AUGUST 1975

CONTRACT NAS 9–13401
DRL NO. T–880 (MA–129TA)

TERSSE

DEFINITION OF THE TOTAL EARTH RESOURCES SYSTEM FOR THE SHUTTLE ERA

VOLUME 9

EARTH RESOURCES SHUTTLE APPLICATIONS

PREPARED FOR

EARTH RESOURCES PROGRAM OFFICE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

PREPARED BY

GENERAL ELECTRIC
SPACE DIVISION
Valley Forge Space Center
P. O. Box 8555 • Philadelphia, Penna. 19101

This document is submitted by the General Electric Company in partial satisfaction of DRL No. T-880 (Line Item MA-129-TA), Contract NAS 9-13401.

Principal Contributors:

W. K. Stow, Task Leader
U. Alvarado
R. Andryczyk
R. Baker
R. Bianchi
A. Braunwarth
Dr. C. E. Cheeseman
R. Eisenberg
L. Fujii
H. Lachowski
S. Raje
R. Smith
R. Spencer

Approvals:

W. Kent Stow
Study Task Leader

Dr. C. E. Cheeseman
Technical Director

D. W. Keller
Program Manager

Any questions or comments regarding this document should be addressed to:

Dr. C. E. Cheeseman, or
W. Kent Stow
General Electric Company
Valley Forge Space Center
P.O. Box 8555
Philadelphia, Penna. 19101

John Mitchell
Technical Monitor
Earth Resources Program Office
National Aeronautic and Space Administration
Johnson Space Center, Code HD
Houston, Texas 77058

PREFACE

The pressing need to survey and manage the earth's resources and environment, to better understand remotely sensible phenomena, to continue technological development, and to improve management systems are all elements of a future Earth Resources System. The Space Shuttle brings a new capability to Earth Resources Survey including direct observation by experienced earth scientists, quick reaction capability, spaceborne facilities for experimentation and sensor evaluation, and more effective means for launching and servicing long mission life space systems.

The Space Shuttle is, however, only one element in a complex system of data gathering, translation, distribution and utilization functions. While the Shuttle most decidedly has a role in the total Earth Resources Program, the central question is the form of the future Earth Resources system itself. It is only by analyzing this form and accounting for all elements of the system that the proper role of the Shuttle in it can be made visible.

This study, entitled TERSSE, Total Earth Resources System for the Shuttle Era, was established to investigate the form of this future Earth Resources System. Most of the constituent system elements of the future ER system and the key issues which concern the future ER program are both complex and iterrelated in nature. The purpose of this study has been to investigate these items in the context of the total system utilizing a rigorous, comprehensive, systems oriented methodology.

The results the initial phase of this study were reported in eight separate volumes plus an Executive Summary; their titles are:

Volume 1	Earth Resources Program Scope and Information Needs
Volume 2	An Assessment of the Current State-of-the-Art
Volume 3	Mission and System Requirements for the Total Earth Resources System
Volume 4	The Role of the Shuttle in the Earth Resources Program
Volume 5	Detailed System Requirements: Two Case Studies
Volume 6	An Early Shuttle Pallet Concept for the Earth Resources Program
Volume 7	User Models: A System Assessment
Volume 8	User's Mission and System Requirement Data

Executive Summary.

A subsequent activity, part of TERSSE, was undertaken to investigate the Space Shuttle in more detail and to study the Shuttle's contribution to the Earth Resources Program when operating in its sortie flight mode; this activity is reported in:

Volume 9 Earth Resources Shuttle Applications

Executive Summary of Earth Resources Shuttle Applications.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (cont)

SECTION 1
INTRODUCTION AND SUMMARY

The Shuttle as an Earth Resources platform is both unique and complementary to the other Earth Resources platforms, polar and synchronous satellites and aircraft. The Shuttle provides the capability (Table 1-1) to deliver payloads to orbit, to recover payloads, to vary orbits and to return with hard copy data. Its crew will be available to perform sensor operations and its large volume and weight capacity will lower launch and payload costs. And, in particular, the Shuttle can provide resolutions of 10-20 meters at substantially lower sensor costs than from polar satellites.

The role of the Shuttle in the Earth Resources Program of the 1980's was defined in previous TERSSE Volumes as consisting of two major parts: the provision of transportation and maintenance services for automated satellites and the acquisition of data from Shuttle-borne sensors in the sortie mode for a wide range of Program objectives. The function of Shuttle in the sortie mode was further broken down into four separate roles (Figure 1-1), each to support a specific portion of Earth Resources Program activities:

1. Sensor Development Role
2. Technique Development Role
3. Applications Development Role
4. Operational Platform Role

TABLE 1-1. SPACE SHUTTLE AS A PLATFORM

- RECOVERABLE PAYLOADS
  - RECONFIGURABLE
  - MAINTAINABLE
  - MULTIPLE FLIGHTS
- ORBIT VARIABILITY
  - VARIABLE LIGHTING ALTITUDE, REPEAT CYCLE
  - MANEUVERABILITY ON-ORBIT
- LOW PAYLOADS COSTS
  - LARGE WEIGHT, VOLUME, POWER
  - SOFT RIDE (?)
- LARGE SENSOR ACCOMMODATION
  - WEIGHT, VOLUME AVAILABLE
- SENSOR PERFORMANCE IMPROVEMENT
  - HIGH RESOLUTION AT LOWER COST
  - MULTI-SENSOR SYNERGISM
- CREW PRESENCE
  - CONTROL
  - REPAIR
  - RECONFIGURE
  - INTERPRET
- HARD COPY DATA RETURN
  - FILM
  - TAPE

It has been the purpose of the effort reported herein to study in more detail these four ERS roles of Shuttle in the sortie mode.

The Space Shuttle is the key element in the Space Transportation System, STS, which can be defined to consist of: the Space Shuttle (Orbiter, External Tank, and Solid Rocket Boosters); upper stages for the Shuttle; and the Spacelab (pressurized module, and standardized pallets). The STS has been designed to deliver, retrieve, and service automated and manned spacecraft on-orbit. It will also support in its sortie flight mode the conduct of space operations and experiments at low earth orbit for missions up to 30 days in length. The Shuttle and upper stages of the STS are being built by NASA and DOD, the Spacelab by the European Space Agency, ESA. The STS goal is to support all space operations by NASA, DOD, other U.S. agencies, foreign national agencies, and the domestic/international private sector. This study addresses the Space Shuttle and its Spacelab when operating in the sortie flight mode.

A number of parallel efforts are currently underway to define the major building blocks upon which the NASA Office of Applications will base its Space Shuttle utilization for Earth Observations. These efforts are, in the main, focused on the definition or design of individual sensors, sensor groupings, and laboratory facilities which will be carried by the Shuttle. Examples of these efforts include:

- ACPL, Atmospheric Cloud Physics Laboratory - a technology experiment to explore cloud chamber phenoma under long duration conditions of weightlessness with a well instrumental facility within the Spacelab module.
- EVAL, Earth Viewing Applications Laboratory - a Spacelab research and development facility which will support Earth oriented investigations with either the Spacelab module, or pallets, or both.
- SEOPS, Standard Earth Observational Package for Shuttle - an operational concept to permit the relatively autonomous utilization of Shuttle on a high proportion of Shuttle flights.
- SIR, Shuttle Imaging Radar - a dual frequency, dual polarization phased array radar designed as a sensor for the Space Shuttle.
- SIMS, Shuttle Imaging Microwave System - an eleven frequency, high resolution passive microwave radiometer designed as a sensor for the Space Shuttle.
- MMAP, Microwave Multiple Application Payload - a facility for Earth Observation and Communications R&D.

This study is integrative in nature in that it addresses the use of Shuttle for Earth Resources from a program wide viewpoint, within the broader picture of OA Shuttle utilization for both operational and R&D uses. This study was performed in cognizing of the afore mentioned parallel efforts and used information from them to place its results in the perspective of the OA Shuttle Program.

There exist several critical problems with respect to payload selection, integration, and mission planning which are addressed in this study (which the nature of the preceeding parallel efforts did not require). This study began with an expanded examination of each of the four Shuttle roles, in the sortie mode, and continued through to an integrated Earth Resources Shuttle program. The approach taken was to perform several representative conceptual mission designs of Earth Resources missions which used the Shuttle sortie as

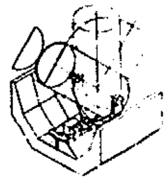
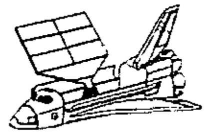
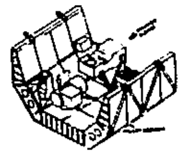
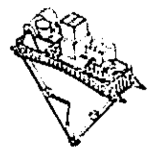
TECHNIQUE DEVELOPMENT	**EARLY INVESTIGATIONS OF UNDERLYING SCIENTIFIC FRAMEWORK** **– SIGNATURES** **– CUT AND TRY** **– LAB INSTRUMENTS**	
SENSOR DEVELOPMENT	**ENGINEERING DEVELOPMENT AND EXPERIMENTATION TO FINALIZE SENSOR DESIGN** **– PERFORMANCE VERIFICATION/CAL** **– INCREMENTAL BUILDUP**	
APPLICATIONS DEVELOPMENT	**DEVELOPMENT AND EXERCISING OF PROTOTYPE END-TO-END APPLICATIONS SYSTEMS TO DEMONSTRATE OPERATIONAL POTENTIAL**	
OPERATIONAL PLATFORM	**APPLICATIONS ROUTINELY CARRIED OUT TO SATISFY INFORMATION NEEDS OF AN OPERATIONAL RESOURCE MANAGER.**	

Figure 1-1. The Four Roles for Sortie Flights

their platform and which collectively spanned the four Shuttle roles. An Integrated Flight Program based on these missions was then developed for the first two years of Shuttle flights. A set of broad program implications concerning the uses of Shuttle for Earth Resources was the result.

The remainder of section 1.0 describes the four roles and the associated missions studied, the resulting integrated flight program, and the conclusions reached concerning Earth Resources Program planning for Shuttle.

1.1 SENSOR DEVELOPMENT MISSIONS

In its Sensor Development role the Shuttle provides a convenient test bed platform. It can be used to fly (in an extreme case) essentially breadboard equipment, so long as flight safety rules are not violated and the equipment is packaged to withstand the flight environment. The availability of flight crew onboard provides the capability for inflight adjustment of hardware. The fact that the hardware is returned to earth provides the potential for modification and reflying experimental hardware at low cost. This latter function can be used to advantage in phased development programs where sensor characteristics, e.g. mechanical, electrical and thermal can be evaluated independent of full systems operation.

Some problems remain to be resolved, however. Experience with aircraft sensor development has shown that multiple-flight programs, each with limited objectives and each building on the experience gained in ear... flights, is the preferred methodology. For the Shuttle, however, those very sensors for which this philosophy is of paramount importance are those for which this philosophy is most difficult to implement because of size, weight, power and data handling requirements. These requirements naturally increase pre-flight costs, consequently the balance between the costs and development-effectiveness of a "do little and fly often" versus "fly little and do a lot" approach must be evaluated very carefully for sensor development missions.

A further problem which must be overcome is the one created when external pressures are applied to provide data to applications users too early in the development process. It must be recognized that the primary function of a sensor development mission is sensor development. In order to reduce the data dissemination problem the recipients of data should be restricted to the sensor development team (and possibly the few application users with an urgent need).

1.2 TECHNIQUE DEVELOPMENT MISSIONS

Technique development using shuttle promises to be one of the more efficient uses of the frequent flight opportunities and the recoverability of experiment hardware offered by the shuttle sortie. Technique developments are, by their very nature, disposed to be cut-and-try efforts; this is precisely why aircraft have proven to be of such value in the past (and why they will also continue to be so in the future). Frequent flight and intact recovery will permit the use of hardware not designed for the rigors of long (say, years) spaceflight but for obtaining the specific sets of measurements required to scientifically interrelate the resource phenomenon and the remote sensing technique under study.

Technique development missions are intended to provide early investigations of the underlying scientific principles of a measurement which is being considered as a remote sensing method. Orbits, test sites, and equipment configurations may be varied from flight to flight, thus offering the Technique Development manager a variety of conditions under which he can determine the effectiveness of the candidate methods and sensors. Sensor complements can be varied which offer the advantage of concurrent coverage with several sensors which may be used in a complementary manner.

1.3 APPLICATIONS DEVELOPMENT MISSIONS

For Applications Development missions the Shuttle is used to exercise prototype end-to-end applications Systems to demonstrate operational potential and to verify the selection of the all-up operational system configuration. The ultimate users of the operational system are heavily involved in the applications development missions, since it is their evaluation of the utility of the acquired data which is the key factor in any decision to proceed with a fully operational mission. Thus, detailed data processing and information dissemination as well as publication procedures and agreements are part of the Applications Development mission design. Since in many cases users will be in the private sector, a need exists for formal agreements and guidelines for joint research programs, similar to that between NASA/JPL and Exxon for oil and mineral exploration image processing technology development.

The Applications Development mission is an important phase before a remote sensing system becomes operational and relies heavily on the results of sensor and technique development missions. A unique characteristic of an Application Development mission is that it represents a final operational demonstration of an application verifying its concept and is complete with documentation, hardware and all necessary software to support operational use.

Although, in principle, the Shuttle could be used for applications development missions for (ultimately) unmanned operational programs, such a role is not considered in this context. Thus, the missions of concern are those for which, operationally, the Shuttle would be used as the primary platform, and consequently have the same justification for Shuttle use as the operational mission.

1.4 OPERATIONAL MISSIONS

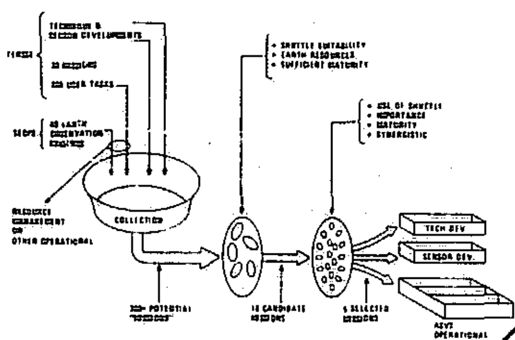
Operational missions are distinct from other Shuttle sortie activities by virtue of the fact that they serve a user-agency administered function. In this case the Shuttle is the vehicle by which the payload (the actual operational sensor complement) achieves orbit and is operated there; the data is returned for processing, reduction, analysis and dissemination. Operational missions consist of sensors of various technology disciplines which have been developed and proven, integrated into an operational system designed to fly in one of several Shuttle sortie modes (e.g. with Spacelab, pallet mounted, etc.) and previously demonstrated applications development missions.

Although flying an operational mission, the Shuttle sortie flight may not be the only, or even the primary, platform in use for the Earth Resource management task in question. It is possible to view the role of the Shuttle sortie operational flight as that of a complementary or secondary platform in a system which includes sensors in polar or geosynchronous orbit. Thus, although flying an operational mission, the sortie flight may not be the primary platform in the Earth Resources management system.

A prime example of this role in operational missions is in the use of the Shuttle as a platform for camera systems. Polar and geosynchronous satellites, by their nature, are not suitable vehicles for return of photographic film, and to provide sensors with spatial resolution on the order of 5-10 meters may severely overload data transmission link capabilities. Thus, for missions where high resolution photographs of specific, well defined regions are required, the Shuttle can be used as a complement to the unmanned vehicle. The Shuttle also provides capabilities for quick reaction, low orbital altitude flights with variable orbital characteristics. These factors may be of importance in certain classes of operational missions.

1.5 MISSION DESIGN

Based on the potential roles of the Shuttle in Earth Resources programs, and on a variety of other selection criteria discussed in Section 2 of this report, five missions were selected for detailed study. These missions were considered as a representative set of potential missions, and consisted of one each for Sensor Development and Technique Development, and three Applications Development missions. (Figure 1-2)



ROLE	MISSION	IDENTIFIED USER	CONCEPT MATURITY	BENEFIT/NEED	PHYSICAL ACCOMMODATIONS	SENSOR TECHNOLOGY	PROCESSING/DIST. TECH
TECHNIQUE DEVELOPMENT	SOIL MOISTURE	CROP YIELD	LOW-MED	KEY DEV.	LARGE SENSOR	μW PASSIVE	SCIENTIFIC MEAS.
SENSOR DEVELOPMENT	SAR	MULTI	READY BY 1980	KEY SENSOR	LARGE SENSOR, HIGH POWER	μW ACTIVE	ENG. MEAS.
APPLICATION DEVELOPMENT	TIMBER INVENTORY	USFS	HIGH	KNOWN	↑	↑	↑
APPLICATION DEVELOPMENT	URBAN & REGIONAL PLANNING	LOCAL GOV'T	MED	UNKNOWN	SMALL SENSORS, PIGGY BACK	VIS/IR, FILM, ELECTRONIC	ELECTRONIC FILM, EXTRACTING DEMO
APPLICATION DEVELOPMENT	MINERAL EXPLORATION	PVT	HIGH	KNOWN	↓	↓	↓

THE MISSION SET WAS CHOSEN TO COLLECTIVELY SPAN THE ROLES OF SHUTTLE WITH HIGH-PRIORITY DEVELOPMENTS

Figure 1-2. Mission Selection

The overall concept of each mission was developed to the point where mission design criteria could be established for

- User community and benefit mechanism
- Shuttle role in the specific mission (Figure 1-3)
- Sensor requirements
- Flight requirements and test sites
- Data processing and analysis
- Information dissemination

Following the development of the mission requirements, sensor selection was made which provided optimum integrated payload configurations, and an integrated Shuttle flight program was developed (Figures 1-4 to 1-8). A conceptual design for a Shuttle Earth Resources Data Processing Facility was defined (Figures 1-9, 1-10), and a cost comparison was made between aircraft and the Shuttle. Finally, a set of development recommendations for the Shuttle Earth Resources flight program was outlined.

1.6 STUDY CONCLUSIONS AND RECOMMENDATIONS

As a result of this study several conclusions can be drawn and recommendations may be made.

	SOIL MOISTURE	SAR DEVELOPMENT	TIMBER INVENTORY	URBAN & REG. PLNG.	MINERAL EXPLORATION
SIMULTANEOUS FILM AND ELECTRONIC DATA			U	U	U
FREQUENT FLIGHTS	C	C			
RECOVERABLE P/L	C	C			
HARD COPY RETURN		U	U	U	U
HIGH RESOLUTION			C	C	C
LARGE P/L CAPACITY	U	U			
QUICK RESPONSE (EASY INTEGRATION)			U	U	U
VARIABLE ORBITS CLOUD AVOIDANCE VARY SUN ANGLE	U	U	U	U	U
MAN AVAILABLE	U	U	U	U	U
LOW-COST EQUIPMENT	U	U	U	U	U

U – UNIQUE FOR SHUTTLE

C – COST ADVANTAGE OVER OTHER SPACE PLATFORMS

Figure 1-3. Advantages of Shuttle for Selected Missions

		MISSION					
		SOIL MOISTURE	RADAR DEVELOPMENT	MINERAL EXPLORATION	URBAN/REGIONAL PLANNING	FOREST INVENTORY	REMARKS
IMAGING SPECTRO-RADIOMETERS	4-BAND MSS					√	SCAN MECHANISM MODIFIED FOR USE AT SHUTTLE ALTITUDES
	5-BAND MSS			√ OR	√ OR	OR	
	THEMATIC MAPPER	(√)		(√)	(√)	(√)	
FILM CAMERAS	S-190A 6-CAMERA PKG				(√)		MODIFIED TO INCREASE FOCAL LENGTH; PRESSURE HOUSING REQ'D
	S-190B 5" FILM CAMERA			√ OR		√ OR	PRESSURE HOUSING REQ'D
	LG. FORMAT (9" x 18") CAMERA			(√)		√	PRESSURE HOUSING REQ'D
MICRO-WAVE	IMAGING RADAR (SAR)	(WHEN AVAILABLE) (√)	(√)				
	IMAGING μW SYSTEM (SIMS)	(√)					
	PHOTO-POLARIMETER	(√)					SPACE-QUALIFIED VERSION OF AIRCRAFT SENSOR

√ - ADEQUATE

(√) - PREFERRED

Figure 1-4. Candidate Sensors

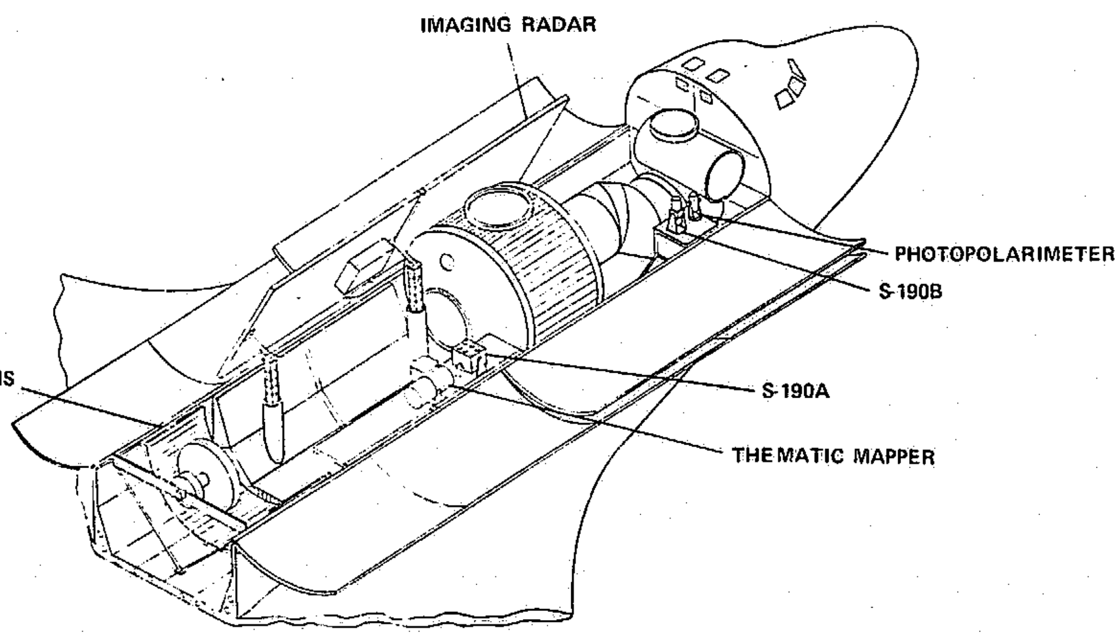


Figure 1-5. Typical Configuration — Short Lab with 2 Pallets, SIMS and SAR

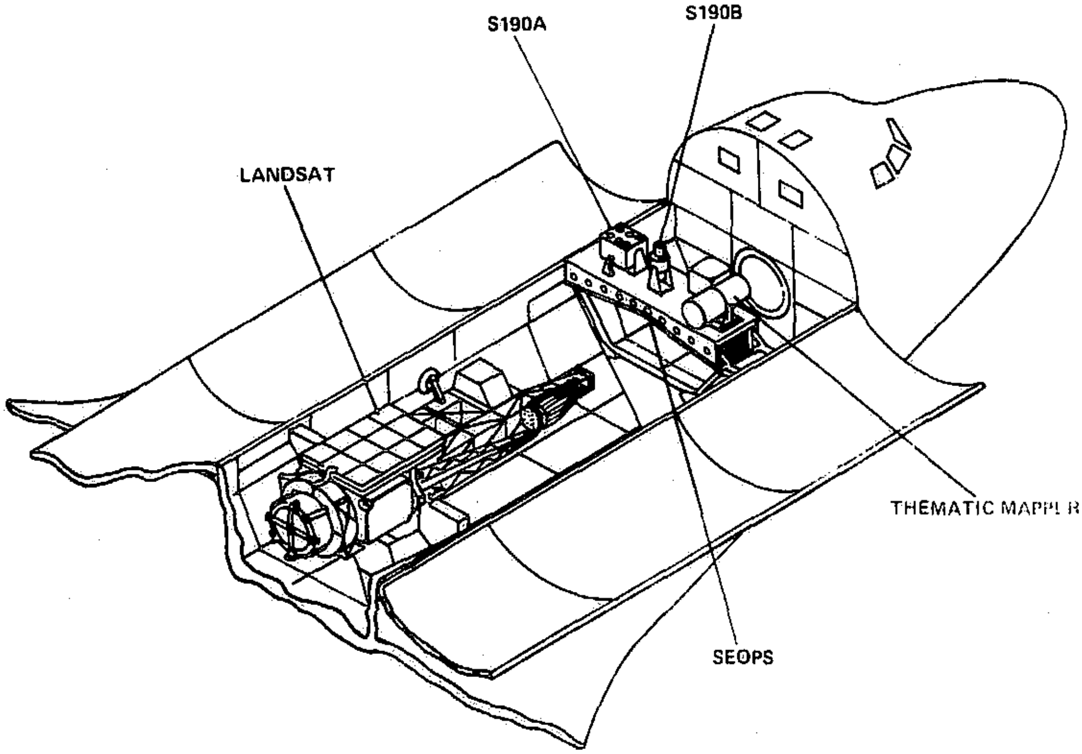


Figure 1-6. Typical Configuration — Standard Earth Observation Package with Landsat Delivery

- FLIGHTS SCHEDULED AS NECESSARY
- SIMS AND SAR DO NOT FLY TOGETHER

	YEAR 1				YEAR 2			
	1ST Q	2ND Q	3D Q	4TH Q	1ST Q	2ND Q	3D Q	4TH Q
CONFIGURATION	SHORT LAB + 2 PALLETS 6 PALLETS		SHORT LAB + 2 PALLETS	5 PALLETS	SHORT LAB + 2 PALLETS	SEOPS	SHORT LAB + 2 PALLETS	5 PALLETS
PAYLOAD	EARLY SIMS PHOTO POLARIMETER TM S190B	SAR TM S190A S190B	INT. SIMS SCANNING POLARIMETER TM S190B	SAR TM S190A S190B	ADV. SIMS SCANNING PHOTOPOL. TM	TM S190A	ADV. SIMS SCANNING PHOTOPOL	SAR
MISSIONS SERVED	EARLY SOIL MOISTURE MINERAL EXPLORATION	SAR ENG. MINERAL EXPLORATION TIMBER VOL. URBAN/REG. PLANNING	INT. SOIL MOISTURE MINERAL EXPLORATION	SAR CAL MINERAL EXPLORATION TIMBER VOL URBAN/REG PLANNING	ADV. SOIL MOISTURE	URB/REG. PLANNING	ADV. SOIL MOISTURE	SAR FLT PROOF
OTHER OA PAYLOADS	① ZERO-G CLOUD PHYSICS LASER R'GNG STARS/PADS LASER XCVR LASER ALT NO/YAG LASER	② LASER ALT LASER R'GNG NO/YAG LASER LASER XCVR OPTICAL SCAT STARS/PADS	SAME AS ①	SAME AS ②	SAME AS ①		SAME AS ①	SAME AS ②

Figure 1-7. Integrated Flight Program 1

- FLIGHT FREQUENCY CONSTRAINT OF 2 SPACELABS/YEAR
- SIMS AND SAR FLOWN CONCURRENTLY

	YEAR 1				YEAR 2			
	1ST Q	2ND Q	3D Q	4TH Q	1ST Q	2ND Q	3D Q	4TH Q
CONFIGURATION	5 PALLETS	SEOPS	SHORT MODULE + 2 PALLETS	SEOPS	R 5 PALLETS (ON ORBIT RETROFIT)	SEOPS	5 PALLETS	
PAYLOAD	EARLY SIMS PHOTOPOL. SAR TM S190B	TM S190A S190B	INT. SIMS SCANNING POLARIMETER TM S190A S190B	TM S190A S190B	ADV. SIMS SCANNING PHOTO POL. SAR TM	TM S190A	SAR ADV SIMS SCANNING PHOTOPOL.	
MISSIONS SERVED	EARLY SOIL MOISTURE SAR ENG MINERAL EXPL	MINERAL EXP 2 TIMBER VOL URB/REG PLANNING	INT. SOIL MOISTURE MINERAL EXPL	MINERAL EXPL TIMBER VOL URBAN/REG. PLANNING	ADV. SOIL MOISTURE SAR CAL	URB/REG PLANNING	SAR FLT PROOF ADV SOIL MOISTURE	
OTHER OA PAYLOADS	1 LASER R'NG ND/YAG LASER		ZERO G CLOUD PHYS. LASER R'GNG STARS/PADS LASER XCVR LASER ALT ND/YAG LASER		SAME AS 1		SAME AS 1	

Figure 1-8. Integrated Flight Program 2

(1) The Space Shuttle and the Earth Resources Program

- The Space Shuttle has a viable role in the Earth Resources Program.

  The Shuttle provides several unique capabilities which are of value to certain types of Earth Resources missions. These include

  - The capacity for heavy, large volume, high power, sensor packages
  - The capacity to accept essentially unproven hardware for flight experiments
  - The ability to return photographic and other hard copy data following a flight
  - The potential for rapid turnaround and quick reaction flights with specially tailored payloads
  - The capability of flying at different altitudes in different orbits, with orbital changes during a flight
  - The cost effectiveness of Shuttle as a carrier over other methods of acquiring equivalent data
  - The ability to fly small Earth Resources packages, such as SEOPS, to make use of available Shuttle resources (e.g. space, power, time) in conjunction with non-Earth Resources missions
  - The availability of trained flight crew members.

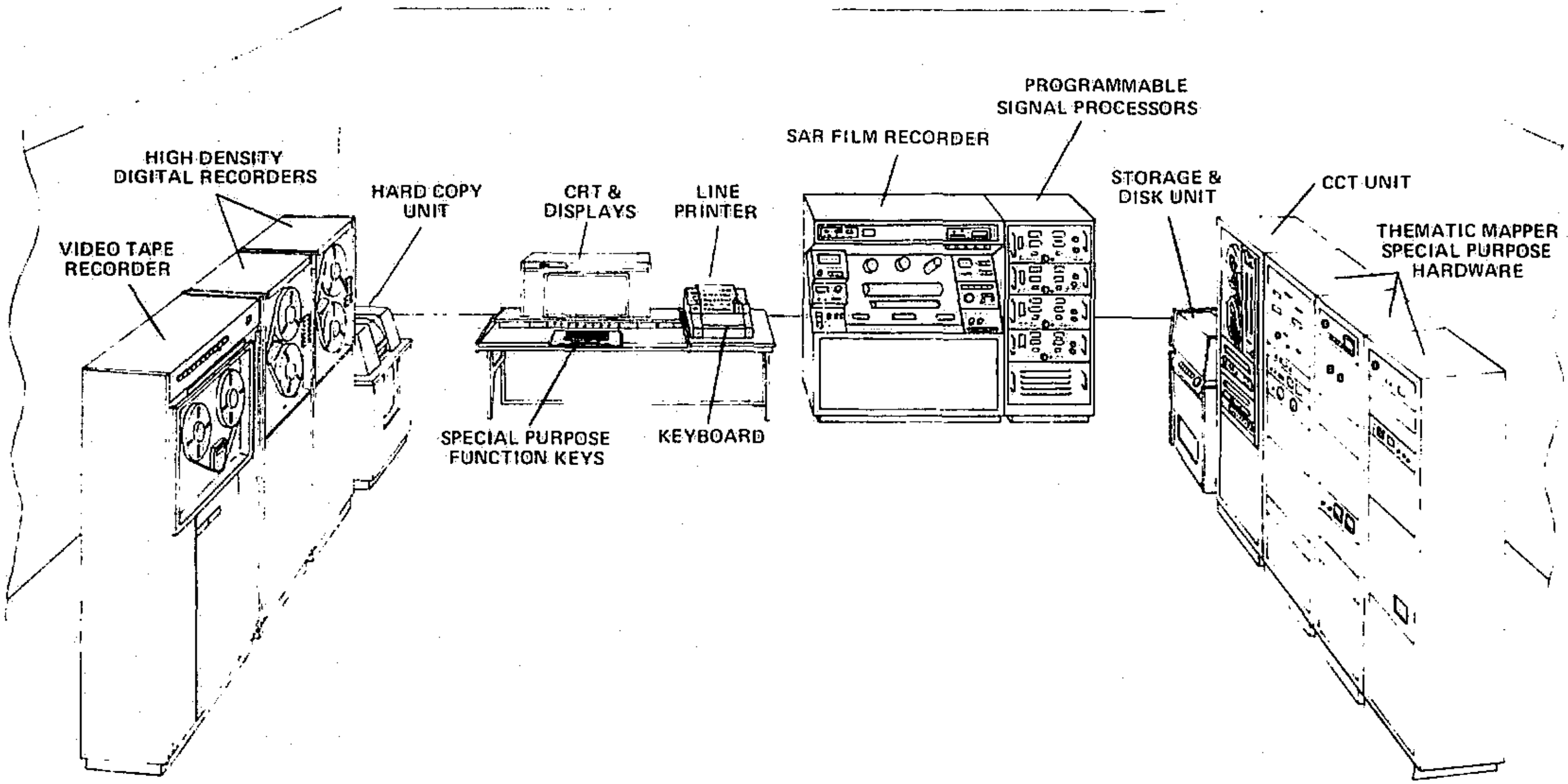


Figure 1-9. Conceptual Design for Shuttle Earth Resources Data Processing Facility — Preprocessing and Analysis

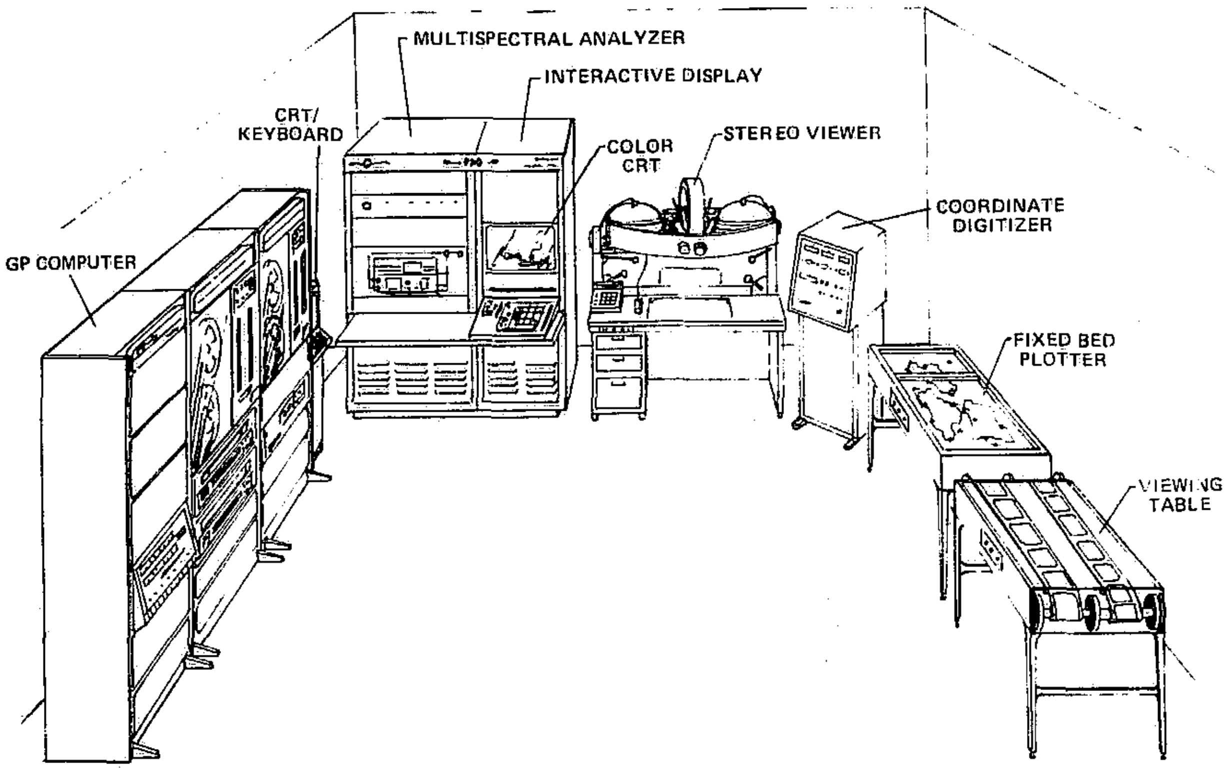


Figure 1-10. Conceptual Design for Shuttle Earth Resources Data Processing Facility — Extractive Processing and Analysis

Each of the selected missions makes use of some or all of these unique characteristics.

- Shuttle should be used as a complement to other Earth Resources data acquisition methods.

  The Shuttle has a limited duration on-orbit for any given flight, currently estimated as typically 7 days with approximately 30 days maximum. Thus, the Shuttle is not an appropriate vehicle for missions requiring global coverage, or repetitive coverage over several orbit repeat cycles. It can, however, provide a capability for intensified coverage of limited geographical areas in conjunction with polar or geosynchronous spacecraft. The Shuttle can also be used for periodic "revisits", such as seasonal repetition, of small geographic areas.

(2) Mission Selection Criteria

- Shuttle missions should be planned carefully to coordinate user requirements.

  Although the Shuttle is a very cost effective vehicle for many Earth Resources missions which require single or relatively infrequent overflights of specific test sites it is still quite expensive. The cost effectiveness becomes more apparent when several users' needs can be satisfied on a single flight with a given payload. Thus, caution should be exercised in considering the shuttle as a candidate vehicle for a specific mission unless one or more of the following criteria are satisfied.

  — The mission requires flight of non-proven or unique sensors which are impractical for long life unmanned spacecraft.

- The considerable payload resources of shuttle (weight, power, volume, and data acquisition capacity) are essential for the specific mission.

- The mission can be flown in conjunction with several others using the same sensor complement and orbit characteristics.

- Photographic imagery is mandatory for successful mission completion.

- Mission objectives should be well defined and the specific objectives for each flight should be clearly identified.

  In order to provide a clear justification for the use of the Shuttle as a vehicle for any specific mission, a clear set of mission objectives must be established. It should be remembered that the primary questions to be asked when justifying the use of Shuttle are those relating to the criteria established above.

  In addition, this conclusion implies well developed mission definitions for the Applications Development missions, with proven sensors and data analysis techniques and processing systems.

(3) User Involvement

- Potential and actual users of Shuttle data should be involved in Applications Development missions at a very early stage.

  Data acquired using Shuttle-borne sensors have unique characteristics however there are constraints imposed by the Shuttle vehicle which are different from other Earth Resources data acquisition platforms. Users and potential users must be made aware of these characteristics in order that they may gain confidence in its use in operational systems, and thus should be intimately involved from the mission design, through the definition phases, to the ultimate flight program.

SECTION 2
MISSION SELECTION

Previous TERSSE study tasks have identified nearly 300 potential Earth Resource applications tasks in 30 broad missions. In addition, a related study, Standard Earth Observations Package for Shuttle (SEOPS), has considered 40 operational Shuttle missions. Several requirements have also been identified by the TERSSE study for sensor and technique development missions which lend themselves to utilization of the Shuttle or will be required in support of various identified applications missions.

From this inventory of over 300 potential tasks/missions a selection of five was made for detailed study, consisting of one sensor development mission, one technique development mission and three application development missions. This selection of the five missions was made by a two stage screening process: first, the inventory of over 300 tasks/missions was screened to identify 18 candidate missions, and second, five specific missions for detailed study were chosen from this subset of 18.

2.1 SELECTION OF CANDIDATE MISSIONS

The basic criteria used in the first screening of the potential missions, from the over 300 previously generated by the TERSSE and SEOPS studies, was that of a) Space Shuttle suitability and b) restriction to Earth Resources missions (some candidate SEOPS missions are oriented at other Earth Observations areas such as Weather & Climate and were thus excluded). This first screening reduced the 300+ potential missions to a more manageable set of 18 candidate missions.

The restriction to Earth Resources tasks/missions was straightforward; those SEOPS missions which were defined as being part of another (non ER) discipline within the Earth Observation area were eliminated. Previous TERSSE efforts have addressed the suitability of the Space Shuttle for the Earth Resources Program in two basic ways. These two suitability approaches are:

- Consideration of the Shuttle as a single element in an integrated multi-platform system.
- Consideration of the Shuttle's capability to contribute without regard for other platforms.

The first suitability approach regards all platform elements of a multiplatform operational Earth Resources system as in place and operational. Each Earth Resources mission is then considered and the appropriatness of each platform for that mission addressed. The methodology and results of this platform suitability assignment are discussed in Section 4 of TERSSE Final Report Volume 3. With respect to the Shuttle as a platform, each mission was assigned an A or B where:

A - indicates that platform provides all or major part of data needs for the mission

B - indicates that platform provides partial satisfactions of data needs for the mission

The major platform assignment characteristics used were:

- Spacecraft for repeated observation missions are more cost effective than aircraft over large areas.
- Where appropriate, a geosynchronous spacecraft is more effective than multiple polar spacecraft.
- Shuttle sortie missions are effective platforms for high spatial resolution requirements.
- Geosynchronous spacecraft are not appropriate for global coverage.
- Shuttle sortie missions should be unique (not appropriate for long life spacecraft).

The second basic approach to determining Shuttle suitability begins from a different starting point; instead of considering the Shuttle as part of an integrated multi platform system, consider the Shuttle alone and determine what the Shuttle can contribute to each potential mission in each of four categories:

1. Prime Platform - indicates that Shuttle can fully (or nearly fully) acquire all the necessary data to satisfy the application mission requirements
2. Partial Mission - indicates that Shuttle can fully satisfy the data needs for a portion of the mission, where a mission actually consists of several more specific sub missions or tasks (e.g. collect all of the required global data for a few, but not all, required crops).
3. Partial Data - indicates that Shuttle can acquire a part (limited in spatial or temporal extent) of the data required for the full mission (e.g. all Rangeland survey data needed at one, not all, points during the year.)
4. Development Platform - indicates that Shuttle can acquire data and provide a significant contribution as a development platform to the operational evolution of a mission.

The results of these two different approaches to Space Shuttle suitability for the Earth Resources missions are tabulated in Table 2-1, where an X indicates that suitability exists according to the various criteria just described. By considering those missions which had a good concensus of suitability, as indicated on the table, a total of twelve missions were identified as candidate Application Development missions.

TABLE 2-1. EARTH RESOURCE MISSION/SPACE SHUTTLE SUITABILITY

RESOURCE MANAGEMENT AREA	REFERENCE	APPLICATION MISSION CATEGORIES	OPERATIONAL SHUTTLE UTILIZATION		SHUTTLE AS AN ER PLATFORM				SEOPS	
			A	B	PRIME PLATFORM	PARTIAL MISSION	PARTIAL DATA	DEVELOPMENT PLATFORM		
AGRICULTURE	AG 1	U.S. CROP SURVEY		X				X		
	AG 2	INSECT, DISEASE, & STRESS				X				
	AG 3	FARMING PRACTICES		X		X	X	X	X	*
	AG 4	IRRIGATION WATER DEMAND				X				
	AG 5	GLOBAL CROP SURVEY		X		X		X	X	*
	AG 6	PASTURE/RANGE SURVEY					X			
ENERGY MINERALS	EM 1	MINERALS SURVEY		X		X	X	X	X	*
	EM 2	GEOTHERMAL SOURCE SURVEY				X				
	EM 3	SUBMARINE OIL SURVEY					X	X	X	
	EM 4	EXTRACTION POLLUTION MONITOR		X		X	X	X	X	*
	EM 5	PIPELINE MONITOR					X			
	EM 6	OIL POLLUTION MONITOR					X			
	EM 7	THERMAL POLLUTION MONITOR		X		X		X	X	*
	SEOPS E/M 5	NATURAL DISASTER ASSESSMENT							X	
FORESTRY	FOR 1	TIMBER INVENTORY	X		X	X	X	X	X	*
	FOR 2	INSECT, DISEASE STRESS				X		X	X	
	FOR 3	FIRE MONITOR & ASSESSMENT		X		X	X	X	X	*
LAND USE	LU 1	U.S. LAND USE INVENTORY	X		X	X	X	X	X	*
	LU 2	LAND FORM & COVER MAPPING	X		X		X	X	X	*
	LU 3	COASTLINE SURVEY		X		X	X			
	LU 4	GEOLOGICAL HAZARD MAPPING					X	X		
	SEOPS LAND 3	U.S. CENSUS							X	*
MARINE	MAR 1	OCEAN DYNAMICS MONITOR				X	X	X	X	*
	MAR 3	FISH ENVIRONMENT & LOCATION					X			
	MAR 4	MARINE POLLUTION MONITOR					X			
	MAR 5	NAVIGATION HAZARD MONITOR		X		X				*
	SEOPS MAR 2	EROSION MONITORING							X	
	SEOPS MAR 3	OCEAN SHOAL MAPPING							X	
WATER	WAT 1	URBAN/AG SUPPLY INVENTORY				X	X	X	X	
	WAT 2	HYDROELECTRIC SUPPLY INVENTORY					X	X	X	
	WAT 3	GREAT LAKES ICE						X	X	
	WAT 4	WATER QUALITY MONITOR				X	X	X	X	
	WAT 5	FLOOD MONITOR				X	X			
	WAT 6	COASTAL WETLANDS MONITOR		X		X		X		
	SEOPS WAT 4	SNOWMELT RUNOFF PREDICTION							X	

* = SELECTED MISSION FOR FURTHER ANALYSIS

In the areas of technique and sensor developments, the previous TERSSE activity identified the need for several development activities. Those that were identified and their applicability to the 30 comprehensive basic TERSSE missions are shown in Table 2-2. With respect to potential technique developments, both those previously identified by TERSSE plus Remote Sensing of Soil Moisture and the Role of Man were considered as candidates. Of the sensor recommendations shown on Table 2-2 three were eliminated from further consideration:

- Radar (multi-parameter) - necessary technique development to adequately define this sensor not yet accomplished.
- Atmospheric Condition Sensors - necessary technique development to adequately define these sensors not yet accomplished.
- Spectrometry - necessary technique development to adequately define these sensors not yet accomplished.

Three technique development and three sensor development missions thus remain as candidate missions.

The eighteen candidate missions which resulted from this first screening step of the selection process consist of:

12 Application Development Missions
3 Technique Development Missions
3 Sensor Development Missions

and are listed in Table 2-3. These eighteen missions were then more thoroughly examined in the second phase of the mission selection process in order to select the five representative missions.

2.2 SELECTION OF REPRESENTATIVE MISSIONS

The selection of the five missions to be studied in detail during the remainder of the effort required a further evaluation of the eighteen candidates. Each of the candidates was expressed in terms of a concise mission description and entered in Table 2-4. Each of these was evaluated with regard to the following selection criteria:

- Use of Shuttle
- Importance or Need
- Mission/Concept Maturity
- Contribution to a representative integrated program

Use of Shuttle: each of the representative missions should have a significant requirement for using the Shuttle as opposed to other remote sensing platforms. This can be expressed in terms of the unique Shuttle features being exploited and the importance of those to the mission success.

