Prepared for the
GEORGE C. MARSHALL
SPACE FLIGHT CENTER
Huntsville, Alabama

MAY, 1975

Contract No. NAS8-31009
IBM No. 75W-00072

IUS/TUG ORBITAL OPERATIONS and MISSION SUPPORT STUDY

FINAL REPORT

Vol. II of V - Interim Upper Stage Operations

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Classification and Content Approval ______________________

Data Manager Approval ______________________

Program Office Approval ______________________

PHILCO
Philco-Ford Corporation
Western Development Laboratories Division

IBM Federal Systems Division, Space Systems/Huntsville, Alabama

FOREWORD

This final report of the IUS/Tug Orbital Operations and Mission Study was prepared for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center by the IBM Corporation in accordance with Contract NAS8-31009.

The study effort described herein was conducted under the direction of NASA Contract Officer's Representative (COR), Mr. Sidney P. Saucier. This report was prepared by the IBM Corporation, Federal Systems Division, Huntsville, Alabama, under the direction of Mr. Roy E. Day, IBM Study Manager. Technical support was provided to IBM by the Philco-Ford Corporation, Western Development Laboratories Division, Palo Alto, California, under the direction of Dr. W. E. Waters, Philco-Ford Study Manager. The study results were developed during the period from June, 1974, through February, 1975, with the final report being distributed in May, 1975.

The results of this study have been documented in five separate volumes.

Volume I	Executive Summary
Volume II	IUS Operations
Volume III	Tug Operations
Volume IV	Project Planning Data
Volume V	Cost Estimates

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ACRONYMS AND ABBREVIATIONS

ACN - Ascension Island, STDN Ground Station
ACS - Attitude Control System
ADS - Advanced Data System
AFSCF - Air Force Satellite Control Facility
AFSTC - Air Force Satellite Test Center
AGE - Automated Ground Equipment
AGO - Santiago, Chile - STDN Ground Station
AOS - Acquisition of Signal
AZ-EL - Azimuth - Elevation

BDA - Bermuda (U.K) - STDN Ground Station
BITE - Built-In-Test-Equipment
B/U - Backup

C&D - Control and Display
C&W - Caution and Warning
CCTV - Closed Circuit Television
CMDS - Command
COMM - Communications
C/O - Checkout
CPU - Central Processing Unit (Computer)
CYI - Canary Island - STDN Ground Station

DCS - Digital Command System
DDT&E - Design, Development, Test and Evaluation
DFCS - Digital Flight Control System
DMS - Data Management System
DoD - Department of Defense
DSN - Deep Space Network
DTE - Digital TV Equipment

EIUS - Expendable Interim Upper Stage
EVA - Extravehicular Activity

FPS - Feet Per Second

GDS - Goldstone, Calif. - STDN Ground Station
GMT - Greenwich Mean Time
GN&C - Guidance, Navigation and Control
GND - Ground
GPCF - General Purpose Control Facility
GSE - Ground Support Equipment
GSFC - Goddard Space Flight Center, Greenbelt, MD.
GWM - Guam Island - STDN Ground Station

HAW - Hawaii - STDN Ground Station
HSK - Honeysuckle Creek (Canberra), Australia - STDN Ground Station

IGPS - Inertial Guidance Power System
IGS - Inertial Guidance System
IMU - Inertial Measuring Unit

IUS - Interim Upper Stage
IUS/OC - Interim Upper Stage Operations Center

JPL - Jet Propulsion Lab, Pasadena, California
JSC - Johnson Spacecraft Center, Houston, Texas

KADS - Kilo-Add Instruction Executions Per Second
KBPS - Kilobits Per Second
KM - Kilometers
KOPS - Kilo-Operations Per Second
KS - Kick Stage
KSA - Ku-Band Single-Access
KSC - Kennedy Space Center, Cape Canaveral, Florida

LOS - Loss of Signal/Line of Sight
LPS - Launch Processing System

MA - Multiple Access
MAD - Madrid, Spain - STDN Ground Station
M&O - Maintenance and Operations
MBPS - Megabits Per Second
MCC - Mission Control Center
MED - Manual Entry Device
MDM - Multiplexer/Demultiplexer (Orbiter)
MHz - Megahertz
MIL - Merritt Island, Florida - STDN Ground Station
MODEM - Modulator/Demodulator
MPS - Main Propulsion System
MR - Mixture Ratio
MSFC - Marshall Space Flight Center, Huntsville, Alabama
MSS - Mission Specialist Station (Orbiter)

NASA - National Aeronautics and Space Administration
NASCOM - NASA Communications Network
NOCC - Networks Operations Control Center

ODS - Orbit Determination System
ORR - Orroral, Australia - STDN Ground Station
OS - Operating System (Software)

PABX - Private Auxiliary Branch Exchange
PCM - Pulse Code Modulation
PDI - Payload Data Interleaver (Orbiter)
PMOCC - Pioneer Mission Operations Control Center
PMS - Performance Monitoring System
PN - Pseudonoise
POCC - Project Operations Control Center
PSP - Payload Signal Processor (Orbiter)
PSS - Payload Specialist Station (Orbiter)
PU - Propellant Utilization

QUI - Quito, Equador - STDN Ground Station

ACRONYMS AND ABBREVIATIONS (Continued)

RCS - Reaction Control System (Orbiter)
RF - Radio Frequency
RFI - Radio Frequency Interference
RIUS - Reusable Interim Upper Stage
RMIS - Remote Multiplexer Instrumentation System (IUS)
RMS - Remote Manipulator System (Orbiter)
RMU - Remote Multiplexer Unit (IUS)
ROS - Rosman, N.C. - STDN Ground Station
R&RR - Range and Range Rate
RTCC - Real Time Computer Complex
RTS - Remote Tracking Station

SA - Single Access
SC - Spacecraft
SCF - Satellite Control Facility
SCOC - Spacecraft Operations Center
SGLS - Space Ground Link System
SIC - Simulated Input Control
SIRD - Support Instrumentation Requirements Document
SOC - Shuttle Operations Center
SPO - Space Project Office
SSA - S-Band Single Access
STDN - Spaceflight Tracking and Data Network

TAN - Tananarive, Malagasy Republic - STDN Ground Station
TBD - To Be Determined
TDRS - Tracking and Data Relay Satellite
TDRSS - Tracking and Data Relay Satellite System
TM - Telemetry
TOC - Tug Operations Center
TTY - Teletype

ULA - Fairbanks, Alaska - STDN Ground Station

ZOE - Zones of Exclusion

ΔV - Delta Velocity

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

INTRODUCTION 1

This volume contains the background data and study results for the Interim Upper Stage (IUS) operations phase of the IUS/Tug Orbital Operations and Mission Support Study. For the purposes of this final report, the contract name has been shortened to Orbital Operations Study. This volume provides the basic analysis results and data for the Transition Phase Analysis (Phase 4) which is the transition from IUS to Tug operations, contained in Volume III, and for the IUS costing which is detailed in Volume V. All IUS data, except closing details, are included in this volume.

1.1 BACKGROUND

The Space Transportation System will include a propulsive stage that is carried to low earth orbit by the Space Shuttle (Orbiter). The Interim Upper Stage will be developed by the Department of Defense (DoD) and will be a modification to an existing space vehicle for use by both NASA and DoD from 1981 until a more capable Space Tug will be operational in 1984. The Expendable IUS may also be used for selected missions after 1984. The IUS is a storable propellant vehicle defined by NASA as a baseline for this study effort. It is an existing vehicle modified to meet the IUS requirements. Presently, DoD study contracts are being performed to better define the IUS requirements and associated designs, which will lead to a selection of an IUS vehicle.

