projects on solar heating and cooling which should answer some of the key questions regarding its use. These projects are summarized below. The National Science Foundation, which has the lead agency role for solar energy, is fully informed of these projects as a result of joint NSF-NASA planning in this area.

<u>Project Title:</u> Residential Building Solar Heating and Cooling

General Need and Approach:

One of the largest users of electrical energy in the United States is the residential sector. This sector is one of the least amenable to major change and those changes that can be made are subject to local factors of climate, government, labor, material and tradition. The present project is a first step in the experimental examination of engineering parameters that will affect the large scale use of solar heating and cooling for residential buildings.

Project Objective:

The objective of this project is to contribute to the development of a technically sound, economically viable system for the solar heating and cooling of buildings.

Project Plan:

At MSFC, a residential solar heating and cooling unit is being prepared for engineering testing. This unit uses a high performance, low-cost thermal coating and solar collector, and employs technologies developed at MSFC in spacecraft environmental control systems. For the engineering tests, a 1,500 ft^2 solar collector is being installed as a free-standing "roof" over three trailers which simulate a living area. In addition to the collector and its fluid flow and heat-transfer-and-insulation components, the system includes a 3-day energy storage tank using water as the storage medium; a modified, commercially available absorption-type air conditioning unit; and an automatic control system built from commercially available equipment. An auxiliary heater is provided to heat the water when the stored thermal energy is inadequate. Significant testing will have been accomplished by the end of FY-74.

This plan involves operation of the residential solar heating and cooling engineering test unit for a year. In addition, performance trade-off studies aimed at development of lower cost components (thermal coating, collector, thermal storage, low temperature absorption air conditioner) will be conducted. The applicability of this residential solar heating and cooling technology to commercial buildings will be evaluated. Progress in all three areas is expected through application of FY-74 funding.

NASA Centers and Relation to Other NASA Work:

The project is being conducted at MSFC. The work is related to the solar heating and cooling technology program in progress at LeRC, the office building solar heating and cooling demonstration being readied at the Langley Research Center (LaRC), and the earth-based solar-thermal power conversion and delivery systems study at MSFC.

FY-74 Resources:

Total R&D Funding	$400K[3]
NASA Direct Man-Years	14.5

<u>Project Title:</u> Full-Scale Solar Collector Test Bed

General Need and Approach:

Another major use of electrical energy in the United States is the heating and cooling of large commercial buildings. Full-scale testing of means to use solar energy to accomplish such heating and cooling involves many factors that differ from those for residential buildings, including size, location, maintenance, long-term versus short-term costs, and others. This project will examine these and other factors experimentally using simulations and full-scale operational systems.

Project Objective:

This project is directed toward obtaining full-scale test data and operating experience on solar heating and cooling systems suitable for large (~ 50,000 ft) buildings.

3. Funded under authorization for energy-related work in Section 1(a)(7) of NASA Authorization Act, 1974.

Project Plan:

The small-scale solar simulation test facilities in use in the solar heating and cooling technology programs at LeRC are being used to evaluate the current state-of-the art and to define and justify needed technology improvements. Full-scale component and system test data are needed to verify that the small-scale tests are valid representations of realistic applications. In addition, realistic operating experience is needed to verify the limitations and advantages of solar heating and cooling systems.

The overall plan is to utilize the Systems Engineering Building (SEB) at the NASA Langley Research Center as a solar heating and cooling system test bed. The SEB uses steam to heat water for both heating and cooling purposes. Thus it will be relatively simple and inexpensive to operate the building using hot water from solar collectors. Present plans call for the construction of up to 15,000 ft^2 of test collectors. Controls, hot and cold thermal storage tanks, and associated plumbing and test instrumentation will be located next to the collectors. Thus the SEB can be operated either by the conventional steam energy source or the collectors or both as conditions require. Building operation is planned to begin in the latter part of CY-75. Several test collector concepts will be selected on the basis of small-scale simulator tests at LeRC. Test results obtained from the LeRC simulator facilities (component and system) will be compared with the SEB test results. Operation of the SEB collector farm for several years is expected.

Center:

This project is under the direction of LaRC, which is responsible for the installation of the test collector farm, tanks, plumbing, controls, etc., and test operations. LeRC will design the system and furnish the test collectors.

FY-74 Resources:

Total R&D Funding	$60K of FY-73 Funds
NASA Direct Man-Years	2

The total cost of this project will be $300-500K, mostly from FY-73 funds.

Project Title: Solar Heat and Cooling System Technology

General Need and Approach:

Among the major obstacles delaying the utilization of solar heating and cooling systems is the lack of commercially available, low-cost, solar collectors and other subsystems. Preliminary estimates based on current technology indicate that capital costs would be from 2 to 4 times higher than conventional systems and that the efficiency of thermally powered cooling systems needs to be improved by a factor of 2. In addition there is an urgent need for standardized test data for both components and systems.

Project Objective:

The objectives of this project are to develop and determine the performance of economically competitive solar heating and cooling components and systems for use in NASA buildings in cooperation with the NSF program.

Project Plan:

This technology program will (1) determine and assess the current component and system state-of-the-art and (2) explore the needed component technology improvements. Standardized test data are being obtained in small-scale, solar simulation facilities, both component and system at LeRC. In addition full scale tests will be conducted on selected components in order to verify that the small-scale system tests are valid representations of full-scale applications (see the Full-Scale Solar Collector Test Bed project). Based on and concurrent with these tests, the needed technology improvements are being undertaken, first, for the pacing components (e.g., collectors and cooling systems) and, later, for controls and energy storage systems.

One contracted study and experimental program is being conducted on collectors. Collectors from this contract as well as many (10 to 20) other sources are being tested at LeRC. Similar study and experimental programs for cooling systems are in the initial procurement phase.

Center:

This program is being conducted by LeRC using both in-house and contracted efforts.

FY-74 Resources:

Total R&D Funding	$470K of FY-73 Funds
NASA Direct Man-Years	7.5

c. Wind Energy Systems. The NASA project involving wind generator systems as a source of energy is described below.

Project Title: Wind Electric Power Generation

General Need and Approach:

Wind patterns are remarkably repeatable and predictable. The energy contained in the winds over the U.S., the Aleutian arc, and the Eastern seaboard is substantial (approximately equal to current U.S. consumption of electricity). The chief drawbacks to be overcome in utilizing wind energy effectively are the high capital and maintenance costs of wind systems. Since the last large (100 kW) wind generator was built some 14 years ago, many technological advances and techniques have been developed that can be applied to reducing wind system costs and increasing efficiency.

Project Objective:

This project is aimed at developing wind energy systems that will be practical and that will supply significant amounts of energy at a cost and environmental impact competitive with alternative systems.

Project Plan:

This NASA project is in support of NSF's 5-year wind energy program and is directed and funded by NSF. The central core of the project will be to develop low-cost, reliable wind generator systems which will be built at two power levels, nominally 100 kW and 1000 kW. In addition, studies of available winds, siting criteria, energy storage, social and environmental impacts, etc., will be conducted.

A 100 kW unit is being designed in-house at LeRC and is planned for operation in mid-1975. Industrially designed 100 and 1000 kW units aimed at reducing cost are planned for operation in late CY-76. In addition, to gain information and experience quickly, a 5 kW unit, an off-the-shelf item, will be procured and placed in operation in the Cleveland area in 1974.

NASA-LeRC has prepared a Project Development Plan (PDP) that is presently under review. Approval signatures by NASA-LeRC, Headquarters, and NSF on the PDP will constitute an interagency agreement.

Center:

This program is being conducted by LeRC, utilizing personnel skilled in aerodynamics, stress and system analysis, electrical power generation and materials. A small complementary effort on low-cost, low-power wind generators is underway at the NASA Langley Research Center.

FY-74 Resources:

Total R&D Funds	$865K (NSF Funding)
NASA Direct Man-Years	10

d. Energy Conversion, Transmission and Storage. Effective utilization of energy requires means to convert it to other forms, to transmit it to the user, and to store it in convenient forms. These functions are an integral part of the use of energy in aeronautics and space missions. However, the unique nature of aerospace applications of energy has required that NASA extend the technical frontiers in energy conversion, transmission, and storage. This factor places NASA in a position to contribute to terrestrial energy R&D in these areas through its own programs and through assistance to other agencies.

In addition to the specific energy R&D projects described below, a broad range of other research and technology work is being conducted that may make possible major advances in energy conversion, storage, and transmission.

Project Title: Potassium Rankine Topping Cycle Study

General Need:

Conventional steam rankine stationary power plants operate at approximately 35 percent thermal efficiency. The waste of energy can be reduced by increasing power plant efficiency through the use of topping cycles that operate at higher peak cycle temperatures than permitted by steam systems.

Project Objectives:

The objectives are to assess the technical and economic advantages (fuel economy, low cost electricity, and reduced environmental impact) of a fossil-fueled potassium topping cycle plant to provide a sound basis for planning future programs in this area of energy R&D.

Project Plan:

At the request of the Office of Coal Research (OCR), Department of the Interior (USDI), a 6 month study of potassium topping cycle power plants was concluded in November 1973. This preliminary analysis indicated that overall plant thermal efficiencies greater than 50 percent at an electricity cost equal to or less than the cost of steam rankine electricity could be achieved. With this efficiency increase, 40 percent more electricity could be produced for a given quantity of fuel consumed.

A follow-on contract to continue the analysis in more detail is approaching the final stages of negotiation. The extended study will culminate in:

(1) A preliminary engineering design of a 1200 MW plant from which system construction and operational cost estimates will be derived.

(2) Identification of areas requiring technology advances or "scale-up" verification of available technology.

(3) A conceptual design of a pilot plant to include site and system cost estimates.

(4) Preparation of a technology program plan which will provide for successful operation of the potassium system components under realistic conditions.

The follow-on contract will be funded by OCR and managed by NASA.

NASA Center and Relation to Other NASA Work:

This work is being performed by LeRC. It is an extension of potassium rankine energy conversion research and development work performed for nuclear-electrical power generation systems for spacecraft.

FY-74 Resources:

Total R&D Funding	\$132K (NASA Funding) \$200K (OCR Funding) \$1,000 (Under study with OCR)
NASA Direct Man-Years	2

Project Title: Energy Conversion Alternatives Study

General Need:

Government policymakers must have objective reference concerning candidate system capabilities to guide their decisions pertaining to R&D support of advanced energy conversion systems.

Objective:

The objective of this study is to evaluate candidate energy conversion systems for central station power generation on a common basis to place their relative technological capabilities in perspective and to assess the impact of their use on the National economy, environment and natural resources.

Project Plan:

Funding support is being obtained from NSF and OCR. A statement of work has been prepared for contractual support of an in-house evaluation group and a request for proposals (RFP) will be released once formal intent of funding support from user agencies has been obtained. Two contractors will be hired to proceed essentially in parallel under the guidance of an in-house technical evaluation group. The following systems will be studied: open and closed cycle gas turbine, supercritical CO_2 turbine, liquid metal rankine, organic rankine, advanced steam rankine, magnetohydrodynamics, and fuel cells. Use of coal, coal oil, coal gas and methanol will be considered in suitable combination with appropriate combustion techniques.

Concurrently, an in-house energy system assessment team will determine the positive or negative benefits to accrue through widespread national use of selected systems in the future.

Contractual studies will be completed in 9 months from contract initiation now planned for mid-June 1974. In-house System Technical Evaluation and Impact and Benefit Draft Reports are scheduled 4 months later.

An ad hoc review group composed of representatives from user agencies will be established to meet at critical milestones during the study. This is designed to help ensure that study results will be responsive to user needs.

NASA Center and Relationship to Other NASA Work:

This work will be performed by Lewis Research Center. The study effort builds on a power conversion system analysis capability of long standing from the aeronautics and space mission of NASA.

FY-74 Resources:

Total R&D Funding	$1,000K (NSF Funding)
	750K (OCR Funding)
	300K (NASA Funding)
Total	$2,000K
NASA Direct Man-Years	8

Project Title: Microwave Energy Transmission and Reception

General Need and Approach:

Ultimately, the earth will deplete its present fuel sources and may have to rely on importing additional energy from space. Microwaves and lasers are the only technically feasible methods of transferring major amounts of energy through space with reasonable efficiency. Microwave energy transmission has been demonstrated in laboratories at low power levels over short ranges.

Project Objective:

This project will extend the present knowledge so that the feasibility of transmitting significant amounts of energy by microwave at great ranges with high efficiency can be understood. The ultimate objective is to develop the capability to transmit thousands of megawatts of power over great distances with efficiencies as high as 90 percent.

Project Plan:

This project will encompass expanded theoretical investigations of microwave energy transmission, the design of critical components, the development of some of the subsystems, and verification tests of a microwave energy transmission.