TABLE 2-2. SENSOR AND TECHNIQUE DEVELOPMENT ROLES IN TERSSE MISSION EVOLUTION

	AGRICULTURE						ENERGY MINERALS							FORESTRY			LAND USE				MARINE				WATER					
	U.S. CROP SURVEY	INSECT, DISEASE & STRESS	FARMING PRACTICES	IRRIGATION WATER DEMAND	GLOBAL CROP SURVEY	PASTURE RANGE & SURVEY	MINERALS SURVEY	GEOTHERMAL SOURCE SURVEY	SUBMARINE OIL SURVEY	EXTRACTION POLLUTION MONITOR	PIPELINE MONITOR	OIL POLLUTION MONITOR	THERMAL POLLUTION MONITOR	TIMBER INVENTORY	INSECT, DISEASE STRESS	FIRE MONITOR & ASSESSMENT	U.S. LAND USE INVENTORY	LAND FORM & COVER MAPPING	COASTLINE SURVEY	GEOLOGICAL HAZARD MAPPING	OCEAN DYNAMICS MONITOR	FISH ENVIRONMENT & LOCATION	MARINE POLLUTION MONITOR	NAVIGATION HAZARD MONITOR	URBAN AG SUPPLY INVENTORY	HYDROELECTRIC SUPPLY INVENTORY	GREAT LAKES ICE	WATER QUALITY MONITOR	FLOOD MONITOR	COASTAL WETLANDS MONITOR
TECHNIQUE DEVELOPMENT																														
– MULTI-ASPECT SIG. RESEARCH	x	x	x		x	x								x	x		x	x				x	x							x
– RADAR (MULTI-PARAMETERS)	x	x	x	x	x	x						x		x	x		x	x	x		·									x
SENSOR DEVELOPMENT																														
– MODULAR, TAILORED SCANNERS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
– RADAR (CLOUD-FREE B&W PHOTOGRAPHY)				x			x	x	x		x						x	x	x	x				x	x	x	x	x	x	x
– RADAR (MULTI-PARAMETER)	x	x	x	x	x	x						x		x	x		x	x	x		x									
– MICROWAVE GRID MEASUREMENT	x	x		x	x	x								x	x	x					x				x	x	x		x	x
– ATMOSPHERIC CONDITION SENSORS	x	x			x	x				x		x		x	x		x	x	x			x	x					x		x
– SPECTROMETRY	x	x			x	x				x		x		x	x		x	x	x			x	x					x		x

TABLE EXTRACTED FROM TERSSE FINAL REPORT VOLUME 4, SECTION 3

TABLE 2-3. CANDIDATE SORTIE MISSIONS

REFERENCE #	APPLICATION DEVELOPMENT	REFERENCE #	TECHNIQUE DEVELOPMENT
AD 1	POWER PLANT THERMAL POLLUTION MONITOR (EM-7)	TD-1	REMOTELY SENSED SOIL MOISTURE
AD 2	MINERAL EXTRACTION POLLUTION MONITOR (EM-4)	TD-2	MULTI-PARAMETER RADAR SIGNATURE
AD 3	AGRICULTURAL FARMING PRACTICES (AG-3)	TD-3	MULTI-ASPECT SPECTRAL SIGNATURE
AD 4	FOREST FIRE DAMAGE/REGROWTH ASSESSMENT (FOR-3)	**REFERENCE #**	**SENSOR DEVELOPMENT**
AD 5	WORLD CROP SURVEY (AG-5)		
AD 6	MINERAL EXPLORATION SURVEY (EM-1)	SD-1	MODULAR/TAILORED SCANNER
AD 7	MARINE NAVIGATION HAZARD MONITOR (MAR-5)	SD-2	ACTIVE IMAGING RADAR
AD 8	URBAN LAND USE/CENSUS (SEOPS LAND 3)	SD-3	PASSIVE MICRO-WAVE IMAGER
AD 9	TIMBER VOLUME INVENTORY (FOR-1)		
AD 10	US LAND USE INVENTORY (LU-1)		
AD 11	LANDFORM AND COVER MAPPING (LU-2)		
AD 12	IMPOUNDED WATER SUPPLY INVENTORY (WAT-1)		

TABLE 2-4. EVALUATION OF REPRESENTATIVE MISSIONS — CANDIDATE TECHNIQUE DEVELOPMENT MISSIONS

REFERENCE NUMBER	TITLE	SHUTTLE ROLE	DESCRIPTION	TYPICAL USER	USE OF SHUTTLE	NEED FOR TECHNIQUE	CONCEPT MATURITY	REMARKS
TD 1	REMOTE SENSING OF SOIL MOISTURE	TECHNIQUE DEVELOPMENT	ESTABLISH THE USE OF THERMAL IR, PHOTO-POLARIMETRY, AND MICROWAVE FRE-QUENCIES, BAND-WIDTHS, AND ACTIVE OR PASSIVE NATURE NECESSARY TO MEA-SURE SUB-SURFACE SOIL MOISTURE FOR VARIOUS USER MIS-SIONS; EVALUATE EFFECTS OF SURFACE VEGETATION, AT-MOSPHERIC CONDI-TIONS, INCIDENCE ANGLE	JSC/S&AD TAMU LRC GE	ABILITY TO CARRY LARGE, MODIFIABLE SENSORS ON REPETITIVE FLIGHTS. ABILITY TO TAILOR ORBITS FOR SPECIFIC TEST SITES, AND VIEW-ING ANGLES.	MAJOR INPUT TO AGRICULTURE, FORESTRY MISSIONS; INPUT TO WATER RESOURCES MISSIONS	S-193, S-194, ESMR AND SEVERAL ACTIVE AND PASSIVE AIR-CRAFT SENSORS FLOWN; USER RE-QUIREMENTS NOT FIRMLY ESTABLISHED; POTENTIAL ACCURACY NOT KNOWN; ACTIVE MICROWAVE WORKSHOP HELD	IMPORTANT FOR SEVERAL NEAR-TERM APPLICA-TIONS (E.G. WATERSHED RUNOFF AND/OR CROP YIELD)
TD 2	MULTI-PARAMETER RADAR SIGNATURES	TECHNIQUE DEVELOPMENT	DETERMINE THE MEA-SURABILITY OF A BROAD SPECTRUM OF RESOURCE PARAM-ETERS USING MULTI-FREQUENCY, MULTI-POLARIZATION SAR; EVALUATE EFFECTS OF SURFACE VEGETATION, MOISTURE, INCIDENCE ANGLE, AND ATMO-SPHERIC CONDITION. COMPARE WITH VISIBLE/IR TECHNIQUES	JSC/S & AD CRES (U OF KANSAS) ERIM JPL	ABILITY TO CARRY LARGE MODIFIABLE SENSORS ON REPETITIVE FLIGHTS; ABILITY TO TAILOR ORBITS FOR SPECIFIC TEST SITES AND VIEW-ING ANGLE.	UNINTERRUPTED COVERAGE BY RADAR COULD REPLACE OR AUGMENT VISIBLE/IR MEASURE-MENTS IN ALL RESOURCE MANAGEMENT AREAS	AIRCRAFT SAR FLIGHTS HAVE DEM-ONSTRATED CAPABILITY TO DIS-CRIMINATE SOME PARAM-ETERS; SEVERAL THEORETICAL EFFORTS EXIST; POTENTIAL ACCURACY NOT KNOWN; ACTIVE MICROWAVE WORKSHOP HELD	IMPORTANT FOR ALL WEATHER, DAY/NIGHT REMOTE SENSING
TD 3	MULTI-ASPECT SPECTRAL SIGNATURES	TECHNIQUE DEVELOPMENT	DETERMINE THE ILLUM-INATION AND VIEWING ANGLE-DEPENDENT VISIBLE AND NEAR IR SIGNATURES OF A BROAD SPECTRUM OF RESOURCE PARAM-ETERS; EVALUATE CONTRIBUTION TO CLASSIFICATION IM-PROVEMENT OF USING MULTI-ASPECT DATA FOR (A) COR-RECTION FOR VIEWING, LIGHTING VARIATIONS, (B) AS ADDITIONAL DATA DIMENSIONS IN MULTI-FEATURE ANALYSIS, AND (C) AS CONTRIBUTOR TO SIGNATURE EXTENSION	JSC/S & AD ERIM	ABILITY TO CARRY LARGE POINTABLE TELESCOPE ON MULTIPLE FLIGHTS; ABILITY TO TAILOR ORBIT FOR MULTIPLE LIGHTING AND VIEWING ANGLES OF TEST SITES.	DISCRIMINATION IMPROVEMENTS REQUIRED IN AREAS SUCH AS CROP STRESS. OFFSET POINT-ING SIGNATURE EFFECTS NEEDED FOR FUTURE POLAR SPACECRAFT	SEVERAL THEORETICAL EFFORTS EXIST; GROUND MEASURE-MENTS DEMON-STRATE TECHNIQUE FOR SEVERAL CROPS. POTENTIAL INCREASES IN CLASSI-FICATION ACCURACY NOT KNOWN.	

TABLE 2-4. EVALUATION OF REPRESENTATIVE MISSIONS (Continued) — CANDIDATE SENSOR DEVELOPMENT MISSIONS

REFERENCE NUMBER	TITLE	SHUTTLE ROLE	DEVELOPMENT OBJECTIVES	TYPICAL USER	USE OF SHUTTLE	NECESSITY FOR SENSOR	CONCEPT MATURITY	REMARKS
SD 1	MODULAR/ TAILORABLE SCANNER	SENSOR DEVELOPMENT	DEVELOP AND DEMONSTRATE A MULTI-SPECTRAL SCANNER SYSTEM WITH INTERCHANGEABLE MODULES FOR VISIBLE AND IR BANDS; DEMONSTRATE THAT THE MODULES OPERATE PROPERLY WITH THE SENSOR SYSTEM AND PROVIDE DATA WHICH MEETS USER REQUIREMENTS	JSC/E & D	ABILITY TO PROVIDE MULTIPLE FLIGHTS FOR VARIOUS CONFIGURATIONS TAILORED LIGHTING CONDITION	BROAD APPLICATION OF MULTI-SPECTRAL SENSING REQUIRES HIGHER RESOLUTION AND MISSION TAILORED SPECTRAL BANDS	FEASIBILITY ESTABLISHED; CONCEPTUAL DESIGN STARTED; SPECTRAL PACKAGE SELECTION NOT PERFORMED; TECHNOLOGY LEVEL VS COST TRADES NOT MADE	AEROJET DESIGN STUDY UNDERWAY
SD 2	IMAGING RADAR	SENSOR DEVELOPMENT	DEVELOP AND DEMONSTRATE SAR SYSTEMS FOR USE IN PROVIDING HIGH-RESOLUTION CLOUD-FREE IMAGES; EVALUATE ALTERNATE ANTENNA, PROCESSING APPROACH; DEMONSTRATE ANTENNA, PROCESSING, AND TRANSMITTER SUBSYSTEM COMPATIBILITIES; AND ABILITY OF SYSTEM TO PROVIDE DATA WHICH MEETS USER REQUIREMENTS	JSC E & D JPL HUGHES	ABILITY TO CARRY AND DEPLOY LARGE ANTENNA SYSTEMS; ABILITY TO PROVIDE MULTIPLE FLIGHTS FOR VARIOUS CONFIGURATIONS	SEVERAL MISSIONS REQUIRE HIGH RESOLUTION UNINTERRUPTED COVERAGE AND MAY NOT RELY ON MULTI-SPECTRAL PROPERTIES OF RADAR INITIALLY (E.G. WATER INVENTORY)	OPERATIONAL USE FROM AIRCRAFT; FEASIBILITY FROM SPACECRAFT ESTABLISHED; SEASAT INSTRUMENT BEGINNING DEVELOPMENT; ANTENNA, PROCESSING APPROACH CRITICAL	JPL AND HUGHES BOTH HAVE DESIGN STUDY UNDERWAY
SD 3	PASSIVE MICROWAVE SENSOR	SENSOR DEVELOPMENT	DEVELOP AND DEMONSTRATE LARGE-APERTURE PASSIVE MICROWAVE SYSTEM; EVALUATE ALTERNATE ANTENNA AND SCAN MECHANISM APPROACHES; DEMONSTRATE PROPER INTER-RELATIONSHIP AMONG FREQUENCIES HAS BEEN ACHIEVED AND THAT DATA SATISFIES USER REQUIREMENTS	JSC JPL	ABILITY TO CARRY AND DEPLOY LARGE ANTENNA SYSTEMS; ABILITY TO PROVIDE MULTIPLE FLIGHTS FOR VARIOUS CONFIGURATIONS	SEVERAL MISSIONS REQUIRE UNINTERRUPTED LOW RESOLUTION COVERAGE OF MICROWAVE SENSIBLE DATA	MAJOR SYSTEM PARAMETERS NOT DETERMINED (E.G. ANTENNA SIZE, FREQUENCY, SCAN MECHANISMS; SCMS SCALE UP OF LARGE ANTENNA TECHNOLOGY PROBABLY REQUIRED.	JPL - SIMS DESIGN STUDY UNDERWAY

TABLE 2-4. EVALUATION OF REPRESENTATIVE MISSIONS (Continued) — CANDIDATE APPLICATION DEVELOPMENT MISSIONS

REFERENCE NUMBER	TITLE	SHUTTLE ROLE	DESCRIPTION	TYPICAL USER	USE OF SHUTTLE	MISSION IMPORTANCE	MISSION MATURITY	COMMENTS
1 (EM-7)	POWER PLANT THERMAL POLLUTION MONITOR	APPLICATION DEVELOPMENT	PERIODICALLY MONITOR THE EFFLUENT COOLANT TO DETERMINE AND ASSESS THE EXTENT & EFFECT OF THERMAL DISCHARGE PATTERNS OF POWER-PLANTS ON THEIR REGIONAL ENVIRONMENTS	ENVIRONMENTAL PROTECTION AGENCY, BUREAU OF SPORT FISHERIES AND WILDLIFE, POWER COMPANIES	ABILITY TO ORTHOGRAPHICALLY RECORD REGIONAL CONTEXT SIMULTANEOUSLY AT HIGH RESOLUTION, ABILITY TO TAILOR OVERFLIGHT TO LOCAL TIME	MODERATE-LOW, IMPORTANT TO ASSESS ENVIRONMENTAL IMPACT DIRECT ECONOMIC BENEFITS DIFFICULT	LOW, THERMAL SURFACE MEASUREMENTS DEMONSTRATED BY AIRCRAFT, BUT REGIONAL ENVIRONMENTAL EFFECTS NOT YET WELL-UNDERSTOOD	MAY BE COMBINED INTO REGIONAL ENVIRONMENTAL MONITORING AND PLANNING EFFORTS
2 (EM-4)	MINERAL EXTRACTION POLLUTION MONITOR	APPLICATION DEVELOPMENT	PERIODICALLY MONITOR AND INVENTORY THE AREAL EXTENT OF STRIP MINING OPERATIONS, THE QUALITY, PROGRESS, AND LEGAL COMPLIANCE OF THEIR RESTORATION.	ENVIRONMENTAL PROTECTION AGENCY, U.S. GEOLOGICAL SURVEY, BUREAU OF LAND MANAGEMENT, BUREAU OF MINES, MINING COMPANIES	EFFICIENT COVERAGE OF STATEWIDE AREAS	MODERATE-HIGH, STATUTORY REQUIREMENTS FIRMING.	MODERATE-HIGH, SEVERAL LANDSAT AND AIRCRAFT PROJECTS HAVE ACHIEVED RESULTS	
3 (AG-3)	AGRICULTURAL FARMING PRACTICES	APPLICATION DEVELOPMENT	PROVIDE THE REMOTELY SENSED INPUTS TO AN INTEGRATED FARMING PRACTICES CORRELATION MODEL INCLUDING DATA ON CULTIVATION CYCLES, METHODS, AND CROP YIELD	SOIL CONSERVATION SERVICE, ECONOMIC RESEARCH SERVICE, AGRICULTURAL RESEARCH SERVICE, STATE AGRICULTURE DEPTS.	EFFICIENT MULTI-RESOLUTION COVERAGE OF WIDELY DISPERSED SITES	MODERATE-LOW, REMOTE SENSING NOT A MAJOR PART OF TOTAL REQUIREMENTS BUT OVERALL ECONOMIC BENEFITS HIGH.	LOW-LANDSAT INVESTIGATIONS NOT SIGNIFICANTLY ADDRESSING AREA	INTEREST LIKELY TO INCREASE RAPIDLY IF CAPABILITY CAN BE SHOWN
4 (FOR-3)	FOREST FIRE DAMAGE/ REGROWTH ASSESSMENT	APPLICATION DEVELOPMENT	PERIODICALLY MONITOR AREAS WHICH HAVE BEEN DEVASTATED BY FOREST FIRE TO INVENTORY THEIR EXTENT, QUALITY OF RESTORATION, AND REGIONAL ENVIRONMENTAL EFFECT	US FOREST SERVICE, NATIONAL PARK SERVICE, STATE FORESTRY DEPTS, BUREAU OF LAND MANAGEMENT, PRIVATE LUMBER COS.	EFFICIENT MULTI-RESOLUTION INVENTORY OF WIDELY DISPERSED SITES; ABILITY TO ORTHOGRAPHICALLY RECORD REGIONAL CONTEXT SIMULTANEOUSLY AT HIGH RESOLUTION	MODERATE-LOW, POTENTIAL QUALITY INCREASE FOR EXISTING FUNCTION	MODERATE-SEVERAL AIRCRAFT AND LANDSAT PROJECTS USED FOR SPECIFIC FIRE-DAMAGED REGIONAL PROJECTS	WILL REQUIRE CONSIDERABLE ON-SITE OBSERVATIONS

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 2-4. EVALUATION OF REPRESENTATIVE MISSIONS (Continued) CANDIDATE APPLICATION DEVELOPMENT MISSIONS (Continued)

REFERENCE NUMBER	TITLE	SHUTTLE ROLE	DESCRIPTION	TYPICAL USER	USE OF SHUTTLE	MISSION IMPORTANCE	MISSION MATURITY	COMMENTS
5 (AG-5)	WORLD CROP SURVEY	APPLICATION DEVELOPMENT	OBTAIN HIGH RESOLUTION FIELD SAMPLE DATA ON A GLOBAL BASIS TO INCREASE ACCURACY AND NUMBER OF CROP PRODUCTION FORECASTS.	STATISTICAL REPORTING SERVICE, FOREIGN AGRICULTURE SERVICE, UNITED NATIONS (FAO)	ABILITY TO PROVIDE HIGH-RESOLUTION ON A GLOBAL BASIS FROM TAILORED ORBITS	HIGH-WILL PROVIDE PREVIOUSLY UNOBTAINABLE DATA; LEADS TO GLOBAL SATELLITE SYSTEM	MODERATE, LACIE PROGRAM UNDERWAY; MUCH EFFORT ALREADY EXPENDED	SHUTTLE UTILIZATION NOT YET CONSIDERED
6 (EM-1)	MINERAL EXPLORATION SURVEY	APPLICATION DEVELOPMENT	PROVIDE IMAGERY FOR GEOLOGICAL ANALYSIS IN ORDER TO ACCOMPLISH PRELIMINARY MINERAL EXPLORATION RECONNAISSANCE SURVEYS	PRIVATE MINERAL FIRMS, US GEOLOGICAL SURVEY, BUREAU OF MINES, STATE GEOLOGY OFFICES	ABILITY TO PROVIDE REGIONAL CONTEXT SIMULTANEOUSLY AT HIGH RESOLUTION; ABILITY TO TAILOR AND/OR VARY LOCAL LIGHTING FOR MAXIMUM INTERPRETABILITY	HIGH (POTENTIAL), CURRENT PRIVATE EXPENDITURES INDICATIVE OF USER SUPPORT	MODERATE-HIGH, SEVERAL SUCCESSFUL LANDSAT INVESTIGATIONS	GOOD CANDIDATE FOR TASK 6 CONSIDERATION OF A PRIVATE COMMERCIAL USER
7 (MAR-5)	MARINE NAVIGATION HAZARD MONITOR	APPLICATION DEVELOPMENT	PROVIDE HIGHLY ACCURATE INFORMATION ON EXTENT AND LOCATIONS OF DYNAMICS OF NAVIGATION HAZARDS SUCH AS SAND BARS, SHOALS, LAND MASS, AND REEFS	NOAA US COAST GUARD, FOREIGN OCEANOGRAPHIC OFFICES*	ABILITY TO PROVIDE HIGH RESOLUTION ON A GLOBAL BASIS FROM TAILORED ORBITS; ABILITY TO TAILOR LOCAL LIGHTING FOR WATER PENETRATION.	MODERATE, POTENTIAL COST AND QUALITY IMPROVEMENT IN PRODUCING EXISTING PRODUCTS	LOW-SIGNIFICANT QUESTIONS EXIST CONCERNING THE ABILITY TO ROUTINELY SENSE HAZARD DYNAMICS	
8 (SEOPS LAND 3)	URBAN LAND USE/ CENSUS	APPLICATION DEVELOPMENT	PROVIDE HIGH RESOLUTION CAMERA AND MULTI-SPECTRAL DATA TO URBAN MANAGERS FOR LAND USE PATTERN DETECTION	METROPOLITAN PLANNING COMMISSIONS, CITY/COUNTY GOVERNMENTS, US CENSUS BUREAU*	ABILITY TO PROVIDE HIGH RESOLUTION COVERAGE SIMULTANEOUS WITH REGIONAL CONTEXT OVER WIDELY-DISPERSED URBAN AREAS	SIGNIFICANT IMPROVEMENT TO USERS; INVOLVEMENT OF NON FEDERAL GOVERNMENT; MODERATE-HIGH ECONOMIC BENEFITS; TECHNOLOGY IMPETUS TO USERS	MODERATE, EXPERIENCE WITH AIRCRAFT DATA, POSITIVE INDICATIONS FROM LANDSAT INVESTIGATIONS	GOOD FOUNDATION LAID WITH PREVIOUS TERSSE ACTIVITY

*ADDED TO PREVIOUSLY-IDENTIFIED USERS IN TERSSE FINAL REPORT, VOL. 3.

TABLE 2-4. EVALUATION OF REPRESENTATIVE MISSIONS (Continued) — CANDIDATE APPLICATION DEVELOPMENT MISSIONS (Continued)

REFERENCE NUMBER	TITLE	SHUTTLE ROLE	DESCRIPTION	TYPICAL USER	USE OF SHUTTLE	MISSION IMPORTANCE	MISSION MATURITY	COMMENTS
9 (FOR-1)	FOREST TIMBER VOLUME INVENTORY	APPLICATION DEVELOPMENT	INVENTORY THE LOCATION, VOLUME AND QUALITY OF USEABLE TIMBER SUPPLIES TO ASSIST IN HARVEST MANAGEMENT DECISIONS	US FOREST SERVICE BUREAU OF LAND MANAGEMENT BUREAU OF INDIAN AFFAIRS PRIVATE LUMBER COS.	ABILITY TO PROVIDE MULTIPLE RESOLUTION COVERAGE OF LARGE REGIONS NECESSARY FOR MULTI-STAGE SAMPLING	MODERATE-HIGH, POTENTIALLY SIGNIFICANT COST AND QUALITY IMPROVEMENT IN [illegible]ORMATION [illegible]PUTS TO TIMBER LEASE, HARVESTING MANAGEMENT DECISIONS	HIGH-LANDSAT AIRCRAFT, AND APOLLO EXPERIENCE HAVE PROVIDED BACKGROUND	HIGH CURRENT INTEREST
10 (LU-1)	US LAND USE INVENTORY	APPLICATION DEVELOPMENT	PERIODICALLY PROVIDE DATA FROM WHICH LAND USAGE CLASSIFICATIONS CAN BE OBTAINED AS THEMATIC OUTPUTS AND TEMPORAL CHANGES DETECTED OVER THE ENTIRE UNITED STATES	US GEOLOGICAL SURVEY BUREAU OF LAND MANAGEMENT STATE PLANNING DEPTS. REGIONAL PLANNING DEPTS.	ABILITY TO TAILOR LIGHTING, RESOLUTION SPECTRAL RESPONSE TO LEVEL AND CLASS OF LAND USE SOUGHT	MODERATE-HIGH, PENDING LAND USE LEGISLATION LENDS IMPORTANCE, AREA REQUIRES FOCUS AND ORGANIZATION	MODERATE, AIRCRAFT EXPERIENCE AND INVESTIGATIONS ENCOURAGING	
11 (LU-2)	LANDFORM AND COVER MAPPING	APPLICATION DEVELOPMENT	PERIODICALLY PROVIDE DATA FROM WHICH A VARIETY OF PHYSICAL CHARACTERISTICS THEMES MAY BE MADE AND THEIR TEMPORAL CHANGES DETECTED OVER THE UNITED STATES	US GEOLOGICAL SURVEY BUREAU OF RECLAMATION SOIL CONSERVATION SERVICE STATE NATIONAL RESOURCE DEPTS	ABILITY TO PROVIDE SYNOPTIC COVERAGE AT HIGH RESOLUTION OVER REGIONAL AREAS; ABILITY TO TAILOR LIGHTING SPECTRAL RESPONSE, AND RESOLUTION	MODERATE - ECONOMIC BENEFITS NOT DETERMINED	MODERATE, AIRCRAFT EXPERIENCE AND LANDSAT INVESTIGATIONS ENCOURAGING	
12 (WAT-1)	IMPOUNDED WATER SUPPLY INVENTORY	APPLICATION DEVELOPMENT	PROVIDE DATA ON AT LEAST A REGIONAL BASIS TO ALLOW THE INVENTORY OF IMPOUNDED (MAN MADE AND NATURAL) SURFACE WATER SUPPLIES	CORPS OF ENGINEERS BUREAU OF RECLAMATION SOIL CONSERVATION SERVICE STATE WATER AGENCIES	ABILITY TO SIMULTANEOUSLY COVER REGIONS WITH SYNOPTIC AND HIGH-RESOLUTION SENSING	MODERATE, POTENTIAL QUALITY AND COST IMPROVEMENTS OF AN EXISTING OPERATION	LOW-LITTLE EXPERIENCE ON REGIONAL BASIS; SOME LOCAL EFFORTS SUCCESSFUL	

Importance: each of the representative missions should qualify as being significant to the Earth Resources Program (ERP). This criteria involves consideration of several aspects including:

- economic benefits attributable to the mission
- synergism with other parts of ERP
- importance of the mission to the user and his resource management function
- recognition of limiting item for technique and sensor development missions

All of these aspects, taken together, comprise the importance criteria.

Maturity: each of the representative missions should be sufficiently established so that reasonable confidence exists for success during the early Shuttle program (nominally the first two years). This concept of maturity includes success of previous efforts and expected availability of sufficient expertise for its continued progress.

Integrated Program: the five representative missions selected for further study should be typical of the breadth and range of Shuttle applications anticipated for the Earth Resources Program. To the extent practical in a selection of five, the missions should be selected with an eye on their ability to represent the various extremes of applications.

Each of the candidate missions was evaluated with respect to these criteria and the results indicated in Table 2-4. Based on consideration and evaluation of these criteria the five representative missions selected are:

SHUTTLE SORTIE ROLE	REFERENCE #	EARTH RESOURCES MISSION
TECHNIQUE DEVELOPMENT	TD-1	REMOTELY SENSED SOIL MOISTURE
SENSOR DEVELOPMENT	SD-2	ACTIVE IMAGING RADAR
APPLICATION DEVELOPMENT	AD 8	URBAN LAND USE/CENSUS
	AD 6	MINERAL EXPLORATION SURVEY
	AD 9	TIMBER VOLUME INVENTORY

The five missions have several significant characteristics when considered collectively as a set (in addition to their individual one-at-a-time merits.) The three application development missions involve three different types of resource managers: Timber Inventory (Federal Agency), Urban Land (non-Federal governments, i.e. city, county, state) and Mineral Exploration (private mineral exploration and mining companies).

The five missions span the entire spectral range with active radar, passive microwave, visible, and infrared sensors. Each is utilized for missions which reflect the maturity of their use (e.g. visible and infrared sensing for application development, and microwave for soil moisture technique development). The orientation of these five missions is towards a broad-spectrum research and development program as opposed to solely on operational objectives. The Remotely Sensed Soil Moisture and Active Imaging Radar missions support early-phase R&D while the application development missions are more mature system demonstration R&D objectives.

It should be noted that, for this second stage of selection no attempt was made to identify "better" missions or to quantify each mission's suitability against the selection criteria. The set of five missions selected represents an optimal set for the purposes of the study, and the inclusion or exclusion of a specific mission should not be construed as indicative of its relative importance to either the Earth Resources Program or the Space Shuttle Program in the whole.

SECTION 3

MISSION DESCRIPTIONS

In this section each of the five selected missions is analysed in depth to define the following mission related factors:

- Detailed mission description
- User community and benefit mechanism for the mission
- Shuttle flight justification
- Sensor requirements
- Flight program requirements
- Test site selection
- Data processing requirements
- Data analysis and information presentation requirements.

A full understanding of all these factors is essential to the implementation of a comprehensive program which efficiently accomplishes the objectives of each mission.

The five missions addressed in this section are:

- Remotely Sensed Soil Moisture
- Active Imaging Radar
- Urban Land Use/Census
- Mineral Exploration Survey
- Timber Volume Inventory

The Soil Moisture mission represents the use of Space Shuttle in its Technique Development role and the Imaging Radar mission is representative of the Sensor Development role. The latter three missions are representative examples of using the Space Shuttle sortie flights in the Application Development role.

3.1 REMOTE SENSING OF SOIL MOISTURE

The Remote Sensing of Soil Moisture is a mission which is representative of using the Space Shuttle sortie flights in the Technique Development role. Technique development is a research oriented activity whose goal is to identify and perfect a basic remote sensing technique; the Shuttle serves as a space borne platform.

3.1.1 BACKGROUND AND MISSION DESCRIPTION

The objective of this mission is the development of remote sensing techniques for the determination of the amount of free water in a particular soil sample from a space platform. Free water implies the potential for this water to be used in various hydrological processes as opposed to water which is hygroscopically or molecularly bound to the soil and is unavailable for drainage, runoff, evaporation, or use by plant life. The application of soil moisture data to resource management spans a surprisingly wide range of disciplines. In agriculture, soil moisture data is believed to be a key ingredient in the ability to predict crop yield. Although it has been shown that monitoring vegetation vigor can determine the health of a particular species, once drought-caused stress occurs, it is too late to prevent damage. A measure of soil moisture (or lack of it) prior to damage could signal trouble. In addition, if soil moisture data could be obtained on a fine scale (≈50 m or less) it would be beneficial to individual agricultural units in aiding judgement as when to fertilize or irrigate. With accurate soil moisture data it should be possible to time these two very important phases more precisely and effect savings while increasing yield and efficiency. There are several other agriculture related applications for which remotely sensed soil moisture data would be beneficial. These include monitoring of federal rangelands to determine optimum grazing times as well as the number of head of cattle (or animal units) which the range can support.

In the field of hydrology several important applications exist which require soil moisture data input. The study of natural watershed areas and predictions of their runoff potentials is at best an approximate science at the present time. However, it is felt that with good soil moisture data as well as accurate watershed boundary delineation these runoff potentials could be calculated more accurately, thus, providing valuable information for flood control, dam construction and water resource management in general.

In the field of meteorology there is an important application of soil moisture data. As a part of large scale weather generation processes, evaporative heat transfer at the air/soil interface is a major contributor of heat to the environment. This is very important to prediction of weather patterns on a large scale and present models for this predictive process require inputs of soil moisture data. The ability to routinely collect soil moisture data at the right spatial scale will aid in the improvement of global weather pattern predictions.

Several additional uses of soil moisture data may be grouped together under the general title of soil conservation. These include monitoring of critical flood plain areas such as the Mississippi and small scale monitoring of unstable soil slopes to predict slope failure (landslide). These applications are less mature at this time than the others mentioned and require further development based on the availability of soil moisture measurement techniques.

Three basic measurement approaches have been suggested for obtaining soil moisture information by remote sensing methods. Two of these operate in the visible and near infrared region of the electromagnetic spectrum, while the third utilizes energy in the microwave region. Within these basic approaches there are subsets with slight variations, such as purely active or purely passive sensors. At the present time none of the approaches can be considered operational but are mature enough in terms of being based on sound analytical models and fairly well developed instruments so that they can be realistically considered for the Soil Moisture technique development mission.

The first approach, which uses optical methods, measures surface soil moisture to a depth of a few μm. through the phenomena of polarization of scattered light. As the surface soil moisture content increases, light from an unpolarized source (the sun) experiences more polarization when scattered from the soil. By using a sensitive instrument called a photopolarimeter it is possible to measure the degree of polarization and correlate it to the amount of soil moisture. Figure 3-1* demonstrates the degree of polarization observed as a function of soil moisture based on laboratory and aircraft flight measurements.

A photopolarimeter may be designed with a small instantaneous field of view yielding the fine spatial resolution required by some soil moisture applications. Current instruments are "single spot" types, however mechanical scanning can provide wide area coverage, and the emergence of photodiode arrays allow solid state imaging sensors to be developed. Several unknown areas must be investigated before this approach may be considered viable, including operation over vegetative cover, operation with multiple spectral band coverage, and determination of sensitivity to viewing angle in the principal plane. One very encouraging result noticed to date in measurements over bare fields was a lack of sensitivity to soil type. Due to the reliance on sunlight as the source of illumination, however, this approach suffers all the classical drawbacks of other optical or spectral analysis systems and must have clear atmospheric conditions and operate in daylight.

A second measurement approach is termed spectral analysis. This implies that total radiance in a specific spectral band is the parameter of interest rather than the degree of polarization. Within this approach class of spectral analysis are two subsets: spectral reflectance in the region from .4 μm to 2.0 μm (visible to near infrared, IR) and the measurement of diurnal temperature differences using far infrared (10 μm). The spectral reflectance method is based on the fact that as soil moisture content

*Source: Stockoff, E. H. and Frost, R. T.; "Remote Detection of Soil Surface Moisture", 9th International Symposium on Remote Sensing of Environment; Ann Arbor, Mich., 1974

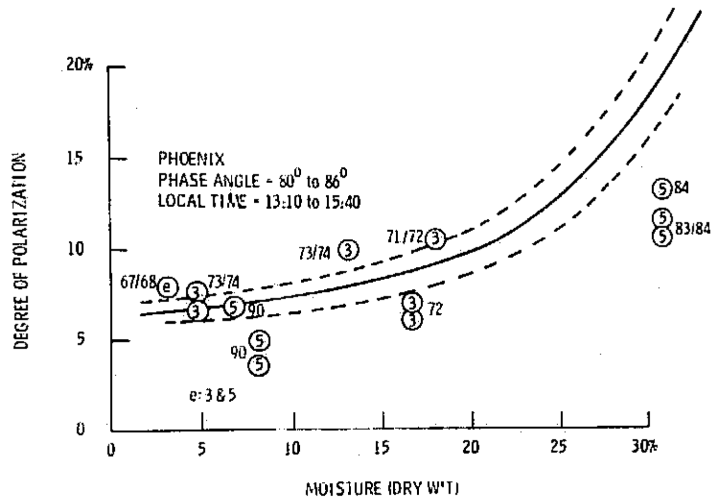


Figure 3-1. Degree of Polarization vs Soil Surface Moisture (0 - 1/4 inch)

increases, the reflectance from that soil decreases. Figure 3-2* demonstrates this effect for a particular soil type. The diurnal temperature difference method relies on the increased thermal capacity of moisture laden soil and the corresponding difference in heating and cooling rates during the day.

Both methods can be implemented through the use of a multispectral scanner such as the MSS flown on Landsat or the S192 used on Skylab. In addition, the diurnal ΔT approach can also use imaging IR radiometers to make the measurement. Each of the methods enjoys the advantages of relatively fine spatial resolution achievable with scanners or imaging IR radiometers but each also has several serious disadvantages which raise questions as to its application as a quantitative measurement. For example, it has been seen that the spectral radiance in all portions of the visible spectrum is highly dependent on the type and density of vegetation present as well as on the composition and roughness of the soil.

The third basic technique which has been shown to be useful in remote determination of soil moisture is the application of microwave sensors, both active and passive. Three different applications of microwave

*Source: Blanchard, M. B., Greeley, R. and Goettleman; "Use of Visible, Near-Infrared, and Thermal Infrared Remote Sensing to Study Soil Moisture", 9th International Symposium on Remote Sensing of Environment, Ann Arbor, Mich., 1974

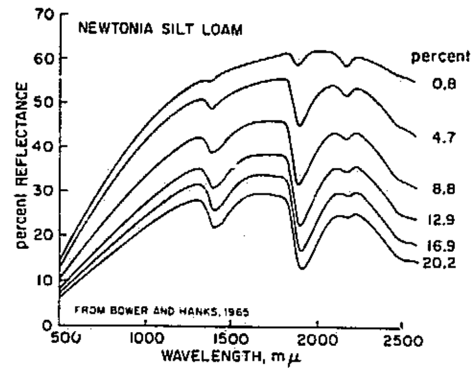


Figure 3-2. Percent Total Reflectance vs Wavelength for Various Moisture Contents Showing Water Absorption Bands at 1.4 and 1.9 Microns

measurements are available: scatterometer (active), imaging radar (active) and microwave radiometry (passive).

The methodology used in the application of both scatterometers and imaging radar is very similar. It has been shown that the backscatter cross section σ_0 for soils is a function of the soil moisture, (see Figure 3-3*). Thus, a determination of backscatter cross section at some (or several) incidence angles less than 20° can provide a measure of soil moisture. The scatterometer makes this measurement as an average over a relatively large area, the imaging radar provides the potential for such measurements over a smaller instantaneous field of view within the total ground area viewed by the sensor.

The use of a passive microwave radiometer depends on the fact that a good correlation has been established between the brightness temperature of soil samples and the moisture content. Figure 3-4** shows the empirical relationship in graphical form for measurements using a 1.5 GHz microwave radiometer.

*Source: Ulaby, F. T.; Chilar J.; and Moore R. K. "Active Microve Measurement of Soil Water Content"; Remote Sensing of Environment (3); pp 185-203; 1974.

**Source: Schmugge, T.; P. Gldersen; Wilheit, T.; and Geiger F.; "Remote Sensing of Soil Moisture with Microwave Radiometers"; Journal of Geophysical Research (RED); Vol 79; No 2; Jan. 10, 1974; pp 317-323.

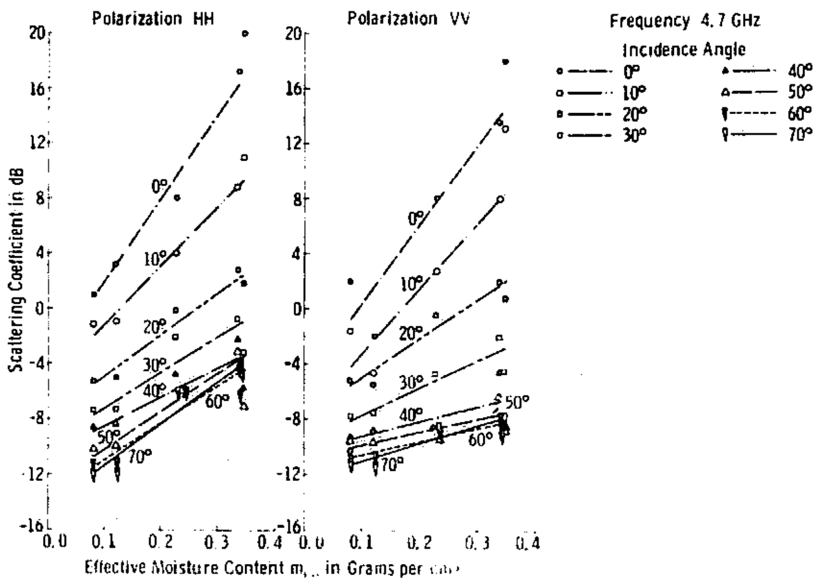


Figure 3-3. Scattering Coefficient as a Function of Effective Moisture Content. Frequency is 4.7 GHz

Table 3-1 summarizes the various methods discussed and their limitations and development requirements. The Technique Development mission for Remote Sensing of Soil Moisture will be conducted via a series of flights using several sensors simultaneously. A primary goal of the mission is the further investigation of the limitations of each of the methods, and an evaluation of the extent to which use of two or more of the methods simultaneously can provide a significant improvement in measurement accuracy at the desired spatial resolution.

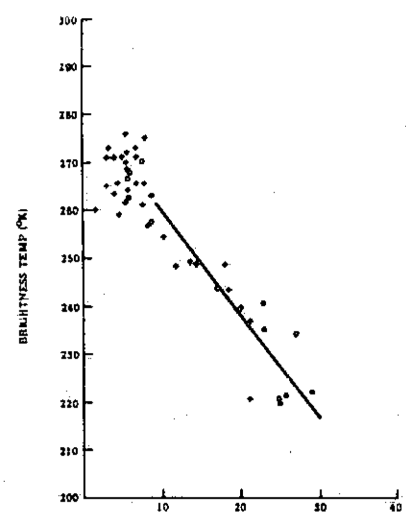


Figure 3-4. Plot of 21-cm Brightness Temperatures versus Soil Moisture for Bare Fields. Plus signs Indicate Sandy Loam; Open Circles Indicate Clay Loam.

TABLE 3-1. SOIL MOISTURE MEASUREMENT TECHNIQUE SUMMARY

	POLARIMETER	SPECTRAL ANALYSIS	DIURNAL TEMPERATURE	IMAGING RADAR	SCATTEROMETER	MICROWAVE RADIOMETER
OBSERVABLE PARAMETERS	POLARIZATION OF REFLECTED SOLAR RADIATION	CHANGE IN SPECTRAL SIGNATURE OF SOIL	DIFFERENTIAL HEATING AND COOLING OVER THE DIURNAL CYCLE	RADAR BACKSCATTER CROSS-SECTION	RADAR BACKSCATTER CROSS-SECTION	SURFACE BRIGHTNESS TEMPERATURE
SPATIAL RESOLUTION	>50 METERS	>50 METERS	50 - 500 METERS	>20 METERS	>1000 METERS	>500 METERS
MEASUREMENT ACCURACY	±1% MOISTURE	±2% MOISTURE	±2% MOISTURE	UNKNOWN	±1% MOISTURE	±1% MOISTURE
LIMITATIONS OF METHODS	• OBSCURATION BY CLOUDS • CLEAR SUNLIGHT REQUIRED • VEGETATION OBSCURES MEASUREMENT	• VARIATION DUE TO PRESENCE OF VEGETATION, SOIL TYPE, ETC. • REQUIRES UNOBSCURED (CLOUD FREE) VISION • REQUIRES SUNLIT SCENE	REQUIRES 2 FLIGHTS APPROX 12 HOURS APART WITHOUT OBSCURATION, AND NO MOISTURE CHANGE	COMPLEX, COSTLY SENSOR HIGH DATA RATE COMPLEX DATA PROCESSING REQUIREMENTS	COARSE RESOLUTION SENSITIVE TO VEGETATIVE COVER	COARSE RESOLUTION
STATUS OF METHOD	CORRELATION OF POLARIZATION VS SOIL MOISTURE WELL BEHAVED. LITTLE FLIGHT EXPERIENCE WITH AIRCRAFT OR S/C	PROBABLY NOT ADEQUATE FOR QUANTITATIVE MEASUREMENTS BUT USEFUL IN SUPPORTIVE ROLE (e.g., ELIMINATION OF EFFECTS OF VEGETATIVE COVER) DO NOT REQUIRE NEW SENSOR, MUCH FLIGHT EXPERIENCE AVAILABLE FOR MULTISPECTRAL SCANNERS AND IR RADIOMETERS.		NO SENSORS CURRENTLY AVAILABLE FOR S/C FLIGHTS. UNCERTAINTY AS TO METHOD OF EXTRACTING SOIL MOISTURE DATA FROM RADAR IMAGERY	SENSOR TECHNOLOGY WELL DEVELOPED, GOOD THEORETICAL MODELS OF PHENOMENA AVAILABLE WITH HIGH POTENTIAL FOR QUANTITATIVE RESULTS	GOOD CORRELATION OF BRIGHTNESS TEMPERATURE WITH SOIL MOISTURE. GOOD AGREEMENT BETWEEN THEORETICAL MODELS AND FLIGHT EXPERIMENT RESULTS
FUTURE DEVELOPMENTS	DEVELOP A/C SENSOR FOR IMAGING POLARIMETERS. CONTINUE A/C FLIGHT PROGRAM TO VERIFY THEORETICAL MODELS	CONTINUE CURRENT FLIGHT PROGRAMS		CONTINUE A/C FLIGHT PROGRAM TO DEVELOP METHODOLOGY AND ANALYTICAL TOOLS	CONTINUE A/C FLIGHT PROGRAM TO VERIFY AND EVALUATE EFFECTS OF VEGETATION, SOIL ROUGHNESS AND PARTICLE SIZE, AND SELECT OPTIMUM FREQUENCIES	FURTHER AIRCRAFT FLIGHTS REQUIRED TO IDENTIFY OPTIMUM FREQUENCIES AND CHARACTERIZE RESPONSE TO SOIL TYPE, ROUGHNESS, VEGETATION. DEVELOPMENT OF SPACEBORNE SENSOR

The techniques to be investigated during the initial phase of the technique development mission will be limited due to the non-availability of the active microwave sensors (scatterometer and synthetic aperture radar). In addition, the diurnal temperature method is impractical for Shuttle flights because of orbital constraints which do not permit coverage of the same test site every 12 hours. Thus, the techniques which will be evaluated are:

- Polarimeter measurement
- Spectral Analysis
- Microwave Radiometry

3.1.2 USER COMMUNITY AND BENEFIT MECHANISMS

Technique development missions are intended to provide a groundwork upon which a specific method of obtaining remotely sensed earth resource data may be developed. Their end goal is not to actually collect the particular data in question (this is done in an Application Development or operational mission) but to test various methods and verify the technique being considered. For this reason a technique development mission may encompass several flights, each having a different end objective, but the overall goal is to finally arrive at a preferred way of gathering the required data.

In this instance the required data will be soil moisture and the mission is to investigate various possible ways of remotely measuring soil moisture and to verify which technique will ultimately satisfy the requirements. Although the mission (by its unique definition) produces no data for a specific application, there is still a community of users who support the mission and are vitally interested in its progress. The immediate users of results from this mission consist of those researchers involved in evaluating and recommending soil moisture measuring techniques. These consist of academic scientists and researchers, engineers and scientists at the interested NASA centers and several potential users of actual soil moisture data such as USDA. These users will concentrate on evaluations of the utility of a specific approach in gathering soil moisture and the applicability of the technique to eventual operational use. Thus the users for a technique development mission differ from the users for an operational mission.

Several of these users have been involved in research and basic investigation of soil moisture for several years and presently are participating in the NASA funded efforts which continue this work. In addition to those users already identified there are several other potential users of remotely sensed soil moisture data including regional land use agencies, the National Weather Service, the Army Corps of Engineers and the Soil Conservation Service of the USDA; most of these however, are ultimate operational users not Technique Development users.

Similarly, because of the nature of the technique development mission, the benefit mechanism is also not clearly defined. It is not possible to stipulate direct cost benefits to be derived from the development of operational techniques - such benefits result indirectly from the improvements in applications missions which use, in this case, soil moisture data as a part of the overall data input.

3.1.3 JUSTIFICATION FOR SHUTTLE PROGRAM

Shuttle sortie missions flown for technique development purposes are intended to provide the foundation upon which is built the application of a remote sensing technique for use in several resource management applications. This is accomplished through early investigative flights utilizing various promising remote sensing approaches designed to explore specific techniques. It is important to realize that the object here is not the actual data for application to a resource management problem, but the verification of the techniques proposed in order to effect eventual maturation into an operational class. It is felt that the Technique Development role is an important one for Shuttle and fits several emerging remote sensing practices and resource management needs.

To these ends the Shuttle lends many valuable characteristics such as the ability to recover a payload intact and perform subsequent repairs, refurbishment or modifications.

A further key aspect of the application of the Shuttle to the technique development mission selected (Soil Moisture measurement) is the ability to fly various payloads representing the different experimental methods described earlier so that different combinations of these methods may be evaluated. This flexibility also includes the capability for verifying techniques with improved sensors as they become available.

A final reason for using Shuttle as the platform for soil moisture technique development where passive microwave sensors are concerned lies in the size of the aperture required to achieve meaningfully homogenous data cells on the Earth's surface. The largest passive microwave radiometer to be flown in space by the early 1980's will have been the Scanning Multichannel Microwave Radiometer (SMMR) which is scheduled to fly on Seasat A. An effective resolution increase of 10x can be achieved with the use of the Shuttle Imaging Microwave Sensor (SIMS) on Shuttle. This results from both increase in aperture (~5x) and lower flight altitude (~2x).

3.1.4 SENSOR REQUIREMENTS

The intent of the technique development mission is twofold - to develop individual techniques and to evaluate the improvements to be derived as a result of using the different individual techniques in a complementary manner. The sensors required for the mission must, therefore, be flown as a single package whenever possible.

The sensor requirements for this soil moisture mission consist of those sensors which in existing experiments have shown realistic promise of providing measurements relatable to soil moisture. Four major sensor types have shown (refer to Figures 3-1 through 3-4) promise for being able to indicate soil moisture content, either alone or in combination with each other. These four are optical polarization, multispectral signature, passive microwave radiometry, and active microwave scatterometry. High resolution, large aperture, microwave scatterometry requires a sensor such as the Synthetic Aperture Radar (SAR); the SAR and its development are the subject of section 3. 2 of this report.

The sensor requirements are tabulated in Table 3-2. From this table it will be seen that a spot photopolarimeter of the type currently being flown on the NASA CV-990 aircraft, the Thematic Mapper, and the Shuttle Imaging Microwave Sensor (SIMS) will be required to satisfy the sensor needs.

TABLE 3-2. SOIL MOISTURE MISSION SENSOR REQUIREMENTS

	POLARIMETER	MULTISPECTRAL SCANNER	MICROWAVE RADIOMETER
SPECTRAL BANDS	10-15 NM in 400-1000NM SPECTRAL REGION	6 BANDS IN 400-2500NM SPECTRAL REGION	11 BANDS IN 0. 6-120 GHz REGION
INSTANTANEOUS FIELD OF VIEW	1°	30 μRAD (~15 METERS)	0. 1 to 17°, DEPENDING ON FREQUENCY
TOTAL FIELD OF VIEW	SPOT SCAN WITHIN ±60° OF NADIR	60 KM	±60° OF NADIR
SENSITIVITY	±0. 5% POLARIZATION	1% REFLECTANCE	±1°K

In as much as the photopolarimeter is a relatively unfamiliar sensor, the following few paragraphs will provide a brief summary description.

Laboratory and CV-990 flight test of the photopolarimeter instrument have shown that polarization of reflected visible light is one of the more sensitive techniques available for remote detection of soil surface moisture. One of the advantages of this technique is the relatively large amount of reflected power available within narrow bandwidths which can be selected to minimize unwanted light, such as that from sparse foliage on a nearby bare field, and the relatively high quantum efficiency of available detectors in the visible range of wavelengths. The one degree instantaneous field of view affords a suitable area resolution from the minimal orbit altitude to correlate soil moisture measurements with the prime instrument, SIMS. Following is a brief description of the measurement technique.

The moisture content of the soil surface viewed by the polarimeter is measured by determining the angle through which the light has been scattered by the soil and by observing the degree of polarization of this light produced during its interaction with the soil. The polarimeter then measures this degree of polarization in terms of the first three Stokes parameters, called here I, Q and U. Q and U are measured by the polarimeter as the difference between two readily measured light intensities. A development of the representation of polarized light in terms of these parameters may be defined as follows.