1.2 PURPOSE AND SCOPE

The basic purpose of this phase of the Orbital Operations Study was to develop IUS operational concepts, an IUS Baseline Operations Plan, and to provide cost estimates for IUS operations. An overall study approach for the IUS Operations Phase is shown in Figure 1.2.0-1. The basic IUS study approach was to compile and evaluate baseline concepts, definitions and system, and to use that data as a basis for the IUS operations phase definition, analysis and costing analysis. The operational analysis led to the IUS operational concepts and the IUS Baseline Operations Plan. In addition, special emphasis trades and analyses were performed.

Both expendable and reusable IUS configurations were analyzed during the IBM study and two autonomy levels were specified for each configuration. During the latter phases of this study, a basically autonomous expendable IUS was baselined for major emphasis for the remainder of the study effort and most of the detailed concepts and analyses assumed this configuration as the baseline. The reusable IUS and the two autonomy levels were developed early in the study to provide a basis for preliminary costing and operations evaluation. Transition phase costing was based on the expendable IUS configuration and operations.

The major emphasis items for the IUS study was on-orbit operations and interfaces with the Orbiter, the Tracking and Data Relay Satellites and ground station support capability analysis, and flight control center sizing to support the IUS operations.

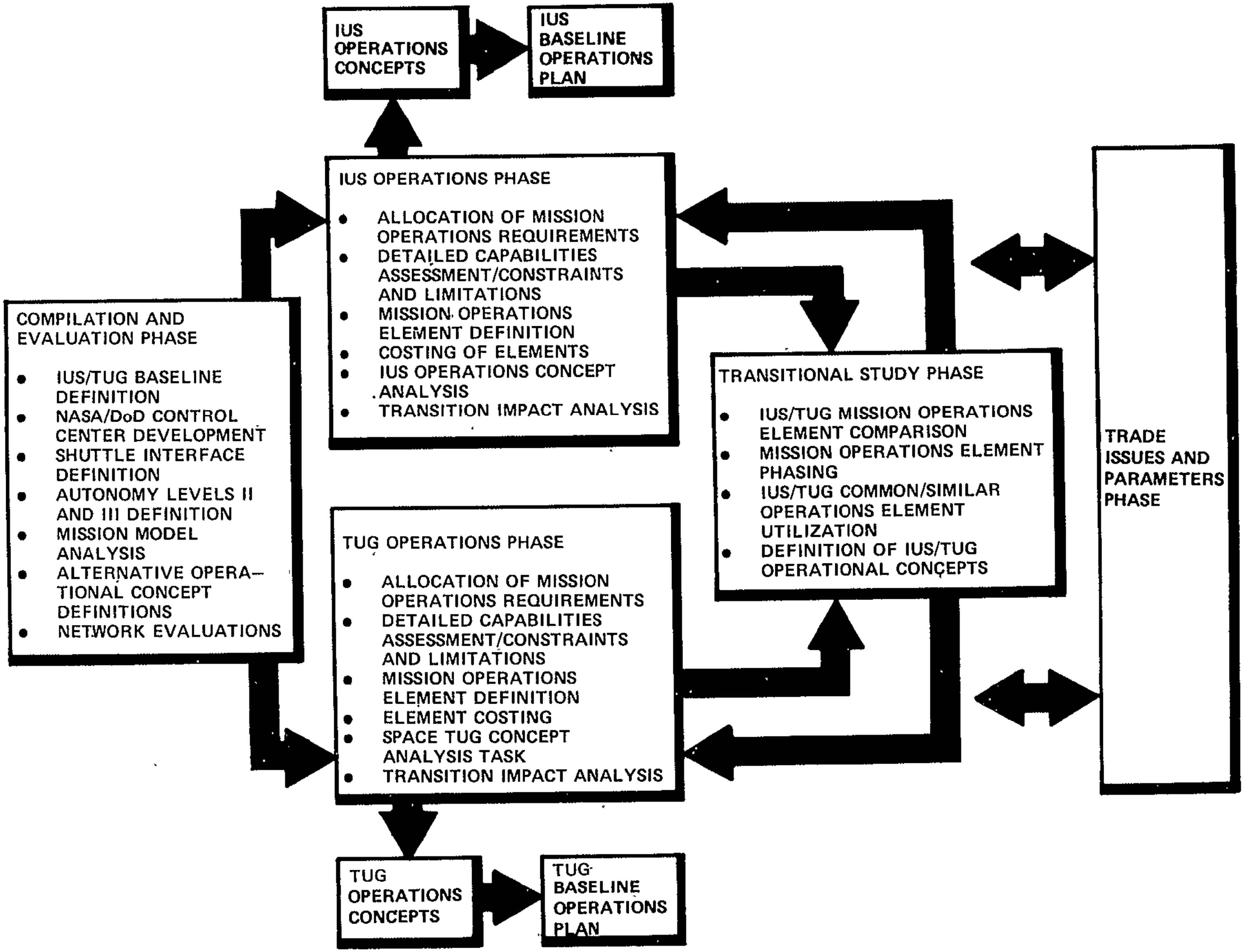

Figure 1.2.0-1. IUS/Tug Overall Study Approach

1.3 DOCUMENT OUTLINE

The following paragraphs give a brief overview of the type of information continued in each of the sections included in this volume:

- Section 2.0 - gives a summary of the IUS operational and interface requirements with emphasis on the on-orbit checkout requirements, Orbiter interface and operational requirements, and safety requirements.

- Section 3.0 - gives a brief summary of the three types of reference missions based for the IUS and details for the mission functional flows and timelines derived for the IUS missions.

- Section 4.0 - gives an overview of the IUS subsystems, with emphasis on component description and operations which would be used in the flight operations analysis.

- Section 5.0 - provides the operational interfaces definitions for the IUS interface with the Orbiter, the Spacecraft, Ground Support Equipment, and the IUS ground control center, with emphasis on the IUS/Orbiter operational interfaces, and Caution & Warning parameter definitions.

- Section 6.0 - gives a detailed discussion of the Expendable IUS on-orbit predeploy and post deploy operations prior to the EIUS first burn. Items emphasized include checkout philosophy, activation and monitoring functions, and Orbiter software impacts to support the EIUS.

- Section 7.0 - discusses the operations related to the Spacecraft deployment by the IUS. Major emphasis is the discussion of IUS support during the deployment operations.

- Section 8.0 - gives an overview of the STDN and TDRSS characteristics and data flow, an analysis of the communication interface support available for IUS missions, discussion of the IUS, Spacecraft, and Orbiter operations center interfaces and operations, and an analysis of potential problem area in the design of a new operations center.

- Section 9.0 - is the IUS Baseline Operations Plan. It contains the mission plan overview, the functional organization for flight control and flight support personnel, the mission control group functions and definitions, the ground and flight support hardware and software descriptions and summarizes the IUS cost estimates made during the study.

- Section 10.0 - gives an overview of potential problem areas or impact areas defined during the study effort.

- Section 11.0 - gives the references used to aid in the development of Volume II.

IUS REQUIREMENTS SUMMARY 2

The IUS operations, safety and interface requirements are included in Reference 1 ("Basic IUS System Requirements - Part I", SR-IUS-100) and Reference 2 ("IUS System Detail Safety Requirements", Appendix IV to SR-IUS-100). The requirements from the above references which were used as the basis for interface deployment (checkout) operations are summarized in this section. The corresponding paragraph number for the above references are given in parenthesis. No major operational discrepancies for the IUS were noted except as discussed in Section 6.2.1.

2.1 IUS OPERATIONS AND INTERFACE SYSTEM REQUIREMENTS

This section gives a summary of the pertinent IUS system operation and interface requirements from Reference 1.