The subsystems in a microwave transmission system include a transmitter to convert electrical energy into microwaves, a transmitting antenna to beam the microwave energy onto the receiver, a receiving antenna to collect the beamed energy, and a rectifier to convert the collected microwave energy into a more useful form of electrical energy.

The study plan covers a 5-year period and involves overall systems engineering, transmitter tube development, and technology advances in the receiver system, transmitting antenna development, verification tests, and the fabrication of the large rectennas to be used in the tests. These tests will increase the transmission range and the power levels by a hundred-fold and will provide field tests of high power rectennas. These rectennas will be designed in modular form so that further power increases can be attained by adding modules.

The FY-74 effort will establish a modest test range, conduct field measurements at the receiving site, and demonstrate the transfer of power on the kilowatt level over a range of approximately 1 mile (1.6 km).

NASA Centers and Relation to Other NASA Work:

The work will be done at JPL and LeRC. The work is related to NASA's studies of the Satellite Solar Power Station and the Passive Power Relay Satellite concepts and to NASA's technology program to develop low cost, high performance solar cells.

FY-74 Resources:

Total R&D Funding	$500K
NASA Direct Man-Years	2.3

<u>Project Title:</u> Survey of Hydrogen Production Methods and of Their Potential for Replacing Fossil Fuels

General Need and Approach:

During the past few years there has been increased recognition of the potential of hydrogen as a means for storing, transporting, and using energy. Evaluations of hydrogen as a nonpolluting energy storage medium have been in progress under government and industry sponsorship [7-9].

Increased hydrogen production is called for in the recommended national energy research and development program submitted to the President by the Chairman of the Atomic Energy Commission in December 1973 [2]. The proposed energy R&D program calls for a breakthrough in the production of hydrogen for use in gasification and liquefaction of coal and indicates a need to develop methods of producing hydrogen at low cost, to be used in exploiting long term energy resources (fusion, solar and geothermal energy), beyond the year 2000.

Major applications of hydrogen are currently known. Research is needed to identify additional uses of hydrogen as a replacement for fossil fuels and to establish approaches which would make them economically competitive.

Project Objective:

The initial project objective is to survey comprehensively and to catalog all facets of hydrogen production and to identify likely applications in which hydrogen could substitute for fossil fuels. The ultimate objective is to evaluate the use of hydrogen as a clean medium for storage, transmission, and utilization of energy from various sources.

Project Plan:

Following the initial survey of hydrogen production methods, these methods will be assessed and areas potentially amenable to efficiency improvement or to a cost reduction will be identified and investigated. Emphasis will be placed on the production of hydrogen from ordinary water and from sea water by electrolysis and by catalyzed thermochemical processes. Surveys, studies, and conceptual designs will be performed to identify valid applications of hydrogen as a replacement for fossil fuels in the industrial, commercial, residential, electrical utility, and transportation energy sectors.

NASA Centers and Relation to Other NASA Work:

The work will be conducted by MSFC and JPL. Other NASA work includes development of technologies for safe storage and handling of liquid hydrogen and for reacting hydrogen with oxygen, advances in the hydrogen/oxygen fuel cell, research on hydrogen embrittlement of pipeline materials, and basic compressor technology applicable to pumping the gas. A NASA-supported literature survey of available thermochemical reactions for obtaining hydrogen from water is underway. A study of hydrogen as an energy carrier was performed jointly by NASA and the American Society for Engineering Education in the summer of 1973 [9].

FY-74 Resources:

Total R&D Funding	$270K[4]
NASA Direct Man-Years	1.75

4. Funded under authorization for energy-related work in Section 1(a)(7) of NASA Authorization Act, 1974. $65K of FY-73 funds have been applied to this project.

Project Title: Survey of High-Energy-per-Acre Crops

General Need and Approach:

Organic material in the form of crops specifically grown for the purpose and/or agricultural and urban waste material (trash, garbage, sludge, etc.) can be converted by several commercially available processes to clean liquid, solid, or gaseous fuels. This concept has the potential of furnishing 10 to 30 percent of the Nation's total energy needs, as well as relieving the growing waste disposal problem. One of the major uncertainties in assessing the practicality of this concept is the net energy yield (BTU's) per acre versus unit cost that may be possible if plants were selected and grown for their total energy content rather than their food value. Such information exists in the agricultural community but has not been assembled in a useful form.

Project Objective:

The project objective is to survey the agricultural information available to determine which species of crops offer the highest net energy yield per unit cost.

Project Plan:

A 1-year research grant is underway with the Ohio (State) Agricultural Research and Development Center to conduct the survey. The project was discussed with NSF prior to its initiation and is complementary to the NSF program.

Center:

The survey is being conducted under the direction of LeRC, utilizing personnel skilled in systems analysis and hydrocarbon fuels chemistry.

FY-74 Resources:

Total R&D Funding	$35K of FY-73 Funds
NASA Direct Man-Years	0.5

e. <u>Transportation Propulsion Systems</u>. Transportation accounts for a major share of the use of petroleum and contributes significantly to pollution. Recent trends in automobile design have reduced efficiency and increased fuel consumption. It may be possible to reverse this trend by improving conventional engines by developing new forms. Two projects concerned with this work are being conducted in association with the Environmental Protection Agency (EPA). These projects, which are described below, draw on NASA's experience in combustion, chemistry, materials, Brayton power systems, and aircraft gas turbine engines. Evaluation of hydrogen injection in engines began in NASA for the purpose of finding means to reduce pollution produced by aircraft used in general aviation without causing serious increases in fuel consumption. For convenience, automobile engines have been utilized in tests of hydrogen injection. The EPA has become interested in this program and has offered to support some of the work.

NASA's knowledge in aerodynamics is also being applied to reducing the drag of large road vehicles, which will cut fuel consumption in the trucking industry. This project is also summarized below.

<u>Project Title</u>: Hydrogen Injection for Automobiles

General Need:

Vehicles using the internal combustion engine consume a major fraction of the Nation's petroleum and are also the largest contributor to air pollution. The concept of hydrogen injection has the potential for providing both aircraft and automotive engines which consume 25 percent less fuel while meeting 1977 Federal emission standards.

Project Objectives:

The hydrogen injection concept involves the injection of relatively small quantities of hydrogen, generated from onboard gasoline, into the primary fuel/air system to improve the efficiency of the internal combustion engine. The objective of this program is to explore the feasibility and demonstrate the potential of this concept for application to aircraft. For reasons of expediency and economy, the initial phases of this effort make use of standard automotive components and vehicles.

Project Plans:

Concept feasibility has been demonstrated both in the laboratory and the field, by the use of an automobile equipped with bottled hydrogen. Although the ultimate objective of meeting or exceeding 1977 Federal emission standards was not attained, the pollutants were significantly reduced and fuel consumption was cut by 25 percent as measured over the Federal Driving Cycle.

Future effort will focus on better understanding of the fundamental processes involved in adapting this concept to practical use with automobiles and the technology og generating the required hydrogen from gasoline on board the vehicle. This program is being conducted in cooperation with the EPA. In addition, the American automotive companies and DOT are being kept informed on the program progress.

NASA Center and Relation to Other NASA Work:

The automotive work is being conducted at JPL, with LeRC providing technology support in the area of hydrogen generators. LeRC is also investigating application of this concept to light aircraft and other transportation systems.

FY-74 Resources:

Total R&D Funding	$1,465K (NASA Funding) $ 300K (EPA Funding)
NASA Direct Man-Years	3

<u>Project Title:</u> Automotive Gas Turbine

General Need:

Automobiles consume a major fraction of the Nation's petroleum and are also the largest contributor to air pollution. The use of turbines offers potential for developing environmentally-acceptable, efficient automobiles.

Project Objective:

The objective of this project is to provide technological assistance to the EPA in demonstrating an automotive gas turbine engine having exhaust emissions that meet the 1977 Federal standards, with increased fuel economy.

Project Plan:

LeRC has established the Automotive Power Systems Office which directs this element of EPA's technology development program, including management of several EPA contracts. A baseline Chrysler automotive gas turbine engine is presently being used in a test where it is undergoing a detailed performance analysis.

A redesign of internal aerodynamic components for incorporation into an upgraded engine is underway. This work will culminate in complete systems testing in an automobile by October 1975. Along with the specific EPA project, LeRC conducts a program to advance automotive gas turbine technology.

NASA Center and Relation to Other NASA Work:

This work is being performed at LeRC, utilizing technical capabilities established in aircraft propulsion system and power conversion system R&D projects.

FY-74 Resources:

Total R&D Funding	\$392K (NASA Funding) \$200K (EPA Funding)
NASA Direct Man-Years	18

<u>Project Title:</u> Aerodynamic Drag of Large Road Vehicles

General Need:

The drag coefficient of trucks and other "square-box" vehicles is high. At road speeds of 50 mph more than 50 percent of the engine horsepower is used to overcome aerodynamic drag. As speeds increase this horsepower requirement increases as the velocity cubed [10]. With the large and increasing number of trucks currently in operation, reduction in drag could result in significant reductions in National fuel consumption.

Project Objective:

The objective is to evaluate the impact of changes in aerodynamic configurations on the fuel economy of trucks and other large road vehicles.

Project Plan:

Controlled experiments to quantify the reduction in drag that can be obtained through configuration changes on a baseline "square-box" vehicle are being conducted by the Flight Research Center. In addition, a program is being developed with the Transportation Systems Center of DOT to evaluate the effect of existing devices such as air shields, vortex stabilizers, turning vanes, etc., on the fuel economy, stability of the parent vehicle, and the effect on neighboring vehicles.

Baseline drag coefficient data have been obtained on a rectangular test vehicle using two separate deceleration measurement techniques. A test conducted with rounded vertical corners yielded a 30 percent reduction in drag at speeds of 55 to 60 mph.

The effect of other configuration changes on the baseline vehicle will be obtained. A program plan for testing of existing aerodynamic "aids" is being jointly considered by DOT and NASA. It is expected that the presently planned program will be completed by mid-FY-75. Subsequent work in this area will be contingent upon the results of the current program.

NASA Center and Relationship to Other NASA Work:

This work will be conducted by the Flight Research Center. The basic technology and instrumentation techniques used in the project derive from the aeronautics flight test program

FY-74 Resources:

Total R&D Funding	$42K (NASA Funding) $65K (DOT Funding)
NASA Direct Man-Years	2 (Current)

f. <u>Energy and Environment Conservation.</u> The knowledge and techniques used to sustain and protect life in manned space flight involve energy conservation to the highest degree. Perhaps of greatest significance to this field is system engineering and management, because many problems of energy and environment on earth can be solved by proper management of existing resources and available energy.

The Modular Integrated Utility System (MIUS) project, described below, is an example of systems engineering to utilize existing capabilities to the fullest extent to conserve resources and improve the environment. The project on the production of fuels from urban wastes, summarized below, is an effort to enhance future MIUS-type systems.

Other projects in this section deal with the use of NASA capabilities to determine the extent and source of atmospheric pollutants related to energy production.

Project Title: Modular Integrated Utility System (MIUS)

General Need and Approach:

Combined pressures of population growth and the increased mobility of society have indicated a need for large-scale community development including new communities, addition to existing ones, and large-scale redevelopment of out present population centers. To make these developments liveable, certain utilities are required: electricity, heating, air conditioning, potable water, and waste treatment and disposal. The distribution networks to make these services available must be provided. Furthermore, increasing urban population is pressing the limits of environmental capacity. The availability of resources and increasing unit cost and demand suggest the need to increase our productivity in supplying utility services.

Energy in the forms of electricity and primary fossil fuels is in short supply. The energy picture is uncertain, particularly when the supply problem is coupled with the necessity to restore and preserve the environment. The cost of solid waste management is increasing at a rate faster than the population growth because of the lack of close-in land fill and the requirement to improve on current disposal practices. Liquid waste treatment facilities have not kept pace with the requirements of increased load and a higher degree of treatment demanded by society today.

Obviously, new approaches are needed to supply these needs of society in a manner consistent with conservation of our limited resources and the need to improve and protect the environment.

Project Objectives:

The objective of the MIUS concept is to provide the community with the desired utility services consistent with reduced use of critical natural resources, protection of the environment, and minimized cost.

Project Plan:

The Department of Housing and Urban Development (HUD) is conducting the MIUS Program which is devoted to development and demonstration of the technical, economic, and institutional advantages of integrating the systems for providing all or several of the utility services for a community. The utility services include electric power, heating and cooling, potable water, liquid waste treatment, and solid waste management. The program goal is to foster, by effective development and demonstration, early implementation of the integrated utility system concept by the organization, private and public, selected by a given community to provide its utilities.

