FINAL REPORT OF THE SPACE SHUTTLE PAYLOAD PLANNING WORKING GROUPS

EARTH AND OCEAN PHYSICS

MAY 1973

.UME 8

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

GLOSSARY

Abbreviation	Description
EOPAP	Earth and Ocean Applications Program
EVA	Extra Vehicular Activity
GEOS	Geodetic Orbiting Satellite
GEOPAUSE	Space Reference Coordinate System
GRAVSAT	Gravity Field Satellite
LAGEOS	LAser GEOdynamic Satellite
MINILAGEOS	Small, Dense Laser-Reflector Satellite
SEASAT	Ocean-Dynamics Monitor Satellite

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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.

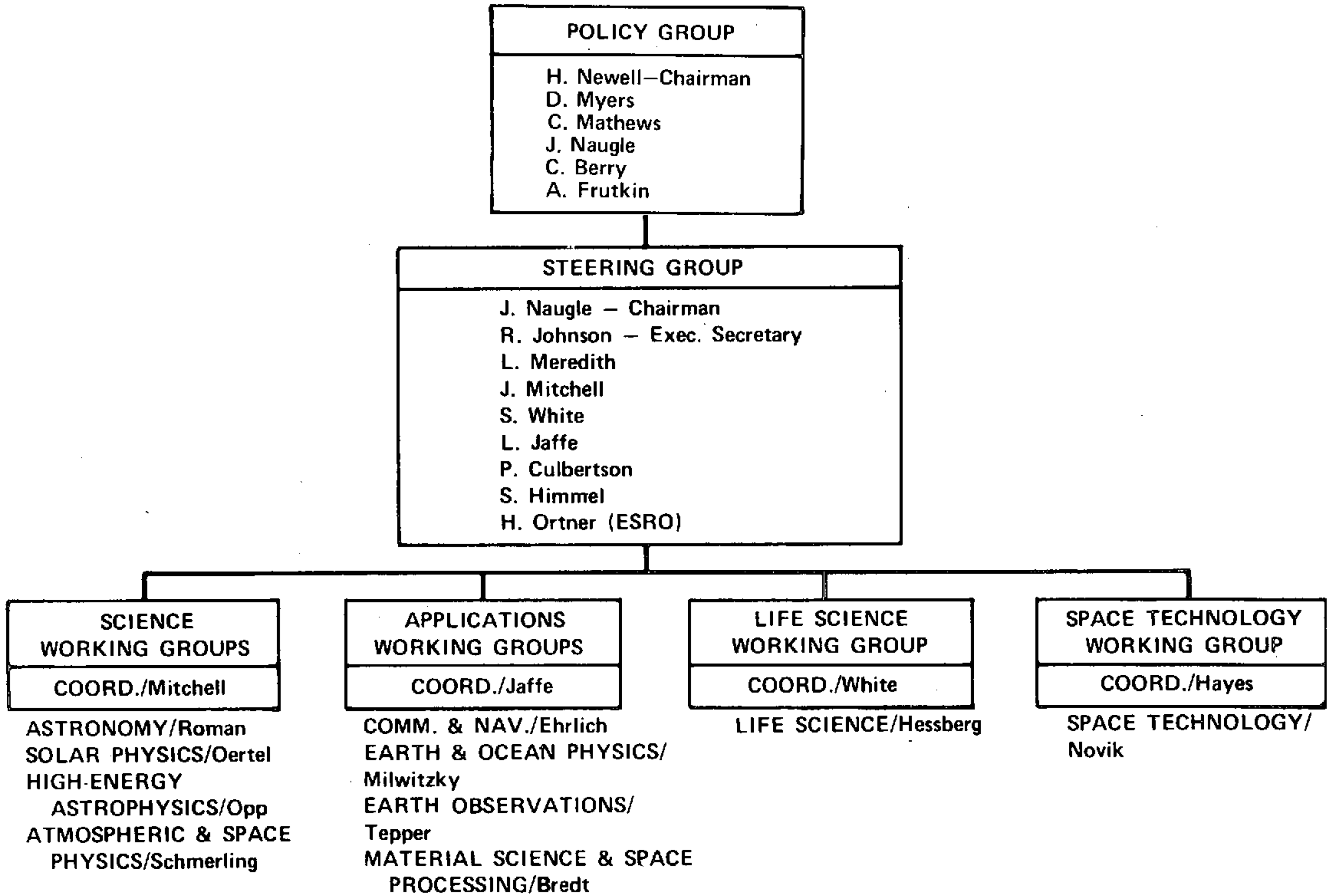
Finally it is evident from these reports that many individuals and groups have devoted appreciable effort to this important planning activity. I would like to express my appreciation for this effort and stress the importance of such activities if we are to realize the full potential of space systems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

