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Contract No. NAS8-32047

PAYLOAD SOFTWARE TECHNOLOGY

MIDTERM REPORT

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Prepared for:

George C. Marshall Space Flight Center
NASA
Marshall Space Flight Center, Alabama 35812

M&S COMPUTING, INC.

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1. INTRODUCTION

The purpose of this report is to document the midterm results of the Payload Software Technology Study performed by M&S Computing for the Marshall Space Flight Center under Contract No. NAS8-32047.

During the completed part of this study, two main tasks were performed. First, a software analysis was performed of known STS sortie payload elements and their associated experiments. This provided basic data for STS payload software characteristics and sizes. Secondly, a set of technology drivers was identified based on a survey of future technology needs and an assessment of current software technology.

During the remainder of the study, the results derived to date will be used to evolve a planned approach to software technology development. The purpose of this plan is to ensure that software technology is advanced at a pace and a depth sufficient to fulfill the identified future needs.

This report is organized into seven sections as summarized in Table 1-1. Section 2 provides the executive summary and is adequate to obtain an overview of the results obtained to date. The sequence of the remaining sections generally reflects the sequence of tasks performed during this phase of the study.

MIDTERM REPORT OUTLINE

SECTION 1 - INTRODUCTION DESCRIBES THE PURPOSE OF THIS REPORT, THE STATUS OF THE STUDY, AND THE MANNER IN WHICH THIS REPORT IS ORGANIZED.

SECTION 2 - STUDY SUMMARY IS THE EXECUTIVE SUMMARY.
2.1 OBJECTIVES DESCRIBES THE PURPOSE AND SCOPE OF THE STUDY.
2.2 APPROACH DESCRIBES THE STUDY PLAN USED AND THE ASSOCIATED MAJOR MILESTONES.
2.3 RESULTS SUMMARIZES THE RESULTS OF THE STUDY.

SECTION 3 - PAYLOAD SELECTION DESCRIBES THE RATIONAL FOR SELECTION OF THE SPECIFIC COMPLEMENT OF EXPERIMENTS ANALYZED DURING THE STUDY.

SECTION 4 - SPACE TECHNOLOGY FORECASTS REVIEW DESCRIBES THE IDENTIFICATION AND CLASSIFICATION OF SOFTWARE TECHNOLOGY AREAS SELECTED FOR EMPHASIS.

SECTION 5 - EXPERIMENT ANALYSIS DESCRIBES THE APPROACH AND MATERIAL USED TO PERFORM THE EXPERIMENT ANALYSIS AND SUMMARIZES THE RESULTS.

SECTION 6 - TECHNOLOGY DRIVER SELECTION SUMMARIZES THE TECHNOLOGY DRIVERS SELECTED AND THE REASONS FOR THEIR SELECTION.

SECTION 7 - FUTURE PLANS DESCRIBES THE EFFORTS REMAINING TO BE PERFORMED UNDER THIS CONTRACT.

APPENDIX A - MISCELLANEOUS

APPENDIX B - SOFTWARE FUNCTIONS PROVIDES A COMPLETE DESCRIPTION OF THE DERIVED EXPERIMENT SOFTWARE FUNCTIONS AND THEIR SIZING PARAMETERS.

APPENDIX C - EXPERIMENT ANALYSIS SHEETS CONTAINS SHEETS FOR EACH ANALYZED PAYLOAD ELEMENT AND THEIR ASSOCIATED EXPERIMENTS DESCRIBING MAJOR COMPONENTS, DATA CHARACTERISTICS, AND FUNCTIONS TO BE PERFORMED.

APPENDIX D - SOFTWARE ANALYSIS MASTER MATRIX

Table 1-1

2. STUDY SUMMARY

This section provides a brief review of the study and a summary of the results to date. Section 2.1 describes the intended objectives of the study. Section 2.2 explains the methods used. Section 2.3 summarizes the results.

2.1 Objectives

The prime objective of this study is to define programmatic requirements for the advancement of software technology required to enhance future space applications. Future space applications are those planned or desired to be operational towards the end of the century.

Although it is recognized that software technology requirements are likely to exist for ground as well as on-board facilities, the scope of this study primarily addresses on-board software technology. It is expected that a similar effort will be performed at a later date for ground-based software technology.

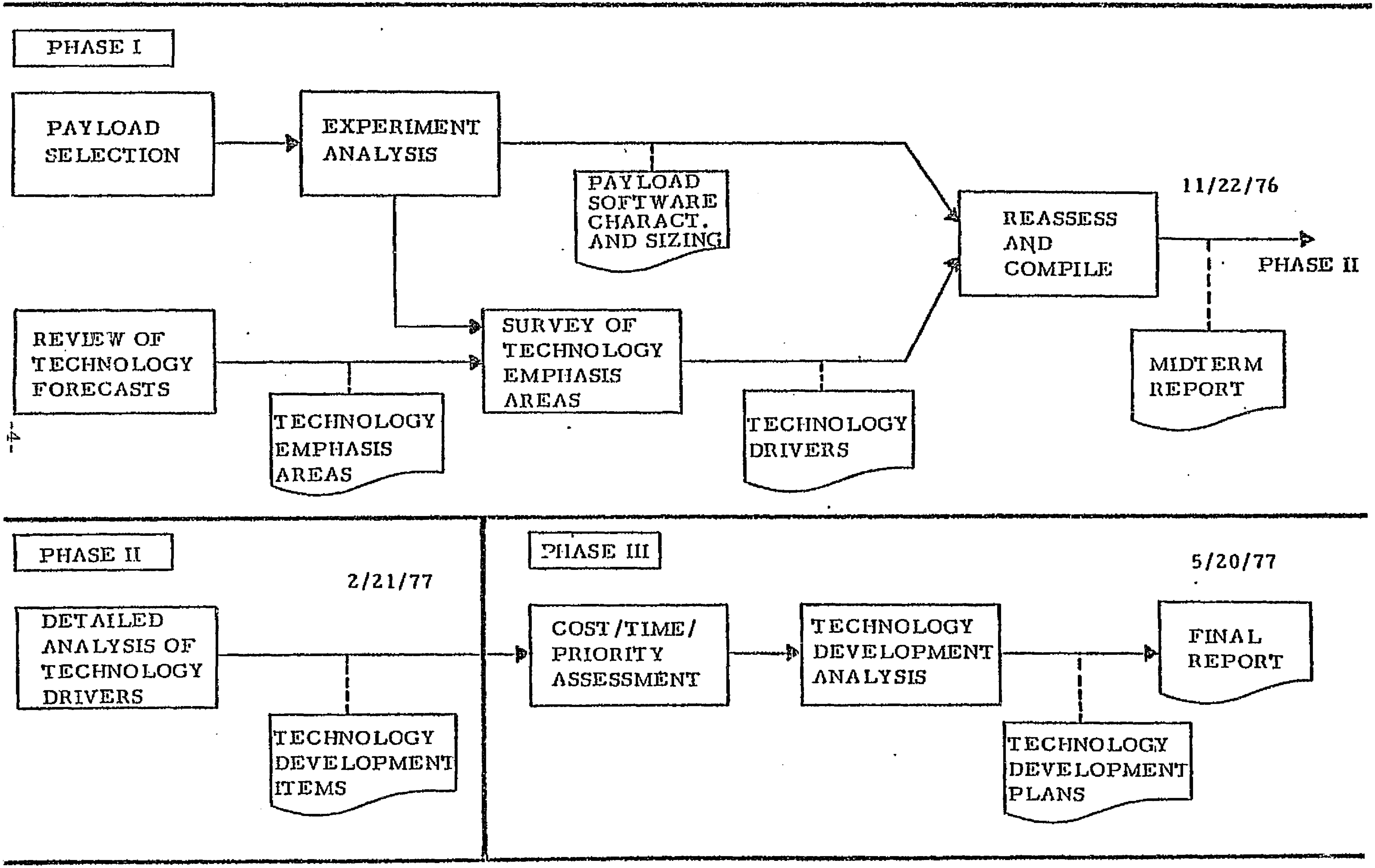
The technology development plans resulting from this study must be implementable during the 1980's in order to meet the requirements in the 1990's. It is assumed, for this study, that the primary development vehicle during this time will be the Space Transportation System. Therefore, payload analyses performed during this study will be limited to those payloads currently planned to be carried on the Space Transportation System.

Finally, it should be noted that we are primarily concerned with software technology; not with computer systems technology. No attempt was made to analyze future Data Management Systems, as a whole, to drive out technology requirements. Such an effort certainly has merit, and might result in software technology requirements; however, many software technology requirements can be identified without an end-to-end data management analysis, and that is the road which we elected to follow.

2.2 Approach

As shown in Figure 2-1, the study consists of three consecutive phases. The purpose of the first phase was to identify technology drivers, i.e., major areas of concern and technology problems to be solved. Two types of analysis were performed during this phase: an analysis of a set of known experiments to identify significant software functions with their complexities and sizing; and, concurrently with that analysis, a technology survey was performed to identify the potential future technology needs of experiments. The results of these analyses are combined and summarized into a set of Technology Drivers.

PAYLOAD SOFTWARE TECHNOLOGY
STUDY PLAN



PHASE I
PAYLOAD SELECTION
EXPERIMENT ANALYSIS
PAYLOAD SOFTWARE CHARACT. AND SIZING
REASSESS AND COMPILE
11/22/76
PHASE II
MIDTERM REPORT
REVIEW OF TECHNOLOGY FORECASTS
TECHNOLOGY EMPHASIS AREAS
SURVEY OF TECHNOLOGY EMPHASIS AREAS
TECHNOLOGY DRIVERS
PHASE II
2/21/77
DETAILED ANALYSIS OF TECHNOLOGY DRIVERS
TECHNOLOGY DEVELOPMENT ITEMS
PHASE III
COST/TIME/ PRIORITY ASSESSMENT
TECHNOLOGY DEVELOPMENT ANALYSIS
5/20/77
FINAL REPORT
TECHNOLOGY DEVELOPMENT PLANS

Figure 2-1

During the second phase, these Technology Drivers are further analyzed to identify possible Technology Items. A Technology Item is an identified technology development program to resolve one or more aspects of a Technology Driver.

Of course, alternate Technology Items may be identified for one Technology Driver. Also, the total number of Technology Items identified may be impossible to implement within the resource constraints. Therefore, during this phase, cost estimates and priorities are assigned to the Technology Items.

The result of the third phase will be a recommended set of Software Technology Development Planning Guidelines. These are obtained through evaluation and selection of the most cost effective set of Technology Items. This selection depends upon cost, priority, interrelationships between the Technology Items, and dependencies on other technologies.

Additional detail for each of these phases is provided in the appropriate sections in the remainder of this report.

2.3 Results Summary

The set of Technology Drivers resulting from Phase I is listed in Table 2-1. At this point, the Technology Drivers associated with Software Development must be considered the most important. Unless significant improvements are made in this area, all other related technologies will be stunted because the associated software will be too costly and/or too unreliable.

In Software Systems Architecture, most of the Technology Drivers are related to LSI technology; i.e., the availability of very low-cost processing systems. These systems are particularly suitable for on-board usage and therefore receive significant emphasis during this study.

The remaining Technology Drivers are primarily based on anticipated increases in on-board processing of image type data, as well as on anticipated increases in the rates of data to be acquired.

Some other conclusions that can be drawn from the results to date are the following:

1. Currently planned experiments, with few exceptions, do not project a significant use of on-board data management system capabilities.

TECHNOLOGY DRIVER SUMMARY

o SOFTWARE DEVELOPMENT:
- SOFTWARE DESIGN ENGINEERING
- TREND TOWARD S/W DEVELOPMENT BY NON-PROGRAMMERS
- FAULT-FREE SOFTWARE
- APPLICATION ORIENTED LANGUAGE DESIGN METHODOLOGY
- LOW COST DEVELOPMENT OF AOL COMPILERS

o SOFTWARE SYSTEMS ARCHITECTURE:
- (DISTRIBUTED) SYSTEM PARTITIONING/ INTERCONNECTION TECHNIQUES
- VERY LARGE STORAGE ACCESS SIMPLIFICATION
- SOFTWARE FAULT (OWN OR INDUCED) DETECTION
- SOFTWARE RECOVERY (AFTER FAULT DETECTION)
- HIGH-SPEED BUFFERING TECHNIQUES
- DESIGN AND CONTROL OF ADAPTIVE SOFTWARE PROCEDURES.

o SOFTWARE APPLICATIONS:
- USE OF "NATURAL" COMMUNICATION METHODS
- EFFICIENT LARGE ARRAY SEARCH AND SORT PROCEDURES
- PARALLEL PROCESSING TECHNIQUES
- EFFICIENT LARGE ARRAY MANIPULATION PROCEDURES.

Table 2-1

This is to some extent due to the known limitations of the Baseline Spacelab-Data Management System, but probably even more so it is due to traditional approaches and/or fears of integration problems. It does point to a significant "application technology gap" between computer system usage in the early 80's and what is anticipated to be needed in the 90's.

2. The currently planned Spacelab Data Management System is not adequate for technology development.

Because various cost constraints have been imposed on Spacelab, the data management system is relatively limited in its capabilities. This became obvious as we analyzed potential uses of on-board software. These limitations will probably not be of significance during support of the early years of flight, but the limitations will create a major shortcoming in the late 80's because of the constraints placed on technology development.

3. No "esoteric" software technology requirements were identified.

No surprising requirements were uncovered during the first phase of the study. Nevertheless, it will not be a simple effort to derive an effective technology development plan. Many of the significant requirements have been under study before, and technology advancements have been previously attempted with little tangible success. The real key to satisfactory results from this study will lie in the recognition of imaginative, realizeable technology development items.

3. PAYLOAD SELECTION

The purpose of this task was to select applications which, through analysis, could yield information relevant to this study. Advanced space missions are currently not defined in sufficient detail to allow relatively quick identification of software technology development requirements. Therefore the emphasis of this study is on potential subsets of future payloads, i.e., payload elements.

Certain practical criteria were established to guide the initial payload selection process. These were:

- Data availability.
- U. S. experiments only.
- Broad instrument mix and varied output forms.

To obtain broad coverage, the Shuttle Sortie Payload Descriptions (July 1975), Level B, were selected as the starting point. Data availability for these payload elements is still a major problem but a portion of the problem was resolved during the subsequent task through various means such as comparison to similar instrumentation types, extrapolation of data rates for increasing resolution criteria and surveys of state-of-the-art detectors and sensor technology.

The payload elements which were analyzed in sufficient detail to yield useful data are listed in Table 3-1.