Under HUD direction several agencies are participating in the MIUS Program, including the Atomic Energy Commission, the Department of Defense, EPA, NASA, the Department of Health, Education, and Welfare, and the National Bureau of Standards. The National Academy of Engineering is providing an independent assessment of the Program. The multiagency program is a three-phase effort:

<u>Phase I</u>

- Development, demonstration and evaluation of individual technology.
- Detailed analysis (performance, cost, etc.), conceptual design selection, preliminary design and planning for Phase II demonstrations and evaluations.
- Preliminary subsystem and integration testing.

<u>Phase II</u>

- Demonstrate and evaluate several integrated utility systems in real-life situations.

<u>Phase III</u>

- Disseminate information, promote technology transfer and encourage private utility institutions to enter integrated utility systems business.

The first demonstrations will utilize "Articles of Commerce" (existing technology) in the MIUS design. The system benefits will accrue from integration of the components at the systems level, which results in a technological device (MIUS) that allows the institutional forces of developers, utilities, local municipalities, etc., to marshall their resources to ensure implementation of this alternate approach to providing utility services.

Status

The MIUS Program is currently in Phase I (design, development and test). The conceptual design studies have been completed for specific applications, such as apartments, office buildings, hospitals, schools, shopping centers, and phase-developed total communities. The MIUS system requirements have been defined and reviewed with all program participants. The first draft of a generalized standard method MIUS system performance specification has been delivered to HUD. A final version suitable for RFP for specific site consideration is being developed.

NASA Centers and Relation to Other NASA Work:

The MIUS program in NASA is conducted by the Johnson Space Center (JSC). A Memorandum of Understanding (MOU) has been executed by HUD and NASA. The document indicates NASA program participation through CY-76. It further provides for HUD to reimburse NASA for the cost of certain skills not available in NASA and other expenses required to accomplish the program.

FY-74 Resources:

Total R&D Funding	$736K[5]
NASA Direct Man-Years	35

Project Title: Development and Evaluation of Gaseous Fuel Production by Pyrolysis of Municipal Waste

General Need and Approach:

In the future, communities will need to provide for a substantial portion of their energy from sources other than oil or nuclear energy. Conversion of municipal waste to fuels may offer a solution to such problems and eliminate some disadvantages of current waste handling methods. If the alternate fuel capability is proven economically feasible, it will enable communities to install integrated utility systems in a well-planned fashion.

Project Objectives:

The objective of the program is to identify and evaluate the optimum process for the conversion of municipal refuse into a fuel for use within an integrated utility system consisting of power generation, liquid waste treatment,

5. Reimbursable from Department of Housing and Urban Development.

solid waste processing, heating and cooling systems, and fresh water processing. Such provision of integrated systems in conjunction with the pyrolysis plant can reduce fuel consumption by over 50 percent. The fuel produced by the pyrolysis plant could also be further processed to be utilized in pipelines within the surrounding community served by the integrated utility system. A second objective is to evaluate the potential of utilizing the same process equipment with modifications and/or additions for processing other fuels such as coal, shale oil, wood, etc.

Project Plan:

There are currently several competing technological processes available. They have been developed either through EPA or OCR funded activities. Some have advanced to the early pilot plant stage. None have involved integration with the other utility systems, which can substantially improve the economics and overall utility of this solid waste processing concept. The concept could potentially provide from refuse approximately 10 percent of the energy required by the residential and commercial elements of a community.

The initial phase of the program consists of determining the preferred process for conversion of refuse into gas, designing a suitable pilot plant to resolve the technical details of the process and system, and testing of the pilot plant at the existing integrated utilities test facility at JSC. Cost studies will be conducted to determine the economic feasibility of this process.

It is anticipated that by the end of FY-74, a contractor will have been selected and the most promising pyrolytic process identified. Testing of the system should begin early in FY-75.

Later phases of this program will involve the design, fabrication and evaluation of the additional process equipment required to expand the capability of pyrolysis system to include handling of alternative fuels such as coal or residual oils.

The pyrolysis project is a direct extension of the MIUS program work which is presently being carried out at JSC. The MIUS concept involves the integration of all of a community's utility service into a single package plant. This would include electrical power, building heating and cooling, and solid and liquid waste processing. The MIUS program is directed by HUD and includes various other agencies of the Federal government. EPA has expressed an interest in the pyrolysis program that NASA has proposed and discussions are underway between the two agencies concerning joint endeavors in this field.

NASA Centers and Relation to Other NASA Work:

The pyrolysis program will be managed by the Urban Systems Project Office at the Lyndon B. Johnson Space Center. This office also is responsible for the MIUS program described above. Successful development of a pyrolysis process would have a beneficial effect on the design of integrated utilities systems and other urban systems.

FY-74 Resources:

Total R&D Funding	$380K[6]
NASA Direct Man-Years	6.0

Project Title: Remote Sensing of Smokestack Pollution

General Need:

About 50 percent of the particulate and gaseous air pollution is attributable to fixed plant installations. The EPA has been assigned the task of monitoring and regulating fixed plant emissions of pollutants. This task is quite difficult and time consuming when conventional sampling methods are used.

Project Objective:

The project objective is to determine the feasibility of using optical techniques to remotely monitor stack plumes.

Project Plan:

In October 1972 Langley Research Center successfully measured SO_2 and NO pollutant emissions from a power station in North Carolina. Measurements were made with a laser radar modified to detect Raman light emissions by the pollutant gases of interest. Langley is now in the process of determining their instrument calibration constants.

A prototype instrument for detecting SO_2 and NO will be designed in FY-75 and tailored to meet EPA needs. This will complete the original task objective assigned by EPA.

6. Funded under authorization for energy-related work in Section 1(a)(7) of NASA Authorization Act, 1974.

NASA Centers and Relation to Other NASA Work:

Work is being performed by LaRC. The laser radar used to verify the measurement concept was originally developed for NASA meteorological measurements in support of the aeronautics and space mission.

FY-74 Resources

Total R&D Funding	$112K
Direct NASA Man-Years	2

<u>Project Title:</u> Air Pollution Source Identification

General Need:

Trace elements (lead, beryllium, etc.) and compounds (asbestos, benzypyrene) in the air create a physiological hazard. Source identification techniques are needed.

Project Objectives:

The objective is to relate trace elements/compounds in ambient air samples to specific pollutant sources.

Project Plan:

This project was initiated at the request of Cleveland Air Pollution Central Board in January 1971. An ambient air sampler for use in an urban air contamination measurement matrix has been developed and a computerized analytical model for identifying unique pollution sources by trace element "fingerprint" is nearing readiness for field test. The program is strongly endorsed by the Cleveland Pollution Control Board and negotiations are underway to conduct a 2-year joint operational test with the State of Ohio EPA.

Starting in FY-75, a system operational test will be conducted with the State of Ohio EPA. This could include a test in the Cleveland urban area, at other selected industrial sites in Northern Ohio, or both.

NASA Centers and Relation to Other NASA Work:

Work is being performed by the LeRC and is directly related to sampling techniques and instrumentation developed for the aircraft air pollution reduction program.

FY-74 Resources:

Total R&D Funding	$250K
NASA Direct Man-Years	8

2. REMOTE SENSING APPLIED TO ENERGY RESOURCES

There is a need to locate new energy sources and to properly develop existing ones. Remote sensing from space can contribute significantly to meeting these needs. Analysis of data from the Earth Resources Technology Satellite (ERTS-1) has shown that with remote sensing it is possible to explore for oil and for geothermal areas, detect subsurface fractures which control rockfalls in underground coal mines, and monitor strip mining and land reclamation. Expanded application and further development of remote sensing capabilities are planned.

Several projects are involved in the energy-related remote sensing activity. There combined objective is to apply relevant data and imagery from the ERTS and Skylab missions to locate new energy sources, monitor the development and environmental effects of existing sources, and to further develop the capabilities of space sensing for energy-related applications.

The on-going investigations using ERTS imagery involve petroleum exploration in Oklahoma and Texas; study of the petroleum potential of Northern Alaska; and correlation of data on deep mine and strip mine rock falls, and monitoring of strip mines and land reclamation in Indiana. ERTS follow-on investigations will stress demonstration of operational applications with bona-fide users. More than 600 proposals have been reviewed by technical panels and selection of investigators is underway.

The data and imagery from the Skylab Earth Resources Experiment Package (EREP) will be compared with the ERTS data. The Skylab/EREP data will be used for advances in applications beyond those achieved with ERTS; this is made possible by the more advanced EREP instrument capabilities. New applications will be investigated, using Skylab data to detect geothermal features in Nevada, Utah, Wyoming, and elsewhere in the United States.

The Heat Capacity Mapping Mission is proposed as a new start in FY-75, for launch in 1977. This low cost satellite will produce maps of various rock types which will be useful for oil exploration. In addition, it may detect some of the hotter, known geothermal areas.

A joint research program with U.S. Geological Survey is in planning; data from the Heat Capacity Mapping Mission will be used to develop more advanced remote sensing techniques for geothermal exploration. This research will involve thermal modeling, aircraft investigations of detection limits, laboratory and field measurements at geothermal sites, and development of advanced infrared thermal scanners. Research on microwave detection of geothermal anomalies will continue at the Jet Propulsion Laboratory. JPL is also performing research on enhancement of imagery by digital computers; this technology has successfully detected mineralized areas at Goldfield, Nevada. Effort is in progress to develop imagery enhancements useful for petroleum exploration.

This work is in progress at the Goddard Space Flight Center (GSFC), JSC, and JPL. It is part of the larger program of earth resources survey and is related to the pollution monitoring program and the overall energy activity in progress at NASA.

Funding for these programs is included in total Earth Resources Survey funding for FY-74.

3. FUEL CONSERVATION IN AERONAUTICS

NASA's charter in aeronautics research and technology (R&T) has led to a comprehensive program to improve the performance and environmental characteristics of civil and military aircraft. Fuel consumption has always been an important factor in the measurement of that improvement, even when jet fuel was relatively inexpensive. The impact of the recent emphasis on fuel conservation has caused NASA to modify certain priorities within the aeronautics R&T program; however, that program has retained its basic structure.

The FY-74 aeronautics R&T program is funded at $168 million and is supported by 3870 direct NASA positions. Although it is not feasible to extract a distinct entity which might be labeled the "energy program," we estimate that approximately $21 million of the total FY-74 aeronautics funding is applicable to energy conservation efforts. This quantity is expected to increase about 25 percent in FY-75.

For the purposes of this report, the NASA aeronautics program is discussed under the headings of Operating Systems, Propulsion, Aircraft Design and Advanced Concepts. The discussions include activities conducted within the R&T base programs in the various technical disciplines, and also activities conducted as part of the focused Systems and Experimental Programs.

a. Aeronautical Operating Systems. Operating systems experiments with important fuel-conservation implications are being conducted in the Terminal Configured Vehicle (TCV) program for long- and medium-haul aircraft and in the STOL and VTOL Operating Systems Experiments programs for short-haul aircraft. These programs have multiple objectives in the areas of safety, congestion relief, noise reduction and fuel conservation.

The principal ways in which these programs enhance aviation fuel conservation are through smoother, speedier flow of traffic both enroute and in the terminal area and through increased efficiency of individual maneuvers. The magnitude of fuel savings from many relatively small increments in operational efficiency is difficult to predict and credit. However, the combination of procedure changes and the gradual introduction of advanced operating systems technology is expected to reduce civil jet fuel use by 5 to 10 percent.

b. Aeronautical Propulsion. By its very nature, aeronautical power plant research supports goals of minimizing fuel consumption. For example, component research has made possible in many ways the achievement of lower engine fuel consumption. The NASA program encompases all major components of air-breathing propulsion systems, with particular emphasis on advanced compressors and turbines, where fuel savings potential is significant. For near-term applications, technology is now available for low leakage compressor and turbine shaft seals. Improved combustion chambers developed for reduced emissions will be available within 5 years.

A vigorous effort is underway to expedite the introduction of this kind of technology advance into existing and new production hardware. The corresponding fuel savings would be something like 3 percent but, looking perhaps a decade ahead, we would expect a new engine incorporating advanced technology throughout to offer 10 percent fuel savings.

Recent additions to the aeronautical propulsion program, which place additional importance on energy use, are analyses of advanced engine cycles and an experimental effort in alternate fuel characterization. These activities will determine whether or not minimization of fuel use and the introduction of nonpetroleum jet fuels call for modified engine cycles and fuel specifications.

c. Aircraft Design. The recent Advanced Transport Technology (ATT) studies examined the integrated benefits of advanced in aerodynamics, materials, propulsion, controls and auxiliary subsystems. The technical advances all tended to reduce aircraft weight and improve efficiency and, therefore, contribute directly to fuel economy. Because of the changed outlook on fuel cost, a new study has been initiated imposing minimum fuel consumption as a primary design requirement but otherwise following much the same approach as the ATT studies. The results are expected to show potential fuel savings relative to current aircraft considerably in excess of the 30 percent calculated in the ATT study.