NASA AD HOC ORGANIZATION FOR SHUTTLE PAYLOAD PLANNING



ATTACHMENT B

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CONTENTS

TABLES

FINAL REPORT OF THE EARTH AND OCEAN PHYSICS WORKING GROUP SPACE SHUTTLE SORTIE WORKSHOP

The expanded Earth and Ocean Physics Working Group met on December 12–13, 1972 at the Goddard Space Flight Center, with the following participants present:

Dr. L. R. Alldredge, NOAA/Earth Sciences Laboratory
Dr. J. A. Apel, NOAA/Atlantic Oceanographic and Meterological Laboratory
Captain L. S. Baker, NOAA/National Geodetic Survey
Dr. J. O. Ballance, NASA/MSFC
Dr. W. E. Benson, National Science Foundation
Dr. D. E. Bowker, NASA/LRC
Dr. J. C. Cain, NASA/GSFC
Dr. G. P. Eaton, U.S. Geological Survey
Dr. M. Graber*, NOAA/National Ocean Survey
Dr. P. J. Hart, National Academy of Sciences
Dr. A. A. Loomis, Jet Propulsion Laboratory
Mr. B. Milwitzky, NASA HQ, Chairman
Mr. J. P. Murphy, NASA HQ
Dr. H. Orlin, NOAA/National Ocean Survey
Dr. W. J. Pierson, New York University
Dr. C. H. Scholz, Lamont-Doherty Geophysical Observatory, Columbia University
Dr. J. W. Siry, NASA/GSFC
Dr. D. E. Smith, NASA/GSFC
Dr. F. O. Vonbun, NASA/GSFC, Co-chairman
Dr. G. C. Weiffenbach, Smithsonian Astrophysical Observatory

*for Dr. H. Orlin, Dec. 12, 1972

AGENDA

1. Review Space Shuttle Concept, J. Hammersmith, NASA HQ
2. Review Shuttle Sortie Mode, R. Lovelett, NASA HQ
3. Review Earth and Ocean Physics Applications Program

Introduction	B. Milwitzky, Chairman
Earthquake Hazard Assessment & Alleviation	A. A. Loomis
Ocean Dynamics	J. Apel
Global Surveying and Mapping	A. A. Loomis
Systems and Techniques	J. Siry
Implementation Plan	B. Milwitzky

4. Review Report of in-house Working Group on Earth and Ocean Physics, NASA Space Shuttle Sortie Workshop, July 31–August 4, 1972.
5. Develop additional plans and recommendations in accordance with established Work Plan, as appropriate.

EARTH AND OCEAN PHYSICS WORKING GROUP

EXECUTIVE SUMMARY

EOPAP OBJECTIVES

The primary objectives of the Earth and Ocean Physics Applications Program (EOPAP) are to merge geophysics and oceanography with space techniques to provide practical benefits in ocean dynamics monitoring and solid-earth dynamics, with the expectation of significant contributions to the forecasting of ocean-surface conditions on a global basis, and earthquake prediction.

In order to attain these objectives, certain requirements must be met, i.e.,

- The definition of precision measurement requirements for earth and ocean physics experiments
- The definition, development, and demonstration of new and improved sensors and analytical techniques
- The acquisition of "surface-truth" data for evaluation of new measurement techniques
- The conduct of critical experiments to validate geophysical phenomena and instrumental results
- The development and validation of analytical/experimental models for global ocean-dynamics conditions and solid-earth dynamics/earthquake prediction.