PAYLOAD ELEMENTS

Payload Element No.	Name
AS-01-S	1M Shuttle IR Telescope Facility
AS-03-S	Deep Sky UV Survey Telescope
AS-04-S	1m Diffraction Limited UV-Optical Telescope
AS-05-S	Very Wide Field Galactic Camera
AS-15-S	3m Ambient Temperature IR Telescope
AS-63-S	Sortie Medium Aperture Optical Telescope
HE-11-S	X-Ray Angular Structure
HE-15-S	Magnetic Spectrometer
HE-19-S	Low Energy X-Ray Telescope
HE-25-S	Transition Radiation Detector
SO-01-S	Dedicated Solar Sortie Mission
SO-11-S	Solar Fine Pointing Payload
SO-15-S	Solar Activity Early Payload
SO-17-S	Solar Activity Growth Processes
AP-06-S	Atmospheric, Magnetospheric, and Plasmas in Space
AP-08-S	LIDAR System
AP-09-S	Electron Accelerator
AP-10-S	Chemical Release
AP-11-S	Diagnostic Payload

Table 3-1

PAYLOAD ELEMENTS

Payload Element No.	Name
AP-12-S	Throw-Away Detector Satellites
AP-13-S	Low Light Level TV
LS-04-S	Free-Flying Teleoperator
LS-09-S	Life Sciences Shuttle Laboratory
LS-10-S	Life Sciences Mini-Laboratory
LS-13-S	Life Sciences First US/ERO Spacelab Mission
EO-01-S	Zero G Cloud Physics Laboratory
EO-05-S	Shuttle Imaging Microwave System
EO-06-S	Scanning Spectroradiometer
EO-19-S	Mark II Interferometer
EO-20-S	Earth Resources Shuttle Imaging Radar
EO-21-S	Shuttle Imaging Microwave System
EO-22-S	Mark II Interferometer - Earth
OP-02-S	Multifrequency Radar Land Imagery
OP-03-S	Multifrequency Dual Polarized Microwave Radiometery
OP-04-S	Microwave Spectrometer
OP-05-S	Multispectral Scanning Imagery
OP-06-S	Laser Altimeter/Profilimeter Experiment
*SP-01-S	SPA No. 1 - Biological (Manned) Laboratory

Table 3-1 (Continued)

PAYLOAD ELEMENTS

Payload Element No.	Name
*SP-14-S	SPA No. 14 - Manned/Automated Laboratory
*SP-15-S	SPA No. 15 - Automated Furnace/Levitation
SP-31-S	First Spacelab Mission (Biological and Furnace Subelements and Core)
ST-08-S	Integrated Real-time Contamination Monitor
ST-31-S	Drop Dynamics
CN-04-S	Electromagnetic Environment Experiment
CN-05-S	CO_2 Laser Data Relay Link
CN-08-S	TWT Open Envelope Experiments

Table 3-1 (Continued)

4. SPACE TECHNOLOGY FORECASTS REVIEW

It was recognized early that analysis of payload elements by itself would uncover only a limited set of technology drivers. Concurrently with the experiment analysis, a technology survey was necessary to uncover additional technology drivers. During this survey, the identification of technology emphasis areas (i. e., broad identifications of problem areas) was the main goal. These areas are subsequently analyzed for technology drivers as described in Section 6, Technology Driver Selection.

The major publications reviewed are listed in Table 4-1. The main emphasis was placed on the Outlook for Space and the OAST workshop results. The publications provide technology requirements on various levels: from a very broad identification of areas of interest, to specific recommendations on technology development items. The air of the review was to summarize the indicated technology areas specifically enough to provide clear direction, but broadly enough not to prejudice the results of the study.

4.1 Software and Software Technology

In pursuing the goals of this study, certain definitions and understandings are necessary to communicate the software roles and needs in the systems being analyzed.

A data system is considered to be made up of hardware, software, and mathematical (or system logic) elements. Software represents the enabling mechanization of the desired mathematics or logic functions on the computing hardware of that system. Systems concepts may require certain mathematical functions to be performed on data being processed by the system; however, these functions are not software, per se, but rather are inputs to the software process.

Software technology is, therefore, that technology which converts mathematical or logic requirements into computer programs that can operate on the available computer hardware. Software technology advancements will be required wherever hardware, space, processing time, or resources in general impede or limit this desired conversion.

4.2 Payload Scenario

The 1980-1990 payload scenario characteristics which drive the payload software technology requirements can be summarized as follows:

- High data acquisition rates are probably the main driving force behind the technology requirements. This reflects more data per payload, as well as an increased number of concurrently active payloads.

REVIEW OF TECHNOLOGY FORECASTS
PRIME REFERENCES

1. OUTLOOK FOR SPACE, JANUARY 1976.

2. A FORECAST OF SPACE TECHNOLOGY 1980-2000, JANUARY 1976.

3. OAST SPACE THEME WORKSHOP, APRIL 1976 (QUICK-LOOK COMMENTS AND WORKING PAPERS).

4. SPACE ELECTRONICS TECHNOLOGY SUMMARY, MARCH 1976.

5. OAST SUMMARY WORKSHOP, AUGUST 1975.

6. INFORMATION PROCESSING/DATA AUTOMATION IMPLICATIONS OF AIR FORCE COMMAND AND CONTROL REQUIREMENTS IN THE 1980's (CCIP's), 1975.

7. FINDINGS AND RECOMMENDATIONS OF THE JOINT LOGISTICS COMMANDERS SOFTWARE RELIABILITY WORK GROUP, NOVEMBER 1975.

8. KEY DEVELOPMENTS IN COMPUTER TECHNOLOGY: A SURVEY, IEEE COMPUTER MAGAZINE, NOVEMBER 1976 (LATE INPUT).

Table 4-1

- Increased utilization of software is a logical consequence of the increased sophistication of space systems and the availability of relatively low-cost, minaturized processor hardware.

- Real-time user-system interaction is dictated to perform the real-time data selection and the systems control required to effectively apply the planned operational systems.

- Increased systems autonomy is dictated through an increased emphasis on unmanned exploration, as well as the need to decrease the manpower cost required to support long-duration missions and operational systems.

- Data and facility sharing networks are visualized to prevent a duplication of large processing and very large storage facilities for data common to many diverse users.

4.3 Software Technology Categories

To present the information in a somewhat digestible form and to eventually be able to group related development items, three categories of software technology were established:

- Software Development Technology includes those areas associated with the project management, design, implementation, testing, verification and validation of software in general.

- Software Systems Architecture contains those areas concerned with software system structures and attributes required to fulfill general systems concepts and capabilities not solely associated with specific applications.

- Software Applications Technology encompasses those areas related to certain broad classes of applications which operate and control experimental or operational equipment. These areas are, thus, specifically driven by the type of planned space applications more so than any other category.

4.4 Software Emphasis Areas

The review resulted in the identification of 16 emphasis areas. Some of these do not directly affect on-board software technology, and are not directly analyzed for technology drivers. These areas are indicated by asterisks in the following summary.

4.4.1 Software Development Technology

Technology emphasis in the software development category is prime to any other significant software technology advancement. Lack of adequate development technology is perhaps the most significant deterrent to increased degrees of automation. Technology areas recognized are:

- o Cost/time reduction methods.
- o Software reliability.
- o Cost/performance evaluation.
- o Software/hardware standardization.

These technology emphasis areas are not unique to space systems; however, the last two carry far more significance for space applications than for most groundbased systems.

4.4.2 Software Systems Architecture

This category contains most of the technology emphasis areas identified and is indicative of the quantum jump in software utilization for the 1980-1990 space applications. This quantum jump is made feasible by the fantastic pace at which processor hardware technology has progressed. The following areas of emphasis were identified.

- o Functional distribution of processing.
- o Fault tolerance systems.
- o Intelligent instruments.
- o Human/System interfacing.
- *o Utilization of high-rate data processors.
- *o Data distribution/sharing networks.
- *o Very large data base management.
- *o Multidimensional data base systems.

It is noticeable that many of these areas are interrelated with the hardware or systems technology they are to operate with.

4.4.3 Software Application Technology

The line between software technology and other data management system technologies is even more difficult to draw for the emphasis areas identified here.

- o Image processing and pattern recognition.

- o Data compression.

- o Automated intelligence.

- *o Automation of ground-support functions.

5. EXPERIMENT ANALYSIS

Experiment analysis is a basic element of the Payload Software Technology Study. An understanding of instrument function and data characteristics is required to identify those parts that go beyond the state-of-the-art of software/system technology and, consequently, comprise the technology drivers.

This section describes the approach and material used to perform the experiment analysis and summarizes the results.

5.1 Objectives

Five specific objectives were established for the experiment analysis activity of Phase I. These are:

- Identify significant processing functions associated with STS payloads.
- Identify "next generation" on-board processing functions.
- Determine data management system technology drivers.
- Assess software development load.
- Provide the basic method and data for future experiment software analysis.

Significant processing functions are those payload oriented functions which drive resource utilization into the margin or beyond the capability of currently defined data management systems. The basic resources against which the processing functions were measured are:

- Processor main memory.
- Processor speed (in equivalent adds per second).
- Input/output data rate.
- Mass memory capacity.
- Display capability.

The "next generation" on-board processing functions are those that will be added (or transferred from ground systems) to accelerate the accumulation and distribution of more and higher quality data to the end user, at reduced cost, and within the physical limitations of bandwidth, ground handling, and archival facilities.

Data management system technology drivers are those functions which are mandatory to enable a mission, enhance a mission, and/or reduce overall cost, but for which new technology must be developed. Some of this technology is pure hardware, and a lesser amount is pure software, but the major part is system technology which synthesizes the complementary hardware/software attributes into an optimum mix of cost, convenience, and rate of return.

Assessment of the software development load covers the 1980-1990 time frame. The purpose of this objective is two-fold:

o Bound the software development facility requirements.

o Reveal areas in which software development technology items could improve software reliability and reduce development cost.

The last objective is to provide the form and structure of a data base that would be required to relate software function to experiment, to provide a simple tool for combining experiment loads into payload element loads, and payload element loads into mission loads, while retaining the flexibility to add new software functions and new experiment or payload elements without structure redefinition.

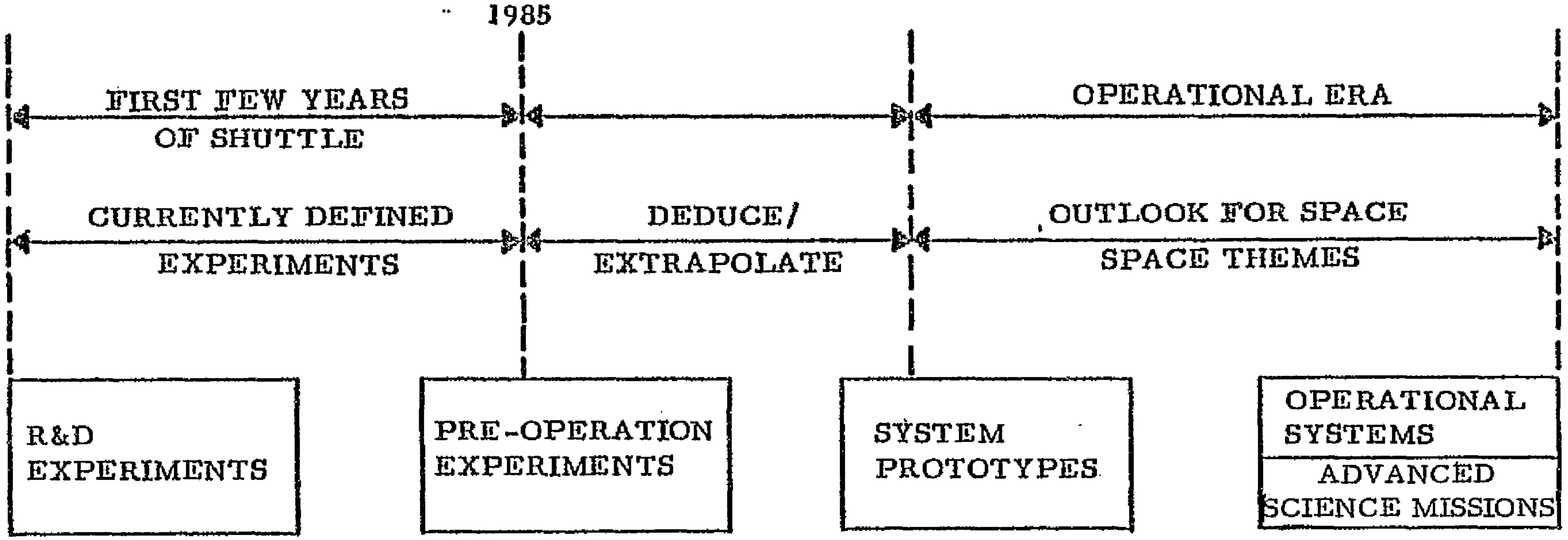
5.2 Scope

Experiment analysis includes the evaluation of currently defined experiments, pre-operational and operational prototype systems, and encompasses those end-of-the-century operational space system goals established by NASA and the scientific/industrial community. The scope is depicted in Figure 5-1.

The first few years of Shuttle Operations are based on currently defined payloads which are primarily payloads or improvements to payloads that have flown before. The main thrust of this period will be toward sensor development.

The pre-operational and system prototype periods will encompass the development and testing of new concepts and new techniques to enable digestion of orders of magnitude increases in data at drastically reduced costs.

EXPERIMENT ANALYSIS SCOPE



1985

FIRST FEW YEARS OF SHUTTLE

OPERATIONAL ERA

CURRENTLY DEFINED EXPERIMENTS

DEDUCE/ EXTRAPOLATE

OUTLOOK FOR SPACE SPACE THEMES

R&D EXPERIMENTS

PRE-OPERATION EXPERIMENTS

SYSTEM PROTOTYPES

OPERATIONAL SYSTEMS

ADVANCED SCIENCE MISSIONS

SENSOR DEVELOPMENT

- RAW DATA
- DATA SCRUTINY
- LITTLE AUTOMATION
- CALIBRATION REQUIREMENTS

INFO HANDLING TECHNIQUES

- DATA COMPRESSION
- DATA CALIBRATION
- AUTOMATED CONTROL
- "MANUAL" DATA EXTRACTION
- DATA INTERPRETATION CRITERIA

CONCEPT VERIFICATION

SYSTEM OPERATIONS

REFINE:

USE:

- AUTONOMOUS OPERATION
- AUTOMATED INFO EXTRACTION
- DATA DISTRIBUTION METHODS
- INFORMATION MANAGEMENT SYSTEMS
- AUTOMATED DATA INTERPRETATION

Figure 5-1

The operational phase entails full implementation of long-life, production-oriented satellites and space stations. Routine repair and refurbishment in space will be common activities. Preprocessing by the data collection systems, coupled with final processing and direct distribution of the finished product from space stations, will greatly enhance space utilization and reduce traffic to and between ground facilities. Concepts and technologies developed during the early years of STS will directly affect the utility and cost of future systems.

