FINAL REPORT
OF THE
SPACE SHUTTLE
PAYLOAD PLANNING WORKING GROUPS

EARTH OBSERVATIONS

VOLUME 7

MAY 1973

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND 20771

GLOSSARY

Abbreviation	Description
ATS	Applications Technology Satellite
AWM	All Weather Monitoring (Satellite)
BUV	Backscatter Ultraviolet
EMS	Environmental Monitoring Satellite
EREP	Earth Resources Experimental Package
EOS	Earth Observation Satellite
ERS	Earth Resources Satellite (Also, Earth Resources Survey)
ERTS	Earth Resources Technology Satellite
EV	Extra Vehicular
EVA	Extra Vehicular Activity
GOES	Geostationary Operational Environmental Satellite
HRIR	High Resolution Infrared Radiometer
ITOS	Improved Tiros Operational Satellite
MSS	Multi Spectral Scanner
SEOS	Synchronous Earth Observation (Observatory) Satellite
SMS	Synchronous Meteorological Satellite
SPEOS	Single Purpose Earth Observation Satellite
WTR	(Also AFWTR) Western Test Range

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FOREWORD*

In January 1972 the United States decided to develop a new space transportation system, based on a reusable space shuttle, to replace the present expendable system.

By January 1973 planning had progressed to the point that through the European Space Research Organization (ESRO) several European nations decided to develop a Space Laboratory consisting of a manned laboratory and a pallet for remotely operated experiments to be used with the shuttle transportation system when it becomes operational in 1980.

In order to better understand the requirements which the space transportation must meet in the 80's and beyond; to provide guidance for the design and development of the shuttle and the spacelab; and most importantly, to plan a space science and applications program for the 80's to exploit the potential of the shuttle and the spacelab, the United States and Europe have actively begun to plan their space programs for the period 1978-1985, the period of transition from the expendable system to the reusable system. This includes planning for all possible modes of shuttle utilization including launching automated spacecraft, servicing spacecraft, and serving as a base for observations. The latter is referred to as the sortie mode. The first step in sortie mode planning was the Space Shuttle Sortie Workshop for NASA scientists and technologists held at the Goddard Space Flight Center during the week of July 31 to August 4, 1972. For the purposes of that workshop, shuttle sortie missions were defined as including those shuttle missions which employ observations or operations (1) from the shuttle itself, (2) with subsatellites of the shuttle, or (3) with shuttle deployed automated spacecraft having unattended lifetimes of less than about half a year.

In general the workshop was directed towards the education of selected scientific and technical personnel within NASA on the basic capabilities of the shuttle sortie mode and the further definition of how the sortie mode of operation could benefit particular disciplines. The specific workshop objectives included:

- Informing potential NASA users of the present sortie mode characteristics and capabilities
- Informing shuttle developers of user desires and requirements
- An initial assessment of the potential role of the sortie mode in each of the several NASA discipline programs
- The identification of specific sortie missions with their characteristics and requirements

*Reprinted from the volume entitled "Executive Summaries"

- The identification of the policies and procedures which must be changed or instituted to fully exploit the potential of the sortie mode
- Determining the next series of steps required to plan and implement sortie mode missions.

To accomplish these objectives 15 discipline working groups were established. The individual groups covered essentially all the space sciences, applications, technologies, and life sciences. In order to encourage dialogue between the users and the developers attendance was limited to about 200 individuals. The proceedings were, however, promptly published and widely distributed. From these proceedings it is apparent that the workshop met its specific objectives. It also generated a spirit of cooperation and enthusiasm among the participants.

The next step was to broaden the membership of the working groups to include non-NASA users and to consider all modes of use of the shuttle. To implement both objectives the working group memberships were expanded in the fall of 1972. At this time some of the working groups were combined where there was appreciable overlap. This resulted in the establishment of the 10 discipline working groups given in Attachment A. In addition European scientists and official representatives of ESRO were added to the working groups. The specific objectives of these working groups were to:

- Review the findings of the GSFC workshop with the working groups
- Identify as far as possible the missions (by mode) that will be required to meet the discipline objectives for the period 1978 to 1985
- Identify any new requirements or any modifications to the requirements in the GSFC report for the shuttle and sortie systems
- Identify the systems and subsystems that must be developed to meet the discipline objectives and indicate their priority and/or the sequence in which they should be developed
- Identify any new supporting research and technology activity which needs to be initiated
- Identify any changes in existing procedures or any new policies or procedures which are required in order to exploit the full potential of the shuttle for science, exploration and applications, and provide the easiest and widest possible involvement of competent scientists in space science
- Prepare cost estimates, development schedules and priority ranking for initial two or three missions

In order to keep this planning activity in phase with the shuttle system planning the initial reports from these groups were scheduled to be made available by the spring of 1973. It was also felt necessary that the individual working group activities be coordinated both between the groups and with the shuttle system planning. As a result, the steering group given in Attachment B was established.

Early in 1973, NASA and the National Academy of Sciences jointly decided that it would be appropriate for a special summer study to review the plans for shuttle utilization in the science disciplines. This summer study has now been scheduled for July 1973. It is anticipated that the results of the working group activities to date will form a significant input into this study.

In the following sections of the summary document are the executive summaries of each of the working group reports. While these give a general picture of the shuttle utilization plan, the specific plan in each discipline area can best be obtained from the full report of that working group. Each working group report has been printed as a separate volume in this publication so that individuals can select those in which they are particularly interested.

From these working group reports it is apparent that an appreciable effort has been made to exploit the full capability of the shuttle. It is, however, also apparent that much work remains to be done. To accomplish this important work, the discipline working groups will continue.

Finally it is evident from these reports that many individuals and groups have devoted appreciable effort to this important planning activity. I would like to express my appreciation for this effort and stress the importance of such activities if we are to realize the full potential of space systems in the 1980s.

John E. Naugle

John E. Naugle, Chairman
NASA Shuttle Payload Planning
Steering Group

LIST OF WORKING GROUPS

	GROUP NAME	CHAIRMAN	CO-CHAIRMAN
1.	ASTRONOMY	Dr. N. Roman (HQ)	Dr. D. S. Leckrone (GSFC)
2.	ATMOSPHERIC & SPACE PHYSICS	Dr. E. Schmerling (HQ)	Mr. W. Roberts (MSFC)
3.	HIGH ENERGY ASTROPHYSICS	Dr. A. Opp (HQ)	Dr. F. McDonald (GSFC)
4.	LIFE SCIENCES	Dr. R. Hessberg (HQ)	Dr. D. Winter (ARC)
5.	SOLAR PHYSICS	Dr. G. Oertel (HQ)	Mr. K. Frost (GSFC)
6.	COMMUNICATIONS & NAVIGATION	Mr. E. Ehrlich (HQ)	Mr. C. Quantock (MSFC)
7.	EARTH OBSERVATIONS	Dr. M. Tepper (HQ)	Dr. W. O. Davis (DoC/NOAA)
8.	EARTH AND OCEAN PHYSICS	Mr. B. Milwitzky (HQ)	Dr. F. Vonbun (GSFC)
9.	MATERIALS PROCESSING AND SPACE MANUFACTURING	Dr. J. Bredt (HQ)	Dr. B. Montgomery (MSFC)
10.	SPACE TECHNOLOGY	Mr. D. Novik (HQ)	Mr. R. Hook (LaRC)

ATTACHMENT A

NASA AD HOC ORGANIZATION FOR SHUTTLE PAYLOAD PLANNING

POLICY GROUP

H. Newell—Chairman
D. Myers
C. Mathews
J. Naugle
C. Berry
A. Frutkin

STEERING GROUP

J. Naugle – Chairman
R. Johnson – Exec. Secretary
L. Meredith
J. Mitchell
S. White
L. Jaffe
P. Culbertson
S. Himmel
H. Ortner (ESRO)

SCIENCE WORKING GROUPS

COORD./Mitchell

ASTRONOMY/Roman
SOLAR PHYSICS/Oertel
HIGH-ENERGY ASTROPHYSICS/Opp
ATMOSPHERIC & SPACE PHYSICS/Schmerling

APPLICATIONS WORKING GROUPS

COORD./Jaffe

COMM. & NAV./Ehrlich
EARTH & OCEAN PHYSICS/Milwitzky
EARTH OBSERVATIONS/Tepper
MATERIAL SCIENCE & SPACE PROCESSING/Bredt

LIFE SCIENCE WORKING GROUP

COORD./White

LIFE SCIENCE/Hessberg

SPACE TECHNOLOGY WORKING GROUP

COORD./Hayes

SPACE TECHNOLOGY/Novik

ATTACHMENT B

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EARTH OBSERVATIONS WORKING GROUP

EXECUTIVE SUMMARY

INTRODUCTION

This report is based on Shuttle data available in January 1973. It is an analysis of how the Space Shuttle may be used to support national efforts which require observation of the earth from space. As a first report of its kind, it serves to provide a general overview and guidance for detailed mission planning and instrument design which must follow. It is a technical report, and while it does not address itself to questions of economic or social costs and benefits, it does define a set of potential applications and systems which may now be used as a basis for socio-economic studies.

The goal of all Earth Observation missions is to conduct monitoring over long periods of time of the physical state and dynamic behavior of the earth's land surface features and of the three other elements of the global environment — air, water, and ice; and to provide for the operational application of the observations. To achieve this goal, the following phased development process is required:

- Establishment of quantitative relationships between observable parameters and geophysical variables.
- Development, test, calibration, and evaluation of eventual flight instruments in experimental space flight missions.
- Demonstration of the operational utility of specific observation concepts or techniques as information inputs needed for taking actions.
- Deployment of prototype and follow-on operational Earth Observation systems.

OBJECTIVES FOR THE 1980's

The disciplines encompassed in Earth Observations are all involved in the application of space technology to the solution of terrestrial problems. They share a number of mission characteristics. Some of the common requirements to satisfy these characteristics in Earth Observations are:

- Earth viewing capability from a stabilized platform.
- High inclination orbits or geostationary orbits.
- Orbital altitudes in the range of 400 km to 1700 km and geostationary (36,000 km).
- Global coverage for most applications.
- Repetitive viewing of same regions to identify changes with time.
- Ground and low level correlated measurements.

The goals and objectives in Earth Observations programs are intimately related to the application objectives of remote sensing of the earth from space. In general these focus on:

- Atmospheric Monitoring
- Ocean Monitoring
- Land Monitoring

The disciplines of meteorology and atmospheric environmental quality are concerned with how the atmosphere works as a complex fluid-dynamical system. The solution to these problems is feasible. The Earth Observations programs over the next decade should be focused on capabilities from space necessary to support:

- Weather Prediction
- Air Quality Assessment
- Weather and Climate Modification
- Weather Dangers and Disaster Warnings

In ocean monitoring spaceborne remote sensors will play a significant role in meeting the needs for information about the spatial and time variations of key oceanic parameters such as surface temperature, sea state, sea ice, water color, circulation, and the relation of ocean features to meteorological prediction. The program in ocean monitoring in the 1980's should concentrate on:

- Fisheries Resources Management
- Coastal Zone Activities
- Maritime Activities
- Water Pollution Monitoring, Control and Abatement

Monitoring of resource and environmental characteristics of the land surface can be expected to increase in importance. The unique characteristics of observation from space are rapidly being demonstrated. Improvements in capability and efficiency of operation will be needed in:

- Agriculture, Forestry, Range Resources
- Mineral and Land Resources
- Land Use Classification and Changes
- Water Resources
- Mapping and Charting
- Environment Quality and Models

SHUTTLE USES FOR EARTH OBSERVATIONS

The Space Shuttle may be used to meet the objectives of the Earth Observation program in three general ways:

- To launch and place into orbit unmanned automated satellites for both research and operational purposes and eventually to retrieve and/or refurbish such satellites.
- To place instruments and scientists into satellite orbit in a Sortie mode to conduct experiments for limited periods of time.
- To perform certain operational or contingency missions with instruments carried routinely on the Shuttle Orbiter and operated either by man or in an automated mode.

The use of the Space Shuttle system to meet research and development objectives of the Earth Observations program falls into two categories:

- Limited missions: i.e., those that can be accomplished under the time and space constraints imposed by a Shuttle Sortie mission.

- Extended missions: i.e., those that require the increased time and/or orbital characteristics afforded by the Shuttle capability to launch automated spacecraft into orbit.

Typical limited R&D missions which may be performed using the Space Shuttle include development, test and optimization of new optical, IR and microwave sensors; simulation experiments which can take advantage of a low-gravity environment; and certain other micro-meteorological experiments which require this type of environment, e.g., certain cloud physics experiments.

Extended R&D missions would include the launch of experimental satellites into polar or geostationary orbits, such as Earth Observation Satellites (EOS) or Synchronous Earth Observation Satellite (SEOS), as well as certain smaller Single Purpose Earth Observation Satellites (SPEOS).