I = total intensity of light

$Q = IP \cos(2X)$

$U = IP \sin(2X)$

where P is the degree of polarization of the light and X is the angle formed between a reference plane, defined by the viewing direction and, usually, the vertical, and by the plane of polarization of the light. To obtain maximum angular scanning range through the aircraft window, the reference plane was oriented as shown in Figure 3-5 with $\beta = 22.5°$ relative to the "plane of incidence" of the window. The plane of incidence is defined by the normal to the window and the viewing direction. One of the three optical barrels of the polarimeter measures I, in the form I/2, while each of the other two barrels measures the intensity of light as transmitted through a polarizing prism. The resulting intensity B, in one case for the prism whose transmitting axis is oriented as shown and labeled "B" in Figure 3-5, and intensity D, in the other case for which an axis labeled "D" is shown, were then combined electronically to produce Q and U as follows.

$Q/2 = B - 1/2$

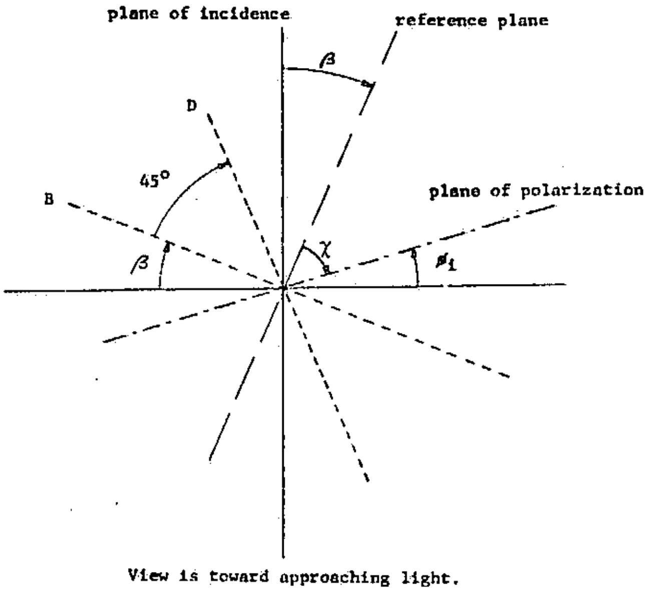
$U/2 = D - 1/2$

Two of the three parameters, I, Q and U, are sufficient to calculate the degree of polarization but, to permit a choice of which combination is used, to minimize error in the calculation, all three are measured and recorded. Because it was necessary to make the measurements by oblique viewing through a window in the pressure hull of the aircraft, a correction must be applied to the data to account for 1) the change in magnitude and orientation of plane of polarization of the polarized compartment, 2) the attenuation of the unpolarized compartment and 3) the generation of a polarized component from the unpolarized component, all due to the presence of the window.

A photodiode array polarimeter would be used as an advanced version of this sensor in later flights if the spot-scanning instrument bears out the fruitfulness of the polarization sensing approach.

3.1.5 FLIGHT PROGRAM AND TEST SITES

In order to accomplish the objectives of the mission, and to gather data for as wide a range of soil moisture conditions as possible, several flights of the full sensor complement should be made at different times of



ORIGINAL PAGE IS
OF POOR QUALITY

Plane of Incidence: Plane defined by normal to window in aircraft and viewing direction.

Reference Plane: Plane from which orientation of plane of polarization is measured.

Plane of Polarization: Plane in which electric vector of light has its maximum value.

B: Plane of transmission of polarizing prism in one of the barrels of the photopolarimeter. This plane is normal to the reference plane.

D: Plane of transmission of polarizing prism in another of the barrels of the photopolarimeter. (Plane of transmission means plane in which electric vector of light is completely transmitted.)

β: Arbitrary angle between photopolarimeter reference plane and normal to window. In the work reported here, $\beta = 22.5^{\circ}$.

ϕ_i: Angle indicating orientation of plane of polarization of light after having passed through aircraft window.

χ: Angle indicating orientation of plane of polarization relative to reference plane; used in general expression for Q & U.

Figure 3-5. Orientation of Planes Identified in the Discussion of Stokes Parameters

the years. Each flight must be correlated closely with extensive ground truth and aircraft underflights. For the soil moisture technique development mission, several Shuttle sortie flights will be required, one at least during each season in order to gather data under different weather and vegetative cover conditions. In addition, the Shuttle orbit should be (or be adjusted, refer to Section 5, to be) such that a short revisit cycle, on the order of a couple days, is obtainable to assess the temporal effects. The Shuttle flight must have a nominal orbit inclination (approximately 35°) sufficient to include several calibration and well instrumented test sites such as swamps, deserts, and controlled fields (varying area, bare, vegetated, irrigated, etc.).

Because of the research nature of technique development, it will be necessary to conduct a sizeable ground truth and auxillary data acquisition program to obtain measurements coincident (within two hours) with the Shuttle flights. These measurements must include the obtaining of soil samples, weather and atmospheric observations, detailed descriptions of the test sites, and similar data. It may be necessary to schedule supporting aircraft underflights with well instrumented aircraft over the same areas.

3.1.6 DATA PROCESSING AND INFORMATION DISSEMINATION

Sensor data for the soil moisture technique development mission will be preprocessed in the Shuttle data preprocessing facility. Further analysis will be performed using both the extractive processing facility and general purpose computers by individual members of the technique development program team. Figure 3-6 schematically shows the data processing steps required.

Because of the limited research nature of the mission, information dissemination can be conducted by informal transfer of information between team members, with publication of the methodology and results as the final dissemination step.

3.2 SYNTHETIC APERTURE RADAR (SAR) DEVELOPMENT

The Synthetic Aperture Radar (SAR) Development mission is one which is representative of using the Space Shuttle sortie flights in the Sensor Development role. The goal of sensor development is to perfect and optimize, in an engineering sense, a sensor whose utility has been established in technique development and for which there is an application(s) need. The role of the Shuttle is that of a space borne engineering laboratory test platform.

3.2.1 BACKGROUND AND MISSION DESCRIPTION

The intent of the sensor development mission for a Synthetic Aperture Radar is the verification, by flight of prototype hardware, of the design of the SAR as a sensor. It is not intended as a means of providing SAR data to applications users or resource managers. In this respect the sensor development mission is similar in purpose to the technique development mission - namely to provide a vehicle for the development of optimum flight hardware which may subsequently be used as an operational sensor. The final product is the detailed sensor design requirements for an operational sensor. The immediate user of data from the sensor development mission is the sensor development manager.

The SAR is an outgrowth of two decades of development, starting with the development of the synthetic aperture concept in 1950. Early attempts at flying imaging radars in aircraft resulted in the SLAR (Side Looking Airborne Radar) which used brute force techniques with long antenna aperture and high peak powers to achieve fine resolution imagery. The synthetic aperture approach permits the synthesis of an "effective aperture" which can be several times longer than the vehicle on which the radar is carried as a result of

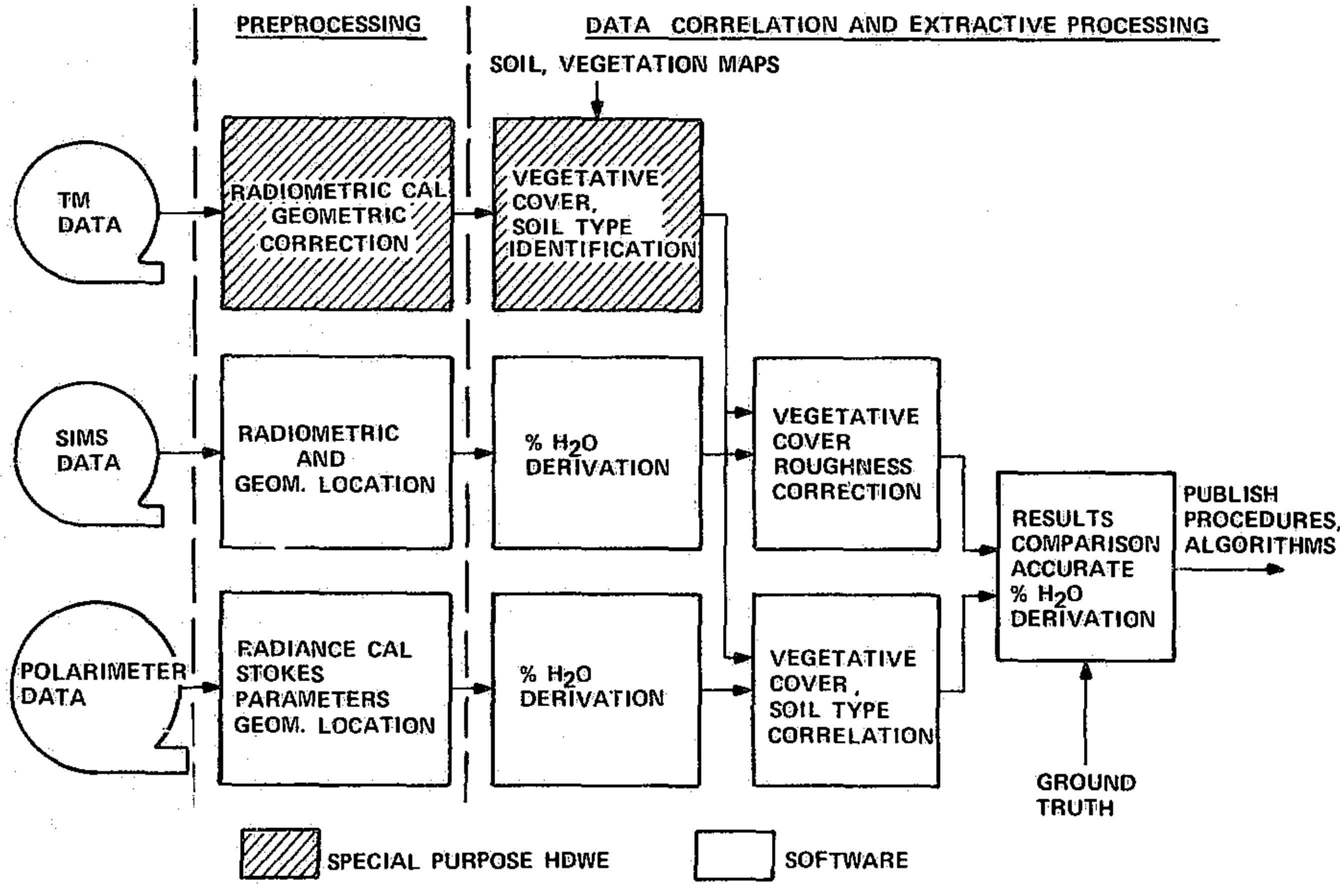


Figure 3-6. Soil Moisture Mission Data Processing

successive observations of the same area with a small antenna at different positions, and using the concept of phase coherent summation of several returns from the same resolution element as the radar moves in position. In this fashion it is possible to synthesize very large antenna "apertures" and achieve spatial resolution (azimuth) that are independent of radar altitude (range). The techniques for achieving this fine resolution impose severe complexity, power, weight and data requirements upon the radar and even affect attitude requirements of the platform. The imagery that can be produced from this technique is of very high quality and lends itself readily to applications such as terrain mapping, geological studies and other established radar uses.

The SAR development mission is designed to use the capabilities of the Shuttle as a platform for the further development and flight testing of a SAR hardware design. The mission will consist of initial flights to verify mechanical and electrical integrity of the design, especially the unfurling of a very large (3m x 12m) antenna and the electromagnetic compatibility of the SAR. Subsequent flights will then be used to perform analyses of performance parameters such as sensitivity, spatial resolution, transmitter efficiency, etc. for the sensor. Modifications to the sensor may be made between flights based on analysis of data from earlier flights. The final output from the mission will be a detailed understanding of the requirements and design of operational flight hardware.

3.2.2 USER COMMUNITY AND BENEFIT MECHANISM

The user community for the sensor development mission is, initially, simply the sensor development manager and his support staff. As the mission progresses, however, and the sensor matures through flight experience, it is probable that this community will widen through involvement of applications oriented users, thus changing gradually from a sensor development to a technique development program.

The direct benefits of developing a new sensor, such as the SAR, are difficult to quantify and assess. The SAR will produce data of a dramatically different type and quality than anything now in existence. The need for, and benefits from, SAR are assumed to have been established for the purpose of this study. There are many potential users of SAR data for applications in geology, meteorology, hydrology, and oceanography, and it is the ultimate satisfaction of these applications needs for currently unobtainable data which provides the ultimate benefit mechanism for the sensor development.

3.2.3 JUSTIFICATION FOR SHUTTLE PROGRAM

The Shuttle offers several unique capabilities when considering a vehicle for an orbital sensor development mission:

- Large payload capability
- Large power and data storage capacity

- Recoverability
- Manned interaction on orbit.

Each of these Shuttle capabilities will be seen to contribute to the SAR development.

The large payload capability enables SAR design without constraining (within reason) the configuration of the hardware, its design state or weight - providing it meets operating and safety requirements of the flight. As an extreme, it should not be considered undesirable to fly a breadboard configuration during the latter phases of sensor development if it were suitably packaged to withstand the launch and orbital environment.

Large amounts of available power preclude the need for constraining design with a tight power budget and avoids high design/development costs. Once development is complete, suitable packaging can be accomplished for the specific application.

Recoverability enables early operation of the sensor or its components under the expected (orbit) environment without undue concern for failure, and the circuitry design can be evaluated with preplanned variable input parameters and the results evaluated. Exhaustive and costly ground simulations of the expected environment can be avoided.

With appropriate consideration to the sensor component design and with suitable test/telemetry points available for orbital troubleshooting and repair as necessary, maximum use can be made of the man-in-orbit/machine interface and substantial savings should result from accomplishment or near accomplishment of the planned orbit objectives. Skylab has shown that even under extremely difficult conditions repairs in orbit can be accomplished. With proper preliminary consideration, repairs or adjustment in orbit can become relatively routine.

3.2.4 SENSOR REQUIREMENTS

The hardware design of the candidate SAR sensor is currently being pursued by both Hughes Aircraft and the Jet Propulsion Laboratory. The Hughes design is for a dual frequency system (X&L band) and employs all-digital techniques for data recording. In addition it has a limited on-board processing and display capability. The design chosen uses a processing technique (clutter tracking) which greatly eases Shuttle attitude control problems in azimuth pointing.

The antenna design allows imaging of a 90 km swath within a 290 km possible illumination range at angles of 20° to 60° off nadir.

Although quite similar to the Hughes design, the JPL design approach incorporates a third frequency (Ku Band - 15 GHz), operates at only one nominal resolution and requires considerably more power. In addition no definite approach to data recording, handling or preprocessing has been selected, although several trade-offs and comparisons have been considered. Table 3-3 summarizes the salient features of the two designs.

TABLE 3-3. SAR SENSOR DESIGN SUMMARY (PRELIMINARY)

	HUGHES			JPL
FREQUENCY PLAN	X & L BAND (9 GHz, 1 GHz)			Ku, X, L BAND (15 GHz, 8.3 GHz, 1.3 GHz)
SWATH WIDTH IN VIEW	290 Km			100 Km max. 40 Km max.
SWATH WIDTH IMAGED	90 Km	60 Km	30 Km	40 K to 100 Km
RESOLUTION	25 m	12.5 m	6 m	25 m
DATA RATE	480 Mbps			UNKNOWN
ANTENNA SIZE	12 x 3 m, 2 FOLDS			10 x 3.1 m
WEIGHT	1060 Kg			813 kg.
VOLUME	11.8 m^3			UNKNOWN
POWER	4 Kw			7.8 kw
POLARIZATION	VV & VH HV & HH			VV & VH HV & HH

3.2.5 FLIGHT PROGRAM

The unique Shuttle capability for intact recovery of payloads lends itself to an evolutionary sensor development program. One evolutionary approach would be to orbit all (or most) of a sensor and incrementally acquire sensor data to check out the sensor's suitability for different applications. An alternate evolutionary approach (discussed in this section because of its uniques in order to stimulate further thought in the community) is to incorporate the sortie flights as part of the sensor engineering development and test cycle. With this approach, the sensor would be incrementally flown in subsystems which would each be checked out with the actual Shuttle environment and conditions.

The SAR flight test program will be a phased development program starting with purely mechanical and electrical integrity/compatibility tests. This will then be continued through to the final flights for performance analysis and initial ground processing together with interpretive technique development. The objectives and procedures for each flight will be established based on the results obtained from previous flights thus providing the phased approach towards a complete flight sensor development. Table 3-4 describes the purpose of each of the three phases of the flight program, and Figure 3-7 shows candidate test site areas for the later flights in the program.

TABLE 3-4. SAR DEVELOPMENT FLIGHT PROGRAM

FLIGHT PROGRAM PHASE	NUMBER OF FLIGHTS	PURPOSE
SYSTEM VERIFICATION	1 OR 2	• VERIFY MECHANICAL INTEGRITY AND ANTENNA FOLDING AND UNFOLDING • VERIFY ELECTRICAL OPERATION OF LOW POWER EQUIPMENT • VERIFY OPERATION OF HIGH POWER & RF EQUIPMENT • PERFORM EMI & RFI COMPATIBILITY TESTS • VERIFY OPERATION OF ONBOARD MONITOR EQUIPMENT
SYSTEM PERFORMANCE ANALYSIS	1	• ANTENNA PATTERN MEASUREMENTS WITH GROUND BEACONS & CORNER REFLECTORS • MEASURE SYSTEM SIGNAL-TO-NOISE AND SPATIAL RESOLUTION • OBSERVE SELECTED GROUND TEST SITES DURING DAY & NIGHT, CLOUD FREE & CLOUD COVER CONDITIONS. • RECORD DATA FOR LATER PROCESSING ON GROUND.
SENSOR APPLICATIONS	1	• RECORD DATA FOR APPLICATIONS TYPE PROCESSING ON THE GROUND • CONTINUE SYSTEM PERFORMANCE MEASUREMENTS

The baseline flight program provides for a single flight for each development phase, however an alternate, evolutionary approach has some desirable advantages.

This alternate approach would provide two flights for the first phase of the program, the first being a non-operating flight and the second being the initial flight for a fully operating sensor.

During the first flight a full test of the mechanical and thermal properties of the hardware, especially the antenna unfolding and thermal and mechanical stability, would be evaluated. Additional tests would determine satisfactory operation of low power equipment and warmup time, etc. Table 3-5 shows a typical set of operations for the first flight.

The second flight would be used to verify the performance as a result of actions taken to correct problems discovered during the first flight, and would also be used to verify operation of high power RF equipment and RF loading of the antenna. EMI and RFI tests would be made during the flight, and checkout of onboard monitoring equipment will be performed.

COVERAGE

- SEVERAL CONTROLLED TEST SITES
  - METROPOLITIAN AREA
  - NEAR SHORE OCEAN
  - AGRICULTURAL AREAS
  - GEOLOGICALLY ATTRACTIVE

VIEWING CONDITIONS

- VARIATIONS DESIRED IN
  - DAY/NIGHT
  - CLOUD FREE/OBSCURED
  - SEASONAL GROUND COVER

ANCILLARY DATA

- GROUND TRUTH
- METROLOGICAL DATA
- SOIL CHARACTERISTICS
- HYDROLOGICAL DATA

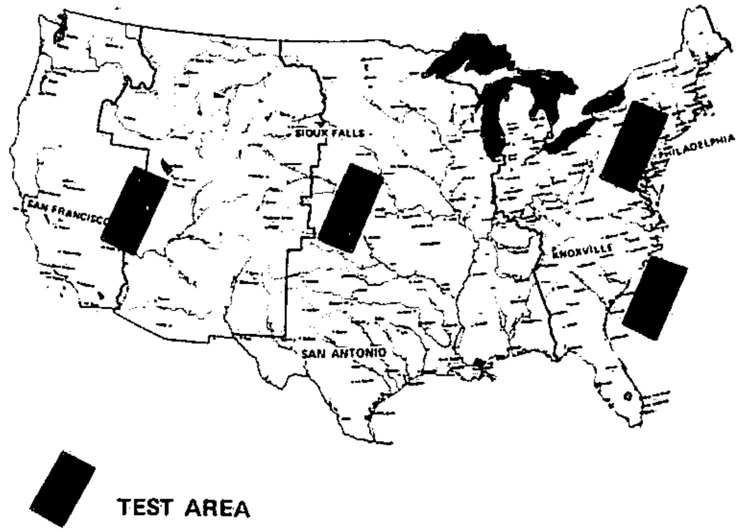


Figure 3-7. Candidate SAR Test Sites

TABLE 3-5. TYPICAL OPERATIONS, EVOLUTIONARY FLIGHT NO. 1

COMPONENT OR OPERATION	POTENTIAL PROBLEMS	APPROACH TO CHECKOUT
1. ANTENNA	• MECHANICAL CONTROL • THERMAL DISTORTION • FAULTY OPERATION, MECHANICAL	• LIMIT SWITCH INDICATORS OPTICAL ALIGNMENT CHECKS • OPTICAL MULTI-POINT INSTRUMENTATION, CHECK OVER SEVERAL DAYS • MANUAL DEPLOY/STOW EXERCISE EMERGENCY JETTISON SIMULATION
2. RECEIVERS & PROCESSORS	• INTERFERENCE ON-BOARD • OPERATION, PARTIAL SYSTEM • OPERATOR PERFORMANCE	• CHECK WITH OTHER EQUIPMENTS OPERATING-SINGLY, IN MULTIPLE • GROUND TRANSMITTERS, SPACED – ALSO MEASURE BEAM PATTERN • PARTIAL EXERCISE OF PROCEDURES TO IDENTIFY PROBLEM AREAS
3. THERMAL	• TRANSFER OF TRANSMITTER HEATING – EFFECT ON ANTENNA AND NEARBY EQUIPMENTS	• SIMULATE TRANSMITTER HEAT DISSIPATION – INSULATION CHECK ON ANTENNA BACK – USE THERMOCOUPLES TO EVALUATE – CHECK DISTORTION
4. ENVIRONMENT	• LOCAL GAS POCKETS • VACUUM EFFECTS	• GAS DETECTOR, STRATEGIC LOCATIONS • EXERCISE MECHANICAL JOINTS CHECK PRESSURE INTERFACES FOR LEAKAGE

3.2.6 DATA PROCESSING AND INFORMATION DISSEMINATION

Data Processing for the SAR Development Program will be of three basic types:

- Analysis of mechanical and electrical test data
- Preprocessing of SAR signal data
- Evaluation of preprocessed SAR data

The analysis of mechanical and electrical test data will be performed by the subsystem and system development engineers using general purpose computers. The function of this analysis will be the verification of mechanical and electrical integrity and compatibility of the SAR with the Shuttle, and the analysis of thermal data to verify proper heat dissipation and component temperatures.

The preprocessing of SAR signal data will be performed on a special purpose SAR preprocessor, whose function is the application of the two dimensional transforms to the raw SAR data in order to generate the desired imagery data. This imagery data will then be evaluated by use of standard image processing techniques to determine signal-to-noise performance, resolution and geometric accuracy parameters for the sensors. This analysis will also be conducted by the system development engineers.

Applications data from the SAR preprocessor will be evaluated for its utility by a select team of applications scientists which has been incorporated into the sensor development team for this purpose. This team will evaluate the imagery data for technique and applications related parameters of interest, and will subsequently develop the requirements for a technique development program for the SAR as a quasi-operational sensor.

Since the data gathered during this flight program is primarily for the system development team, all dissemination will be conducted informally. Detailed dissemination plans for user-oriented agencies will not be prepared until the development of the Technique Development plan for the sensor.

3.3 TIMBER VOLUME INVENTORY

The Timber Volume Inventory mission is one of three missions discussed in this report which are representative of using the Space Shuttle sortie flights in the Application Development role.

3.3.1 BACKGROUND AND MISSION DESCRIPTION

About one third, 300 million hectares (750 million acres), of the land in the United States are under some kind of forest cover. Of that, about 200 million hectares (500 million acres) are considered to be of commercial value. Commercial forest lands are defined as those whose stable soils, favorable climatic environment, and accessibility make them suitable and permanently available for growing continuous tree crops of high quality and large volume. Figure 3-8 shows an approximate distribution of forested area in the continental United States. No accurate maps showing commercial forest areas in the U. S. currently exists; their spatial distribution is very complex. Figure 3-9 shows the U. S. Forest Service's division of the United States into sections and regions.

As shown on Figure 3-10 nearly three quarters of commercial forest is located in the eastern half of the U. S. about equally divided between the North and the South sections. These forests cover 80% of the total land area in New England, and more than half of the area along the Atlantic Coast. In the Central region, about 15% of the total land area is in the commercial timberland category. The one-quarter of the Nation's commercial timberland located in the West is concentrated in the Pacific Coast States of Oregon, Washington and California, and in the Rocky Mountain States of Montana, Idaho and Colorado.

The interior of Alaska contains an estimated 40 million hectares (100 million acres) of forest land, or about 30% of Alaska's total land area. An estimated 20% of these forests have a good growth potential, however, because of geographic and economic remoteness, none of the forest land in the interior of Alaska has been included in the statistics for commercial timberland.

Forest land is broken down into three broad ownership classes. As shown on Figure 3-11 about 21% of the commercial forest land belongs to the Federal government, about 6% belongs to state and local governments, and the rest is in the private sector of our society. Approximately 95% of the commercial forest belonging to the Federal government is in the National Forest System. These forests are located largely in the Rocky Mountain and Pacific Coast Sections. The remainder of the Federal commercial forest belongs to the Bureau of Land Management, Bureau of Indian Affairs, and various other agencies.

Commercial forest lands held by business and professional people, wage and salary workers, railroad, mining, and other corporations, and other non-farm owners represent the largest class of forest ownership. As on Figure 3-11 this represents 33% of the total commercial forest land (about 67 million hectares or 165 million acres). Another 26% belongs to farm owners. The 27 million hectares (67 million acres) in

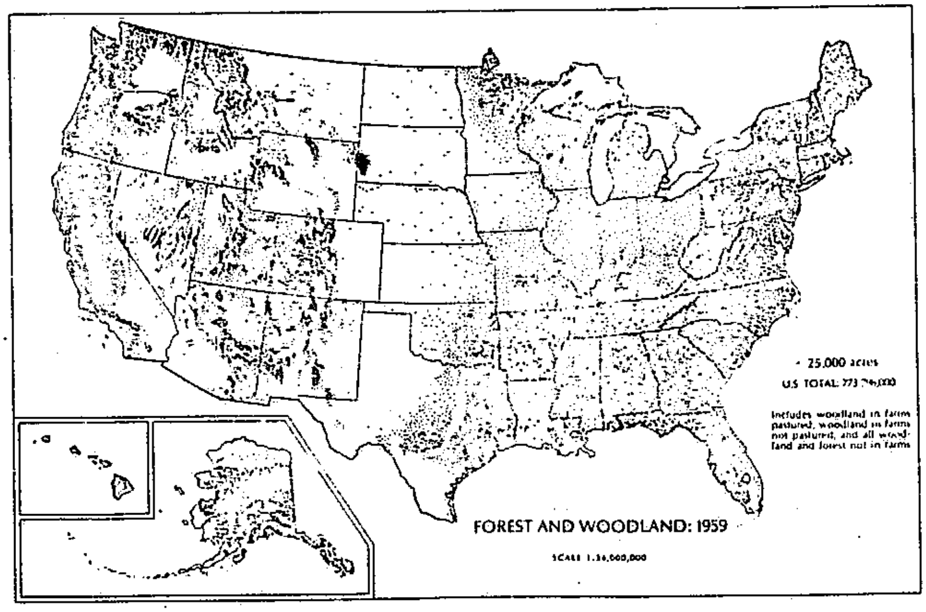


Figure 3-8. Geographical Extent of Forested Lands in the United States

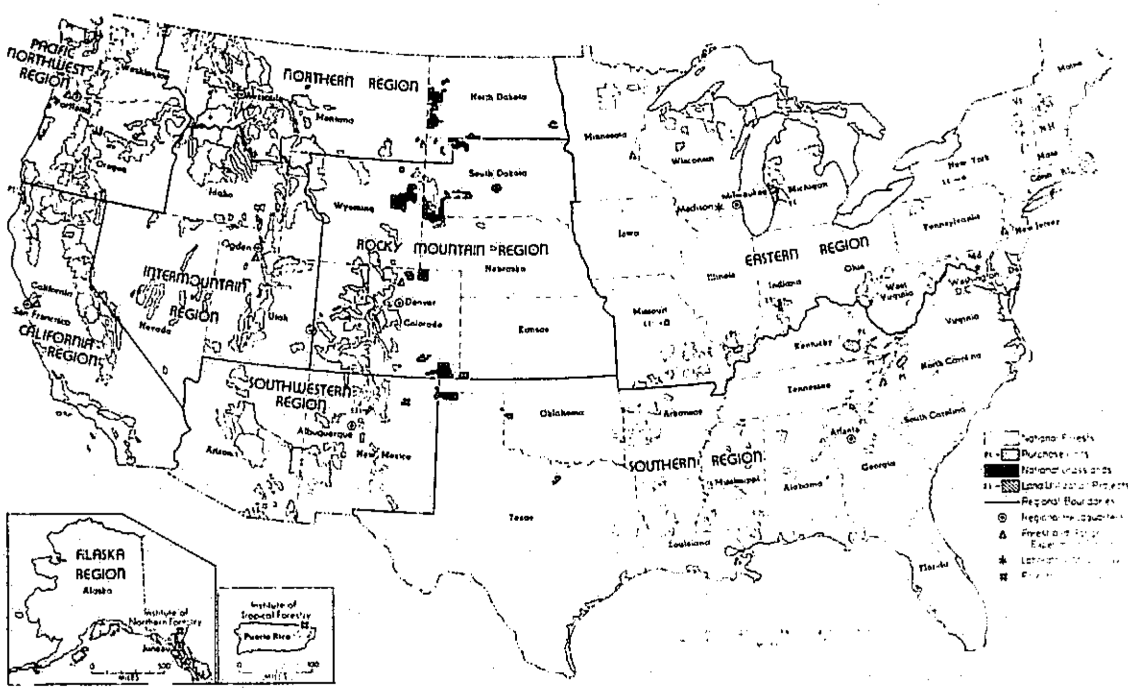
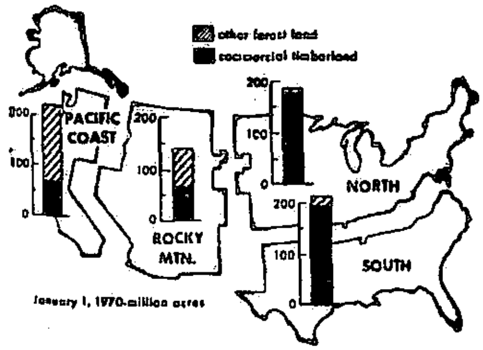


Figure 3-9. Forest Regions of the United States (defined by U.S. Forest Service)



3/4 – EASTERN US
1/4 – WESTERN US

Figure 3-10. Regional Distribution by Section of Forested Lands in the United States

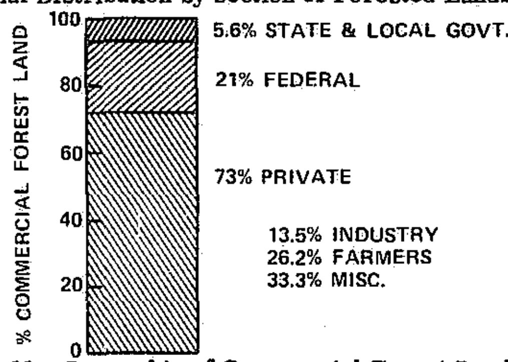


Figure 3-11. Ownership of Commercial Forest Land in U. S.

forest industry holdings (about 13.5% of the total) includes some of the Nation's most productive timber growing areas. About 52% of these industrial lands are in the South, 26% in the North, and the remaining areas on the Pacific Coast. It is worth noting that of all the commercial forests in private ownership, 74% are in holdings of under 2,000 hectares (5,000 acres), which explains the complexity of land ownership patterns in the U.S., and their associated management problems.

The principal purpose for the forest inventory is to help the forester in the variety of management activities involving land, the plants and animals growing on it, man and his desires to use the land, and the products and services he can obtain from it.

Since most forest inventories have been and continue to be timber estimates, a forest inventory may be defined as an attempt to describe the quantity and quality of forest trees and many of the characteristics of the land area on which the trees are growing. With the increasing importance of recreation, watershed management, forage and wildlife (the so called non-wood values of forest), the concept of forest inventory has been widened.

To obtain information for a forest inventory it is necessary to make a number of measurements of the trees composing the forest, and additional observations regarding the land occupied by them. These measurements may be taken directly in the forest itself and/or by remote sensing such as with aerial photographs. The specific measurements will depend on the kind of information required, and may vary for different inventories. These measurements can be taken for the entire area of a forest and all the trees therein (called a complete or 100% inventory). When the measurements are taken only on representative portions of the forest it is called a sampling inventory.

A thorough forest inventory for timber evaluation provides the following basic elements of information:

1. A description of the forested area including ownership and accessibility
2. Estimates of parameters of quantity in the standing trees, such as volume or weight, and estimates of growth and depletion
3. Additional information on wildlife, areas of recreational and tourist interest, soil and land use capabilities and watershed values.

There are no distinct inventories for different purposes, but a flexibile continuum with varying emphasis on these information elements. For example, inventories of private forest holdings may require more detailed information on volume by species, size classes, precise stand location, than would be needed for a general appraisal of the total forest area or volume on a national or regional basis.

Since it is too costly and time consuming to measure all trees in a large forest area, sampling is used to provide the necessary information at a much lower cost and greater speed. Sampling involves measuring only a portion of the forest, allowing greater care in measurements, and often producing more reliable results than a complete inventory. Sampling units, from which estimates are obtained for the entire population (entire forest area under consideration), may consist of stands, compartments, administrative units, fixed area plots, strips or sampling points. Various sampling designs can be employed depending on inventory objectives and on the total forest area to be inventoried. Basic sampling designs may be considered in the following categories:

A. Probability Sampling
    1. simple random sampling
    2. stratified random sampling
    3. multistage sampling
    4. multiphase sampling
    5. sampling with varying probabilities
B. Non-random sampling
    1. selective sampling
    2. systematic sampling

In probability sampling, the probability of selecting any sampling unit is known a priori. This probability is greater than zero and may be equal for all units at all times, or it may vary as sampling proceeds. In non-random sampling the sampling units are not chosen by the laws of chance, but by personal judgement or systematically. Sampling on successive occasions is a means of determining changes which have taken place over a period of time and can employ any of the basic inventory designs.

Aerial photography, the most common form of remote sensing, has been utilized in forest inventory for the past three decades. Inventory work can be carried out without the use of aerial photographs, but it is usually less efficient and restricts the inventory planner in designing his procedures. Aerial photography is currently used in the so-called two-stage inventory. The first stage is the photointerpretive stage in which a forest is prestratified according to various timber volume strata, or other parameters. In the second, or ground stage, various strata are sampled on the ground for detailed information. In addition to stratification, photo-interpretation and photogrammetric techniques have been developed which, in essence, let the forester sample the forest using the photographic images of the trees rather than the trees themselves on the ground. The photographs do not provide the same amount of detail or accuracy that is attainable in the field measurements; however, the advantages of speed and lower cost offset the approximate nature of the estimates (especially where highly accurate results are not essential).

Imagery obtained from earth orbiting space vehicles (e.g., Landsat-1, Skylab) demonstrated that its use further increases the efficiency and cost effectiveness of forest inventory. J. Nichols of the University of California, and P. Langley of Earth Satellite Corp. investigated Landsat-1 multispectral scanner imagery in a multistage sampling system. In both experiments, a gain in sampling precision was obtained by using Landsat data in the first stage, as compared with not using any supplementary data in the first stage. The Timber Inventory application development mission will combine the preliminary work done by Landsat investigators with other up-to-date technological developments to arrive at the most efficient operational scheme to improve the current periodic timber inventory.

The objective of the Timber Inventory mission is to estimate the amount (volume) and quality of commercial timber in the United States. To accomplish this, stands of trees (comprising larger forest units) will be located and their boundaries determined. Also, parameters necessary for estimation of timber volume per acre will be obtained. These parameters will include the crown diameter and the average crown closure, which are closely related to the tree stem diameter, and volume per acre, respectively.

The area within the United States to be inventoried amounts to about 300 million hectares (750 million acres), two thirds of which is considered to be of commercial value, with the majority of the forested areas containing commercial timber located in the eastern half of the U.S.

The desired frequency of inventory as currently defined by the U.S. Forest Service for its various regions is given in Table 3-6 below.

TABLE 3-6. INVENTORY FREQUENCY IN MAJOR REGIONS OF THE U. S.

REGION	FREQUENCY
SOUTH AND SOUTHEAST	8 YEARS
ALASKA AND HAWAII	15 YEARS
ALL OTHER AREAS	10 YEARS

Due to consistently inadequate budget appropriated by Congress to the US Forest Service, these goals have not been fulfilled. With sharply increased demand for timber products and the requirements of the Forest and Rangeland Renewable Resources Planning Act of 1974, the inventory frequency will have to be reduced to 5 years.

3.3.2 USER COMMUNITY AND BENEFIT MECHANISM

Forest inventory is a continuing endeavor as mandated by the McSweeney-McNary Forest Research Act of 1928. This Act directs the Secretary of Agriculture to cooperate with States and other agencies,

> "... in making and keeping current a comprehensive survey of the present and prospective requirements for timber and other forest products in the United States, and of timber supplies, including a determination of the present and potential productivity of forest land therein, and of such other facts as may be necessary in the determination of ways and means to balance the timber budget of the United States..."

Its objective is to periodically inventory the Nation's forest lands to determine their extent, condition, and volumes of timber, growth and depletions. This kind of up to date information is essential to frame intelligent forest policies and programs. USDA Forest Service regional experiment stations are responsible for conducting forest inventories and publishing summary reports for individual states.

Forest inventory is important in the private forest industry sector for evaluating sources of raw materials and for detecting trends in forest resource availability. The inventory information is useful for long-range planning decisions, and for industrial investment allocation decisions. It is also essential for state governments and private industry in identifying opportunities for economic development of the states based on forest resources.

As a general rule individuals or organizations that own, use, or regulate the use of a particular resource have an active interest in the most current information about that resource. This holds true in the area of forest resources, where the source of information about the resource is the periodic forest inventory. Following this rule, users of forest inventory information can be divided into three major categories:

1. Federal government
2. State and local government
3. Private owners and users.

The single largest user of forest inventory information is the USDA - Forest Service. In addition, the USFS conducts research on all phases of forest management and utilization, and assists state and private owners in achieving their management goals. Figure 3-12 gives a summary of the major activities of USFS with some recent statistics on various forest resources. Most of the activities listed require a considerable amount of information supplied as a result of forest inventory.

Other Federal agencies such as the Bureau of Land Management, and Bureau of Indian Affairs require forest inventory for management of forest land under their jurisdiction.

Second in line, but not necessarily in importance, are the users on state and local government level. Their share in ownership of forest land is small, however, most of their resources are quite heavily utilized. This requires sound management planning, and therefore periodic inventory. In addition to this, forest inventory information is essential for state and local governments in identifying opportunities for economic development of the states or regions based on forest resources.

The last group of users is in the private sector of our society, and it includes forest related industries, farmers and non-governmental owners. Most of the forest land belonging to, or utilized by wood-producing industries is under intense management. Goals here are to produce the most wood of desirable quality in the shortest possible time. To attain this goal, forest land has to be inventoried periodically. For management of specific tracts of land, the demand is for detailed point-specific information currently supplied by consulting companies.

Over half of the Nation's forest lands are owned by several million nonindustrial private owners — farmers, businessmen, power companies, and numerous other occupational groups. These owners have many objectives in owning forest lands, and varying willingness and capacity to invest funds in timber growing. A small percentage of these owners consider timber growing as their principal objective. Most of the land owned by these owners is in small tracts (74% in holdings of under 2,000 hectares or 5,000 acres). The need for forest inventory in this part of the private sector is not as urgent as it is in the forest industry. However, growing concern about future timber supply might encourage more intensive forestry on private lands, and therefore, increase the need for forest inventory.

A periodic forest inventory allows forest managers to make evaluations of present and future timber supplies, and to make comparisons with the projected demand for these supplies. Such evaluations are essential to forecast supply problems in the wood-using industries, and to allow for any necessary changes in forest policies and programs. Forests are a slow growing renewable resource, however the demand for timber is changing rather rapidly. The demand for industrial timber products in the United States increased

U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE

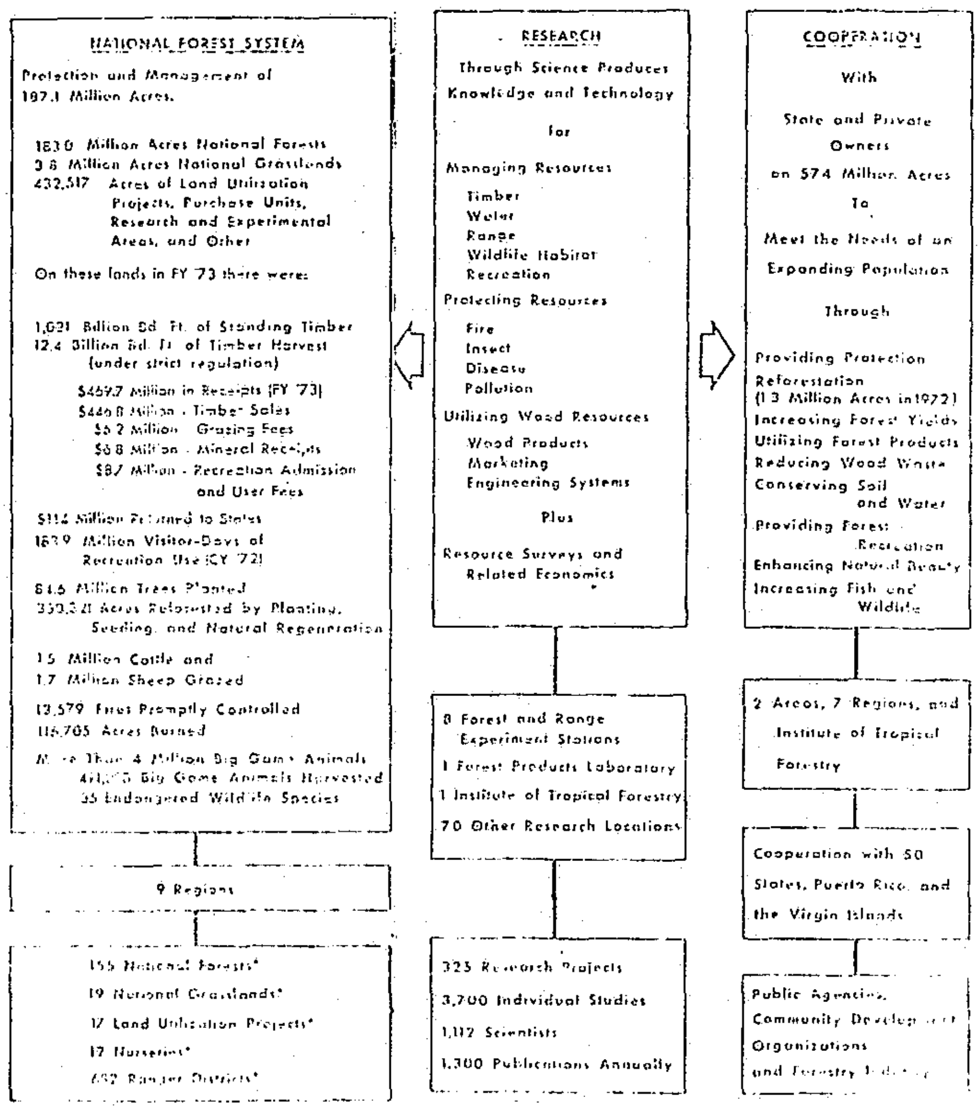


Figure 3-12. Major Activities of the USFS, from: <u>What the Forest Service Does</u>, Oct. 1973

by about 70% in the past 25 years. Figure 3-13 gives an indication of present and future timber consumption. Even more rapid are the recent changes in demand for recreational uses of forest areas and for management of forest cover for watersheds (essential to our growing population). Also, when considering forest lands, one should not overlook the wildlife habitat, and the preservation of scenic values. This so called multiple-use management of forest lands puts additional constraints on traditional timber production and harvest practices, and at the same time elevates the importance of timely and accurate inventory.

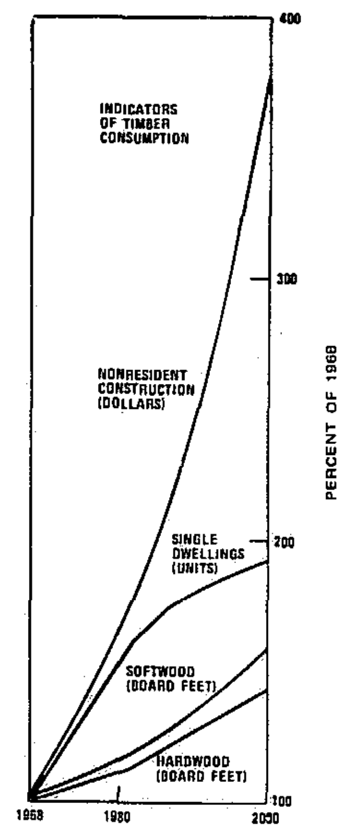


Figure 3-13. Present Timber Consumption and a Projection for the Year 2,000

A well conducted inventory should provide basic inputs necessary for appraising the effectiveness of existing forest management programs, and to indicate opportunities for economic development of timber resources. Since timber products make up almost 20% of all industrial raw materials consumed in the United States, the information on our timber situation has far reaching economic and environmental importance. The timber industry employs millions of workers; many of them in rural areas and cities where timber is the principal support of the local economy. Concern over prospective depletion of mineral resources which are nonrenewable, and the higher energy requirements resulting from use of nontimber resources (in place of wood products), also emphasize the increasing importance of timber in our economy.

Figure 3-14 shows trends in the U. S. import - export balance. The graph indicates that since the early 1900's our country has been gradually changing from a net exporting country to a net importer. (By 1950 the United States was dependent on foreign sources for about 10% of all timber products consumed). It is expected that a more intensive management of our forest lands will improve the import-export balance, and therefore improve the overall balance of trade for the U. S.

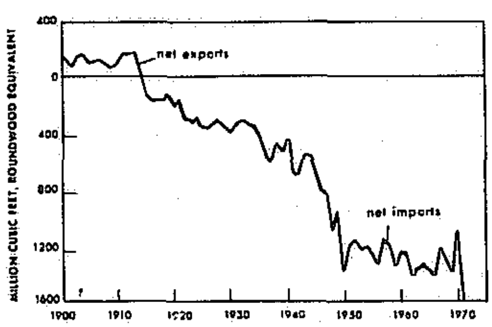


Figure 3-14. U. S. Timber Import-Export Balances (1900 - 1970)

3.3.3 JUSTIFICATION FOR SHUTTLE PROGRAM

A fully operational remote sensing program for the Timber Volume Inventory mission for the United States is expected to encompass a variety of remote sensing platforms. These platforms will include: low orbit sun synchronous polar spacecraft (such as Landsat), Space Shuttle sortie flights, high altitude aircraft, and ground based survey teams. Previous TERSSE reports (TERSSE Final Report Volumes 3 and 5) discussed the potential and role of the various platforms in a total operational remote sensing system. This report addresses the use of the Space Shuttle in its sortie flight mode as an integral part of this multi-platform system.

The Shuttle provides a unique platform for a major element in the Timber Volume Inventory mission because of its ability to carry a comprehensive complement of sensors, including photographic cameras. The Shuttle is, in fact, the only vehicle currently contemplated through the 1980's which provides for the return of photographic film.

Other benefits accruing to the mission which result from incorporation of the Shuttle into the program follow directly from the Shuttle's capabilities:

- The flexibility for scheduling Shuttle flights and orbits as a function of coverage desired.
- The lower altitude and higher resolution capability of Shuttle sensors than is available on polar spacecraft of the LANDSAT type.

As with nearly all Application Development type missions, there is no overwhelming mission requirement for the Timber Volume Inventory mission that irrefutably demands usage of the Space Shuttle. Most, if not all, of the mission requirements could conceivably be met through a combination of polar spacecraft and high altitude aircraft. The real question is: "What combination of remote sensing platforms can most efficiently satisfy the mission requirements?" Because of the large area to be covered (relatively in frequency) and the need for high resolution, the Space Shuttle has a definite role in the Timber Volume Inventory mission.

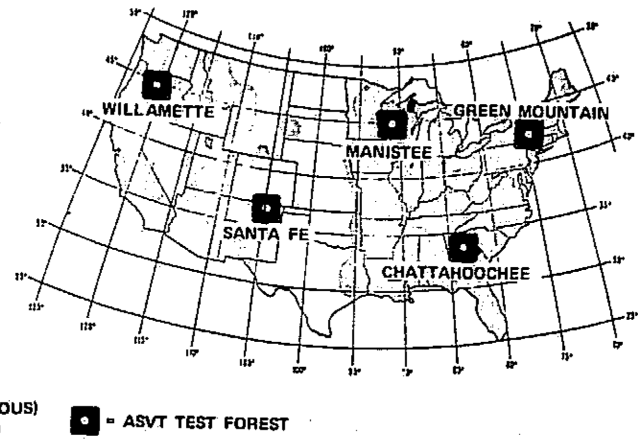
3.3.4 SENSOR REQUIREMENTS

The remote sensors required for this mission include both a high resolution camera and a multi-spectral electronic scanner. As shown in Section 4-1, the selected Shuttle-borne sensors for the Timber Inventory Application Development are the Thematic Mappers and the S190B high resolution camera.