SAFETY STATUS AND CONTROL OF IUS/SPACECRAFT (3.1.8)

The IUS System shall provide data to the Orbiter concerning the status, or condition, of safety critical IUS and spacecraft functions. Provisions shall also be made for Orbiter control of those safety critical functions.

SYSTEM VERIFICATION (3.1.9)

The IUS System shall verify the ability of the IUS to perform its mission at a time after Orbiter ascent but prior to deployment. The data transmission to the Orbiter shall be compatible with the interface per Paragraph 4.1.3.2.

The IUS System shall accommodate a limited closed loop checkout/verification of the spacecraft by the Orbiter prior to separation of the spacecraft and stage from the Orbiter. The limited go/no-go checkout will be conducted independent of the IUS avionics subsystems.

DEPLOYMENT - UPPER STAGE (3.2.1)

The IUS with attached spacecrafts(s) shall be capable of being deployed from the Orbiter within TBD hours after insertion into the nominal Orbiter parking orbit.

TELEMETRY, TRACKING AND COMMAND (TT&C) (3.2.6)

The TT&C subsystem shall be compatible with the Orbiter and with the SGLS/STDN ground stations.

TELEMETRY - When the telemetry downlink is addressed to either the visible Orbiter, or to visible ground stations, the effective radiated power shall be adequate to provide a Bit Error Rate (BER) of 10^{-6} at the receiving station independent of IUS attitude. The period over which the telemetry downlink shall be available is from Orbiter/IUS - spacecraft deployment until the time of completion of the IUS/Spacecraft separation maneuver.

TRACKING - The SGLS/STDN compatible radio links shall be capable of coherent turn-around of the PRN modulation used to determine range and range rate at the AFSCF/STDN ground stations.

COMMAND - The IUS shall be able to accept commands from the Orbiter and the SGLS/STDN ground stations. The table of commands shall be adequate to provide the necessary safety and executive controls of the IUS. The command reception capability shall be available at all, and any, orientation attitudes.

SAFETY STATUS VERIFICATION (3.2.7)

The IUS shall provide to the Orbiter that data during deployment, and while in the near vicinity of the Orbiter, that permits evaluation of the status, or condition, of safety critical functions. The transmission method shall be compatible with Orbiter systems and have an error rate of 10^{-6} at ranges of 0 to 20 nautical miles. The capability shall be available at all orientation attitudes.

ORIENTATION (3.2.9)

During unpowered coasting flight modes, the IUS shall provide the capability for attitude hold, preferential orientation, or predetermined roll or any combination of the three maneuvers for the purpose of providing spacecraft thermal control, telemetry transmission, solar array orientation or spacecraft deployment.

TELEMETRY DIPOUTS (3.2.9.1.2)

Specific orientations to provide satisfactory IUS telemetry transmissions shall not be required by the IUS.

VENTING (4.1.2.4)

The IUS, while in the payload bay, shall be capable of controlled venting of fluids and gases as required through the fluid interface connections from the IUS to the Orbiter in the veritical and horizontal positions.

SAFETY STATUS AND CONTROL (4.1.3.1)

The IUS shall provide, while in the payload bay, adequate data to establish the safety status of the IUS/Spacecraft. The type and handling of the data shall be in accordance with Section 5.2. Control of potential hazardous conditions, as defined in Section 5.2, shall be provided. The data and control configuration shall be compatible with the Orbiter.

IUS DATA AND COMMAND (4.1.3.2)

The IUS shall be compatible with the Orbiter and able to communicate its status and receive commands which it may require for status monitoring and checkout from the Orbiter while stowed in the payload bay.

INITIALIZATION AND UPDATE (4.1.3.3)

Orbiter navigation data derived by Doppler techniques from STDN stations (NASA) and SGLS stations (DoD) and from ground tracking data (STDN and SGLS) through the respective NASA and DoD Orbiter Communication system may be used by IUS. For NASA availability of the tracking and Doppler data may be augmented by the use of TDRSS. The accuracies of these update possibilities as a function of Orbiter timelines is TBS.

Control of mechanical alignments of IUS to Orbiter and optical platform alignment transfer techniques will not be provided. Selected update means for attitude, position, and velocity shall not result in NASA/DoD peculiar guidance system mechanizations.

COMMAND AND CONTROL (4.2.3.1)

The IUS System shall accommodate the transmission of commands from the Orbiter to the spacecraft while the spacecraft and stage are attached to the Orbiter. Data rates for commands sent to the spacecraft will be compatible with the Orbiter.

The IUS shall provide the capability for sending a spacecraft separation signal to the spacecraft/IUS separation system. This single separation signal will have to service multiple satellite separation.

TELEMETRY (4.2.3.2)

The IUS System shall accommodate the transmission of spacecraft telemetry and safety data to the Orbiter while the spacecraft and IUS are attached to the Orbiter. Spacecraft telemetry will be sent from the spacecraft to the Orbiter at rates up to 16 Kbps.

The IUS shall be capable of transmitting to the ground: (1) state vector and attitude data at the transfer orbit injection and final orbit injection of the IUS/Spacecraft, and (2) verification of IUS to spacecraft separation event.

IUS SYSTEM GROUND INTERFACES (4.3)

The IUS System shall be compatible with interfacing KSC (Kennedy Space Center) facilities and AGE, including items of the Shuttle System and special IUS items of AGE and facilities. The IUS System shall also utilize the DoD and NASA ground networks.

IUS IN PAYLOAD BAY (4.3.2.1)

The IUS interfaces with the Orbiter shall be compatible to permit required telemetry and command link operation with appropriate SGLS/STDN ground stations.

IUS OUTSIDE ORBITER (4.3.2.2)

The telemetry, tracking, and command links between the IUS and the appropriate SGLS/STDN ground stations shall be compatible with the operating characteristics of those ground stations. The effective radiated power of the downlink communications, and the noise figure of the uplink receiving equipment shall be adequate to provide the required service within the capabilities of those stations. The communication links shall be operative at all orientation attitudes of the IUS.

SAFETY (5.2)

The IUS System shall meet the safety requirements of JSC 07700, Vol. XIV, Paragraph 11.0, "Safety Assurance for Space Shuttle Payloads", Revision TBD.

(5.2.2) During launch and on-orbit, the IUS System shall be capable of manned safety operation during Shuttle-powered flight, pre-deploy checkout, deployment from the Orbiter and post-deploy while still in the vicinity of the Orbiter.

(5.2.4) The IUS System shall be capable of being safed for all Shuttle abort and back-out conditions and the interface attachments to the Orbiter must be capable of surviving crash design load factors.

(5.2.5) The IUS System shall be capable of having all safety critical items monitored in the Orbiter and by ground link during all phases of Shuttle operations, including deployed while still in the vicinity of the Orbiter.

(5.2.6) The IUS System shall be capable of being maintained and/or commanded safe at all times when installed in the Orbiter and when deployed in the vicinity of the Orbiter.

2.2 IUS OPERATIONS AND INTERFACE SAFETY REQUIREMENTS

This section gives the pertinent IUS safety requirements related to IUS interfaces and operations summarized from Reference 2.

GENERAL OPERATIONS (3.1.1)

- Under all nominal, contingency or emergency operations: (1) no single failure of a dynamic system of the IUS System, or (2) no two (2) sequential procedural errors shall result in the transmission of an accident potential to or from the IUS System and its interfaces including flight and ground personnel.

- No single failure of a dynamic system of the IUS System shall result in an accident which jeopardizes the general public/private property, or the ecology.

- Shuttle missions are planned to be terminated if failures occur which create a situation where one additional failure can cause injury to personnel or loss of Orbiter. Therefore, all dynamic systems of the IUS System shall be capable of tolerating at least one failure before requiring mission termination.