5.3 Experiment Analysis Task Flow

The experiment analysis task flow is shown in Figure 5-2. The task consists of two parts: (1) payload element analysis, and (2) software function analysis and sizing. These parts are integrated into the Software Analysis Master Matrix (SAMM) from which is derived the Data Management System concepts and software development sizing analysis for the 1980-1990 STS era.

The July 1975, Level B, SPDA was chosen as the model from which payload elements and instrument descriptions would be extracted for the technology study. Other data pertinent to these selected items was fed into the flow to add a greater level of detail. This data included:

- Payload definition studies.
- Integrated Mission Analysis Planning (IMAP).
- User's Information.
- Previous Programs.
- Previous Studies.
- In-house Expertise.

5.3.1 Payload Element Analysis

Payload element analysis consisted of the collection and classification of payload element/experiment data specific to payload software. A compressed form (Figure 5-3) was developed to provide a visible, comprehensive source for future analysis tasks.

Each payload element contained in the Level B SPDA was broken into individual experiments. The experiment number, objective and instrument

EXPERIMENT ANALYSIS TASK FLOW

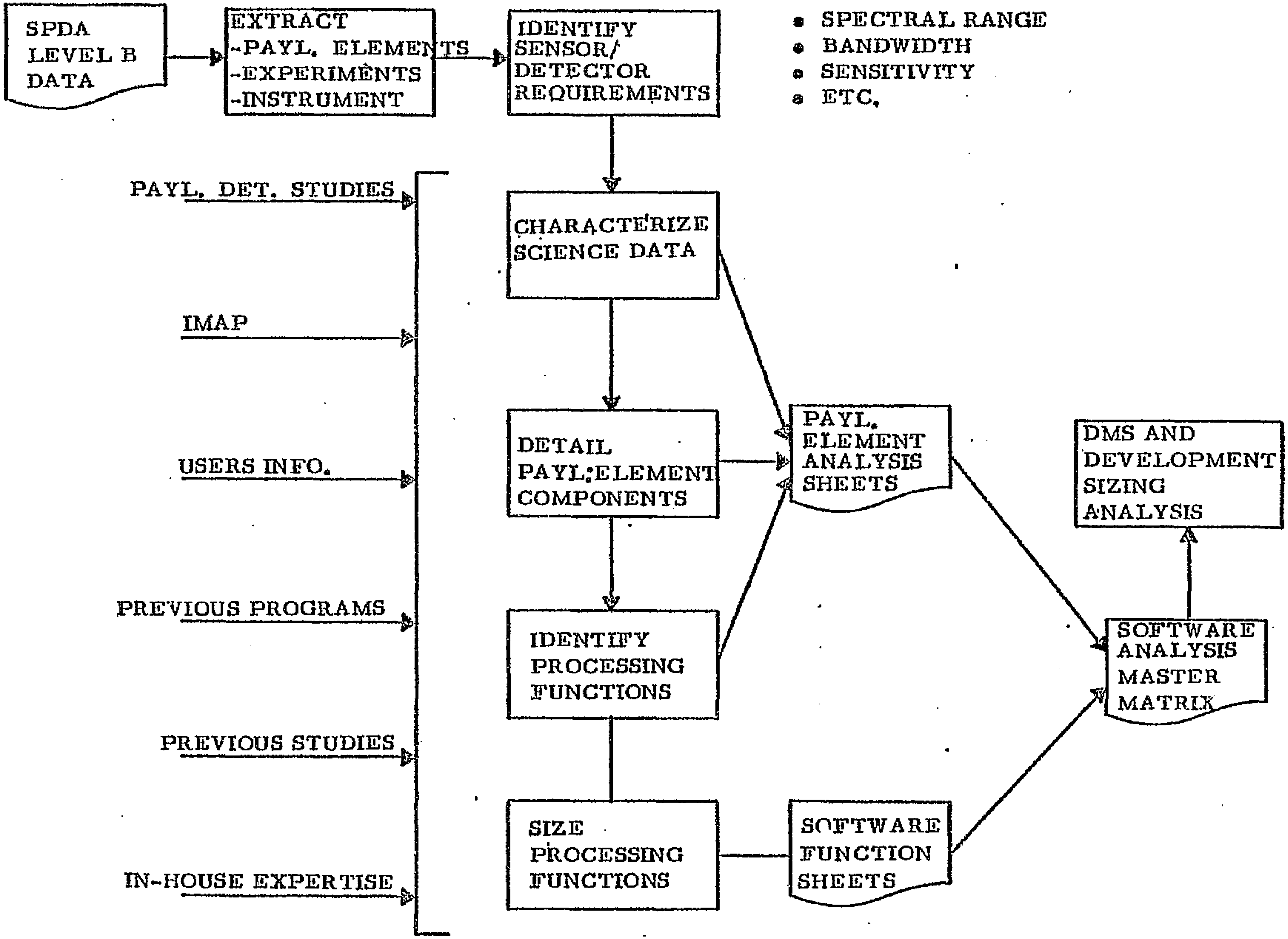

SPDA LEVEL B DATA
EXTRACT -PAYL. ELEMENTS -EXPERIMENTS -INSTRUMENT
IDENTIFY SENSOR/ DETECTOR REQUIREMENTS
• SPECTRAL RANGE
• BANDWIDTH
• SENSITIVITY
• ETC.
PAYL. DET. STUDIES
IMAP
USERS INFO.
PREVIOUS PROGRAMS
PREVIOUS STUDIES
IN-HOUSE EXPERTISE
CHARACTERIZE SCIENCE DATA
DETAIL PAYL. ELEMENT COMPONENTS
IDENTIFY PROCESSING FUNCTIONS
SIZE PROCESSING FUNCTIONS
PAYL. ELEMENT ANALYSIS SHEETS
SOFTWARE FUNCTION SHEETS
SOFTWARE ANALYSIS MASTER MATRIX
DMS AND DEVELOPMENT SIZING ANALYSIS

Figure 5-2

PAYLOAD ELEMENT ANALYSIS

DISCIPLINE Astronomy OFS No ______ PAYLOAD ELEMENT AS-01-S 1m Shuttle IR Telescope Facility

EXPERIMENT NUMBER/NAME	OBJECTIVE/INSTRUMENT CHARACTERISTICS	INSTRUMENT REQUIRED/ SENSOR TYPE	INSTRUMENTATION	SCIENCE DATA CHARACTERISTICS	COMPUTER SOFTWARE FUNCTIONS
XAS 004 Polarimetry, linear and circular	Obtain complex index of refraction and particle size of interstellar matter; gather information on surface of planets, satellites, asteroids and dust clouds of comets.	o AS-001 Telescope, IR, f/3, Cassegrain, 1 m o AS-005 Polarimeter, Linear & Circular o AS-008 Carrier/ Selector, Multiple Instrument o AS-009 Unit, Electronics, Checkout, Test, Control o AS-013 Computer, Digital o AS-014 Display, Multifunction o AS-015 Panel, Indicators/ Switches, Data Flow	o Cassegrain telescope o Polarizing prisms on polarization wheel o Neutral density filter o Field stops o Fibre optic mixer o Filter wheel o Beam selector o Photovoltaic cell o Power supply o Electronics	Parameters measured: o Radiance polarization - Type: Digital - No. of Bits: 6 - Sampling Rate: 100 sps - No. of Channels:	o Monitor and data control o Checkout o Calibration o Experiment sequencing control o Command and control o Pointing control o Reference frame transformations o State vector o Annotation: - Time - Pointing - Wavelength - Polarizer o Alphanumeric: - Display parameters lists o Graphics: - Display intensity versus angle o Editing and decommutation o Time conversions o Convert data to engineering units

Figure 5-3

characteristics, the instrument(s) required, and sensor type were entered onto the payload element analysis form. Sensor/detector requirements were identified, including spectral range, bandwidth, sensitivity, and other distinguishing features leading to the characterization of the data produced.

The payload element analysis was completed with the identification of software functions applicable to each specific experiment.

With this approach, 42 payload elements containing 214 experiments were analyzed and the resulting data was entered onto the payload element analysis sheets.

5.3.2 Software Function Analysis

The software function analysis consisted of identification of standard software functions, a function description, and baseline sizing data. This information is contained in the software function sheets, a sample of which is shown in Figure 5-4. Thirty-nine functions have been identified and described. Each has been assigned a standard name and identification number for subsequent use on the SAMM matrix.

Early in the study, it was determined that many experiments, although different in nature, shared common software functions. Due to independent development and lack of standardization, these common functions were often overlooked in the past because of different names for the same function or because slightly different algorithms accomplished the same end. This study attempts to bring standard functions into view. For instance, a Fourier transform as applied to an interferometer is no different than a Fourier transform as applied to data compression.

The software function descriptions and sizing do not extend to standard operating system functions. They are strictly experiment control/monitor/scientific-data oriented.

The sizing of a software function is based on a typical application which is spelled out in the function description where applicable. The sizing criteria centers on main memory requirements, processor speed in equivalent adds per second (EAPS), and input/output volume and rate. For a given function, the number of instructions remains fairly constant; therefore, the main memory requirement is basically dependent on the size of the I/O buffers. Processor speed is dependent on the number of data words to be processed in a given amount of time. In either case, the prime variables are the number of words per I/O sample and the sample rate. Provision has been made in the SAMM matrix to adjust sizing values because the prime variables change from application to application.

SOFTWARE FUNCTION

401 Calibration (Simple Detectors)

Calibration on a one-time-per-mission basis requires operation of the experiment with known reference sources. These may be black-body sources, light sources, or known values of voltage, current, radiation, and other standards. The output of the sensor/detector is used to generate calibration curves/values with which to modify or correct the source data of interest during operation of the experiment.

Tables - Input Buffer	100 words
Output Buffer	50 words
Data Tables	100 words
Instructions	500 words
Execution Rate	1 per mission
Processing Time	300 sec.
Effective Input Rate	5 BPS
Output Rate	5 BPS
Effective I/O Rate	10 BPS
Effective EAPS	50

Figure 5-4

5.3.3 SAMM Matrix

The SAMM matrix (example shown in Figure 5-5) provides a means of correlating experiments to software function. It was designed to provide an input to an automated data base application should the need arise in future study activities.

The vertical columns contain a sequential list of payload elements, further subdivided into experiments. In many cases, the experiment element serves as an experiment facility (as in AS-01-S); therefore, all functions common to the facility are allocated at the payload element level, and experiment-unique functions are allocated at the experiment level.

The horizontal columns contain the 39 identified software functions. The design intent is that the sizing for each software function would become a part of the data base mentioned above, and thus permit the summing of experiment loads into payload elements and payload element loads into payloads.

In the sample matrix, black dots at the matrix intersections indicate the software functions that apply to a given experiment or payload element. Should the automated data base be generated, these dots would be replaced by numbers representing a complexity factor to be multiplied times the sizing data for a given function. The complexity factor (or multiplier) would be dependent on the I/O volume and rate (i.e., words per sample and sample rate). This approach allows broad flexibility in the combining of payloads and calculating the resulting data management system requirements.

Mass memory requirements have not been specifically discussed in the sizing criteria; however, a capacity of 100 million bits will support any experiment or payload element evaluated. The overriding considerations with mass memory are that it should provide rapid random access and read/write capability.

5.4 Results Summary

Experiment analysis did not generate any real surprises. It did tend to confirm what had here-to-for been intuitively understood. In general, the findings were:

- Currently planned on-board software functions generally do not exceed planned data management system capabilities (possible exception is AMPS).

ORIGINAL PAGE IS OF POOR QUALITY

SOFTWARE ANALYSIS MASTER MATRIX (SAMM)

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR 101	GRAPHIC DISPLAY 102	REFERENCE FRAME TRANSFORM 103	GREY LEVEL TO COLOR 00	TRANSFORM OR CONVOLUTION 201	REGISTRATION 202	RADIANCE UNIT CONVERSION 203	NOISE REMOVAL 204	CONVERT TO ENGINEERING UNITS 205	F.O.V. INSTRUMENT/INERTIA 206	F.O.V. EARTH REFERENCE 207	F.O.V. LAT/LONG. 208	EPHEMERIS DATA COLLECTION 209	GEOMETRIC CORRECTIONS 210	DISPLAY 211	REFORMAT, SKEW REMOVAL 300	EDIT & DECOMMUTATE 301	SCAN LINE OFFSET 302
AS-01-S		●	●		●						●						●		●	
	XAS001			●					●									●		
	XAS002			●					●									●		
	XAS003			●			●		●									●		
	XAS004			●					●									●		
	XAS005			●					●									●		
	XAS006			●					●									●		
AS-04-S		●	●		●												●		●	
	XAS041											●			●					
	XAS042											●			●					
	XAS043				●			●				●			●					
	XAS044											●			●					
AS-05-S		●	●																	
	XAS051						●			●										

Figure 5-5

- "Next generation" on-board software functions can generally not be accommodated within planned data management system capabilities.

- Current generation experiments rely heavily on film. Future generations will use more and more Vidicons and CCD's for data collection.

- Prime software technology emphasis areas are:

  - Pattern Recognition.

  - Image Processing.

  - Data Compression.

6. TECHNOLOGY DRIVER SELECTION

In this task, the technology emphasis area identified in Section 4, Space Technology Forecasts Review, and Section 5, Experiment Analysis, are further analyzed to identify the associated Technology Drivers. This section summarizes the results of that effort.

To ensure a clear understanding, we must first clarify the meaning of the term "Technology Driver." Technology is generally defined as the systematic knowledge of, and its application to, industrial processes. A Technology Driver is, then, an incentive, a need to obtain this systematic knowledge, or apply available systematic knowledge to an industrial process. In other words, Technology Drivers are, simply, problems for which a solution is desired and needed. The idea(s) put forth to solve the problem are, what we call in this study, Technology Items.

Problems, and therefore Technology Drivers, can occur on many levels of detail. For example, the need for a more efficient method of programming computers (the Technology Driver) resulted in the idea (Technology Item) for the use of higher order languages. Subsequently, the use of high order languages presented an efficiency problem (the Technology Driver), resulting in development of optimization techniques (the Technology Item).

Also, a problem may have several aspects, thus requiring multiple, related Technology Items; or it may have several possible solutions, thus, again, resulting in multiple Technology Items.

The technology emphasis areas described in Section 4 were divided into three categories. In this section, the results of the analysis are described in accordance with those categories. It should be noted, however, that the Technology Drivers do not necessarily fall within the same category as the associated emphasis area. For example, a technology emphasis area within the category of software system architecture may point to a Technology Driver associated with the category of software development. The summary presented in Section 2.3, Results, lists the Technology Drivers in the appropriate categories as they were recategorized subsequent to the Technology Driver Section discussed here.