3.3.5 FLIGHT PROGRAM

Figure 3-15 shows the location of candidate Timber Inventory Application Development test forests. The five selected sites are currently well surveyed, and represent a comprehensive and representative sample of the various forest types found in the U. S.

- SENSORS
  - MULTISPECTRAL SCANNER
  - HIGH RESOLUTION CAMERA
- TOTAL COVERAGE
  - FORESTED UNITED STATES $\approx 3 \times 10^6$ KM^2
- UPDATE CYCLE
  - 5 YEARS
- TIMELINESS
  - 2-4 MONTHS
- FLIGHT TIMING
  - APRIL TO OCTOBER (DECIDUOUS)
  - NOT CRITICAL (CONIFEROUS)



- ASVT USING SELECTED FORESTS
  - CURRENTLY WELL SURVEYED FOR VERIFICATION
  - SELECT REPRESENTATIVE TYPES: SOUTHERN PULPWOOD, NORTHERN HARDWOOD, WESTERN CONIFEROUS, MIXED TIMBER
- CONCENTRATE ON CONTINENTAL U.S. – ALASKA WAITS FOR WTR
- MISSION OUTPUTS ARE TABULAR DATA SUMMARIES OF ESTIMATED HARVESTABLE TIMBER VOLUME

Figure 3-15. Candidate Test Forests for the Timber Volume Inventory Mission

Flight scheduling for the Timber Volume Inventory mission requires flights during the April to October time frame for deciduous forests; however, there is no critical timing requirements for coniferous stands.

Data from the Shuttle sensors will be analyzed and used to direct aircraft overflights and ground survey parties (as discussed below), thus resulting in a total operational system.

3.3.6 DATA PROCESSING AND ANALYSIS

Data from the thematic mappers will be subjected to "standard" preprocessing to perform radiometric and geometric corrections.

Subsequent data analysis is intended to satisfy the needs of the Multistage Probabilistic Sampling Strategy; for the Timber Volume Inventory mission, a four stage sampling strategy will be used:

1. Classify observed timberlands into volume strata using thematic mapper data and select sampling sites for each stratum to be used in the second stage.
2. Use photo-interpretive techniques on the S190B photography to establish initial estimates of timber volume and select sampling sites for the third stage (a subset of those previously established).
3. Fly aircraft missions to gather large scale photographs over the second-level sampling sites. Use photointerpretive techniques to refine initial volume estimates and select sample sites for detailed measurement by ground crews.

4. Make measurements on selected trees in the third-stage sample sites using "classical" timber volume measurements from the ground.

From the ground measurements on selected trees in the fourth stage, a further refining of the timber volume estimate established in the second stage can be performed. This then establishes a volumetric figure for each stratum defined in the first stage. As a result of this (volume estimates in each stratum), the total volume in the areas overflown may be determined by statistically aggregating the sample data back through the stratum.

For operational purposes, an additional stage may be added prior to the analysis of Shuttle sensor data, utilizing polar spacecraft multispectral scanner data to perform the initial stratum classification. In this case thematic mapper data gathered by the Shuttle will be used to supplement polar spacecraft data, and the succeeding four stages will remain the same.

A more complete discussion of multistage probabilistic sampling is contained in Appendix A of this report.

Photographic interpretation is widely used in forest inventory. Determination of forest types and tree species is an essential part of forest inventory and can be accomplished successfully by photointerpretation. Basic image characteristics of shape, size, pattern, shadow, tone, and texture vary for different kinds of trees and can therefore be used by interpreters to aid in identification of tree species. Individual tree species have their own characteristic size and crown shape. The arrangement of tree crowns produces a stand pattern that is quite distinct for many species. Tree shadows often provide a profile image of trees and can assist in species identification and also in tree height determination. Variations in relative tone and crown texture are also important in species identification.

Tree crown diameter, which for most species is related to stem diameter, is a useful photographic measurement when estimating tree volumes. Actual determination of crown diameter is a distance measurement, and is accomplished on aerial photographs with either wedges or dot-type scales reading in thousandths of an inch. For example, at a scale of 1:20,000, 0.036 of an inch of crown measure on the aerial photo equals about 60 feet. Crown diameter measurements are most accurate in open-grown stands. In dense stands they are confined to determination of an average of the dominant trees. Crowns can generally be classified by 5 foot classes on photographs with scale between 1:15,000 and 1:20,000. Tree crown closure, important because of its relation to stand volume per acre, is also referred to as crown density and may be defined as the proportion of the forest canopy occupied by trees. Estimates are purely ocular, and stands are commonly grouped into 10 percent density classes. Evaluation of crown closure is much more subjective than the determination of crown diameter. It is almost impossible on small-scale photographs, and its accuracy is highly dependent on the interpreter's judgment.

A conventional inventory considers the following parameters: diameter of bole or crown, species, density (percentage of area occupied by trees or degree of crown closure), height (merchantable or total), and age and overall condition of the stand. The above items can be estimated from high-resolution aerial photographs. Figure 3-16 gives a pictorial representation of ground and aerial measurements. The most widely used photographic measurements are the crown diameter which is related to the stem diameter, and crown closure, related to timber volume per acre. Tree height can be estimated by differential parallax measurements on sterescopic pairs of aerial photographs.

The remaining parameters of interest (tree quality, growth rate and site quality) are obtained by measurements on the ground, and to a limited extent by observations on aerial photographs. Tree quality expresses the percentage of crooked, damaged, or diseased trees that will affect yield. Tree growth rate is estimated by comparing measurements of diameter or volume at different points in time. Site quality is inferred from tree size, volume per unit area, soil type and other factors.

Table 3-7 contains a list of the most frequently used information elements in forest inventory, and the accuracies currently required by US Forest Service for inventory of National Forests.

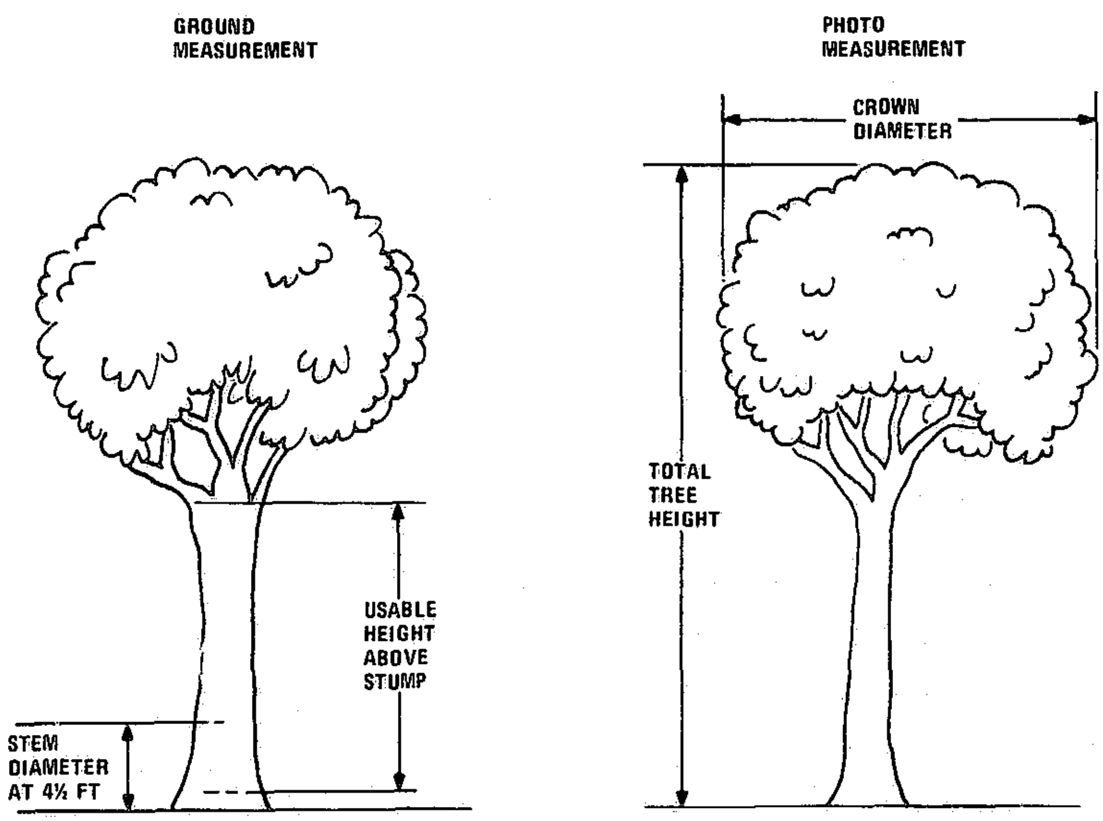


Figure 3-16. Pictorial Representation of Ground and Aerial Measurements

TABLE 3-7. TIMBER INVENTORY INFORMATION ELEMENTS FOR INVENTORY OF NATIONAL FORESTS

INFORMATION ELEMENT	USE	ACCURACY REQUIREMENTS
LOCATE AND MAP TIMBER STAND BOUNDARIES	DETERMINE ACREAGE OF NATIONAL FORESTS BY STANDARD TIMBER LAND USE CLASSIFICATION	± 50 FEET OF ACTUAL LOCATION; MIN. SIZE -10 ACRES
LOCATE AND MAP STAND BOUNDARIES BY FOREST TYPE	DETERMINE STAND AREA BY FOREST TYPE	BOUNDARY - ± 50 FT. OF ACTUAL; MIN. SIZE - 10 ACRES; ± 1% FOR TOTAL AREA
STAND CONDITION AS TO STEM BASAL AREA PER ACRE OF TREES BY AGE AND SPECIES GROUPINGS	DETERMINE CURRENT STAND CONDITIONS IN ORDER TO DEVELOP THE MANAGEMENT TREATMENTS REQUIRED ON ALL COMMERCIAL FOREST LAND	IDENTIFICATION OF SPECIES AND AGE GROUPING - 95%; SQ. FT. STEM BASAL AREA PER ACRE ± 5%
CUBIC FOOT VOLUME BY SPECIES IN EACH TIMBER STAND	DETERMINATION OF EACH NATIONAL FOREST'S POTENTIAL YIELD OF WOOD PRODUCTS	STAND VOLUME ± 10%; BY INDIVIDUAL SPECIES ± 20%

3.3.7 DATA DISSEMINATION

The final data products from this mission will be a set of information describing the current timber inventory in the selected forests. Such information will consist of timber volume estimates broken down by ownership, stand size class, and species. Since inventory will be performed on regional level, the inventory information will be initially published by U.S. Forest Service Regional Experiment Stations: Figure 3-17 shows the information flow process. The smallest unit for which information will be available is a county. All the information will be in tabular form. Examples are shown in Table 3-8, 3-9, and 3-10.

Once compiled, the inventory statistics will be available to all the interested federal, state, and local agencies, as well as to representatives of the private sector (industries, farmers, etc.). In addition to various publications, the USFS offers consultations and special seminars to interested parties.

Upon completion of timber inventory for all the regions, a combined (summary) report will be issued containing timber inventory for all the regions within the United States. The breakdown of statistics is similar to what appears in regional reports, however, the reporting unit is now a single state, not a county. Tables 3-11 and 3-12 are examples of what information should be contained in a combined national report. This information is also available to all the interested parties in the private and public sectors of our society.

On the regional level timber inventory information should be available within 6 months from the time of data collection. The nationwide report should be available within 6 months from the time that all the regional reports are completed.

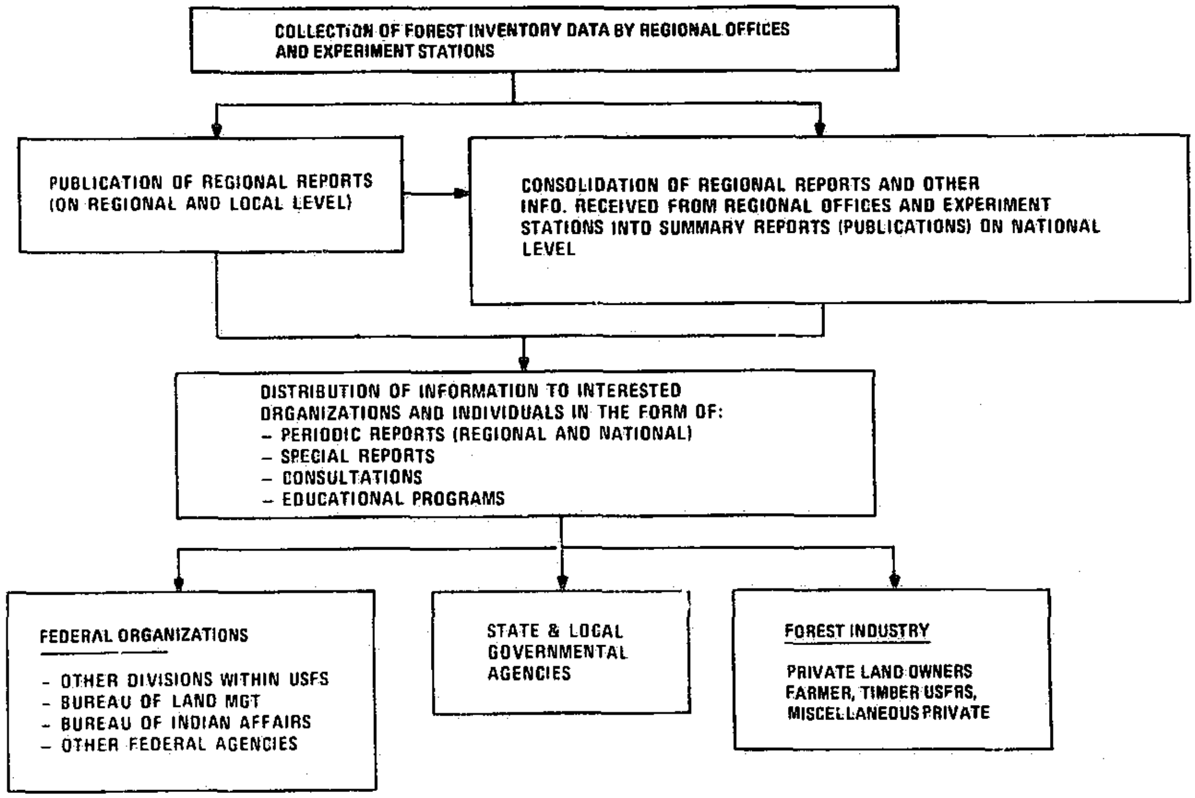


Figure 3-17. Forest Inventory Information Flow

TABLE 3-8. AREA OF COMMERCIAL FOREST LAND, BY STAND-VOLUME AND OWNERSHIP CLASSES, FLORIDA, 1970

Stand volume per acre[1]	All ownerships	National Forest	Other public	Forest industry	Farmer and misc. private
			Thousand acres		
Less than 1,500 bd. ft.	10,135.1	554.7	706.1	3,158.8	5,715.5
1,500 to 5,000 bd. ft.	4,224.8	333.1	286.7	1,374.4	2,230.6
More than 5,000 bd. ft.	1,871.7	147.5	117.4	683.3	923.5
All classes	16,231.6	1,035.3	1,110.2	5,216.5	8,869.6

[1]International 1/4-inch rule.

The update frequency varies from section to section as indicated in Table 3-6. Areas containing fast growing timber receive more attention, and therefore a more frequent inventory.

TABLE 3-9. NET VOLUME OF GROWING STOCK AND SAWTIMBER ON COMMERCIAL FOREST LAND, BY OWNERSHIP CLASS AND SPECIES GROUP, EASTERN OZARKS, MISSOURI, 1972

GROWING STOCK

Ownership class	All species	Shortleaf pine	Other softwoods	Soft hardwoods	Hard hardwoods
	Thousand cords				
National Forest	7,969.0	1,706.2	3.2	178.3	6,081.3
Other federal	61.5	2.9	—	1.7	56.9
State, county and municipal	1,190.6	100.0	9.0	24.5	1,057.1
Forest industry	1,680.0	221.1	—	36.7	1,422.2
Farmer and miscellaneous private	17,144.5	1,073.1	96.8	766.4	15,208.2
All ownerships	28,045.6	3,103.3	109.0	1,007.6	23,825.7

SAWTIMBER

Ownership class	All species	Shortleaf pine	Other softwoods	Soft hardwoods	Hard hardwoods
	Million board feet 1/				
National Forest	1,641.7	512.3	.2	33.4	1,095.8
Other federal	12.7	1.2	—	.4	11.1
State, county, and municipal	241.6	23.9	1.2	—	216.5
Forest industry	308.3	29.7	—	4.0	274.6
Farmer and miscellaneous private	3,082.2	251.3	18.9	166.2	2,645.8
All ownerships	5,286.5	818.4	20.3	204.0	4,243.8

1/ International 1/4-inch rule.

TABLE 3-10. AREA OF COMMERCIAL FOREST LAND, BY STAND-VOLUME AND OWNERSHIP CLASS, EASTERN OZARKS, MISSOURI, 1972

(Thousand acres)

Stand volume per acre 1/ (board feet)	All ownerships	National Forest	Other federal	State, county, and municipal	Forest industry	Farmer and miscellaneous private
Less than 1,500	2,412.1	275.6	3.1	87.7	195.4	1,850.3
1,500 to 5,000	1,505.4	459.3	2.7	67.2	111.9	864.3
More than 5,000	166.5	135.1	—	7.9	—	23.5
All classes	4,084.0	870.0	5.8	162.8	307.3	2,738.1

1/ International 1/4-inch rule.

TABLE 3-11. AREA OF COMMERCIAL TIMBERLAND IN THE UNITED STATES, BY OWNERSHIP AND STAND-SIZE CLASS, SECTION, REGION, AND STATE, JANUARY, 1970

[Thousand acres]

Section, region, and State	Total, all ownerships: Total	Sawtimber stands	Poletimber stands	Seedling sapling	Nonstocked areas	National forest: Total	Sawtimber stands	Poletimber stands	Seedling sapling	Nonstocked areas
New England:										
Connecticut	2,160	366	1,163	583	49	0	0	0	0	0
Maine	16,894	6,142	5,339	5,268	143	37	19	15	2	0
Massachusetts	3,491	414	1,660	1,368	38	0	0	0	0	0
New Hampshire	5,020	1,787	2,369	693	171	568	341	131	96	0
Rhode Island	429	14	233	168	13	0	0	0	0	0
Vermont	4,364	1,796	1,524	1,004	40	226	125	63	37	0
Total	32,367	10,531	12,304	9,086	435	832	488	209	135	0
Middle Atlantic:										
Delaware	390	210	128	45	6	0	0	0	0	0
Maryland	2,892	1,791	753	297	40	0	0	0	0	0
New Jersey	2,354	599	794	803	157	0	0	0	0	0
New York	14,459	4,283	2,678	6,201	1,325	0	0	0	0	0
Pennsylvania	17,478	7,665	6,081	3,399	333	488	265	200	7	6
West Virginia	12,092	5,951	3,297	2,596	248	879	543	312	23	0
Total	49,685	20,500	13,732	13,341	2,110	1,367	808	521	30	6
Lake States:										
Michigan	18,600	4,645	8,055	5,506	892	2,423	378	1,223	761	59
Minnesota	16,875	2,360	8,425	4,247	1,841	2,127	837	1,835	295	159
North Dakota	406	63	158	149	34	0	0	0	0	0
South Dakota (East)	223	103	98	19	3	0	0	0	0	0
Wisconsin	14,536	3,093	6,579	4,459	369	1,317	84	749	420	64
Total	50,640	10,272	23,315	14,412	2,641	5,867	600	3,307	1,477	282
Central:										
Illinois	3,680	2,101	934	599	44	214	94	73	29	18
Indiana	3,840	2,065	705	699	70	136	84	23	22	6
Iowa	2,430	942	777	269	442	0	0	0	0	0
Kansas	1,187	681	229	[illegible]	141	0	0	0	0	0
Kentucky	11,826	5,633	2,798	3,317	78	531	426	94	4	5
Missouri	14,600	4,002	4,258	[illegible]	2,848	1,321	318	681	311	10
Nebraska	1,023	253	310	103	355	57	2	27	24	3
Ohio	6,423	1,977	700	3,569	176	129	65	12	32	18
Total	45,008	17,636	10,603	12,383	4,164	2,390	991	912	423	63
Total, North	177,901	58,940	60,156	49,223	9,571	10,458	3,087	4,951	2,067	351
South Atlantic:										
North Carolina	20,192	10,556	4,255	5,195	187	1,035	743	168	102	3
South Carolina	12,410	4,907	3,455	3,649	398	550	368	136	40	0
Virginia	15,859	5,309	5,981	4,472	96	1,202	619	492	75	15
Total	48,463	20,772	13,602	13,315	692	2,789	1,730	815	224	18
East Gulf:										
Florida	16,231	4,987	4,150	4,529	2,563	1,035	419	305	244	66
Georgia	25,102	8,354	4,607	11,426	714	806	492	168	145	0
Total	41,334	13,342	8,758	15,955	3,277	1,842	911	474	389	66
Central Gulf:										
Alabama	21,742	8,885	5,224	7,468	164	623	428	115	81	0
Mississippi	16,891	4,557	3,772	8,427	133	1,118	528	149	440	0
Tennessee	12,819	3,297	4,893	4,595	32	599	257	230	112	0
Total	51,453	16,741	13,889	20,492	330	2,344	1,213	496	634	0
West Gulf:										
Arkansas	18,206	5,443	4,759	7,922	81	2,378	732	863	782	0
Louisiana	15,342	9,439	1,922	3,774	156	551	395	51	99	5
Oklahoma	4,817	1,261	943	2,498	114	233	112	45	75	0
Texas	12,924	7,021	2,184	3,620	97	625	517	37	69	0
Total	51,290	23,185	9,810	17,815	480	3,788	1,758	998	1,026	5
Total, South	192,542	74,041	46,151	67,575	4,771	10,764	5,614	2,784	2,275	89
Pacific Northwest:										
Alaska: Coastal	5,639	5,112	180	300	47	5,144	4,651	173	273	474
Oregon:										
Western	14,635	8,923	1,370	3,576	766	4,830	3,814	459	410	147
Eastern	11,038	7,230	2,458	932	418	7,173	4,731	1,645	632	165
Summary	25,673	16,153	3,825	4,508	1,184	12,003	8,545	2,104	1,042	312

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 3-12. AREA OF COMMERCIAL TIMBERLAND IN THE UNITED STATES, BY OWNERSHIP AND STAND-VOLUME CLASS, SECTION, REGION, AND STATE, JANUARY, 1970

[Thousand acres]

Section, region, and State	Total, All Ownerships				National Forest			
	Total	Less than 1,500 bd. ft.	1,500 to 5,000 bd. ft.	More than 5,000 bd. ft.	Total	Less than 1,500 bd. ft.	1,500 to 5,000 bd. ft.	More than 5,000 bd. ft.
New England:								
Connecticut	2,169	1,802	319	47	0	0	0	0
Maine	16,894	7,580	7,454	1,859	37	5	24	7
Massachusetts	3,491	3,076	371	43	0	0	0	0
New Hampshire	5,020	3,233	1,429	358	568	366	161	40
Rhode Island	429	415	14	0	0	0	0	0
Vermont	4,364	2,464	1,651	249	226	96	112	17
Total	32,367	18,571	11,239	2,556	832	468	298	65
Middle Atlantic:								
Delaware	390	179	107	102	0	0	0	0
Maryland	2,832	1,404	1,024	453	0	0	0	0
New Jersey	2,354	1,754	438	161	0	0	0	0
New York	14,459	8,835	4,984	639	0	0	0	0
Pennsylvania	17,478	11,328	5,061	1,089	483	257	192	37
West Virginia	12,092	5,316	4,843	1,933	679	290	413	175
Total	49,685	28,887	16,439	4,378	1,367	547	605	213
Lake States:								
Michigan	18,600	11,586	5,085	2,148	2,422	1,460	673	288
Minnesota	16,675	14,512	1,535	826	2,127	1,829	193	104
North Dakota	406	341	37	28	0	0	0	0
South Dakota (East)	223	148	64	10	0	0	0	0
Wisconsin	14,536	12,522	1,162	852	1,317	1,135	105	77
Total	50,840	39,110	7,884	3,865	5,867	4,424	972	470
Central:								
Illinois	3,650	1,810	1,420	448	214	105	82	26
Indiana	3,840	1,658	1,405	775	136	48	74	14
Iowa	2,430	1,463	623	343	0	0	0	0
Kansas	1,187	755	368	63	0	0	0	0
Kentucky	11,826	5,728	4,730	1,368	531	98	330	103
Missouri	14,600	12,141	2,340	109	1,321	1,014	306	0
Nebraska	1,023	651	317	53	57	55	2	0
Ohio	6,422	3,125	2,355	942	129	51	40	38
Total	45,008	27,359	13,545	4,103	2,390	1,360	837	183
Total, North	177,901	113,909	49,088	14,903	10,456	6,810	2,714	933
South Atlantic:								
North Carolina	20,192	9,872	6,912	3,407	1,035	266	527	241
South Carolina	12,410	6,046	3,864	2,498	550	71	208	271
Virginia	15,859	7,818	5,834	2,205	1,202	499	562	141
Total	48,463	23,738	16,612	8,112	2,789	836	1,298	654
East Gulf:								
Florida	16,231	10,135	4,224	1,871	1,035	554	333	147
Georgia	25,102	15,891	6,370	2,840	805	216	346	244
Total	41,334	26,026	10,595	4,712	1,842	771	679	391
Central Gulf:								
Alabama	21,742	12,225	6,897	2,619	625	176	309	140
Mississippi	16,891	8,417	6,161	2,323	1,118	258	378	452
Tennessee	12,819	6,953	4,555	1,310	599	153	285	161
Total	51,453	27,595	17,603	6,254	2,344	618	972	753

3.4 MINERAL EXPLORATION SURVEY

The Mineral Exploration Survey mission is one of three missions discussed in this report which are representative of using the Space Shuttle sortie flights in the Application Development role.

3.4.1 BACKGROUND AND MISSION DESCRIPTION

The mineral exploration mission will involve a detailed and comprehensive multi-sensor effort designed to detect geologic evidence of commercial grades and quantities of copper bearing ores (ore being defined as mineral aggregates from which resources can be profitably extracted). Although the Mineral Exploration Survey mission is really much broader than just the search for copper, it was desirable for this study to constrain the mission scope in order to be able to provide more specific requirements and descriptions. When the mission is actually implemented the scope can be expanded, with little impact, to include: other metallic minerals, petrochemicals, geothermal resources, and the reconnaissance of geologically active areas.

The rationale for selection of copper exploration as the narrow mission for focusing this study can be summarized as follows:

- considered to be a scarce metal resource
- strategic/industrial importance
- U.S. consumption exceeds U.S. production
- can be profitably mined from concentrations as low as 0.5%
- demonstrated feasibility for remote sensor exploration (both aircraft and satellite)

Copper minerals are widely distributed throughout the Earth's crust. Mineable concentrations are often sedimentary in origin, occur as veins or associated with contact metamorphism. Commercially significant concentrations can be classified into five major types of which the first three are most significant:

1. Porphyry, vein and replacement deposits, which have a common genetic association with felsic intrusive rocks, and account for approximately two thirds of the world's recoverable copper resources.
2. Sedimentary deposits, which comprise 25% of the known reserves.
3. Volcanic rocks and massive sulfide deposits, which comprise another 5% of the known reserves.
4. Nickel - copper ores related to mafic intrusives (formed by magmatic processes).
5. Native copper ores (Keweenaw type)

While vein deposits are rich (they may exceed 10% copper) they are generally small and not amenable to economic exploitation by large scale mining techniques. Copper production from relatively rich vein deposits has declined markedly, advanced mining technology and bulk processing capabilities have made it feasible to extract the metal from low grade (less than two percent copper) massive sulfide deposits (type 3), resulting from hydrothermal alteration. These porphyry copper deposits (type 1) are commonly characterized by disseminated copper sulfide minerals (usually chalcopyrite) which may be associated with copper oxide minerals and uniformly distributed throughout the ore body. Despite the low concentration of copper, its even distribution throughout the rock makes it possible to utilize large volume (e.g. open pit) mining techniques and thus affect profitable recovery. The deposits are associated with silicic igneous intrusions having a characteristic "porphyritic" texture (large quartz or feldspar crystals set in a fine grained matrix) and are commonly shattered, sheared and faulted. These fractured zones enable mineralizing fluids to thoroughly permeate the intrusion and/or the surrounding country rock, and emplace the massive sulfide minerals. Shattering is thought to result from the force of the intrusion and accompanying volcanism. It has been found that porphyry copper deposits are commonly found associated with volcanic terrains less than 170 million years old.

A recent study analyzed the geological characteristics of 27 major porphyry deposits, and concluded that the "average" deposit has the following characteristics:

> This hypothetical ore body is oval and pipe-like, it measures 3,500 by 6,000 feet in plane and it contains 150 million tons of ore averaging 0.8 percent copper and 0.15 percent molybdenum. Ore below the zone of secondary enrichment contains on the average only 0.45 percent copper. On the average 70 percent of the ore body is in the intrusion, and 30 percent is in the country rock. Sulfide minerals in descending order of abundance are pyrite, chalcopyrite, molybdenite, and bornite. Supergene sulfides may form a higher grade zone of secondary enrichment.

The primary goal of the mission is to locate ore bodies of copper (primarily porphyry deposits due to their large size), but not excluding stratiform (sedimentary sulfide) and vein deposits, in order to satisfy current and projected national needs and decrease dependence on foreign sources. This will be accomplished by detecting and analyzing surface indicators of ore emplacement, including stressed vegetation, characteristic lithologic associations, zones of geochemical alteration (e.g. gossans) and tonal anomalies, lineament concentrations and intersections, and structural setting. These types of geologic indicators have been used successfully in previous mineral exploration missions.

Exploration for mineral deposits has been conducted primarily by conventional ground based field techniques, supplemented in many instances by aerial photography and, more recently, satellite imagery.

Ground based mineral surveys utilize modern mineral prospecting methods of two basic types: geochemical or geophysical techniques. Their sophistication ranges from individually employed basic mapping tools and hand held ore detectors to elaborately outfitted field crews with "black box" technology and the experience and backing of major mineral procedures. Both the geochemical and geophysical exploration approaches are used in conjunction with basic geologic mapping and sampling techniques discussed in numerous basic geology texts and procedures manuals. In addition, information supplemental to the basic exploration approaches is gathered from any available source (e.g., geobotanical evidence, cultural enhancement, previous research, regional geologic framework). In many cases, certain mineral associations enable investigators to locate concentrations of desired minerals through their occurrence with minerals of lesser value which are more easily detectable. For example, placer deposits containing gold and a radioactive mineral (e.g., monazite) may be found using a radiation counter; ultraviolet light sources can detect flourescent calcite, garite or flourite, a possible indicator of nearby metallic minerals.

Other indicators found useful in the exploration of new mineral deposits include unusual discoloration in the surface material overlying the ore body. These tonal anomalies may result from weathering and oxidation, secondary enrichment or depletion, or the formation of characteristic mineral compounds. Gossans (ferruginous deposits filling the upper parts of mineral veins) and brightly colored secondary minerals caused by the oxidation of copper, nickel, cobalt, etc. may also contribute to the unusual and frequently diagnosable surface phenomena.

When mineral deposits are not exposed or evident at the surface, more sophisticated techniques must be employed to locate them beneath an overburden of soil or rack strata. Geochemical prospecting involves the systematic measurement of the chemical properties of rock, soil, glacial debris, sediment, water or vegetation. Chemical properties most frequently measured are concentrations of key "trace" elements, making up geochemical anomalies which are classified as primary or secondary. Primary anomalies result from the outward dispersion of elements from mineralizing fluids, and may migrate significant distances away from the ore bodies along fractures or through conduits within the rockmass. These "halos" are several times larger than the ore body itself, making them useful exploration guides. Secondary anomalies result from the redistribution of elements by weathering. Elements weathered from an ore body may concentrate in residual soils, or may be concentrated by organisms (especially plants and trees). As weathering products are dispersed throughout a drainage basin, the location of a mineral deposit within the basin may be accomplished by measuring trace element concentrations in the streams and sediments, and plotting these concentrations back to the source area. Geochemical prospecting employs wet chemical techniques involving chemical tests for heavy metals, (either in field or laboratory) or instrument techniques, involving emission or x-ray spectrographs, and radioactivation analysis.

Geophysical prospecting techniques can be divided into five basic methods which have been successfully employed in mineral exploration:

- Magnetic
- gravimetric
- electrical
- radiometric
- seismic

Most commonly employed are magnetic and radiometric surveys because they are relatively simple and unexpensive. Magnetic surveys measure the regional and local magnetic fields within an area, as well as deviations in the fields caused by concentrations of certain rock types. In this manner, concealed rock formations may be detected because their average magnetic properties differ from the regional norm. Magnetic fields are measured with "dip" needles or more sophisticated magnetometers. Radiometric methods are well known, involving the search for naturally radioactive elements such as Uranium using geiger and scintillation counters. Once the radioactive rock is located, chemical methods must be employed to determine the elements causing the radioactivity.

Surface or "conventional" mineral exploration techniques are normally carried out at two levels - the surface geologic mapping and terrain analysis, and a second sub-surface approach, consisting of direct data collection (e.g., drilling or removal of overburden) or indirect data collection (e.g., seismic reflection or refraction surveys). In recent years, techniques have been developed for collecting information by remote sensors, which provide information over large regions with timeliness and substantial cost effectiveness. Aerial photographs and multispectral imagery are commonly used to supplement ground based mineral exploration surveys, and have as their main advantage the ability to "target" likely exploration sites using criteria to be discussed in a later section.

A logical extension of the regional overview provided by aircraft sensors is to satellite imagery, and data returned from Landsat, Skylab, Gemini and various meteorological satellites have demonstrated the feasibility of earth resources management and exploration from space. Figure 3-18 illustrates the different levels of exploration techniques utilized in mineral exploration.

Two major trends can be recognized in the application of remote sensing to mineral exploration: a continual improvement of sensors and data interpretation techniques, and an increasingly larger reliance on remotely sensed data to reduce surface exploration to a minimum. As sensor technology improves, and as the costs of maintaining field parties and equipment continue to grow, these trends are likely to continue.

With available technology, the role of remote sensing is still supportive, and must be considered in the context of integrated exploration programs which utilize data from sensors mounted in aircraft, rockets and spacecraft, in combination with information from field studies concerned with ground truth reconnaissance and with detailed follow-up investigations.

	Data Characteristics	Expected Applications
LANDSAT	Small Scale Low resolution Repetitive	Synoptic mapping of: Soil groups Surficial geology Karstic terranes Cultural phenomena Crop distributions Forestry distributions Hydrologic phenomena Identification of temporal aspects of above and changes and patterns of change.
SHUTTLE	Small-medium scale infreq. cover.	
High-Altitude Aircraft (60,000 ft)	Moderate scale Moderate resolution Seasonal	Large-systems analysis of all mentioned above at greater resolution and larger scale Fundamentally a correlation bridge from satellite data to ground truth.
Medium-Altitude Aircraft (30,000 ft)	Large scale High resolution Specific missions	Specific studies and strip monitoring of defined phenomena and processes Correlation of satellite data with ground truth Land use and land capability determinations.
Low-Altitude Aircraft (1000-15,000 ft)	Very large scale Very high resolution Specific missions	Scale modification of above where specific problems require higher resolutions.
Surface Studies	Instrument-acquired data at close range or by contact measurement	Fundamental validation of RS analyses; on organizational format for consolidation of extant and currently acquired earth resources data.
Subsurface Studies	Remotely-sensed geophysical and drilling data	Fundamental validation of airborne RS analysis for surficial geology, bedrock geology, hydrology and soils origins.

Figure 3-18. Mineral Exploration Methods

A major factor in the exploration for new mineral reserves is that most of the deposits in accessible regions of the world which are close to or at the surface have already been exploited. Thus, new deposits required to satisfy present and projected needs must be sought in areas which are largely inaccessible, through geographic remoteness or substantial surface cover. The geographically remote areas can be effectively surveyed by remote sensors, at least on a reconnaissance level. As an extension of this "aerial" overview, investigators have found imagery taken from orbital altitudes to have advantages over the aircraft data, since the space photographs (or images) provide unsegmented synoptic overview of large areas under uniform sun angle and illumination. In addition, space photos are easily rectified to the true vertical position, and have served as base maps for minerals investigators.

Sensors that are most useful to geologists are those that form images-photography, multiband scanners, and side looking radar. The primary advantage of these systems is their regional overview, timeliness and minimal data processing requirements. A disadvantage is that the sensors have limited penetration through the surface cover, thus deposits at depth must be identified by indirect indicators at the surface.

Those criteria found useful for detecting mineral concentrations by remote sensing techniques include the following:

- structural associations
- lithologic associations
- lineament distribution
- surface alteration
- stressed vegetation
- textural features
- radioactivity
- magnetic gravity surveys
- geochemical methods
- temperature differences, including thermal inertia

The primary goal of this mission is to locate new domestic supplies of copper resources in order to increase national independence from unpredicatable foreign supplies. To this end, the exploration effort will be limited to test sites within the continental United States and Alaska. It should be kept in mind that a similar mission could be carried out over foreign test sites, under similar geologic conditions, should such a mission be deemed appropriate.

3.4.2 USER COMMUNITY AND BENEFIT MECHANISM

With an increasing demand for energy and mineral resources brought about by a steadily industrializing world, rapid and cost-effective exploration techniques are required to insure that raw materials will be available when they are needed. In as much as the primary goal is to locate new domestic supplies of copper resources, the users of interest are the Federal and private organizations of the United States.

Foreign users will be discussed only briefly since their exploration requirements are similar to those of domestic users, and since the primary goal of the mission is to provide a measure of mineral resource self sufficiency to the United States. It is anticipated that foreign users will benefit from this mission primarily through the export of copper ore or refined metal from newly discovered domestic reserves, although direct exploration over foreign test sites is feasible and an expanded version (global) of this mission would more directly benefit the foreign users.

It has been reported (Cox et.al) that 70% of the world's identified copper resources fall into four distinct geologic-geographic groups. In decreasing importance they include the porphyry copper deposits of Chile and Peru, porphyry copper deposits of the southwestern United States, sedimentary copper deposits of Zaire and Zambia, and porphyry and sedimentary copper deposits within the U.S.S.R. Other significant groups include the Porphyry copper deposits in Oceania, Mexico and Western Canada, and the porphyry copper and sedimentary copper deposits in southeastern and central Europe. Estimated worldwide reserves of copper resources are shown in Table 3-13. Domestic organizations concerned with the exploration for and development of copper and related mineral resources can be divided into two groups. In the first category are those agencies interested in discovering additional reserves and insuring an adequate supply for future needs. In the second are those organizations involved in developing the reserves and directly utilizing the metal or selling it to manufacturing industries. The first group includes Federal Agencies such as the Department of the Interior and its functional arms such as the U.S. Geological Survey and U.S. Bureau of Mines, State and regional geologic Organizations and some private companies.

TABLE 3-13. IDENTIFIED AND HYPOTHETICAL COPPER RESOURCES, IN MILLIONS OF SHORT TONS

AREA	IDENTIFIED[1]	HYPOTHETICAL[2]
UNITED STATES:		
EASTERN	10	5
WESTERN, EXCEPT ALASKA	64	75
ALASKA	2	20
CANADA	19	50
MEXICO	18	20
CENTRAL AMERICA	1	6
ANTILLES	2	1
SOUTH AMERICA	80	50
EUROPE, EXCLUDING U.S.S.R.	25	20
AFRICA	53	50
U.S.S.R.	39	50
MIDDLE EAST-SOUTH ASIA	4	20
CHINA	3	?
OCEANIA, INCLUDING JAPAN	21	30
AUSTRALIA	3	3
TOTAL	344	400

[1] Identified resources: Specific, identified mineral deposits that may or may not be evaluated as to extent and grade and whose contained minerals may or may not be profitably recoverable with existing technology and economic conditions. Based on all categories of reserve figures plus estimates where no figures are available. Amounts are tentative and accuracy will be refined in subsequent publications.

[2] Hypothetical resources: Undiscovered mineral deposits, whether of recoverable or subeconomic grade, that are geologically predictable as existing in known districts. Based generally on identified resource figures times a factor assigned according to geologic favorability of the region, extent of geologic mapping, and exploration.

These private companies are comprised mainly of exploration arms of major copper producers, and consulting engineering firms who provide mineral exploration services to clients. The second group is comprised of direct producers (of the metal) and manufacturers of various products.

Federal and private users may be related on a contractual basis, where a consulting firm will conduct a specified research program for a federal user. Conversely, a federal agency can encourage private research by providing access to data or through direct financial support (e.g. the Mineral Exploration Assistance Program).

The information derived from Shuttle and supplemental satellite sensors useful to a mineral exploration mission is made available to federal and private users. Federal agencies use the data to compile mineral reports, conduct research, and classify the mineral potential of federal lands. Private users will use the data to locate mineral resources; either directly (mineral & mining companies) or indirectly (academic research, or interpretations compiled by consultants for clients). In addition to Shuttle and satellite based inputs, conventional information sources, such as the published literature are utilized. From this interchange and accumulation of data, the final test of a geological survey, namely drilling and sampling at specific locations, can be performed more quickly and with a greater chance of locating workable ore bodies. It is from this process that the primary economic benefit of the mission will be realized.

3.4.3 JUSTIFICATION FOR THE SHUTTLE PROGRAM

Use of the Space Shuttle as a remote sensing platform provides several advantages which apply to several different types of missions. Those directly applicable to the Mineral Exploration Survey mission are:

1. The design of the Shuttle mission will be to complement rather than duplicate measurements which can be made by unmanned satellites.
2. The Shuttle will be maneuverable, enabling investigators to obtain real-time measurements, and to alter the mission plan as appropriate in the light of data just received.
3. The Shuttle system could provide a selectable real-time observation capability to receiving stations on the ground, via down-link communication channels. When a selected site is approached, real time monitors in the shuttle or in the ground station could scan the various imaging sensors and select the most appropriate combination for viewing the scene.
4. The substantial payload capability will enable potential users to enjoy flexibility in employing a wide variety of sophisticated sensors. They will be accessible in flight for adjustment, calibration and repair, and available for post-mission inspection and evaluation.

For earth surveys in general, observations of the earth's surface taken simultaneously with a variety of sensors can be compared to yield information useful to earth scientists and applicable to commercial activities such as prospecting, fishing, farming and transportation. The quality of the results of experiments carried out by Shuttle will be optionum since the investigators themselves will be on the scene to alter the mission experiment plan as necessary, combining user expertise with shuttle mission flexibility.

The Shuttle characteristics will support the mission requirements for greater spatial resolution, stereo photographic coverage, and simultaneous use of different sensor systems. The synoptic regional overview combined with high resolution imagery permitted by returnable camera systems will enable investigators to pin point subtle surface features indicative of mineral concentration. Further, the large payload capacity will permit a variety of sensors with adequate power facilities to be utilized. Since this mission is designed to operate primarily over the U.S., where regional geology has been fairly well defined, the existing regional information can be verified and improved by high resolution images from Shuttle. Acceptable resolution/area coverage trade-offs would be made for the specific missions (e.g. 3 meter resolution for a 50x50 kilometer area, or 20 meter resolution for 150x150 kilometer area). Smaller area higher resolution coverage would be more useful where lineament intersections or rock relationships are of interest. Larger area lower resolution coverage would be effective for exploring for surface color changes associated with massive porphyry copper deposits. Whatever the resolution requirements, imagery should be calibrated and metrically correct, in order to facilitate the transfer of information onto base maps. Stereo side lap photography will facilitate the interpretation of geologic structure, perhaps providing an alternative to computer enhancement techniques.

For camera or scanner sensing systems, true color imagery is important for discriminating lithologies, especially in arid regions. Color infrared imagery is useful for enhancing vegetation and soil types, as well as soil moisture content.

Shuttle payload capabilities would make it possible to carry a scanner system with high resolution (approximately 1/3 of that of Landsat) which would maintain a 59 km swath width. Besides the coverage in the .45 to 2.35 micron region (specific bands to be determined) a thermal channel could be included covering the 10.4 - 12.5 micron band.

3.4.4 SENSOR REQUIREMENTS

The generic sensor types which are required for the mineral exploration mission are summarized below in Table 3-14.

TABLE 3-14. GENERIC SENSOR REQUIREMENTS FOR MINERAL EXPLORATION

REQUIREMENT	PURPOSE
1. OVERLAPPING PHOTOGRAPHS FOR STEREO VIEWING	ACCURATE DETERMINATION OF LANDFORMS, TOPOGRAPHY
2. 10-20m SPATIAL RESOLUTION IMAGERY	LOCATE SMALL ROCK OUTCROPS, LINEAMENT PATTERNS, SURFACE TONAL ANOMALIES
3. MSS SCANNER - .45 to 2.35 MICRONS - 10.4 to 12.5 MICRONS (SPECIFIC BANDS TO BE DETERMINED SEE TEXT)	SPECTRAL RESOLUTION AND ADVANCED INTERPRETATIVE TECHNIQUES (E.G. ADDITIVE COLOR VIEWING, COMPUTER ENHANCEMENTS) TO: DISCRIMINATION OF GROSS ROCK TYPES, DELINEATION BETWEEN ALTERED AND UNALTERED ROCKS, BETWEEN ROCKS AND SURFICIAL COVER.
4. CAMERA SYSTEM	TRUE COLOR AND COLOR INFRARED TO DETECT SURFACE TONES, TYPES OF GEOCHEMICAL PROCESSES
5. IMAGING RADAR (LATER)	CLOUD AND VEGETATION PENETRATION, TO DETECT SURFACE "ROUGHNESS" AND LINEAMENTS
6. ILLUMINATION REQUIREMENTS	
- LOW SUN ANGLE	TO EMPHASIZE LINEAMENTS BY SHADOW EFFECT
- HIGH SUN ANGLE	TO EMPHASIZE TONAL DIFFERENCES AND MINIMIZE OBSCURING EFFECT OF SHADOWS
7. INFORMATION GRID SIZE	50 METERS

Color photography is of considerable value, especially for detecting color anomalies, e.g. geochemical alteration. The color photography has excellent information capacity, and high reliability. Thermal infra-red imagery readily identifies thermal features, but can be poor in analyzing subtle geological phenomena. The recognition of thermal features may indicate near surface igneous intrusions or sulfide bodies which produce heat through oxidation. In regions where permafrost exists, the heat given off by oxidizing sulfide bodies may cause destruction of the permafrost near the deposit, a feature readily detectable from orbital altitudes. Radar imaging can also be a useful tool for distinguishing lithologic units, as well as showing topography clearly, especially surface traces of fault systems.

Requirements for the remote sensing mineral exploration mission developed during this study included the following, as shown in Table 3-15.

- Primary sensing technique - visual color imaging, metric quality desirable.
- Supplementary sensing techniques - radar imaging
- Alternate sensing techniques - Infra red imaging covering the spectrum between 3 to 4.2 microns and 8 to 12 microns. Passive microwave imaging and absorption spectrophotometry.

The geological objectives include production of basic small-scale geologic maps at two scales (1:10,000 and 1:250,000) in order to complete and up-date existing map series. The sensing techniques with greatest applicability for geology are visual imaging, with metric quality desired for the geologic mapping objectives. Ground resolution requirements range from 6 to 30 m desired and 30 to 120 m acceptable. The most stringent resolution requirement comes from the 1:250,000 mapping objective.

Radar imaging has considerable potential for geologic applications as it tends to emphasize important topographic and geologic features while suppressing effects of some non-geologic features. Ground resolution element requirements are similar to or slightly greater than those for visual imaging. Thermal IR imaging is useful for applications requiring information on the ground surface temperature distribution. The desired ground resolution is similar to that for radar imaging but ground resolutions of up to 300 m or even 3 km for volcano reconnaissance are considered acceptable.

The frequency of observation requirements for the various geologic objectives are quite similar and in fact, for many objectives the same. Since geologic conditions are essentially static on any time scale considered in the normal course of events, the requirement is basically to obtain complete coverage of the areas of interest once. The time of year is generally selected as summer or autumn so that snow cover will be minimal, and there is some preference for the autumn end of this time period as native vegetation correlates in some instances with geologic composition of areas, and identification of some vegetation types is facilitated by the presence of autumn coloration. Also the detection of surface features may be easier in some areas when deciduous forests have lost their leaves.