To meet operational objectives, the Space Shuttle would be used for the launch, retrieval and/or refurbishment of systems such as the operational Earth Resources Survey (ERS) satellites, the Geostationary Operational Environmental Satellites (GOES), and later the advanced Environmental Monitoring Satellites (EMS) and the All-Weather Monitor (AWM) satellites. In general, these satellites require orbits which will need the space tug or at least an injection stage. This capability may not be available until approximately 1983-4.

A tentative schedule of Earth Observation missions prior to and during the transition from conventional to Shuttle launch capability is given in the attached table.

PRINCIPAL CONCLUSIONS

- The Shuttle affords to the Earth Observation program a capability which provides for a good mix of unmanned and manned missions (in the Sortie mode).

- The Shuttle may be used to launch unmanned automated satellites into earth orbit. However, since most Earth Observation missions require a polar orbit at altitudes ranging from 400 - 1700 km, this capability will not be available until 1983-4, some four to five years after the Shuttle comes into operation. Conventional launch vehicles will continue to be required until approximately 1983-4.

- The Shuttle may be used in a Sortie mode to carry experiments into space, together with the scientists to perform them. Of particular importance to the Earth observation program will be the ability to erect large (>100 m) antennas in space and perform experiments to perfect high resolution all-weather environmental sensing techniques. Other important techniques to be investigated in this mode would be active laser systems requiring the presence of a human operator.

- The low-g environment in the Shuttle opens up a host of new possibilities for conducting important cloud physics and fluid circulation experiments in space.

- The Space Shuttle may eventually be used to retrieve and/or refurbish unmanned automated spacecraft, which could have significant impact on launch costs and system efficiency over a period of time.

Earth Observations Working Group Mission Model

	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
R & D																		
ERTS	X			X														
NIMBUS		X			X													
EOS						X		X		X		(R)						
SPEOS					X	X												
TIROS N, O				X					X									
SMS	X	X			X													
SHUTTLE LAUNCHED																		
EOS											X	X R	X R	X R	X R	X R	X R	X R
SEOS								X				RF				RF		
SPEOS							2	2	2	X	X	X	X	X	X	X	X	X
SORTIE							4	4	4	4	4	4	4	4	4	4	4	4
TIROS P															X			

	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
OPERATIONAL																		
TIROS N, O.	X	X	X	(X)	X	X	X											
ENV. MON. SYSTEM									(X)	X								
FOREIGN SMS					2													
GOES	(X)	(X)																
ERS - LOW ORBIT					X	X		X		X								
SHUTTLE LAUNCHED																		
EMS											X		X		(X)		X	
FOREIGN SMS								X					X			X		X
GOES							X		X		X		X		X		X	
OSEOS														X				RF
SPEOS								X		X								
ERS - LOW ORBIT												X		X		X		X
AWM													X		RF		RF	
SORTIE							X				X				X			

R = RETRIEVAL
RF = REFURBISH
() = NON ADD

PREFACE

The Earth Observation Working Group (EOWG) consisting of seven NASA people and representatives from six agencies, plus invited specialists, met in Wallops Station, January 17-19, 1973, to review the three reports (Meteorology, Oceanography and Earth Resources) developed in the Space Shuttle Sortie Workshop held at the Goddard Space Flight Center in the summer of 1972 and modified since that time by the expanded Panels in these three disciplines. The objective of the Wallops meeting was to consolidate and amplify the three reports into a single Earth Observation Document. This report is the result of these efforts.

The report is based on the Shuttle data available in January 1973. It is an analysis of how the Space Shuttle may be used to support national efforts which require observation of the earth from space. As a first report of its kind, it serves to provide a general overview and guidance for detailed mission planning and instrument design which must follow. It is a technical report, and while it does not address itself to questions of economic or social costs and benefits, it does define a set of potential applications and systems which may now be used for socio-economic studies.

The material prepared during the Wallops Station meeting was assembled and edited by Mr. E. A. Neil of the Meteorology Program Office (Lead Center) at GSFC. This material was in turn reviewed and edited by the members of the EOWG to produce the attached report.

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EARTH OBSERVATION WORKING GROUP

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*Attended for D. Hunt (NSF) at January 17-19, 1973 meeting.

REPORT OF THE EARTH OBSERVATIONS WORKING GROUP ON SHUTTLE UTILIZATION

THE 1980 PROGRAM ACTIVITY

OBJECTIVE FOR THE 1980's

General

The disciplines encompassed in Earth Observations are all involved in the application of space technology to the solution of terrestrial problems. They share a number of mission requirements and mission objectives. Some of the common requirements in Earth Observations are:

- Earth viewing capability from a stabilized platform
- High inclination orbits
- Orbital altitudes in the range of 740 km (400 n.m.) to 1660 km (900 n.m.) and geostationary (36,000 km)
- Most applications involve global coverage
- Repetitive viewing of same regions to identify time changes
- Usefulness of ground and low level correlated measurements

The Earth Observations disciplines also share in one other unique utilization of space research. This is the evolution of an "operational" system for a given discipline. Such systems, while having high utility also become quite expensive. The utilization of the Space Shuttle can be expected to do much in reducing the total cost.

A prime utilization of the Space Shuttle in Earth Observations will be to place medium sized spacecraft into polar orbit together with eventual refurbishment and/or retrieval. As shown in the report that follows, polar orbit capability for the necessary altitude and weight is not planned before 1983, some four to five years after the Shuttle comes into operation. The Earth Observations program will have significant, operational requirements throughout this period that could capitalize on the Shuttle polar capability, if it were available sooner.

The goals and objectives of NASA in Earth Observations are intimately related to the application objectives of remote sensing of the earth's resources from space. In general these focus on:

- Identifying space observable parameters that will contribute to the needs of the users
- Meeting the data needs of the user community for the time period, and
- Reducing cost and increasing the effectiveness of data acquisition from space

Achievement of these goals and objectives must involve a combination of efforts by NASA, other government agencies (federal, state and local), industry and the community of citizens.

Programmatic

The objectives for the 1980's in Earth Observations can be viewed in terms of their contribution to three prime categories. These are:

- Atmospheric Monitoring
- Ocean Monitoring
- Land Monitoring

The principal endeavors for each of these categories for the 1980's time frame are summarized below:

Atmospheric Monitoring — The disciplines of meteorology and atmospheric environmental quality are concerned with how the atmosphere works as a complex fluid-dynamical system. Although research in these disciplines is primarily basic, any increase in understanding of the system can be applied to immediate, practical benefits. In the 1980's we must direct more attention towards intelligent control of air pollution, timely warnings or even perhaps, modification of dangerous weather events, and development of more accurate weather forecasts to capitalize on their growing economic and social importance. The solutions to these problems are feasible and the NASA program in Earth Observations over the next decade should be focused on providing the observational capabilities from space necessary to support the following objectives:

- Weather Prediction — Extend the capability for accurate prediction of the weather and atmospheric processes.
- Air Quality — Develop the capability to monitor and manage the concentrations of air pollutants.

- Weather and Climate Modification — Establish means for the examination of deliberate and inadvertent modification of weather and climate.
- Weather Dangers and Disasters — Substantially reduce human casualties, economic losses and social dislocations caused by the weather, through a combination of the proceeding objectives.

Ocean Monitoring — Spaceborne remote sensors will play a significant role in meeting the needs for certain types of information about the spatial and time variations of key oceanic parameters such as surface temperature, sea state, sea ice, water color and circulation. NASA's Earth Observation program in ocean monitoring in the 1980's should concentrate on those oceanic parameters needed to improve weather forecasting and to progress in four prime areas in the field of oceanography. These are:

- Fisheries Resources — Reliable forecasts and ability to locate schooling fish by type and quantity are necessary for economic and cost effective fishing operations and improved management of fisheries resources.
- Coastal Zone Activities — Coastal zone management requires better baseline information on the coastal environment. The kind of information to be obtained includes basic data on estuarine flushing rates, beach erosion rates, swells, tides, surf, storm surges, ocean currents, tidal currents, salinity, ice conditions, biological content, turbidity, bathymetry, plant cover, land use, squalls, surface films and surface winds. Such data will ensure better modeling and contribute to more accurate predictions and assessments of the overall impact of the ocean on the environment, and contribute to better coastal zone management.
- Maritime Activities — The conduct of efficient and safe maritime activities requires accurate nautical charts, and information on sea ice, currents, sea state, shoals, surface winds, sea ice thickness and age, ship density, icebergs, thermocline depth, vertical density, salinity, and underwater turbidity. Ship operators must be able to move cargo at minimum cost and minimum damage, taking advantage of a knowledge of ocean currents and sea state conditions wherever possible. No global system exists for the measurement of sea state and ocean currents having the required density of coverage. Satellite remote sensing data will provide the necessary broad area, repetitive, synoptic information of sea state, currents and ocean surface wind fields to permit improved description and prediction.
- Water Pollution Monitoring, Control and Abatement — Water pollutants can be classified into five types from the standpoint of remote sensing: Oil pollutants, Organic wastes, Suspended sediment, Chemical and toxic wastes (that produce a detectable effect) and Thermal effluents. The observables that provide clues to these pollutants are: Variations in water color, Surface temperature, Surface roughness, Emissivity and Polarization

of surface-reflected sunlight. NASA's efforts in these areas will continue into the 1980's time frame with the expectation that such measurements will be increasingly useful and more likely, essential.

Land Monitoring — Land monitoring from space in the 1980's will cover a broad gambit of man's activities and endeavors. Some of the principal efforts are:

- Agriculture, Forestry, Range Resources — Includes identification measurement and monitoring, plant stress detection, and yield and loss predictions
- Mineral and Land Resources — The determination of mineral and land resource identification and location together with reliable predictions of geological hazards and terrain mapping to delineate continental structures
- Land Use Classification and Changes — Data needed for regional planning, archeology, disaster assessments and demography
- Water Resources — Water distribution and changes, snow surveys, soil moisture, water quality evaluation, estuarine dynamics, and flood prediction and assessment
- Mapping and Charting — Soil/vegetation relationships, land mapping, coastal zone mapping, climatic mapping, and aeronautical charting
- Environment Quality and Models — Ecological assessments, and public health/epidemiology

Each will contribute to a direct understanding of man's role and impact on his planet earth as well as contribute to man's needs and wants within that role.

User Identification

User Needs — One aspect of the Earth observation program for the 1980's which is clear, based on operating experience to date with the research satellites of the TIROS, Nimbus, and ERTS missions, is the high utility of the data and the rapid evolution of the requirement for an operational system based on this research effort. It is evident that as the NASA sponsored research effort in the necessary space systems proceeds together with the development, test, and evaluation of the feasibility and utility of remote sensor technology in cooperation with "user" agencies, the necessity and high utility of an operational system will become evident. Long term user needs for data have been identified in the Annual Federal Report on Earth Resources Survey Programs prepared by the Interagency Coordinating Committee for the Earth Resources Survey Program dated August 30, 1972. User needs were identified in the areas of mineral and land resources, land use, water resources, marine resources, environmental monitoring, agriculture, forestry and range, and mapping and charting. In each of these categories, uses are identified with regard to location and assessment, monitoring and prediction, and control and management. Meeting these needs requires the availability of remote sensors in the regions of the electromagnetic spectrum which can penetrate the atmosphere and interact with the environment. Both passive and active sensors are required.

User Community — The potential user community is very extensive encompassing the national and international community of scientists as well as Federal, State and Foreign governments and industrial concerns. Some members of the user community are:

- Federal Government — Department of Agriculture, Department of Interior, Department of Commerce, Department of Transportation, Corps of Engineers, Environmental Protection Agency, National Science Foundation, Atomic Energy Commission, National Academy of Sciences, and National Academy of Engineering
- State and Local Governments — All the state and local governments which are involved in such activities as land use planning, environmental monitoring and control, and the effects of such phenomena within their state
- Industry — Extractive industries, including minerals and petroleum products; forest and agriculture industries; manufacturing industries, particularly those which may introduce pollution or products which may affect the environment, into the atmosphere, land or water areas
- Foreign Users — Government agencies, industry, international committees, commissions, associations, councils, etc.
- Academic Community — Professional societies and their symposiums and workshops, universities

Manpower Requirements

Establishing requirements, developing instrumentation and interpreting the measurements obtained from space will require a great number of extremely capable scientists and engineers in such disciplinary sciences as meteorology, oceanography and earth resources, as well as expanded work in computer based modeling for utilizing the measurements. The number of people being attracted to these disciplines appears to be diminishing. Likewise, support for research in these areas is not expanding. The scientists who will be in their most productive years during the period of availability of data in the 1980's will be entering the universities in the next few years. It is essential that future plans support research in the universities in the applicable areas in order to maintain faculty interest and motivate students.

Basic Systems and Instrument Requirements

Having described the goals and objectives of the Earth observation program through the 1980's, it is necessary to summarize the technical and instrument requirements which this program will impose.*

So far as the possible use of the Shuttle system is concerned, the Earth observation program will require it's use in two basic technical modes. The first of these uses is to launch automated spacecraft, either R&D or operational, into specified orbits and in certain cases to retrieve and/or refurbish these spacecraft at later times. The second use is in the form of a carrier of equipment and personnel to conduct measurements or experiments in the form of a manned Earth Observation platform.