SPACE SHUTTLE EXTENSION OF EOPAP

The Space Shuttle has the potential to make significant contributions to the extension of EOPAP, using both the Sortie and launch modes.

In the Sortie mode, the Shuttle provides a test bed and observational platform for development and evaluation of new instrumentation and techniques. In addition, in this mode man can be used effectively to make equipment adjustments (gain changes, frequency adjustments, etc.) to optimize matching sensor characteristics to the observables, to observe and correlate with remote sensing, and to make critical judgments as necessary to provide flexibility in the use of equipment and in programming experiments.

In the launch mode, the Shuttle can be used to launch and retrieve free-flight and tethered satellites. The Shuttle is especially advantageous for low-altitude, short-lived satellites, such as free-flying and tethered magnetometer satellites.

Earth Dynamics Test Bed

- Typical instrumentation for the earth dynamics test bed includes the following:
  - Precision multi-frequency imaging radars (see through foliage for topographic features, geology, hidden faults, and near-surface geothermal mapping)
  - Imaging radar for double-exposure holography (3-dimensional strain fields, erosion, volcanic motion, post-glacial uplift)
  - FM correlation radar (baseline measurements)
  - Multi-frequency laser and microwave differential refraction experiment (model atmospheric, tropospheric, and ionospheric corrections)
  - Laser ranging/altimeter
  - Multispectral scanners (topographic features and geology)
- Weight of sensors: 700 kg
- Peak power: 5 kw
- Data rate: 5 MHz
- Stabilization and pointing: 1 arc minute
- Orbit: 200 km, circular; inclination: not critical
- Mission duration: 1 week
- Flight frequency: 1 per year

FREE FLIGHT SATELLITES

- Geopause-B: Precision tracking satellite for extreme-accuracy measurements to support gravity field and ocean dynamics missions. Weight: 500-1000 kg; altitude 24000 km, polar orbit.

SHUTTLE SORTIE MISSIONS

Ocean Dynamics Test Bed

- Typical instrumentation for the ocean dynamics test bed includes the following:
  - Radar altimeter (sea-surface topography, sea state, salinity, rain)
  - Microwave scatterometer (surface roughness, wind speed)
  - Precision multifrequency coherent imaging radar
  - Multifrequency, dual polarized microwave radiometer, C and L Bands; frequencies: 1, 5, 10, 20, 50 GHz; resolution: 10 km; antenna: 4 meters (foam, wind speed, salinity, surface temperature, atmospheric corrections)
  - Vertical temperature profile radiometer
  - Laser altimeter
  - Laser profilometer
  - Laser scatterometer
  - Laser scanning photometer
  - Receiver for bistatic wave spectrum analysis
- Weight of sensors: 700 kg
- Peak power: 7 kw
- Data rate: 15 MHz
- Stabilization and pointing: 1 arc minute
- Orbit: 200 km, circular; inclination 60°
- Mission duration: 1 week to 1 month
- Flight frequency: 1 per year

- Gravity Gradiometer Satellites: Measure fine structure of gravity field and geoid. Weight: 3000 kg; altitude: 200 km, polar orbit.

- Minilageos: Small, dense, passive spheres covered with laser retro-reflectors for precision earth-motion studies. Weight: 100 kg; altitude: 300-1000 km, various orbital inclinations.

- Magnetometer Satellites: Low altitude vector magnetometer satellites to determine fine structure of magnetic field. Weight: 150 kg; altitude: 400 km, circular orbit; 3 satellites separated by 4-hours local time.

- Magnetic Field Monitor Satellite: Weight: 200 kg; altitude 1000-2000 km, orbital inclinations 0-28°.

- Tethered Vector Magnetometer Satellite: Weight: 150 kg; trails Shuttle by 2 miles.

MISSION MODEL

The EOPAP Mission Model, covering both the pre and post Shuttle periods, is shown in Table 1.