6.1 Software Development

During the review of Software Development Technology, two major points recurred in various guises:

- o There is no facet of software development that is considered to be satisfactorily performed in a production mode. That is, major shortcomings are identifiable in every step of the development process (with the possible exception of coding). There is a general feeling of inadequacy, dissatisfaction, and a lack of confidence in the merits of proposed solutions.

- There have been only two major breakthroughs in the history of software development. The first one was the use of higher order languages, and the second was the identification of structured programming techniques. The former is now practically and generally implemented and has resulted in tangible improvements. The latter is only sporadically applied and, therefore, is not yet generally used in a production mode.

Almost every facet of software development can, therefore, be a Technology Driver. Further investigation into the problems, proposed solutions, and status of technology development revealed, however, a common cause of difficulties. The key to this common cause is the lack of Software Design Engineering technology. Software Design Engineering is conceived to cover interpretation of requirements and creation of a design, but not the physical implementation of the software.

This software design problem is an even more difficult problem in the area of payload software than it is in most other areas. Payload Software is generally part of an "embedded" system, that is, a computer system that is only part of, and integrated into, an equipment complex such as an avionics system. The software design problem itself is difficult enough, but in the "embedded" system, these difficulties are multiplied by the external constraints imposed by the total system.

We will not try to describe here all the facets of Software Design; however, some of the issues are discussed below:

- Visibility of Design; for example, how early in the cycle can a design be made visible so that proper planning can be performed? How should a software design be described so that is provides sufficient direction for the next level of design or so that is can be evaluated against level of design? (Note that a design becomes a requirement for the next lower level of design.) This brings us to the even more basic questions of: what should be specified in a software requirements document, what is really essential, and how it should be described? How is traceability maintained? There are, or course, many other questions.

- Design Techniques; for example, how should a software system be structured to be manageable? ...Testable? ...Modifiable?

It is generally believed that no hard and fast rules can be derived. We are therefore looking for principles that can be applied to a specific system to derive the rules and standards for a particular project. Furthermore, they must be usable in a normal production environment.

- Design Evaluation; for example, how can a design be realistically evaluated before the full implementation is started? Assuming that we can describe the design and have used sound principles of design, how can we establish that the physical product will be satisfactory? A satisfactory software producı must have desirable qualities with respect to its man-machine interface; it must be relevant to the system functions it purports to serve; and it must be reliable in its operation.

As can be seen from such issues, Software Design Engineering has multiple interrelated facets. Current and past technology developments have primarily addressed the development cycle from the point that a complete design specification is available. Some effort has been made in formalizing the design specification (Ref. Table 6-1); however, only recently has recognition been given to the fact that all successes and failures of systems start with the proper design principles or lack thereof. The interrelationships between these facets are not yet well understood.

We made an attempt to subdivide Software Design Engineering into multiple Technology Drivers. However, because this area is so undeveloped. this seemed to be presumptuous. We have to analyze/understand Software Design Engineering as a whole before we can see and develop the parts.

6.2 Software Systems Architecture

Within this category are grouped those areas concerned with software system structures and attributes required to fulfill general system concepts and capabilities not solely associated with specific applications.

Note that this technology is closely associated with other technologies that relate to the system as a whole. This is particuarly true of onboard data management systems where the computer and its software have a more subordinate role than in most groundbased computer applications.

Four emphasis areas were previously identified within this category which could affect onboard processing:

- Functional distribution or processing.

- Fault Tolerant Systems.

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Table 6-1

- o Intelligent instruments.
- o Human-system interface.

The area of "Intelligent Instruments" turned out to be a subset (as far as its software implications are concerned) of the more general area of "Functional Distribution of Processing" and is therefore not analyzed by itself.

The remaining areas are each briefly discussed in the following paragraphs.

6.2.1 Functional Distribution of Processing

A distributed system, as the term is used here, it a system which contains multiple processors, each with its own executive, performing dedicated functions as part of a single partitioned system, usually each housing its own main memory. The concept is not particularly novel. However, it is only recently, through the advent of microcomputers, that is has become eminently practical.

A distributed system has two major advantages, within the context of this study:

1. Simplified development/modification of the system.
2. Ability to perform parallel processing.

Simplified development/modification of the system comes about through the relative independency of the subsystems. That is, the computer process becomes a more integral part of the subsystem it is assigned to and thus it can be designed, adapted, and verified almost independent of the other subsystems. Particularly note, however, that the system design as a whole does not become any simpler, only more flexible. The very flexibility may make the system design, or the choice of system design, more difficult. Any network of computers has, for the software as well as the hardware, the inherent problem of selecting interprocess communication techniques and selection of functions to be or not to be distributed. This is, generally, an ill-defined area. It thus results in a Technology Driver entitled "System Partitioning/Interconnection Techniques."

The ability to perform parallel processing is of particular advantage in "hard real-time" systems such as process control systems and payload control systems. These systems are often characterised by the requirement to very rapidly respond to randomly (and therefore possibly simultaneously) occurring external events. This is classically a major problem in the use of centralized systems and often becomes a trivial problem in distributed systems.

The availability of low-cost processors has, in fact, a stronger effect than just the distribution of processes that previously were performed in a central processor. It has the additional effect of "computerizing" processes that previously were hardwired. This is particularly noticeable in current instrument development. A natural consequence of this intensified usage of computers is that an increasing number of programs are being written by engineering personnel rather than professional programmers. This eliminates the problems associated with the classical engineer/programmer communication gap, but forces a significant need for truly user-oriented software development systems and methods. This trend toward software development by non-programmers must therefore be considered a Technology Driver.

A hardware technology that is associated with the availability of low-cost computers, but currently lagging, is the availability of low-cost, large, rapid-access storage. Accessing such memories and using them effectively is currently a specialized software area. To enable engineering personnel to use such storage devices on a routine basis requires some method of simplifying the use. This is another Technology Driver.

To summarize, "the Functional Distribution of Processing Technology" emphasis area has three Technology Drivers directly associated with it:

1. System partitioning/interconnection techniques.

2. The trend toward software development by non-programmers.

3. Very large storage access simplifications.

6.2.2 Fault Tolerant Systems

The most all-encompassing definition of a fault tolerant system is that which is normally used in the IEEE publications: "A Fault Tolerant System is a system that has the ability to execute specified algorithms correctly, regardless of hardware failures, system flaws, or program fallacies."

This has been a fascinating, much-studied subject for a considerable period of time. There is, however, no system in existence that completely meets the definition, and, in fact, one may never exist. Nevertheless, a close, cost-effective approximation of such a system may filfill a real need for many applications.

A major stumbling block for many designs has been the high cost of the redundant hardware which is a basic requirement for such a system. This stumbling block is now being removed through the current advances in LSI technology.

The ideal fault-tolerant computer system would be a system in which hardware failures are totally masked by instantaneous correction. Assuming that such a system is technically feasible, the next stumbling block is the low reliability of the software. Minimizing the number of faults that are introduced into the software is a developmental problem that has been previously addressed under that category (Section 6. 1). What we are concerned with is proving that there are no software faults left in a particular software package. As this is still beyond the state-of-the-art, it must be considered a Technology Driver.

It may, for various reasons, never be truly feasible to provide absolute proof of software correctness. It therefore behooves us to study an alternate means of preventing the software from causing a system failure. This approach is detection of software failures during execution. It is not clear if and how this is truly feasible; nevertheless, it is the only currently known alternate and must therefore be listed as a Technology Driver.

Associated with the problem of fault detection is the problem of fault correction and recovery. In many hardware schemes, and in all known software schemes of fault detection, one or more instructions have been executed by the time a fault is detected. Recovery from such unwanted instruction execution is still an unsolved problem and must therefore still be considered a Technology Driver.

To summarize, there are three highly significant software Technology Drivers associated with the feasibility of fault-tolerant systems:

1. Fault-free software.

2. Software fault detection.

3. Software recovery.

6.2.3 Human/System Interface

This area is concerned with the ease and effectiveness of the communication of instructions and information between humans and computer systems. This has been a fruitful area for technology development for a long time, and it remains to be a high-priority emphasis area.

As noted in the above paragraph, two distinct types of interfacing can be distinguished. The first one deals with the, essentially one-way, communication that takes place when a user is instructing, i.e., programming, the computer. The second one deals with the interaction which may take place between a human and a computer system as the system is executing an application.

With the increased utilization of computers, a new type of user, i.e., the non-programmer, is starting to dominate software development (as pointed out in Section 6.2.1). With this, a shift to an increased emphasis on application-oriented languages (as apposed to General-Purpose Higher Order Languages) must be anticipated. Language design is one of those typical software areas which have no real guidelines, standards, or evaluation criteria which can aid in the quick development of high order languages. Language design is frequently a costly process of long duration. Therefore, the development of an application-oriented language design methodology must be considered a Technology Driver.

A compiler is needed for each language which will be designed and for each computer the language will be used for. Although considerable research and development effort has been expended, compilers remain as very expensive items. The potential proliferation of languages and computer systems obviously requires that these developmental costs be decreased significantly. This Technology Driver, in this context, is separately identified, but actually, it is closely related to the preceding Technology Driver.

We will not elaborate here upon the need for and uses of interactive communication between users and computer systems. This has been well described in many other publications. We believe, however, that spaceborne applications are more likely to need more "natural" interactive communication methods than most groundbased applications. This belief is based on the severe constraints placed on numbers of personnel, time, utilization, training, etc., for manned space vehicles. Much emphasis is being placed, within the industry, on the development of interactive methods. The technology driver, as fas as NASA is concerned, is the development of more natural communication methods, such as voice, patterns, etc., which can complement industrial developments.

To summarize, the Technology Drivers within this emphasis area which are of particular importance to spaceflight are:

1. Application-oriented language design methodology.

2. Low-cost development of AOL compilers.

3. Use of "natural" communication methods.

6.3 Software Applications

The software applications category encompasses those areas which operate and control experimental or operational equipment. These areas are driven by the type of planned space utilization more so than any other category.

The natural emphasis has been on the feasibility of onboard implementation of the state-of-the-art software available for these applications. Each application area calls for a unique set of software functions. However, some of these functions are common to more than one application area and represent a set of basic functions which are performed onboard; for example, the functions associated with monitor, control, sequencing, and other housekeeping chores. Other functions are more specialized but still need to be performed onboard (such as pointing control, reference frame transformation, and scanning control). There are yet other functions which could conceivably be performed onboard, depending on cost/benefit ratios. Some typical functions belonging to this category are pattern classification, image enchancement, registration and geometric correction, and filtering and noise removal.

Three emphasis areas have been previously defined within this category that could affect onboard processing:

- Pattern recognition and image processing.
- Data compression.
- Automated intelligence.

6.3.1 Pattern Recognition and Image Processing

This encompasses all the necessary processing involved in deriving a classified (recognition) map which has been geometrically corrected to fit a reference map (or image). Generally, this involves processing of multidimensional data such as those obtained from multispectral scanners and, consequently, the computational demands are far more severe.

The classification or recognition activity involves three distinct phases:

- Feature selection.
- Learning.
- Classification or labeling.

Each phase involves a variety of software functions, the choice of which is heavily dependent on the data environment and its characteristics. This is illustrated for a few typical cases in the Data Environment Scenario versus Software Function Matrix depicted in Table 6-2. A study of this matrix and underlying concepts shows that classification, which is repetitively deployed to derive the labels of all the input data samples, is the single most important and common function. Accordingly, optimization of the computational needs

DATA ENVRIONMENT SCENARIO VS. SOFTWARE FUNCTION (DESF) MATRIX

SL NUMBER	SOFTWARE FUNCTION → PATTERN RECOGNITION ENVIRONMENT DESCRIPTIONS - TYPICAL CASES	Parametric Feature Selection	Non-Parametric Feature Selection	Probabilistic Assignment of Labels	Estimation of Level of Supervision	Learning Distribution Parameters	Non-Parametric Discriminants Design	Parametric Classification	Non-Parametric Classification	Clustering Procedure	Self-Learning the Number of Classes	REMARKS
1	• Minimum number of features. • Known number of classes. • Known probabilistic descriptions. • Known distribution parameters.							▨				Ideal Case. Theoretically maximum classification efficiency attainable. Hardly practical data environment scenario.
2	• Large number of features. • Unknown number of classes. • No probabilistic descriptions. (Only the samples awaiting classification are available).		▨				▨		▨	▨	▨	Most Critical Case. Minimum information available. Relatively high computational loads. Reliability of results not very high.
3	• Large number of features. • Known number of classes. • Known distributions. • Unknown distribution parameters. • Reliably labeled Training Samples.	▨				▨		▨				A Typical Case assumed in most studies and existing pattern recognition systems. Assumptions, not always realistic, made for mathematical convenience.
4	• Large number of features. • Known number of classes. • Unknown distributions. • Reliably labeled Training Samples.		▨				▨		▨			A more realistic case backed by a large number of studies and resultant methodologies less computational loads than in Case 3. feasible under some methods.
5	• Minimum number of features. • Known number of classes. • Known distributions. • Unknown distribution parameters. • Unlabeled Training Samples.			▨		▨		▨				A fairly powerful approach to a rather severe class of problems. Referred to as learning with a probabilistic teacher.
6	• Large number of features. • Known number of classes. • Known distributions. • Unknown distribution parameters. • Labeled Training Samples. • Reliability of labels unknown.	▨		▨	▨	▨		▨				Significantly more versatile approach catering to a highly realistic class of scenarios. Referred to as a unified approach to feature selection and learning in unfamiliar teacher environments.

Table 6-2

of this phase is of considerable significance in the context of the constraints of onboard processing. The actual classification method to be employed depends to a large extent on the data environment. Some of the commonly encountered classification concepts are "the nearest neighbor," "maximum likelihood," and "linear and piecewise linear." There are, of course, numerous variations, both conceptual and computational. A commonly employed computational alternative is the so-called "table lookup" approach which is based on a trade-off of memory versus computational time. It should be noted that, actually, the table lookup approach is not an independent classification method, but only an implementation scheme which can be used in conjunction with the maximum likelihood concept or any other parametric classification concept. Table lookup schemes appear feasible only for relatively low resolution or limited channels because of the memory requirements associated with this approach.

This problem may be overcome by a recently proposed alternative table lookup scheme, wherein only the table corresponding to a set of prototypes need by stored. These prototypes are derived through a multidimensional histogram analysis. However, in this histogram analysis process, the critical factor is the CPU time. This is mainly due to the associated large array search. Therefore, crucial to the onboard implementation of many of the software functions associated with pattern recognition and image processing activities, is the need for efficient software procedures for performing large array searches and sorting, which is accordingly viewed as a software Technology Driver. In addition, the classification processing of individual picture elements or samples can be carried out independently for each pixel and hence there is a natural incentive for considering parallel processing as a means of reducing the computational demands of this function. This can be achieved by restructurin and/or modifying the presently available software towards obtaining the maximum benefits of parallel processing. Parallel processing techniques are also viewed as an important Technology Driver arising from this emphasis area.