NASA has major technology programs in composite materials and structures, aircraft controls technology, and supercritical aerodynamics, which (along with propulsion) were the major contributors to the ATT study benefits. Flight programs are underway to demonstrate the serviceability of composite secondary structures; primary structures will be flown in the near future. Digital fly-by-wire flight experiments are providing design techniques and a technology base for active control aircraft development. Supercritical aerodynamics is a relatively advanced technology finding application in a number of aircraft modifications and designs. The introduction of a supercritical wing is estimated to yield a 15 percent fuel saving in a transport aircraft.

These aircraft technology programs, plus the propulsion program described previously, will serve as the basis for the next few generations of civil transport aircraft in the mid- to late-1980's. Further advances, stemming from today's more speculative technology, are being sought for longer-term applications. One example, which the energy situation has brought back into active consideration, is boundary layer control. Studies and wind tunnel experiments will be conducted at an exploratory level to see whether the combination of high fuel costs and recent technology advances make any of the schemes for skin friction drag reduction practical.

d. Advanced Air Transportation Concepts. Looking beyond the time period of the next generation of conventional aircraft and beyond the fossil-fuel era, NASA has increased system study activity in advanced aeronautical concepts. One area of interest is hydrogen-fueled aircraft; another is a new assessment of lighter-than-air (LTA) vehicles.

Configurations, performance, economics and technology requirements of liquid-hydrogen-fueled aircraft are being analyzed. Principal attention is being given to hydrogen cost (in terms of both dollars and energy input), storage (in flight and at the airport), and operational practicality. Although major hardware activity does not appear warranted at this time, systems studies will continue and long lead time technology requirements will be identified for possible inclusion in OAST R&T programs.

Among the unconventional systems being studied are LTA and very-large aircraft. The studies will make broad assessments of potential applications and attainable performance with current and advanced technology.

The NASA aeronautics R&T program is contributing to the National energy conservation effort in a manner analogous to its familiar contribution to air transportation. The NASA program has been closely coordinated with related efforts by DOT/FAA and the several energy agencies (e.g., the AEC Energy R&D program submitted to the President) and will be directed so as to accelerate the achievement of National energy self-sufficiency.

4. RELEVANT SPACE AND NUCLEAR RESEARCH AND TECHNOLOGY PROGRAMS

Under its charter to enhance capabilities for the exploration and utilization of space, NASA conducts a wide range of activities in the physical sciences concerned with sources of energy and conversion, storage, and transmission of the energy. While the motivation for these programs is found in space missions and they are funded by the Space and Nuclear R&T budget, their very nature makes them have relevancy to energy R&D for earth-based systems. In most cases, however, the applications for these technologies on earth may not occur for several decades in the future. Nevertheless, a report on energy research and development in NASA would not be complete without including a summary of relevant Space and Nuclear R&T programs.

Two major categories of programs are included in this section: (a) those NASA Space and Nuclear R&T programs which deal with energy conversion, transmission, and storage, and (b) programs in NASA dealing with nuclear energy sources.

When presenting resources for the relevant Space and Nuclear R&T programs, the total budget amounts are presented and no attempt has been made to assign a value to potential terrestrial uses vis-a-vis space applications.

a. Energy Conversion, Transmission and Storage. In these areas NASA has a number of on-going programs for future space missions. They are discussed in the following paragraphs.

Program Title: Solar Cells and Arrays

Objective:

The objective of this program is to reduce array costs by up to 90 percent (from $400/W to $40/W), improve power density (from 30 to 50 W/lb), and reduce dynamic interaction problems. To do so requires greater radiation resistance, a large decrease in the efficiency of conversion (from solar radiation to electricity), and novel modular design and construction techniques.

Targets:

- Space qualify 14 percent-efficient Comsat ("violet") solar cell in FY-74.

- Space qualify low-cost Teflon covers for solar arrays in FY-74.

- Fly new primary standards of solar cells on balloons and distribute to users by FY-75 for calibration of equipment, cells, and arrays.

- Achieve pilot production of thin (4-mil instead of 8-mil) solar cells for lightweight arrays by FY-76.

- Make available the potentially low-cost, single-crystal silicon ribbon cell for test and evaluation by FY-76.

- Make available lightweight (50 W/lb instead of present 30 W/lb) solar array technology in FY-77.

- Demonstrate resistant (18 percent efficiency at end of life) 8-mil solar cells by FY-78.

- Low-cost ($40/W instead of $400/W) array technology will be available by FY-78.

Need and Relevancy:

Power is an absolute necessity for the operation of any spacecraft. Solar power systems have been successfully employed on many spacecraft, in particular, Skylab's solar power system, which proved very reliable, consisted of over 2,000 ft^2 of solar cells and could generate more than 20 kW of electrical power. However, as future space mission times get longer, as deep-space probes move farther away from earth, as more hostile conditions are faced by spacecraft, as distances from the sun change drastically when compared with past missions, as solar electric propulsion becomes a necessity for certain types of missions, improvements in the weight, cost, quality, and reliability of solar arrays become imperative. The high costs of procurement, quality control, and qualification must be reduced. A byproduct of these developments will be a lowering of the cost of solar photovoltaic power that will make such devices more competitive on the ground. We already find them in remote weather stations, light buoys, beacons, and road telephones here and abroad. Other specialty uses are being uncovered and the demand for lower cost solar arrays is increasing.

This work is being conducted by LeRC, JPL, universities, and industry.

FY-74 Resources:

Total R&D Funds	$2,136K
NASA Direct Man-Years	43

Program Title: Chemical Energy Conversion and Storage

Objective:

The objective is to attain long life, high energy densities, and high reliability of electrochemical energy storage and conversion devices. This requires advances in component technology, in operating techinques, and in test and evaluation procedures.

Targets:

- Determine the effects of zero-g on high power output (limiting current density) of nickel-cadmium and silver-zinc cells in FY-74.

- Achieve a doubling of the life of Ni-Cd batteries (10 year target with 6,000 cycles/yr versus current 5-year capability) by means of nongassing construction (FY-75) and screening through nondestructive testing (FY-76).

- Triple energy density of batteries for 5-year use in synchronous orbit (400 cycles/yr, from 8 to 10 W-h/lb to 20 to 30 W-h/lb) by use of silver-sinc batteries with new, inorganic separators by FY-78.

- Screen candidate solid ionic electrolytes to select those that offer potential for operation below 100°C with alkali metal or alkaline earth anodes for very high energy density (150 W-h/lb) and indefinite shelf and cycle life.

Need and Relevancy:

Energy storage aboard a spacecraft is needed for those times when some other primary power source (solar or nuclear) is not functioning, e.g., on takeoff, during maneuvering, while in eclipse; for peak power demands; for emergency; and, of course, for the relatively short missions (Mercury, Gemini, Apollo) where such stored energy represents the only available energy source. Batteries were taken over from ground applications with few modifications. Years of testing and experience have taught us that neither the construction nor the mode of usage should remain unchanged. We are continuing to evolve higher quality products, having started with small cells that lasted for weeks and are presently flying large batteries for up to 5 years. In turn, our experience is being reflected in improved consumer products that accept fast changes, can be both stored and used longer, and are safer and more reliable.

This work is performed by LeRC, JPL, GSFC, and on contract with industry.

FY-74 Resources:

Total R&D Funds	$2,606K
NASA Direct Man-Years	40

Program Title: Power Processing

Objective:

The objective of this program is to advance the technology of electrical power conditioning, distribution, and management to (1) achieve multikilowatt, high voltage capability, (2) enable unattended operation of from 10 to 12 years, (3) reduce cost through modularization and standardization, and (4) provide new, improved concepts. Improvements in efficiency and weight are also part of these objectives.

Targets:

- Complete in FY-74 the evaluation of an advanced, uninterruptable power processing system in a remote microwave FAA ground repeater station.

- Demonstrate in FY-74 the application of series resonant, silicon control rectifier inverter technology to ion thrusters.

- Familiarize in FY-74 potential users with the theory and application of newly-developed control modules which can lead to the standardization of the regulation and control functions in all power converters.

- Demonstrate in FY-75 the concept of using on-the-array regulation of kilovolt, high power solar power systems applicable to ion propulsion and communications satellites.

- Demonstrate in FY-75 a 50 kW, 2 μsec gate assisted silicon control rectifier suitable for multikilowatt power processing.

- Test in FY-76 a first generation modularized, multikilowatt power conditioning concept.

- Evaluate by FY-77 an experimental 100 to 300 Vdc distribution system.

- Develop by FY-78 electrical propulsion power conditioning equipment which reduces power processing system specific weight from 20 lb/kW to 2 lb/kW.

Need and Relevancy:

Power processing systems are a necessary part of all manned and unmanned spacecraft. In the first decade of space flight, each power processing system was individually fashioned from state-of-the-art technology of components and circuitry in accordance with project needs and which incorporated expedient solutions to problems encountered.

New power processing capabilities must be provided to meet the needs of near-term missions and missions in the 1980's. These missions include high power communication satellites, solar electric propulsion, outer planet spacecraft, large high power observatories, and manned missions to be built on shuttle capabilities. The new capabilities which will be required include high voltage and power processing, longer operational lifetimes, improved reliability, onboard self-diagnostics, and advances in the power source. This power processing technology could have wide usage in the energy field and other terrestrial applications, such as communications, electronic control, and computers.

This work is being conducted by LeRC, JPL, and on contract with industry.

FY-74 Resources:

Total R&D Funds	$1600K
NASA Direct Man-Years	8

Program Title: Thermomechanical Energy Conversion

Objective:

The objective is to provide the technology of advanced thermomechanical energy conversion systems which will lead to (1) lower cost space nuclear power systems, (2) manned space vehicle peaking power systems, and (3) improved energy utilization with reduced environmental impact ground power systems.

Targets:

- Complete in FY-75 performance tests of a proof-of-concept 400 hp O_2/H_2 reusable peaking power unit for Space Shuttle applications.

- Complete 10,000 hours of test in FY-78 of a 500 to 2,000 W, 25 percent efficient experimental gas turbine conversion system which, when used with the AEC-developed 2,000°F isotope heat source, can reduce space isotope power system costs from the present value of $20,000/W to under $5,000/W.

Need and Relevancy:

A lightweight turbine powered APU is required on the Shuttle Orbiter to provide the high hydraulic power needs required by aerodynamic control surfaces. This need will be met by either hydrazine or O_2/H_2 APU. However, there are significant technical uncertainties with regard to the latter, and NASA has undertaken a technology program to resolve these uncertainties in order to assure its potential availability for the Shuttle Program.

Isotope power systems, on the order of a few hundred watts of power, have been proven in space flight. Radioisotope thermoelectric generators (RTG's) have been successfully employed to power the Apollo Lunar Surface Experiment Packages (ALSEP) which are still operating on the lunar surface. In addition, Pioneer 10 and 11 spacecraft each have four RTG's which provide the spacecraft with over 100 W of electric power. The Viking Mars lander will also employ an isotope power system. Higher isotope system power levels will be needed for future outer planet missions and for special telecommunication satellites. In all cases today, relatively low efficiency but high reliability thermoelectronics have been the chosen conversion mode. Because of the very high cost of isotope fuel and the need to conserve the scarce fuel, high efficiency conversion is required if isotopes are to be used for these higher power levels. Gas turbine conversion is the prime conversion candidate for 0.5 to 20 kW isotope power systems because of its high efficiency, ready adaptability to zero-g, and the already extensive technology base.

Work in the area of thermomechanical energy conversion for space missions relates closely to potential needs for central station and mobile power plants on earth.

This work is conducted by LeRC and on contract with industry.

FY-74 Resources:

Total R&D Funds	$1,543K
NASA Direct Man-Years	8

Program Title: Thermionic Energy Conversion

Objective:

The objective is to establish the knowledge required to design and develop low-temperature thermionic converters suitable for a wide range of space and terrestrial power generation applications utilizing various heat sources including solar energy. This requires analytical and experimental studies required to understand the fundamental physical processes involved in the operation of thermionic converters, and systems design and applications studies to determine the merits of various heat sources and areas of application where thermionic energy conversion is cost competitive.

Targets:

- Perform analytical and experimental studies of surface effects and plasmas, especially for the low-temperature operating region (900°K). (FY-75)

- Using above data, determine how to design a thermionic diode with reduced collector work function, collector double sheath, and plasma voltage drop. (FY-75-76)

- Build and test thermionic converters to demonstrate successful operation at low temperatures (900°K) and high conversion efficiencies (15 to 30 percent). (FY-75-79)

- Perform technology base evaluation. (FY-75)

- Perform application studies. (FY-75-77)

- Perform system design studies. (FY-75-77)

Need and Relevancy:

The major significance of this research and technology effort is its potential to provide an energy conversion device which when operated in the low-temperature regime shows promise of wide range of applications. In a topping cycle for conventional fossil fueled steam power plants, it is possible that thermionic converters could increase efficiency of such plants from 35 to 40 percent to 50 to 60 percent overall. Furthermore, the cost per installed electrical kilowatt of the thermionic converters may be in the same range as that for the conventional power plant. Also, low-temperature thermionic diodes can be heated with parabolic solar energy collectors. This may be a more economical approach than large solar cell arrays for utilizing solar energy to generate electrical power for terrestrial applications.