Table 1

Earth and Ocean Physics Mission Model

	CY	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
EOPAP Satellites																		
GEOS-C		1																
LAGEOS				1														
SEASAT A, B					1					1*								
GEOPAUSE							1											
GRAVSAT							1											
Sortie Missions																		
Test Bed Flights							1	2	2	2	2	2	2	2	2	2	2	2
Shuttle Launched																		
SEASAT B										1*								
Gravity Field								1		1								
Earth Motion								6					6					
Magnetic Field									5					5				5
Operational Systems																		
Earth and Ocean Dynamics Monitors														3				3

*SEASAT-B. Prototype operational ocean dynamics monitor satellite. Last mission in current EOPAP plan. Could be launched by Shuttle with propulsion stage or Tug.

REPORT OF THE EARTH AND OCEAN PHYSICS WORKING GROUP

INTRODUCTION

This Report is intended primarily for use by the Space Shuttle Program Office as a basis for initial planning and preliminary design studies. It does not contain the detailed programmatic and technical discussions of the Earth and Ocean Physics Working Group, which will be reported elsewhere. The report is divided into three principal discipline areas:

- Solid Earth Dynamics/Earthquake Mechanisms
- Ocean Dynamics Monitoring
- Global Surveying and Mapping.

When the Space Shuttle goes into operation, the Earth and Ocean Physics Applications Program (EOPAP) will have been underway about six years. It is expected that three unmanned spacecraft, GEOS-C, LAGEOS, and SEASAT-A will have been flown and a complex of ground-based instrumentation will be in existence to support the objectives of EOPAP. Satellites planned for EOPAP subsequent to 1978, e.g., GEOPAUSE, GRAVSAT, and SEASAT-B, are logical candidates for Shuttle launching. In addition to providing launch services, the Shuttle can contribute to EOPAP by providing, in the Sortie Mode, a test bed for the development and evaluation of new and improved instrumentation to be subsequently incorporated in operational systems.

SOLID-EARTH DYNAMICS/EARTHQUAKE MECHANISMS

GOALS AND OBJECTIVES

The goals and objectives of the solid-earth dynamics/earthquake mechanisms discipline area are to develop and exploit space techniques for a better understanding of the dynamic processes of the solid earth, with special attention to those associated with earthquake mechanisms. The following phenomena are addressed: tectonic plate structure and motions, fault motions, hidden faults, strain fields, polar motion and earth-rotation variations, core/mantle interactions, pole/mantle relative motions, solid-earth tides, glacial rebound, spatial and temporal variations of the gravity and magnetic fields as they relate to the earth's internal structure and dynamic processes, volcanic and geothermal phenomena, erosion processes, and mineral detection.

POTENTIAL CONTRIBUTIONS OF THE SORTIE MODE

a) Provide a test bed and observational platform for the development and evaluation of new and improved instrumentation to be subsequently incorporated in operational systems.

b) Use man as an observer to correlate with remote sensing and use his judgment to provide flexibility in the observing program and in the use of the equipment (changing gains, frequencies, making adjustments, etc.).

c) Launch free-flying and tethered satellites to demonstrate new techniques, and to acquire observational data.

TITLES OF SORTIE MISSIONS

- Solid-Earth Dynamics Test-Bed Missions
- High-Resolution Telescope/Camera
- Free-Flying Satellite Deployments
- Tethered-Satellite Deployments

TEST-BED MISSIONS

The advantages of the Sortie Mode are: the availability of a human operator, weight and power, massive data retrieval, plus rapid turnaround for changes and retest.

Solid-earth dynamics Instrumentation would consist of:

- Precision multi-frequency imaging radars (see through foliage for topographic features, geology, hidden faults, and near-surface geothermal mapping).
- Imaging radar for double-exposure holography (3-dimensional strain fields, erosion, volcanic motion, post-glacial uplift).
- FM correlation radar (baseline measurements).
- Side-tone ranging system (multilateration).
- Multi-frequency laser and microwave differential refraction experiment (model atmospheric, tropospheric, and ionospheric corrections).

- Laser ranging/altimeter.
- Multispectral scanners (topographic features and geology).