TABLE 3-15. RECOMMENDED VALUES OF MEASUREMENT PARAMETERS

MEASUREMENT PARAMETERS:	USEFUL RANGE	RECOMMENDED VALUES
GROUND RESOLUTION:		DESIRED (ACCEPTABLE)
VISUAL (COLOR) IMAGING	6-30m 100-450m	6m (90m)
RADAR IMAGING	3-30m 100-450m	30m (90m)
THERMAL IR IMAGING	3-30m 100-450m	30m (300m)
PASSIVE MICROWAVE IMAGING		30m (300m)
THERMAL RESOLUTION:	0.5°C	
SUN ANGLE:	30° and 60°	20-40° and 60-90°
	(LOW SUN ANGLE TO ENHANCE LINEAMENTS, HIGH SUN ANGLE TO ENHANCE SURFACE TONES)	
SWATH WIDTH:	180km (BASED ON 100m RESOLUTION) BUT MAY BE TRADED OFF FOR HIGHER RESOLUTION	
LOCATION TO BE OBSERVED:	SOUTHWESTERN U.S., ALASKA, APPALACHIANS, KEWEENAWAN AREA.	
OBSERVATION SCHEDULE:	AT LEAST TWICE, ONCE AT EACH SUN ANGLE. (POSSIBLY MORE IF THERMAL INERTIA MEASUREMENTS WANTED)	JULY-OCTOBER PREFERABLY SEPTEMBER OR OCTOBER
RESPONSE TIME:	NOT CRITICAL	

Sun angle plays an important role in the specification of visual imagery for geological applications. Low sun angles increase the visibility of minor topographic features because of shadowing whereas high sun angles are desirable for high-quality color photography from which compositional variations may be inferred. Accordingly, two Sun-angle ranges have been specified for the geology objectives, 20-40° and 60-90°.

Single, vertical photographs are useful for recognizing or classifying specific features on the earth's surface; however, the single photo (or image) enables the viewer to perceive only two dimensions, length and width. Geologic mapping involves not only the spatial distribution of surface deposits, but actually the recognition of 3 dimensional geologic structures and how they are expressed at the surface. This expression may be manifest in two ways - landforms themselves, which may not expose rocks at the surface, but will influence local topography (such as domes, basins and folded strata) and actual rock and alluvium exposed at the surface through glaciation, lack of vegetation (e.g. arid climate) or erosion.

In both cases the third dimension of depth is required to accurately measure the shapes of the landforms, degree of erosion, or the angle at which rock strata "dip" beneath the surface cover. These measurements are critical in constructing both topo and geologic maps - topographic maps which rely on accurate land form analyses to measure elevations and the distribution of surface features, and geologic maps which rely on accurate measurements of the attitude of strata to infer the underlying structure, and interpret the geologic history of a region.

In order to acquire the third dimension, the viewer must apply his natural "depth" perception ability. When objects greater than 450 to 600 meters away are viewed by unaided eyes, the special ability of depth perception is essentially lost. At such distances, lines-of-sight from each eye converge very little; in fact, they are practically parallel, as when the eyes are focused at infinity. If the human eye base (inter-pupillary distance) were increased from the normal 6.5 cm, the perception of depth could be greatly increased. In a manner of speaking, this feat can be accomplished through aerial (or space) stereo photography. From an airplane in level flight, overlapping camera exposures are made at intervals of several thousand feet. When any two successive prints are viewed through a simple stereoscope, each eye "occupies" one of the widely separated camera stations. This "stretching" of the human eye base results in a greatly exaggerated three-dimensional photograph for study and interpretation.

Stereo viewing is useful to the geologist for:

- recognizing linears
- defining direction and magnitude of dips
- determining lithologies by their relative resistance to erosion
- recognizing landforms
- locating glacial deposits
- assessing slope stability
- determining tonal differences and their relative relief

Spatial requirements for the mineral exploration survey mission deemed necessary by most potential users are ten to twenty meter ground resolution and a minimum of 50x50 kilometer aerial coverage. The ten or twenty meter spatial resolution is necessary for locating small rock outcrops, lineament patterns and surface tonal anomalies. Specific spectral requirements need to be determined. Candidate bands include:

- Multispectral scanner

  .45 - .50μ, Ferrons iron absorption.

  .52 - .56μ, Strong green absorbance of rocks with iron oxide stain; increased reflectance of rocks containing minerals with Ferrons iron.

  .63 - .68μ, Strong red reflectance of rocks with iron oxide strain.

  .85 - .90μ, Ferric iron absorption band.

  1.1 - 1.35μ, 1.55 - 1.75μ, 2.05 - 2.35μ, Best bands for separating altered versus unaltered rocks.

  10.4 - 12.5μ, Differentiating soil and rock types using thermal inertia techniques.
- Camera systems for high resolution stereo color and color IR, for detecting surface tones, vegetation type, and geochemical information.
- Imaging radar - (SLAR) for cloud penetration, structural discrimination, drainage, lineaments, and "structural grain" or surface "roughness".

Auxiliary data useful for supplementing the information provided by the sensor systems is primarily in the form of ground truth, published information, and test site familiarity (experience of the interpreter).

3.4.5 FLIGHT PROGRAM

Test sites to be evaluated in this survey include known copper-producing regions and adjacent areas to duly utilize existing ground truth and proven exploratory techniques in particular, the "copper belt" of the Southwestern United States, including large portions of Arizona, New Mexico, Utah and Colorado and smaller regions of Idaho and Wyoming (see Figure 3-19). The copper region is composed of "belts" trending roughly north-south, covering an area of approximately 27,000 square miles. The existence of proven copper mineralization in this area increases the likelihood that other deposits will be discovered under similar geologic conditions; thus they are considered to be high potential exploration targets.

In addition to the prime exploration site in the southwestern and western U.S., other exploration sites show copper mineralization potential. These areas can be characterized by igneous intrusions and metamorphic terrain, especially near lithologic contacts and where major lineaments are concentrated. Portions of southern Alaska and the Alaskan pan handle fall into this category, as does the Keweenawan Peninsula and adjacent territories surrounding the Great Lakes and extending into Canada. In addition, igneous and metamorphic portions of the southern and northern Appalachians fall into this group, including portions of Georgia, Alabama and Tennessee and northern New England. In total, areas of potential copper mineralization which should be surveyed in this mission approach 78,000 square kilometers. (30,000 square miles). Their exact distribution are summarized in Figure 3-19 which also shows the locations of the selected test sites relative to the known locations of copper mineralization in the United States.

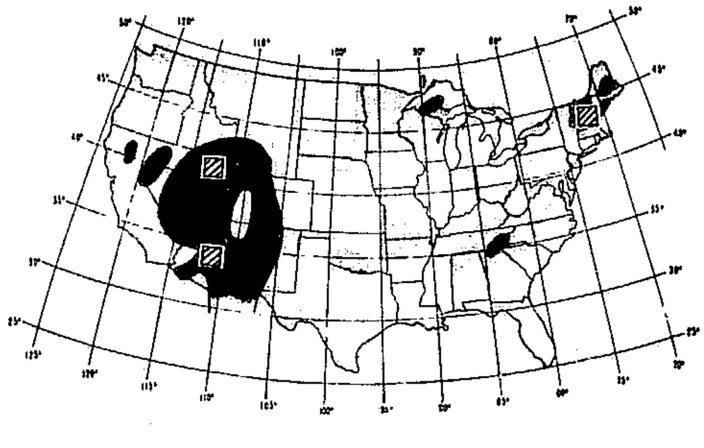


Figure 3-19. Known and Potential U.S. Copper Deposits with Candidate Test Sites

Analyzing specific data requirements as expressed by potential users yields the following constraints:

1. Optimum information grid size desired by a majority of potential users for mineral resources information is 50 meters.
2. Timeliness requirement (the interval between data collection and actual availability to the investigator) is between two to six months. For geologic phenomena, timeliness is not a critical concern.
3. Update cycles requested most frequently are seasonal (quarterly) to take advantage of changes in vegetation and sun angle. In some investigations, the update cycle is yearly or one time only, due to the slow rate at which most geological processes take place.

In addition, progressive changes in vegetation or seasonal snow cover, resulting from long term climate fluctuations may enhance the underlying terrain to different degrees, necessitating quarterly coverage over a series of years. Investigators in the Landsat program report that in many cases, each seasonal cycle contributes new information to a given study, and so continuing coverage is valuable even though actual terrain conditions remain relatively static.

3.4.6 DATA DISSEMINATION

The formats in which data, obtained by the Shuttle Mineral Exploration Survey Mission, will serve the user community are varied. Products will include an overall report of the mission, containing specific information such as area covered, orbital parameters, sensors utilized and initial evaluation of the test sites. In addition to the report, overlay maps will be prepared containing pertinent geologic information derived from ground truth and mission data, including surficial geology and known mining localities where possible. Timeliness is less critical in geology than in a field such as agriculture; barring artificial time constraints imposed through contracts or legislation. Two to six months timeliness should be sufficient for most mineral exploration applications.

The information derived from Shuttle (primary) and supplemental satellite (secondary) sensors useful to a mineral exploration mission (geology, lineaments, surface alteration) is made available to federal and private users. The overall flow of information is shown in Figure 3-20. Federal agencies use the data to compile mineral reports, conduct pure research, and classify the mineral potential of federal lands. Private users will use the data to locate mineral resources; either directly (mineral & mining companies) or indirectly (academic research, or interpretations compiled by consultants for clients). As additional inputs, conventional information sources, such as the published literature are utilized.

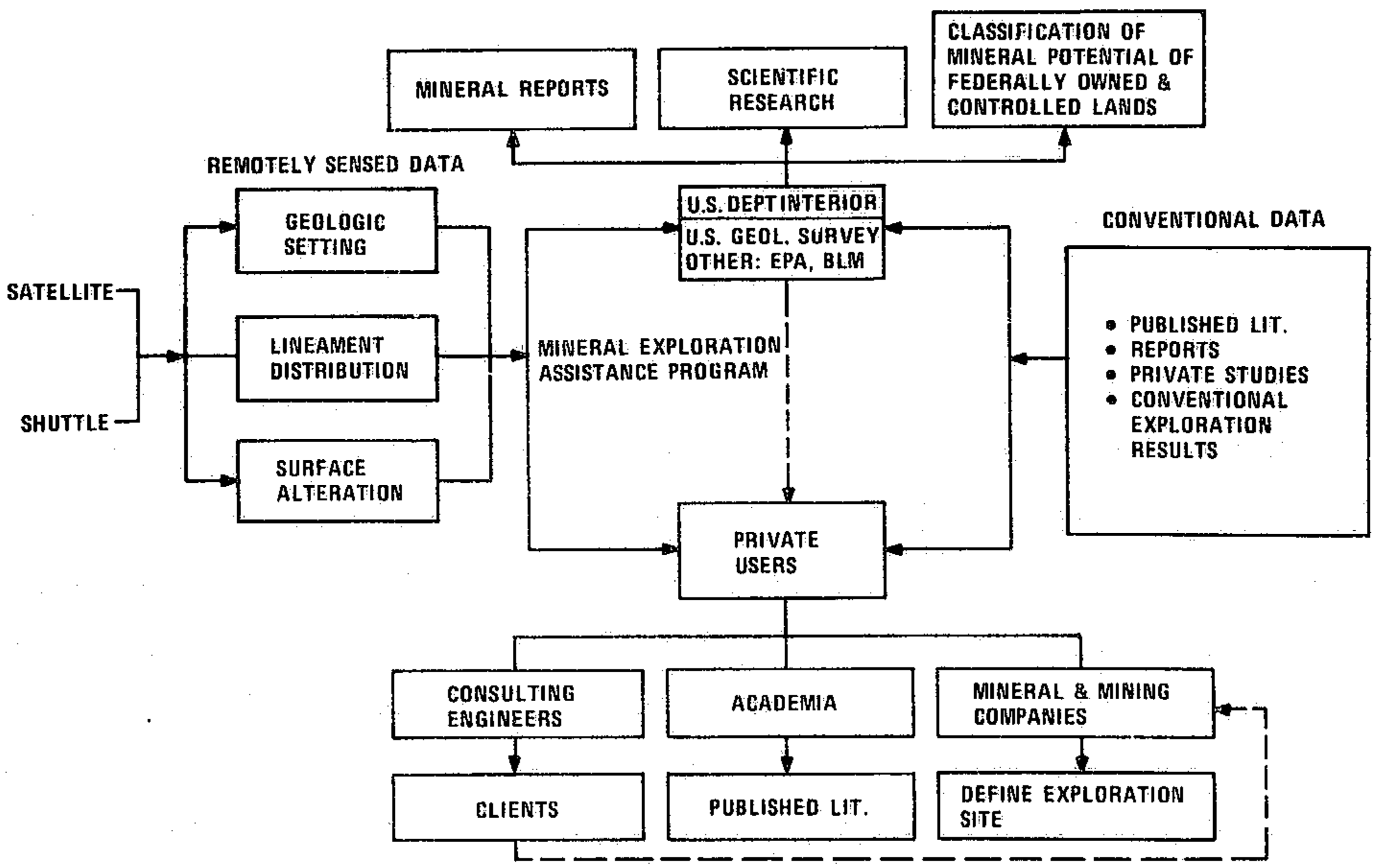


Figure 3-20. Mineral Exploration Survey Information Flow

3.5 URBAN AND REGIONAL PLANNING

The Urban and Regional Planning mission is one of three missions discussed in this report which are representative of using the Space Shuttle sortie flights in the Application Development role.

3.5.1 BACKGROUND AND MISSION DESCRIPTION

The utilization of our land resources consists of several related activities; one of these activities, the planning for land utilization, is the focus of this mission. This focus on planning should not be misconstrued to represent that planning is the sole (or even major) activity within land utilization; rather, planning was selected in order to provide a single focal point for an earth resource survey mission. The urban and regional planning mission will utilize the Space Shuttle as a data acquisition platform to obtain remotely sensed data which can be employed by planning authorities as inputs to research, plan preparation, and decision implementation. Uses for remotely sensed data, other than planning, in the area of land utilization include: strategic management, monitoring current utilization, publicity, and other more day-to-day operational uses. In discussing this mission, it would be useful to begin by touching upon the nature of planning activities, and also commenting briefly on some of the more recent work which has been directed towards demonstrating the feasibility of utilizing a remote-sensing technology as an aid to planning efforts.

In the most general sense of the term, planning may be defined as a process which leads to the formulation and clarification of goals and objectives, and to the reduction or translation of these goals and objectives into specific courses of action. Planning activities which are oriented towards shaping the pattern of human activities over space may be differentiated from one another in terms of the level of spatial aggregation at which they are carried out. For this Application Development mission, two basic forms of land-oriented planning may be identified: (1) urban, or city planning; and (2) regional planning. As the terms imply, regional planning is carried out within the context of supra-urban space (i.e., within areas which include more than one city), while urban planning is conducted within the context of intra-urban space. Moreover, the two forms of planning can also be distinguished from one another by the fact that urban planning focuses on problems pertaining to the quality of the micro-environment (e.g., urban design, the staging of small-scale changes in land-use patterns, the provision of public facilities and services, and the evaluation and management of a housing stock), while regional planning is primarily concerned with the economic problem of resource allocation and development.

Regional and urban planning is concerned with the development of the functional linkages which connect metropolitan regions to one another. The major concern is with the transportation of people and commodities; however, interest also focuses on problems related to the development of power grids, communications networks, and water supply channels. This planning also deals with the developmental problems of the so-called peripheral areas which lie outside of the metropolitan regions. In many instances such areas lag far behind the rest of the nation in terms of economic development even though they include potentially valuable natural resources (Appalachia is an example). Generally speaking, planning efforts in this context are directed mainly towards resource development.

At this juncture, it would seem appropriate to say a few words about the sequence of activities involved in land-oriented planning. A more or less conventional formulation of the planning process is as follows:[1]

1. Resource inventory: appraisal of existing resources in categories such as land and water, species, and human population.
2. Data acquisition and processing: collection, manipulation, and storage of information using conventional surveys, aerial photography, and remote sensing.
3. Analysis of data in terms of existing status or use, quantity, quality, location, trends, and relationships.
4. Plan formulation and implementation: forecasting, development of alternatives, simulation, modeling, and selection of a course of action.
5. Monitoring and enforcement: measurement and performance in terms of rate of change, type of change, location, quality, and amount; and adjudication of conflicts.
6. Evaluation of policies, priorities, technology, organization, and legislation to identify places and methods for improvement.
7. Repetition of the process.

As this outline indicates, the activities of planning authorities are not confined solely to the preparation of plans. Indeed, a large part of their efforts is directed towards the resolution of problems of an immediate nature. For example, a major function of urban planning agencies is the enforcement of zoning regulations. Also, in recent years, planning authorities at all levels of spatial aggregation have become increasingly involved in matters relating to the protection of the environment - such as the preparation of environmental impact statements for proposed developments.

Historically, there has been a tendency in this country to downgrade the importance of planning. There are now indications, however, that the situation may be changing. The recent surge of environmental awareness has given tremendous thrust to the maintenance of a quality environment. Thus, in ever growing numbers, Americans have come to recognize the vital importance of effective planning institutions. Evidence of this trend is the so-called "quiet revolution" in land-use controls which is taking place in many State governments, and the movement at the Federal level towards the establishment of a national land-use policy.

The growing interest in planning has fostered concern in many quarters about the adequacy of the data upon which planning decisions are formulated. As cities have pointed out, planners all too often are forced to

1. Schechter (1973), as quoted by Council of State Governments (1974, p. 5)

make decisions based more upon intuition than upon solid fact. Clearly, the necessity of having to rely upon such an approach increases the probability of making bad decisions, and thereby seriously weakens the argument for careful and thoughtful planning itself. Thus, poor data may not only lend directly to a bad planning decision; but, may also lead to a general weakening of the planning process itself. A general weakening or lack of respect for the planning process will utilimately lead to the total disregard of planned land utilization and the return of individual uncoordinated decisions.

The importance of this problem has encouraged search for new approaches to improving the data base for planning. One line of research has focused on exploring the potential contribution of remote sensing technology. Numerous land use investigations employing remote sensing have been conducted using both manual and automated interpretation techniques. The results to date have shown that land use can be classified and portrayed on thematic maps using both manual and automated techniques. Various levels of classification have been achieved depending on the types remote sensing platform used to obtain the data. Some generalized conclusions which may be drawn from these investigations include:

- There is utility in Landsat data for urban and regional planning.
- It would be desirable for future work of this kind to maintain the synopoticity obtainable in the field of view of a standard Landsat image, i.e., 185 x 185 kilometers (100 by 100 nautical miles).
- It would be desirable for Landsat imagery in the future to have higher resolution, perhaps with a future series of resources satellites.
- The nature of a standard Landsat image in terms of both a wide field of view and multispectrality was unique and unconventional to many planners who are used to working with the traditional land use data sources such as large scale black and white aircraft imagery.
- The periodicity of global coverage by Landsat every 18 days was judged to be sufficient to allow for meaningful temporal evaluation of the Los Angeles area.
- The unconventional and supplemental nature of Landsat products and the nature of the planning process makes it very difficult to directly measure the cost effectiveness of Landsat products for urban and regional planning.

Landsat experimental investigations have demonstrated the utility of space borne remote sensing to the area of land utilization in general and to urban and regional planning in particular. Information products such as available from aircraft and satellite may prove to be even more useful as a data source for the less developed areas of the world having less elaborate existing data bases and fewer alternative or complementary data sources. Thus, the utility of applying remotely sensed data to the planning activity has been established. The next step is to develop a system suitable for the routine and operational acquisition of this data of a type and format useful to planners (at least, and probably others involved with land utilization as well).

It is worth repeating, that the preceeding discussion and emphasis on planning is provided because this mission is oriented specifically at that single aspect of land utilization. That is not to imply that planning is the only application of remote sensing for land utilization, but only that planning is the single aspect selected to provide a focal point for designing a Space Shuttle Application Development mission. This rather narrow focal point was required because past experience in land utilization mission planning has showed that the wide diversity of the field and the multiplicity of users is too great. In the past this diversity and multiplicity has led to too much general discussion and dilution in an attempt to solve all problems. The approach taken here was to restrict the scope to a singular focal point and design a mission accordingly. It is fully recognized that the data which results from this mission will have much wider applicability in the management of land resource utilization.

The purpose of this Shuttle urban and regional planning mission is the bridging of the gap between the sucessful experimental results and a fully operational system, using the Shuttle as a platform to gather higher-resolution electronic and photographic imagery simultaneously. This imagery data will then be used as input to the planning process described.

3.5.2 USER COMMUNITY AND BENEFIT MECHANISM

The urban and regional planning mission is unique of the three selected Applications Development missions in that the user community is extremely diversified, and each user is interested in data only for a limited geographical region. (Some Federal agencies are exceptions to this rule because of their national responsibilities but can be considered as special cases).

The user agencies are primarily in the public sector, as opposed to private, although some private land developer and large landowners may also be interested users. The public sector user may be further broken into three categories:

(1) Local level users:

- City and county planning departments

(2) Metropolitan region level users:

- Metropolitan planning agencies (Delaware Valley Regional Planning Commission is a good example)
- Councils of governments (COG's) - these are groups of city and county governments which are formed for the purpose of dealing with area wide problems
- Large county planning agencies - like LA county

(3) Regional level users:

- Special commissions: e.g. Delaware River Basin Commission, Appalachian Regional Commission, TVA, etc.
- State planning agencies

- Coastal zone planning organizations
- Federal agencies such as the Bureau of Reclamation, Corps of Engineers

This multiplicity of "special interest" users presents a significant problem in data dissemination, since each must be serviced individually, and each will have special data and information needs. This problem will be discussed in a later section.

The key to the benefit mechanism of the urban and Regional planning mission is the improvement in several critical areas of the planning process:

- <u>Organization of Data Collection</u>

  Much of the potential usefulness for existing data is lost because the data are not comparable. A high-priority objective then, is to make data gathered by one group, organization, or source compatible with and useful to other agencies. Data comparability is needed not only among different agencies at one level of government but also among the various governmental levels; there should certainly be sufficient comparability to enable the transfer of information beyond governmental jurisdictions. This requires a common format covering such aspects as: classification, area, identifier (data index), etc. It is unnecessary and appears undesirable to centralize the total data collection function within any given level or organization of government.

- <u>Access</u>

  Another high-priority objective is to improve access to data. The most important aspect of access is to improve the identifier or coding system. Given the requirements of environmental planning, geographic coding systems should be strived for when possible.

  Another aspect needing improvement is real-time access, as compared to the often long turn-around times currently found in many information-retrieval systems. Two key tasks in planning physical environments would greatly benefit from real-time access. The first of these is the ability to speculate about alternative possibilities and breakthrough improvements, and to enhance learning by doing so. The second is the ability to answer questions quickly about the possible adverse impacts of specific development proposals.

  A third, and growing, issue is to extend access beyond the current group of technical experts to include citizens, elected officials, and Government administrators. The problem is related to the division and mistrust between the professionals and those who must accept or reject their work. It is a concern in some parts of the country with technocracy and in other places with unresponsive Government. Information is power, and access to information and the ability to use the same tools as the professional is a growing demand on the part of public officials and citizens.

- <u>Data Classification</u>

  There are two main weaknesses in using current classification schemes to solve problems relating to the physical environment. The first is uniformity of classes. There is a tendency for data collectors to use their own classification schemes. In addition, many of the existing standard land-use classification schemes are based largely on economic criteria and/or on the nuisance value of side effects. Neither of these attributes is particularly useful in evaluating environmental implications of alternate development possibilities. Therefore, the objective of evolving a uniform or compatible classification scheme which is both responsive to disparate users and internally consistent to allow users to exchange results should receive early attention.

- <u>Data Acquisition: Method, Frequency, Priorities</u>

  The range of methods for data acquisition is increasing from direct interviews in attitude surveys to remote sensing via satellite. Many of these approaches, although expensive, yield very useful information; others, though inexpensive, produce data of less reliability. Still others are expensive and produce data of questionable utility. An objective for data improvement would combine methods to achieve cost savings while achieving high reliability.

Frequency must relate directly to the data and their intended use. It will always be highly variable. Yet there is need to establish coordinated periods for improved data comparability.

Finally, because data are expensive, priorities must be set on their collection and incorporation into information systems. The capacity to adequately store, retrieve, and manipulate all the data now pouring in from the various satellites does not exist. Selectivity is necessary so that a maximum of useful information can be derived from the wealth of data available.

- System Capability: Point, Line, Area Resolution

  The adequate study of environmental problems demands a system capable of handling point, line, and area data. An example is the need to coordinate data from a point emission with a stream and the surrounding natural and developed area. Most systems today handle data in only one of these modes. As data-handling improvements are made, this should receive attention. The setting of water-quality policy for all the lakes of a State, for example, requires a different resolution than that to prepare a program of action to correct the pollution of a specific lake. The task is to retain the ability to aggregate data and yet have comparability at a given scale.

- Machine Coordination

  This is a less-immediate objective, but one requiring study. If data remain stored in a variety of locations, and if access to information is to be achieved on anything approaching a real-time basis, some linking of machines and agencies would appear to be necessary. The IRIS data system proposed for the State of Illinois would create an interlocked set of computers located at various points throughout the State and a cluster of remote terminals tied to each computer. The whole issue is very complicated, but the ability to achieve coordination will decline as time passes if no action is taken.

- Education

  Progress in environmental planning and controls requires a massive education program. Far more people know how the land market works than know ecological linkages, perhaps because there is a strong incentive in the market to learn. Information systems with direct man/machine interface can be useful tools in problem solving and policy formulation. They also have the potential of being used for programmed learning, a potential that bears exploring.

It is difficult at this point to evaluate overall cost effectiveness and cost benefits to be derived from the mission, primarily because problems are being solved whose economic benefits are not known nor easily assessed, and yet for which there is no practical alternate solution. Thus, the benefits derive from doing new things rather than making the old process more efficient, e.g.

- High resolution, synoptic imagery provides common data for large areas - this is not available now, and the need will grow as metropolitan growth continues.
- Because there will be many primary uses for the Shuttle's output, unit costs will be relatively low. One example of a benefit is land use inventories which are not now undertaken at frequent intervals because of their high cost, can be undertaken more often.

3.5.3 JUSTIFICATION FOR THE SHUTTLE MISSION

The primary justification for the use of Shuttle as part of this mission is the availability of a cost-effective combination of high resolution photographic camera with medium resolution electronic sensors, providing synoptic coverage of areas of interest due to Space Shuttle. Shuttle not only provides the only visible space platform (through the 1980's) for obtaining synoptic photographic coverage; but, it is also the most cost effective platform (in comparison with high altitude aircraft) for obtaining the volume of photographic data required. The cost effectiveness of the Space Shuttle is discussed at greater length in Section 7 of this report.

The key factor in the cost effectiveness of the Shuttle is the ability to amortize the cost over several similar users. Most urban and regional planners require the same type of data - just over different locations. Another factor related to the cost effectiveness is the use of "standard" Shuttle sensors which have been proposed for several missions, further amortizing the cost of data acquisition for specific users.

Other factors which are unique to the application of the Shuttle to this mission are:

- Quick response capability for Shuttle flights to aid evaluation of emergency conditions e.g. severe floods, hurricane damage
- Variable orbit characteristics
- Man available to provide discretionary decisions
- The ability to use relatively low cost equipment which does not meet the full unmanned spacecraft-reliability criteria.

3.5.4 SENSOR REQUIREMENTS

A cartographically-useful film output is desired for planning and field use. Spatial resolution sufficient to allow the delineation of streets is necessary. A candidate sensor is the S190B camera flown on Skylab. Films used should produce a resolution of approximately 5 meters.

For fulfilling (or approaching the fulfillment of) the functional requirement for multispectral data, the spectral characteristics of the data and machine processing are more critical than spatial resolution. Ground resolution between 15 and 20 meters effective field of view, with spectral gray levels of between 64 to 128 levels over the spectral range are required. Five or six bands covering the spectral range of 0.42 to 1.1 um plus 2.0 to 2.6 um and 10.4 to 12.5 um are the required spectral ranges of a scanner for machine-based urban land use classification.

Both a multi-band camera and a multispectral scanner are desired sensor types for this use. In the former category, the S190A camera used on Skylab is a candidate, and the thematic mapper will satisfy the scanner requirement.

3.5.5 FLIGHT PROGRAM AND TEST SITE SELECTION

The purpose of the missions developed in this study is to demonstrate the capability of staisfying user information needs through Shuttle borne remote sensing. This is distinct from operationally satisfying the users needs for a large number of users or over a long period of time. For this Urban and Regional Planning mission it was decided that a small set (five) of representative test sites would be adequate to demonstrate the capability. The five were selected as being representative not only of their geographic region and the other factors listed below; but, also representative of the type of urban and regional planning involvement of each:

CRITERIA:

Size: population, area
Region: physiographic, demographic
Age: settlement, development
Site: coastal/inland, river basin, airshed
Hinterland: vegetative, forestation, arid zone
Socioeconomy: industry, commerce
Uniqueness: critical areas, special features, ethnicity, etc.

After an initial screening of the urbanized areas of the Unites States, the following locations were selected as potential candidates:

Philadelphia*	Memphis	Knoxville*
Los Angeles	Louisville	Salt Lake City
San Francisco*	Birmingham	Huntsville
Seattle	Albuquerque	Amarillo
San Antonio*	Tucson	Sioux Falls*

*indicates area selected as test site.

Five cities were selected as representative initial test sites for the Urban and Regional Planning mission; they are, as shown in figure 3-21:

PHILADELPHIA: An older, larger Eastern port city, along a major mid-Atlantic river. City population 2 million, standard metropolitan statistical area (SMSA) ~ 5 million, density over 15,000 persons/sq. mile. Readily accessible for data. Regional entity: Delaware Valley Regional Planning Commission.

SAN FRANCISCO: A medium-sized western harbor, with a large urban area surrounding a bay. City population ~ .7 million, SMSA, ~ 3 million. Density over 15,000 persons/sq. mile: Association of Bay Governments/USGS-HUD study.

SAN ANTONIO: A south-western, inland city with an urban area of about same population ~ .7 million. Some critical environmental factors, under intensive study. Outstanding urban design - HUD aware.

KNOXVILLE: A southern city with a larger SMSA (.17 to .40 million). Extensive planning locally and by the Tennessee Valley Authority.

SIOUX FALLS: A northern mid-western interior town, with dispersed SMSA (all ~ 1 million).

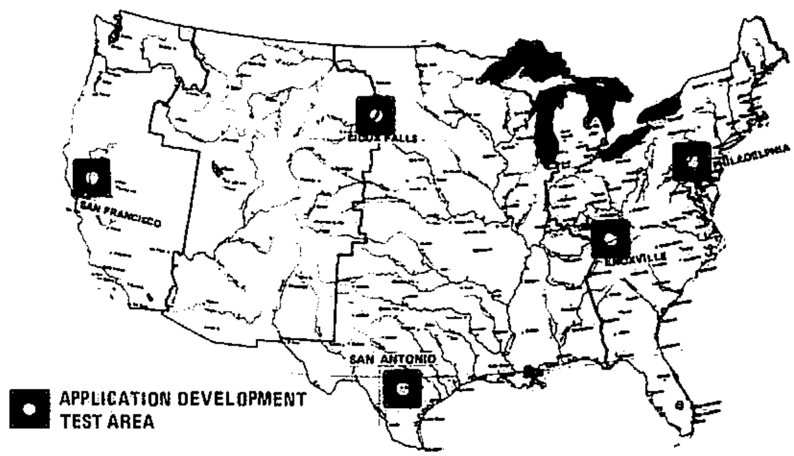


Figure 3-21. Urban and Regional Planning Test Sites

The Applications Development mission will require two flights, one in the Spring and the other in the Fall over each test site area. There are no other critical flight parameters except for a requirement for an adequate (> 30°) sun angle.

3.5.6 DATA PROCESSING AND ANALYSIS

The data processing and analysis will involve both manual and machine aided interpretation of photographic and electronic image products. The purpose of the analysis is the extraction of land use theme data in accordance with the indexing scheme used by each planning agency and the specific needs of the agency.

The electronic imagery will be used for the preparation of generic land use themes, the photography will be interpreted and used to generate large scale map overlays of specific themes and areas within the planning region of interest.

The data processing and analysis will, of necessity, require close cooperation with the local planning authority; this authority will be responsible for the dissemination of information resulting from the study.

SECTION 4

SHUTTLE ACCOMMODATION OF THE MISSIONS

The Shuttle Orbiter has the capability, in the sortie mode, to provide a number of payload configurations to the user: combinations of short or long Spacelab pressure modules and pallets; a pallet-only configuration for which the control of the payload is provided from the Orbiter flight-deck; and Standard Earth Observations Package for Shuttle (SEOPS), a smaller sensor support mount which can be flown with any of the Spacelab configurations as well with automated spacecraft as the primary payloads.

Several major issues are present in the question of Shuttle accommodation of the missions. The first is the matching of the physical requirements of each mission to a Shuttle configuration in order that the range of carrier configuration options can be considered. Second, and more important, is the range of issues raised by the subject of combining multiple missions to achieve higher utilization of the Shuttle on each flight. These issues include substantive engineering questions, such as whether to design the SAR antenna to fold, in order that it may fly with a Spacelab pressurized module, or to restrict it to pallet-only flights and save the development costs and operational complexity of the folding antenna. A second engineering issue concerns the mutual design of the SAR and SIMS to enable these two sensors to be flown (and operated) concurrently without undue electromagnetic interference, in order that their complementary forms of data may be gathered over the same ground areas.

Also to be considered are programmatic questions, such as whether the Earth Resources experiments will be flown simultaneously with other application experiments and, if so, what should the characteristic of their companions be. A second related programmatic issue concerns the frequency with which Earth Resources payloads will be flown aboard Spacelab. The needs of the representative missions treated herein (and, indeed, most Earth Resources missions suitable for Shuttle) dictate fairly tight seasonal scheduling (say $\pm$ 45 days) and multiple flights per mission in one year. It is clear that the Earth Resources Program will not require many or even several, full Spacelabs in a year during the early Shuttle era. Flight sharing by several means should be investigated: sharing launch costs with other applications payloads aboard Spacelab; sharing launch costs with non-applications Spacelab payloads through the use of SEOPS; and sharing launch costs with applications satellites.

With these issues in mind, the subject of Shuttle accommodation was addressed the following way: first, the physical resources demanded by each of the missions were defined and compared to the resources available to establish the range of payload/carrier options. Then the most likely options were detailed into concept designs for use in structuring of the integrated Flight Program. These options included:

- a camera and scanner combination on the SEOPS, the pallet-only Spacelab, and the module-plus-pallet Spacelab,
- the Synthetic Aperture Radar on both the pallet-only and module-plus-pallets Spacelab
- the Synthetic Aperture Radar both in conjunction with and excluding the Shuttle Imaging Microwave System.

A selection of typical experiments from the list of those comtenplated by the Office of Applications was used as a contextual backdrop for the analysis of the accommodations for the Earth Resources experiments. These experiments were selected from those identified by various NASA discipline specialists and documented by GE under the Shuttle Transportation System Payload Definition Activity (STSPDA). The non-Earth Resources Experiments were selected to be compatible with those under study in this task but do not represent either a firm intent on the part of NASA to fly them nor a recommendation by the TERSSE team that such be the case.

4.1 SENSOR DEFINITIONS

The mission requirements developed in Section 3 were used to select acceptable sensors as the next step in defining Shuttle accommodations. In the case of the SAR, the sensor is defined inherently by the nature of the mission itself: SAR development. In the soil moisture mission, the objective of microwave and optical spectrum measurements lead to the selection of: the Shuttle Imaging Microwave System (SIMS) under study by JPL, either the 5-band Multispectral Scanner (MSS) from the Landsat Program or the newer Thematic Mapper (TM), and a visible-wavelength scanning polarimeter. The three applications development missions all require camera(s) and a scanner of varying performances. The candidate cameras were chosen from existing designs to avoid/minimize development costs; likewise, the scanner candidates were chosen to be the MSS and the TM.

Matching of the mission requirements against the candidates' characteristics led to the set of preferred sensors illustrated in Table 4-1. A brief description of each of the sensors follows:

Shuttle Imaging Microwave System (SIMS). The SIMS (Figure 4-1) is a high resolution, passive microwave system used for measurements of the thermal emissions from the Earth's surface and atmosphere in the 0.6 to 118.79 GHz spectrum. The instrument is comprised of a four-meter-wide reflector antenna, a rotating feed assembly, and a series of receiver/processors for each of its eleven frequencies. Each radiometer feed sweeps a cross-track swath of ±30 degrees as it rotates past the reflector. The amount of the reflector which is illuminated is varied with frequency to provide an instantaneous field of view ranging from 0.1 degrees (at 118.79 GHz) to 17 degrees (at 0.6 GHz). The instrument is currently configured to mount directly to the cargo bay longerons and replaces a pallet section in a Spacelab configurations. The SIMS weighs 952 Kg and requires 930 watts of power.

TABLE 4-1. SELECTED SENSORS

		MISSION					
		SOIL MOISTURE	RADAR DEVELOPMENT	MINERAL EXPLORATION	URBAN/REGIONAL PLANNING	FOREST INVENTORY	REMARKS
IMAGING SPECTRO-RADIOMETERS	4-BAND MSS					✓	SCAN MECHANISM MODIFIED FOR USE AT SHUTTLE ALTITUDES
	5-BAND MSS			✓ OR	✓ OR	OR	
	THEMATIC MAPPER	(✓)		(✓)	(✓)	(✓)	
FILM CAMERAS	S-190A 6-CAMERA PKG				(✓)		MODIFIED TO INCREASE FOCAL LENGTH; PRESSURE HOUSING REQ'D
	S-190B 5" FILM CAMERA			✓ OR		✓ OR	PRESSURE HOUSING REQ'D
	LG. FORMAT (9"x18") CAMERA			(✓)		✓	PRESSURE HOUSING REQ'D
MICRO-WAVE	IMAGING RADAR (SAR)	(WHEN AVAILABLE) (✓)	(✓)				
	IMAGING μW SYSTEM (SIMS)	(✓)					
	PHOTO-POLARIMETER	(✓)					SPACE-QUALIFIED VERSION OF AIRCRAFT SENSOR

✓ - ADEQUATE

(✓) - PREFERRED

WEIGHT: 952 KG

POWER: 930 WATTS

FIELD OF VIEW: 60° x 17°

FREQUENCIES:		
	0.61	GHz
	1.413	GHz
	2.695	GHz
	6.6	GHz
	10.69	GHz
	20	GHz
	22.2	GHz
	37	GHz
	53	GHz
	94	GHz
	118.7	GHz

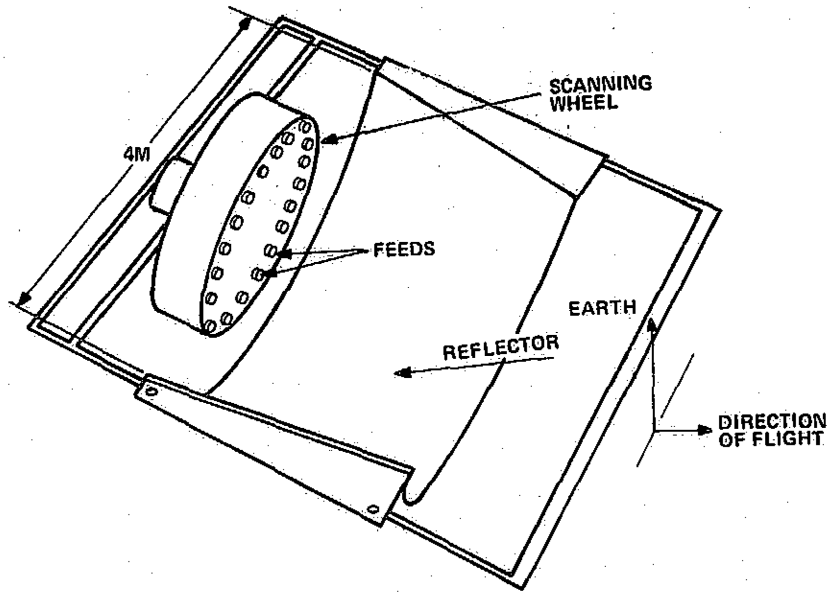


Figure 4-1. Shuttle Imaging Microwave System (SIMS)

Spot-Scanning Photopolarimeter. The polarimeter (Figure 4-2) is a three-channel device which measures the polarized components of usable light with a spectral bandwidth as narrow as 100-150 A (final value to be determined). It is comprised of a small telescope, with three optical barrels (one for each polarization channel) a polarizing prism and a photodetector/amplifier assembly. Its IFOV is 1.0 degrees. The entire instrument is scanned cross-track by a single-axis gimbal over a range of ±60 degrees. The instrument weight, with gimbal, is 27.2 kg; a maximum and average power of 45 and 20 watts, respectively, are required.

Synthetic Aperture Radar (SAR). The design configuration selected for use in the study (Figure 4-3) is based on studies underway by JPL and Hughes. The SAR is a two-frequency (X, L band) instrument operating with dual polarization in both frequencies. Transmitted power (peak) is 6.8 Kw (L-band) and 17 kw (X-band). Clutter tracking is used to ease Shuttle pointing requirements. A 10-meter flat array antenna is used, producing a nominal ground resolution of 25 meters with a maximum-swath width on the ground of 100 km. Processing and recording of the data is performed digitally; the data rate is variable with an upper limit of 480 Mb/sec at maximum resolution (~6m). The instrument weighs 1248 kg including support structure, and consumes 4 Kw of power.

- WEIGHT: POLARIMETER & GIMBAL

  6.8 KG
  20.4 KG
  27.2 KG

- POWER: 20 WATTS (AVERAGE)
  45 WATTS (MAXIMUM)
- SPECTRAL BANDWIDTH: 100-150A° (WITHIN 0.4-1.0 MICRON REGION)
- SPOT IFOV: 1°±0.1°
- VIEWING ANGLE: ±60°
- NUMBER OF CHANNELS: 3 (CORRESPONDING TO EACH STOKE PARAMETER)

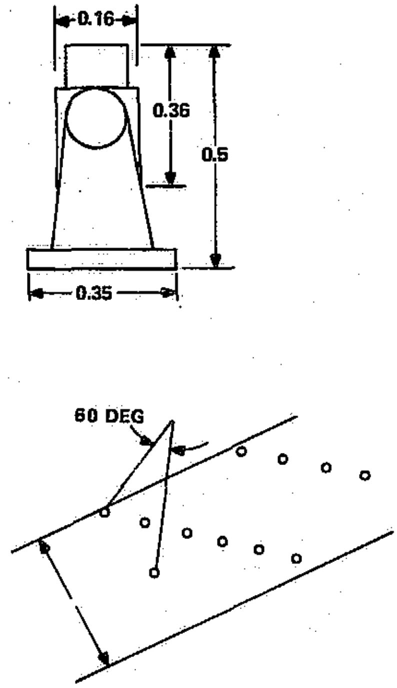


Figure 4-2. Spot Scanning Photopolarimeter

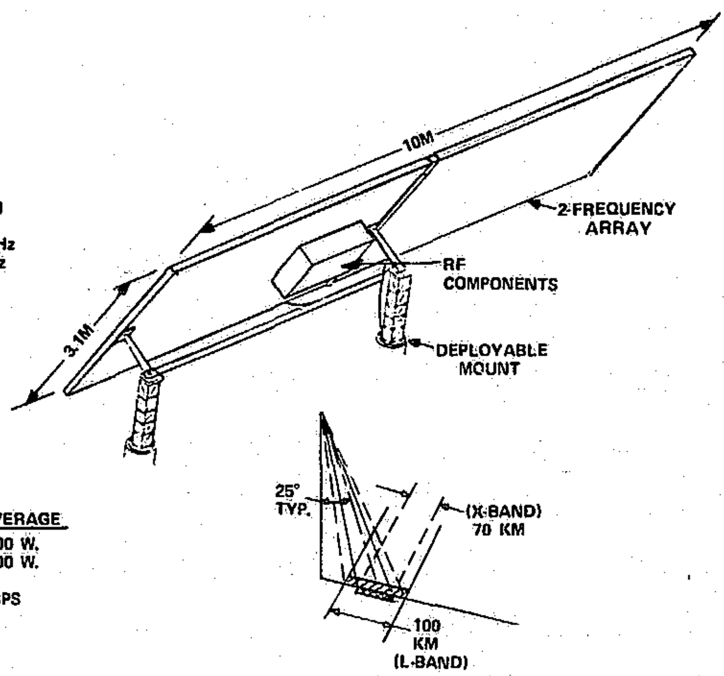
WEIGHT: 1248 KG

POWER: 4000 WATTS

RESOLUTION: 25M

SWATH WIDTH: 30 to 100 KM

BANDS: L-BAND 1.04 GHz
X-BAND 9.0 GHz



TRANSMITTED POWER:

BAND	PEAK	AVERAGE
L-BAND	6.8 KW	200 W.
X-BAND	17.0 KW	500 W.

DATA RATE (MAX.): 470 MBPS

Figure 4-3. Imaging Radar

Thematic Mapper (TM). The TM (Figure 4-4) is an advanced scanning spectroradiometer which permits simultaneous imaging of visible, near-infrared, and thermal infrared energy spectra. The folded telescope has a collection aperture diameter of 46 cm (18 inches) which produces an instantaneous field of view of 30 micro-radians in the usable and near-IR spectral region. The scanning mechanism is mechanically operated through the use of a servo motor-driven mirror. (Three scanning mechanisms are under study for this sensor: conical, rectilinear, and rotating flat reflector. The concept illustrated in Figure 4-4 is the rectilinear scan configuration.) An array of sixteen detectors is used for each visible or near-IR band.

The development of this sensor is currently being pursued for use in polar spacecraft operating at an orbital altitude of approximately 700 km. For use in the Shuttle, two modifications will be necessary: the scan mirror drive will be modified to decrease the swath width (scan angle) and increase the scan rate. And the passive (radiation) cooler for the thermal detectors will be replaced by a solid-cryogen cooler. The scan drive modification will result in a 17m IFOV and a 59 Km swath width. The data rate for the modified sensor will be maintained at 89.4 mb/sec. The TM weighs 180 Kg and requires 260 watts of power.

WEIGHT: 180 KG

POWER: 260 WATTS

SWATH WIDTH: 59 KM. AT 443 KM. ALTITUDE

IFOV: 30 μRAD.

DATA RATE: 89.4 MB/SEC.

SPECTRAL CHANNELS: 4 VISIBLE/NEAR IR
2 MID IR
1 THERMAL IR

MODIFICATIONS:

- VARIABLE SCAN MIRROR DRIVE
- ADD ROLL OFF NADIR ROTATION
- PROVIDE CAPABILITY TO CHANGE SPECTRAL BANDS FOR DIFFERENT MISSIONS

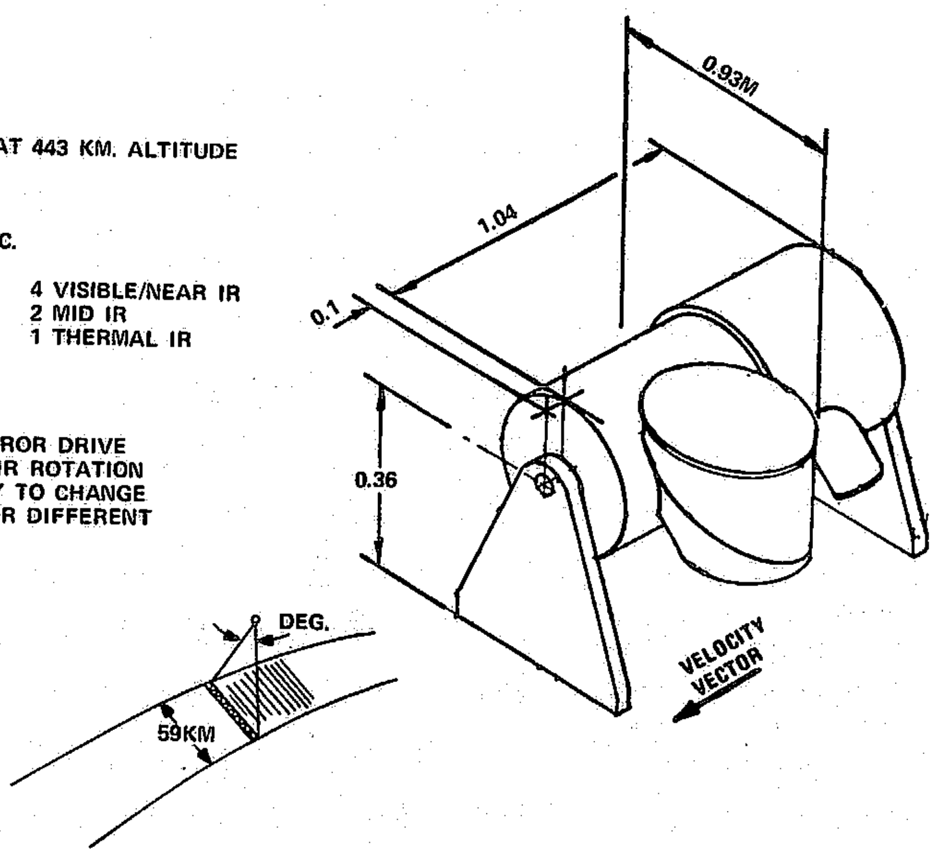


Figure 4-4. Thematic Mapper

S-190B CAMERA. The high spatial resolution requirements of the Mineral Exploration and Forest Inventory missions are met with the S-190B cartographic type camera. With a focal length of 45.7 cm., this camera will produce images with a resolution of five meters. Several existing cameras were considered, as exemplified by the two alternates shown in Figure 4-5. The choice of the S-190B is based on the combination of high resolution, medium-size format, and wide swath width (110 x 110 Km).