In another area of pattern recognition and image processing, the process of correcting the image to fit a reference map or frame of coordinates must be considered. This process involves two major software functions: registration, defined as the task of deriving the transformations (rotation, translation as scale changes) needed for obtaining the best fit; and geometric correction, defined as the task of applying these transformations to derive the transformed or corrected image. These operations, especially registration, involve a certain amount of human interactions. The high computational loads associated with the geometric correction function can again be viewed as a problem calling for more efficient large array manipulation procedures. Also, viewing the large image as a set of smaller images, the advantages of parallel processing may be realized.

In summary, the software Technology Drivers associated with the area of pattern recognition and image processing, are:

- Efficient large array search and sort procedures.

- Parallel processing techniques.

6.3.2 Data Compression

Both the Outlook for Space (OFS) report and, to a greater extent, the OAST Summer Workshop Data Processing and Transfer report recognize the key role of data compression technology in the advancement of the state-of-the-art space-related information management systems. In particular, imagery data from a variety of multispectral scanners, as well as radar experimental packages, are expected to dictate the demand levels to be met by these systems. Of course, each application calls for a different minimum level of fidelity in the data as it is received on the ground. Neglecting, for the present, communication channel (downlink) noise, and considering only the fidelity in terms of level of detail required in the data by the different applications, at least four distinct categories of applications can be identified as those requiring:

Category 1: Exact reconstruction of the multispectral imagery at each point or picture element (pixel) in each of the scanned frequency ranges.

Category 2: A good approximation of the imagery at each point and in each frequency range with little visually perceptible degradation.

Category 3: A single recognition map (derived by, say, multispectral classification onboard of the scanned imagery data) which leads to lower data rates as compared to transmission of the entire set of raw multispectral imagery data.

Category 4: Identification of only a limited number of special features or changes in the image resulting in further reduced data rates.

The vast number of data compression techniques reported in the literature can be categorized into two groups:

- o Redundancy-reduction-oriented and information-preserving encoding schemes such as run coding, block coding, etc., which result in a relatively low level of data compaction, but which retain all of the information contained in the original picture.

- o High-compaction-oriented approximate approaches which result in significantly higher levels of data compressions, but which sacrifice some of the information.

The needs of categories III and IV applications are not of much concern here because the onboard recognition processing (cluster coding) envisaged for these applications automatically brings down the data rates to reasonable levels. Of course, in these applications, the problem of concern is the feasibility of such onboard recognition processing in real time.

However, the compression ratios attainable under the present state-of-the-art, without exceeding tolerable levels (3 percent) of degradation of the imagery, fall short of the requirements of categories I and II. As is illustrated in Table 6-3 the first category of applications calls for approaches which are essentially information-preserving approaches, such as encoding schemes. While the actual compression ratios attainable under any approach is application or data dependent, the ratios generally achieved by these encoding schemes are rather too low to be of significance in the context of the data rates expected in future missions. Thus, the needs of applications requiring exact reconstruction of imagery represent a technology driver at a basic level; this calls for communications technology advancements and/or advancements in data compression algorithms. The needs of the category II applications, which require an approximate reconstruction of imagery, can perhaps, however, be met through more efficient implementation of presently known techniques or combinations thereof.

As discussed above, transform coding (possibly in conjunction with predictive coding schemes such as DPCM or projection schemes) is viewed as one of the more promising approaches for onboard implementation of imagery data compression. This technique can provide a compression ratio of up to 5:1 when combined with variable length encoding. However, this is still insufficient to meet future demands, and, therefore, more complex combinations

DATA COMPRESSION: REQUIREMENTS AND CURRENT STATUS CHART

CLASS OF APPLICATIONS (REQUIRING)	OFS PROJECTED* (BY THE YEAR 2000) COMPRESSION RATIO	CURRENTLY AVAILABLE APPROACHES	ASSOCIATED RANGE OF COMPRESSION RATIOS	IMPLEMENTATION COMPLEXITY RATING	REMARKS
EXACT RECONSTRUCTION OF THE ORIGINAL IMAGE IN EACH CHANNEL (I CATEGORY)	8	ENCODING SCHEMES	1.2 - 2	1	COMPRESSION RATIOS CURRENTLY ATTAINABLE TOO SMALL. MAJOR CONCEPTUAL/TECHNOLOGICAL ADVANCEMENTS NEEDED
GOOD APPROXIMATION OF THE ORIGINAL IMAGE WITH LITTLE VISUALLY PERCEPTIBLE DISTORTION IN EACH CHANNEL (II CATEGORY)	16	DPCM AND OTHER APPROXIMATE APPROACHES IN A STANDALONE MODE	1.4 - 3	2	THESE APPROACHES BY THEMSELVES FALL FAR SHORT OF THE REQUIREMENTS OF THIS CATEGORY
		1-D TRANSFORM IN SPECTRAL DOMAIN COMBINED WITH DPCM AND HUFFMAN CODING	3 - 5	3	MOST PROMISING APPROACH AS PER TRW STUDY WHICH STILL DOES NOT LEAD TO DESIRED COMPRESSION RATIOS
		OTHER ALTERNATIVES, SUCH AS 2 AND 3D TRANSFORMS IN SPATIAL (AND SPECTRAL) DOMAIN FOLLOWED BY DPCM AND ENCODING TECHNIQUES, NOT EVALUATED BY THE TRW STUDY	?	6	NEEDS DETAILED ASSESSMENT AND FURTHER STUDY TO DETERMINE THE EFFECTIVE COMPRESSION RATIOS AND IDENTIFY PROBLEMS (IF ANY) IN THEIR ONBOARD IMPLEMENTATION
ONLY A RECOGNITION MAP (III CATEGORY) OR ONLY CERTAIN KEY FEATURES OR CHANGES IN THE SCENE (IV CATEGORY)	400 - 2000	CLUSTER CODING, CLASSIFICATION, CHANGE DETECTION METHODOLOGIES	10 - 100	10 OR MORE	FAIRLY HIGH COMPRESSION RATIOS ATTAINABLE. HOWEVER, OTHER ONBOARD IMPLEMENTATION PROBLEMS ARISE

* OFS PROJECTIONS OF "WHAT WILL BE" FALL SHORT OF "WHAT IS DESIRED" (IN VIEW OF THE EXPECTED DATA RATES IN FUTURE MISSIONS) IN THE FIRST TWO CATEGORIES OF APPLICATIONS.

Table 6-3

(including possibly two three-dimensional transforms of the multispectral imagery), along with adaptive concepts, have to be investigated. Also, implementation involving two-dimensional transforms in the spatial domain do not need, a priori, band-to-band registration and are of value when individual band imagery is needed separately, possibly by different users. The scope of this approach for onboard implementation has not been explored fully in view of the inherent computational complexities. As for example; consider a 1024- by 1024-pixels image. It is obvious the image cannot reside in the core of the onboard processor, even with the projected advancements in hardware technology. Thus, the process of matrix manipulations, such as transpositions, which are essential to application of the two-dimensional transform to the image matrix, pose a software implementation problem. Preliminary assessments derived by an awareness of the resource requirements has brought out the existence of a possible Technology Driver in terms of a need for improved software procedures for matrix transposition of large matrices. The other Technology Driver of importance to this area is high-speed buffering techniques which arise in view of the very high data rates expected in future missions.

In summary, the major Technology Drivers associated with the area of data compression are:

- o Efficient large-array (two-dimensional) manipulation procedures.

- o High-speed buffering techniques.

6.3.3 Automated Intelligence

The area of automated intelligence is still in an embryonic stage, and as such, the system concepts are not yet fully developed. While it has different conditions to different disciplines, in the context of space exploration, automated intelligence can be viewed as the ability of systems to automatically adapt their behavior to the environment and its characteristics. As for example, it could be the ability to make decisions, based on the results of preliminary experiments about the design of further experiments. In effect, it extends the range of human facilities such as sensing, recognition, and decision making to remote environments wherein direct real-time manual control is not feasible. Basic to such capabilities are the fields of development generally referred to as scene analysis and adaptive and learning control systems. Technology associated with automated intelligence systems covers many disciplines, and, accordingly, the drivers are at different levels; conceptual, algorithmic, and software procedures. Even with scene analysis, there are distinct hardware and software related problems. The software functions associated with automated scene analysis, a requisite to automated intelligence, are numerous and still in the developmental stage. They range in complexity from simple functions, like the smoothing of an image, to complex functions of three-dimensional object recognition and total scene descriptions using picture grammars and related languages. There is a growing body of literature on techniques and algorithms to perform these functions. Thus, one can visualize an impressive array of individual pieces of software being available for the analyst. However, the major problem would be to develop an efficient system which will be capable of adaptive selection and deployment of these individual functions to suit the environmental needs and constraints. While the interest in the individual disciplines ensure progress in all those areas related to automated intelligence, the requirements of the space-related activities require coodination of these developments. In terms of software technology, this translates into pursuing the design and control of adaptive procedures.

In summary, the major Technology Driver associated with automated intelligence is the design and control of adaptive software procedures.

7. FUTURE PLANS

7.1 Phase I

Completion of Phase I has established the data base and background information required to begin the final phases of the payload software study. Figure 7-1 depicts completed activities (crosshatched area) and the activities yet to be performed.

Coordination of activities and sharing of results with the NASA Centers, as well as interfacing with other on-going studies within MSFC, will be a continuing effort. Travel during the final phases will be dictated by needs.

7.2 Phase II

Phase II was initiated the last week of November 1976. Phase II represents a consolidation and evaluation of the large amount of data accumulated in Phase I as preparation for the final Phase III activity which centers on generation of technology development plans. Specifically, Phase II will consist of the following items:

- Detailed analysis of Technology Drivers.
- Derivation/evaluation of Technology Items.
- Merging unique automated payloads data into the data base as it becomes available.

7.3 Phase III

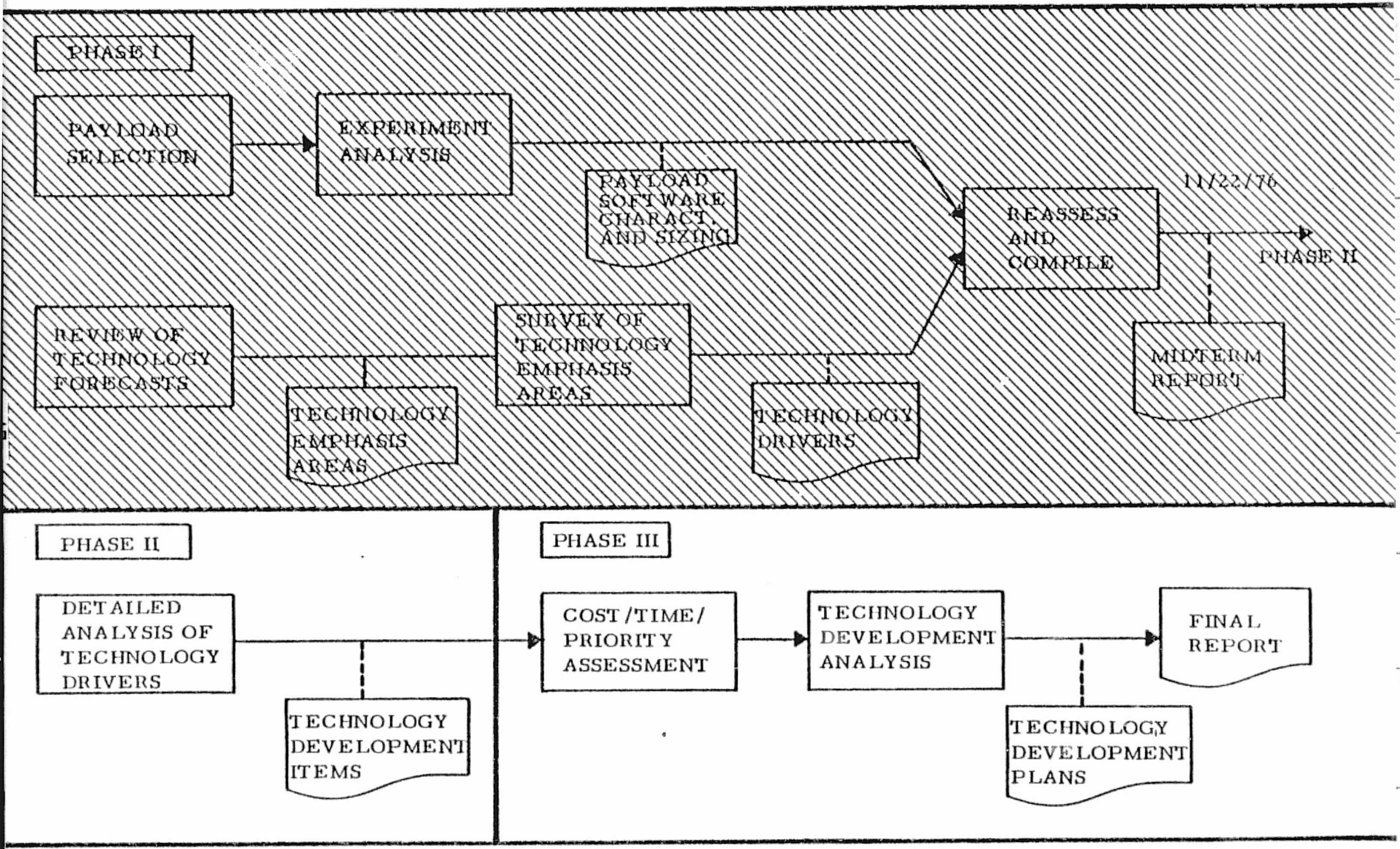
Phase III is the culmination of the current study. Activities for this phase will be:

- Cost/time/priority assessment of software Technology Items.
- Technology development analysis.
- Technology development planning guide preparation.
- Publication of final report.

7.4 Added Effort

Another effort, not originally part of the Payload Software Technology Study but closely related, is an analysis of the Spacelab flight 1 and 2 AO responses for additional software Technology Items.

PAYLOAD SOFTWARE TECHNOLOGY STUDY OVERVIEW



PHASE I
PAYLOAD SELECTION
EXPERIMENT ANALYSIS
PAYLOAD SOFTWARE CHARACT. AND SIZING
REASSESS AND COMPILE
11/22/76
PHASE II
REVIEW OF TECHNOLOGY FORECASTS
TECHNOLOGY EMPHASIS AREAS
SURVEY OF TECHNOLOGY EMPHASIS AREAS
TECHNOLOGY DRIVERS
MIDTERM REPORT
PHASE II
DETAILED ANALYSIS OF TECHNOLOGY DRIVERS
TECHNOLOGY DEVELOPMENT ITEMS
PHASE III
COST/TIME/ PRIORITY ASSESSMENT
TECHNOLOGY DEVELOPMENT ANALYSIS
FINAL REPORT
TECHNOLOGY DEVELOPMENT PLANS

Figure 7-1

APPENDIX A - MISCELLANEOUS

DEFINITION OF TERMS

- EXPERIMENT

  - A CONTROLLED PROCEDURE CARRIED OUT TO DISCOVER, TEST, OR DEMONSTRATE THROUGH THE USE OF A GROUP OF RELATED OR COMPLEMENTARY INSTRUMENTS, USED IN VARIOUS COMBINATIONS AND OPERATING MODES, TO COLLECT DATA PERTAINING TO SPECIFIC ASPECTS OF THEIR DOMAIN.