- The IUS shall provide at all times such information concerning the status or condition of safety critical IUS Systems (audible and visual caution and warning) while in the Orbiter bay or near vicinity of the Orbiter. Provisions shall be made for Orbiter crew command override of these functions for adequate corrective action. Adequate redundancy of these systems shall be required.

- All safety critical data, displays, and controls shall be capable of being verified functional prior to the initiation of the safety critical event.

- Any procedure which, if erronously executed, can cause a hazard to the Shuttle shall be identifed as a Safety Critical Procedure.

- A safe interface between the Shuttle and the IUS, and the IUS and its spacecraft shall be maintained under all nominal, contingency, and emergency operations of either the Shuttle, the IUS, the IUS spacecraft or the IUS support equipment.

FLIGHT OPERATIONS (3.1.3)

- Propellant tank pressures shall not be increased to operational values until a safe distance from the Orbiter after deployment.

- The attitude control system of the IUS shall be capable of being checked for accuracy by the Orbiter crew before IUS release.

- IUS propellant tank integrity shall be verified, pressures shall be reduced to a manned safety value, and safety critical subsystems shall be safed or verified functional before IUS recovery operations begin.

- IUS attitude control or IUS main engine thrust shall not be used for initial separation of the IUS to a safe distance from the Orbiter.

PROPULSION (3.2.2)

- No single operation shall result in a flow of propellant through the IUS propulsion system while the IUS is in the Orbiter payload bay.

- Interlocks shall be provided to assure that propulsion systems will not be fired while in the Orbiter cargo bay or that propellants will not be dumped in the payload bay.

- IUS propulsion system start sequence logic status and valve positions shall be monitored and message signals shall be provided at the Shuttle Data Management Interface.

- Inadvertant main engine start sequence shall be positively inhibited.

AVIONICS (SYSTEM) (3.2.3)

- Message signals from the IUS System shall be provided at the Shuttle Data Management System Interface. Measurements shall include IUS latched/released indications, deploy mechanism position indications, discrete pyrotechnic event indications, sequence logic status, valve positions, temperature and pressure measurements, and failure indications. This information shall also be available prior to recovery.

- RF communication capability shall be available between the Orbiter and the IUS from command and control functions while separated from the Orbiter and up to a separation distance of 20 n mi.

- Commands affecting safety critical equipment status must have associated data transmission to provide a positive functional verification.

- IUS autonomous navigation commands for attitude control and translation maneuvers shall be disabled until a safe separation distance is achieved.

ELECTRICAL (3.2.4)

- Safety critical control circuits shall be capable of being verified.

- Positive indications of IUS electrical systems shut down status shall be provided to the Orbiter flight crew prior to recovery.

- IUS shall have a means of shutting off its electrical power under emergency conditions.

PYROTECHNIC (3.2.5)

- Sequence logic and pyrotechnic firing circuits shall be at least dual redundant.

INTERIM UPPER STAGE (IUS) MISSION OPERATIONS ANALYSIS 3

The IUS missions consist of delivery of spacecraft to orbits outside the performance range of the Shuttle Orbiter. Missions are currently planned in the following spacecraft disciplines: Astronomy, High Energy and Solar Physics, Atmospheric Physics, Earth Observation, Communication and Navigation, and Planetary. Mission sources for this study include NASA, commercial and foreign users. This section represents typical sets of IUS Missions which were analyzed to determine operational requirements.

Two typical mission models were utilized during the study for the years 1981-1991. These models contained representative payload (Spacecraft) classes, flight frequency, and estimated payload weights and dimensions. They were grouped according to destination: (1) sun synchronous, (2) geosynchronous, and (3) interplanetary. The two mission models used in this study were (1) Space Shuttle Traffic Model, October 1973, and (2) a summary traffic model developed by the NASA Tug Task Team during the course of the study. From the mission models, the most dense launch year (1983) was extracted and presented in Figure 3.0.0-1. This figure illustrates the mission type, the anticipated launch schedule, maintenance time, mission planning, training and simulation time intervals. As can be seen, no mission overlaps exist which results in the operational elements being sized to support a single mission.

It should be kept in mind that these data are only representative of what should be expected. In particular, planning and operations analyses should investigate the impact of variations in the relative frequency of the various classes, changes in the spacecraft characteristics, and other factors that may change and are a part of operational planning.

3.1 REFERENCE MISSION DESCRIPTIONS

The following paragraphs describe the types of reference missions evaluated during the study. To enable the identification of operational requirements from the many diverse missions, the individual missions were grouped into three major classes and analysis performed on each class. The three classes used were (1) Geosynchronous missions, (2) Sun Synchronous missions, and (3) Interplanetary missions. Characteristics of these mission classes are discussed below.

3.1.1 Geosynchronous Missions

Several types of Geosynchronous missions are defined in the current traffic models. The IUS vehicle currently defined for this study has the capability to deploy spacecraft, but cannot retrieve spacecraft from any mission profile. Therefore, two distinct deployment classes of IUS missions exist for this study. They are, (1) expendable missions, where following spacecraft deployment, the IUS vehicle is expended, and (2) reusable missions, where following Spacecraft deployment, the IUS vehicle returns to the Orbiter rendezvous box, and is retrieved by the Orbiter for return to earth.

A typical Geosynchronous mission is shown in Figure 3.1.1-1 for an IUS reusable (RIUS) deployment mission. As in the case of Space Tug missions, it was determined that missions could be represented by a standard set of building blocks where each block (or module) contained those operational functions (or tasks) required for mission completion. Once these buildings blocks were