Research on thermionic energy conversion and system studies is presently being conducted at JPL. Plans are underway to continue a program at LeRC. NASA is providing funds through the AEC to support two industrial firms which have a long history of research and development activities in the thermionic converter field.

FY-74 Resources:

Total R&D Funds	$350K
NASA Direct Man-Years	6

Program Title: Magnetohydrodynamic Power Generation

Objective:

This program is aimed at establishing the knowledge required to utilize MHD generators for advanced electrical power systems of potential importance to the aerospace role of NASA and to understand the fundamental physical processes involved in these plasmadynamic energy systems.

Targets:

- Demonstrate high-power density (10 to 100 times greater than in previous tests) operation of a closed-loop MHD generator system operating at a temperature of 2,100°K. Complete program during FY-74.

- Demonstrate operation of a combustion-driven (H_2-O_2) MHD generator suitable for flight applications (high power density, 100 W/cm^3; short length; high magnetic field). Conduct critical tests during FY-77.

Need and Relevancy:

The major significance of the research conducted in MHD energy systems is its potential to provide new capabilities for missions in aeronautics and space. Generation and utilization of energy in the plasma state affords prospects for innovation in power generation and space propulsion. MHD generators in the high-power range may provide lightweight power systems suitable for military aeronautical and space applications. In addition, these generators may also contribute to producing low-cost electrical power for terrestrial needs from natural and artificial fuels.

Research on MHD energy conversion in NASA is conducted entirely at the Lewis Research Center. The world's largest closed-loop MHD experiment has been designed, built, and operated at conditions that might be achieved, with high-temperature nuclear reactors expected as an outgrowth of nuclear rocket technology. To date, the closed loop MHD generator has operated at temperatures above 2000° K for many hours and provided a fund of basic data on generator performance. A new combustion-driven MHD experiment has been started using existing magnet and rocket facilities. A combustor is being developed for stoichiometric burning of hydrogen and oxygen, and a means to seed the hot gases with cesium hydroxide to increase electrical conductivity is being provided. This experiment will use strong magnetic fields produced by a neon-cooled, cryogenic magnet in order to achieve a high power density ($\geq$100 W/cm^3).

This work is conducted at the Lewis Research Center.

FY-74 Resources:

Total R&D Funds	$330K
NASA Direct Man-Years	28

Program Title: Magnetics and Cryophysics

Objectives:

The objectives are to achieve intense magnetic field in large volumes with a minimum of mass and power required; to conduct research on superconducting materials and processess; and to study the effects of low temperatures and intense fields on materials and devices of significance to space applications.

Targets:

- Demonstrate the capability for stable operation at high current density in superconductive devices (magnet, motors generators) at temperatures of 4°K (liquid helium). Current approach: To produce twisted filamentary structure with Nb_3Sn ribbon and tests in large-scale experiments in FY-75-77.

- Demonstrate operation of a neon-cooled cryogenic magnet (25-35K) at a field strength of 30T. By FY-78 to provide a substantial advance in magnet technology designed specifically for use with an MHD generator at a field strength of 5 to 7 T by the end of FY-78.

- Search for superconductors with high values of critical temperature, current density, and field strength. In the near term, extend the temperature range over which excursions due to local heating can be tolerated in superconducting magnet. For the long range, discover useful superconductors to operate at temperatures associated with liquid hydrogen of higher-temperature cryogens.

- Demonstrate during FY-75 the principles of a magnetic refrigeration system (1 W power level) operating between 20°K and 4°K to establish an efficient means to cool superconductors for a wide range of applications.

- Evaluate the potential for magnetic cooling using ferromagnetic materials at temperatures up to room temperature and demonstrate a small-scale air-conditioning or heat-pump machine by FY-76.

- Explore the usefulness of the unique facilities for high magnetic field strengths, large volume and cryogenic environments for conducting relevant basic physics research.

Need and Relevancy:

Larger, higher field, lighter, more reliable, and cheaper magnets are needed for use in space propulsion and power schemes based on MHD or on fusion. Research in this area is directed at improving fundamental parts of the magnet system, e.g., the superconducting material itself, the magnet structure system, and the refrigerating system to keep it cold. While of major importance to future space power and propulsion systems, greater significance is added to this research in the context of the energy crisis. The development of MHD magnets (and the supporting fundamental work) is significant because of the increase in overall generating efficiency when the MHD topping cycle is used. Other basic components of the generating and distribution network (generators and transmission lines in particular) will likely be superconducting in the future to overcome size limitations and losses that occur in current practice. The development of a high efficiency magnetic refrigerator would reduce capital and operating costs of all superconducting systems, especially the transmission line. More efficient refrigeration at higher temperature could impact costs on tonnage air separation plants, thereby affecting heavy industries like steel, and could provide substantial economies in home and office heating and cooling.

This work is conducted at the Lewis Research Center.

FY-74 Resources:

Total R&D Funds	$270K
NASA Direct Man-Years	11

Program Title: High Power Laser Systems

Objective:

This program will provide the research and technology base needed to evaluate the potential usefulness and to demonstrate the areas for practical applications where long-range energy transmission of laser power and conversion to electricity (heat or propulsive thrust) would be cost competitive, efficient, and reliable. These objectives require that R&T efforts be placed on high power laser systems studies, high power laser devices to convert the power in the laser beam directly to electrical power (or heat or propulsive thrust), and to perform high resolution spectroscopy of the earth's atmosphere with tunable lasers for aid in analyzing atmospheric transmission under a variety of conditions (altitude, humidity, and direction).

Targets:

- Evaluate the technical problems in closed loop, CO_2 laser systems for operation at high power levels for long periods of time. (FY-75)

- Investigate the characteristics of various laser concepts to permit selection of optimal laser system in terms of efficiency, power capability, and wavelength for power transmission and conversion to electrical or other forms of energy. (FY-74-76)

- Investigate and advance state-of-the-art in methods to convert laser beams directly into electricity with an efficiency greater than 50 percent. (FY-75-77)

- Establish the limits for transmitting laser beams through the earth's atmosphere under all conditions. (FY-74-77)

- Continue and complete by FY-79 evaluation for laser power systems to provide technology goals, to assess technical progress, and to determine benefits of high power laser systems to terrestrial power needs and future NASA missions. (FY-74-79)

Need and Relevancy:

The significance of the high power laser systems program is its potential for providing new capabilities as part of a terrestrial energy system and/or space missions. The capabilities of lasers to transmit power over great distances and at tremendous energy densities seem certain to make a great impact on future energy systems. In addition, laser power transmission at an almost unlimited per unit area beam cross section may significantly improve the terrestrial power distribution systems. Results of laser power conversion research will also contribute to improved power utilization efficiency.

This work is conducted at the Ames, Langley and Lewis Research Centers and at JPL.

FY-74 Resources:

Total R&D Funds	$1,500K
NASA Direct Man-Years	35

Program Title: New Horizons in Propulsion

Objective:

The objective of this program is to generate new propellants and propulsion concepts which have the potential for specific impulse of 1,000 seconds or greater.

Targets:

- Establish the feasibility of stabilizing for 12 months or longer activated states of elements, with energy potential of 50 Kcal/gram or more.

  - By 1975, determine if atomic hydrogen can be stabilized by strong magnetic fields (10 T).

  - By 1976 determine if metallic hydrogen produced by megabar pressure is metastable at normal pressure.

  - By 1977 determine if triplet state helium can be stabilized in the liquid or solid state.

- Define and evaluate propulsion systems based on energy transmitted by laser beam from a remote source.

  - By 1975 evaluate designs for transferring laser energy to hydrogen working gas.

  - By 1975 measure the losses in transmission of laser beams through earth atmosphere.

  - By 1977 determine the economic and mission effectiveness of the concept of laser-energized propulsion.

Need and Relevancy:

Propulsion has historically been one of the key pacing technologies in the advancement of space exploration. Current chemical propulsion systems are achieving close to the theoretical maximum performance, about 500 seconds specific impulse. These systems, augmented by solar electric propulsion systems with high specific impulse but very low thrust, will probably be adequate for anticipated missions through the 1990's. More difficult missions within the solar system after that time, and the impetus to reduce trip time to the outer planets and to begin exploration beyond the solar system will call for more energetic propulsion systems. In addition, the establishment of entirely new concepts for storage and use of energy would result in large reduction in the size of propulsion elements for missions within the solar system. The fundamental nature of the analysis and experiment in this program may be expected to result in contributions to physics, chemistry and other sciences, extending beyond the realm of space programs.

This work is conducted at the Lewis Research Center and the Jet Propulsion Laboratory.

FY-74 Resources:

Total R&D Funds	$862K
NASA Direct Man-Years	25

b. Nuclear Energy. NASA has been deeply involved in nuclear energy systems for over a decade (e.g., nuclear rockets and space nuclear-electric power systems). Although the level of effort has now been greatly reduced, there is a continuing effort in advanced nuclear energy sources, especially in the area of plasma physics involving both fusion and fission plasmas and related research and technology efforts. Two significant areas of research are discussed below.

Program Title: High-Temperature Plasma (Fusion) Research

Objective:

The objective is to establish the knowledge required to produce, confine, and utilize plasma for advanced power and propulsion systems of potential importance to NASA, and to understand the fundamental physical processes involved in plasmadynamic energy systems, specifically, to investigate processes for producing thrust and power from high-temperature (fusion) plasmas. Major investigations currently planned should be completed by FY-77-78.

Targets:

- To determine whether fusion-like plasmas can be produced in the superconducting magnetic mirror apparatus (a large-volume, high-field, magnetic mirror).

- To understand plasma heating by turbulence generated in direct current discharges.

- To determine the capabilities of a closed, toroidal magnetic field in the form of a bumpy torus to confine and heat plasmas.

Need and Relevancy:

In the long term, fusion energy sources appear to offer the ultimate in performance potential for space missions extending great distances into space. The prospects in this case are a propulsion system with a specific impulse in the 100,000-second range and a low specific mass which will allow spacecraft to voyage throughout the solar system with moderate trip times. In addition, the NASA research on high-temperature plasmas will aid in the achievement of fusion power on earth.

NASA research on high-temperature (fusion) plasma is conducted entirely at the Lewis Research Center and is an outgrowth of more than 10 years of in-house research in the field of plasmadynamics, utilizing experimental equipment and apparatus which has been acquired during the past several years. The approach being taken in high-temperature (fusion) plasma research is to first establish a capability to produce fusion-like plasmas for further research into energy conversion, thrust production, and fusion reactor technology. Included in this approach is recognition of and coordination with the strong program of the AEC in controlled fusion research.

An in-house program permits NASA to assess and extend progress in fusion research for NASA needs and provides a means for the flow of NASA technology into a program of major significance to future National energy needs.

FY-74 Resources:

Total R&D Funds	$345K
NASA Direct Man-Years	28

Program Title: Uranium Plasma (Gas-Core) Reactor Research

Objective:

The objective of this research is to establish the scientific knowledge and basic engineering know-how for gaseous core nuclear reactors operating at wide ranges of temperature and power for use in space applications and earth-based power plants.

Targets:

- Conduct experiments with UF_6 and uranium vapor in FY-75 using a fast burst reactor (Godiva) as neutron sources.

- Operate at near-zero-power, self-critical gaseous $^{235}UF_6$ experiments in FY-76.

- By increasing the power of self-critical gaseous $^{235}UF_6$ experiments during FY-77 up to 10 kW, determine the ratio of optical versus thermal convection power output, depending on temperature and pressure.

- Define and conduct a follow-up series of self-critical gaseous core experiments that can demonstrate plasma core reactor operation over temperature ranges from near room temperature up to several 10,000° K, at power levels from a few kilowatts up to thousands of megawatts.

Need and Relevancy:

Plasma core reactors have the potential of being greatly superior to other nuclear energy sources for the following reasons:

(1) Temperatures ranging from near room temperature up to several 10,000° K.

(2) Potential for nonequilibrium optical radiation power output.

(3) Improved operational safety.

(4) Significant reduction of long-lived radioactive waste production.

High temperature operation results in high efficiency of power generation. On earth, this could mean improved fuel utilization and decreased rates of thermal pollution. Gas core reactors may provide space propulsion at an Isp approaching 5000 seconds and at a thrust-to-engine-weight ratio of about unity. No other projected scheme of propulsion is seen to be competitive for manned exploration of the near planets or for heavy cargo lunar ferry operation.