- INSTRUMENT

  - A DEVICE FOR MEASURING AND SOMETIMES RECORDING THE VALUE OF A QUANTITY UNDER OBSERVATION.

- INSTRUMENTATION

  - THE HARDWARE COMPONENTS USED FOR DETECTION, OBSERVATION, DATA COLLECTION MEASUREMENT, AUTOMATIC CONTROL, AUTOMATIC COMPUTATION, COMMUNICATION OR DATA PROCESSING IN SUPPORT OF OUR EXPERIMENT OBJECTIVE.

- SENSOR

  - THE GENERIC NAME OF A DEVICE THAT SENSES EITHER THE ABSOLUTE VALUE OR A CHANGE IN A PHYSICAL QUANTITY (E. G., PARAMETERS SUCH AS TEMPERATURE, PRESSURE, OR THE INTENSITY OF LIGHT, SOUND, OR RF) AND CONVERTS THAT VALUE OR CHANGE INTO A USEFUL INPUT SIGNAL FOR AN INFORMATION GATHERING SYSTEM.

- DETECTOR

  - DETECTS THE PRESENCE OR ABSENCE OF A PHYSICAL QUANTITY, SUCH AS RADIATION, CHEMICALS, ETC.

DEFINITION OF TERMS (CONTINUED)

- PAYLOAD ELEMENT
  - A RELATED COMPLEMENT OF INSTRUMENTS, SPACE HARDWARE AND SOFTWARE CARRIED TO SPACE TO ACCOMPLISH A MISSION OR DISCRETE ACTIVITY. CAN CONTAIN ONE OR MORE EXPERIMENTS.

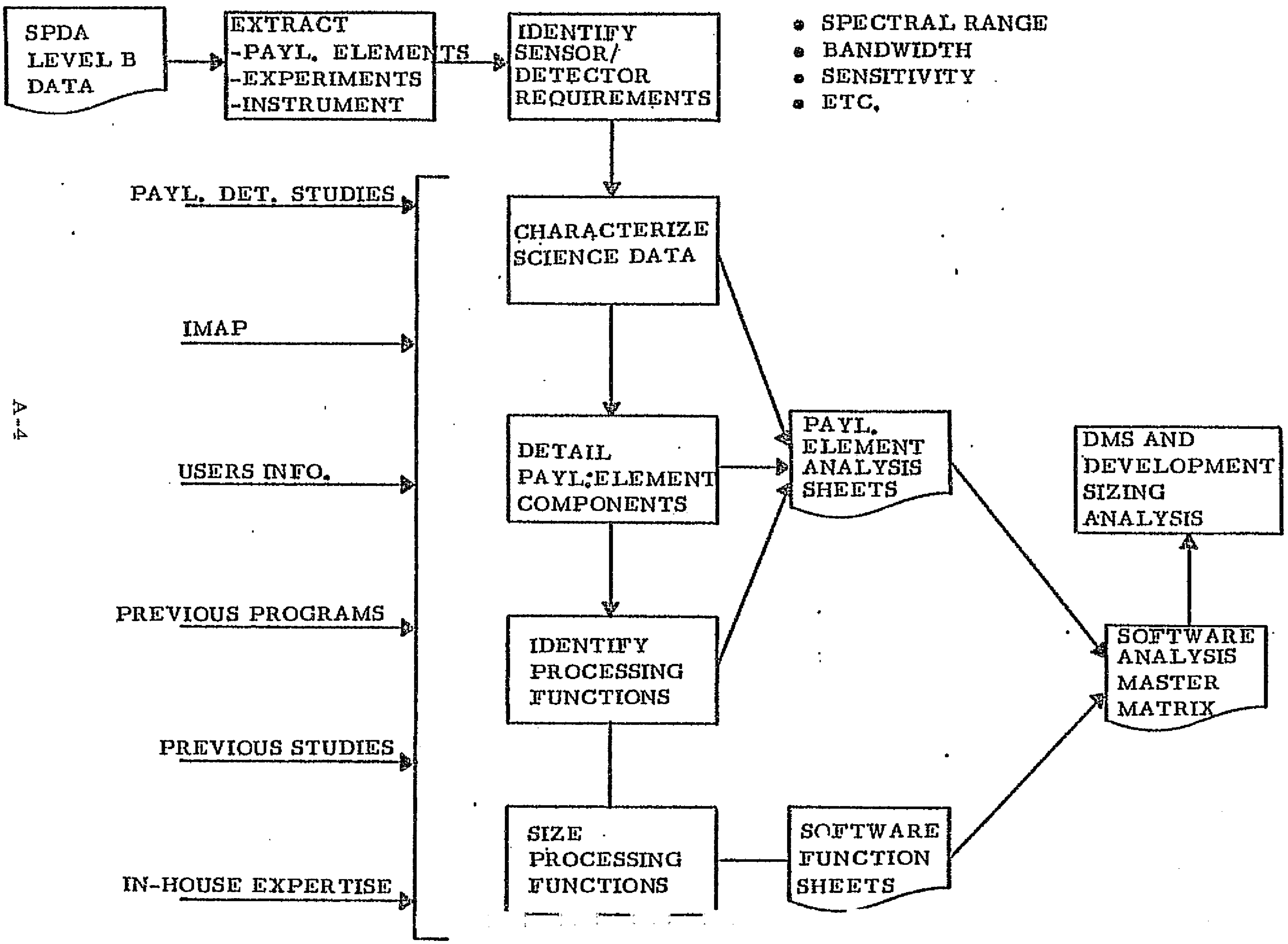
- INSTRUMENT FACILITY
  - A GENERAL-PURPOSE DEVICE CONTAINING MULTIPLE SENSORS AND DETECTORS TO SUPPORT THE PURSUIT OF SCIENTIFIC DATA WITHIN A GIVEN DISCIPLINE.

- PAYLOAD
  - ONE OR MORE PAYLOAD ELEMENTS, EITHER AUTOMATED OR SORTIE, CARRIED TO SPACE BY THE SPACE TRANSPORTATION SYSTEM.

- FLIGHT
  - TRANSPORT OF ONE PAYLOAD TO SPACE.

- MISSION
  - THE PERFORMANCE OF A COHERENT SET OF INVESTIGATIONS OR OPERATIONS IN SPACE TO ACHIEVE PROGRAM GOALS OR OBJECTIVES (ONE OR MORE FLIGHTS).

EXPERIMENT ANALYSIS TASK FLOW



SOFTWARE FUNCTION SIZING

- CORRELATED WITH AVAILABLE DATA WHERE POSSIBLE.
- NEXT GENERATION ON-BOARD PROCESSING FUNCTIONS SIZED WITH ASSUMED LIMITATIONS MAY DIFFER FROM GROUND PROCESSES SIZING.
- FUNCTION SIZING INFORMATION IS "TYPICAL." SAMM ENTRIES PROVIDE "COMPLEXITY FACTOR" WHERE APPROPRIATE.
- OPERATING SYSTEM FUNCTIONS AND FUNCTIONS UNIQUE (BUT RELATIVELY MINOR) TO SINGLE EXPERIMENT NOT INCLUDED.

EXPERIMENT ANALYSIS
DATA MANAGEMENT SYSTEM ASSUMPTIONS

- COMPUTATION CAPABILITY
  - 1 COMPUTER PLUS BACKUP, 64K OF MAIN MEMORY EACH - 128K 16-BIT WORDS
  - 1 μS CYCLE TIME, 340K EQUIVALENT ADDS PER SECOND PER COMPUTER

- MASS STORAGE
  - TAPE OR EQUIVALENT
  - READ/WRITE CAPABILITY

- * RAPID ACCESS STORAGE
  - DRUM, DISK, OR ADVANCED TECHNOLOGY DEVICES (CCD, BUBBLE, ELECTRON BEAM)
  - MINIMUM 100 MEGABITS CAPACITY
  - READ/WRITE

- * DISPLAYS
  - MONITOR/FOV COLOR CRT WITH REFRESH
  - ALPHANUMERIC/GRAPHICS DISPLAY (COLOR CRT WITH REFRESH)

- INPUT/OUTPUT
  - DATA BUS IMB (440KB EFFECTIVE)
  - SUFFICIENT NUMBER OF RAU'S
  - DMA

- INPUT/OUTPUT LIMITATIONS ARE RECOGNIZED, BUT IT IS ASSUMED THAT ADVANCING TECHNOLOGY WILL REDUCE OR EVEN REMOVE THESE LIMITATIONS THROUGH:
  - DISTRIBUTED SYSTEMS
  - HIGHER-RATE BUS

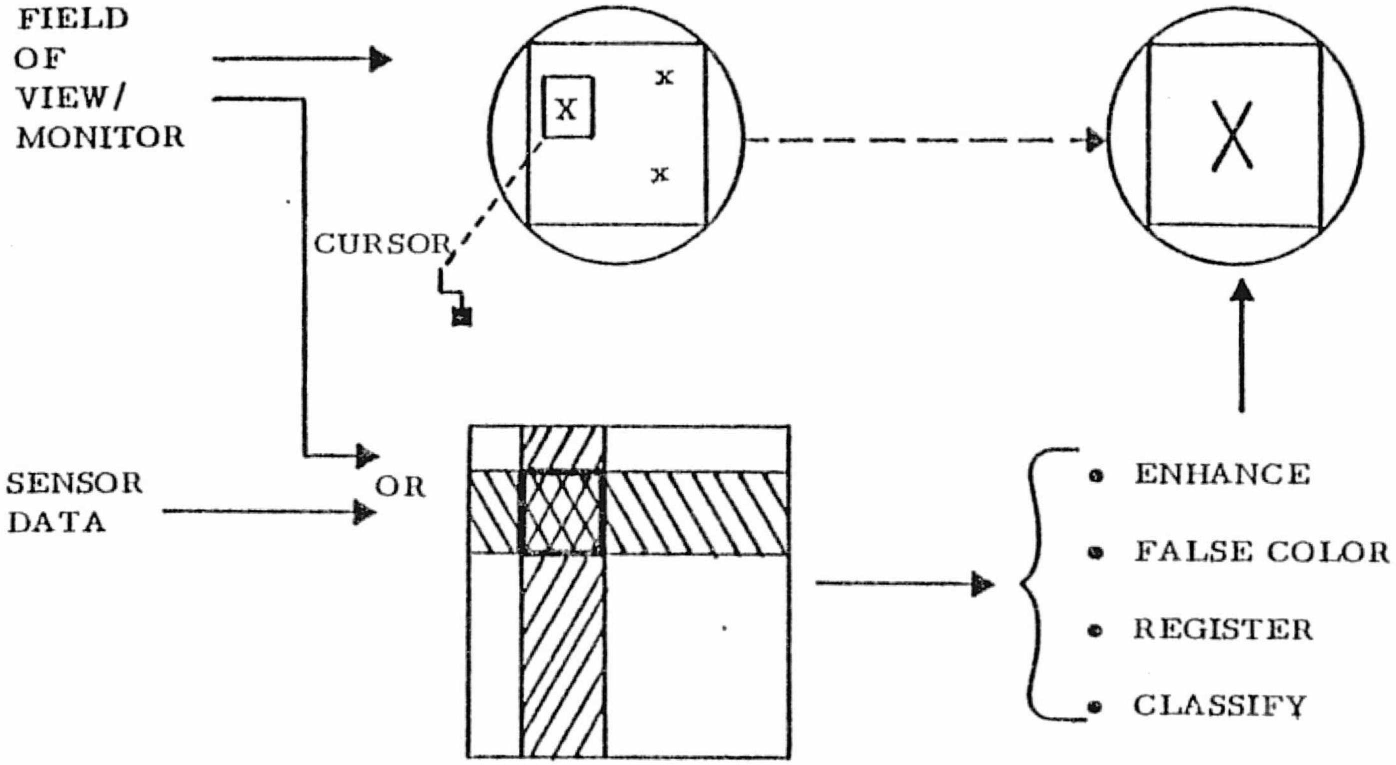
* NOT NOW AVAILABLE ON SPACELAB

ON-BOARD APPLICATION SOFTWARE FUNCTIONS - TYPICAL

- COMMAND AND CONTROL, DISPLAY, AND DATA ROUTING.
- POINTING AND SCANNING.
- TABLE-ORIENTED SEQUENCE AND MONITOR (INCLUDING C&W).
- ANNOTATION AND ENGINEERING UNIT CONVERSION.
- SENSOR ORIENTED GEOMETRIC CORRECTIONS (IMAGE).
- DETECTOR CALIBRATION AND CORRECTION.
- VIDICON FILTER AND CORRECTION.
- SPECIAL COORDINATE OVERLAYS ON FOV MONITOR.
- ENHANCEMENT AND FALSE COLOR FOR ANY IMAGING EXPERIMENT.
- REGISTRATION FOR MULTISPECTAL IMAGES (BAND TO BAND).
- CLASSIFICATION FOR MULTISPECTRAL IMAGES (SCIENCE AND E.O.).
- FOURIER ANALYSIS FOR INTERFEROMETERS, SAR, ETC.
- TRANSFORMS AND DPCM FOR DATA COMPRESSION.