Modified S-190A Camera. In order to attain the required 10 meter resolution in the multi-spectral camera for the Urban Planning mission, the focal length of the S-190A camera will be increased from 15 cm to 33 cm. Reduction in the field of view will be well within the required 80 x 80 km for this mission. The lenses for the 33 cm focal length have been developed and can operate with a 70 mm format. (Figure 4-6)

4.2 CARRIER COMBINATIONS

The different carrier configurations possible with the Shuttle each have different capabilities for payload weight, volume, crew operating space and transportation costs. Sensors can be flown on Spacelab and/or the Standard Earth Observation Package for Shuttle (SEOPS). SEOPS capability is essentially constant for all payload combinations, although weight and power may be compromised by the demands of the remaining payload. The capability available for sensors mounted on Spacelab pallets is highly dependent on

WEIGHT: 37 KG

POWER: 100 WATTS

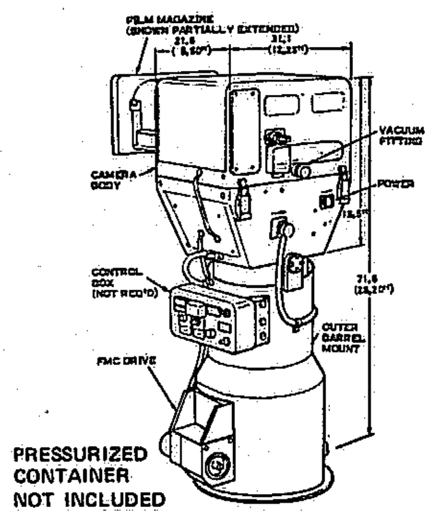
FORMAT: 4.5 X 4.5 INCHES
14 X 14 DEGREES

110 X 110 KM @ 443 KM

SPECTRAL CHANNELS:

1 BAND DETERMINED BY FILTER/FILM COMBINATION

PRESSURIZED HOUSING REQUIRED



ALTERNATES

1. 9 X 18-IN 24-IN F.L. HR-732 CAMERA IN USAF INVENTORY
2. SPACE-QUALIFIED 9 X 18 CAMERA

Figure 4-5. S-190B Camera

WEIGHT: 155 KG

POWER: 200 WATTS

FORMAT: 70 MM X 70 MM
10° X 10°
75 KM X 75 KM @ 443 KM

SPECTRAL CHANNELS:

4 VISIBLE/NEAR IR
1 COLOR IR
1 TRUE COLOR

REQUIRED MODIFICATION: INCREASE FOCAL LENGTH FROM 15 CM TO 33 CM. TO ATTAIN HIGHER RESOLUTION

PRESSURIZED HOUSING REQUIRED

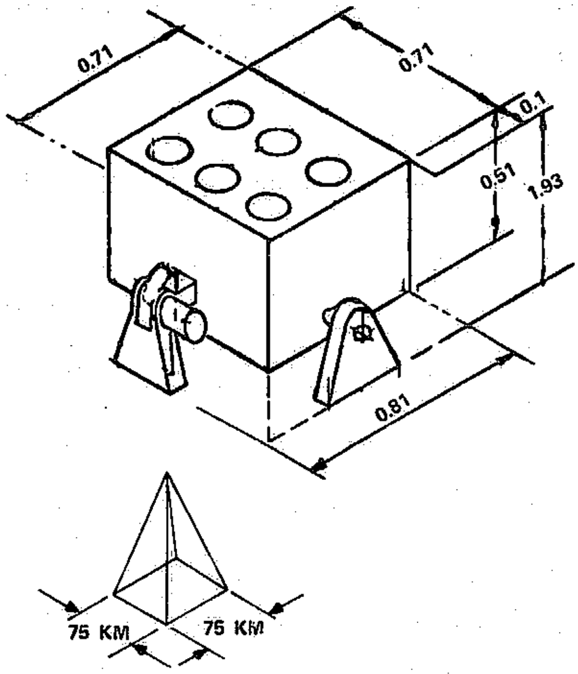


Figure 4-6. Modified S-190A Camera

the specific combination of Spacelab hardware flown. Table 4-2 shows the mass, pressurized volume, pallet area, and electrical power capabilities of four basic Spacelab configurations and the SEOPS bridge. The pallet-only mode affords the largest weight, viewing areas, and power capabilities; however, it has very limited pressurized volume (in the orbiter) which severely constrains control and display area and crew-involvement.

TABLE 4-2. SHUTTLE CONFIGURATION RESOURCES

CARRIER CAPABILITIES	SHORT MODULE & 3 PALLET SEGMENTS	SHORT MODULE & 2 PALLET SEGMENTS	LONG MODULE & 2 PALLET SEGMENTS	PALLET-ONLY 5 SEGMENTS	SEOPS
PAYLOAD WEIGHT (KG)	5500	6000	4500	8000	1125
RACK SPACE IN PRESSURE MODULE (STD. RACKS)*	2 DOUBLE RACKS 2 SINGLE RACKS	2 DOUBLE RACKS 2 SINGLE RACKS	6 DOUBLE RACKS 2 SINGLE RACKS	–	–
PALLET VIEWING AREA (M^2)	34.5	23	23	57.5	5.2
POWER (WATTS)	4190	4190	4420	5810	2000

*SINGLE RACK: 0.63 M^3
DOUBLE RACK: 1.28 M^3

The screening of Shuttle/Spacelab configurations in terms of requirements versus capabilities is summarized in Table 4-3, which shows that the cameras and scanner of the Mineral Exploration, Forest Inventory or Urban Planning missions can be accommodated by any configuration. The short module and two-pallet segment configuration is compatible with any of the five missions. Because of the large diameter of SIMS, the soil moisture mission is incompatible with any configuration where Spacelab uses the entire cargo bay. The Imaging Radar can be accommodated in any Spacelab configuration but requires folding of the microwave array in all but the pallet-only configurations.

The range of carrier configurations was analyzed and correlated with the five TERSSE missions. In all cases, except where the SEOPS alone was installed for a satellite delivery mission, there was additional capacity to accommodate other experiments on board. Representative sets of compatible OA experiments were selected for incorporation in these configurations.

4.3 PAYLOAD CONFIGURATIONS

The analysis considered four Spacelab modes of accommodation in determining the payload flight configurations: (1) the short module plus three pallets, (2) module plus two pallets, (3) long module plus two pallets, and (4) the pallet only mode.

TABLE 4-3. PHYSICAL ACCOMMODATION COMPATIBILITY

CARRIER / MISSION					
SOIL MOISTURE	SIMS REQUIRES 11.6 M^2 P/L BAY AREA WITHOUT PALLET	OK	SIMS REQUIRES NON-PALLET AREA	SIMS REQUIRES NON-PALLET AREA	INSUFFICIENT WEIGHT, AREA
SAR DEVELOPMENT	OK • USES MOST OF POWER • REQUIRES 1 FOLD	OK • USES MOST OF THE POWER • REQUIRES 1 FOLD	• REQUIRES 1 FOLD • CENTER OF GRAVITY CONSTRAINTS EFFICIENT USE OF PRESS. VOLUME	OK • PERMITS UNFOLDED MOUNTING • VERY LIMITED PRESSURIZED VOLUME	INSUFFICIENT WEIGHT, AREA
MINERAL EXPLORATION	OK	OK	OK	OK	OK
URBAN PLANNING	OK	OK	OK	OK	OK
FOREST INVENTORY	OK	OK	OK	OK	OK

In addition, the SEOPS configuration with the direct mounting of a large sensor (i.e. SIMS) onto a non-palleted section of the Shuttle cargo bay was analyzed. The primary questions addressed in this portion of the study task are as follows:

- Which Spacelab modes can best accommodate the missions?
- What is the compatibility of the mission requirements with the Shuttle, Spacelab, and SEOPS capabilities and interface provisions?
- Are the missions amenable to integration with additional Shuttle payloads on the same flights?
- Which of the Earth Resources missions can be performed concurrently on the same flight?

The results showed that all Spacelab modes can accommodate at least four missions: either #1 (Soil Moisture) or #2 (S.A.R. Development) plus #3 (Mineral Exploration), #4 (Urban Planning), and #5 (Forest Inventory). All the five missions can be accommodated in the short module plus two pallet segments. The SEOPS mount can accept the camera and scanner instruments for the Application Development missions (#3, #4, and #5). In all cases examined, the mission requirements and interfaces were found to be compatible with the capabilities of the Space Transportation System (STS). Furthermore, many additional payloads can usually be accommodated on the same flight configuration. Only in the case where all five missions are integrated on the same flight are the viewing area/volume capabilities of the Spacelab utilized almost fully, leaving little capability to perform other experiments.

The sections that follow contain a description of the four principal configurations considered and a discussion of typical interface requirements.

4.3.1 PAYLOAD CONFIGURATIONS

The payloads in each configuration pertain to compatible TERSSE missions, and additional experiments. The latter were selected from representative Office of Application candidate missions consisting of experiments in Earth Observation, Communication & Navigation, and Earth and Ocean Physics.

CONFIGURATION 1, depicted in Figure 4-7, consists of a short Spacelab module and two pallets accommodating the Thematic Mapper, S-190A camera, S-190B camera, SIMS and the Photopolarimeter. These sensors permit the performance of missions 1, 3, 4, and 5. This configuration demonstrates that these TERSSE missions can be integrated in a Spacelab flight carrying a large complement of Earth Observation and Communication experiments and, in fact, represents a higher concentration of sensors than any of the other ones analyzed. Among these is a set of microwave antennas, including a 3 x 3 meter array, which are deployed outside the main portion of the Shuttle cargo bay to prevent interference with other earth-looking sensors such as the Thematic Mapper and the S-190A camera package.

The SIMS sensor was mounted aft of the Spacelab pallet as its 4-meter diameter does not fit the pallet envelope. Other equipment mounted outside the pallet include the open TWT experiment and Solar Environmental Monitor Instrument Sensor (SEMIS). The Atmospheric Cloud Physics Laboratory (ACPL) is totally contained within the pressurized module and is housed in two standard 0.47 meter wide racks. Sufficient additional rack space is available inside the module to accommodate the various experiment monitoring and control panels necessary to perform the Earth Resources mission, as well as other experiments, in this configuration.

The predominant accommodation factor in this configuration was the geometric limitation due to field-of-view requirements and viewing area. Careful arrangement in three dimensions was necessary to prevent the sensors from obstructing each other's fields-of-view. This is illustrated by the fact that the viewing area capability of the pallet is 23 m^2 and only 18.1 m^2 was able to be utilized due to field of view limitations. Ample weight carrying capability exists in the Spacelab to handle this configuration, namely 6000 kg., whereas only 4842 kg. were required.

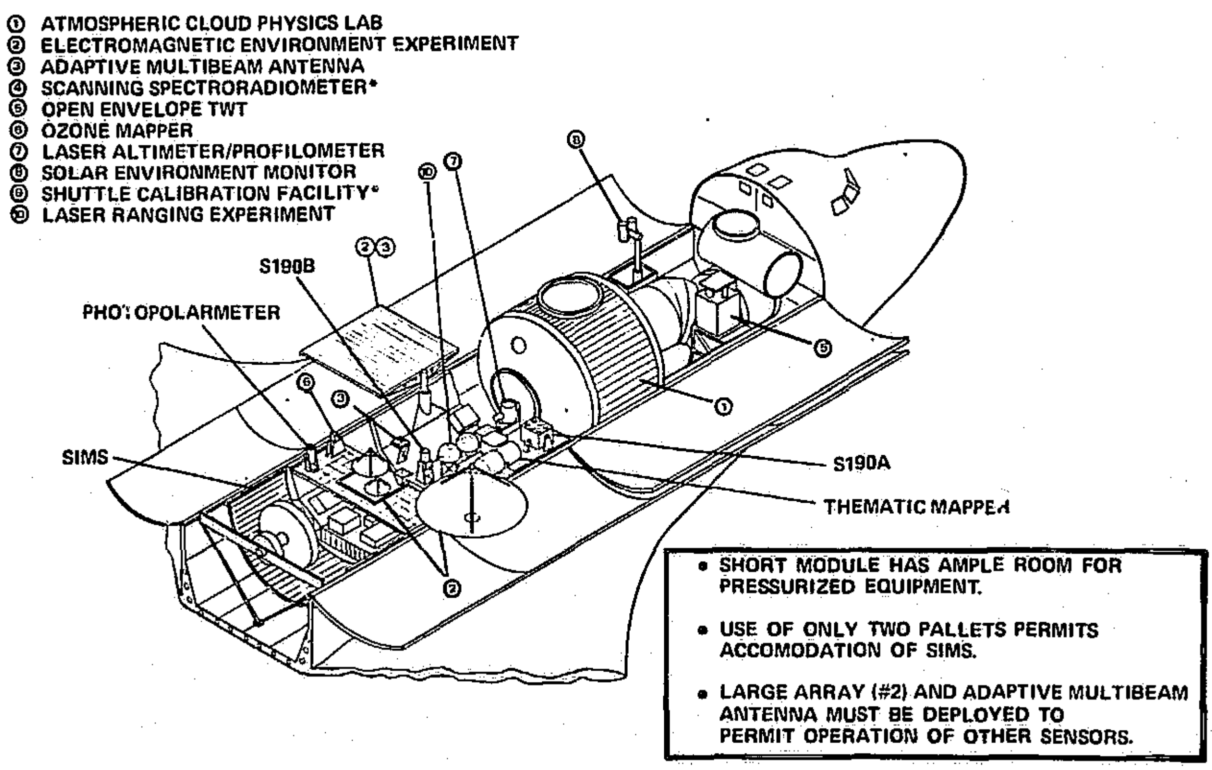


Figure 4-7. Configuration 1 — Short Lab with 2 Pallets and SIMS

CONFIGURATION 2 integrates the Imaging Radar of mission 2 in a Spacelab consisting of a short module and three pallets, as shown in Figure 4-8. Because of the large size of the antenna array (31 m^2) it was necessary to fold the antenna and provide an extension mechanism in order to clear the Spacelab module when the payload is stowed. In this configuration the Shuttle Orbiter can fly in the minimum drag configuration, with the Y axis perpendicular to the orbital plane. Consideration was given to placing the longitudinal axis of the antenna perpendicular to the Orbiter's X-axis, however, this was rejected since the Orbiter then would have been required to fly with its velocity vector perpendicular to the X-axis. This in turn would have required that all earth scanning sensors such as the Thematic Mapper be oriented with the scanner rotor axis perpendicular to the X-axis of the Orbiter.

The configuration accommodates the sensors for missions 2, 3, 4 and 5 plus those for six additional Earth Observation and Communication/Navigation experiments. In order to accommodate these without obstruction from the Imaging Radar antenna which rises high above the pallet, it was necessary to place the other sensors on platforms supported at the top edge of the pallet. In some cases, the large fields of view of other candidate sensors precluded them from being integrated into this configuration. In the case of the 10.6 micron laser transceiver, the sensor required mounting on a framework approximately 1 meter above the top of the pallet.

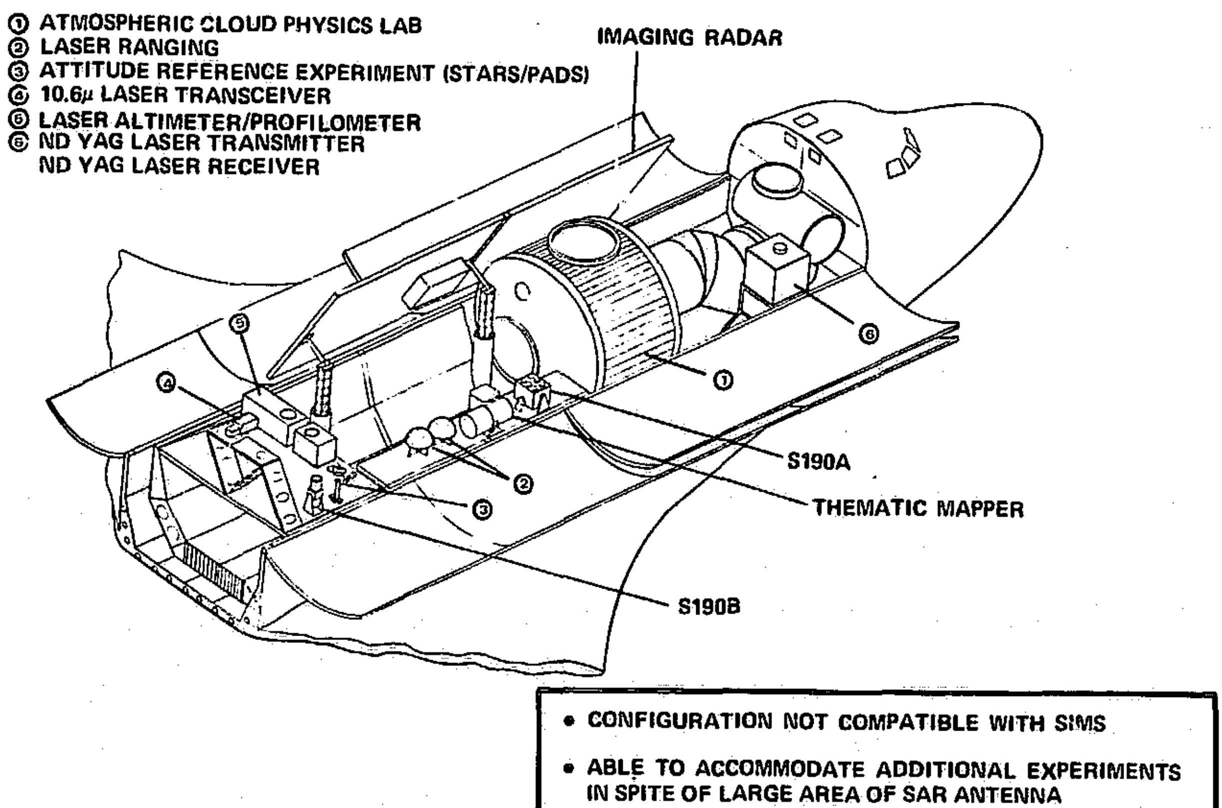
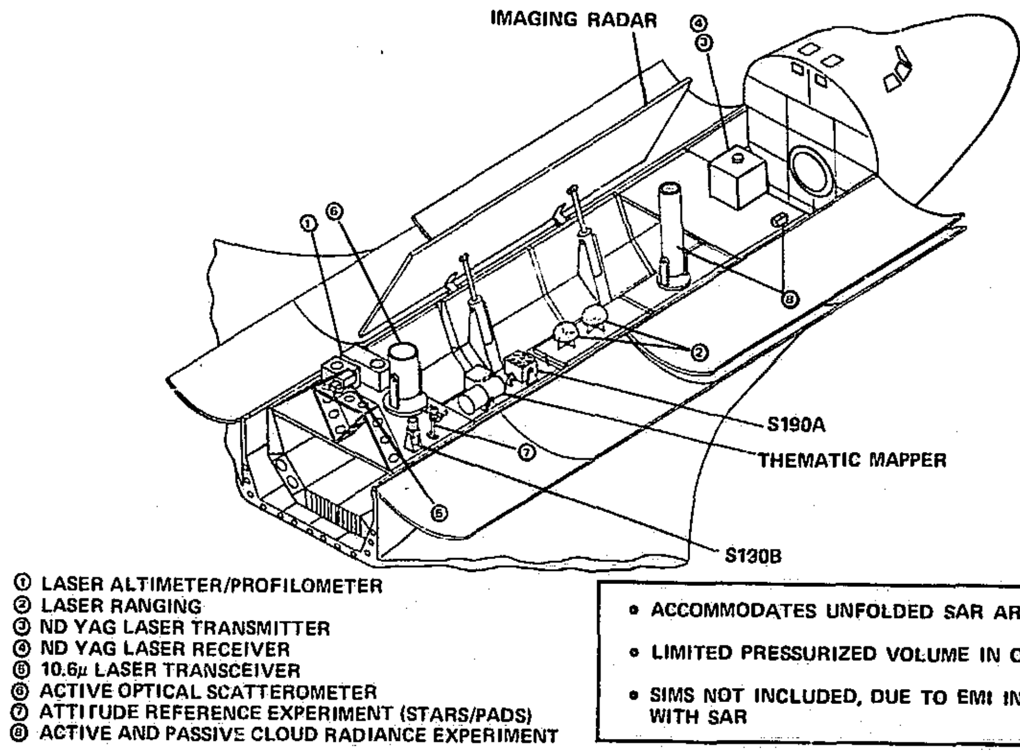


Figure 4-8. Configuration 2 — Short Lab with 3 Pallets and SAR

Mission 1 is not compatible with this configuration since the Spacelab module and three pallet segments occupy the entire Shuttle cargo bay. The SIMS sensor requires the use of the aft portion of the cargo bay and – in its present configuration – cannot be mounted on the pallet.

CONFIGURATION 3, shown in Figure 4-9 incorporates the pallet only Spacelab mode, which features five pallet segments. The large viewing area afforded by the pallet (57.5 sq. meters) makes it possible to integrate the Imaging Radar antenna without the need to fold or elevate it as required in configuration 2. The advantage in this design of the antenna array is the simplification in the attainment of antenna flatness tolerance, which is a small fraction of wavelength. The mounting of the antenna is also made simpler, since the array is hinged at the edge and eliminates the need for a boom extension deployment mechanism.

Included in this configuration are the sensors for missions 2, 3, 4, and 5. The same laser experiments shown in configuration 2 are included here; in addition, the ample pallet area available makes it possible to add large experiments such as the active Optical Scatterometer and Active/Passive Cloud Radiance.



- ACCOMMODATES UNFOLDED SAR ARRAY
- LIMITED PRESSURIZED VOLUME IN ORBITER
- SIMS NOT INCLUDED, DUE TO EMI INCOMPATIBILITY WITH SAR

Figure 4-9. Configuration 3 — Pallet Only, 5 Pallets and SAR

The main limitation in this configuration is the small pressurized volume available as an orbital control center for the various experiments due to the absence of a pressurized Spacelab module. The only space available for monitoring and control panels is in the payload specialist station located in the rear of the Orbiter's crew compartment aft section. This implies limited crew involvement and possible ground-control for several of the sensors.

The SIMS sensor would be compatible with the pallet-only configuration, if the last pallet section in the rear of the cargo bay were removed. The problem of incompatibility between the Imaging Radar and SIMS is discussed in Section 5.3 of this report.

CONFIGURATION 4 — accomodates all five of the missions. It is similar to configuration 2, with a short module and two pallet segments (Figure 4-10). The Imaging Radar antenna is folded and requires extension above the Spacelab module. The SIMS radiometer is located in the aft section of the Orbiter cargo bay, in place of the third pallet segment. The Thematic Mapper and S-190A Camera are mounted on a platform at the top edge of the pallet; this location, opposite the Imaging Radar antenna, offers no obstruction to the sensors' field of view. The Photopolarimeter, which is required in the Soil Moisture mission is installed alongside the S-190B type mount forward of the Spacelab module.

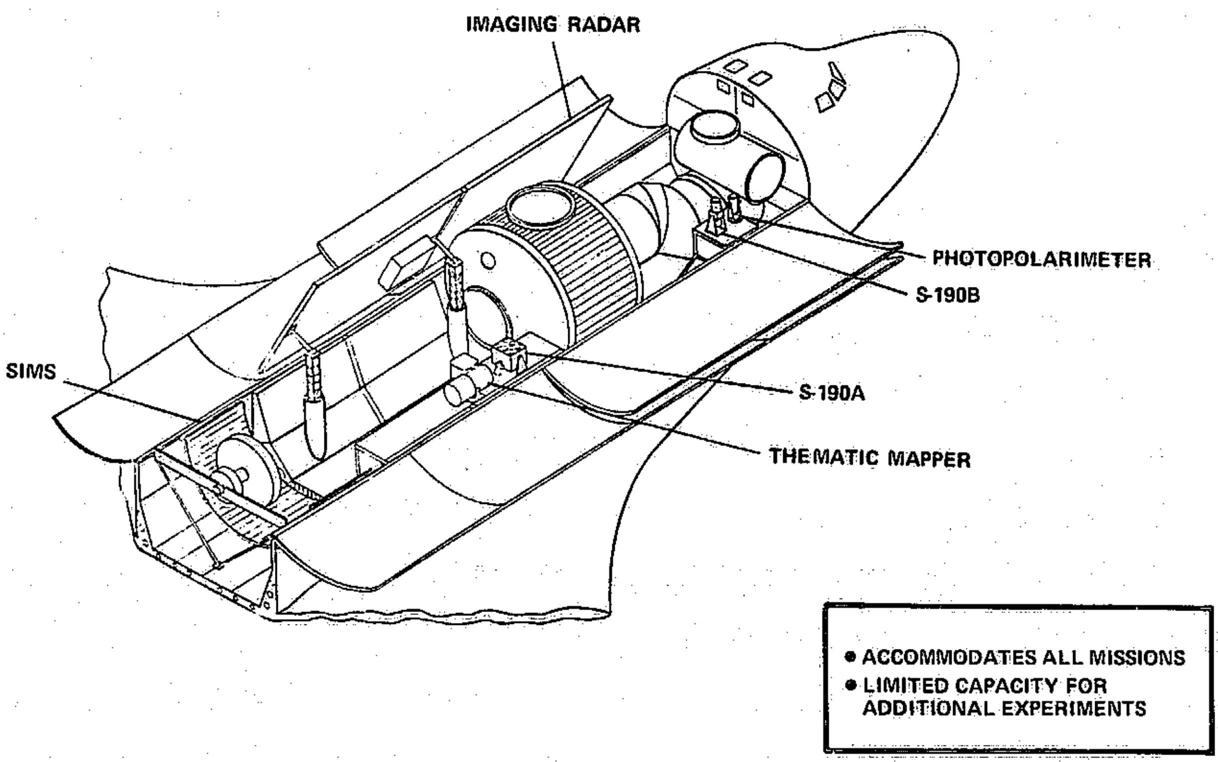


Figure 4-10. Configuration 4 — Short Lab with 2 Pallets, SIMS, and SAR

Unlike the pallet only mode, this configuration offers ample room in the pressurized module. This operational advantage is traded for the added complexity of folding the antenna array. Very few additional experiments may be included in this configuration due to the high degree of utilization of the available viewing area by the sensors. Possible additions may be experiments such as the Atmospheric Cloud Physics Laboratory which are contained within the pressurized Spacelab module. Also, a larger configuration SEOPS mount may be used to provide additional installation area.

CONFIGURATION 5 — utilizes the SEOPS mount to incorporate the Thematic Mapper, S-190A camera and S-190B camera during Shuttle mission to deliver an automated payload in low earth orbit. Figure 4-11 shows this configuration during the delivery of an advanced LANDSAT. The latter is representative of large satellite vehicles to be placed in orbit by the Shuttle. This configuration is also applicable in many missions where an Intermediate Upper Stage (IUS) is included with the payload. The aft section of the Orbiter cargo bay (not shown in Figure 4-11) may include the payload docking frame and erection mechanism, Special Purpose Manipulator System/resupply module enchange mechanism and the resupply module storage magazine. Even in cases where all these aft components are required on-board, the SEOPS-mounted sensors can be included in the mission provided the automated payload (plus kick stage, if present) does not exceed approximately 9.5 meters in length.

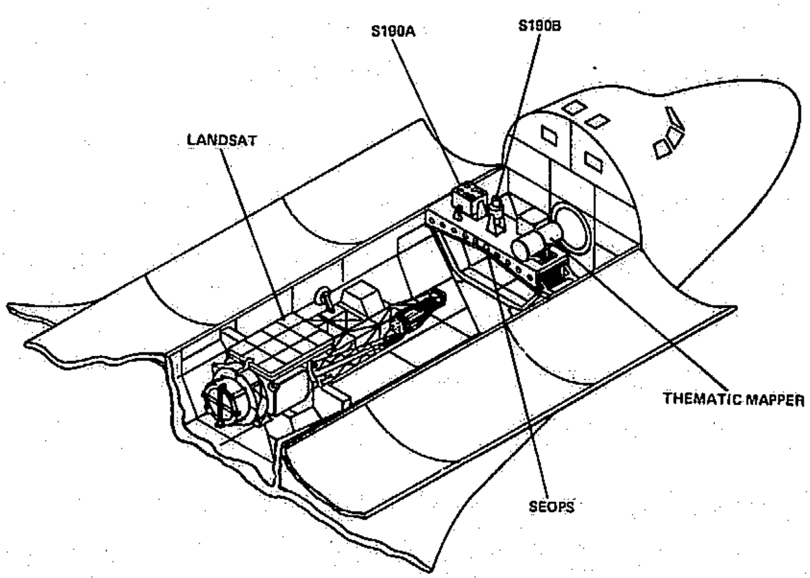


Figure 4-11. Configuration 5 — Standard Earth Observation Package with Landsat Delivery

Operation of the sensors is nominally restricted to periods other than the erection of the payload from the cargo bay, prior to its separation from the orbiter. This period may include a cursory checkout of the payload subsystems and should last less than four hours.

4.3.2 INTERFACES

The typical configuration involves fairly complex interfaces between the sensors and the Spacelab module and/or pallet, between the Earth resources sensors and other sensors, and between the sensors and the Shuttle. (An exception is Configuration 5, which uses the relatively clean SEOPS bridge.) A thorough understanding of all interfaces is needed to do a realistic job of integrating the sensors into viable Shuttle payloads. A major step toward this understanding is construction of a payload system schematic, as illustrated in Figure 4-12.

The system schematic shows how experiments (in block diagram form) connect with the subsystems and services provided by Spacelab and Shuttle. Potential conflicts can be easily identified, and interfaces can be indexed for later detailed analysis. The Configuration 1 system schematic contains several examples of interface problems and requirements that may not be otherwise evident. A unique feature of this configuration is the placement of SIMS aft of the two pallet segments, which requires special provisions for extending Spacelab services beyond the last pallet and shows that the needed extensions are the data bus, DC power line, and high rate digital channel.

Two other sensors, the Electromagnetic Environment Experiment and the Adaptive Multibeam Antenna, have a number of antennas dispersed about the pallet. The cross-pallet signal cables required by this dispersal are a potential source of EMI.

Forward mounting of the Open Envelope TWT and the Solar Environment Monitor experiments poses the question of how they are to be powered and controlled. Current Spacelab design provides for feed throughs in the module aft end cone only. Three options suggest themselves: (1) run data bus and power line through the aft feed-through and forward around the module, (2) construct a special feed-through in the forward end cone, and (3) power and control the forward mounted sensors directly from the Orbiter. Each option has advantages and disadvantages which should be assessed in detailed interface analyses.

4.4 SHUTTLE ACCOMMODATION SUMMARY

In summary, the investigation of the five Earth resources missions' ability to be accommodated by the several possible Shuttle carrier configurations leads to the following conclusions:

- Any of the carrier configurations examined are physically capable of carrying the cameras and scanner required by the three Applications Development missions. The integration complexity (and cost) associated with these missions is at a minimum with SEOPS and at a maximum with Configuration 1 which contains a large number of field-of-view integration complexities.

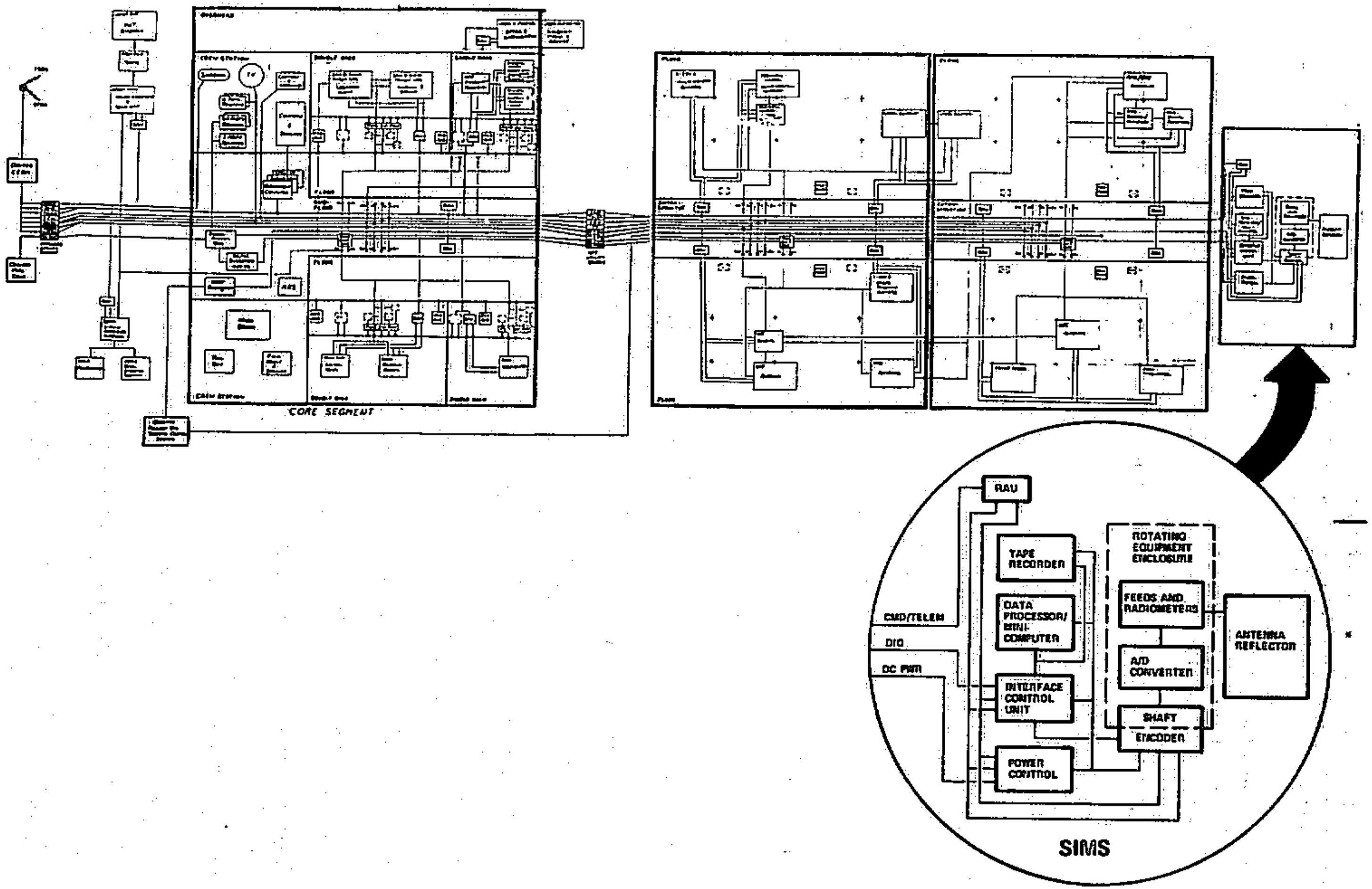


Figure 4-12. Configuration 1 — System Schematic

- The SIMS, in its present configuration which replaces a Spacelab pallet section, is best located at the aft end of the cargo bay. Special provisions must be made for routing data, power, and command lines to this station. Extending the Spacelab services to meet this need is indicated.

- The SAR antenna must be folded for launch and deployed on orbit if the Spacelab pressurized module is used, regardless of the antenna's orientation. The recommended SAR carrier is the pallet-only Spacelab configuration, with the SAR antenna hard-mounted lengthwise in the cargo bay. This configuration will eliminate the cost and complexity of deployment mechanism design, fabrication, test, and orbital operations, and simplify thermal shadowing analysis and mounting design.

SECTION 5

INTEGRATED FLIGHT PROGRAM

The requirements of the five representative missions are such that they lend themselves to combination on various Shuttle flights. In this section a nominal design orbit is selected and typical mission profiles are discussed. An integrated flight program which accomplishes the objectives of the five-mission program in a two-year period is established.

The critical question in the construction of an Integrated Flight Program is the satisfaction of individual mission requirements while simultaneously making optimum use of the variety of payload carriers and services of the Shuttle. Two alternate approaches are outlined here: the first investigates the maximum use of Spacelabs as OA facilities which support not only the Earth Resources missions studied here but other Applications experiments. This approach maximizes the number of other (non-Earth-resources) Applications experiments flown but results in an OA Spacelab facility flight frequency of four per year - a high-budget program. The second approach considers the OA Spacelab facility flight frequency to be constrained to two per year and employs several concepts to meet this constraint while fulfilling the mission requirements within a two-year flight program:

- use is made of the Standard Earth Observation Package (SEOPS) to carry out flight requirements which do not demand a full Spacelab.
- joint flights of the Synthetic Aperture Radar (SAR) and the Shuttle Imaging Microwave System (SIMS) are scheduled, carrying the implication that these two sensors can be integrated during their design phase to operate simultaneously.
- on-orbit reconfiguration of the SIMS/Soil Moisture package on a 30-day flight is used in place of two flights in the spring of year 2.

As the OA Shuttle Program evolves, additional variations on these themes will receive attention, such as more use of mixed-mode flight (captive payloads such as SEOPS or Spacelab pallet being flown in conjunction with automated Spacecraft launches). The conclusion at this point must be that a single-carrier approach (a Spacelab facility) to accomplishing Earth Resources missions is insufficiently flexible to be both effective and affordable.

5.1 ORBIT SELECTION

A nominal orbit that gives good coverage for all five representative missions is desired for mission design purposes. A common design orbit allows compatible sensors and missions to be flown in many potential combinations. The nominal orbit is used for initial mission design and may require further optimization for design refinement of a specific Shuttle flight.

A circular orbit with an altitude of 440 Km and an inclination of 48.1° was analysed in depth during a previous TERSSE Task, TERSSE Final Report, Vol. 4). The orbit is designed to provide full coverage of the continental U.S. (to 49°N) within the sensors' field of view capabilities. The density of coverage is maximized by lowering the orbit inclination as much as possible, and extent of coverage is optimized by matching period of repetition to mission duration. A five-day repeat cycle is provided, consistent with a seven-day Shuttle flight where the first and last days are devoted to launch and deorbit activities. Ground traces over the U.S. are shown in Figure 5-1 for this nominal orbit. The nominal orbit provides ample coverage of both urban and rural areas.

One of the major drivers in the use of any orbital platform for large area coverage in a short (7-30 day) flight is cloud-avoidance. Previous studies have focussed on the duration of the flight necessary to obtain a given probability of full coverage (e.g. 21 days of overflight for a probability of 90% coverage). The Shuttle introduces a new dimension to the problem in its ability to maneuver in orbit and thus alter its overflight schedule to synchronize with forecasted cloud conditions. Our study of the problem focussed on this capability and explored the fuel costs of a range or orbital maneuvers which could be used to avoid clouds by revising the basic 5-day repeat cycle of the nominal orbit.

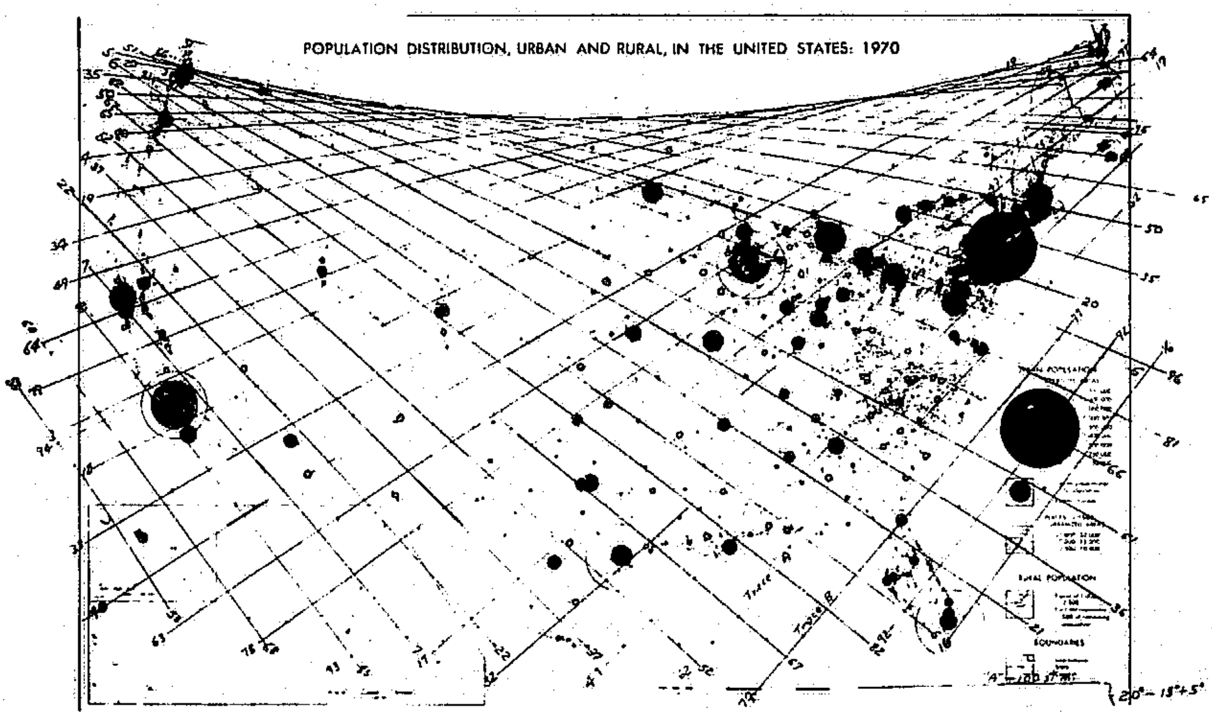


Figure 5-1. Coverage of Continental U.S. by Nominal Orbit

The extremes of the orbit of flexibility options considered are given in Table 5-1. The first example shows that for a modest delta-V it is possible to effect a two-impulse Hohmann transfer to change to a one-day repeat cycle. This maneuver would be used to cover a previous swath which was unavailable on the previous day due to cloud cover. Similarly, the second example shows the small delta-V requirement in changing from the nominal orbit to one yielding an eight-day repeat cycle. This change may be useful in a 14 day mission to provide coverage during days 8 thru 13 for swaths that were not possible during days 1 thru 7. The nominal orbit can be easily modified to other, less fuel-demanding, repeat cycles to compensate for clouds and to exploit extended sortie durations of up to 30 days. These two orbit modification examples represent reasonable extremes and were selected for that reason.

TABLE 5-1. ORBIT FLEXIBILITY OPTIONS

MISSION SITUATION	ORIGINAL ORBIT	NEW ORBIT	ΔV	REMARKS
RE-COVER SAME SWATH ON SUBSEQUENT DAY FOR CLOUD AVOIDANCE	239, nm 5-DAY	203 nm 1-DAY	126 fps	2, 3, 4-DAY TRANSFERS ALSO POSSIBLE AT LOWER ΔV
TRANSITION TO INTERLACING ORBIT FOR FILL-IN COVERAGE DURING DAY 8-13	239 nm 5-DAY	248 nm 8-DAY	31.5 fps	6, 7 DAY INTERLACES ALSO POSSIBLE AT LOWER ΔV

5.2 MISSION PROFILES

Consideration of the typical configurations presented in Section 4.3 illustrates that TERSSE flights can range from nearly-dedicated missions to shared sortie missions to satellite delivery/retrieval missions. In all cases TERSSE operations are constrained to the five or six orbits per day which pass over the continental U.S. (unless additional applications missions are served where non-U.S. target areas are specified). TERSSE operations may be further limited by the requirements of shared experiments on payloads.

A general TERSSE mission profile is given in Figure 5-2. "Orbital operations" include TERSSE operations and shared experiment/payload operations. A typical portion of a detailed experiment timeline for Configuration 1 is shown in Figure 5-3. The TERSSE sensors plus Electromagnetic Environment-Experiment (EEE), Adaptive Multibeam Antenna (AMA), Laser Altimeter, and Laser Ranging are operated for the duration of each pass over the Continental U.S., the S190 and the Thematic Mapper might be used outside the U.S., so potential passes over South America are shown. EEE and AMA devote a portion of their time to ocean coverage, as illustrated by the two Pacific passes which appear in the timeline. The Ozone Mapper and Solar Energy Monitor In Space (SEMIS) operate continuously. No operations for

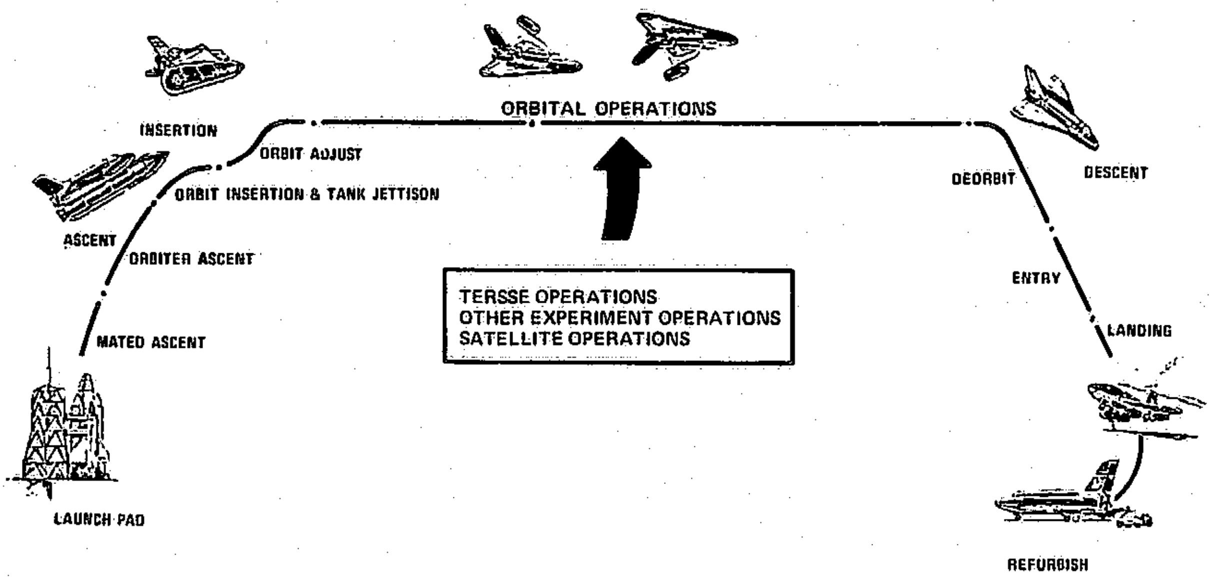


Figure 5-2. General TERSSE Mission Profile

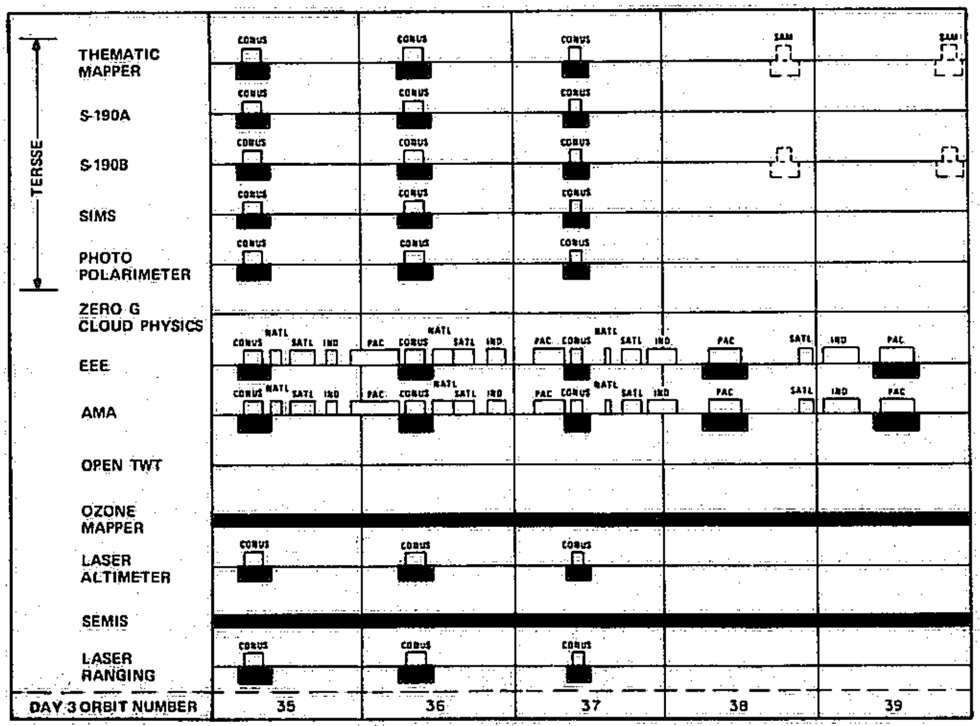


Figure 5-3. Typical Detailed Timeline, Configuration 1

Atmospheric Cloud Physics and Open TWT are shown; these relatively crew intensive activities are assumed to occur at times when targeted activities are at a minimum.

A potential problem is bunching of activities over the Continental U.S., where nine sensors operate simultaneously. This implies that these sensors should be fairly well automated and/or gang controlled. Experiments that operate in "off" periods can be less automated or more crew intensive, as is the case with the Atmospheric Cloud Physics and Open TWT.

Configuration 5 combines a satellite delivery with three TERSSE sensors. As shown in Figure 5-4, satellite deployment occupies the first twelve hours on orbit; after that the flight can be devoted to TERSSE operations. The TERSSE sensors are assumed to operate over the continental U.S. with potential use outside the U.S., as was the case with Configuration 1. A problem with this configuration is the relatively poor utilization of mission time during the TERSSE portion of the flight, since a significant portion of each day contains no presently identified target areas.