The prospects for nonequilibrium light radiation from a gas core reactor are of significant interest. If this is shown to be feasible, the reactor may then be operated at low temperature, which would greatly ease engineering problems and enhance operational reliability, while its energy is delivered as rays of light. The light rays could provide heat to a power system, cause chemical reactions to occur as in the photolysis of water to make hydrogen, or activate a powerful laser.

Since plasma core reactors do not contain excess reactivity, catastrophic power excursions or meltdowns are impossible. Fuel circulation makes possible continuous on-site fission products processing and eliminates radioactive waste accumulation in the reactor and the needs of radioactive fuel rod transportation to processing plants. The continuous recycling of the gaseous nuclear fuel makes it possible to feed back into the reactor the radioactive actinides and to destroy them by fission or other transmutations.

Research on gas-core reactors is conducted by Langley Research Center, the AEC's Los Alamos Scientific Laboratory, and at the United Aircraft Research Laboratory.

FY-74 Resources:

Total R&D Funds	$1,000K
NASA Direct Man-Years	2

5. TECHNOLOGY UTILIZATION AND ENERGY RESEARCH AND DEVELOPMENT

The objectives of the Technology Utilization Program include the application of technology developed by NASA to assist in solving important problems in fields such as medicine, environmental control, and other areas of public concern, including energy. Applications of NASA technology in projects related to energy conservation, to electric vehicle propulsion, and to safe handling of liquid natural gas are now being developed by the Technology Utilization Program in coordination with other Federal and local government agencies.

Project Title: Ferrofluid Separators for Nonferrous Scrap Metal

Relation to National Energy R&D Programs:

It is conservatively estimated that 7 million automobile hulks will be shredded in 1974, producing 192,000 tons of mixed zinc, aluminum, and copper. If all that scrap were reclaimed it would have a market value of $27 million ($140 per ton) at today's prices. The same scrap would have a value of $105 million ($550 per ton) if it were separated into fractions of each metal. The energy savings would amount to 1 billion kW-h if that 192,000 tons of reclaimed metal were reprocessed and used instead of virgin metal. That energy savings is equivalent to 570,000 barrels of oil.

Scope of Project/Study Plan:

This project was awarded originally as a result of a Technology Utilization request for proposals for practical ideas embodying NASA technology that could contribute to solving problems in solid waste management. The feasibility of utilizing NASA's research on the properties of magnetically responsive fluids, called "ferrofluids," under zero gravity conditions was proposed by Avco Corporation as a way of separating nonferrous scrap metal. A prototype sink-float ferrofluid nonferrous metal separator has been built and evaluated under NASA funding. The prototype equipment is currently undergoing further evaluation leading toward commercialization by Avco.

Funding Amount/Personnel:

FY-72 funds in the amount of $75K were used. The final report was received in January of 1974. Approximate NASA FY-72 Civil Service man-years were 0.1; contractor man-years prorated for FY-72, -73, and -74 per year were approximately 0.5.

Status and Potential of Technology:

Ferrofluids are very stable suspensions of microscopic magnetic particles in a fluid, such as kerosene. NASA obtained a patent on ferrofluids and awarded Avco Corporation a license to use it. Avco then developed a system for separating nonferrous metals by a ferrofluid levitation process which uses three magnetic liquids in a suitable magnetic field to float, or levitate, nonmagnetic objects having a density higher than the ferrofluid. Avco is currently pursuing opportunities to demonstrate the economic viability of the process.

Expected Results from FY-74 Funded Efforts:

Feasibility has been demonstrated; no FY-74 funding is planned. Progress is subject to commercialization efforts.

Relation to On-Going NASA Projects and Existing Technology:

Ferrofluids are a NASA Lewis Research Center invention with a NASA patent and were evaluated for use as propellant orientation control in zero gravity conditions.

Project Title: Nickel-Zinc Battery Application

Relation to National Energy R&D Programs:

Electric vehicles will probably plan an increasingly important role in our national transportation future. Battery technology will play a major part in the feasibility of such vehicles.

Scope of Project/Study Plan:

Applications development of nickel-zinc battery with high-recharge, high-energy density capability is planned. The project scope includes field demonstration of the nickel-zinc batteries in a U.S. Postal Service electric vehicle and potential utilization in other vehicles.

Funding Amount/Personnel:

Funding is $50K for FY-74 and $35K for FY-75. Civil Service professional personnel is 0.25 man-years; contractor support is 2.0 man-years.

Status and Potential of Technology:

The basic separator technology developed by McDonnell Douglas and NASA is being applied to low volume production of nickel-zinc batteries for the field test evaluation. The potential of the technology is the development and production of nickel-zinc batteries with energy densities of up to three times that of lead-acid, with half the weight and a comparable price.

Expected Results From FY-74-Funded Efforts:

Fabrication of the nickel-zinc batteries for the field test phase is expected.

Relation to On-Going NASA Projects and Existing Technology:

The NASA Lewis Research Center developed battery separator technology in the course of extensive research of silver-zinc batteries for space vehicle electric power supply. The basic technology of the separator material has solved zinc electrode deterioration in space-oriented batteries.

Project Title: Risk Management Technique for Design and Operation of LNG Facilities and Equipment

Relation to National Energy R&D Programs:

Liquid natural gas (LNG) and liquid gas in general will be useful for energy storage and utilization for many years to come. These materials constitute a continuous safety and handling problem that must be solved.

Scope of Project/Study Plan:

The scope of the project is to develop a risk management and facilities certification methodology applicable to LNG facilities. The Kennedy Space Center (KSC) with its experience with management of hazardous materials facilities will work with the New York City Fire Department in applying their risk management and certification techniques to new LNG facilities planning and construction.

Status and Potential of Technology:

Effort was initiated in January 1974. Expected potential of this management technology, if demonstrated to be acceptable as an application for New York City, is widespread use by the Nation's port cities which are faced with LNG facilities safety problems.

Expected Results From FY-74-Funded Effort:

Initial documentation and application of the risk management/certification system by New York Fire Department is expected.

Relation to On-Going NASA Projects and Existing Technology:

Techniques used at KSC for hazardous material cryogenic tank farm facilities construction and management are employed in this program.

Funding Amount/Personnel:

FY-74 funding is $45K; Civil Service professional personnel is 1.0 man-years; contractor support personnel is 1.0 man-years.

6. REFERENCES

1. Dupree, W.G., Jr. and West, J.A.: United States Energy Through the Year 2000. U.S. Department of the Interior, Dec. 1972.

2. Ray, Dixy Lee: The Nation's Energy Future, A Report to Richard M. Nixon, President of the United States. U.S. Atomic Energy Commission, Dec. 1, 1973.

3. Space Shuttle Payloads, Hearing Before the Committee on Aeronautical and Space Sciences, United States Senate, First Session on Candidate Mission for the Space Shuttle, Oct. 31, 1973, Part 2;

   a. Statement of Dr. Peter E. Glaser, pp. 11-62.
   b. Statement of Dr. Krafft A. Ehricke, pp. 63-90.

4. Glaser, Peter E. et al.: Feasibility Study of a Satellite Solar Power Station. NASA CR-2357 (to be published).

5. Solar Energy for Heating and Cooling, Hearings Before the Subcommittee on Energy of the Committee on Science and Astronautics, U.S. House of Representatives, June 7 and 12, 1973:

   a. Honorable Mike McCormack, Introductory Remarks.
   b. Statement of Dr. George Lof.

6. Statement by Dr. James C. Fletcher Before the Subcommittee on Energy, Committee on Science and Astronautics, House of Representatives, Nov. 13, 1973.

7. Energy Research and Development — Problems and Prospects. Prepared at the Request of Henry M. Jackson, Chairman, Committee on Interior and Insular Affairs, United States Senate, Serial No. 93-21 (92-56), U.S. Government Printing Office, Washington, D.C., 1973.

8. Gregory, D.P.: A Hydrogen-Energy System. Prepared for the American Gas Association by the Institute of Gas Technology, Aug. 1972.

9. A Hydrogen Energy Carrier. NASA-American Society for Engineering Education Cooperative Study report, Vols. I and II, Sept. 1973.

10. Hoerner, Sighard F.: Fluid Dynamic Drag. Chapter 12, 1965.

IV. APPENDIX TO CHAPTER IX

TABLE OF CONTENTS

DETAILED ANALYSES OF SELECTED STUDIES

1. PAST STUDIES

a. 1967-1968 National Academy of Sciences-National Academy of Engineering (NAS-NAE) Summer Study on the Useful Applications of Earth-Oriented Satellites. In the 1967-1968 NAS-NAE Summer Study, cost-benefit relationships were explored. A number of consultant economists and economist-engineers analyzed the systems postulated by the various application disciplines panels, estimated the costs of development and operations, and appraised foreseeable benefits. These findings were then reviewed by an Economic Analysis Panel. The concensus of this group of specialists at the conclusion of the Summer Study was, "...these new and challenging fields of satellite and sensor technology are advancing so rapidly that caution must accompany any attempts at economic appraisal. The conventional cost-benefit analysis approach is not suitable for judging technologies in the fluid, formative state. Instead, in evaluating the different space applications, we are advised to use guides that have been widely adopted by business for planning and developing new products, processes and services."[1]

The method, essentially a typical industrial concept, used by these economic specialists throughout the study was comprised of the following four steps, with a spread of from 5 to 10 years involved:

(1) Basic and exploratory research (least costly).

(2) Development: early design, limited testing.

(3) Pilot plant: market-testing programs.

(4) Operation: design, construction, and operations of commercial plant.

It was stated that prior to making the greatest cost commitment, sufficient data should be available to the decision-maker to assess relevant costs and benefits.

(1) Conclusions. Two approaches were used to develop systems costs. The first was the costing of each discipline as a separate system. The second was the costing of the system requirements of several disciplines (i.e., agriculture-forestry, geology, hydrology, meteorology, and oceanography) on

1. Report of the Central Review Committee, 1967-1968 NAS-NAE Summer Study, pp. 10-11.

a common-use (single system of satellites) basis. Recognizing the problems and difficulties cited below, it was concluded that with a common-use system oriented to the several disciplines above, approximately $83 million could be saved over separate discipline systems in a 7-year time frame. The study recommended a benefit-cost analysis using a disciplined, methodological approach to systems analysis. The study further cautioned that if a benefit-cost ratio were calculated, it should not be used as the sole criterion on which a project is judged, particularly at the R&D stage of development.

(2) Comment. Not included in the costing, but recognized as major cost items which would be incurred upon the implementation of any particular system were the following:

(a) Costs incurred by user agencies for education or extensive training and upgrading of personnel and procedures.

(b) Costs of analysis and interpretation (e.g., photographic interpretation) of the data received by user agencies.

(c) Any costs incurred by individuals or organizations "downstream" from the user agencies, e.g., costs to a farmer to revise his farming methods or to replace machinery due to new information provided by the satellite system.

(d) Consideration of extensive or intensive trade-off analyses for each system.

(e) Costs and quantifiable benefits were not discounted at any specified rate.

(f) The impact of inflation was not considered.

This early study could be considered as introductory and contributed little to our capability to assess cost-benefits. As indicated above two separate approaches were defined. At one point the study stated that "the conventional cost-benefit analysis approach is not suitable for judging technologies in the fluid, formative state." At another point, the study recommended "a benefit-cost analysis using a disciplined, methodological approach to systems analysis." The study focused principally on costs and did not give sufficient attention to quantifying benefits.

b. Interplan Corporation Study — Review and Appraisal: Cost-Benefit Analyses of Earth Resources Survey Satellite Systems, March 1971. The purpose of this study was to review and appraise certain cost-benefit studies which relate to the economic benefits to be obtained from Earth Resources Survey (ERS) satellite systems. The three objectives were:

(1) To assess the extent to which previous studies are adequate indicators of the expected cost-benefit effectiveness of future operational ERS satellite systems.

(2) To assess the value of these studies for directing R&D activities.

(3) To indicate the appropriate nature of future economic studies in the ERS Program.

(1) Conclusions. Benefit estimates, considered valid order-of-magnitude estimates, totalled $1.4 billion to be realized annually by the U.S. from the implementation of 43 nonoverlapping specific applications. Five specific applications noted below accounted for one billion dollars of the total estimated benefits considered valid:

(a) Minimizing flood damage — $306 million.

(b) Improving forecasts of irrigation water availability — $282 million.

(c) Detecting fungi stresses in small grains — $231 million.

(d) Expediting exploration of petroleum — $125 million.

(e) Providing world wheat production forecasts — $114 million.

It was determined that the system cost estimate of $20 to 50 million per satellite-year is an adequate indicator of the cost of a future operational system. Benefit estimates developed by the study were considered to be very conservative.