Mission requirements for the solid-earth dynamic test-bed flights are:

- Length of flights: 1 week
- Orbit: 200 km, no special inclination
- Data requirements: 5 MHz
- Role and number of personnel in orbit: 1 experiment specialist
- Stabilization and pointing: 1 arc minute
- Power and Thermal: 5 kw, 100 kw-hrs
- Weight of instruments: 700 kg
- EVA requirements: none
- Correlative measurements: ground truth
- General support equipment: wide-bandwidth video tape recorder
- Documentation requirements: no special requirements
- Special operating constraints: international radio-frequency agreements
- Contamination requirements: no special requirements

HIGH RESOLUTION TELESCOPE/CAMERA

The purpose of this mission is to provide high-resolution ground imagery including laser-retroreflector returns for baseline and strain measurements.

Resolution and image-motion compensation are required to 5-10 cm for bright targets (retroreflectors).

Ancillary equipment includes a laser illumination/pointing system.

Implementation: Phase A study to investigate possible modification of Large Space Telescope (LST).

FREE-FLYING AND TETHERED SATELLITES

GEOPAUSE — Weight: 1000 kg; diameter: 4m; orbit: 30,000 km,. polar, circular

VECTOR-MAGNETOMETER SATELLITES — Weight: 150 kg; diameter: 1m folded, 4m deployed; orbits: 400 km circular; 3-satellites separated by 4 hours local time, operating simultaneously for six months.

TETHERED VECTOR MAGNETOMETER SATELLITE — Weight: 150 kg; diameter: 1m folded; 4m deployed; trailing Shuttle by 2 miles.

MAGNETIC-FIELD MONITOR SATELLITE — Weight: 200 kg; diameter 1m folded, 4m deployed; orbit: 1000-2000 km, circular; inclinations 0-28°.

GRAVSAT — Drag-free satellites; weight: 3000 kg each; diameter: 2m; orbit: 2 satellites at 200 km altitude, separated by 200 km; polar, circular.

GRAVITY GRADIOMETER — Weight: 3000 kg; diameter: 4m; orbit: 200 km, polar, circular.

MINILAGEOS — Small, dense laser-reflector satellites; weight: 100 kg, diameter: 1/2 meter; orbits: 300-1000 km; various inclinations.

OCEAN-DYNAMICS MONITORING

GOALS AND OBJECTIVES

The goals and objectives of the Ocean-Dynamics monitoring discipline area are to: develop and exploit space techniques for a better understanding of ocean-dynamic phenomena; demonstrate and evaluate techniques leading to an Ocean Dynamics Monitoring System to provide near-real-time data on ocean-surface conditions on a global basis. The following phenomena are addressed: sea state, currents, global circulation, ocean tides, pile up, storm surges, tsunamis, air/sea interactions and meteorological implications, surface winds, ocean temperature and salinity, sea, lake and river ice.

POTENTIAL CONTRIBUTIONS OF SORTIE MODE

a) Provide a test bed and observational platform for the development and evaluation of new and improved instrumentation to be subsequently incorporated in operational systems.

b) Use man as an observer to correlate with remote sensing, and his judgment used to provide flexibility in the observing program and in the use of the equipment (changing gains, frequencies, making adjustments, etc.).

c) Launch free-flying satellites to demonstrate new techniques and to acquire observational data.

TITLES OF SORTIE MISSIONS

- Ocean Dynamics Test-Bed Missions
- Free-Flying Satellite Deployments

TEST-BED MISSIONS

The advantages of the Sortie Mode are: the availability of the human operator, weight and power, massive data retrieval, plus rapid turnaround for changes and retest.

Ocean Dynamics Instrumentation would consist of:

- Radar altimeter (sea-surface topography, sea state, salinity, rain).
- Microwave scatterometer (surface roughness, wind speed).
- Percision multifrequency coherent imaging radar.
- Multifrequency, dual polarized microwave radiometer, C and L bands; frequencies: 1, 5, 10, 20, 50 GHz; resolution: 10 km, antenna: 4 meters (foam, wind speed, salinity, surface temperature, atmospheric corrections).
- Vertical temperature profile radiometer.
- Laser altimeter.
- Laser profilometer.