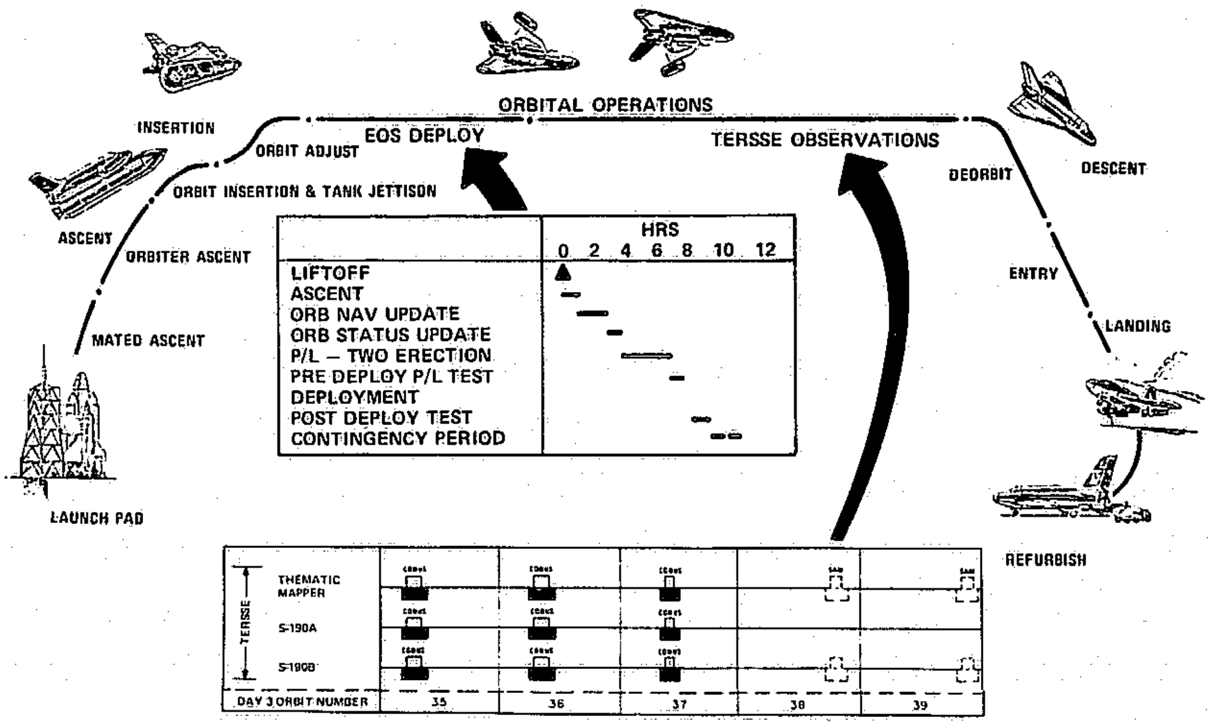


Figure 5-4. Configuration 5 - Mission Profile and Timeline

5.3 INTEGRATED FLIGHT PROGRAM

The first step in establishing an integrated flight program is to assess commonality among flight dat. What is required is the tailoring of a flight schedule which both fits the individual mission requirements and also meets realistic physical accommodation and flight cost constraints. The desired scheduling for the five representative missions is shown in Table 5-2. The configurations are used in which all missions can be flown together, a minimum total of eight flights would be needed to meet this schedule. Two versions of the Integrated Flight Program were analyzed: one version employs the maximum number of integrated Spacelab facility flights; the other constraints Spacelab flight to two per year and uses the SEOPS to complete the schedule.

TABLE 5-2. FLIGHT SCHEDULING

MISSION	NO. FLIGHTS	FIRST SHUTTLE YEAR				SECOND SHUTTLE YEAR			
		SPR	SUM	FALL	WINT	SPR	SUM	FALL	WINT
SOIL MOISTURE	5	1		1		2		1	
IMAGING RADAR	3	1			1			1	
MINERAL EXPLORATION	4	1	1	1	1				
FOREST TIMBER VOLUME	2		1		1				
URBAN/REGIONAL PLANNING	3		1		1		1		

The maximum integration case meets all five missions' requirements by joint OA Spacelab facility flights. A more reasonable availability of OA flights is two per year with four to eight months separation between flights. At this rate it would take at least four years to meet all of the mission requirements for the 5 missions analyzed, which is twice as long as desired. It could take longer due to limited flexibility with respect to flight opportunities. This case also has the disadvantage of coupling season-critical application development missions with research flights. To relieve the problem of excessive OA Spacelab facility flight frequency, the application development mission sensors can be mounted on a SEOPS bridge and flown separate from the research sensors where appropriate. This increases flight opportunities and scheduling flexibility since only the research missions would be constrained to two OA flights (those two with Spacelab) per year.

A major question concerning mission combination is EMI compatibility of SIMS and SAR. Figure 5-5 illustrates the relative frequency positions of SIMS (11 receiver frequencies) and SAR (2 transmitter frequencies and harmonies). Factors to be considered in assessing SIMS/SAR EMI compatibility include antenna

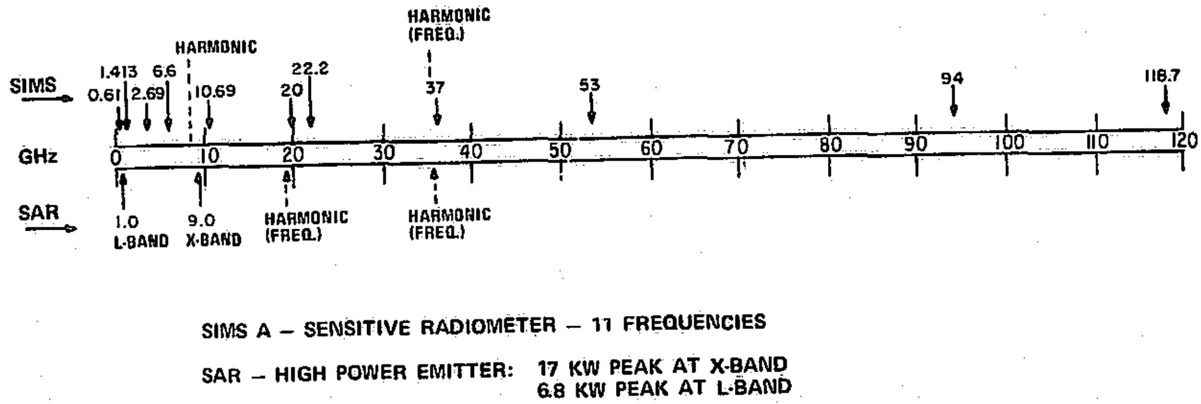


Figure 5-5. SAR/SIM Electromagnetic Interference Compatibility

patterns and system proximity, accounting for spillover and back lobes. Transmit/receive energy, (fundamental or harmonics) including sidelobes and look angles, must be considered. Serious problems can be solved through mutually exclusive operations or time-shared/sequenced operation, but joint operations are desirable. Further study of the two designs and their integration is warranted.

Under conditions of no flight frequency constraint and separate SIMS and SAR flights. The five-mission integrated flight program will require eight Spacelab flights and one SEOPS flight. A summary of this flight program is given in Figure 5-6. All mission requirements are satisfied in two years. (The program would require approximately four years at a flight frequency of two Spacelabs per year.)

By flying SIMS and SAR concurrently and making maximum use of SEOPS as a gap filler, the five-mission flight program can be accomplished with four Spacelab flights and three SEOPS flights. This assumes that the dual soil moisture flight in the first quarter of year 2 can be accomplished by on-orbit reconfigurations during a single flight; otherwise an additional Spacelab flight will be required. A summary of this flight program appears in Figure 5-7. All mission requirements are satisfied in the desired two years.

- FLIGHTS SCHEDULED AS NECESSARY
- SIMS AND SAR DO NOT FLY TOGETHER

	YEAR 1				YEAR 2			
	1ST Q	2ND Q	3D Q	4TH Q	1ST Q	2ND Q	3D Q	4TH Q
CONFIGURATION	SHORT LAB + 2 PALLETS	5 PALLETS	SHORT LAB + 2 PALLETS	5 PALLETS	SHORT LAB + 2 PALLETS	SEOPS	SHORT LAB + 2 PALLETS	5 PALLETS
PAYLOAD	EARLY SIMS PHOTO POLARIMETER TM S190B	SAR TM S190A S190B	INT. SIMS SCANNING POLARIMETER TM S190B	SAR TM S190A S190B	ADV. SIMS SCANNING PHOTOPOL. TM	TM S190A	ADV. SIMS SCANNING PHOTOPOL.	SAR
MISSIONS SERVED	EARLY SOIL MOISTURE MINERAL EXPLORATION	SAR ENG. MINERAL EXPLORATION TIMBER VOL. URBAN/REG. PLANNING	INT. SOIL MOISTURE MINERAL EXPLORATION	SAR CAL MINERAL EXPLORATION TIMBER VOL URBAN/REG PLANNING	ADV. SOIL MOISTURE	URB/REG. PLANNING	ADV. SOIL MOISTURE	SAR FLT PROOF
OTHER OA PAYLOADS	① ZERO-G CLOUD PHYSICS LASER R'GNG STARS/PADS LASER XCVR LASER ALT NO/YAG LASER	② LASER ALT LASER R'GNG NO/YAG LASER LASER XCVR OPTICAL SCAT STARS/PADS	SAME AS ①	SAME AS ②	SAME AS ①		SAME AS ①	SAME AS ②

Figure 5-6. Integrated Flight Program 1

- FLIGHT FREQUENCY CONSTRAINT OF 2 SPACELABS/YEAR
- SIMS AND SAR FLOWN CONCURRENTLY

	YEAR 1				YEAR 2			
	1ST Q	2ND Q	3D Q	4TH Q	1ST Q	2ND Q	3D Q	4TH Q
CONFIGURATION	5 PALLETS	SEOPS	SHORT MODULE + 2 PALLETS	SEOPS	R 5 PALLETS (ON ORBIT RETROFIT)	SEOPS	5 PALLETS	
PAYLOAD	EARLY SIMS PHOTOPOL. SAR TM S190B	TM S190A S190B	INT. SIMS SCANNING POLARIMETER TM S190A S190B	TM S190A S190B	ADV. SIMS SCANNING PHOTO POL. SAR TM	TM S190A	SAR ADV SIMS SCANNING PHOTOPOL.	
MISSIONS SERVED	EARLY SOIL MOISTURE SAR ENG MINERAL EXPL	MINERAL EXP 2 TIMBER VOL URB/REG PLANNING	INT. SOIL MOISTURE MINERAL EXPL	MINERAL EXPL TIMBER VOL. URBAN/REG. PLANNING	ADV. SOIL MOISTURE SAR CAL	URB/REG PLANNING	SAR FLT PROOF ADV SOIL MOIS .RE	
OTHER OA PAYLOADS	1 LASER R'NG ND/YAG LASER		ZERO-G CLOUD PHYS. LASER R'GNG STARS/PADS LASER XCVR LASER ALT ND/YAG LASER		SAME AS 1		SAME AS 1	

Figure 5-7. Integrated Flight Program 2

SECTION 6

DATA PROCESSING

The processing of Earth Resources data has now been recognized for several years as a critical part of the development process. Data processing forms the critical link between the sensors and flight operations used to gather the data and its use to meet the objectives of an Earth Resources mission. The critical nature of data processing will become even more important in the Shuttle era. In particular, the first few years of Earth Resources flights by the Shuttle require special attention because of both the highly varied nature of the developments which will be served by Shuttle and the fact that the use of Shuttle is itself a new and different means of collecting Earth Resources data.

Table 6-1 summarizes the considerations of present importance in this regard. The types of mission objectives to be met are more widely varied than with current Earth Resources platforms; the variety of objectives makes more complex the decisions on data processing flow paths and the spectrum of accuracy and timeliness requirements which must be met.

TABLE 6-1. FIRST TWO YEARS OF SHUTTLE — DATA PROCESSING

MISSION OBJECTIVES WIDELY VARIED – PHYSICAL SCIENCE – SOIL MOISTURE – ENGINEERING – SAR DEVELOPMENT – APPLICATION DEV.	AFFECTS DECISIONS ON PROCESSING FLOW, ACCURACY, TIMELINESS
USER INVOLVEMENT IN PROCESSING VARIED – PRINCIPAL INVESTIGATORS – SOIL MOISTURE – ENGINEERS – SAR DEVELOPMENT – RESOURCE MGRS – APPLICATIONS	AFFECTS DECISIONS ON IN-HOUSE VS OUT-HOUSE, SEPARATE VS. INTEGRATED FACILITY
SOME EQUIPMENT COMMON, OTHER UNIQUE – INTRA PROGRAM COMMONALITY – INTER-PROGRAM/EXOGENOUS DESIGNS	IMPACTS COSTS OF ALTERNATIVE APPROACHES

CURRENT UNDERSTANDING:

- SAR, TM REQUIRE SPECIAL PURPOSE EQUIPMENT; MOST OTHER PROCESSING IMPLEMENTABLE IN SOFTWARE OR WITH STANDARD EQUIPMENT
- SIGNIFICANT COST ADVANTAGES ACCRUE FROM CO-LOCATION, BUT OPERATIONS, USER INTERFACES MORE DIFFICULT

$\boxed{\text{THE EARLY SHUTTLE ER PROCESSING SYSTEM IS A KEY ELEMENT — FURTHER STUDY OF ITS CONFIGURATION IS REQUIRED.}}$

The level of involvement of the users in the processing itself will be varied as a result of the different types of missions; technique development and sensor development data processing will necessarily be carried out with the user (scientist or sensor developer, respectively) much more involved with the inner workings of the instrument itself than for those missions whose users are resources managers. The architecture of the Shuttle Earth Resources data processing facility is affected by this variability of user-involvement; the degree of hands-on control by the user should influence the choice of ownership and location of the facilities.

A third issue which must not be lost sight of, is the ability of Shuttle Earth Resources data processing to profit from a growing body of processing equipment already in existance or under development for use with other Earth Resources platforms. The costs of implementing a series of Shuttle Earth Resources missions, such as discussed in this report, will in no small way be governed by the need to process the data. Sharing equipment among each of the Shuttle missions and among the different Earth Resources programs is warranted to the extent that it does not compromise the Shuttle Earth Resources mission objectives.

The processing of data from all Shuttle flights (not just those for Earth Resources purposes) is a question which has massive implications and which demands creative and realistic attention. The projected volume of such data is sufficiently large to require totally new approaches to its handling once back on the ground and even during its collection in orbit. The processing of Earth Resources data is a portion of this larger problem which possesses several unique driving requirements (e.g. data rate). Its solution must be undertaken early, in parallel with both the design and development of the individual Earth Resources payloads and the refinement of the overall philosophy of how the Shuttle is to be utilized to support further Earth Resources developments.

The five missions analyzed in this report provide a good framework for discussion of the foregoing issue, for these missions are sufficiently varied in their characteristics to require attention to the entire range of data processing system drivers which will be present during the critical first two years of Shuttle Earth Resources flights. Figure 6-1 illustrates the division of the processing requirements for the reference missions into four classes of processing. Each class of processing presents its own unique set of requirements in terms of methodology, hardware and algorithms. In addition, a unique set of mission-peculiar requirements is superimposed onto these basic sets. The purpose of this analysis of data processing requirements is the description of top level functional requirements to satisfy the data processing needs of the five selected missions and the preliminary definition of a Shuttle Earth Resources Data Processing Facility concept.

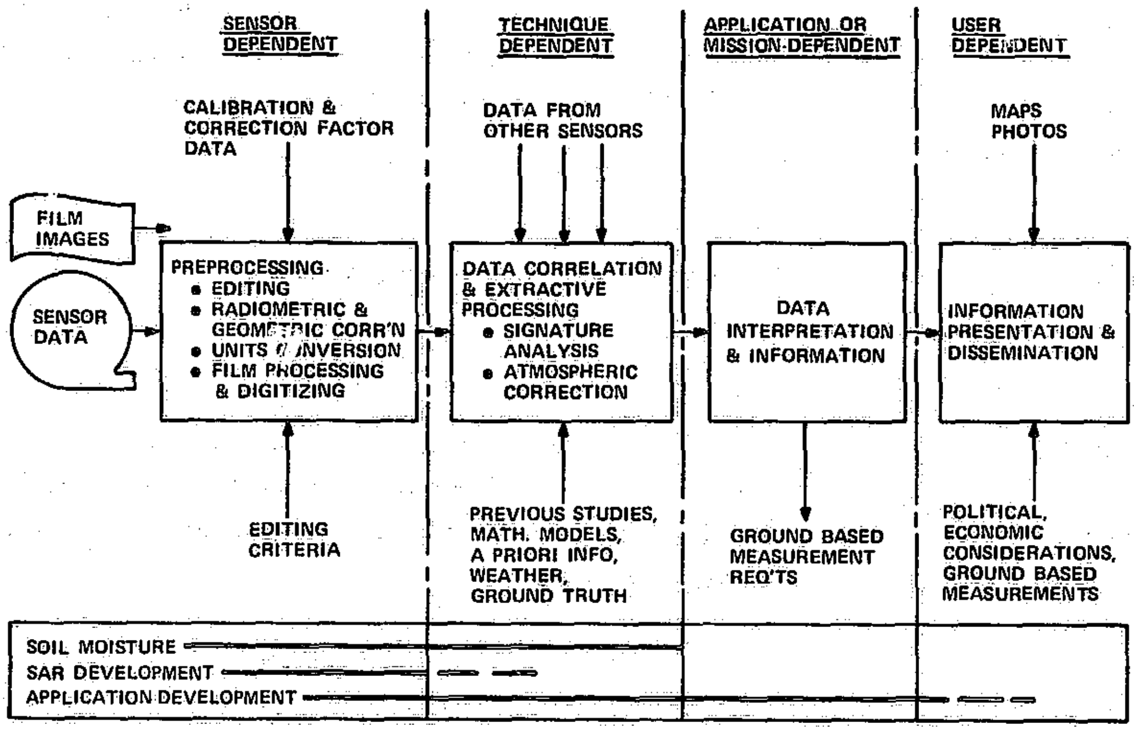


Figure 6-1. Shuttle Sensor Data Processing Classes

6.1 PREPROCESSING

The sensor dependent preprocessing facility for the Shuttle missions will provide those functions necessary to perform:

- Data Editing and Quality assessment
- Radiometric and Geometric correction of Thematic Mapper and SAR data
- Conversion of SAR digital data into imagery data
- Correction and conversion of SIMS data into brightness temperature images.

All processing and correction of the data will be accomplished in the digital domain to achieve the desired output product accuracy requirement and to satisfy the needs of the particular user community that performs digital extractive processing to derive information from the data.

Data Editing and Quality Assessment

A post-flight assessment of the data recorded on board the Shuttle is necessary to identify regions of useful data and to determine their characteristics for cataloging and processing scheduling. Parameters to be determined include such characteristics as data signal quality, cloud cover, and failed detectors or other sensor-related parameters. In addition, a reformatting function must be performed to produce a serial data stream that has a format which is optimized for ground processing. For example, the output format of the Thematic Mapper must be band-to-band registered, spectrally interleaved, and linearized (all pixels along a straight line in sequence) prior to its entry into the subsequent radiometric and geometric preprocessing functions.

Radiometric Correction

Radiometric correction of each of the sensors includes the following functions:

- Calibration of the received intensity in units of signal radiance or power.
- Normalization of inter-detector variations to a common standard.

Thematic Mapper radiometric correction involves the calibration of each digital pixel by use of internal sensor calibration data obtained from calibration lamps and recorded as part of the primary image data stream. The process requires the stripping out of the calibration pixels, the calculation of a calibration function, and its application to the image pixels as a multiplier.

Radiometric calibration of the Synthetic Aperture Radar (SAR) is accomplished by computing the ratio of return power to transmitted power. The use of an attenuated transmitter signal which is measured by the receiver provides the basic calibration reference which is stripped from the video data stream recorded during orbital operation and used to prepare the calibration function. A second radiometric processing step to be taken for selected images is the calculation, for each pixel, of the scattering coefficient, σ_o. This is performed by solving the radar range equation. Inputs are the transmitted and received power levels, slant range, and atmospheric attenuation correction factors.

The Shuttle Imaging Microwave System (SIMS) also requires the use of an independent calibration source to provide an intermittent reference for post-flight-calibration. SIMS is a total-power radiometer in its present configuration in which the Earth-radiated signal is not chopped with a calibration source many times during each pixel reading, as with a Dicke-type radiometer. The total power radiometer provides a greater signal-to-noise ratio than the Dicke-type but demands greater stability of the radiometer receiver. The calibration operation, as with the other sensors, requires the stripping out of the calibration data stream, the calculation of the calibration function, and the application of it to the radiometer pixels in each of the eleven frequency bands to produce T_b, brightness temperature.

Geometric Correction

Geometric correction of each of the sensor data streams is required to reconstruct the pixels in a geometric configuration which usefully represents the earth surface which has been imaged. To be accounted for are the attitude and attitude rate errors of the Shuttle, the distortions produced by off-axis pointing, if any, earth curvature, and apparent displacement caused by terrain relief. Geometric processing of the Shuttle Earth Resources sensors produces the important quality in the resulting imagery of superimposability which permits the 6-channel TM, the 11-channel SIMS, and the 4-channel SAR to be used in a coordinated fashion with each other and the film data.

The Thematic Mapper and SAR data will be corrected for all of the foregoing factors* by complete digital resampling of each band of the image. The use of ground control point selected from the raw imagery will provide the primary reference with the Earth. Ancillary data will include attitude and ephemeris data peculiar to the flight and topographic data, where available from external sources, for terrain relief displacement correction.**

Geometric correction of the SIMS data should not require resampling of the image pixels, as the ground resolution of the SIMS is on the order of kilometers. Reassignment of the existing pixels to new addresses can be based on a correction function generated using the same input data as for the other sensors without concern for terrain relief displacement in most instances.

6.2 EXTRACTIVE PROCESSING

Extractive processing of the Shuttle Earth Resources sensor data will involve a wide variety of techniques. Some will be peculiar to a particular sensor and involve only it, such as the analysis of SAR signal data to determine transmitter, antenna, and receiver engineering performance. Others will be general-purpose and will not only be useful for several sensors individually but will also involve the use of multi-sensor data. The most exciting of the latter type is simultaneous multispectral analysis of data from the several spectral regions, active and passive, provided collectively by the SIMS, SAR, and Thematic Mapper.

Special-Purpose Extractive Processing

Because of the developmental nature of the Soil Moisture and SAR Development missions, a substantial amount of data analysis will be performed on small individual sets of the sensor outputs. In the case of the Soil Moisture mission, regression analysis and other correlative modelling techniques will be used to relate soil moisture as a function of depth and cover to the data from the various sensors involved. The approach to soil moisture signature development described in this study involves the use of a wide variety of active and passive, polarized and unpolarized sensors in both the microwave and visible/IR spectral regions: SIMS, TM, SAR, photopolarimeter. Spot data from all these sensors will be combined with ground truth and exhaustively analyzed to determine the dominant measureable characteristics.

---

* Terrain relief displacement for the nadir-looking Thematic Mapper will not be corrected in many applications.

** The film cameras to be carried can provide such data from stereo pair photography.

In the case of the SAR special-purpose extractive processing, the concern is primarily one of engineering performance. Here again, spot data representing the range of parameters such as antenna temperatures, atmospheric conditions, transmitter power, and receiver temperature will be selected and exhaustively analyzed to determine the SAR orbital performance and to compare it to design and ground test predictions. One of the key elements in this analysis will be the four-band calibration of the radar over the range of conditions under which it will be operated. The future utility of the SAR in applications development will largely depend on this calibration. The special-purpose extractive processing so described will be performed primarily through the use of tailored software on general-purpose machines to afford the flexibility required to meet unforeseen discoveries.

Multispectral Analysis

The three Applications Development missions will require heavy use of multispectral analysis of Thematic Mapper data on a machine such as the Image 100. The analysis of the combined properties of the multispectral images in a rapid, interactive manner is the primary tool upon which the development of these applications depend.

Development of parameter estimation procedures for multispectral stratification of forest land classification techniques for urban land cover categories, and image enhancement procedures for geological interpretation are key to the exploitation of the higher resolution multispectral data provided by the Shuttleborne Thematic Mappers.

In addition, the existence of SAR, SIMS, and TM data taken simultaneously from orbit over identical or overlapping regions will afford the opportunity for multi-sensor multi-spectral analysis. The special-purpose processing of soil moisture data referred to earlier will be complemented by a broad-based multi-spectral image analysis effort where the combined twenty-one channels of data from the three imaging sensors, SIMS, SAR and TM, will be used to generate parameter-estimation algorithms for soil moisture and to extend the point data from the special-purpose analysis to larger geographical regions for evaluation.

6.3 INTERPRETATION OF PHOTOGRAPHIC IMAGERY

Photointerpretation is essentially a manual process, relying on the skill and experience of a trained photointerpreter, with some machine assistance, to extract the desired information. The cameras of the Shuttle Earth Resources mission will provide valuable detail, stereo capability, and the imagery for base photomap preparation.

The data processing requirements of the three applications development missions require photointerpretation to perform the following functions:

- Evaluate stereo pairs to determine and map geological lineaments and other features.
- Perform aerial and linear measurements on forest strata to determine strata extent and tree size.
- Evaluate photographic images for cultural and other indicators of urban land use.

These functions will be performed manually using such equipment as viewing tables, a stereoplotter and coordinate digitizer, and a flatbed plotter as aids in interpretation and presentation of results. In addition, the multispectral analysis system will have the capability of accepting inputs from the digitizers to permit registration and comparison of the two types of data.

6.4 SHUTTLE ER DATA PROCESSING FACILITY CONCEPT

The combined requirements of preprocessing and extractive processing of the Shuttle Earth Resources missions are sufficiently demanding to make attractive the investigation of a single combined facility where the bulk of the processing would be accomplished and where a maximum amount of equipment and personal commonality can be maintained. Such a concept is illustrated in Figures 6-2 and 6-3. The Preprocessing and Analysis Segment of the Shuttle ER Data Processing Facility contains both the high-data-rate special purpose hardware necessary for the TM and SAR and computer peripheral equipment driven by the general-purpose computer shared with the Extractive Processing and Analysis Segment. The latter contains, as well, the multispectral analyzer and film analysis equipment necessary to perform combined analysis of the various electronic and film data formats of the Shuttle Earth Resources sensors.

Much of the hardware illustrated in the concept either exists or is under development. The Preprocessing and Analysis Segment contains video and high-density tape recorders and special-purpose TM hardware which will also be used in the Landsat Program; a hard-copy unit, CRT, line printer, storage disc unit, and tape deck which are off-the-shelf; and special-purpose SAR hardware for digital-to-film conversion of radar imagery. The TM special-purpose hardware for radiometric and geometric correction can be adapted to be shared with the SAR data.

Similarly, the Extractive Processing and Analysis Segment contains hardware similar to that now purchasable. Some modification to the Image 100 Multispectral Analyzer will be required to provide for multisensor multispectral analysis but no major development will be required to produce such modifications.

The value of the early Shuttle missions defined in this report stems from the breadth of the advances possible by carrying a range of sensor types. And these sensors require a broad range of processing functions to be carried out. But, through the use of common equipment in a central location and close

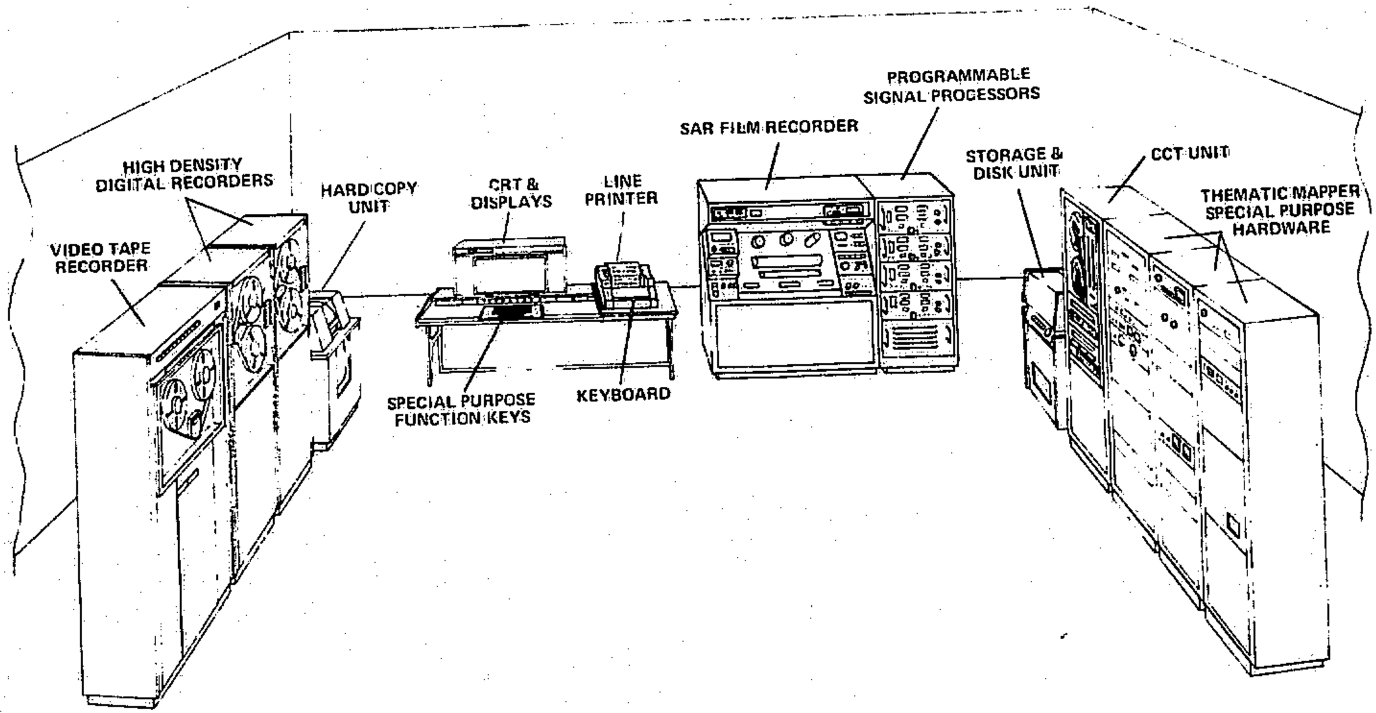


Figure 6-2. Conceptual Design of Shuttle ER Data Processing Facility — Preprocessing and Analysis Segment

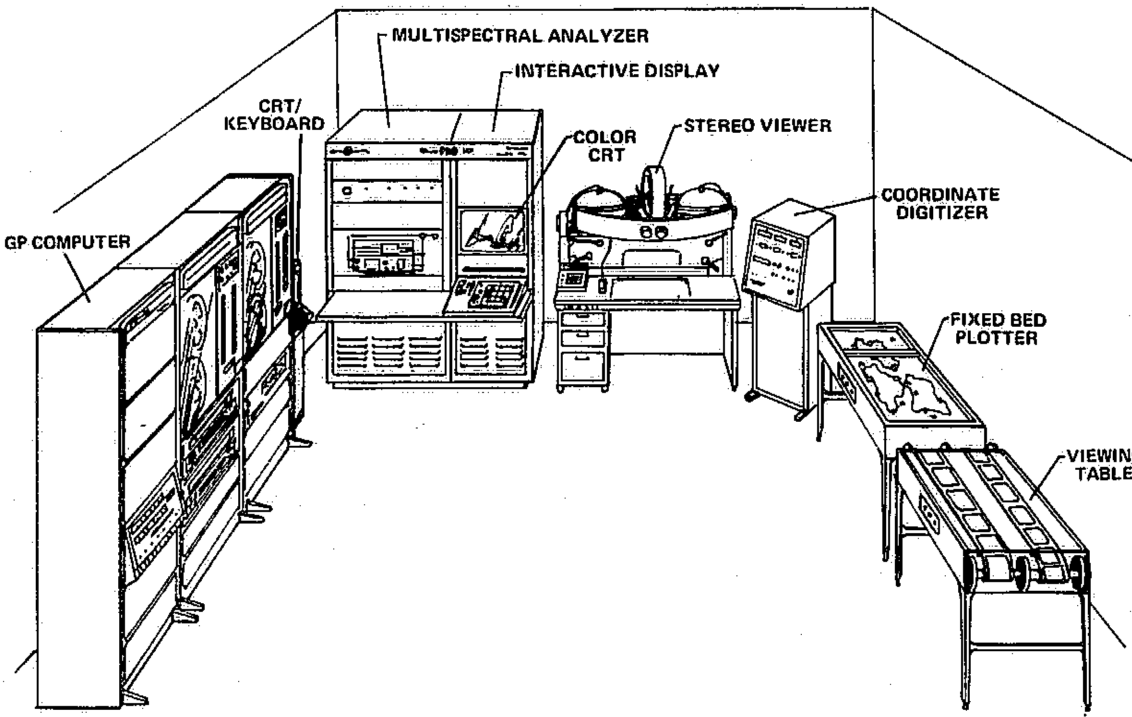


Figure 6-3. Shuttle ER Data Processing Facility — Extractive Processing and Analysis Segment

attention to providing the necessary flexibility in processing facility scheduling and operations, the needs of the missions can be met without major new equipment R&D. The avoidance of equipment R&D costs is important, for it permits the allocation of R&D funds to the area of technique and new procedure development so critical to the success of the set of Shuttle Earth Resources missions.

SECTION 7

A COST ANALYSIS OF SHUTTLE AS AN OPERATIONAL EARTH RESOURCES PLATFORM

The use of the Space Shuttle in the sortie mode as an Applications Development platform must be based on its ultimate potential for performing operationally the missions which are developed. Thus, while the use of the Shuttle in an R&D mode may be justified on grounds other than cost-effectiveness (such as its availability for flights at a desirable time) no mission analysis of the Shuttle (or any other platform) would be complete without a portion being devoted to a comparison of the costs of performing the intended operational mission with alternate means.

7.1 APPROACH

Five major considerations governed the approach used in this cost analysis:

- The context of the operational missions was taken to be the early 1980's and therefore alternative platforms were narrowed to high-altitude aircraft; polar spacecraft were excluded as being incapable of 10-20 meter multispectral electronic data acquisition and high resolution film data acquisition during that timeframe.

- The cost comparison with aircraft was conservatively based on data acquisition costs alone without regard for processing costs. The latter costs, while not analyzed during this study,* may be described as at best equal for aircraft and the Shuttle and almost certainly significantly higher for aircraft as a result of the more extreme view angles and larger number of image frames or swaths which must be corrected and combined.

- Data acquisition costs result from two major sources: flight operations and the procurement cost of sensors. The analysis of each platform was structured to keep separate these two cost elements.

- The basis for comparison used in computing cost data was the ability of each platform to provide 10-meter IFOV data over a given area. No value was added for, in the case of the aircraft, the ability to provide better than 10m IFOV data nor, in the case of the Shuttle, the ability to provide such data in a one-week flight rather than the three months assumed for aircraft data gathering.

- Since the operations considered span only a two year time period all costs are computed in 1975 dollars, without regard for the effects of a particular discount rate.

One further consideration was acknowledged in the structuring of the approach: the need for generalization to conclusions concerning the cost-effectiveness of Shuttle for many missions from the results of analyzing but a few. The three application development missions selected for study (Timber Volume Inventory, Regional/Urban Planning, and Mineral Exploration Survey) are but representative of the many missions

---

*Nichols et. al. reported in "Cost Effectiveness Comparison of Existing and ERTS-Based Timber Resources Inventory Systems". NGL05-003-404" that the cost to carry out a timber volume inventory of the million-acre Plumas National Forest using LANDSAT data were roughly half (4¢/acre) the costs of conventional aerial and ground methods." It is significant to note that, in the referenced work, imagery acquisition costs were not included - a merging of that effort and the one reported herein could produce a more complete picture.

which can be performed by the Shuttle in the early 1980's. Since the Shuttle, as with all space platforms, has a cost-effectiveness which is very sensitive to the volume of data collected, the cost analysis of these missions must therefore be performed in such a manner that some amount of generalization to larger numbers of missions may be made. This generalization is provided through the approach to first, perform a cost analysis in a single mission and then a similar analysis of the three missions as an aggregate. The flight frequency and volume of data resulting from the single mission tested the cost-effectiveness of Shuttle in the area of its "initial minimum increment" of work. The three aggregated missions will have jointly a substantially higher volume of data and provide a cost-effectiveness test of Shuttle in the mid-range of its region of superiority. Extrapolation to larger numbers of missions from these two points is straightforward.

7.2 SHUTTLE COST ESTIMATING RELATIONSHIPS

The cost for acquiring data for an applications mission by Shuttle may be subdivided into (1) those associated with the acquisition of the required sensors and (2) those associated with the transportation of the sensors into orbit, their operation there, and their recovery. Of the two, the costs of Shuttle flight operations are the less well-defined and it was to this area that the greater amount of study was devoted.

7.2.1 SHUTTLE FLIGHT OPERATIONS COST ELEMENTS

The Shuttle is significantly different from expendable boosters in such a large number of ways that few current bench marks for developing user cost schedules exist. Its large weight-carrying capacity and other physical resources lend themselves to multiple-user payloads to whom some apportionment of charges must be made. Shuttle's high inflight flexibility and the large array of services which it can furnish makes additionally complex the subdivision of charges among users. And the intact recoverability of the shuttle with its payloads is a feature for which the value (and hence the down-flight charges) is largely unestablished in any quantitative way.

The simplest model, and the one in "current" use for such effort as the Earth Observatory Satellite Phase B Study in 1974, is based on the resource of Shuttle payload weight. Several variations of this model have been used; all are based on a straight-line charge in dollars/kilogram (or pound) and differ only in their assignment of overhead payload weight. Table 7-1 contains two such models. Model #1 is useful for automated spacecraft delivery, retrieval, and servicing analysis. It presumes the equivalence of value of a kilogram delivered to orbit and a kilogram retrieved from orbit (which is subject to question.) It includes as overhead an 0.8 utilization factor (to allow for the fact that the Shuttle will not fly totally full 100% of the time.) Other "overhead" charges such as pallets, cradles, or the Spacelab are chargeable directly as a component of Wx. Model #2 has been tailored for use on Spacelab sortie flights where the entire payload is recovered. The existence of the Spacelab and pallets as the host to the "payload" is assumed to consume as

TABLE 7-1. STRAIGHTLINE WEIGHT SHUTTLE USER CHARGE MODELS

STRAIGHTLINE WEIGHT MODEL #1: UP COST $= \left[\dfrac{Wx}{W_{TU} \times U}\right] \times \$5.25M$ DOWN COST $= \left[\dfrac{Wx}{W_{TD} \times U}\right] \times \$5.25M$	WHERE Wx = USER'S CHARGEABLE WEIGHT W_{TU} = TOTAL PAYLOAD WEIGHT CAPABILITY W_{TD} = 14,500Kg. (32,000 LB) U = UTILIZATION FACTOR
STRAIGHTLINE WEIGHT MODEL #2: UP AND DOWN COST $= \left[\dfrac{Wx}{6600}\right] \times \$10.5M$	WHERE Wx = USER'S CHARGEABLE WEIGHT 6600 = NOMINAL PAYLOAD WEIGHT AVAILABLE FOR SPACELAB-EQUIPPED SORTIE FLIGHTS, IN Kg

"overhead" 7900 Kg (17,500 lb) of the 14,500 Kg (32,000 lb) maximum landing weight, leaving 6600 Kg (14,500 lb) as chargeable user payload weight. The payload which must be included in the charging schedule is thus only the sensors or experiments themselves and their associated unique support equipment.

A second type of user charge model is the Multi-Element Model, where the services provided by the Shuttle are more explicitly allocated and charged either according to their cost or to achieve desired incentives toward their use. One of the more complex of such models, under development by GE, is illustrated in Table 7-2. The total costs are computed by those incurred in each of three phases of the flight: up-transport, on-orbit, and down-transport. These three phases are, in turn, subdivided into cost elements which allocate the costs of the services or resources utilized. The particular coefficients used

TABLE 7-2. MULTI-ELEMENT SHUTTLE USER COST MODEL

TOTAL FLIGHT COST $= C_1 + C_2 + C_3$	
C_1 = UP TRANSPORT COSTS $= K_1 V + K_2 W_u$ • VOLUME (V): K_1 = \$13,757/m^3 • WEIGHT (W_u): K_2 = \$108.81/Kg	• SPECIFIC COEFFICIENTS HAVE BEEN DERIVED BASED ON POSTULATED INCENTIVE/DISINCENTIVE RATIOS • THE COST COEFFICIENTS CAN BE ADJUSTED EASILY WITHIN THE STRUCTURE OF THIS GENERALIZED MODEL
C_2 = ON-ORBIT COSTS $= K_3 C + K_4 T + K_5 D + K_6 P$ • CREW TIME (C): K_3 = \$6446/MAN-HOUR • DATA TRANSMISSION (T): K_4 = \$4286/MHz • DATA PROCESSING (D): K_5 = \$2.36/WORD STORAGE • POWER CONSUMED (P): K_6 = \$1721/KWh	
C_3 = DOWN TRANSPORT COST $= K_7 W_D$ • WEIGHT (W_D): K_7 = \$184.44/Kg	

here have been generalized using the current NASA Traffic Model (1973) and are based on two considerations:

- recovery of all operations costs on a year-by-year basis (as is currently done in other transportation industry rate structuring) rather than on a flight-by-flight basis.
- incentivation of the efficient use of the total cargo bay up-volume and onboard processing of data to reduce ground processing costs.

7.2.2 SHUTTLE SENSOR COST ELEMENTS

The requirements of all three application development missions are met by the use of a 10-20 meter IFOV six-channel multispectral scanner with associated recorder, a high-resolution large-format film camera such as the S-190B, and a high-resolution multi-spectral camera such as a modified S-190A. Table 7-3 contains the acquisition cost values used in the analysis for these hardware items.

Two methods were used in accounting for the Shuttle sensor costs:

a) a wholly-owned method, where the full acquisition costs of the sensor package are borne by the mission(s) served.

b) an amortizing method, where the acquisition costs are allocated to the missions on the basis of the total flight life of the sensor package.

The wholly-owned method is the more conservative, as it does not rely upon an assumption of other missions generating demand for the use of the sensor package over its useful lifetime. The annual flight rate (10 per year) and the package lifetime (5 years) used for the amortizing method are, however, very conservative by current standards[1] and result in more realistic sensor costs.

TABLE 7-3. COST VALUES USED FOR SHUTTLE SENSORS

ITEM	ACQUISITION COST	PER-FLIGHT AMORTIZED COST *	ASSUMPTIONS
MULTISPECTRAL SCANNER	$3M	$60K	MODIFICATION OF PROTO-TYPE, THEMATIC MAPPER (MULTIPLE UNITS NOT REQUIRED)
RECORDER	$1M	$20K	IDENTICAL TO LANDSAT-D MODEL
CAMERA PACKAGE	$2M	$40K	MODIFICATIONS TO S190A AND B (INCLUDE PRESSURIZATION PROVISIONS)

*BASED ON 10 FLIGHTS/YR FOR 5 YEARS.

(1) For example, the current HR-732 cameras in use by NASA on the U-2 aircraft are well over 10 years old and fly several times as often as the foregoing flight rate.

7.3 AIRCRAFT COST ESTIMATING RELATIONSHIPS

As with the Shuttle, the costs for gathering data for an applications mission by aircraft may be subdivided into the acquisition costs of the sensors and the flight operations associated with their use over the areas of interest. A substantial body of information exists on this subject, in contrast to the situation with the Shuttle. Models developed by Cheeseman(1) are specifically tailored for cost/performance analysis of Earth Resources missions such as the three under consideration here.

The performance element which is used to calculate operations costs is the flight hour. For a given day of data acquisition for an application, the total flight time available is consumed as climb time, level flight to the first target (if not reached during the climb), flight time to collect data from the first target, level flight to the second target, and so on, and descent time (with additional level flight time if the descent does not bring the aircraft within the base flight pattern).

Data collection flight time for each target is obtained by a set of algorithms(2) which are used to first calculate the geometric relationship between the aircraft and the target (covering such questions as: are multiple passes required?) and second to calculate the flight times involved in series of targets. The input data to the algorithms is a Target Variable Set and an Aircraft Variable Set; the abbreviated version from the Cheeseman model (1) used in this analysis is listed in Table 7-4.

TABLE 7-4. TARGET AND AIRCRAFT VARIABLE SETS

LEN	-	LENGTH OF TARGET, Km
WID	-	WIDTH OF TARGET, Km
LAT	-	LATITUDE OF TARGET, DEG.
LON	-	LONGITUDE OF TARGET, DEG.
UNC	-	RADIUS OF UNCERTAINTY OF KNOWLEDGE OF TARGET LOCATION, Km
OBL	-	PERMISSIBILITY OF OBLIQUE VIEWING
FOV	-	MAXIMUM ALLOWABLE FIELD OF VIEW (HALF-ANGLE) OF SENSOR, DEG.
LOS	-	MAXIMUM ANGLE OF THE SENSOR LINE-OF-SIGHT WITH LOCAL VERTICAL DEG.
RES	-	SPATIAL RESOLUTION REQUIRED, m
MOS	-	PERMISSIBILITY OF MOSAICS ON THE FINAL IMAGE
CYC	-	CYCLE TIME FOR REPETITIVE ACQUISITION OF DATA, DAYS
DUR	-	MAXIMUM DURATION OF SENSING PERIOD FOR ONE COMPLETE CYCLE, DAYS
V	-	AIRCRAFT SPEED, Km/HR
H	-	AIRCRAFT ALTITUDE, Km
M	-	MAXIMUM NUMBER OF IFOV ELEMENTS IN SWATH
L	-	TIME TO COMPLETE A 180° TURN FOR MULTIPLE FLIGHT LINES, MINUTES

(1) Cheeseman, C. E., "A Cost/Performance Analysis of Aircraft and Satellites Used As Earth Resources Survey Vehicles." Ph.D dissertation, University of Pennsylvania, 1973.

(2) Those interested in a complete description of the algorithms and their use are referred to Cheeseman (1973), Proceedings of the Am. Soc. of Photogrammetry Conference on Earth Resources, Sioux Falls, October 1973.

The operations cost unit is the flight hour; the cost per flight hour used in the analysis was \$1600/hr[1] which includes fuel, maintenance, and crew (and is very much equivalent to the \$10.5M cost per Shuttle flight.) Sensor package costs were treated, as for the Shuttle sensors, in both wholly-owned and amortizing approaches. The sensor cost values used are contained in Table 7-5.

TABLE 7-5. COST VALUES USED FOR AIRCRAFT SENSORS

ITEM	ACQUISITION COST	PER FLIGHT HOUR AMORTIZED COST*	ASSUMPTIONS
200 μR SCANNER AND RECORDER	\$2M each	\$400/HR	6-8 BAND, CRYO-COOLED
70 MM MULTISPECTRAL CAMERA (6-BAND)	\$1.5 M each	\$300/HR	SIMILAR TO AIRCRAFT VERSION OF S190A

* BASED ON 1000 FLIGHT HOURS/YR FOR 5 YEARS

7.4 COST ANALYSIS

Data acquisition costs for the three missions were analyzed as follows:

- The costs of performing the Regional/Urban Planning mission were first obtained to provide comparison of the Shuttle and aircraft on a basis most favorable to the aircraft: a single mission, and one which involved scattered point targets.

- The costs of performing the aggregated three missions were then obtained to indicate the comparative cost trends for the two platforms as additional data collection volume is added to their requirements.

7.4.1 COST ANALYSIS DESCRIPTION

The cost analysis was structured according to the sequence illustrated in Figure 7-1. Each of the steps in the sequence, explained in the following paragraphs, is keyed to a number on the figure.

The analysis began with the assignment of values to the Aircraft Variables (1) and the Target Variables (2). The values used are contained in Table 7-6.

The Spatial Relationships (3) are used to relate the geometry of the target to that of the aircraft altitude and sensor swath to produce the number of swaths to image each target. The Aircraft Variables and the Spatial Relationships are both used as inputs to a set of flight time algorithms which produce Aircraft

[1] Private conversation with Edward Gomersall, NASA/AMES Research Center, California.

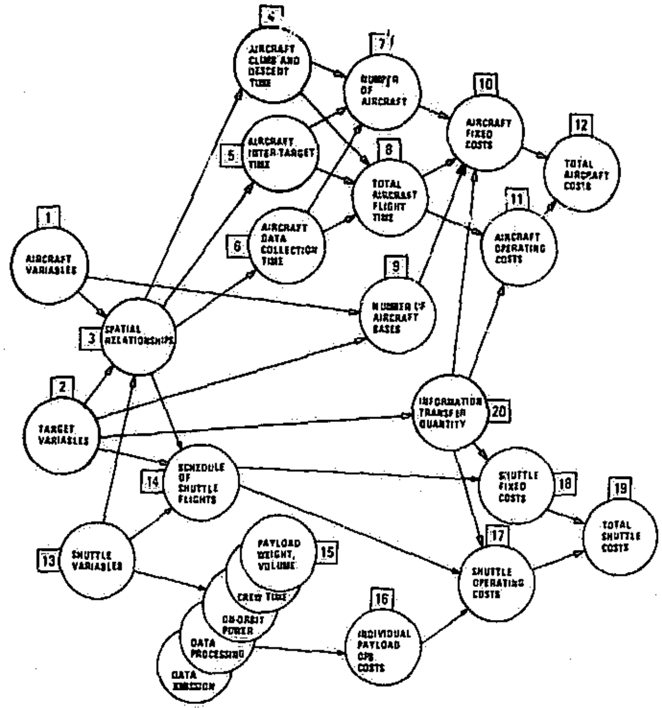


Figure 7-1. Cost Analysis Sequence

Climb and Descent Time (4), Aircraft Inter-target Time (5) for non-contiguous targets, and Aircraft Data Collection time (6). These elements of flight time are obtained by comparing the required flight path with the aircraft performance dynamics such as climb time, speed, and turn time. The resulting calculations of flight time are used to obtain a Total Aircraft Flight Time (8) by summation of (4), (5), and (6). The number of Aircraft (7) are obtained by dividing the required flight time by the possible flight hours per day per aircraft and an aircraft utilization factor for spares and down-rate.