Considerable experience has now been gained with remote sensing instruments operating from space in the visible, near IR and thermal IR regions of the spectrum. Much more limited experience has been gained in the microwave region. It now appears that during the 1980's the principal areas where data needs will not have been met by unmanned systems will be in the microwave region and with systems based on lasers or other active optical means of detection and identification of surface features. Because of the size of the antenna which must be flown for the purpose of obtaining high-resolution passive microwave observations of the Earth's surface, it appears likely that the antenna will have to be assembled in space, thus requiring the presence of a man. Similarly, early investigations using laser systems from space will probably require a human operator. There will also be certain additional unique experiments which require the presence of a man.

While new data needs may lead to only a limited requirement for Space Shuttle deployment, there are other advantages to be gained, particularly in terms of use of the Shuttle for launching unmanned automated systems in such a manner as to both reduce cost and increase effectiveness of data acquisition from space. If full utilization can be achieved, the use of a Shuttle launch should lead to overall lower launch costs for unmanned systems. Regardless of initial launch costs, the use of the Space Shuttle (with upper stages, as required) will permit the use of larger, heavier spacecraft with greater availability of payload capacity and power, and hence, greater redundancy of systems and components with implied

*Primary source of reference data for this chapter is the "Proceedings of the Space Shuttle Sortie Workshop," Vol. II, dated July 31–August 4, 1972 and a revision of the Report of the Panel in Meteorology and Atmospheric Environmental Quality dated December 28, 1972. Changes from the material presented in these two references reflect inputs and updates by the working group which met at Wallops Station from January 17 to 19, 1973.

longer lifetimes. It will also provide for a greater variety of sensors to be directed at an object or region under observation if required. The ability to use the Shuttle to check out systems in space at the outset of operations, repair and refurbish satellite systems as required, and eventually to retrieve and replace spacecraft, should make an important contribution to system effectiveness in the future.

For each type of application of remote sensing from space, it is usually necessary to go through a research and development phase using spacecraft of the Nimbus or ERTS variety, and then when instruments are proven, to proceed to operational deployment of systems based on the space qualified sensors. The availability of the Shuttle and man in space may shorten the time necessary to qualify new sensors for such deployment.

It is thus likely that the Space Shuttle program may lead to both new opportunities and greater efficiencies in future Earth observations systems.

The following sections will describe the two flight modes in greater detail. It must be recognized that in most uses, Earth observations systems require earth pointing platforms utilizing stabilization systems; a global coverage through either high inclination polar orbits or geostationary orbits, and lifetimes to provide for data observations based on annual or long term time variables.

<u>The Launch Requirements</u> — The Earth observation program has as its basic mode of operation the launch into orbit of a variety of spacecraft with various sizes and weights into essentially two orbits:

- Sun-synchronous, polar orbits at altitudes ranging from 400 to 1,700 km
- Geostationary orbits at 36,000 km.

As we view the progress into the 1980's, it would be economically advantageous to have capabilities not only for inserting spacecraft into these kinds of orbits but also to be able to visit the spacecraft after insertion and make replacements, repairs or updating, or retrieval and return to earth. The retrieval aspect opens the possibility of refurbishing, modifying, or redeploying the satellite for future operational service.

<u>Classes of Automated Satellites</u> — The weights of the Earth observation automated satellites foreseen in the '80's vary from 300 to 4500 kilograms. We foresee four classes of automated satellites.

- Small Single Purpose Satellites — These satellites are characterized by their relatively small size, moderate lifetime requirements, specific orbital characteristics, and single purpose objective. This class of satellite will weigh up to 300 kilograms. Its orbital altitude can range up to 1,000 km and its orbital inclination is variable. Broadly speaking, the requirement will be between one and two per year through the 1980's.

- Small Operational Satellites — These satellites, members of operational systems, will usually be versions of successfully flown R&D or prototype operational satellites. Their sensors and instruments have already operated successfully in space, and thus, their main requirement is to provide regular and continuous uninterrupted operational data to the users.

  Examples of these satellites will be the follow-on operational series to the ERTS satellites and the Geosynchronous Operational Environmental Satellites (GOES) as a follow-on to the SMS prototype satellite.

  This class of satellite weighs from 700 to 1200 kilograms and requires either polar orbiting sun-synchronous orbits or geostationary altitude orbits.

  Retrieval capability is highly desirable if it will reduce the cost of operation of the operational system. It is expected that satellites in this class will be launched at the rate of about one every two years. The main objective, of course, is to maintain continuous operation in orbit.

- Medium Size Observatories — This group of satellites is of two basic types. The first type represents a further evolution of the TIROS series into its operational derivatives such as the Environmental Monitoring Satellites (EMS) and the second is the Earth Observation Satellite (EOS) series.

  The first type will require the placing of a 1400 kilogram satellite into near polar sun-synchronous orbit with altitudes up to 1700 km. The second type will also require near polar, sun-synchronous orbits of somewhat lesser altitude (700 to 1000 km) but will weigh about 4200 kilograms.

  The EMS will be launched on two year centers in order to maintain continuity of observations; however, it is expected that this launch rate will be reduced towards the end of the period to four year centers if refurbishment is possible.

The larger EOS requiring polar orbit would be launched from the Western Test Range (WTR). In view of the multiplicity of disciplines serviced by this satellite, a yearly launch is anticipated.

- Large Automated Satellite Systems — This group of satellites is typified by the requirement to place relatively large satellites into geostationary orbits of 36,000 km. Payload weights would be about 2300 kilograms. This class of satellite has been called the Synchronous Earth Observatory Satellite (SEOS) and will be used to monitor continuously or on command earth activities within its direct or pointable field of view. The cost and sophistication of the satellites makes refurbishment very desirable. The launch of the first of these large satellites is expected early in the decade with refurbishment as frequently as necessary to maintain operations.

Research and Development Requirements

The goal of all Earth observation missions is to conduct monitoring over long periods of time of the state and dynamic behavior of the earth's land surface features and of the three other elements of the global environment — air, water, and ice; and, to provide for the operational application of the observations. Ultimate Earth observation systems, therefore, tend toward automatic, long-lived, unmanned platforms. To achieve effective operation of long-lived, automatic Earth observation platforms, the following phased-development process is required:

- Establishment of quantitative relationships between observable parameters and the needed atmospheric or geophysical variables ("signature studies") or the scientific test of a measured concept.

- Development, test, calibration and evaluation of eventual flight instruments in experimental space flight missions (the technological test of new instruments or systems)

- Demonstration of the operational utility of specific observation concepts or techniques on a global scale as information inputs needed for taking actions, (including the correlation of space observations with aircraft and surface based "truth measurements", as well as the analysis of the observations from space together with those from "conventional techniques", as required, to form a total system)

- Deployment of prototype operational Earth observation systems

The early experimental unmanned Earth Observation Satellite sensor systems provided the opportunity for determining feasibilities and potentialities. However, the results have indicated that there is an increasing requirement from space for finer spatial and spectral resolution capability, along with greater geometric image accuracy. A manned system of the Shuttle Sortie type could provide the R&D platform not only for the latter but also for the development of more adequate spectrometers operating in the visible, near IR and thermal IR regions, as well as for the development of greater capability in active and passive measurements in the microwave region.

Increased understanding of the physical processes governing the dynamic behavior of the earth's environments will enhance the specification and utilization of Earth observational capabilities. The zero-gravity environment of the Shuttle and the ability to produce variable strength gravitational fields provide unique opportunities to conduct investigation into some of these processes.

AVAILABLE SYSTEM CAPABILITY APPLICABLE TO EARTH OBSERVATIONS

INTRODUCTION

The Earth observations Working Group in its deliberations, recognized that the present Space Shuttle and Shuttle Sortie program is a dynamic one with changing values of the many parameters to be expected, as the effort proceeds. The EOWG utilized the data available in January 1973 during its Wallops Station Workshop. The following represent the assumptions concerning the Shuttle program that were used in its planning. While it is expected that these data will be modified as the development effort proceeds, the assumptions made have validity for planning purposes in Earth observations.

SHUTTLE VEHICLE CONCEPT

The primary goal for the Space Shuttle program is to provide low cost, reusable vehicles capable of space and atmospheric flight that can transport payloads of equipment and instrumentation into orbit, support a program of observations or equipment deployment/retrieval while in orbit, and return to earth with the accumulated data. *

*Additional and subsequent information may be found in the "Shuttle Payload Accommodation Document," issued by Shuttle Program Office, JSC.

VEHICLE DESCRIPTION

Space Shuttle Launch System

The Space Shuttle system consists of an orbiter with an external propellant tank and two solid rocket motors. Figure 1 shows the Shuttle system as the vehicles are combined for the launch and initial boost phases of the mission. Although the orbiter vehicle is reusable, its propellant tanks are expended on each mission.

Orbiter Vehicle

The baseline orbiter is a manned reusable delta-winged vehicle. Contained within the main fuselage of the orbiter are the crew compartment, a payload bay capable of accommodating single or multiple payloads up to 15 ft. (4.6 meters) diameter by 60 ft. (18.3 meters) long, support subsystems, an orbital maneuvering system, and the main propulsion system engines.

Flight Control/Crew Accommodations

The orbiter crew compartment houses the flight crew, passengers, controls and displays, as well as most of the avionics and environmental control system.

SHUTTLE OPERATIONAL USE

While the Space Shuttle is in orbit, a variety of operations can occur, falling into two general categories:

- Delivery, service, and retrieval of payloads
- Sortie Laboratory/Pallet Science and Applications activity

Delivery, Service & Retrieval

The operational capability of the Space Shuttle will make possible the placement, service, and retrieval of free-flying or automated satellites. More than one satellite can be deployed or recovered for each mission, depending on the mission and characteristics of the satellite. Many times, smaller satellites of this

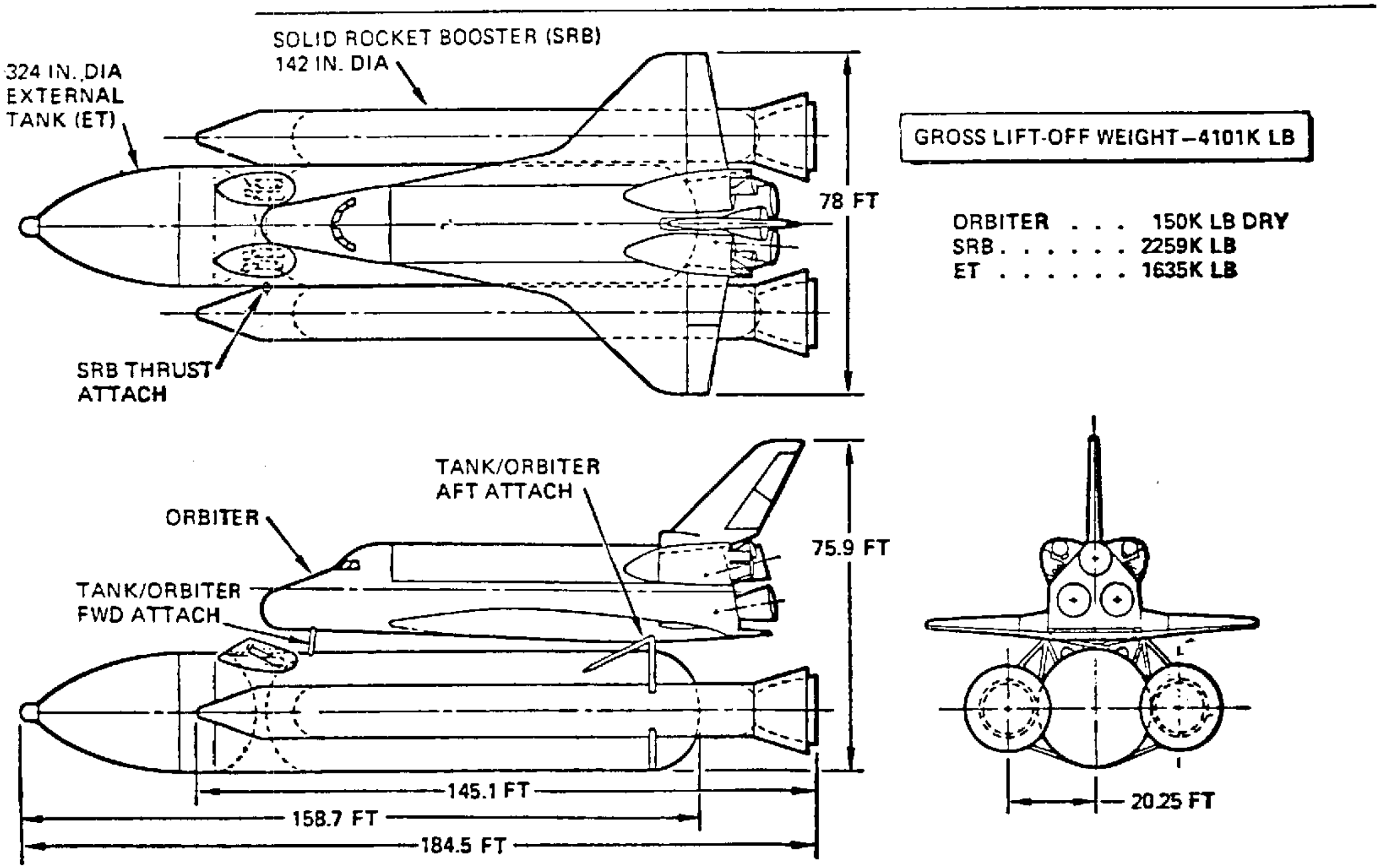


Figure 1. Space Shuttle Vehicle

payload class may be part of a mission payload made up primarily of the Sortie Lab activity. The stabilized platform environment of the Space Shuttle payload bay should also benefit the satellite payload class that uses upper kick stages. This capability allows payloads to be placed into higher circular orbits, higher elliptical orbits, and trajectories for deep space probe missions. Depending on the size of the propulsion stage selected, more than one kick stage can be used with a payload for a single mission.