The data base developed in the course of the study could be of value in R&D planning. It is essentially a priority ranking of potential applications by users, if used with estimated development costs, time frames, etc. An R&D decision model, which would integrate (at the ERS system level) findings of the past and supplementary studies on benefits, costs, and technologies required by all major applications studied, was recommended for development.

(2) Comment. Differences in the scope and content of the 10 economic studies furnished by NASA and comprising the data base for the study made comparisons difficult. Differences in the coverage of technological requirements also influenced the accuracy of comparisons.

Differences in system complexity and program size resulted in widely divergent overall systems costs. Users' (both intermediary and ultimate users) costs as highlighted by the 1967-1968 NAS-NAE Summer Study were also considered by Interplan to be essential to any prefeasibility benefit analysis. The 1967-1968 NAS-NAE Summer Study Panel Reports discuss potential benefits in terms of broad disciplines (i.e., agriculture, oceanography, etc.) and not in terms of specific applications. Thus the findings could not be integrated with those of most of the other studies which did address specific applications (i.e., fungi stress detection, petroleum exploration, etc.)

The following is a comment by an economic analyst:

"The Interplan Study is useful as a summary and integration of many early economic benefit studies in Earth Resources Survey (ERS) Systems. Since it was not the intent of the study to estimate benefits for ERTS-1 on any specific applications, it is virtually useless as a basis for estimating those benefits. Nevertheless it does tend to indicate that agriculture may be the key area to focus upon for benefits."

c. Dynatrend Study — Evaluation of Benefits and Systems Features of Earth Resources Satellite, August 31, 1973. The purpose of this study was to evaluate the potential benefits which would accrue from several system modification options identified in the baseline document for the Earth Resources Survey Operational System. While not stated as such, the intent of the study was to reassess the benefits outlined in the Interplan study and to reconfirm these benefits based upon ERTS-1 results.

(1) Methodology

(a) Phase I. A survey questionnaire was sent to the Principle Investigators (PI's) in the 85 specific applications areas identified by the Interplan Study to determine their attitudes toward several system modification options. The survey questionnaire was sent to 276 U.S. and foreign PI's with the purpose of obtaining users' assessments of the utility of the system modifications in an ERTS-1 configured operational system.

(b) Phase II. The survey results were integrated with the benefits noted by Interplan in 85 specific applications areas. The intent was to determine:

1 What technical capability or system modification needs to be achieved to realize the benefits (the aggregate of which was estimated at $200 million in the Interplan study).

2 To what extent ERTS-1 has demonstrated the capability to achieve the benefits.

3 The percentage of the benefits which are realizable.

(2) Conclusions. There was general agreement, based upon the survey results, that the PI's are satisfied with the current ERTS-1 capability with a few exceptions, which include:

(a) Higher frequency of coverage (than present 18 day cycle), particularly in the field of hydrology.

(b) Desirability for local receiving stations (for sensor data).

(3) Comment. It should be recognized that the majority of the ERTS-1 PI's are research-oriented and perhaps the wrong audience to survey for ERTS system modifications related to benefits. At the time of the survey, data for a full growing season had not yet been received in important applications areas of agriculture. The utility of remote sensing data hinges in some cases on the development of auxiliary techniques and models (e.g., in water resources). Thus the full impact of such future developments is not taken into consideration. The operational level user's capability or competence to use remote sensing data is an unknown quantity and an important factor in the implementation of an operational program. Unfortunately the majority of the survey responses focused on only a few specific applications of ERTS which appear to have only slight potential benefits to the U.S. Costs (or savings) attending system modifications options while within the purview of the study, are not yet available.

d. Mathematica Study – Cost-Benefit Analysis for ERTS Experiments, Volume I, June 30, 1973. The purpose of this study was to provide a comprehensive treatment of the principles of economic analysis.

Comment. The usefulness of this study is that it will permit the uninitiated to gain an understanding and appreciation of the techniques and terms of cost-benefit analysis.

The main drawback of this study is that it does not include the treatment of a case study which would demonstrate clearly how the techniques and terms explained are used.

e. Mathematica Study — An Example of the Potential Benefits of ERTS Imagery for Environmental Control, June 30, 1973. This study was conducted to provide an example of how ERTS-type imagery may be used in conjunction with conventional data-gathering techniques (man, aircraft) to provide resource surveys for environmental control (e.g., surface minimg control in the eastern Kentucky coal mining region).

(1) Conclusions. Depending on values assigned to the parameters which are in part controllable (i.e., technology employed) and in part uncontrollable (i.e., weather), a "two-tiered" (satellite/man), or a "three-tiered" (satellite/aircraft/man) surveying system may be economically worthy of serious consideration. Assuming a 10 percent discount rate and a 20 year program started in 1972 and based upon a "three-tiered" surveying system, the study estimates that benefits amounting to about $494 million may be possible.

(2) Comment. Values of the various parameters used in this study were assumed ones. A review of the assumptions by competent authorities may improve the results of the study.

The value of this study lies in its actual application of a cost-benefit methodology, essentially the case study missing from the previous Mathematica study (Section 1.d). A combination of the two studies makes a significant contribution to our capability to assess cost benefits.

f. Mathematica Study — An Econometric Model of the U.S. Telecommunication Industry. The objective of this Mathematica project was to formulate an econometric model of the U.S. telecommunications industry which would be designed particularly for use in evaluating Government policy alternatives. Specific areas of interest to be investigated in light of the model included the rate of return to research and development in the telecommunications industry, the effect of Government research and development activities on telecommunications technology, and the effect of Government regulation of the "fair rate of return" to capital in the industry. In contrast to most published studies of the

U.S. telecommunications industry, the Mathematica model was to take special account of interrelationships among the various components of supply and demand, rather than analyzing supply or demand in isolation.

(1) Conclusion. Contribution to our capability to assess cost-benefits is considered good, since it takes into account interrelationships and the effects of R&D.

(2) Comments

(a) The model. The Mathematica model, outlined in a memorandum entitled "An Econometric Model of Telecommunications in the United States," consists of 13 equations which fall into three groups. The first group concerns demand and revenue relationships and includes separate demand functions for individual consumers and for business and government. The second group contains supply and cost relationships, including a production function, factor input demand functions for labor and capital, and a cost function. The third group deals with supplementary relationships such as gross investment and new employment. As a first step, the model has been designed to apply to the telephone and telegraph industry, alone, but it should not be difficult to extend its scope to cover the communications industry as a whole.

In considering the production function, the study recognized the importance, especially in view of its particular objectives, of incorporating explicitly in the production function a means of accounting for the effect of technological progress. Such explicit inclusion is necessary to make it possible to assess the effect of research and development on technological progress and the rate of return to research and development expenditure.

(b) Preliminary results. The preliminary results of an effort to estimate empirically the parameters in the model were reported in a memorandum entitled, "The Demand and Supply of Telecommunication Services in the United States: Preliminary Empirical Results." Empirical relationships estimated include demand for telecommunication, derived demand for capital and labor, and production of telecommunication services. Estimates were based on data from the period 1947-1970.

The plausibility of the results varied. The results for residential demand were very satisfactory, while those for business demand were less satisfactory; even these, however, were considered promising.

The results for the production function appeared successful and suggested a very significant conclusion with important policy implications. Specifically, they showed that while the returns to capital and labor in direct production of telecommunication services, with a given technology, are relatively low, the return to R&D expenditure is very high.

Results for input factor demands for capital and labor were not fully satisfactory. Apart from difficulties in the estimation procedure, the study noted that the empirical estimates for these input requirement functions did not attempt to take into account technological progress, as they ideally should. Instead, estimates were limited to static formulations. The report concluded that this element of the model requires further investigation.

(c) Dynamic simulations of the model. After estimating the parameter values in the model, Mathematica did a dynamic simulation of the model for the period 1947-1970 and worked out several projections into the future (1970-1990). The projections were designed to test the sensitivity of these projections to some of the relatively uncertain parameter values using the model. The results of the dynamic simulations were then compared to a projection based on a simple extrapolation which included a trend factor. The results of this exercise were outlined in a memorandum entitled, "Dynamic Simulation of U.S. Telecommunication Industry: Some Preliminary Projections." The simulation for the past period corresponded reasonably well with the observed data, except with respect to two price variables. The trends, however, in these variables were in line with the observed pattern. The simulations for the future were not completely satisfactory, but the memorandum stated that they "appear to indicate that the model as specified, toegther with the specific set of estimated values of the parameters, can be used for preliminary projections of the U.S. telecommunications industry."

The projection based on extrapolation differed from that based on the model in several respects. The extrapolation approach, however, did not take into account the interrelationships among variables, as the model did. Several discrepancies stem from this deficiency. For example, the extrapolation method projected an entirely unreasonable cost increase, from $17 billion in 1971 to $6,665 billion in 1990. Anomalous results, such as these, perhaps call into question the reliability of the extrapolation method as a check of the model, but they also indicate the need to account for the interrelationships among variables, which the model does.

g. University of Wisconsin Study — Multidisciplinary Studies of the Social, Economic, and Political Impact Resulting from Recent Advances in Satellite Meteorology, June 1971-August 1972. These multidisciplinary studies which encompass almost 1,000 pages in four separate volumes explore and evaluate the impact of the meteorological satellite and the concomitant impact of the data derived from it on various user groups. As expected, the primary impact was related to those who would use satellite data for weather prediction and related purposes. A secondary impact was in the area of international concerns where the Global Atmospheric Research Program (GARP) and other international meteorological activities were affected and international law was developed. A tertiary impact was exemplified by satellite photographs utilized in advertising and related materials. The case studies, supporting studies, and independent studies all emphasize the potential of the meteorological satellites.

Volume I covers the following subject areas:

(1) The international legal impact resulting from recent advances in satellite meteorology.

(2) Impacts of recent advances in satellite meteorology on water resources management.

(3) The impact of accurate 1 week forecasts, provided by satellite, on the demand of outdoor recreation.

(4) The potential impact of advanced weather forecasting in the skiing industry, a case study.

Volume II covers individual case studies in the following major categories:

(1) Natural resources utilization and impact.

(2) Agricultural impact.

(3) Commerical activities impact.

Specifically there were included studies in agricultural production (i.e., lettuce, peas, sweet corn, and hay), the communications of weather satellite data, and industrial activities (i.e., highway and home construction, trucking, and the recreational boat industry).

Volume III includes a detailed analysis of the social, legal, organizational, and economic benefits of satellite meteorology. Also included are studies on the comprehension and use of weather information by various agricultural groups in Wisconsin and on the economic impact of long range weather information on the production of peas in Wisconsin.

Volume IV describes the management and organizational system utilized by the Meteorological Satellite Program in NASA. The study focuses on the structure, process, and functioning of the program, making possible the successful linking of multiple systems of space science technology. By exposition of the process and problems encountered, it is expected that the lessons learned may be of benefit to other organizations concerned with complex developmental planning.

Comment. As stated in the study's overview (Vol. III), the entire University of Wisconsin analysis "should not be considered as a benefit cost study." The study was focused principally on the identification and quantification of potential net benefits of better weather forecasts. Social costs associated with providing weather data were assumed to be available elsewhere.

It is of interest that the conclusion is reached that in both the construction and transportation studies the researchers found that, even though weather losses may have been significant, the potential savings which would result from accurate long-range weather forecasts were extremely small and probably insignificant. This is attributed to the existence of institutional constraints. For example, in the construction industry a large number of small firms are involved, resulting in inflexibility in shifting work crews both because of only one or two projects at a time and the local nature of small firms. Another reason is the lack of management skills to use advanced weather information effectively. In a similar way large firms which subcontract to a number of small firms are also hampered by a high degree of inflexibility in operations.

The study concludes that it did achieve its objective of determining the weather information required by a user in order to obtain a specified benefit. The educational function objective of informing a large number of people about the potential of weather satellite capabilities was not achieved. A general conclusion is that in terms of quantitative evaluation more could be done. Cost-benefit and cost-effectiveness analyses are almost totally lacking throughout the study.

The study does recognize that most activities upon which weather forecasts can have an effect (expect for a few areas such as hay production) are very complex and the effect of the forecast is marginal in contrast to the effects of the actual weather. The conclusion is reached that, using the microanalytic methodology developed by the study in the treatment of various case studies, the policy decision-maker can be provided with the information needed to bring about potential benefits that have been identified.

While not related to economic analysis directly, the study treats and describes the management and organizational system used by the Meteorological Satellite Program at NASA with the expectations that the lessons learned could be applied by other organizations concerned with complex developmental planning. Core features of the NASA design are enumerated at the end of the study and tend to over-simplify the complex process in the weather satellite program with little useful guidance for surmounting the complexities being encountered in the Earth Resources Survey Program.