ON-BOARD PARTIAL IMAGE PROCESSING

FOV/MONITOR



FIELD OF VIEW/ MONITOR

CURSOR

SENSOR DATA

OR

- ENHANCE
- FALSE COLOR
- REGISTER
- CLASSIFY

DATA ENVIRONMENT SCENARIO VS. SOFTWARE FUNCTION (DESF) MATRIX

SL. NUMBER	SOFTWARE FUNCTION → PATTERN RECOGNITION ENVIRONMENT DESCRIPTIONS - TYPICAL CASES ↓	Parametric Feature Selection	Non-Parametric Feature Selection	Probabilistic Assignment of Labels	Estimation of Level of Supervision	Learning Distribution Parameters	Non-Parametric Discriminants Design	Parametric Classification	Non-Parametric Classification	Clustering Procedure	Self-Learning the Number of Classes	REMARKS
1	• Minimum number of features. • Known number of classes. • Known probabilistic descriptions. • Known distribution parameters.							▨				Ideal Case. Theoretically maximum classification efficiency attainable. Hardly practical data environment scenario.
2	• Large number of features. • Unknown number of classes. • No probabilistic descriptions. (Only the samples awaiting classification are available).		▨				▨		▨	▨	▨	Most Critical Case. Minimum information available. Relatively high computational loads. Reliability of results not very high.
3	• Large number of features. • Known number of classes. • Known distributions. • Unknown distribution parameters. • Reliably labeled Training Samples.	▨				▨		▨				A Typical Case assumed in most studies and existing pattern recognition systems. Assumptions, not always realistic, made for mathematical convenience.
4	• Large number of features. • Known number of classes. • Unknown distributions. • Reliably labeled Training Samples.		▨				▨		▨			A more realistic case backed by a large number of studies and resultant methodologies less computational loads than in Case 3, feasible under some methods.
5	• Minimum number of features. • Known number of classes. • Known distributions. • Unknown distribution parameters. • Unlabeled Training Samples.			▨		▨		▨				A fairly powerful approach to a rather severe class of problems. Referred to as learning with a probabilistic teacher.
6	• Large number of features. • Known number of classes. • Known distributions. • Unknown distribution parameters. • Labeled Training Samples. • Reliability of labels unknown.	▨		▨	▨	▨		▨				Significantly more versatile approach catering to a highly realistic class of scenarios. Referred to as a unified approach to feature selection and learning in unfamiliar teacher environments.

DATA COMPRESSION: REQUIREMENTS AND CURRENT STATUS CHART

CLASS OF APPLICATIONS (REQUIRING)	OFS PROJECTED* (BY THE YEAR 2000) COMPRESSION RATIO	CURRENTLY AVAILABLE APPROACHES	ASSOCIATED RANGE OF COMPRESSION RATIOS	IMPLEMENTATION COMPLEXITY RATING	REMARKS
EXACT RECONSTRUCTION OF THE ORIGINAL IMAGE IN EACH CHANNEL (I CATEOGRY)	8	ENCODING SCHEMES	1.2 - 2	1	COMPRESSION RATIOS CURRENTLY ATTAINABLE TOO SMALL. MAJOR CONCEPTUAL/TECHNOLOGICAL ADVANCEMENTS NEEDED
GOOD APPROXIMATION OF THE ORIGINAL IMAGE WITH LITTLE VISUALLY PERCEPTIBLE DISTORTION IN EACH CHANNEL (II CATEGORY)	16	DPCM AND OTHER APPROXIMATE APPROACHES IN A STANDALONE MODE	1.4 - 3	2	THESE APPROACHES BY THEMSELVES FALL FAR SHORT OF THE REQUIREMENTS OF THIS CATEGORY
		1-D TRANSFORM IN SPECTRAL DOMAIN COMBINED WITH DPCM AND HUFFMAN CODING	3 - 5	3	MOST PROMISING APPROACH AS PER TRW STUDY WHICH STILL DOES NOT LEAD TO DESIRED COMPRESSION RATIOS
		OTHER ALTERNATIVES, SUCH AS 2 AND 3D TRANSFORMS IN SPATIAL (AND SPECTRAL) DOMAIN FOLLOWED BY DPCM AND ENCODING TECHNIQUES, NOT EVALUATED BY THE TRW STUDY	?	6	NEEDS DETAILED ASSESSMENT AND FURTHER STUDY TO DETERMINE THE EFFECTIVE COMPRESSION RATIOS AND IDENTIFY PROBLEMS (IF ANY) IN THEIR ONBOARD IMPLEMENTATION
ONLY A RECOGNITION MAP (III CATEGORY) OR ONLY CERTAIN KEY FEATURES OR CHANGES IN THE SCENE (IV CATEGORY)	400 - 2000	CLUSTER CODING, CLASSIFICATION, CHANGE DETECTION METHODOLOGIES	10 - 100	10 OR MORE	FAIRLY HIGH COMPRESSION RATIOS ATTAINABLE. HOWEVER, OTHER ONBOARD IMPLEMENTATION PROBLEMS ARISE

* OFS PROJECTIONS OF "WHAT WILL BE" FALL SHORT OF "WHAT IS DESIRED" (IN VIEW OF THE EXPECTED DATA RATES IN FUTURE MISSIONS) IN THE FIRST TWO CATEGORIES OF APPLICATIONS.

SPACELAB MISSION 1 (STRAWMAN)

COMMON FUNCTIONS		INST.	DATA
Command and Control		630	576
Annotation and Time Tag		300	562
Display		350	432
Monitor		400	576
Convert to Engineering Units		500	1024
		2180	3170
AP-09-S	Checkout	500	550
	Scanning Control	520	1024
AP-13-S	Pointing Control	600	36
EO-01-S	Checkout	500	550
	Calibration	500	250
	Operation	1200	250
	Graphic Display	400	2048
LS-13-S	Operation	270	150
APE-01	Checkout	500	550
	Operation	430	20
	Graphic Display	400	2048
APE-07	Calibration	500	250
	Operation	360	72
	Graphic Display	400	2048
SPE-01		---	---
SPE-80/85	Operation	310	72
STE-10	Operation	780	82
	Graphic Display	400	2048
ASE-01		---	---
EOE-01	Operation	730	206
		11480	15424
Total			
		26904	

SPACELAB MISSION 2 (STRAWMAN)

COMMON FUNCTIONS		INST.	DATA
Command and Control		630	576
Annotation and Time Tag		300	562
Display		350	432
Monitor		400	576
Convert to Engineering Units		500	1024
		2180	3170
SO-01-S/SO-11-S/54	Checkout	500	550
	Pointing Control (IPS)	600	36
	Operation	1200	250
	Graphic Display	400	2048
SO-01-S/SO-11-S/S-3b	Checkout	500	550
	Pointing Control (IPS)	600	36
	Scanning Control	520	1024
	Operation	1200	250
	Graphic Display	400	2048
SO-52	Checkout	500	550
	Pointing Control	600	36
	Operation	1200	250
SO-01-S/S-5	Checkout	560	550
	Pointing Control (Minimount)	600	36
	Operations	1200	250
G-VII	Checkout	500	550
	Operation	1200	250
		14400	12434
Total		26834	

OAST TECHNOLOGY ITEMS
(WORKSHOPS 75/76)

- SOFTWARE DEVELOPMENT:
  - COORDINATION OF NASA R&D IN COMPUTERS AND INFORMATION SCIENCE
  - SOFTWARE GENERATION AND HUMAN-MACHINE INTERACTION
  - SOFTWARE MANAGEMENT
  - SOFTWARE VERIFICATION AND VALIDATION
  - OPERATIONS LANGUAGES
  - EVOLUTIONARY SOFTWARE
  - PROGRAMMING METHODOLOGY
  - SOFTWARE COMMONALITY
  - PROGRAMMING LANGUAGE AND TRANSLATORS
  - SIMULATION
  - EFFICIENT EMULATION
  - AUTOMATED PROGRAMMING

- SOFTWARE SYSTEMS ARCHITECTURE:
  - NETWORKING FOR NASA COMPUTER FACILITY AND SOFTWARE SHARING
  - MULTIDIMENSIONAL DATA SYSTEMS
  - SOFTWARE FOR SYSTEMS INTEGRITY
  - INTELLIGENT EXECUTIVE PROGRAMS
  - HIGH-VOLUME DATA BUFFERING
  - SYSTEM SECURITY SOFTWARE

- SOFTWARE APPLICATIONS:
  - AUTOMATION OF GROUND SUPPORT FUNCTIONS
  - INFORMATION EXTRACTION AND DATA COMPRESSION
  - RECOGNITION PROCESSING OF IMAGE TYPE DATA ON-BOARD SPACECRAFT
  - ON-BOARD PREPROCESSING OF MULTISPECTRAL SCANNER DATA
  - MODULAR PARALLEL PIPELINE PROCESSOR
  - MISSION PLANNING AND SCHEDULING TOOLS
  - PATTERN RECOGNITION
  - AUTONOMOUS SYSTEMS WITH ARTIFICIAL INTELLIGENCE
  - ALGORITHMS/NUMERICS
  - AUTOMATED INTELLIGENCE SUPPORT

MIDTERM REPORT OUTLINE

SECTION 1 - INTRODUCTION DESCRIBES THE PURPOSE OF THIS REPORT, THE STATUS OF THE STUDY AND THE MANNER IN WHICH THIS REPORT IS ORGANIZED.

SECTION 2 - STUDY SUMMARY IS THE EXECUTIVE SUMMARY.
2.1 OBJECTIVES DESCRIBES THE PURPOSE AND SCOPE OF THE STUDY.
2.2 APPROACH DESCRIBES THE STUDY PLAN USED AND THE ASSOCIATED MAJOR MILESTONES.
2.3 RESULTS SUMMARIZES THE RESULTS OF THE STUDY.

SECTION 3 - PAYLOAD SELECTION DESCRIBES THE RATIONAL FOR SELECTION OF THE SPECIFIC COMPLEMENT OF EXPERIMENTS ANALYZED DURING THE STUDY.

SECTION 4 - SPACE TECHNOLOGY FORECASTS REVIEW DESCRIBES THE IDENTIFICATION AND CLASSIFICATION OF SOFTWARE TECHNOLOGY AREAS SELECTED FOR EMPHASIS.

SECTION 5 - EXPERIMENT ANALYSIS DESCRIBES THE APPROACH AND MATERIAL USED TO PERFORM THE EXPERIMENT ANALYSIS AND SUMMARIZES THE RESULTS.

SECTION 6 - TECHNOLOGY DRIVER SELECTION SUMMARIZES THE TECHNOLOGY DRIVERS SELECTED AND THE REASONS FOR THEIR SELECTION.

SECTION 7 - FUTURE PLANS DESCRIBES THE EFFORTS REMAINING TO BE PERFORMED UNDER THIS CONTRACT.

APPENDIX A - SOFTWARE FUNCTIONS PROVIDES A COMPLETE DESCRIPTION OF THE DERIVED EXPERIMENT SOFTWARE FUNCTIONS AND THEIR SIZING PARAMETERS.

APPENDIX B - EXPERIMENT ANALYSIS SHEETS CONTAINS SHEETS FOR EACH ANALYZED PAYLOAD ELEMENT AND THEIR ASSOCIATED EXPERIMENTS DESCRIBING MAJOR COMPONENTS, DATA CHARACTERISTICS, AND FUNCTIONS TO BE PERFORMED.

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APPENDIX B

SOFTWARE FUNCTIONS SIZING

(AVAILABLE ON REQUEST)

APPENDIX C

PAYLOAD ELEMENT ANALYSIS SHEETS

(AVAILABLE ON REQUEST)

APPENDIX D

SOFTWARE ANALYSIS MASTER MATRIX

PAGE IS
QUALITY

AYLOAD EMENT	EXPERIMENT	COMMAND & CONTOL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFOSMATION 106	DATA COMPRESSION (SIMPLE)107	DATA COMPRESSION (COMPLEX)108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON)209	CALIBRATE STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405
AS-01-S		1	1	1	1	1		1				1			1		1											1			1	1		1	1											1	1					1					
	XAS-001						1																																														1				
	XAS-002						1																	1		1										1		1															1	1			
	XAS-003						1																		1																												1				
	XAS-004																																																				1				
	XAS-005						1																																														1				
	XAS-006						1																																															1		
AS-03-S		1	1		1	1		1				1			1		1															1		1																		1	1				
	XAS-031																																																								
	XAS-032																																																								
	XAS-033																																																								
	XAS-034																																																								

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	ALPHANUMERIC DISPLAY 102	GRAPHIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION(SIMPLE)107	DATA COMPRESSION(COMPLEX)108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE). 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELDS OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON)209	STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	CHECKOUT 305	CALIBRATION DETECTOR 400	CALIBRATION (IMAGERS & ARRAYS) 401	CALIBRATION (INTERFEROMETERS) 402	403	404	405	
AS-04-S		1	1		1	1		1				1			1		1															1		1																		1	1					
	XAS-041																																																									
	XAS-042																																																									
	XAS-043																																																									
	XAS-044																																																									
AS-05-S		1	1		1	1						1			1		1															1		1																		1	1					
	XAS-051																																																									
AS-15-S		1	1	1	1	1		1				1			1		1														1	1		1	1											1	1					1						
	XAS-151						1																			1										1		1																1				
	XAS-152						1																			1										1		1																1				
	XAS-153																																																				1					
	XAS-154																																																				1					
	XAS-155																																																				1					

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION (COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121
AS-63-S		1	1		1	1						1			1		1						
	XAS-631																						
	XAS-632							1															
HE-11-S		1	1	1	1	1		1				1			1		1						
	XHE-111																						
	XHE-112																						
HE-15-S		1	1	1	1							1		1	1		1						
	XHE-151																						
	XHE-152																						
	XHE-153																						

PAYLOAD ELEMENT	EXPERIMENT	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON)209	STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405
AS-63-S											1		1																		1	1			
	XAS-631																																		
	XAS-632																																		
HE-11-S										1	1		1												1	1					1	1			
	XHE-111																																		
	XHE-112																																		
HE-15-S										1	1		1												1	1					1	1			
	XHE-151																																		
	XHE-152																																		
	XHE-153																																		

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OF POOR QUALITY

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION(COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206
HE-19-S		1	1		1	1		1				1			1		1													
	XHE-191																							1						1
	XHE-192																							1						1
	XHE-193			1																										
	XHE-194			1																										
HE-25-S		1	1	1	1							1		1	1		1													
	XHE-251																													
SO-01-S		1	1		1							1	1		1		1													
	XSO-001					1		1																1						1
	XSO-002			1		1		1																1						1
	XSO-003					1		1																						
	XSO-004			1		1	1	1																						
	XSO-005			1		1		1																						1
	XSO-020			1		1		1																						1

PAYLOAD ELEMENT	EXPERIMENT	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON) 209	STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION 215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION 300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405	
HE-19-S		1	1		1				1								1	1					1	1					
	XHE-191			1			1																						
	XHE-192			1			1																						
	XHE-193																												
	XHE-194																												
HE-25-S		1	1		1												1	1					1	1					
	XHE-251																												
SO-01-S		1			1												1	1					1						
	XSO-001		1	1			1		1															1					
	XSO-002		1	1			1	1	1															1					
	XSO-003		1						1															1					
	XSO-004		1					1	1															1					
	XSO-005		1	1					1															1					
	XSO-020		1	1					1															1					

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE)107	DATA COMPRESSION(COMPLEX)108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON)209	STATE VECTOR 210	CALIBRATE (COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION215	216	217	318	319	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405
SO-01-S	XSO-007			1		1		1																						1		1	1					1															1				
	XSO-008			1		1		1																								1						1															1				
	XSO-009			1		1		1																								1																					1				
	XSO-011			1																																																	1				
	XSO-012			1							1																																										1				
	XSO-013			1							1																																										1				
	XSO-014			1							1																																										1				
	XSO-015			1																																																					
	XSO-016			1																																																					
	XSO-017			1							1																																										1				
	XSO-018			1							1																																										1				