Sortie Lab/Pallet Science & Applications

The Sortie Lab will consist of a combination of the standardized pressurized volumes, airlocks, and mounting platforms (pallets) to support the applications, technology, and science payloads. Baseline definition includes a pressurized/habitable laboratory, a modular pallet for unpressurized payload operations, and several types of special purpose ancillary equipment included with each element. The basic laboratory provides considerable space and support equipment for internal accommodation of various experiments, provides resources such as power and data management to the experimenter, and is designed to allow close interaction with experiments. For selected missions, a shorter module may be more effective. For mounting of sizeable experiments in vacuum or general payload delivery, the pallet alone may be utilized. The pallet is designed to be variable in length and will attach to the end of either the laboratory or directly to the Shuttle.

Additional information regarding the Sortie Lab is presented in the SORTIE LAB section.*

SHUTTLE PERFORMANCE & MISSION CHARACTERISTICS

Data for this section are as of January 1973.

Basic Payload Capability

Orbiter payload capability is baselined as follows:

- Total usable volume — 15 ft (4.6 m) diometer X 60 ft (18.3 m) long
- Total available payload for due east orbit — 65,000 lb (29,500 kg)
- Total available payload for polar orbit — 40,000 lb (18,000 kg)

*Further information is contained in "Sortie Lab Accommodation Handbook" and "Sortie Lab Characteristics" issued by the Office of Manned Space Flight.

Mission Duration

The nominal time from Shuttle lift-off until orbiter return is 7 days. This gives approximately 6.5 days for on-orbit operations with Sortie Lab and orbiter since time for checkout and maneuvering for the vehicle must be considered. Shorter duration missions may be accommodated, if desired. Longer duration missions, up to 30 days, are planned to evolve as the program and requirements indicate. For missions in excess of 7 days, the weight of the expendables will be charged against the payload.

Launch Sites, Inclinations and Payload Limitations

Inclination angles for Shuttle insertion into orbit will be preselected based on mission requirements. From the Kennedy Space Center launch site, orbits of 28.5° to 55° inclination may be achieved at altitudes of 100 n.m. to several hundred nautical miles (depending on the tradeoff of payload and Shuttle orbit maneuvering propellant). For polar (90° inclination) and near polar orbits, the Western Test Range will be required and utilized. An approximate payload capability to various orbit altitudes and inclinations not using injection stages is shown in Figure 2.

LAUNCH FREQUENCY

The objective of the Space Shuttle program is to economically deliver payloads to orbit, perform orbital operations, return from orbit and then quickly refurbish the vehicle for reuse. As such, the baseline for an individual vehicle turnaround time from orbital mission landing to launch readiness is to be less than 14 calendar days.

SCHEDULE ASSUMPTIONS

The preceding paragraphs have described the various characteristics and capabilities of the Shuttle system. These capabilities will become available over a period of time as development proceeds. The use of the Shuttle system for Earth observations missions at any particular time will be determined by its stage of development. Table 1 summarizes the estimated schedule availability of various Shuttle transportation system capabilities of particular interest to Earth observations.

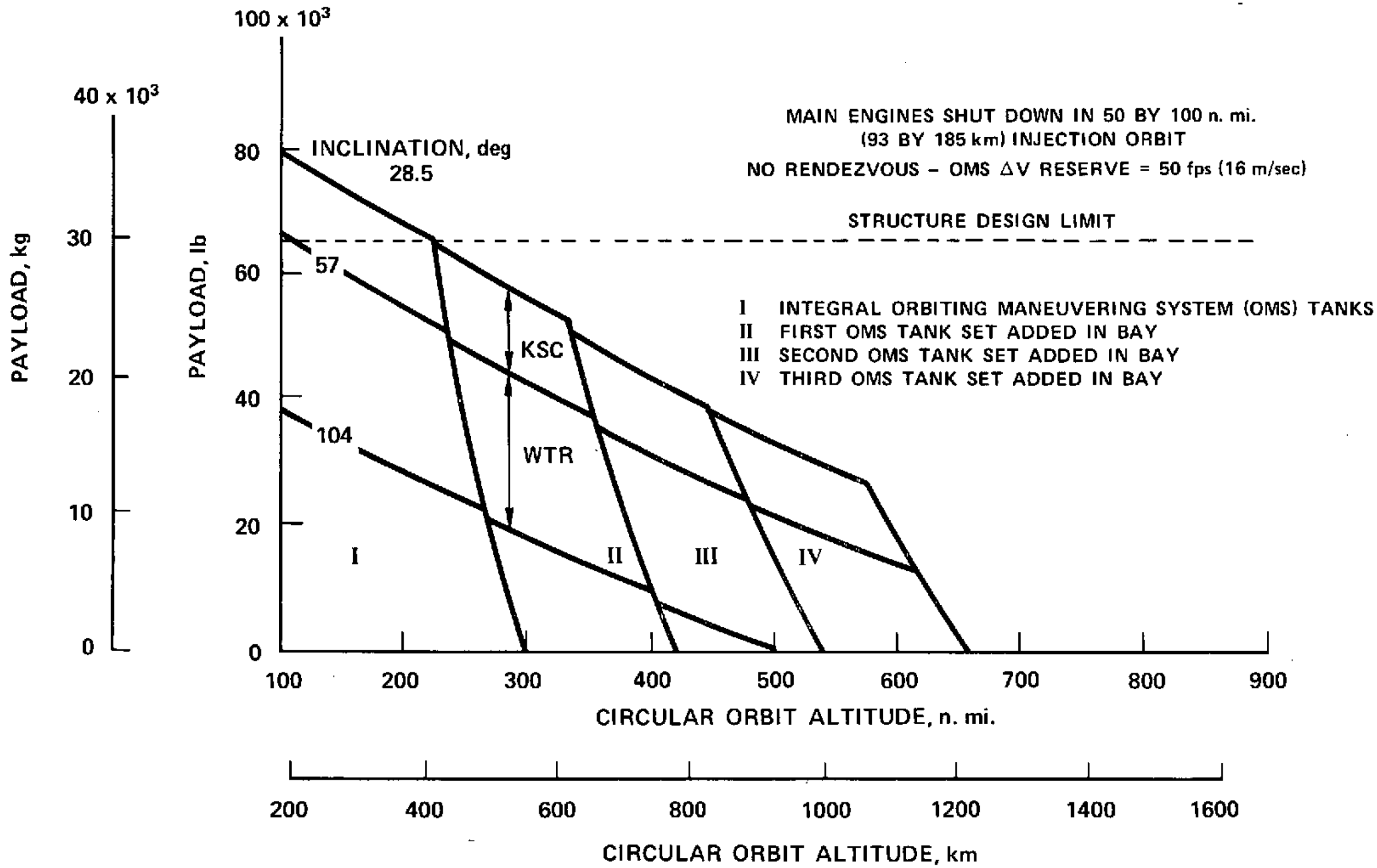


Figure 2. Space Shuttle Payload to Circular Orbits — Without Use of Injection Stage
(Data as of January 1973)

Table 1

Shuttle Schedule in Terms of Performance Capability (Assumptions)

Mode	Configuration	Inc/Alt	Available Wt/#	Year							
				79	80	81	82	83	84	85	86
Deliver	Shuttle only	28.5°/600 n.m.	25,000 lb	X							
Deliver	Shuttle/ Lab	28.5°/250 n.m.	12000-20000[1]	X							
Retrieve	Shuttle/ only	28.5°/600 n.m.	[2]	X							
Refurbish	Shuttle only	28.5°/600 n.m.	[2]	X							
Deliver	Shuttle/ Inj. Stage	Synchronous	12,000 (Centaur)	X							
Deliver	Shuttle/ Lab	Polar/250 n.m.	12000-20000					X			
Deliver	Shuttle only	Polar/500 n.m.	2500					X			
Retrieve	Shuttle only	Polar/500 n.m.	[2]					X			
Refurbish	Shuttle only	Polar/500 n.m.	[2]					X			
Deliver	Shuttle/ Inj. Stage	Polar/1000 n.m.	5000 (Burner IIA) 26,000 (Delta)					X			
Deliver	Shuttle/ Tug	Polar/1000 n.m.	24,000						X		
Retrieve	Shuttle/ Tug	Polar/1000 n.m.	34,000[1]						X		
Refurbish	Shuttle/ Tug	Polar/1000 n.m.	24000-34000[1]						X		
Deliver	Shuttle/ Tug	Synchronous	8,000						X		
Retrieve	Shuttle/ Tug	Synchronous	4,000						X		
Refurbish	Shuttle/ Tug	Synchronous	3,000						X		

[1]based on 40,000 lbs landing weight limit

[2]capability equivalent to delivery

Definitions

- Injection Stage — Any propulsion stage carried in the Shuttle cargo bay and used to propel spacecraft into orbits not attainable by Shuttle alone. Examples are the Delta, Agena, and Centaur upper stages.

- Tug — A particular injection stage which can be returned and reused. It is capable of retrieving spacecraft deployed on previous missions. When suitably outfitted with ancillary equipment it can be used to refurbish spacecraft on orbit by replacing modules; the spacecraft in this case is not returned to the Shuttle, but the tug is retrieved when refurbishment is completed.

- Refurbishment on Orbit — Replacement of modules of a suitably designed spacecraft for the purpose of updating equipment or restoring degraded subsystems to full capability. When equipped with proper ancillary equipment the Shuttle and the tug are capable of performing this service.

- Lab — The Sortie Laboratory and/or equipment pallet. (Described more fully elsewhere in this report and in other documents).

The capability development of the Shuttle evolves in three stages in relation to Earth observation requirements. The Shuttle/lab capability to 250 n.m. in a 28.5° inclination orbit would be about 12,000 to 20,000 pounds (based on 40,000 pound landing limit). The use of a Centaur injection stage would allow a 12,000 pound payload to be placed in geostationary orbit in 1979. In 1983 the polar capability of the Shuttle system will be exploitable due to the availability of the Western Test Range. A "Shuttle only" configuration may be able to deliver, retrieve or refurbish payloads at polar orbits of 500 n.m. A Shuttle/lab configuration with 12,000 - 20,000 pounds of payload could achieve a 250 n.m. polar orbit. The use of an injection stage would allow payloads to be placed in 1,000 n.m. polar orbits. The tug becomes available in 1984. This capability would allow delivery retrieval and refurbishment at polar orbits of 1,000 n.m. or at geostationary orbits as indicated in Table 1.

SORTIE LAB

The Space Shuttle basically serves in the Sortie missions to deliver the complete payload to earth orbit, station keep on-orbit for the mission duration, provide safety monitoring and control over the payload during ascent/return, and provide seating and complete habitability (sleep/eat/waste/etc.) for the crew (nominally four men and up to ten for 7-day missions).

The Sortie Lab and/or pallet constitute the basic experiment carrier system and effect the composite interface with the Space Shuttle through standardized interfaces. The payload crew (nominally 2-6 on-orbit) eat and sleep in the orbiter cabin and enter the Sortie Lab for direct experiment operations. Free movement back and forth is envisioned with compartments separated by a hatch and short tunnel. For operations with only pallet modules, the crew would nominally remain the the orbiter cabin and operate experiment payloads from a special payload provided console located in the orbiter cabin. An EVA airlock will be available in the Shuttle, however the location relative to the cargo bay is to be determined.

Basic Description

The basic Sortie Lab is a pressurized vessel consisting of a cylindrical portion and two removable end bulkheads that provide a habitable environment for the crew and accommodations for conducting experiments in orbit. (See Figure 3).