- Laser scatterometer.
- Laser scanning photometer.
- Receiver for bistatic wave spectrum analysis.

Mission requirements for the ocean-dynamic test-bed flights are:

- Length of flights: 1 week to 1 month
- Orbit: Circular

  Inclination: $\geqq 60^\circ$

  Altitude: as low as possible
- Data requirements: 15 MHz data link; on-board video tape recorder
- Role and number of personnel in orbit: 1 experiment specialist
- Stabilization and pointing:

  Stability: 1 arc second/sec

  Pointing accuracy: 1 arc minute
- Power: 7 kw peak; 200 kw-hours
- Weight of instruments: 700 kg
- EVA requirements: none
- Correlative measurements: surface-truth
- General support equipment: on-board video tape recorder
- Documentation requirements: no special requirements
- Special operating constraints: no special requirements
- Contamination requirements: no special requirements

FREE-FLYING SATELLITES

SEASAT-B — Weight: 1000 kg; orbit: 500-700 km, polar, circular.

GLOBAL EARTH AND OCEAN MONITOR SYSTEM — Operational system, characteristics to be determined, probably 3 satellites in orbit simultaneously.

GLOBAL SURVEYING AND MAPPING

GOALS AND OBJECTIVES

The goals and objectives of the global surveying and mapping discipline area are to develop and exploit space techniques to (a) refine the definition of the geoid and the earth's magnetic field; and (b) determine the precise locations of positions on the surface of the earth.

A specific objective of this Shuttle application is the development and demonstration of a Satellite System for Global Geodetic Control. Such a system can employ satellites in conjunction with doppler stations whose locations are known relative to appropriate geodetic datums and which are all tied into a central computer. For example, a user say a ship, would carry a doppler beacon whose signals would be received by a satellite and relayed to the ground. From the ship-to-satellite doppler and the satellite-to-ground doppler, the central computer would determine the position of any ship that wished to learn its precise geodetic location. Position information would be transmitted from the central computer back to the ground station and thence to the satellite, from which it is relayed to the ship.

Such a system has other practical applications; e.g., horizontal control for land surveys; mapping reefs and shoals; geodetic control for off-shore exploration; harbor control; ship location for gravity surveying and ocean exploration; ship navigation and traffic control, particularly in congested sea lanes; monitoring tankers for violation of environmental regulations, etc.

POTENTIAL CONTRIBUTIONS OF SORTIE MODE

The Sortie mode would provide relatively inexpensive and simple opportunities for testing and demonstrating various versions of such a system (e.g., ranging vs. doppler).

ON-BOARD SYSTEMS

- Various types of low-powered receivers/transponders.
- Telemetry receivers and transmitters.

Table 2

Proposed Flight Schedule

1979	1 GEOPAUSE Satellite 2 GRAVSAT Satellites (1 pair) 1 Sortie Lab Test-Bed flight
1980	1 GRAVITY GRADIOMETER Satellite 6 MINILAGEOS Satellites 2 Sortie Lab Test-Bed flights
1981	3 Magnetometer Satellites 1 Tethered magnetometer Satellite 1 Magnetic-monitor Satellite 2 Sortie Lab Test-Bed flights
1982	1 SEASAT-B Satellite 2 Sortie Lab Test-Bed flights 1 GEOPAUSE Satellite
1983	2 Sortie Lab Test-Bed flights
1984	2 Sortie Lab Test-Bed flights
1985	2 Sortie Lab Test-Bed flights 6 MINILAGEOS Satellites
1986	3 Magnetometer Satellites 1 Tethered magnetometer Satellite 1 Magnetic Monitor Satellite 3 Global Earth and Ocean Monitor Satellites 2 Sortie Lab Test-Bed flights
1987	2 Sortie Lab Test-Bed flights
1988	2 Sortie Lab Test-Bed flights
1989	3 Global Earth and Ocean Monitor Satellites 2 Sortie Lab Test-Bed flights
1990	3 Magnetometer Satellites 1 Tethered magnetometer Satellite 1 Magnetic Monitor Satellite 2 Sortie Lab Test-Bed flights