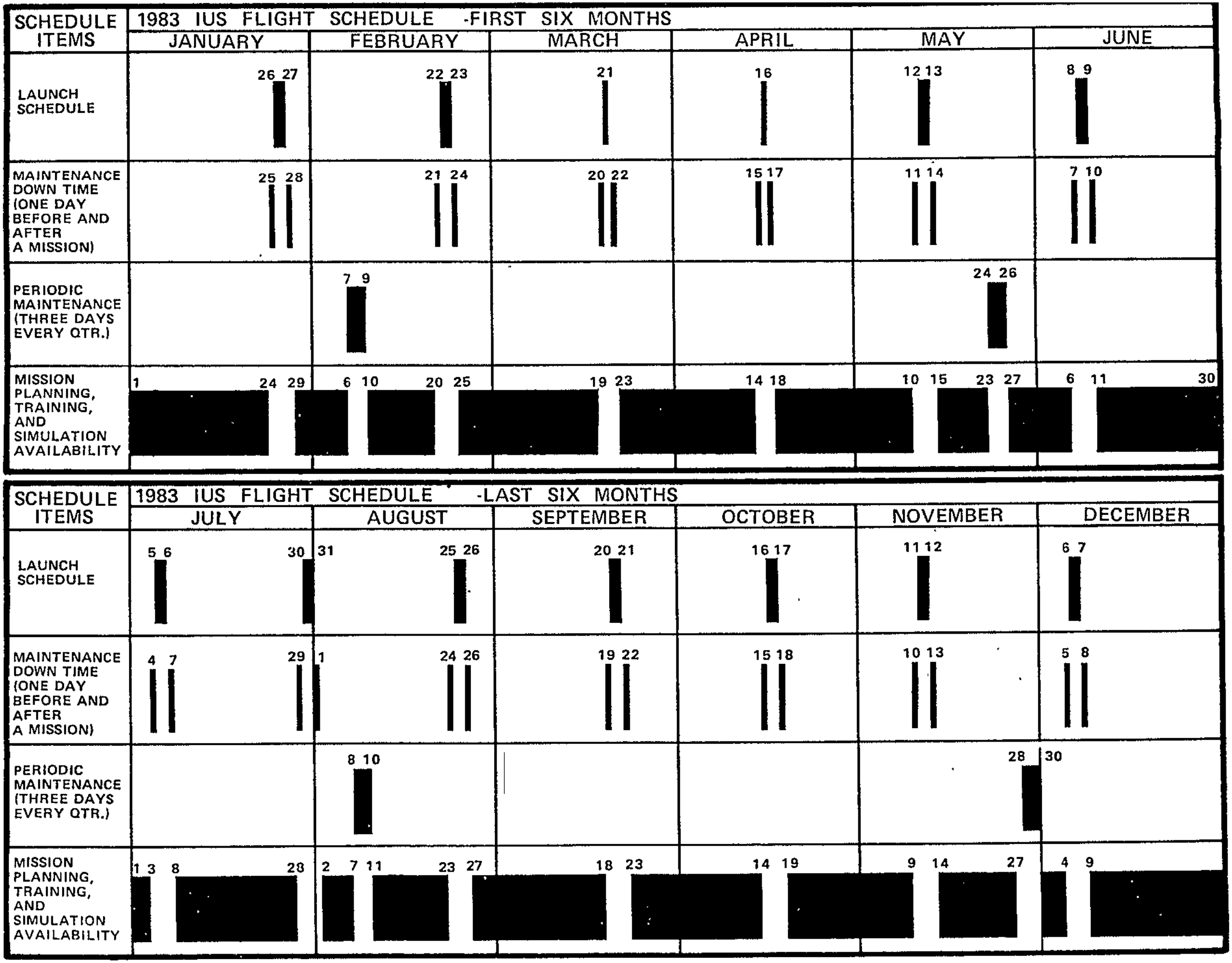

Figure 3.0.0-1. 1983 IUS Launch Density

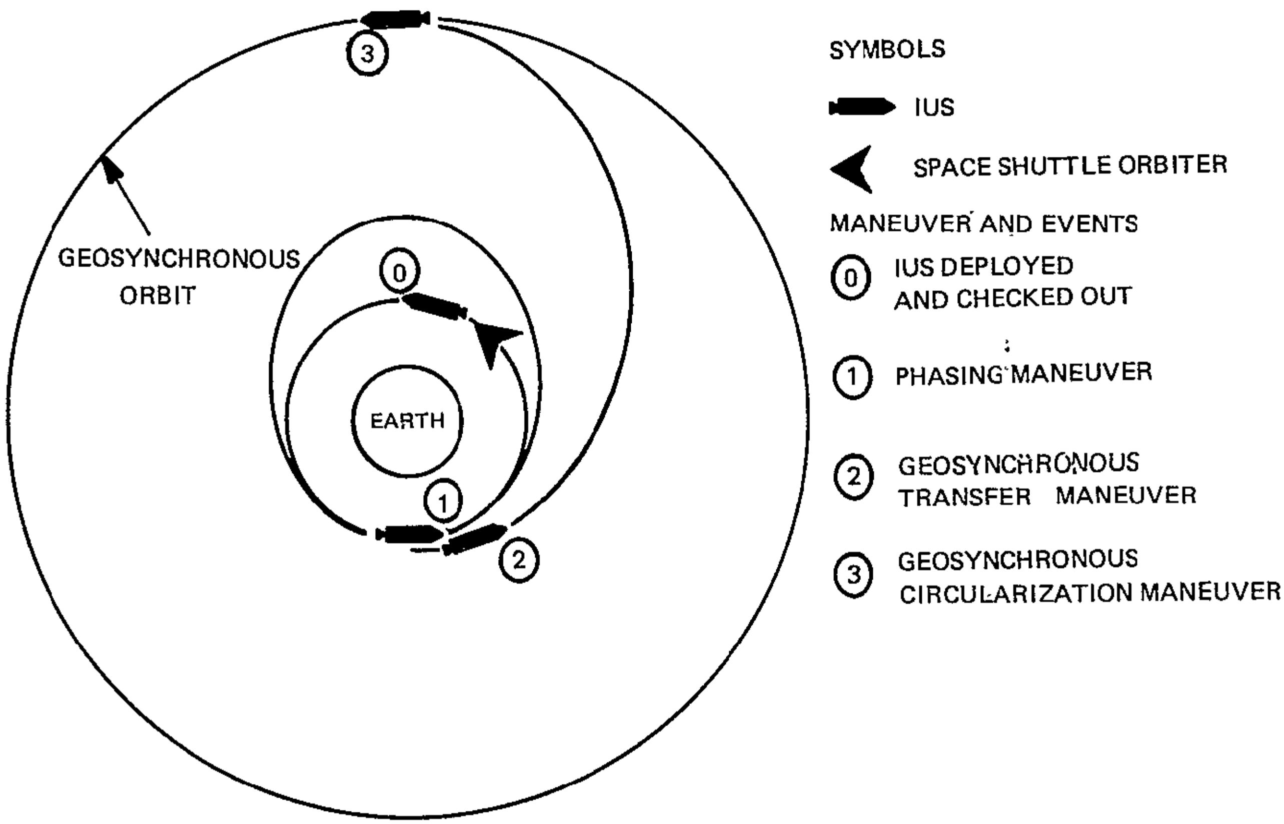

Figure 3.1.1-1. Reusable-IUS Geosynchronous Ascent Profile

defined, they could be interleaved to represent specific missions. Section 3.2 describes this modular approach and contains the functions within each standard module.

As an example, Figure 3.1.1-2 illustrates the typical modules which would be used to represent an expendable IUS (EIUS) single placement Geosynchronous mission.

3.1.2 Sun Synchronous Missions

The Sun Synchronous mission class assumes an IUS deployment in low-earth orbit (≈205 nm) by the Orbiter and a transfer to a spacecraft deployment target in a 900 nm circular orbit. After orbital trims, the IUS deploys the spacecraft, and, (1) in the expendable mission case, is terminated, or, (2) in the reusable mission case, executes a two burn sequence targeted to the Orbiter retrieval box.

As in the Geosynchronous mission class, the standard operational modules were interleaved to represent the Sun Synchronous missions. Figure 3.1.2-1 depicts a Sun Synchronous mission for an expendable IUS mission.