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION(COMPLEX)108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115
SO-11-S		✓	✓		✓	✓		✓				✓	✓		✓		✓
	XSO-001																
	XSO-002			✓													
	XSO-003																
	XSO-004			✓			✓										
	XSO-005			✓													
	XSO-020			✓													
	XSO-007			✓													
	XSO-008			✓													
	XSO-009			✓													

PAYLOAD ELEMENT	EXPERIMENT	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON)209	CALIBRATE STATE VECTOR 210	COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION215
SO-11-S															✓	✓		✓					
	XSO-001							✓						✓			✓			✓		✓	
	XSO-002							✓						✓			✓			✓	✓	✓	
	XSO-003																					✓	
	XSO-004																				✓	✓	
	XSO-005													✓			✓					✓	
	XSO-020													✓			✓					✓	
	XSO-007													✓			✓					✓	
	XSO-008																					✓	
	XSO-009																						

PAYLOAD ELEMENT	EXPERIMENT	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405	
SO-11-S								✓	✓					✓	✓					
	XSO-001																			
	XSO-002																			
	XSO-003																			
	XSO-004																			
	XSO-005																			
	XSO-020																			
	XSO-007																			
	XSO-008																			
	XSO-009																			

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTAOL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION (COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 109	ANNCTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOL UTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON)209	STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405	
SO-15-S		I	I		I							I	I		I		I														I			I												I	I					I						
	XSO-002			I		I		I																I						I		I	I			I	I	I															I					
	XSO-003					I		I																								I						I															I					
	XSO-004			I		I	I	I																								I					I	I															I					
	XSO-005			I		I		I																						I		I	I					I															I					
	XSO-020			I		I		I																						I		I	I					I															I					
	XSO-009			I		I		I																								I						I															I					
	XSO-011			I																																																	I					
	XSO-013			I							I																																										I					
	XSO-015			I																																																						
	XSO-018			I							I																																										I					
	XSO-101					I		I																								I																					I					

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION (COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON) 209	STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION 215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION 300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405	
SO-17-S		I	I		I		I					I			I		I														I	I		I				I								I	I					I	I					
	XSO-301																																																									
	XSO-302																																																									
	XSO-303																																																									
	XSO-304																																																									

PAYLOAD ELEMENT	EXPERIMENT	100 COMMAND & CONTROL	101 MONITOR & DATA CONTROL	102 GRAPHIC DISPLAY	103 ALPHANUMERIC DISPLAY	104 POINTING CONTROL	105 SCANNING CONTROL	106 REFERENCE FRAME TRANSFORMATION	107 DATA COMPRESSION (SIMPLE)	108 DATA COMPRESSION(COMPLEX)	109 TWO BODY COORDINATE TRANSFORMATION	110 ANNOTATION & TIME TAG	111 CYCLIC CHECKOUT	112 PARTICLE TRAJECTORY	113 EXPERIMENT SEQUENCE CONTROL	114 UNIQUE APPLICATIONS	115 CAUTION & WARNING	116	117	118	119	120	121
AP-08-S		I	I	I	I	I						I			I		I						
	XAP-810																						
	XAP-820																						
AP-09-S		I	I	I	I		I				I	I			I		I						
	XAP-910																						
	XAP-920																						
	XAP-930																						
AP-10-S		I	I	I	I	I					I	I			I		I						
	XAP-110																						
AP-11-S		I	I	I	I	I					I	I			I		I						
	XAP-110																						
	XAP-130																						

PAYLOAD ELEMENT	EXPERIMENT	200 PSEUDO COLORING	201 TRANSFORM AND CONVOLUTION	202 SCAN LINE OFFSET	203 REGISTRATION (SUB IMAGE)	204 RADIANCE UNIT CONVERSION/CORRECTION	205 RADIANCE UNIT CALIBRATION	206 NOISE REMOVAL (VIDICON)	207 CONVERT TO ENGINEERING UNITS	208 FIELD OF VIEW CALCULATIONS	209 PHOTOMETRIC CORRECTION (VIDICON)	210 STATE VECTOR	211 CALIBRATE COUNT/AVERAGE	212 IMAGE ENHANCEMENT	213 CLASSIFICATION	214 GEOMETRIC CORRECTION (OPTICS)	215 GEOMETRIC CORRECTION	216	217	218	219	220	221
AP-08-S									I	I	I	I				I							
	XAP-810																						
	XAP-820																						
AP-09-S									I	I	I	I				I							
	XAP-910																						
	XAP-920																						
	XAP-930																						
AP-10-S									I	I		I											
	XAP-110																						
AP-11-S									I	I		I											
	XAP-110																						
	XAP-130					I																	

PAYLOAD ELEMENT	EXPERIMENT	300 REFORMAT, SKEW REMOVAL, TIME CONVERSION	301 DATA EDIT & DECOMMUTATE	302 DATA DECOMPRESSION/DECODING	303	304	305	400 CHECKOUT	401 CALIBRATION DETECTOR	402 CALIBRATION (IMAGERS & ARRAYS)	403 CALIBRATION (INTERFEROMETERS)	404	405	
AP-08-S		I	I					I	I					
	XAP-810													
	XAP-820													
AP-09-S		I	I					I	I					
	XAP-910													
	XAP-920													
	XAP-930													
AP-10-S		I	I					I	I					
	XAP-110													
AP-11-S		I	I					I	I					
	XAP-110													
	XAP-130													

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION (COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSSUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON) 209	STATE VECTORS 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION 215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION 300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405	
AP-12-S		I	I	I	I	I					I	I			I		I											I			I	I		I												I	I					I	I					
	XAP-250																																																									
	XAP-260																																																									
	XAP-270																																																									
AP-13-S		I	I		I	I		I				I			I		I													I	I	I	I	I				I								I	I					I		I				
	XAP-910																																																									
	XAP-930																																																									
	XAP-450																																																									
LS-04-S		I	I		I			I			I	I				I	I														I	I		I												I	I											
	XLS-430																																																									
	XLS-431																																																									
	XLS-432																																																									
	XLS-433																																																									
	XLS-434																																																									
	XLS-435																																																									

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION(COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON) 209	STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION 215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION 300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405	
LS-09-S		1	1	1	1							1			1																1															1	1											
D-12	XLS-100																																																									
	XLS-200																																																									
	XLS-300																																																									
	XLS-400							1			1					1	1																1		1																							
LS-10-S		1	1	1	1							1			1																1															1	1											
	XLS-100																																																									
	XLS-200																																																									
	XLS-300																																																									
	XLS-400							1			1					1	1																1		1																							

PAYLOAD ELEMENT	EXPERIMENT	MONITOR & CONTROL 100	COMMAND & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION(COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON) 209	STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION 215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION 300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	CHECKOUT 305	CALIBRATION DETECTOR 400	CALIBRATION (IMAGERS & ARRAYS) 401	CALIBRATION (INTERFEROMETERS) 402	403	404	405
LS-13-S		I	I	I	I							I			I																I															I	I										
D-13	XLS-710																							N	O	N	E																														
	XLS-720																																																								
	XLS-730																							N	O	N	E																														
	XLS-740																																																								
EO-05-S		I	I	I	I		I	I	I			I			I		I							I		I	I	I	I		I	I		I		I	I		I							I	I	I				I		I			
	XEO-044																																																								

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION (COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121
EO-06-S		I	I	I	I		I			I		I			I		I						
	XEO-045																						
EO-19-S		I	I	I	I		I					I			I		I						
	XEO-047																						
EO-20-S		I	I	I	I	I				I		I			I		I						
	XEO-046																						
EO-21-S		I	I	I	I		I			I		I			I		I						
	XEO-043																						
EO-22-S		I	I	I	I		I	I				I			I		I						
	XEO-034																						

PAYLOAD ELEMENT	EXPERIMENT	PS:UDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON) 209	STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION 215	216	217	218	219	220	221
EO-06-S		I		I	I	I	I		I			I		I	I	I	I						
	XEO-045																						
EO-19-S			I			I	I		I			I				I							
	XEO-047																						
EO-20-S		I			I	I	I		I	I		I		I	I		I						
	XEO-046																						
EO-21-S		I		I	I	I	I		I	I		I		I	I		I						
	XEO-043																						
EO-22-S			I			I	I		I	I		I				I							
	XEO-034																						

PAYLOAD ELEMENT	EXPERIMENT	REFORMAT, SKEW REMOVAL, TIME CONVERSION 300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	CHECKOUT 305	CALIBRATION DETECTOR 400	CALIBRATION (IMAGERS & ARRAYS) 401	CALIBRATION (INTERFEROMETERS) 402	403	404	405	
EO-06-S		I	I	I				I		I				
	XEO-045													
EO-19-S		I	I					I			I			
	XEO-047													
EO-20-S		I	I	I				I		I				
	XEO-046													
EO-21-S		I	I	I				I		I				
	XEO-043													
EO-22-S		I	I					I			I			
	XEO-034													

PAYLOAD ELEMENT	EXPERIMENT	COMMAND & CONTROL 100	MONITOR & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION (COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 109	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	120	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON)209	STATE VECTOR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOUT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405	
OP-02-S		1	1	1	1		1			1		1			1		1							1		1	1	1	1		1			1	1	1	1	1	1							1	1	1				1		1	1			
	XOP-001							1																								1																										
	XOS-007					1																																																				
OP-03-S		1	1	1	1	1	1			1		1			1		1							1		1	1	1	1		1			1	1	1	1	1	1							1	1	1				1	1	1				
	XOP-011																																																									
OP-04-S		1	1	1	1	1						1			1		1											1	1		1			1				1								1	1					1	1	1				
	XOP-009																																																									
OP-05-S		1	1	1	1		1			1		1			1		1							1		1	1	1	1		1			1	1	1	1	1	1							1	1	1				1		1	1			
	XOP-001							1																								1																										
	XOP-007					1			1																																																	
									1																																																	
OP-06-S		1	1	1	1	1									1		1											1	1		1			1				1								1	1					1		1				
	XOP-012																																																									

PAYLOAD ELEMENT	EXPERIMENT	MONITOR & CONTROL 100	COMMAND & DATA CONTROL 101	GRAPHIC DISPLAY 102	ALPHANUMERIC DISPLAY 103	POINTING CONTROL 104	SCANNING CONTROL 105	REFERENCE FRAME TRANSFORMATION 106	DATA COMPRESSION (SIMPLE) 107	DATA COMPRESSION (COMPLEX) 108	TWO BODY COORDINATE TRANSFORMATION 09	ANNOTATION & TIME TAG 110	CYCLIC CHECKOUT 111	PARTICLE TRAJECTORY 112	EXPERIMENT SEQUENCE CONTROL 113	UNIQUE APPLICATIONS 114	CAUTION & WARNING 115	116	117	118	119	I20	121	PSEUDO COLORING 200	TRANSFORM AND CONVOLUTION 201	SCAN LINE OFFSET 202	REGISTRATION (SUB IMAGE) 203	RADIANCE UNIT CONVERSION/CORRECTION 204	RADIANCE UNIT CALIBRATION 205	NOISE REMOVAL (VIDICON) 206	CONVERT TO ENGINEERING UNITS 207	FIELD OF VIEW CALCULATIONS 208	PHOTOMETRIC CORRECTION (VIDICON) 209	STATE VECTOR(OR 210	CALIBRATE COUNT/AVERAGE 211	IMAGE ENHANCEMENT 212	CLASSIFICATION 213	GEOMETRIC CORRECTION (OPTICS) 214	GEOMETRIC CORRECTION 215	216	217	218	219	220	221	REFORMAT, SKEW REMOVAL, TIME CONVERSION 300	DATA EDIT & DECOMMUTATE 301	DATA DECOMPRESSION/DECODING 302	303	304	305	CHECKOLT 400	CALIBRATION DETECTOR 401	CALIBRATION (IMAGERS & ARRAYS) 402	CALIBRATION (INTERFEROMETERS) 403	404	405	
CN-04-S		1	1	1	1	1						1			1		1												1		1			1												1	1					1		1				
	XCN-050																																																									
	XCN-051																																																									
	XCN-052																																																									
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	XCN-058																																																									

PAYLOAD ELEMENT	EXPERIMENT	100 COMMAND & CONTROL	101 MONITOR & DATA CONTROL	102 GRAPHIC DISPLAY	103 ALPHANUMERIC DISPLAY	104 POINTING CONTROL	105 SCANNING CONTROL	106 REFERENCE FRAME TRANSFORMATION	107 DATA COMPRESSION (SIMPLE)	108 DATA COMPRESSION (COMPLEX)	109 TWO BODY COORDINATE TRANSFORMATION	110 ANNOTATION & TIME TAG	111 CYCLIC CHECKOUT	112 PARTICLE TRAJECTORY	113 EXPERIMENT SEQUENCE CONTROL	114 UNIQUE APPLICATIONS	115 CAUTION & WARNING	116	117	118	119	120	121	200 PSEUDO COLORING	201 TRANSFORM AND CONVOLUTION	202 SCAN LINE OFFSET	203 REGISTRATION (SUB IMAGE)	204 RADIANCE UNIT CONVERSION/CORRECTION	205 RADIANCE UNIT CALIBRATION	206 NOISE REMOVAL (VIDICON)	207 CONVERT TO ENGINEERING UNITS	208 FIELD OF VIEW CALCULATIONS	209 PHOTOMETRIC CORRECTION (VIDICON)	210 STATE VECTOR	211 CALIBRATE COUNT/AVERAGE	212 IMAGE ENHANCEMENT	213 CLASSIFICATION	214 GEOMETRIC CORRECTION (OPTICS)	215 GEOMETRIC CORRECTION	216	217	218	219	220	221	300 REFORMAT, SKEW REMOVAL, TIME CONVERSION	301 DATA EDIT & DECOMMUTATE	302 DATA DECOMPRESSION/DECODING	303	304	305 CHECKOUT	400 CALIBRATION DETECTOR	401 CALIBRATION (IMAGERS & ARRAYS)	402 CALIBRATION (INTERFEROMETERS)	403	404	405	
CN-05-S		1	1	1	1	1						1			1		1														1			1				1								1	1					1	1					
	XCN-035																											1																														
	XCN-036																											1																														
	XCN-037																																																									
	XCN-038																																																									
	XCN-039																																																									
CN-08-S		1	1	1	1							1			1		1														1			1												1	1					1	1					
	XCN-026																											1																														
	XCN-027																																																									