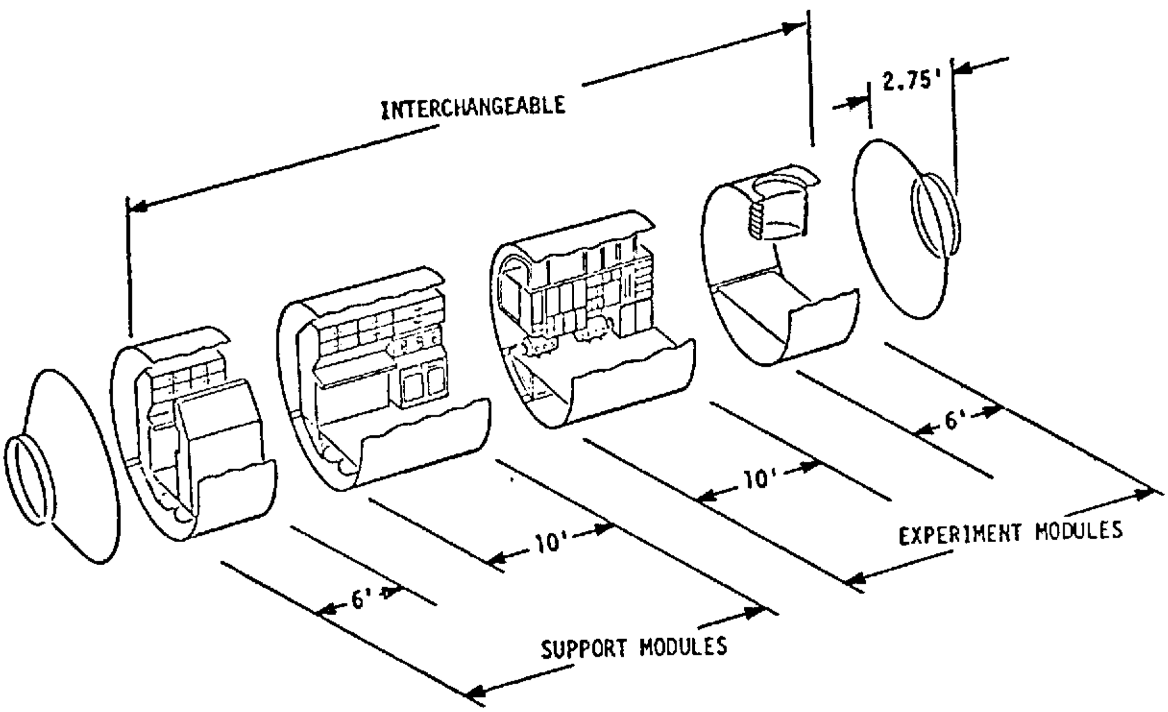


Figure 3. Basic Sortie Lab Interior Arrangement

The Shuttle orbiter cargo bay is 15 feet in diameter and 60 feet long. The overall diameter and length available to the Sortie Lab is 14 feet diameter and either 50 or 36.5 feet long depending upon the use of an OMS kit which uses 13.5 feet at the aft end of the orbiter cargo bay. (The forward 8 feet will be occupied by a docking module.) The present Sortie Lab configuration consists of a habitable pressurized lab which can be made up of up to three cylindrical modules, consisting of a support module and up to two experiment modules; and pallet sections which can be added to the lab or used independently.

The standard lab includes a crew station console for monitoring the operation of the module systems and for experiment operation, a work bench for general operation support, standard equipment racks for electronics, and a crew system cabinet for crew personal items. The design also has provisions for thermal control, electrical power, data management, equipment structural support, storage or accommodation space for experiments, viewports, and large view windows.

The basic resources provided by the standard size Sortie Lab for use by experimenters is summarized in Table 2.

Pallet Description

The pallet (Figure 4) is a variable length platform on which experiments and supporting equipment are mounted and launched to orbit inside the Shuttle payload bay. The size of experiments that can be accommodated can vary from very small up to 120-inch diameter by 680 inches long. Experiments can be conducted with the pallet inside the Shuttle payload bay or with the pallet deployed 90 degrees from the payload bay. Payload elements (such as free-flying or automated spacecraft) can also be separated from the pallet for unmanned operations.

The pallet attached to the lab may range in size from 5 to 45 feet depending upon the lengths of the elements selected for the lab. The pallet sections consist of 5 or 10 foot lengths. The maximum "pallet-only" length is 45 feet.

The pallet may be flown with the lab or separately. Depending on the mission makeup, it may be considered for carrying Sortie mission experiments, piggy back payloads for delivery, or complete payloads for delivery to orbit. For Sortie missions a number of different combinations of lab module-pallet are possible. Figure 5 illustrates the flexible combinations obtainable.

The unpressurized experiments are usually mounted on the pallet and remotely controlled or monitored by the crew inside the module. For extremely long unpressurized payloads the pallet may be flown in the bay without the Sortie Lab and monitored/controlled from payload control stations specially mounted in the orbiter cabin.

Table 2

Lab Nominal Resources Available to Experiments

	Ascent/ Reentry	On-Orbit
Available Volume (ft^3) (nominal)	2000 ft^3	2000 ft^3
Mission Time	TBD	Up to 6.5 days (growth to longer duration)
Electrical Power (d.c.) (kW-ave/pk)	1.0/1.5	1.5 to 2.0/3.0 to 5.0
Active Thermal Control (kW)	1.3	4 - 5
Data Recording Rate (bps)	TBD	100,000
Data Storage Capability	TBD	Mag. tapes as required
Data Transmission Rate (bps)	TBD	25,000 (S Band)
Data Computation	TBD	Up to 32k-32 bit words
Control Consoles	TBD	2 CRT and Keyboards
Crew	1 - 2	2 to 6 men
Atmosphere Pressure (psi)	14.7	14.7
Atmospheric Temperature (°F)	72 ± 5	72 ± 5
Stability	—	± 1 arc min (total vehicle with control moment gyro & stabilization)

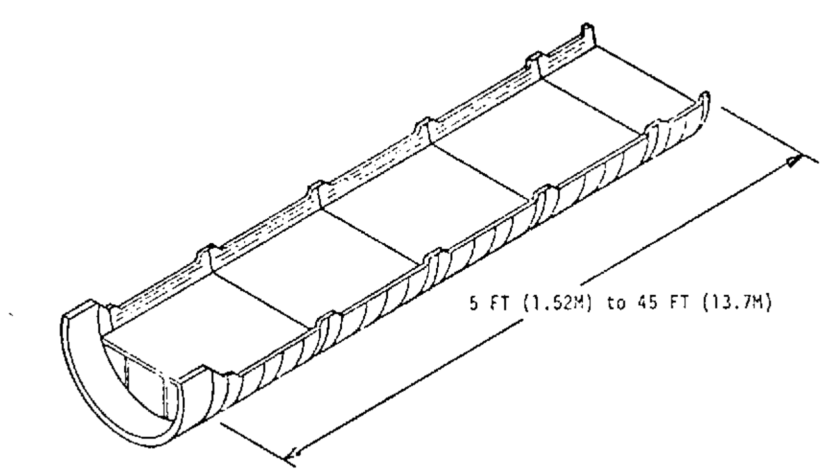
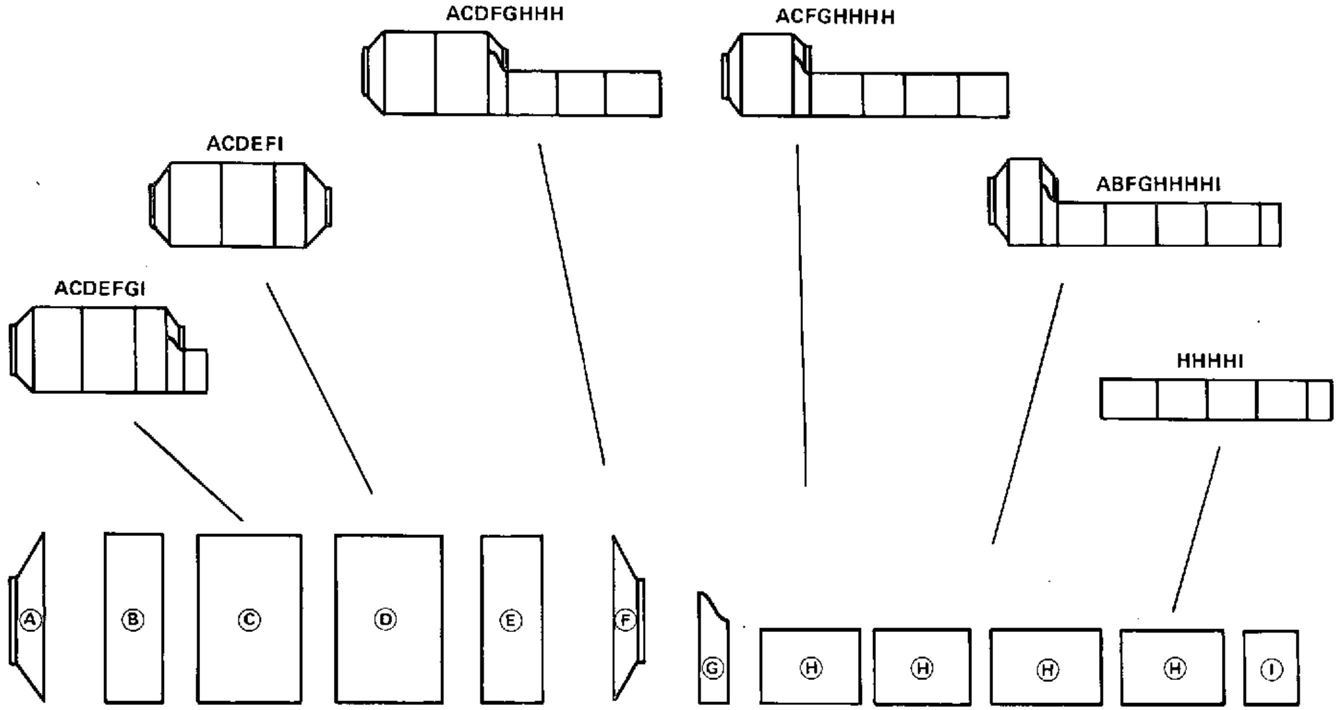


Figure 4. Payload Pallet Modular Lengths



MODULE	FORWARD BULKHEAD	COMBIN-ATION MODULE	SUPPORT MODULE	EXPERIMENT MODULE		AFT BULKHEAD	PALLET					
LENGTH (FEET)	2.75	6	10	10	6	2.75	OVER-LAPS	10	10	10	10	5
WEIGHT (POUNDS)	600	5900	11700	2200	1700	600	300	1200	1200	1200	1200	700

Figure 5. Modularized Sortie Lab Concept

SHUTTLE USES FOR EARTH OBSERVATIONS

INTRODUCTION

The following section serves to illustrate various ways the Shuttle capabilities can be put to use in Earth observations based on present planning in the discipline objectives. It should be recognized that the various uses are not mutually exclusive. Combinations of the planned Shuttle uses are to be expected and fostered. Conversely, some of the discipline objectives will also combine by the 1980's (in a hardware sense) due, in part, to the increased capabilities provided by the Shuttle.

RESEARCH AND DEVELOPMENT USE

The use of the Space Shuttle system to meet the R&D requirements of the program for the 1980's may be divided into the following two categories:

- Limited Missions: i.e., those that can be accomplished under the time and space constraints imposed by a Shuttle Sortie mission.
- Extended Missions: i.e., those that require the increased time and/or orbital altitude characteristics afforded by the Shuttle capability to launch automated spacecraft into orbit.

Limited (Sortie) Missions

A number of R&D requirements may be accomplished in Sortie missions of from 7 to 30 days duration and at orbital altitudes of less than 500 n.m. In the present Earth observations program, the initial activity has often required extensive aircraft "Sorties" such as those that have been conducted with the NASA Convair 990; for example, to determine surface wind speeds from microwave radiometric observations and cloud composition from spectrometric observations. This is followed by experimental flights of sensors and other instruments on observatory spacecraft such as Nimbus and ERTS. Examples of such experimental missions were the instrument tests and demonstrations of global nighttime cloud cover and cloud height mapping with the High Resolution Infrared Radiometer (HRIR) on Nimbus 1, of global temperature profile soundings with the Satellite Infrared Sounder (SIRS) on Nimbus 3, and of ozone profile soundings with the Backscatter Ultraviolet (BUV) monochromator on Nimbus. All of these developments required observing a large variety of globally distributed atmospheric and surface conditions from above the earth's atmosphere and, with the exception of the SIRS (discussed further in the following section), none necessarily required the long-life capability inherent in Nimbus. Hence, all could have benefited substantially from the flexibility that will be inherent in Shuttle Sortie missions.

The Shuttle 'Limited Mission' capability would appear to be particularly useful in the development of passive microwave radiometry systems for all weather ocean monitoring and active microwave radar systems for various aspects of earth and ocean survey.

Sensors operating in the visible and infrared regions of the spectrum can provide much information as to the oceans. In general, they can do so only in cloud free regions. For both meteorological and oceanographic applications there is a recognized need for a global all-weather ocean monitoring capability. Parameters to be measured are sea surface temperature, sea state, and surface wind fields. There are several promising approaches to this type of monitoring using active and passive microwave sensors, but the size of antennas required particularly for passive sensors, has precluded any real space tests of these approaches. The skylab EREP does have a microwave package (S194) which will produce a limited amount of data of rather low resolution. The successful results from the current passive microwave experiment on Nimbus 5, although of even lower resolution, provides additional encouragement for further successful development of these types of systems.