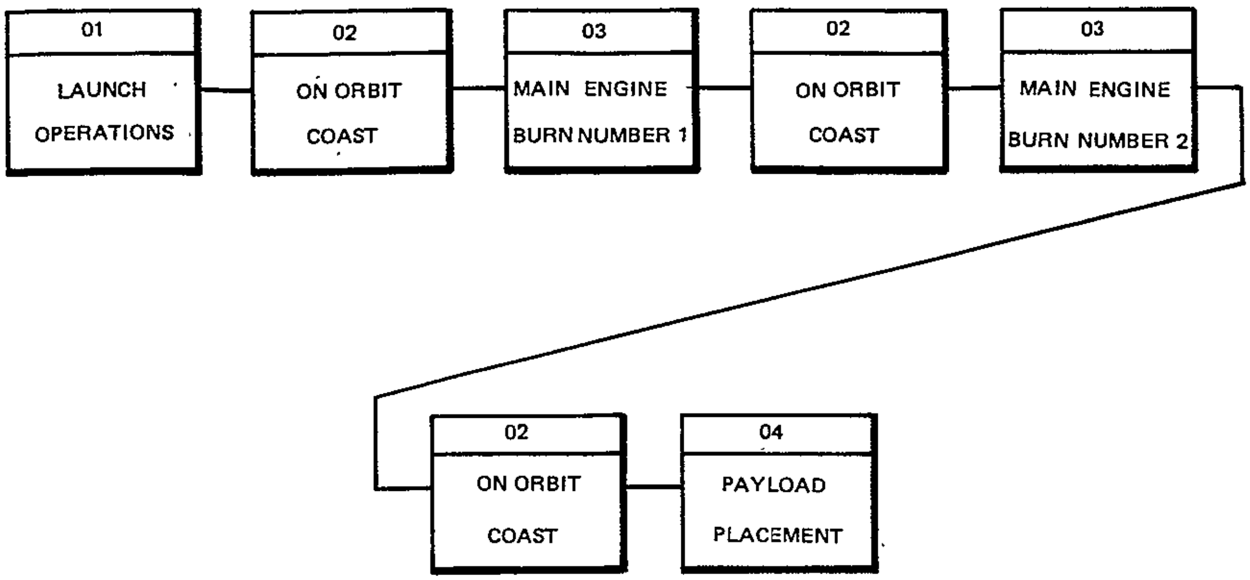

Figure 3.1.1-2. EIUS Mission Module Sequence for Geosynchronous Mission

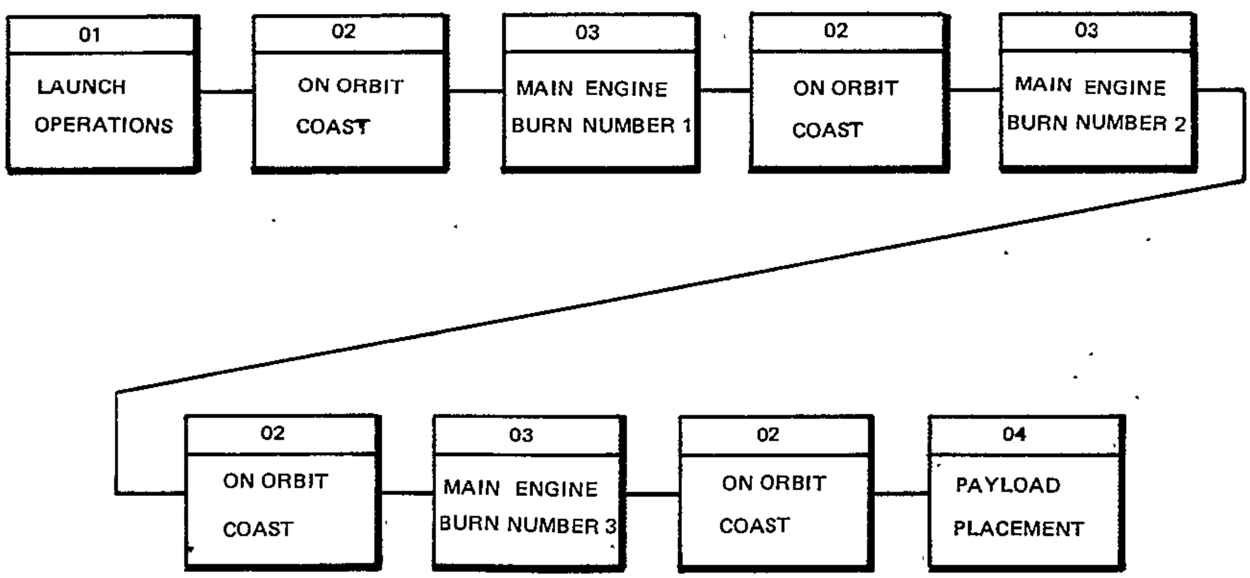

Figure 3.1.2-1. EIUS Mission Module Sequence for Sun Synchronous Mission

3.1.3 Interplanetary Missions

The Interplanetary missions can be characterized as having high delta-velocity requirements and narrow launch windows. For the purpose of this study, only expendable IUS missions have been assessed.

The targeting requirements for using the IUS in a planetary mission are complex and will require a sophisticated prelaunch targeting program to optimize the IUS propellant loading when given a spacecraft description. The complexity of this mission makes it desirable to baseline a day to day launch on time. Prelaunch targeting shall determine the launch time and Orbiter orbital insertion targeting parameters (taken from the Space Shuttle data bank) necessary for IUS deployment and adjustment needs for IUS burns. The IUS onboard targeting for planetary missions is baselined, for this study, to be pre-loaded from the ground.

As in the other mission classes, standard operational modules were interleaved to represent the interplanetary missions. Figure 3.1.3-1 depicts an interplanetary IUS mission for a single placement case.

3.2 MISSION MODULE TIMELINES

3.2.1 Principles of Mission Modularization

Prior Orbital payload placement studies have revealed that mission event sequences (timelines) can be modularized (subdivided into the longest consecutive sequence of events which occur in the same order for a particular function). The modularization of mission event sequences is a common technique used in most airborne flight programs to segregate similar computer functions. This technique simplifies maintenance of the program by limiting the effect of changes to smaller areas of consideration and facilitates the calling of routines when their particular application is required.

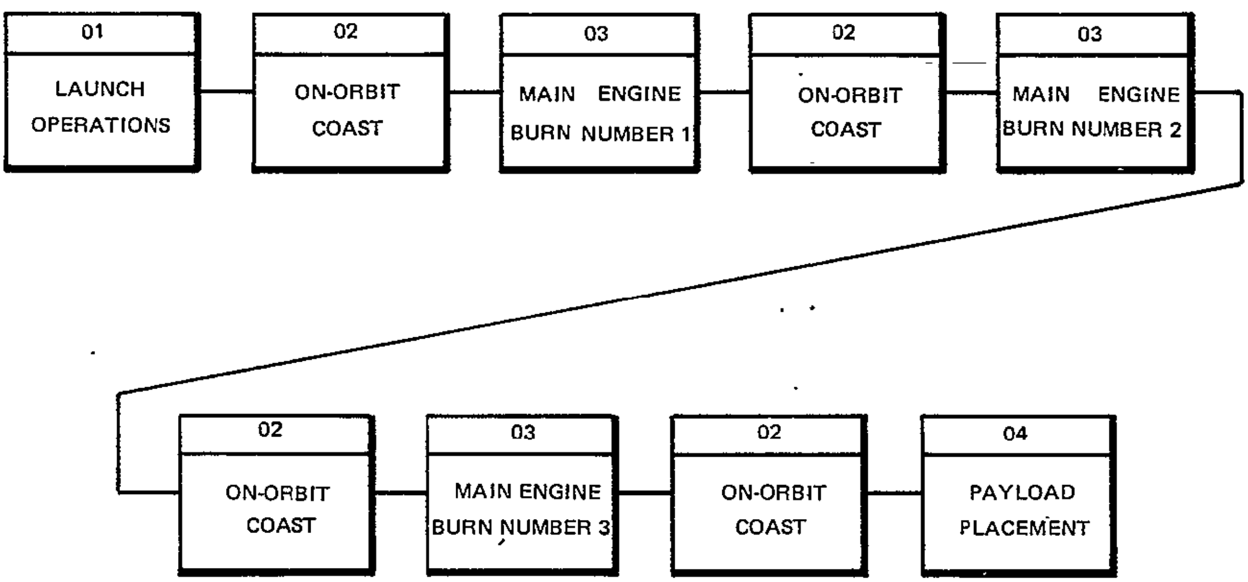

Figure 3.1.3-1. EIUS Mission Module Sequence for Interplanetary Mission

The development of the IUS mission modules (timelines) evolved from work on the NASA Tug studies, candidate IUS vehicle timelines, concurrent analysis, and past experience. The first step in the process was to identify the major functions common to any possible IUS. The major functions for IUS missions were found to be:

- Launch Operations
- On Orbit Coast
- Main Engine Burn
- Payload Placement
- Kick Stage Separation
- Orbiter Retrieval (Reusable IUS only)

With these major functions it is possible to construct a sequence of functions which satisfy the total IUS mission spectrum.

After the identification of the major mission functions, the sub-functional sequence within each module was established. Flow charts are included with each mission module timeline to visually depict the major events within each module. The Orbiter, crew, IUS, and IUS Operations Center (IUS/OC) activities associated with each sub-function were constructed, sequenced, and timed. These activities are the events listed in each timeline.