Although not necessary for this analysis, as no special aircraft basing costs would be incurred, the model provides for calculating the Number of Aircraft Bases (9). Aircraft Fixed Costs (10) are then calculated from the number of aircraft (and thus sensor packages) required. Aircraft Operating Costs (11) are obtained from the total number of flight hours and the aircraft flight hour rate. The Total Aircraft Costs (12) are the sum of (10) and (11).

The sequence to obtain Shuttle costs begins by using the Target Variables (2) and Shuttle Variables (13) to determine the Schedule of Shuttle Flights (14) required to carry out the data acquisition. A portion of this determination includes the use of Shuttle altitude and orbital parameters in combination with the target variable LOS to determine that all targets are accessible. This step was carried out as a separate orbit selection analysis (Section 4); the resulting orbit permits access to all targets for these (or any other)

TABLE 7-6. TARGET AND AIRCRAFT VARIABLE VALUES USED FOR COST ANALYSIS

	VARIABLE	REGIONAL URBAN PLANNING	AGGREGATED TIMBER VOLUME INVENTORY, REGIONAL URBAN PLANNING, MINERAL EXPLORATION SURVEY	REMARKS
TARGET	LEN, Km	10 (AVG)	MAJOR CONTIGUOUS AREAS OF U.S.	SINGLE AIRCRAFT FLIGHT LINE REQUIRE FOR ALL BUT 5
	WID, Km	10 (AVG)		CITIES; THEREFORE TARGET SIZE RANGE NOT A COST DRIVER FOR URBAN REG. PLANNING
	LAT, DEG	UNIFORMLY DISTRIBUTED	$4-6 \times 10^6$ Km^2, DEPENDING ON	ACTUAL DISTRIBUTION OF CITIES APPROXIMATED BY UNIFORM
	LON, DEG	OVER CONTINENTAL U.S.	FLIGHT CHOSEN.	DISTRIBUTION TO CALCULATE INTER-TARGET FLIGHT TIME
	UNC, Km	0	0	NO TARGETS REQUIRE CREW SEARCH TO ACQUIRE
	OBL	YES	YES	OBLIQUITY PERMITTED FOR EFFICIENT ORBITAL ACCESS; NOT REQUIRED FOR AIRCRAFT
	FOV, DEG	UNCONSTRAINED	UNCONSTRAINED	NO USER REQUIREMENTS IMPOSED UPON SENSOR FOV - CONTROLLED BY M, RES
	LOS, DEG	15	15	OBLIQUITY OF 15° PERMITTED FOR EFFICIENT ORBITAL ACCESS; NOT REQ'D FOR AIRCRAFT
	RES, m	10 - 20	10 - 20	
	MOS	YES	YES	MOSAICING OF AIRCRAFT IMAGES PERMITTED FOR MULTI-FLIGHT-LINE CITIES
	CYC, DAYS	180 (2 COVERAGES REQ'D)	FOREST: 180 (2 COVERAGES); MINERALS: 90 (4 COVERAGES)	REPEAT CYCLE IS SEMI-ANNUAL FOR FOREST, URBAN REG. PLNG; QUARTERLY FOR MINERAL
	DUR, DAYS	90	90	COVERAGE FOR ONE CYCLE SHOULD BE COMPLETED RAPIDLY - 90 DAYS MAXIMUM
AIRCRAFT	V, Km/HR	800	800	TYPICAL OF MODERN, HIGH-ALTITUDE AIRCRAFT (U-2)
	H, Km	20	20	TYPICAL OF MODERN, HIGH-ALTITUDE AIRCRAFT (U-2)
	M, ELEMENTS	10,000	10,000	TYPICAL FOR 1980 MULTISPECTRAL SCANNER TECHNOLOGY (THEMATIC MAPPER)
	t, MIN	5	5	

missions in the contiguous 48 states with a 15° roll angle or less. Payload weight and other parameters (15), once judged compatible with Shuttle accommodations, are used to determine Individual Payload Ops Costs (16) for each flight. This result, when combined with the schedule of Shuttle flights, produces the Shuttle Operating Costs (17) for the set of flights considered. Shuttle Fixed Costs (18) are computed from acquisition costs for the sensor package(s) required to meet the flight schedule. The Total Shuttle Costs (19) are the sum of (17) and (18).

Although not included in this analysis, the model provides for calculating the Information Transfer Quantity (20) to determine communication relay costs between ground sites once the data is returned to earth.

7.4.2 COST ANALYSIS OF URBAN/REQUIRED PLANNING MISSION

The flight requirements for this operational mission are the imaging of the 160 U. S. cities with greater than 100,000 population (1970 Census used). Three coverages are required at 6-month intervals to obtain two-season and one-year change data.

For the aircraft platform, since the targets are (nearly) uniformly scattered over the U. S., the inter-target flight time between the 160 cities will comprise the majority of the flight hours required. The inter-target flight time may be expressed as:

$$T_I = \frac{N-1}{V} \left[\sqrt{\frac{AB}{N}} - LEN \right]$$

for a uniform field of targets, where

N = the number of targets

V = aircraft speed

A = the width of the field

B = the length of the field

LEN = the width (or length) of one of the targets (negligible)

For large N (>100) we may approximate N - 1 by N, yielding

$$T_I \cong \frac{\sqrt{ABN}}{V}$$

and the inter-target time becomes

$$T_I = \frac{\sqrt{2300 \times 5500 \times 160}}{800} = 56.25 \text{ hr/coverage}$$

It should be noted that inter-target flight time inefficiencies, such as avoidance of clouded-over targets or adjustments of location by night flight to achieve desirable lighting angles for the next day's flight path will occur in real operations. These are accounted for here by the inclusion of a 90% efficiency factor, yielding a total adjusted inter-target flight time of 61.8hr/coverage.

The flight time to image each target, on the average, is

$$T_{dc} = \frac{LEN}{V} = \frac{10}{800} = 0.0125 \text{ hr/target/coverage}$$

Thus, the total data collection time is

$$T_{oc} = 0.0125 \times 160 = 2 \text{ hr/coverage}$$

The climb and descent times of 0.75 hr each provide for a data collection or inter-target flight time of 5.5 hr/day for a 7-hour sortie. The total flight time is thus

$$T_T = \frac{7}{5.5} \left[61.8 + 2\right] = 81.2 \text{ hr/coverage}$$

or a total of 243.6 flight hours for the three-coverage mission.

The number of aircraft (and thus, wholly-owned sensor packages) required is found from

$$N_A = \frac{T_T}{DUR \times (5.5)} (1.1) = \frac{81.2}{90 \times (5.5)} (1.1) = 0.18 \text{ aircraft } (=1 \text{ aircraft})$$

It will be noted that this aircraft is underutilized by approximately a factor of five.

Table 7-7 contains the aircraft costs for performing the Regional/Urban Planning mission.

TABLE 7-7. AIRCRAFT COSTS FOR REGIONAL/URBAN PLANNING MISSION

THREE COVERAGES OF 81.2 FLIGHT HOURS EACH @ $1600/HR:	3 x 81.2 x 1600 =	$389,760
ONE SENSOR PACKAGE @ $3.5M		$3,500,000
OR		or
243.6 FLIGHT HOURS OF ONE SENSOR PACKAGE @ $700/HR		$170,520
TOTAL COST, WHOLLY-OWNED SENSORS		$3,889,760
TOTAL COST, AMORTIZING SENSORS		$ 560,280

Turning now to Shuttle operations costs for the Urban/Regional Planning Mission the sensor weights may be seen from Section 4 to total 335 Kg*. The conservative inclusion of 200 Kg of "overhead" weight is made to account for support subsystems and structure, yielding a total weight-to-orbit of 535 Kg. Thus, from the Straight-line Weight Cost Model, the costs are shown in Table 7-8:

TABLE 7-8. SHUTTLE COSTS FOR REGIONAL/URBAN PLANNING MISSION COMPUTED FROM STRAIGHT-LINE WEIGHT MODEL

535 Kg X $722/Kg** = 386,270 PER COVERAGE	
OPERATIONS COSTS FOR 3 COVERAGES = 1,158,810	
ONE SENSOR PACKAGE @ $6M = 6,000,000	
OR	
3 FLIGHTS OF SENSOR PKG	
@ $120,000/FLIGHT = 360,000	
TOTAL COST, WHOLLY-OWNED SENSORS	$7,158,810
TOTAL COST, AMORTIZING SENSORS	$1,518,810

The Multi-Element Cost Model approach produces results for the Regional/Urban Planning mission as shown in Table 7-9. It will be noted that no data processing or transmission are required of the Shuttle.

TABLE 7-9. SHUTTLE COSTS FOR REGIONAL/URBAN PLANNING MISSION COMPUTED FROM MULTI-ELEMENT COST MODEL

1.26 m^3 UP VOLUME @ $13,757	=	$ 17,333
335 Kg UP WEIGHT @ $108.81/Kg	=	$ 36,451
16.8 KWh ENERGY @ $1721/KWh	=	$ 28,912
30 hr. CREW TIME @ $6446/hr	=	$193,380
335 Kg DOWN WEIGHT @ $184.44/Kg	=	$ 61,787
PER FLIGHT COST		$337,863
OPERATIONS COST FOR 3 COVERAGES		$1,013,589
ONE SENSOR PACKAGE @ $6M		$6,000,000
OR		
3 FLIGHTS OF ONE SENSOR PACKAGE AT $120,000/FLIGHT		$ 360,000
TOTAL COST, WHOLLY-OWNED SENSORS		$7,013,589
TOTAL COST, AMORTIZING SENSORS		$1,373,589

*Comprised of 180 Kg for the TM and 155 Kg for the S190B.

**From straightline weight model No. 1 with $W_{TU} = W_{TD} = 14,500$ Kg and $U = 1.0$

7.4.3 COST ANALYSIS OF THREE COMBINED MISSIONS

The flight requirements of the three missions (Timber Volume Inventory, Urban/Regional Planning, Mineral Exploration Survey), when combined, involve five coverages of major areas of the U.S. as shown in Table 7-10.

TABLE 7-10. COVERAGE REQUIREMENTS FOR THE THREE JOINT MISSIONS

MISSION	SPRING YEAR #1	SUMMER YEAR #1	FALL YEAR #1	WINTER YEAR #1	SUMMER YEAR #1
TIMBER VOLUME INVENTORY		$3x10^6Km^2$		$3x10^6Km^2$	
URBAN/REGIONAL PLANNING		160 U.S. CITIES		160 U.S. CITIES	160 U.S. CITIES
MINERAL EXPLORATION SURVEY	$4x10^6Km^2$	$4x10^6Km^2$	$4x10^6Km^2$	$4x10^6Km^2$	-
TOTAL	$4x10^6Km^2$	$6x10^6Km^2$	$4x10^6Km^2$	$6x10^6Km^2$	160 U.S. CITIES

The aircraft operations costs for each of the first four coverages (the fifth is identical to that previously calculated) may be found from

O

$$T_{DC} = a\left(\frac{LEN}{V}\right) + (a-1)\,t + m\left(\frac{LEN + UNC}{V}\right) + t$$

where:

T_{DC} = data collection flight time
a = an algorithm-derived parameter indicating the number of individual flight lines;
a=93 for area = $6x10^6Km^2$,
a=62 for $4x10^6Km^2$
LEN = target length (6000 Km, approximate width of U.S.)
V = aircraft speed, 800 Km/hr
t = 180° turn time, 1/12 hr

$$T_{DC} = 93\left(\frac{6000}{800}\right) + \frac{92}{12} + \frac{1}{12} = 705.3 \text{ hr for area} = 6 \times 10^6 \text{ Km}^2$$

$$= 62\left(\frac{6000}{800}\right) + \frac{61}{12} + \frac{1}{12} = 470.2 \text{ hr for area} = 4 \times 10^6 \text{ Km}^2$$

As in the previous example, the total flight time is thus

$$T_T = \frac{7}{5.5}\left[T_{DC}\right] \begin{array}{l} = 897.7 \text{ hr for area } = 6 \times 10^6 \text{ Km}^2 \\ = 598.4 \text{ hr for area } = 4 \times 10^6 \text{ Km}^2 \end{array}$$

Making the simplifying assumption that the coverages of the U.S. cities are performed with only half the flight hours previously calculated when combined with the forest and/or minerals coverages, the total flight time required for all five coverages is obtained from:

Spring, year #1 - 598.4 hr
Summer, year #1 - 897.7 hr + 40.6 hr for U.S. cities
Fall, year #1 - 598.7 hr
Winter, year #1 - 897.7 hr + 40.6 hr for U.S. cities
Summer, year #2 - 81.2 hr.

Total Flight Time: 3154.6 hr.

The number of aircraft and, thus, wholly-owned sensor packages is obtained, as before, from

$$N_A = \frac{T_T}{DUR\,x(5.5)}\ (1.1) \cong 2 \text{ aircraft for a peak quarter of } 938.2 \text{ flight hours}$$

Table 7-11 contains the aircraft costs for performing the three joint missions.

TABLE 7-11. AIRCRAFT COSTS FOR THREE JOINT MISSIONS

3154.6 FLIGHT HOUR @ $1600	=	$ 5,047,360
2 SENSOR PACKAGES @ $3.5M	=	7,000,000
OR		
3154.6 FLIGHT HOURS OF SENSOR PACKAGES @ $700/hr	=	2,208,220
TOTAL COST, WHOLLY-OWNED SENSORS		$ 12,047,360
TOTAL COST, AMORTIZING SENSORS		7,255,580

The Shuttle costs by the Straight-line Model approach are contained in Table 7-12. The Shuttle costs by the Multi-Element Cost Model are contained in Table 7-13. A summary of the total costs for all mission for both platforms is contained in Table 7-14.

TABLE 7-12. SHUTTLE COSTS FOR THREE JOINT MISSIONS, STRAIGHT LINE WEIGHT MODEL

SPRING, YEAR #1	217 Kg + 130 Kg OVERHEAD @ $722/Kg	= $	250,534
SUMMER, YEAR #1	372 Kg + 222 Kg OVERHEAD	=	428,868
FALL, YEAR #1	217 Kg + 130 K OVERHEAD	=	250,534
WINTER, YEAR #1	372 Kg + 222 Kg OVERHEAD	=	428,868
SUMMER, YEAR #2	335 Kg + 200 Kg OVERHEAD	=	386,270
TOTAL OPERATIONS COSTS			$1,745,074
ONE SENSOR PACKAGE @ $6M OR 5 FLIGHTS OF SENSOR PACKAGE @ $120,000/FLIGHT		$6,000,000 OR $600,000	
TOTAL COST, WHOLLY-OWNED SENSORS			$7,745,074
TOTAL COST, AMORTIZING SENSORS			$2,345,074

TABLE 7-13. SHUTTLE COSTS FOR THREE JOINT MISSIONS, MULTI-ELEMENT COST MODEL

	SPRING YEAR #1	SUMMER YEAR #1	FALL YEAR #1	WINTER YEAR #1	SUMMER YEAR #1
UP VOLUME @ $13,757/m^3	1.12m^3-$15,408	1.26m^3-$17,333	1.12m^3-$15,408	1.26m^3-$17,333	1.26m^3-$17,333
UP WEIGHT @ $108.81/Kg	217Kg-$23,611	372Kg-$40,477	217Kg-$23,611	372Kg-$40,477	355Kg-$36,451
ENERGY @ $1721/KWh	10.8KWh-$18,586	16.8-$28,913	10.8-$18,586	16.8-$28,913	16.8-$28,913
CREWTIME @ $6446/hr	30 Hr-$193,380	30-$193,380	30-$193,380	30-$193,380	30-$193,380
DOWN WEIGHT @ $184.44/Kg	217Kg-$40,023	372-$68,612	217-$40,023	372-$68,612	335-$61,787
OPERATIONS COSTS	$291,008	$348,715	$291,008	$348,715	$337,864

TOTAL OPERATIONS COSTS	$1,617,310
ONE SENSOR PACKAGE @ $6M OR 5 FLIGHTS OF SENSOR PACKAGE @ $120,000	6,000,000 600,000
TOTAL COST, WHOLLY-OWNED SENSORS	$7,617,310
TOTAL COST, AMORTIZING SENSORS	$2,217,310

TABLE 7-14. SUMMARY OF AIRCRAFT AND SHUTTLE COSTS FOR THE SINGLE AND JOINT MISSIONS

TOTAL COSTS	URBAN/REGIONAL PLANNING MISSION	THREE JOINT MISSIONS
AIRCRAFT COSTS		
- WHOLLY-OWNED SENSORS	\$3,889,760	\$ 12,047,360
- AMORTIZED SENSORS	\$ 560,280	7,255,580
SHUTTLE COSTS		
- WHOLLY-OWNED SENSORS	\$7,158,810* 7,013,589**	\$ 7,745,074* 7,617,310**
- AMORTIZED SENSORS	\$1,518,810* 1,373,589**	\$ 2,345,074* 2,217,310**

*Straightline wt. model
**Multielement model

7.5 CONCLUSIONS: SHUTTLE COST EFFECTIVENESS

The use of a scanner and camera package on the Shuttle for the acquisition of medium resolution data is a cost-effective approach to gathering such data if the coverage rates are sufficiently high to offset the cost per flight of approximately one-half million dollars. For the comparison aircraft used in this analysis, the point at which the Shuttle becomes cost-effective lies between one and two million square kilometers per coverage, as shown in Figure 7-2. (It should be noted that the comparison aircraft used is itself a very, efficient data acquisition platform when compared to lower-performance aircraft in widespread commercial use today and that the crossover point for Shuttle cost-effectiveness would occur substantially sooner if it were compared to the latter aircraft).

The data acquisition cost savings which the use of the Shuttle would provide for the set of three typical operational resource management investigated is approximately \$5 million for a series of five coverages of substantial portions of the U.S. over a period of 15 months. The savings would increase further if additional demand were generated for additional area to be covered during the flights, that is, if more than three resource management missions were served simultaneously. A data processing cost comparison was not performed; however the Shuttle would afford additional savings in this area because of the greater orthographicity of its images and the smaller number of mosaics which would need to be prepared.

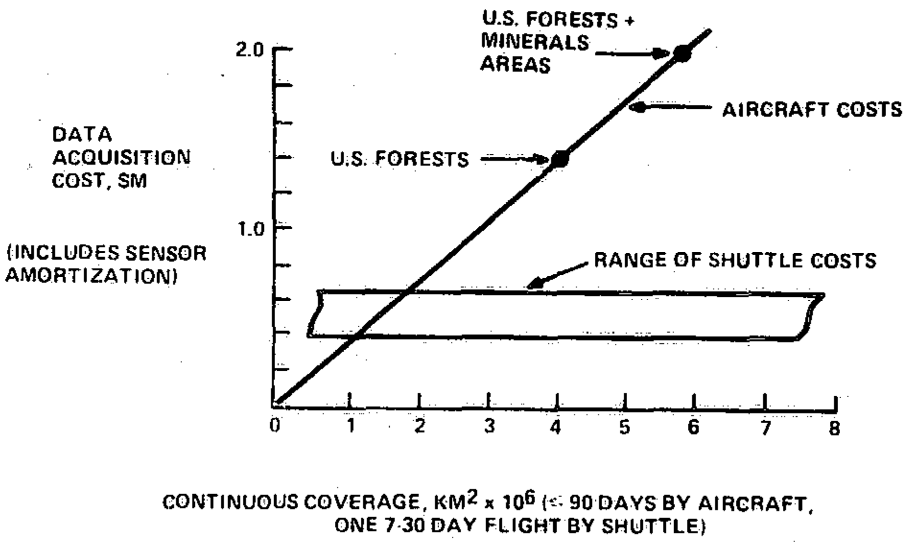


Figure 7-2. Comparison of Shuttle Sortie and Aircraft Data Acquisition Costs for Varying Coverages

Significant questions regarding cost-effectiveness of the Shuttle remain to be answered: transportation charging schedules are yet in a state of flux, Shuttle's ability to maneuver to avoid critical cloud obscurations, and yet serve its other payloads operationally, is a problematical question, and the details of converting the flight prototype Thematic Mapper for use on Shuttle have not yet been analyzed by ourselves or the sensor contractors in detail. But the conclusion is inescapable that, in its element and with strict attention to controlling costs, the Shuttle can cost-effectively fill the gap between the polar satellites and the aircraft in the 1980's.

SECTION 8

SHUTTLE EARTH RESOURCES PROGRAM DEVELOPMENT REQUIREMENTS

As a result of this study several items were identified as requiring further development in order that the Shuttle Earth Resources program may proceed in an orderly manner. These development items can be considered in three categories:

- Programmatic development requirements
- Mission Development requirements
- Shuttle Systems integration development requirements

8.1 PROGRAMMATIC DEVELOPMENT

The major programmatic development requirement is the need for users and potential users to be exposed to the capabilities of the Shuttle-borne sensors and to data acquired from equivalent systems.

This action is necessary to verify the utility potential of Shuttle missions, to catalyze demand for the data, and to provide users with a level of background experience so that they are ready to make full use of Shuttle-acquired data when it becomes available. A further potential benefit is increased user involvement in mission design, with the concomitant increase in confidence in, and commitment to, the Shuttle Earth Resources Program.

8.2 MISSION DEVELOPMENT REQUIREMENTS

As a result of the detailed definition of the five selected missions in this study, several areas needing additional development have been identified.

8.2.1 SOIL MOISTURE TECHNIQUE DEVELOPMENT

The extension of present day soil moisture measurement investigations into the Shuttle Era as a Technique Development Mission requires the accomplishment of several years of technological advances. It is apparent that to transition efficiently into the Shuttle Era, a well coordinated development plan with reasonable objectives is required. This plan must lay the groundwork upon which the first Shuttle flights for soil moisture techniques will be built. It includes continued aircraft flights, closer coordination and feedback between users and conducting agencies, and even new sensors and combination of sensors as first stage investigations. The development program is shown schematically in Figure 8-1.

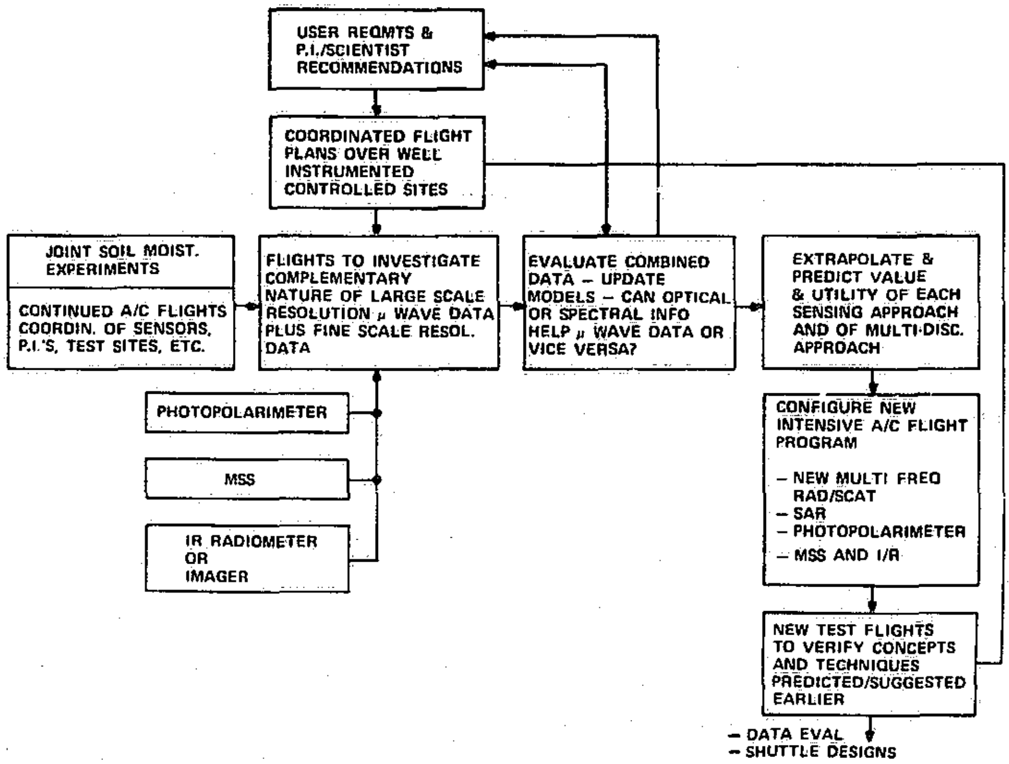


Figure 8-1. Soil Moisture Development Program

The most important "next step" in the development process is the continuation of aircraft flights using microwave and visible wavelength sensors, similar to those proposed for the Shuttle, in order to gain further insight into the detailed needs of the mission in both sensor requirements and data analysis.

8.2.2 SAR DEVELOPMENT MISSION

The primary problems in the development of the SAR Sensor Development mission are related to the detailed design of the sensor and to its integration into the Shuttle vehicle. Figure 8-2 shows the sensor development plan.

In particular, the investigation of integration of the SAR into its carrier vehicle and the development flight program alternatives should receive attention in parallel with the current sensor design efforts. Both integration into Shuttle and the development flight approach ultimately selected (all-up first flight- vs. evolutionary) will impact the sensor design, program funding levels, and ultimate program completion date.

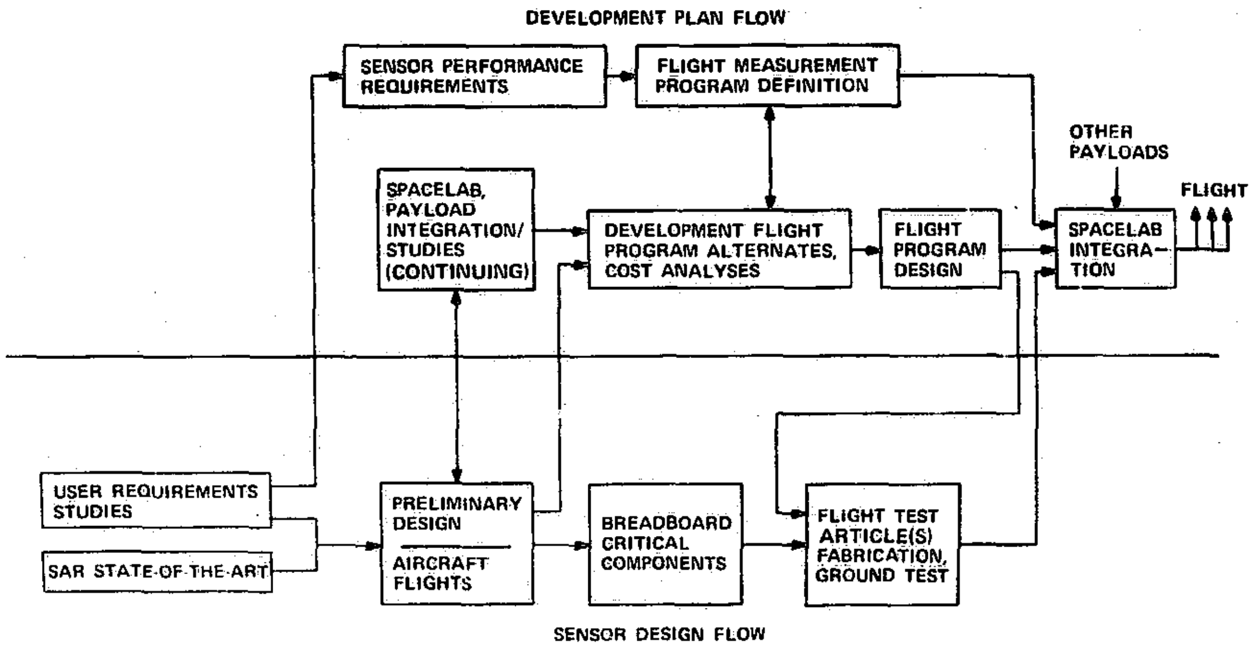


Figure 8-2. SAR Development Plan

8.2.3 APPLICATION DEVELOPMENT MISSIONS

Figure 8-3 shows diagrammatically the developmental activities required for the three missions, and Table 8-1 describes the detailed development requirements for each of the missions, together with the key "next step".

8.3 SHUTTLE SYSTEMS INTEGRATION REQUIREMENTS

Several developmental problems have been identified in the area of overall Shuttle system design and integration:

- Further design definition is required for a multispectral scanner/camera package based on the Thematic Mapper and S190A/B cameras

- Integration of SAR into the Shuttle will present significant problems in EMI (especially with passive microwave systems) cargo bay blockage, deployment operations and thermal considerations.

- SIMS and SAR integration must be undertaken in parallel with the development of these sensors so that a compatible, two sensors complementary package may be developed.

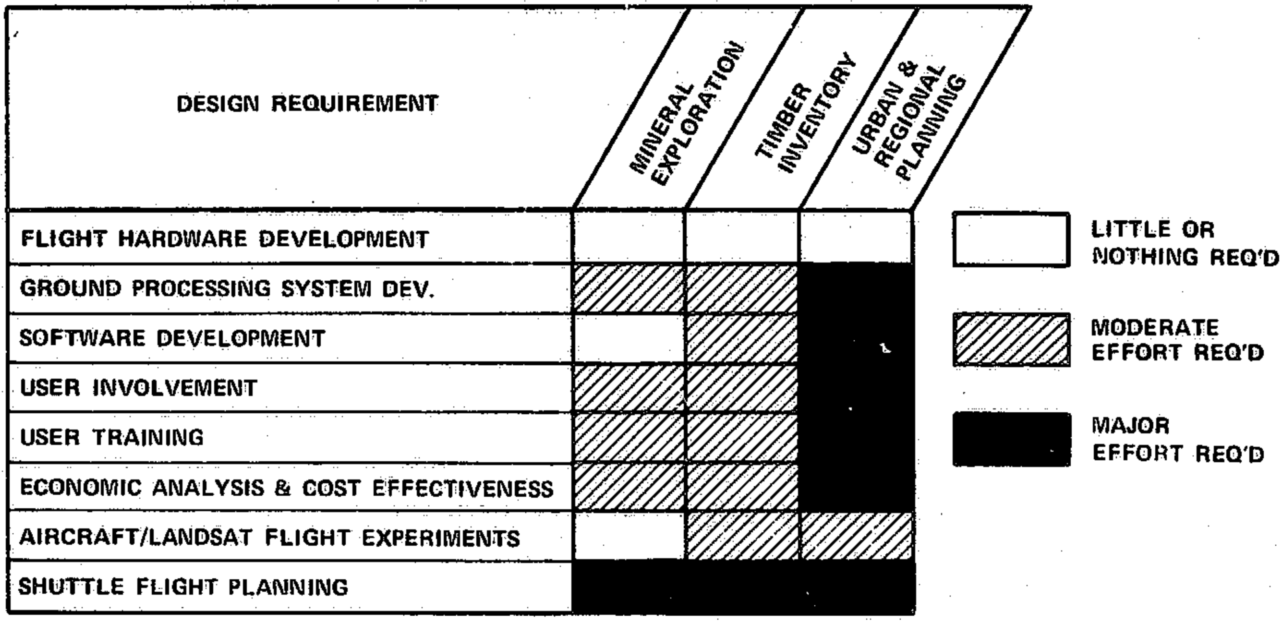


Figure 8-3. Application Development Mission Plans

- Detailed definition and development of a Shuttle Earth Resources Data processing facility is required, with special emphasis on the coordination and correlation of photographic and electronic image data processing methods, and the complementary application of the two data types.

TABLE 8-1. APPLICATION DEVELOPMENT PLANS

<u>TIMBER INVENTORY</u>
• Develop sampling and stage selection strategies and statistics
• Evaluate number of sampling stages
• Involve user (U. S. Forest Service) and prepare to process/use data
• Run A/C & Landsat based experimental measurement program
• Use U2/RB57 to gather data at equivalent resolutions to Shuttle sensors.

TABLE 8-1. APPLICATION DEVELOPMENT PLANS (Continued)

TIMBER INVENTORY (Cont'd) • Investigate optimal resolution requirements for each sampling stage. NEXT STEP: - Get U. S. Forest Service involved in Shuttle and Mission Design
MINERAL EXPLORATION • Continue to prepare user community to use data operationally • Introduce users to Shuttle scanner and film imagery characteristics • Set up user training facility/program using simulated Shuttle data • Establish data dissemination procedures • Define procedures for foreign user involvement • Develop improved methods/hardware for combining digital & photo interpretive analysis techniques NEXT STEP: - Develop user training program
URBAN & REGIONAL PLANNING • Identify data processing/dissemination agency • Identify planning parameters of importance and rank importance, difficulty to accomplish • Involve planners of selected cities in mission design • Establish coverage cycles etc. • Use A/C & LANDSAT data to establish classification themes • Develop user knowledge of/confidence in techniques • Develop standard products & archival/data base method(s) suitable for user community. NEXT STEP: - Involve city planners in Shuttle mission design.

APPENDIX A

THE MULTISTAGE PROBABILISTIC SAMPLING PROCESS

The inventory system currently used by the U.S. Forest Service, called the Continuous Forest Inventory - CFI, involves a two-stage sampling scheme with partial replacement. In the first stage a large number of points or plots are distributed on aerial photographs. Each point is photointerpreted and assigned to a photo-volume stratum based on the estimated volume of timber on the acre surrounding the point. A subsample of these points from each volume stratum are selected for ground examination. The subsample points are selected with probability proportional to the estimated volume of each stratum. The second phase consists of ground measurements of all the selected ground plots using conventional timber cruising techniques. Information from both phases (photo and ground) is then combined to yield total current volume and other statistics.

The aerial photographs used by the U. S. Forest Service are at a scale from 1:12,000 to 1:20,000. The entire inventory system is very time consuming and costly.

Several experiments demonstrated that use of Landsat data increased the accuracy and timeliness of timber inventory. One such experiment was performed by J. Nichols of the University of California. The objective of the experiment was to estimate the standing volume of merchantable timber within the Quincy Ranger District (215,000 acres) of the Plumas National Forest. A three-stage sampling design was used whereby the first-stage involved automatic classification of Landsat 1 data tapes and selection of primary sampling units. The second-stage involved acquisition of large scale aerial photos over selected primary sampling units and selection of photo plots based on manual interpretation. The third-stage required visiting the selected photo plots on the ground and selection of trees to be measured for timber volume.

Nichols and other investigators, after their limited studies, concluded that multistage inventory using satellite imagery for the first stage proved to be a timely, cost-effective alternative to conventional timber inventory techniques. They also concluded that to arrive at an operational stage for such an inventory system, additional research is necessary.

Sampling may be defined as obtaining information from a portion of a larger group, or "universe", about the entire group.

Multistage sampling consists of selecting primary sampling units at the first stage and drawing a series of subsamples from these for sampling in subsequent stages. The procedure is shown diagrammatically in Figure A-1.

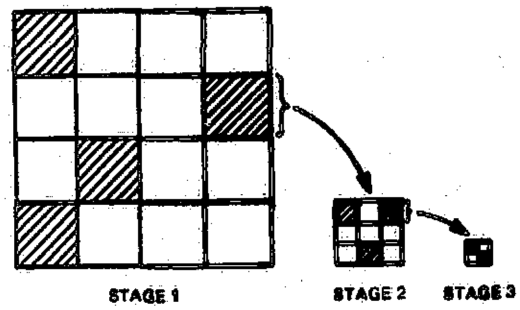


Figure A-1. Diagrammatic Representation of Multistage Sampling

For the purpose of this discussion, a three-stage inventory system will be assumed. Units in the first stage will be called the primary sampling units (PSU), units in the second stage will be sample plots, and in the third stage - sample trees.

To estimate volume in plot j of PSU i

$$\widehat{V}_{ij} = \frac{1}{K}\left(\frac{V_{ij1}}{P_{ij1}} + \dots\dots + \frac{V_{ijK}}{P_{ijK}}\right)$$

Where V_{ijl} - volume of sample tree l

K - number of sample trees

P_{ijl} - sampling probability of sample tree l (of plot j of PSU i)

To estimate volume in PSU i

$$\widehat{V}_i = \frac{1}{J}\left(\frac{\widehat{V}_{i1}}{Q_{i1}} + \dots\dots + \frac{\widehat{V}_{iJ}}{Q_{iJ}}\right)$$

Where J - number of sample plots

Q_{il} - sampling probability of sample plot l (of PSU i)

To estimate total forest volume

$$\widehat{V} = \frac{1}{I}\left(\frac{\widehat{V}_1}{R_1} + \dots\dots + \frac{\widehat{V}_I}{R_I}\right)$$

Where I - number of sample PSUs

R_i - sampling probability of sample PSU i

To choose best probability at each stage (P, Q, R) compute

$$\mathrm{Var}\,(\widehat{V}_{ij}) = \Sigma\, P_{ijk}\left(\frac{V_{ijk}}{P_{ijk}} - V_{ij}\right)^2$$

This equals zero if $P_{ijk} = \frac{V_{ijk}}{V_{ij}}$. An estimate V^*_{ijk} of V_{ijk} is used to estimate a $P^*_{ijk} = \frac{V^*_{ijk}}{V_{ij}}$. It is desired to have V^*_{ijk} "close" to V_{ijk}. The same procedure applies to Q_{ij} and R_i.

To arrive at a least expensive sampling scheme the estimation method has to be optimized. Given here is an example of a cost model. Assumptions are the same as in the previous paragraphs.

Cost Model

$$C_T = C_I + (C_{PSU})\, I + (C_{Plot})\, JI + (C_{Tree})\, KJI$$

Where C_T – total inventory cost

C_I – initial cost – overhead

C_{PSU} – cost of a single PSU

C_{Plot} – cost of a single plot

C_{Tree} – cost of ground measurement of a single tree

Minimize:

$$\mathrm{Var}\,(\widehat{V}) = f\,(I,\ J,\ K,\ .\ .\ .\ .)$$

Result of this is a function of the number of samples at each stage (I, J, K), and of many other factors. Some such factors are: variability of timber volume throughout the forest, accuracy of imagery and measurements at each stage, size of PSU's and plots, number of stages, and others.

Minimizing is done subject to fixed cost C_T. Such a general formula can be obtained by extending standard theory.

Example:

For equal sampling probabilities at each stage and same number of trees per plot

$$\mathrm{Var}\,(\widehat{V}) = (I_o, J_o, K_o)^2 \left[\left(1 - \frac{I}{I_o}\right) \frac{S^2_{\text{PSU Totals}}}{I} + \left(1 - \frac{IJ}{I_o J_o}\right) \frac{S^2_{\text{Plots totals}}}{IJ} + \left(1 - \frac{IJK}{I_o J_o K_o}\right) \frac{S^2_{\text{Trees}}}{IJK} \right]$$

Where I_o, J_o, K_o are population numbers at each stage, and I, J, K are sample numbers.

S^2_{PSU} – Variance among the PSU total timber volumes (each PSU has a total volume)

S^2_{Plots} – The average variance between plots (i.e., calculate a variance among the plots within each PSU and average those variances over the I_o PSU's)

S^2_{Trees} – The average variance between trees in a plot – averaged over all plots and PSU's.

Var $(\widehat{V})$ is minimized by

$$K^* = \frac{S_{trees}}{\left[S^2_{plots} - (S^2_{trees}/K_o)\right]^{1/2}} \left[\frac{\text{Cost per Plot}}{\text{Costs per Tree}}\right]^{1/2}$$

$$J^* = \frac{\left[S^2_{plots} - (S^2_{trees}/K_o)\right]^{1/2}}{\left[S^2_{PSU} - (S^2_{plots}/M_o)\right]^{1/2}} \left[\frac{\text{Cost per PSU}}{\text{Cost per Plot}}\right]^{1/2}$$

$$I^* = (C_I - C_I)\,[\text{PSU Cost} + \text{Plot Cost x } J^* + \text{Tree Cost x } J^* K^*]$$

subject to fixed cost (model above) and choices of PSU and plot sizes. This shows how the best I^*, J^*, K^* depend on costs in each stage and on forest statistics S^2_{Trees}, S^2_{plot}, S^2_{PSU}, which must be obtained.

The example does not show how Var $(\widehat{V})$ depends on the accuracy of P^*_{ijk}, Q^*_{ij}, and R^*_i. The theory can be extended to cover the more general problem.

The accuracy of the P^*_{ijk}, Q^*_{ij}, and R^*_i depends on volume estimates from methods with different image qualities. The effect of different image sources on Var $(\widehat{V})$ needs to be determined.

Comparison of Figures A-2 and A-3 demonstrates the necessity of accuracy vs the cost of imagery trade-offs. To obtain higher accuracy of volume estimation it is necessary to pay higher costs (Figure A-2). Lower resolution imagery is less expensive, but gives less accuracy, i.e., points in Figure A-3 are spread farther away from the 45° line. This is a very important factor in determining the optimum sampling system and should be considered in more detail.

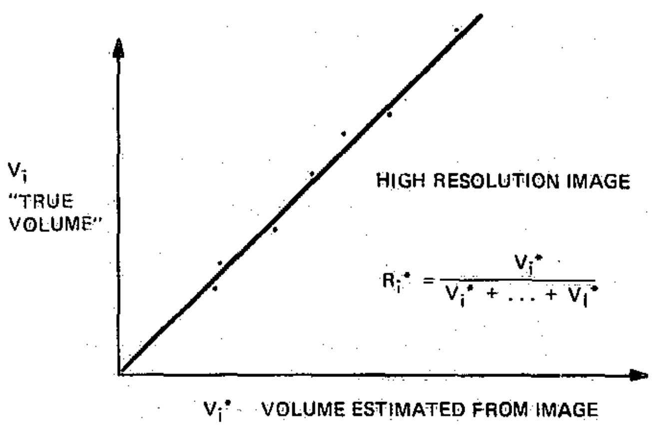


Figure A-2. True Volume vs. Volume Estimated from a High Resolution Image

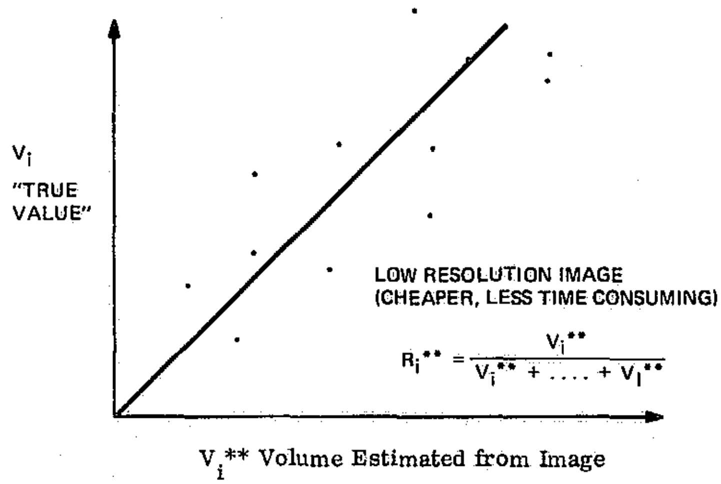


Figure A-3. True Volume vs. Volume Estimated from a Low Resolution Image

APPENDIX B

ADDITIONAL REFERENCES

TIMBER VOLUME INVENTORY

Avery, Eugene T., Forest Measurements, McGraw Book Co., New York

The Outlook for Timber in the United States, Forest Service Report No. 20, Forest Service, U.S. Department of Agriculture, U.S. Government Printing Office, Washington D. C. July 1974.

Committee on Remote Sensing for Agricultural Purposes, Remote Sensing with Special Reference to Agricultural and Forestry, National Academy of Sciences, Washington, D.C. 1970

Nichols, James D. et al, A Timber Inventory Based upon Manual and Automated Analysis of ERTS-1 and Supporting Aircraft Data using Multistage Probability Sampling, Third Earth Resources Technology Satellite-1 Symposium, Washington, D.C. December 1973.

Langley, Phillip G., Multistage Sampling of Earth Resources with Aerial and Space Photography, National Aeronautics and Space Administration - SP-275, Greenbelt, Maryland 1972.

What the Forest Service Does, U.S. Department of Agriculture, Forest Service, U.S. Government Printing Office, Washington, D.C. October 1973.

Cochran, W.G. 1953 Sampling Techniques, John Wiley and Sons, New York, N.Y.

MINERAL EXPLORATION SURVEY

Abdel-Gawad, and J. Silverstein, 1973, "ERTS applications in earthquake research and mineral exploration in California", ERTS-1 Symposium, March 73, 433-450.

Baker, R., 1974, "ERTS updates geology", GEOTIMES, v. 19, n. 8 20-22. and Smith, "Conventional and advanced interpretative techniques applied to ERTS-1 data: a new tool for the geologist", Bull. Assoc. Eng. Geol., v. XII, n. 2, 9-35. May 1975. 1975, "Total Earth Resources System of the Shuttle Era-Mineral Resources Exploration Mission" General Electric Co. report NAS 9-13401.

Beccasio, D., 1973, Application of correlative spacecraft and aircraft remote sensor imagery for operational mineral resources exploration, Proceedings, 6th Symposium on Remote Sensing of the Environment, University of Michigan, Ann Arbor, 213-214.

Carter, W., 1971, ERTS-A, a new apogee for mineral finding, Mining Engineering, May 1971 51-54.

Cole, M. and E. Jones, "Remote sensing in mineral exploration", in Environmental remote sensing, E. Barret, ed., Edward Arnold Publishers, LTD, 1974, 49-67.

Jensen, M., 1973, "Geology of Utah and Nevada by ERTS-1 imagery", ERTS-1 Symposium, March 73, 247-256.

Knepper, D., 1974, NASA/ERTS investigation No. 10260, type II progress report, reported at December 74 ERTS-1 Symposium, paper G 14 by S. Nicolais.

Lasky, 1950, Mineral Resources appraisal by the U.S. Geological Survey, Colorado School of Mines Quarterly, v. 45 (1-A) 1-27.

Lathram, E., 1974, "Geologic application of ERTS-1 imagery in Alaska", ERTS-1 Symposium, December 1974, paper G 31 1-12.

Lovering, T., 1969, Mineral Resources from the Land, in Resources and Man, National Academy of Sciences, W. H. Freeman, Inc. publishers.

Lowman, P., 1972, "ERTS-1 in orbit" GEOTIMES, v. 19, n. 9, September 1972.

Lyon, R. and K. Lee, 1970, "Remote sensing in exploration for mineral deposits, ECONOMIC GEOLOGY, v. 65, 785-800.

National Academy of Sciences, Resources and Man - Committee on Resources and Man, National Research Council, W. H. Freeman, Inc., 1969.

Rowan, L., P. Wetlaufer, A. Goetz, F. Billingsley and J. Stewart, 1975, Discrimination of rock types and altered areas in Nevada by the use of ERTS images, U.S.G.S. prof. paper 883, U.S. Gov. pringing office.

Schmidt, R., 1973, "Use of ERTS images in the search for porphyry copper deposits in Pakistani Baluchistan" ERTS-1 Symposium, March 73 387-395.

Short, N., 1973, "View from 570 miles", GEOTIMES, v. 18, n. 5, May 1973. and P. Lowman, 1973, Earth observations from space: outlook for the geological sciences, NASA/GSFC paper X-650-73-316, Greenbelt, Md.

Sisselman, R., "Spotting minerals via satellite", Engineering and Mining Journal, May 1975, (McGraw Hill, publishers) pages 87-95.

Skinner, B., 1969, Earth Resources, Foundations of earth science series, Prentice-Hall, publishers, Englewood Cliffs, N. J.

Strahler, A., 1973, Environmental Geoscience, John Wiley & Sons, Santa Barbara, California.

U.S. Geological Survey booklet INF-67-2(R-6), Suggestions for prospecting, U.S. gov. printing office, Washington, D.C. 20402.

Viljoen, M., 1973, "ERTS-1 imagery as an aid to the definition of the geotectonic domains of the southern African crystalline shield", ERTS-1 Syn posium, March 1973, paper G-26 483-493.

URBAN REGIONAL PLANNING

Council of State Governments., Data Needs and Resources for State Land Use Planning. Land Use Policy and Program Analysis, No. 2. Lexington, Ky.: Council of State Governments, 1974.

Schechter, B., "A Rationale for Institutional Responsibilities and Technical Methodology". Paper prepared for the National Symposium on Resource and Land Information, Reston, Virginia, 1973.

U.S. Dept. of Agriculture, "Our Land and Water Resources Current and Prospective Supplies and Ages", Economic Research Service Miscellaneous Publication No. 1290, 1974.

Delaware Valley Regional Planning Commission, "Regional Planning Information System - Land Use Pilot Project", Regional Information Series No. 4, April, 1972.

Simpson, Robert B., et al, "Investigation of Land Use of Northern Megolopolis Using ERTS-1 Imagery", NASA CR-2459, 1974.