It would appear that the first opportunity for a test of microwave sensors with high resolution (10-15 km) will occur with the Space Shuttle Sortie Laboratory. Such a test should be an early objective of the program.

In order to acquire resolutions of this order and higher, antenna sizes become quite large, on the order of tens of meters. The deployment of antennas of such size is considered to be beyond present state-of-the-art of automated deployment systems. Consequently, it is believed that the Shuttle system utilizing its manned capability may be the most reasonable approach to the deployment of such large antennas in space; this is the only way that the techniques for fabrication, assembly, and operation can be meaningfully demonstrated. Initial tests would be in developing the techniques for assembly and the evaluation of the mechanical and thermal effects on the electrical characteristics of the antenna.

Active microwave systems such as synthetic aperture radar offer a potentially powerful tool for earth survey and selected ocean measurements. Its distinct advantages in relation to most other instruments include a resolution capability which is independent of orbital altitude, weather conditions, and illumination conditions. The Shuttle system capability to provide large amounts of power and return to earth the "high-rate" data generated by the system would make it a logical candidate for testing and demonstrating of this type of system. The microwave systems described above are representative of requirements for continuing support of instrument development. Such development would be conducted in an instrument development laboratory described below:

Instrument Development Laboratory — This laboratory will utilize the Shuttle plus a pallet or the Shuttle plus the Sortie Lab and pallet. The purpose of the instrument development laboratory is to provide for the development, test and calibration of eventual operational flight instruments in experimental space flight missions.

When utilizing the Sortie pallet on which the instrument clusters and their associated gimbal platforms will be mounted, the components can be used either separately or together. When used separately, the Sortie pallet operation may be limited by available space for the necessary control and display consoles within the Shuttle flight deck. Examples of missions that could be performed are:

- Conduct engineering performance assessment experiments with multifrequency passive and active microwave systems to assess their ability to measure and monitor sea state conditions. Analysis of the data from experiments conducted on a single mission may indicate the need for some modifications to the sensors or adjustments in performance characteristics. The mission profile should make allowance for repeat experiments.

- Determine Earth observation parameters of a particular unique nature, such as land mapping, signature recognition, coastal surveys, damage assessment, etc.

Low Gravity Laboratory — In addition to the use of the Shuttle system for instrument development utilizing limited duration missions, there is a requirement to use the Sortie Lab as an on-orbit laboratory for conducting experiments on phenomena that can be studied better under low gravity conditions, rather than on earth where gravity is a factor in the experiment. Examples are:

- The study of the growth of cloud particles and their role in cloud dynamics. This laboratory would provide long duration observation of the behavior of suspended particles, without the need for artificial supports. This information is essential in establishing the scientific basis of weather modification.

- The study of the optical properties of suspended particulates including their contribution to the reflectivity and absorptivity of the atmosphere.

- The simulation of atmospheric and oceanic circulations in a variable gravity field.

The experiments in these areas will range from the simple to the complex and require manned attendance and conduct of the experiments. However, they place very little constraint on the orbit or altitude of the Shuttle. Examples of the types of experiments to be conducted in this laboratory are:

- Cloud Physics — The development and application of weather modification techniques requires the understanding of numerous microphysical processes and their relation to such aspects as the growth of cloud particles and its role in cloud dynamics. 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.

  It would be a flexible multi-experiment laboratory in which the experiments would vary from the simple observation of cloud chamber actions to complex measurements of physical processes. These include processes such as optical properties. Some experiments would be for the examination of the nucleation properties of soluble, insoluble, and hydrophobic 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.

- Atmospheric Particulates — Fine particles change the heat balance of the earth because they both reflect and absorb radiation from the sun and the earth. In addition, since these particles interfere with the emitted atmospheric and earth radiation, they affect the interpretation of the data from the satellite-borne sensors of atmospheric phenomena and the surface condition of the earth. Particles are introduced into the troposphere and stratosphere from natural sources such as sea spray, windblown dust and volcanoes. While man introduces fewer particles than natural sources, quantities of man-introduced gases of sulfates, nitrates, and hydrocarbons are converted into particles by chemical actions.

The study of these particles in terrestrial laboratories are subject to the same types of problems which affect the study of cloud particles. The Space Shuttle would provide a versatile experimental facility, free of gravitational effects and its necessary attendant artificial constraints. Such experiments would determine the optical properties of the fine particles and the effects of the size and shape of the particles, the effects of size distribution, and the effects of various concentrations. In addition, the effects of the particles on radiative transfer would be determined. The results of the optical and the radiation transfer observations would provide a basis for mathematical models to determine the influence of particles on heat budget, planetary circulation, and the interpretation of satellite observations and electromagnetic measurements of surface reflectance.

- Atmospheric Circulation Simulation — The zero gravity environment would allow the use of a facility which could induce variable gravitational fields on fluid flow so as to ascertain the effects of gravity on the thermal fields of the fluid flow and to motions. Such studies would shed light on atmospheric behavior of other planets (whose gravity differs from earth) and thus increase our understanding of the earth's atmospheric motion.

  It has been possible to learn about Rossby waves and atmospheric circulation through the use of a rotating dish pan heated at the periphery. As an extension, it has been proposed that a fluid model on the Shuttle using a rotating sphere and simulated surface thermal and stress anomalies could provide more realistic approximations of the atmosphere and oceans.*

Extended Missions

Some developments may require the extended time and/or orbital altitude characteristics afforded by the Shuttle capability to launch automated spacecraft into orbit. This capability takes the form of:

- Deployment, Servicing and Retrieval – Delivery of automated spacecraft into orbit with the capability of subsequent visiting for service, repair, or retrieval.

*The purpose is to provide simulated gravity with electric or magnetic fields and using fluids on the surface of a sphere which will be made to flow by electrical and magnetic fields. Thermal anomalies can be simulated by electrical anomalies and a working model of the atmospheric circulation simulated.

- Staging — Orbital deployment of automated spacecraft with one or more propulsion stages.

An example of a technological test that required an extended period in orbit was that of the early TIROS scanning radiometers whose response characteristics degraded progressively over a period of many months in the space environment. Another example concerns the behavior of radiative coolers on advanced instruments using cooled detectors. The first radiative cooler, used with the Nimbus 4 filter wedge spectrometer, caused ice to form on the detector shortly after launch and rendered the infrared measurements useless. The next two radiative coolers were flown on NOAA-2 and Nimbus-5 in the last quarter of 1972, and their performance will be evaluated over periods of many months or even years before present cooler technology can be thoroughly assessed.

An example of a demonstration of the operational utility of specific observation concepts was that of the SIRS instrument flown on Nimbus-3. Although the concept of remotely sounding the temperature profile of the atmosphere was demonstrated with data from only a few orbits, because of the complicated interactive relationships between the satellite soundings and data from conventional sources such as radiosondes, surface observations, ships, aircraft, etc., many months of data were required over all parts of the globe. Only data of this type will yield a sufficiently large sample of observations under enough different weather and geographic conditions to provide a data set of adequate proportions to demonstrate fully the operational utility of satellite soundings.

Another example of a demonstration of the operational utility of observation concepts is that of the Multispectral Scanner (MSS) on ERTS-1. Observations over many months covering different growing seasons, hydrological cycles, etc., will be needed to permit a complete assessment of the operational utility of these data. Of course, once the utility of data from new sensors on R&D spacecraft is demonstrated in a preliminary way, the observations can be utilized in a quasi-operational mode pending the full assessment and incorporation of the techniques on a fully operational satellite system. In this regard, SIRS soundings from Nimbus satellites were used quasi-operationally for more than three years before the first fully operational sounder was flown on NOAA-2. Similarly, data from the MSS on ERTS-1 are currently being used in a quasi-operational mode.

Analogous situations regarding advanced sensors in the future will most certainly arise, requiring the capability of the Shuttle to launch automated spacecraft. In those situations (prior to the development of the tug) where the orbital altitude can be less than approximately 500 n.m., the deployment, servicing, and retrieval capability of the Shuttle will be of great value in maintaining an R&D space system over an extended period of time to demonstrate adequately the operational utility of new types of satellite data. It must be emphasized that all R&D activity involving the Shuttle (or any space capability) should be performed in support of a fundamental objective of designing a global environmental monitoring system that adequately describes the physical state and dynamic behavior of the earth's land surface features and the working fluids, and determines the factors that force their movements.

OPERATIONAL USE

Automated Spacecraft

The Space Shuttle has the capability to launch larger, heavier spacecraft (or a group of spacecraft) with greater availability of payload capacity and power, and, hence, greater redundancy of systems and components with implied longer lifetimes. It will also provide for a greater variety of sensors to be directed at an object or region under observation. However, this greater variety of sensor complement is an advantage only, if reliability can be improved. Perhaps the greatest contribution of the Space Shuttle concept to the deployment of operational Earth observation systems is the ability to visit the spacecraft after insertion and make replacement, repairs, or updating. Also implied is the capability to check out systems in space at the outset of operations and make any minor changes or replacements necessary to insure reliable operation.

The utilization of the Space Shuttle for deployment of operational Earth Observation Satellites will depend upon the types of orbits achievable by the Shuttle with a given payload and will increase with time during the 1980's. The Operational Environmental Satellites of the ITOS-type and projected succeeding generations will require a sun-synchronous orbit at about 1700 km and, hence, Space Shuttle deployment of this type of spacecraft is not projected until about 1983. Earth resources operational satellites, although also sun-synchronous, can be operated at a somewhat lower altitude. Unfortunately, however, the Shuttle will not be capable of launching these satellites into polar orbit until 1983. Polar orbiting oceanographic and pollution monitoring systems will be similarly limited.

Therefore, in order to meet operational requirements, we must plan for the use of Delta (and/or Titan) launches for operational Earth observation satellites until at least 1983 for polar orbiters. By mid-decade, the availability of Shuttle launches should permit the use of more complex spacecraft systems and some merging of meteorological, oceanographic, pollution and earth resources requirements in the design of individual spacecraft with orbit response time and periodicity being the principal constraints.

Other orbits of particular interest for Earth Observations are the geostationary- (of great importance in the coastal zone monitoring and for natural disaster warnings) and, special orbits of interest for precise measurements of the shape and dynamic behavior of the earth. The former should be available from a Space Shuttle, with additional staging, by 1979. Programs pertaining to the precise measurements, shape and dynamic behavior of the solid earth and the oceans are discussed in the report of the Earth and Ocean Physics Working Group.

Mission Classes — The following classes of operational Earth observation missions are visualized:

- Modest resolution, multispectral (including blue and thermal IR) sensors with real-time data availability. Periodicity of coverage in hours (polar orbiters) or minutes (geostationary).

- High resolution, multispectral (including thermal IR) with 24-through 48-hour data availability. Periodicity of coverage 1-18 days (polar orbiting), less than 24 hours (geostationary).

- All weather, low resolution, sea-state, surface temperature and vertical temperature and moisture atmospheric profiles with real-time data availability. Periodicity - daily.

- Very high resolution, metric quality, black and white and color photography for cartographic purposes. Periodicity - once in several years. Real-time data availability not required. Hard film preferred.

Manned Spacecraft

While it is certainly possible to consider the use of Shuttle-launched automated spacecraft for cartographic missions, conventional mapping camera systems carried on Shuttle flights could go a long way toward providing the cartographic data needed by the United States and the world at scales of 1:250,000. The camera could be utilized both in orbit and during the glide phase of the returning orbiter.

Camera systems for cartographic purposes could also be available for certain contingency types of missions, as discussed in the next section, provided proper selection is made of film type, filters, and aspect angles for the event being photographed. This mode of operation, would of course not be suitable for timely warnings of natural disasters.

SPECIAL FEATURES

The Shuttle as a system lends itself to several unique uses which it is well to consider separately. These may be considered in either R&D or operational applications.

Contingency Service Use

The Shuttle contingency service is visualized as a means of providing a ready-stand by, immediate survey capability to meet possible, unforeseen, natural or accidental needs and requirements, with a minimum of delay and relatively quick reaction and dispatch times. In this context, a contingency use is visualized as serving to monitor unforeseen occurrences that may be of national or international significance and/or consequence. These could be catastrophic or holocaustic events ("disasters"), whether due to natural phenomena, man-made activity, or "acts-of-God", that may require emergency information. The earliest possible assessment may in turn assist in the immediate planning for relief and rehabilitation measures. A second class of contingency survey would be for impending disaster which could have great consequences but where there is not the immediacy associated with emergency services. This class of contingency would be typified by a serious crop or forestry infestation outbreak.

Contingency mission service per se should not be construed primarily as an additional basic capability or adjunct for general Earth observations, even though it could be utilized to serve in that capacity. At any given time, one or more Shuttle Sorties will probably be in earth orbit gathering earth resource and/or space data for a variety of reasons and needs. It should be recognized that almost any Sorties in orbit can be applied to a contingency mission(s), if circumstances warranted, regardless of the mission underway — depending upon the contingency at the time.