The identification of events have been accomplished by assigning a two digit number which represents the event position in the module sub-function sequence. This is the number immediately to the right in the identification number column of the timeline tables. The next two digits represent the general sequence of sub-functions within the module. Some sub-functions, like some events, however, are not necessarily sequential. The third double digit set of numbers are the module identification number. It is possible to extend the modules into a next numbering level which would then be the module groupings for a particular mission. The positive identification of events also permits the tracing and quantifying of events for analytical purposes.

Duration times for sub-functions and associated events appear in seconds. These times are tabulated in columns opposite the identification number followed by a mission reference time which is related to a key event within the module. Key events are those events which commit the mission to a new phase. Bar charts to the extreme right have been created to provide a picture of event time duration and sequence relative to total module activity. Times for many events represent best estimates and are subject to change as refinements in mission, vehicle and ground systems definition continue.

3.2.2 IUS Launch Operations

3.2.2.1 General

The orbiter launch operations function begins in the prelaunch phase during the final integrated testing of the IUS and Spacecraft and culminates with the IUS in low earth orbit activated and waiting for convergence of its targeting equations for its first main engine burn. Figure 3.2.2-1 is a flow chart illustrating the sequence of sub-functions during this period. Figure 3.2.2-2 is a listing of the major IUS, Orbiter, and IUS control center events (not allocated in timeline) occurring during a nominal Orbiter launch operation and IUS deployment phase.

3.2.2.2 Prelaunch Operations

Prelaunch operations start at approximately T-2 hours prior to launch and continue until Orbiter lift off. During this time, the terminal countdown is initiated and final activation and ground check out of IUS systems is accomplished. Components active or previously activated and checked out during this period are the computer (DMS), inertial measuring unit (IMU), and decoders and telemetry (RMIS) systems. The IUS will be placed in a safe configuration for the boost to orbit mode.

3.2.2.3 Ascent Operations

During the boost to orbit by the shuttle, both the Orbiter crew and IUS/OC will monitor the safety critical IUS caution and warning parameters. Power to the IUS during this time period will be supplied by the Orbiter. The maintenance of a safe mode may require the venting of propellants which will be an automatic function accomplished by the IUS computer.

3.2.2.4 Deploy IUS

The activation of the remaining IUS subsystems and verification for mission continuance will begin as quickly as possible after the Orbiter has achieved orbit. The Orbiter will initiate the deploy sequence by configuring the Orbiter bay and deployment equipment for deploy operations. The payload bay doors will be opened and the RMS will be mated to the IUS.

Prior to the Orbiter circularization burn, the IUS/Orbiter state vector comparison and navigation and attitude update will be accomplished, if required. During this time the IUS is still secure in the Orbiter bay, a circularization maneuver by the Orbiter may be performed. After the burn, deployment will begin, the IUS electrical power will be transferred from the Orbiter to the IUS battery, and the IUS command and telemetry system will be activated and verified operational. With the IUS status data available via RF, all retaining latches will be released by the crew and the electrical umbilical and propellant dump lines disconnected. The IUS will then be raised from the Orbiter bay by the RMS to a position for release. With the concurrence of the IUS/OC, the Orbiter crew will release the IUS.

3.2.2.5 Enable Attitude Hold

The IUS will maintain a completely safe and non propulsive status for approximately 90 seconds. This should be sufficient time for the Orbiter to separate to a distance safe from any IUS attitude control system malfunction. After 90 seconds, a sequence will be initiated by either the IUS (or Orbiter command) which will activate the IUS attitude control system. The IUS will maintain a programmed attitude maneuver while the Orbiter retreats to a safe distance for main propulsion system activation.

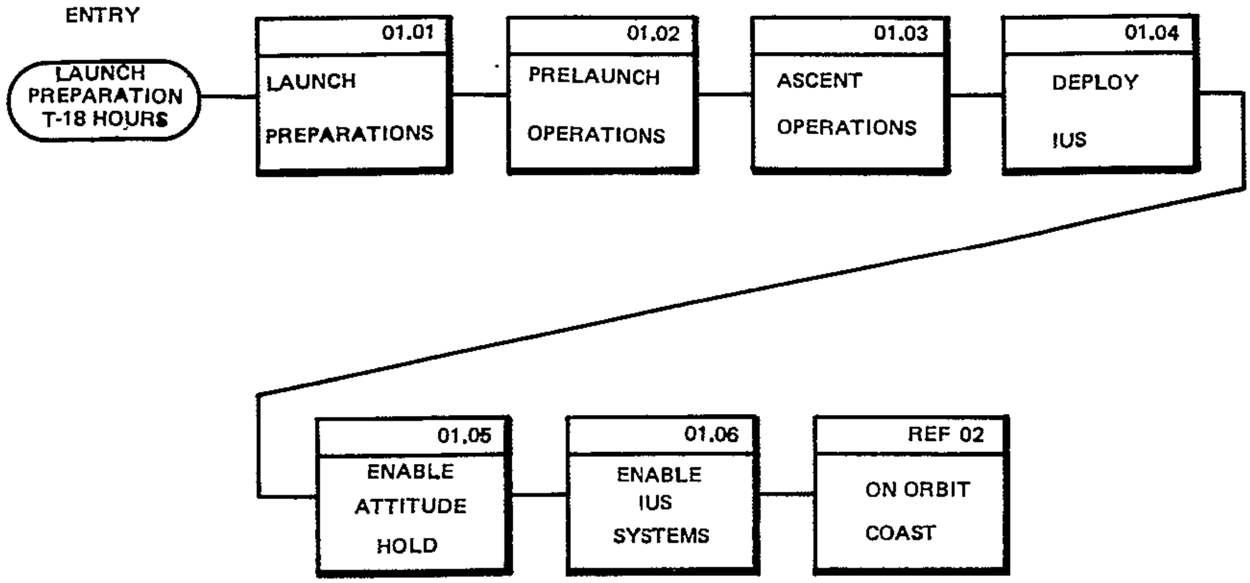

Figure 3.2.2-1. Standard IUS Launch Module Flow

3.2.2.6 Enable IUS Systems

When the Orbiter has reached a safe distance of approximately 3000 feet (approximately 16 minutes), the IUS will begin its activation sequence for ACS and main propulsion system and enable continuance of the IUS mission. At this time the IUS will enter the on orbit coast mode and begin the countdown for first main engine burn.

3.2.3 On Orbit Coast

3.2.3.1 General

The on orbit coast module provides the interim on orbit navigation guidance and control state between active mission modules. During these waiting periods, the overall mission plan can be reviewed and modified to accommodate real time mission variations. The duration of time spent in this module will be a function of the sequenced mission schedule maintained by the computer in the IUS flight program. The navigation update sequence and on orbit mission planning sequence are entered by ground command or as a result of special conditions and represent additional capability. Figure 3.2.3-1 is a flow diagram showing the module functional capability and the potential interface with other modules. Figure 3.2.3-2 is a listing of the major IUS and IUS/OC events common to this module.

3.2.3.2 On Orbit Guidance Navigation and Control

The on orbit GN&C function provides for the maintenance of the IUS attitude and trajectory during the periods between mainstages, trimburns, payload placement, and Kick Stage separation. If a navigation update is required, the sequence can be commanded and accomplished during this time.

STANDARD IUS LAUNCH MODULE (01)

The Orbiter launch operations module begins in the prelaunch phase during the final integrated test during which there is ground operations control center involvement and terminates with IUS in the Space Shuttle orbit activated and awaiting convergence of its targeting equations for its first main engine burn.