Table 3

Estimated Costs ($M)

	R & D	Production Refurbishment
GEOPAUSE	18	16
GRAVSAT	19	12
GRAVITY GRADIOMETER	19	12
SEASAT-B	20	15
Magnetometer Satellite	12	8
Magnetic Field Monitor	12	8
MINILAGEOS	0	0.5
Global Earth and Ocean Monitor	20	20
Solid-Earth Test Bed	45	12
Ocean Dynamics Test Bed	45	12

Table 4

EOPAP Objectives

- Use of Space Techniques to Study Earth Dynamics with the Goal of Developing and Validating Methods Leading to Earthquake Hazard Assessment Models to Predict Probable Time, Location, and Intensity of Earthquakes.

- Development and Validation of Means for Predicting the General Ocean Circulation, Surface Currents, and Their Transport of Mass, Heat, and Nutrients.

- Development and Validation of Methods for Synoptic Monitoring and Predicting of Transient Surface Phenomena, Including the Magnitudes and Geographical Distributions of Sea State, Storm Surges, Swell Surface Winds, etc., with Emphasis on Identifying Existing and Potential Hazards.

- Refinement of the Global Geoid, Extension of Geodetic Control to Inaccessible Areas Including the Ocean Floors, and Improvement of Knowledge of the Geomagnetic Field for Mapping and Geophysical Applications, to Satisfy Stated User Requirements.

Table 5

Earth and Ocean Physics Applications — Advantages of Shuttle

Sortie Mode:

- Provides Test Bed and Observational Platform for Development and Evaluation of New Instrumentation and Techniques
- Uses Man to Make Equipment Adjustments (Gain Changes, Frequency Adjustments, etc.) to Optimize Matching Sensor Characteristics to the Observables
- Uses Man as Observer to Correlate with Remote Sensing
- Uses Man's Judgment to Provide Flexibility in the Use of Equipment and in Programming Experiments

Launch Mode:

- Uses Shuttle to Launch/Retrieve Free-Flight and Tethered Satellites
- Is Especially Advantageous for Low-Altitude (Short-Lived) Satellites, e.g., Free-Flying and Tethered Magnetometer Satellites, Where Launch by Conventional Rockets is not Economically Feasible

Table 6

Shuttle Sortie Missions for Earth and Ocean Physics Applications (EOPAP)

Ocean Dynamics Test Bed

- Number of Sensors Identified: 10 Typical
- Weight of Sensors: 700 Kg
- Peak Power: 7 KW
- Data Rate: 15 MHz
- Stabilization and Pointing: 1 Arc Minute
- Orbit: 200 KM, Circular; Inclination $\geqslant 60°$
- Mission Duration: 1 Week to 1 Month
- Flight Frequency: 1 per Year

Earth Dynamics Test Bed

- Number of Sensors Identified: 7 Typical
- Weight of Sensors: 700 Kg
- Peak Power: 5 KW
- Data Rate: 5 MHz
- Stabilization and Pointing: 1 Arc Minute
- Orbit: 200 KM, Circular; Inclination: Not Critical
- Mission Duration: 1 Week
- Flight Frequency: 1 per Year

Table 7
Ocean-Dynamics Test Bed Missions — Instrumentation

Radar Altimeter (Sea-Surface Topography, Sea State, Salinity, Rain)
Microwave Scatterometer (Surface Roughness, Wind Speed)
Precision Multifrequency Coherent Imaging Radar
Multifrequency, Dual Polarized Microwave Radiometer, C and L Bands; Frequencies: 1, 5, 10, 20, 50 GHz; Resolution: 10 Km; Antenna: 4 Meters (Foam, Wind Speed, Salinity, Surface Temperature, Atmospheric Corrections)
Vertical Temperature Profile Radiometer
Laser Altimeter
Laser Profilometer
Laser Scatterometer
Laser Scanning Photometer
Receiver for Bistatic Wave Spectrum Analysis