It is the uniqueness of the Sortie that will allow for the more or less timely gathering of data in any region of our world.

Equipment required for a contingency survey would consist of a standardized package of sensors including photographic and imaging radar systems. These systems should have high resolutions and at least a degree of pointing capability including oblique coverage. Procedures would also be standardized to minimize time factors. On board data processing would be very valuable in many cases in focusing attention on the special event. However, where such an approach is not feasible, arrangements should be made to provide that data to a group of trained analysts on the ground for interpretation. All Shuttles would have the interface provisions for this standardized package and it would be carried on all

Sorties where it did not conflict with the mission objective. When a particular contingency occurred there would be the choice of redirecting the mission underway, making the next planned mission a joint use mission e.g., contingency and planned objective, or in extreme emergencies, utilizing a Shuttle uniquely to conduct the contingency survey.

It is not expected that all disasters would require Shuttle surveys. Aircraft in many cases would represent a more flexible and cost effective approach. Also, in other cases the nature of the disaster would be such that the survey, while interesting, would offer no particular benefit for immediate and/or longer term rehabilitation.

Cognizance should also be taken that a Sortie contingency use has its limitations with regard to the capability of monitoring all events. Disasters, such as tornadoes, may occur in such a short time period that the Shuttle, in traveling its orbit, will not have the event in view at any time during its incidence.

Manned Operations Use

Man's role in Shuttle operations for Earth observations will be as an inherent part of the overall Shuttle systems capability. The fact that men are aboard and available, allows Earth observations systems and mission designers to exploit this very versatile tool. Since men are available, they will be used whenever it is easier, cheaper, more reliable, and makes good sense to do so. The following are categories of things that the men may be required to do:

- Scientific Experimenter or Observer
- Skilled Sensor or Equipment Operator
- Skilled Technician.

We can expect that scientists can function as experimenters and observers when they are supplied with appropriate controls and displays, permitting a great amount of flexibility in mode selection combinations, on the spot subjective evaluation, and reprogramming operations. In some cases, where actions are taking place on the ground or in aircraft simultaneously, the on-board scientist may coordinate with a team of ground-based scientists. The pointing of high-resolution, small field-of-view instruments will be done by the crew acting in the role of skilled sensor/equipment operators, although the continuous tracking might be done automatically. The technician functions will involve the manual replacement of equipment modules, erection and deployment operations, and miscellaneous trouble-shooting.

Manned functions are identical for both R&D and operational automated satellites. Checkout of automated satellites after launch will be accomplished by simple continuity-type checks before deployment from the Shuttle, followed by actual deployment and Shuttle station-keeping for a short time while the automated satellite is activated and checked out in initial operations. Failures or problems may be corrected by re-acquisition by the Shuttle and return to earth for repair. It is also possible that minor trouble-shooting and/or correctional actions may be accomplished in orbit, and the satellite then redeployed.

Man aboard the Shuttle will have a minimum potential role in the mission when the Shuttle is used to launch automated satellites, either R&D or operational. The Shuttle launch of these satellites provides an opportunity for activities such as check-out, alignment, power level adjustment, electrical activation etc. to be carried out after the accelerations and vibrations of launch have been experienced.

The rationale for conducting such activities in the Shuttle prior to deployment is based on the benefits to be realized from the ability to abort the automated satellite mission at this stage or the ability to make some kind of fix that can be performed aboard the Shuttle; but not after deployment. The type of fix that can be performed aboard the satellite would be the replacement of modular components whose probability of failure drops sharply after launch. The role of man would be in the remote manipulation from the crew station of the replacement mechanisms.

The major role in evaluating the results of these activities is assumed to be vested in the ground team. The satellite is remote from the crew. A significant role of a man aboard the Shuttle as a participant in these activities is not foreseen. He might control such functions as the initiation of such activities, provision of Shuttle power, relay of satellite telemetry to ground control, termination of activity, or disengagement of satellite to Shuttle circuitry.

A technician may have a post-deployment EV role such as erecting antennas, deploying arms or panels or constituting a manual backup for the automated accomplishment of these functions.

A role of the technician in refurbishment would be to manipulate the modular replacement equipment.

In summary, the role of the technician with respect to automated R&D and operational satellites appears in no case to be unique to Earth Observation Satellite missions.

Special Mission Use

A facility could be carried on the Shuttle in the Sortie mode and would consist of one or more clusters of sensors, having response characteristics that cover the spectral range from the ultraviolet to the microwave region, together with associated data management systems. The instruments on each cluster would be boresighted and housed on a precision pointed platform having the capability for simultaneous operation of all of the sensors.

Potential Applications — Potential applications include:

- Instrument Calibration — The absolute and relative calibration and intercomparison of instruments in flight aboard long lived operational and R&D spacecraft previously launched. With duplicate, but absolutely calibrated, sensor systems and/or correlative systems, the Shuttle can fly over the same area, or observe the same phenomena, at the same time as the automated spacecraft.

- High Resolution and Selected Targets — The performance of special purpose missions that required high spatial or spectral resolution, or which concentrate on selected targets. Participation in field programs and short survey flights are among such uses.

  For example, one type could contain a grouping of multispectral remote sensors optimized for coastal zone and environmental surveys. Another type could be optimized for open ocean surveys and meteorological and/or pollution applications.

- Data Collection — The collection of data that would augment that obtained from operational satellites. As an example, although the monitoring of solar radiation is of importance to all aspects of Earth Observations, it probably need be sampled at only a few selected wavelengths on a continuous basis, as long as the detailed spectral distribution was obtained a few times each year.

  At least three clusters can be identified at this time:

- Multispectral Cameras — A main instrument cluster consisting of multispectral cameras, spectrometers, radiometers, imagers, active and passive microwave systems, sounders, etc. Where possible, absolute calibration sources would be carried as an integral part of each instrument. Emphasis would be placed on an open housing leading to the easy interchange of instruments and minimum constraints on shape and size.

- Solar Monitors — A solar radiation monitor instrument cluster, consisting of spectrometers and radiometers. The spectrometers should give high spectral resolution data with relative calibration, the radiometers would supply absolute calibration data at lower spectral resolution.

- Laser System — An active laser system, consisting of fixed frequency and tunable lasers, and their associated spectrometers/radiometers.

Since some of the instruments envisioned have a capability for both high spectral and spatial resolution, data rates are expected to be high. However, use can be made of the capability of the Shuttle to store the data on high fidelity magnetic tapes and return to ground.

EVOLUTION OF SHUTTLE LAUNCHED SYSTEMS

FLIGHT SCHEDULES

Based on the existing Earth observation program flight activity, the Earth observation program requirements, the Shuttle and Sortie capabilities, and the assumptions on performance and availability of the Shuttle systems, a flight schedule into the 1980's was arrived at. The Earth observations program schedules are shown in the following tables.

Table 3 lists the planned utilization of the Shuttle for both R&D and operational launches through 1990. The presently planned launch activity, both R&D and operational is augmented with new starts and new applications that presently can be identified. These launches incorporate the use of the Shuttle at the time the Shuttle capability is assumed to meet the mission requirements.

Table 4 summarizes the mission parameters for those missions that will eventually be Shuttle launched.

It should be noted in Table 4 that the percent utilization varies considerably, from 10 to 100%. Thus, not every entry in Table 3 represents an individual

Table 3

Earth Observations Working Group Mission Model

	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
R & D																		
ERTS	X			X														
NIMBUS		X			X													
EOS						X		X		X		(R)						
SPEOS					X	X												
TIROS N, O				X					X									
SMS	X	X			X													
SHUTTLE LAUNCHED																		
EOS											X	X R	X R	X R	X R	X R	X R	X R
SEOS								X				RF				RF		
SPEOS							2	2	2	X	X	X	X	X	X	X	X	X
SORTIE							4	4	4	4	4	4	4	4	4	4	4	4
TIROS P															X			

	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
OPERATIONAL																		
TIROS OPER. SYSTEM	X	X	X	(X)	X	X	X											
ENV. MON. SYSTEM									(X)	X								
FOREIGN SMS					2													
GOES	(X)	(X)																
ERS - LOW ORBIT					X	X		X		X								
SHUTTLE LAUNCHED																		
EMS											X		X		(X)		X	
FOREIGN SMS								X					X			X		X
GOES							X		X		X		X		X		X	
OSEOS														X				RF
SPEOS								X		X								
ERS - LOW ORBIT												X		X		X		X
AWM													X		RF		RF	
SORTIE							X				X				X			

R = RETRIEVAL
RF = REFURBISH
() = NON ADD

Table 4

Mission Parameters of Shuttle Launched Systems

MISSION		WT. (LBS.)	ALT. (NMI.)	INCLIN.	PRIMARY SENSORS	% SHUTTLE UTIL.
R & D						
EOS		9000	400/900	POLAR	MULTI-SPECT., SOUNDER	50
SEOS		5000	GEO-STAT	EQ.	MULTI-SPECT., SOUNDER	50-100
SPEOS		800	VAR	VAR	SINGLE PURPOSE MISSIONS, INSTRUMENT DEV.	10
SORTIE	1	1000-5000	VAR	VAR	LOW G LAB.	30-50
	2	4000	VAR	VAR	INSTRUMENT DEVEL.	30-50
	3	8000	VAR	VAR	SPECIAL MISSION USE	30-50
TIROS P		3000	900	POLAR	MULTI-SPECT., SOUNDER	30
OPERATIONAL						
EMS		2500	900	POLAR	MULTI-SPECT., SOUNDER RADAR	20
FOREIGN SMS		2000	GEO-STAT	EQ.	MULTI-SPECT., SOUNDER, DCS	20
GOES		1500	GEO-STAT	EQ.	MULTI-SPECT. SOUNDER, SOLAR MONITOR	20
OSEOS		5000	GEO-STAT	EQ.	MULTI-SPECT., SOUNDER	50-100
SPEOS		800	VAR	VAR	SINGLE PURPOSE SURVEYS	10
ERS - LOW ORBIT		2000/9000	400	POLAR	MULTI-SPECT.	50
AWM		5000	400	POLAR	PASSIVE MICROWAVE	50-100
SORTIE		500	VAR	VAR	MAPPING CAMERA	10

launch of a Shuttle. Rather it is expected that a single launch will accommodate several missions of varying program objectives but whose flight parameters are compatible.

A discussion of the evolution of the Shuttle-launched systems that follow the current missions is given in the subsequent sections.

EARTH RESOURCES SATELLITES (LOW ORBIT)

ERTS, Skylab

ERTS-1 was launched on a Thor-Delta in July of 1972. ERTS-B originally scheduled for launch during November 1973, may be delayed up to January 1976. The launch vehicle will be a Thor-Delta. The orbit of both these spacecraft is circular, near polar (99° inclination) and sun-synchronous. The orbit height is 493 nautical miles and the spacecraft weight is about 2000 pounds.

The ERTS-1 and ERTS-B spacecraft have the objective of testing the feasibility of obtaining certain measurements of the earth from orbit and performing some experimental evaluations of the usefulness of applying this capability to ongoing tasks and problems of the nation.

The Earth Resources Experiment Package (EREP) will be launched and operated with Skylab in 1973. It will provide for a relatively short but intensive data collection of the earth to examine the feasibility and utility of finer spectral resolution, finer spatial resolution, and geometric image accuracy, with both active and passive measurements in the microwave region. Very fine spatial and spectral resolution is possible with the astronaut-pointed spectrometer operating in the visible and near and thermal infrared.

Operational ERS

The operational ERS series will utilize the technology developed in ERTS to provide continuing coverage of the United States and to develop routine operational applications of the data. Principal operational applications will be by the U.S. Department of Interior in the areas of geologic applications (including aid to mineral and petroleum exploration), water resources and hydrology, and land use planning. Application of the data will also be made in the areas of agriculture, forestry, range survey and management, and oceanography. The orbits and weights will be similar to the experimental spacecraft. Four to five spacecraft of this type will be needed to initiate the operational program prior to Shuttle availability for polar orbits. These spacecraft will be launched from WTR using Delta launch vehicles. The first launch is planned for 1977 with a one year life expectancy. Follow-on spacecraft of this series are planned for 1978, 1980 and 1982. These spacecraft would be of conventional automated spacecraft design with no intent to optimize their characteristics for Shuttle compatability since the Shuttle will not be available for their launch.

It must be recognized that as EOS development is checked out with flight experience (as outlined in the following section) the operational ERS will grow to incorporate many of the EOS systems and sensors. A schedule and specifics of such growth cannot be projected at this time.