The study omits consideration of the important weather-dependent area of the Coastal Zone and such related aspects as ecological balance, recreation, shipping and off-shore superports (oil tankers and oil spills).

h. ECON, Inc. — The Economic Value of ERTS-B. The study assessed value and cost effectiveness of the ERTS-B Program both taken by itself, assuming it was not to be followed by an operational ERS systems, and as a forerunner contributing to the early development of an operational system.

(1) Conclusions. (Figures are expressed in current values at a discount rate of 10 percent.) The potential value of the ERTS-B Program taken alone was found to be approximately $50 million for mapping applications and an additional potential $150 million for monitoring applications. The potential value of it in bringing about an operational ERS system was estimated to be on the order of $400 million with the possibility that it might reach as high as $1,000 million, depending on continuity of service and user orientation of ERTS-B.

The value of opportunities lost with a gap in ERTS data from October 1974 to January 1976 (Gap I) was estimated to be in excess of $400 million. The value of opportunities lost from a gap between the failure of ERTS-B and the initial operating capability date of an operational ERS system (Gap II) was assessed at $175 to $200 million for each year of the gap.

An operational ERS system was found to be cost effective when compared to other data collection alternatives, particularly high altitude aircraft systems; it was shown to be a cost effective method of continuing technical and user investigation of earth resources.

In recommending the October 1974 launch date, the report took into account the fact that by January 1976 an additional thermal infrared capability could have been added, thus increasing the one-time mapping benefits of ERTS-B taken by itself. The value of this added capability, however, did not outweigh the considerably higher annual opportunity cost found to be associated with Gap I as opposed to Gap II.

The cost effectiveness comparison of ERTS with a high altitude aircraft system showed that, assuming annual rental (instead of acquisition) costs only for the aircraft and an ERTS initial system cost of $40 million in 1973 dollars (for spacecraft, instrumentation, and launch), the break-even point at which ERTS would prove less costly would be at a user coverage requirement of 11.9 million km^2 total, or about 1.35 the total area of the U.S.

The study recognizes and highlights several interesting and profound economic problems that bear on the overall issue of the value of an ERS system and its output of data, the value of these data, and the information extracted from these data. Some of these include:

(a) "The value of information has little, if anything, to do with the cost of obtaining that information."

(b) "The value of information to the nation is different from the price (revenue) for that information when sold in the market place."

(c) "Social efficiency, i.e., for the economy as a whole, clearly warrants the widest possible dissemination of, e.g., agricultural information."

(d) "Nationally available information may greatly benefit some user groups and yet damage others."

(e) "Social gain from improved information, ..., can be traced to three broad sources;

(a) 1) good forecasts permits more efficient disposition of inventories, e.g., of farm products; 2) a potential for changing production decisions exists; and 3) a value of information can be attributed to the degree of certainty itself."

In all cases, the value of the information derives from the fact that it provides for improved decisions. Lack of knowledge as to potential users and user requirements made estimation of the demand for ERS data very problematic.

The study identified three general categories of demand:

(a) "A legal, statutory demand to provide services independent of the existence of an ERS system."

(b) "An institutional demand for ERS service due to responsibility with allocated budgets and activities by federal, state, and local governments and other institutions."

(c) A market user demand for data or information that can be provided by an operational ERS system.

Of the three categories above, (c) is the most indeterminate. As in the case of high speed digital computers, according to the report, any estimate of market demand, at this time, could easily turn out to be low by orders of magnitude.

Both incomplete understanding of benefits and insufficient information on users, according to the report, have been limiting factors in this and other economic studies of remote sensing from space. The report states, "It is important to recognize that none of the economic studies performed to date were fully satisfactory since they do not provide an appropriate classification of benefits, identify specific users and user functions, delineate the user requirements, etc." The report recommends that during the ERTS-B Program continued attention be given to understanding benefits as they develop and identifying the growing group of users, so that data will be available for a more convincing economic demonstration of the operational utility of an ERS system.

Because of its comprehensive approach to the complex problem of cost-benefits, this study makes a substantive contribution toward more effective economic analysis.

(2) Comments. The relative advantages of an October 1974 or a January 1976 launch date were considered. In this regard, the study investigated the economic impact of two possible gaps in the continuity of satellite remote sensing data available to users: a gap (Gap I) between the failure of ERTS-1 and its replacement with ERTS-B and a gap (Gap II) between the placement and subsequent failure of ERTS-B and the establishment of an operational capability. Since ERTS-1 and ERTS-B are oriented primarily toward technology development rather than operational application, the benefits of ERTS-B must be derived, to a large extent, from the projected benefits of a future operational capability. The study, therefore, also addressed the cost effectiveness of an operational ERS system in comparison with alternative data collection systems, in particular high altitude aircraft systems.

The study emphasized that the key to any economic value of ERTS-B lies in the demonstration of the potential use of ERTS data in management decisions.

For the purposes of the study, benefits were divided into two categories: "mapping benefits," benefits derived when ERS data economically replace or augment other data collection and interpretation procedures; and "monitoring benefits," those which accrue as the result of a better control over various processes made possible by use of satellite data on a "closed-loop decision process."

2. CURRENT STUDIES

a. ECON, Inc. — Economic Analysis of the Role of an Earth Resources Satellite (ERTS) System in the Establishment of a Nationwide Land Use Information Data Bank. The analysis will examine the cost of acquiring, processing, storing, and retrieving land use information obtained by a variety of technical means, including ERTS, to develop alternative nationwide land use planning information systems.

Included in the study will be the development of a three-tier land cover and monitoring model which will evaluate the cost-effectiveness of the following systems:

(1) Medium altitude aircraft/manned ground truth.

(2) High altitude aircraft/manned ground truth.

(3) ERS satellite/aircraft/manned ground truth.

These systems are to include a data collection, processing, storage, and retrieval system.

b. O.R.I. Study — Investigation of Weather-Related Programs, An Economic and Social Benefit (Scheduled for May 1974 Completion)

(1) Purpose. The purpose of this study is to determine the current status of activities within the Federal Government concerned with the economic and social benefits of weather forecasting and weather-related programs. To accomplish this, three major task areas are defined:

(a) Literature Search — Reports, studies, data, etc., for the past 5 years will be researched with key words such as cost benefit, cost benefit analysis, economic studies, social implications as related to weather and weather forecasts. Documentation within the following agencies will be searched: NASA, NOAA DOD unclassified data, Agriculture, Commerce, and Transportation.

(b) Specialized Forecasts — These forecasts are currently being supplied by NOAA in areas such as agriculture and severe weather. Applicability, validation, population served, frequency, funds, dissemination and other aspects will be covered.

(c) Plan (Note: This task is subject to completion of a and b above) — A plan or methodology for an in-depth study of selected potential benefit areas will be developed. Outlines of the technical, economic, and social data as required to develop a meaningful cost/benefit analysis will be included.

(2) Comment. The study is about 50 percent complete. It is anticipated that this study will not contribute to the current capability to assess cost benefits.

c. EARTHSAT/Booz Allen Study — Evaluation of Economic, Environmental and Social Costs and Benefits of Future Earth Resources Survey Satellite Systems. The objective of this Department of Interior study is to provide a basis for future Government investment decisions regarding earth resources survey satellite systems.

(1) Methodology. A detailed analysis of the sequence of events from acquisition of earth resources survey data to their utilization, emphasizing the machanisms of the management decisions involved, is to serve as a framework for an evaluation of the benefits and costs associated with specified alternative earth resources survey system configurations. Benefits and costs are to be estimated not only from an economic point of view but also in terms of environmental and social impact.

The study will indicate what performance criteria are necessary for an earth resources survey system to be cost-effective and what institutional issues and problems may be encountered in establishing such a system. For the purposes of detailed cost-benefit analysis, case studies will be based on selected ERTS-1 experiments representing the major areas of potential application.

Four alternative earth resources survey system configurations are under study. The first consists of a satellite program using ERTS-type equipment with additional launches of satellites in order to provide continuous coverage. The second consists of an improved ERTS-type system. This alternative assumes the introduction, within a decade, of a more advanced satellite system with improved sensor and spacecraft characteristics, an improved data processing system, and a more rapid distribution system. The third is an optimized high-altitude aircraft collection system producing data only of the United States, comparable to ERTS data in quality and in frequency of acquisition. The fourth alternative is the "no-system" case; for this case, it is assumed that the proportion of Federal funds now being provided for nonsatellite imagery acquisition will be maintained.

A feature of this study is the emphasis placed on determining exactly what is involved practically in achieving user acceptance of earth resources survey data. Three out of ten tasks identified in the Statement of Work relate to this effort. First, user requirements to which remote sensing might be relevant are identified; processing and interpretation techniques required to render the data usable are defined; and the sensitivity of data requirements to system capabilities is assessed. Second, the value for particular requirement areas of the information obtainable from remote sensing is determined. If the information potential of the data proves substantial, modes of utilization of the data indicating users involved and institutions, industries, and sectors of the economy affected are prepared. The third task is to identify the management sectors and decision and action mechanisms which would be involved in institutionalizing utilization of the data. Attention is to be given to the dissemination rates, learning curves, and accptance rates which would determine the speed with which application of the data could become institutionalized. This study of the process of utilization of earth resources survey data thus indicates both the substantive requirement areas where benefits can be expected and the institutional/management factors to be taken into account in assessing costs and benefits. The contractor notes that most ERTS-1 experiments have concentrated only on the scientific substance of proposed applications and have neglected the management factors.

Other remaining tasks of the study cover the determination of benefits and costs and the evaluation of the alternative configurations in terms of national economic efficiency, distribution of economic impact, environmental impact, social repercussions, and international effects.

(2) Comment. Several aspects of the study make it particularly useful in establishing a capability to assess other alternative configurations. The work being done in isolating the institutional and management factors involved in

applying earth resources survey data is indispensable. The requirement for systematic explanation of methodology greatly enhances the usefulness of the study by making its conclusions verifiable and by making it possible to apply the same technique to other alternatives and obtain compatible evaluations. The study also includes an effort to establish the degree of uncertainty of the evaluations and to test their relative sensitivity to various assumptions and variables. Such careful calibration of the estimating procedure is essential in any economic analysis and will add to the value of the study as a basis for investment decisions.

(3) Conclusions to Date. As of January 25, 1974, three case studies had been completed. The annual benefits estimated to accrue from an operational earth system are as follows: in agriculture (crop estimation) — $14 to $38 million; in water resources management — $9 to $16 million; and in range land management — $15 to $35 million. In general, the study shows that previous benefit estimates, at least in some areas, may have been too optimistic. It appears relatively certain, however, that improvements in agricultural crop forecasting accuracy through use of earth resources survey data can yield benefits. Other areas selected for the case study approach include land use planning, environmental management, forestry management, and environmental monitoring.

Economic efficiency and distribution analyses of alternatives have not been completed. The study is scheduled for conclusion in August 1974.

d. Task Force on Economics of Remote Sensing. The principal objective of the Task Force effort is to demonstrate the economic justification for the NASA Earth Resources Survey Program on the basis of benefit/cost and cost effectiveness analyses. It is designed to develop internal NASA expertise in the techniques of benefit/cost and cost effectiveness analysis and to build NASA skills in interfacing with users.

(1) Methodology. To meet its primary objective, the Task Force will develop detailed benefit/cost and cost effectiveness studies of three major applications. These will include national crop yield forecasting, flood plain mapping, and land use mapping to meet the requirements of pending land use legislation.

The Task Force, which will collect and analyze the data, will be composed of selected NASA personnel; they will have support from two contractors. The Steering Committee, which will guide the task force investigation and draft the final report, will be chaired by a NASA representative and will include contractor personnel and private consultants.

(2) Status. To date, a detailed plan has been drafted for the work to be done on two out of the three major applications selected for thorough examination. A contractor is providing the third detailed plan. During March 1974, the Task Force met to review existing studies, including the Department of Interior study on Benefit/Cost of Selected ERTS Applications. Tasks have been assigned and the major part of the task force work is to be completed by July 1974.

e. <u>ECON — Seasat Economic Assessment</u>

(1) Purpose. The purpose of this study is to estimate the net value of the SEASAT program and to build mutually supporting relationships to enhance development toward an operational SEASAT system. The objective is to assist NASA and the potential users of SEASAT.

(2) Approach. To accomplish these objectives 11 work tasks have been delineated. In general these tasks will:

(a) Define the SEASAT systems capabilities, range of cost, and range of timing.

(b) Provide a preliminary assessment of benefit areas.

(c) Select and perform economic benefit case studies.

(d) Integrate the case studies with the preliminary analysis of other selected areas.

(e) Provide an economic evaluation of the benefits versus the cost versus the timing of the SEASAT program.

SEASAT is a program that is designed to provide information on global ocean dynamics and physical properties of practical and scientific importance to a community of interested Government and private sector user organizations.

☆ U.S. GOVERNMENT PRINTING OFFICE 1974 — 748 298 / 189 REGION NO. 4