Table 8
Ocean-Dynamics Test Bed Missions — Mission Requirements

Length of Flights: 1 Week to 1 Month
Orbit: Circular Inclination: $\geq 60°$ Altitude: As Low As Possible
Data Requirements: 15 MHz Data Link: On-Board Video Tape Recorder
Role and Number of Personnel in Orbit: 1 Experiment Specialist
Stabilization and Pointing: Stability: 1 Arc Second/Sec Pointing Accuracy: 1 Arc Minute
Power: 7 Kw Peak; 200 Kw-hrs
Weight of Instruments: 700 Kg
EVA Requirements: None
Correlative Measurements: Surface-Truth
General Support Equipment: On-Board Video Tape Recorder
Documentation Requirements: No Special Requirements
Special Operating Constraints: No Special Requirements
Contamination Requirements: No Special Requirements

Table 9

Solid-Earth Test Bed Missions — Instrumentation

Precision Multi-Frequency Imaging Radars (See Through Foliage for Topographic Features, Geology, Hidden Faults, and Near-Surface Geothermal mapping)
Imaging Radar for Double-Exposure Holography (3-Dimensional Strain Fields, Erosion, Volcanic Motion, Post-Glacial Uplift)
FM Correlation Radar (Baseline Measurements)
Side-Tone Ranging System (Multilateration)
Multi-Frequency Laser and Microwave Differential Refraction Experiment (Model Atmospheric, Tropospheric, and Ionospheric Corrections)
Laser Ranging/Altimeter
Multispectral Scanners (Topographic Features and Geology)

Table 10

Solid-Earth Test Bed Missions — Mission Requirements

Length of Flights: 1 Week
Orbit: 200 km, No Special Inclination
Data Requirements: 5 MHz
Role and Number of Personnel in Orbit: 1 Experiment Specialist
Stabilization and Pointing: 1 Arc Minute
Power and Thermal: 5 kw, 100 kw-hrs
Weight of instruments: 700 kg
EVA Requirements: None
Correlative Measurements: Ground Truth
General Support Equipment: Wide-Bandwidth Video Tape Recorder
Documentation Requirements: No Special Requirements
Special Operating Constraints: International Radio-Frequency Agreements
Contamination Requirements: No Special Requirements

Table 11

Shuttle Sortie Missions — Earth and Ocean Physics Test Beds

Schedule CY	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Ocean Dynamics Test Bed						1	1	1	1	1	1	1	1	1	1	1	1
Earth Dynamics Test Bed							1	1	1	1	1	1	1	1	1	1	1

Costs FY	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	Total
Ocean Dynamics Test Bed																		
R & D Costs			5	10	10	10	10	5	5	5	5	5	5	5	5	5	5	95
Flight Systems				5	12	12	12	5	5	5	5	5	5	5	5	5	5	91
Subtotal			5	15	22	22	22	10	10	10	10	10	10	10	10	10	10	186
Earth Dynamics Test Bed																		
R & D Costs				5	10	10	10	10	5	5	5	5	5	5	5	5	5	90
Flight Systems					5	12	12	12	5	5	5	5	5	5	5	5	5	86
Subtotal				5	15	22	22	22	10	10	10	10	10	10	10	10	10	176
Grand Total			5	20	37	44	44	32	20	20	20	20	20	20	20	20	20	362

The following are the contents of each volume of this series:

EXECUTIVE SUMMARIES

VOLUME 1 — ASTRONOMY

VOLUME 2 — ATMOSPHERIC AND SPACE PHYSICS

VOLUME 3 — HIGH ENERGY ASTROPHYSICS

VOLUME 4 — LIFE SCIENCES

VOLUME 5 — SOLAR PHYSICS

VOLUME 6 — COMMUNICATIONS AND NAVIGATION

VOLUME 7 — EARTH OBSERVATIONS

VOLUME 8 — EARTH AND OCEAN PHYSICS

VOLUME 9 — MATERIALS PROCESSING AND SPACE MANUFACTURING

VOLUME 10 — SPACE TECHNOLOGY