EOS Contribution to Earth Resources Satellites

General objectives will be to develop the capability to:

- Extend the spectrum of observational capability of ERTS where necessary by providing active and passive microwave sensors
- Provide finer spectral discriminations, particularly in ocean applications
- Extend visible and infrared measurements to permit recognition of smaller spatial features

Two principal configurations and separate mission objectives are identified. For ocean and atmosphere investigation applications development, capability will be provided for experimentally measuring sea surface temperature, color, and some indications of sea surface roughness; together with experimentally measuring both gas and particulate pollutants in the atmosphere. For the terrestrial configuration, a metric camera will be provided for map production, and two versions of scanners will permit greater spectral coverage and finer spatial resolution.

Shuttle Launched EOS and ERS

The spacecraft technology from EOS A should have a direct effect on the design of the first Shuttle compatible operational Earth Resources Satellites. The technology to be demonstrated on EOS satellites will be incorporated into follow-on operational Earth Resources Satellites. Capability to launch into polar orbit and to retrieve should be available from the Shuttle in this time frame. The Shuttle should place the new Earth Resources Satellite into orbit and return one of the experimental EOS satellites (either EOS A or EOS B) for modification and future use as a research observatory, an environmental satellite, or an Earth

Resources Satellite. On each launch of a new satellite of the EOS class an appropriate satellite should be returned for repair or updating.

The Earth Resources Satellites will require replacement at about two year intervals. Some contingency for module and/or sensor replacement is needed for insuring continuous availability of data for operational programs.

ENVIRONMENTAL MONITORING SATELLITES (LOW ORBIT)

The launch of TIROS-1 on April 1, 1960 opened the era of observation of the earth from satellites. The photographs from space from this satellite were in operational use within a matter of hours and similar and improved products of this type have been in use ever since. TIROS-1 was a research satellite and was followed by other research satellites until the first TIROS operational satellite was launched in January 1966 to become the first Environmental Survey Satellite, ESSA-1. This satellite and its successors in the operational series were turned over to the Environmental Science Services Administration (ESSA) for operational control and use after launch and checkout by NASA.

In August 1964, the first of a new series of research satellites, NIMBUS 1, was launched, which provided a larger stabilized platform for research experiments. This series is still continuing, to be succeeded by EOS in the 1980's, which supports this program as well as the Earth Resources Satellites. Thus a pattern has been established in the area of a series of operational satellites supported by a separate series of research satellites. This pattern appears likely to continue into the 1980's.

As new technology becomes available it is incorporated at about 5 year intervals into an operational prototype of a new series of operational environmental satellites. TIROS M, for example, was the prototype of the Improved TOS (ITOS) series, which are renamed NOAA-1, 2, etc., once in orbit. TIROS N is presently planned for 1976 as a prototype to initiate a new series. The improved capability will include data digitalization, higher resolution, and a data collection and location capability which can be used for tracking floating buoys and balloons.

NIMBUS G is scheduled to fly in 1977 and will be oriented toward oceanographic and pollution data acquisition. Based on results from this program a new iteration of the operational series would be anticipated in 1981, TIROS O, which would add ocean color and pollution sensors to the polar operational system and would also introduce modular design for later capability with Shuttle retrieval and for refurbishment.

Shuttle Launched Systems — EMS, TIROS P

All of the spacecraft heretofore described will use either Delta or Titan launch vehicles. The first Shuttle launch of an operational spacecraft evolving from this series to be designated Environmental Monitoring Satellite (EMS) would be possible in 1983, with retrieval and/or refurbishment of earlier spacecraft possible, beginning in 1984. EMS, in general, features real-time data availability, global coverage, and medium resolution (1/4-1/2 miles) multispectral sensors optimized for ocean and atmosphere observations. Coverage is required four times a day during the planned period. An atmospheric sounder and pollution sensing device are also included, as are sensors to monitor solar X-rays and particles.

While the Working Group assumed that there very likely would be a TIROS P late in the decade to introduce new state of the art into the operational program, it is not yet possible to specify exactly what the innovations might be.

Shuttle Launched Systems — All Weather Monitoring (AWM) Satellites

While sensors in the visible and infrared regions of the spectrum can provide much information as to the environment, in general they can only do so in cloud free regions. For meteorological, oceanographic and terrestrial applications, there is a recognized need for a global all-weather environmental monitoring capability. Parameters to be measured are soil moisture, water content of snow, sea surface temperature, sea state, surface wind fields, and vertical temperature and moisture atmospheric profiles. There are several promising approaches to this type of monitoring using active and passive microwave sensors; but the size of antennas required, particularly for passive sensors, has precluded any real space tests of these approaches. The Skylab EREP does have a microwave package (S194) which will produce a limited amount of data of rather low resolution.

It would appear that the first opportunity for a test of microwave sensors with high resolution (10-15km) will occur with the Space Shuttle Sortie Laboratory and such a test should be an early objective of the program.

Based on the results of these Sortie Laboratory tests, an operational all weather monitoring satellite is possible about 1985. The orbit required for this satellite is non-sun-synchronous, so as to avoid tidal effects. It is thus unlikely that this type of requirement could be met with an EOS system. Separate Shuttle launches of a dedicated satellite together with manual antenna erection in space, will be required.

GEOSTATIONARY SATELLITES

The first experimental geostationary environmental satellite, ATS-1, was launched in December 1966 and has remained in service for almost six years. ATS-1 and a later spacecraft ATS-3 have been used on a semi-operational basis for daytime cloud cover observations with great success. An operational system is now being implemented with the launch of a prototype SMS-A planned in early 1974. SMS-A will be augmented by SMS-B for greater area coverage with an operational version (SMS/GOES A) being prepared for launch as needed. SMS will feature nearly continuous coverage of the United States and its vicinity in the visible and thermal infrared for both day and nighttime coverage with real-time data availability. Expected resolution for the prototype will be 1/2 mi. at nadir. SMS also carries sensors to measure solar X-rays and particles and the magnetic field in situ. Later evolutions in the GOES series are also planned to include an atmospheric sounder.

Shuttle Launched GOES

The first Shuttle launch of a GOES spacecraft will be possible in 1979 by using a proper "kick stage" to obtain the desired orbit and altitude. Since Shuttle capability loads to geostationary altitudes will be limited until the availability of the tug in 1984, no major growth of the system is contemplated until that time. Beginning with 1984 and subsequent launches, ocean color sensors will be added and resolution improved on all channels to be comparable to the Polar Environmental Monitoring Satellites.

Careful consideration should be given to the possibility of merging this system into the prototype Operational Synchronous Earth Observatory Satellite (SEOS) proposed for Shuttle launch in 1980, if mission constraints for this program and other elements of the Earth observation program permit.

SEOS and Shuttle Launched OSEOS

The Synchronous (Geostationary) Earth Observatory Satellite would be used to monitor regional areas, with high resolution (less than 100 meters in visible and 1 to 6 km in infrared), in real-time and on command. Frequency of observation would vary from coverage of a 700 x 700 km region every five minutes to daily coverage of the coastal regions of the United States. Discipline uses of the spacecraft would include monitoring of cloud formations for indication of tornados, to provide precise warning of threatened areas after mesoscale meteorology observations, flood warnings and damage assessment, inventory of snow extent for water resources and flood control predictions, forest fire detection, coastal zone management for fisheries location and productivity and pollution monitoring and frost warnings in particular areas.

The satellite would be capable of providing compatible high resolution data as obtainable from low, earth orbit, Earth resources, and environmental satellites, for limited regions of the earth. The advantage of the SEOS system would be in providing near real-time data for limited critical areas while polar orbiting spacecraft cover the entire continent and world less frequently.

The satellite would operate in two basic modes. The telescope could be pointed at a particular region with repetitive images taken in sequence every few minutes to hours or the spacecraft could be used in a slewing mode so that it observed a strip several hundred kilometers wide along a prescribed path.

Operation of the spacecraft would require real-time data transmission from the ground station to the central control point and the availability of other data to direct the operation of the spacecraft. Data inputs for planning the operations would be obtained from polar orbiting environmental Earth resources satellites, data collection platforms and from conventional ground based or aircraft data acquisition systems.

The spacecraft will be a large telescope with several modules that can be replaced as needed. These modules include the basic sensor package that detects surface features as viewed by the telescope, the attitude control module, power module and a communications module. The telescope would be placed into orbit without plans to return it to lower orbit or to earth. The modules would need replacement on failure and updating as more advanced technology is developed. These modules would be replaced using the Shuttle and tug.

The weight of the spacecraft is estimated to be about 5000 pounds. It would be placed in a geostationary equatorial orbit west of 100° west longitude. Station keeping would be required to keep the spacecraft at the proper location and to shift its location if future observation requirements dictate such a change in location.

The initial launch would be in 1980 with full telescope and associated modules. Satellite lifetime in geostationary orbit can be expected to be several years. Revisits for replacement of individual modules using the tug should be planned at four year intervals after the initial launch. A contingency capability to replace modules should be maintained at all times.

Initial use of SEOS should be considered R&D. The types and frequency of data to be obtained will have an immediate and large impact on operational agency programs. The same spacecraft would support operational missions early. There is a high possibility that the spacecraft could be considered part of the operational programs prior to the first module replacement mission.

SINGLE PURPOSE EARTH OBSERVATION SATELLITES (SPEOS)

The Working Group recognized the need for single purpose satellites as a part of the overall Earth Observations program. This need was identified through applications which are incompatible with a standard observatory approach. Specific orbits, satellite cleanliness, short lead times, and cooperative operations are examples of constraints which lead to single purpose satellite applications.

Some example missions using Single Purpose Earth Observation Satellites (SPEOS) are described in the following paragraphs. The particular applications to be discussed can be satisfied with relatively small satellites < 300 kg. These are representative of the Small Applications Technology Satellites recently studied. It is conceivable, however, that future requirements could dictate larger satellites for special "one of a kind" purposes.

Missions

Geothermal/Soil Moisture Surveys — The energy crisis in our nation is causing serious consideration to be given to the exploitation of geothermal energy sources for the generation of electrical power. To achieve this, it will first be necessary to conduct a survey to locate and map geothermally active regions within the United States for more detailed geologic and geophysical study of the potential of the region to provide the necessary energy for the production of power.

Unique to geothermally active regions is an anomaly in ground temperature. Through the use of thermal infrared remote sensors it will be possible to detect and map the temperature anomalies. Measurements will have to be made before dawn when the difference between the geothermally heated ground temperature and the adjacent ground temperature is greatest. Optimum time for the measurements should be about 4:00 a.m. local time from a sun-synchronous orbit.

The mapping of soil moisture concentrations as a function of geographic location can be made with sensitive, thermal infrared, scanning radiometer sensors. Since the contrasts of infrared emissions associated with saturated, partially saturated, and dry soils will be relatively small, the optimum time to make measurements is also before dawn when the dry soils reach minimum temperatures relative to the more moist soils.

A proper mix of thermal infrared sensors with suitable spatial resolutions to allow the conduct of a combined geothermal/soil moisture mission is considered possible.

Mother/Daughter Satellites for Atmospheric Surveys — The use of laser techniques from a mother satellite to a daughter satellite as the daughter is occulting the atmosphere is a viable approach for inferring atmospheric profiles and global distributions of atmospheric aerosols. Tunable laser applications will also allow the inference of atmospheric pollutants and trace constituents. The mother satellite could be the Shuttle Sortie mode with man performing a basic role in the operation of the laser and laser-sounding system. The Shuttle would be used to deploy the daughter satellites into the specific orbits required for observation by the master source, the mother satellite. The mission details remain to be determined.

This investigation is viewed as R&D and is shown in the planning schedule for SPEOS Shuttle launches in CY 1979, with a similar mission shown in CY 1981. Only the R&D missions are shown, and further study and evaluation are required to determine the merit of, and the application of such a technique to an operational stage.

Geomagnetic Surveys — The Working Group recognized the need for better monitoring of the temporal variations of the earth's magnetic field, even though this problem is expected to be addressed by the Earth and Ocean Physics Working Group.

Instrument Development — It is also necessary to provide for the development, test and calibration of eventual instruments in experimental space flight missions for a time period in excess of the Sortie capability.

Shuttle Launched SPEOS

As the Shuttle capability becomes available in 1979 these spacecraft can be readily accommodated in view of their relatively small Shuttle volume utilization.

The other SPEOS missions shown in the schedule were not defined by the Working Group; however their inclusion was considered warranted for planning purposes in the light of our present experience.

SORTIE MISSIONS

In addition to the Sortie related missions discussed in this section, several Sortie missions for Earth observations purposes have been described during earlier discussions of Shuttle uses for Earth observations, under Contingency Service Use, Special Mission Use, Instrument Development and Low Gravity Laboratory and under Operational Use.

Consideration of Contingency Service Uses did not result in additional launches of the Shuttle. Accommodation of this use was ascribed to expediting a planned Sortie or diverting an ongoing Sortie.

The Special Missions use can be expected to increase with the development of models of the environments to accommodate more factors, changing process scales and the interactions between environments. Instrument development work can be expected to be facilitated on the Shuttle. The development of environmental models is also expected to increase the applications of the low gravity laboratory to Earth observation needs. It is anticipated that the total needs of the missions will be characterized by a diverse spectrum of constraints. The use of Sortie missions in support of Earth observations needs are expected to increase with time.

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