ENTRY: T-18 Hours

EXIT: On Orbit Coast

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (SECS)	EVENT START TIME IN MODULE (SECS)	EVENT START TIME IN MISSION (HOURS)
LAUNCH PREPARATIONS	01.01.00	57600	-64800	
START SHUTTLE LAUNCH COUNTDOWN	01.01.01		-64800	
APPLY GROUND POWER	01.01.02		-21600	
START COUNTDOWN PREPARATIONS:PMS:LPS	01.01.03		-20000	
START SHUTTLE STANDBY STATUS	01.01.04		-7200	
PRELAUNCH OPERATIONS	01.02.00	7200	-7200	
START COUNTDOWN	01.02.01	5400	-5400	
ALIGN GUIDANCE COMPLETE	01.02.02	200	-5400	
START SAFETY MONITOR (CAUTION & WANR.	01.02.03	1800	-1800	
LOAD GUIDANCE COMPUTER	01.02.04	200	-1800	
ALIGN IMU	01.02.05	200	-1800	
CALIBRATE SYSTEMS	01.02.06	200	-1800	
COMPARE IUS/ORB. PLATFORM & NAV. DATA	01.02.07	200	-1600	
START COMPUTER SELF TEST ROUTINE	01.02.08	200	-1600	
START PMS LIMIT CHECKS (DMS)	01.02.09	200	-1400	
VERIFY DISCRETE STATUS (DMS)	01.02.10	200	-1400	
VERIFY RESPONSE TO UPLINK COMMANDS	01.02.11	200	-1200	
VERIFY RF PERFORMANCE (QUALITATIVE)	01.02.12	200	-1200	
MONITOR BATTERY	01.02.13	1200	-1200	
VERIFY TANK PRESSURES (PROPULSION)	01.02.14	200	-1000	
VERIFY VALVE POSITIONS (PROPULSION)	01.02.15	200	-1000	
VERIFY SPACECRAFT STATUS	01.02.16	200	-800	
UPDATE NAVIGATION DATA	01.02.17	200	-800	
START SAFETY MONITORING (C&W)	01.02.18	800	-800	
TRANSFER TO ORBIT POWER	01.02.19	10	800	
INITIATE GUIDANCE TO INERTIAL NAV.	01.02.20	3	-3	
ASCENT OPERATIONS	01.03.00	531	0	
MONITOR CAUTION & WARNING	01.03.01	531	0	
PERFORM LIFTOFF	01.03.02		0	
INJECT IN TRANSFER ORBIT	01.03.03	150	531	

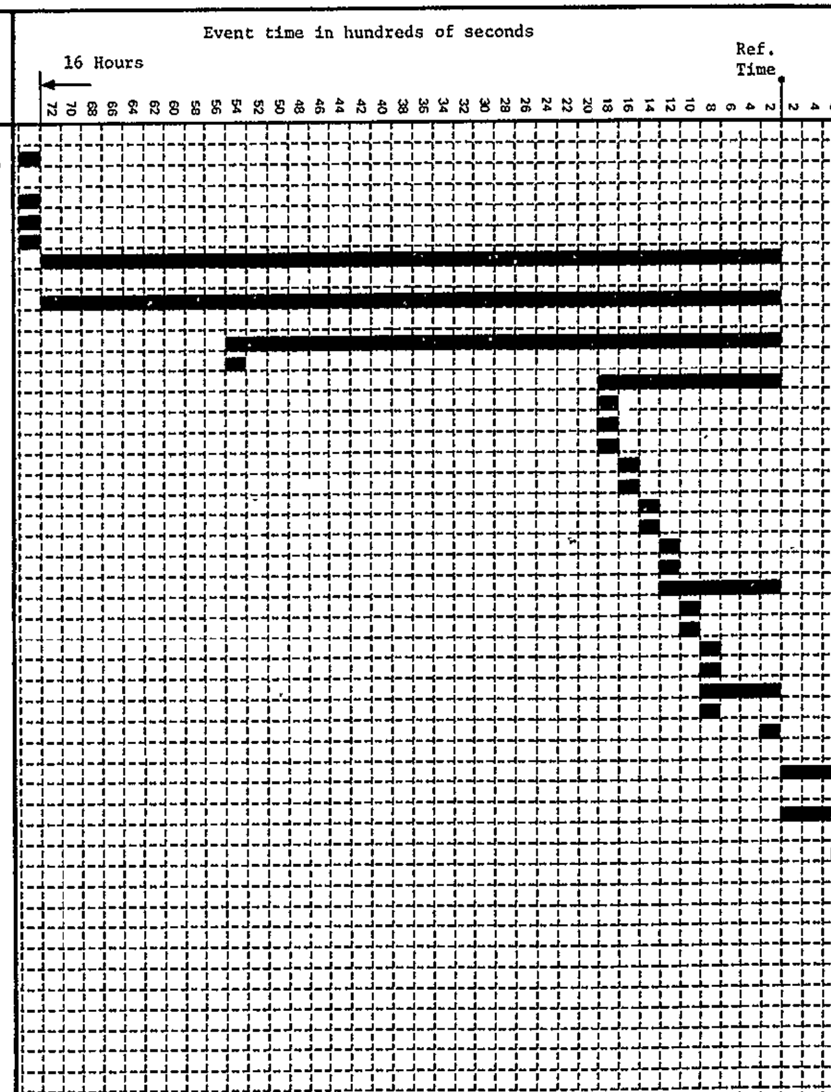

Figure 3.2.2-2. Standard IUS Launch Module Timeline

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STANDARD IUS LAUNCH MODULE (01) (CONTINUED)

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (SECS)	EVENT START TIME IN MODULE (SECS)	EVENT START TIME IN MISSION (HOURS)
DEPLOY IUS	01.04.00	814	681	
VERIFY PAYLOAD BAY DOORS OPEN	01.04.01	10	681	
DEPLOY RMS	01:04.02	180	691	
GRAPPLE PAYLOAD (CCTV)	01.04.03	20	871	
CONFIGURE ORBITER FOR RF COMM.	01.04.04	15	891	
TRANSFER TO IUS POWER	01.04.05	9	906	
RF TELEMETRY & COMMAND VERIFICATION (ACTIVATE UPLINK ARMING BUS)	01.04.06	120	915	
VERIFY IGS BITE STATUS	01.04.07	180	1035	
IUS/ORBITER STATE VECTOR COMPARE	01.04.08	60	1215	
UPDATE IUS NAVIGATION AND ATTITUDE	01.04.09	60	1275	
ORBITER CIRCULARIZATION MANEUVER	01 04.10	70	1335	
DISABLE CRADLE DUMP VALVE STATUS MONITOR FUNCTIONS	01.04.11	10	1405	
OPEN CRADLE DUMP VALVES	01.04.12	10	1415	
DISABLE DEDICATED & BACKUP C&W	01.04.13	10	1425	
RELEASE IUS LATCHES	01.04.14	10	1435	
DISCONNECT ELECTRICAL UMBILICAL	01.04.15	10	1445	
DISABLE DUMP LINE DISCONNECT STATUS MONITORS	01.04.16	10	1455	
DISCONNECT PROPELLANT DUMP LINES	01.04.17	10	1465	
EXTEND PAYLOAD ON RMS (CCTV)	01.04.17	10	1475	
IUS/RMS SEPARATION	01.04.19	10	1485	
ENABLE ATTITUDE HOLD	01.05.00	135	1495	
SEPARATE USING ORBITER RCS (240 ft ? 3 fps ΔV)	01.05.01	90	1495	
DISABLE TPS/IGPS AND ACS ARMING BUS VOLTAGE STATUS MONITOR FUNCTIONS	01.05.02	10	1585	
ENABLE TPS & IGPS BUSES	01.05.03	10	1595	
OPEN ACS PYRO VALVE AND ENABLE ACS ARMING BUS	01.05.04	10	1605	
ACTIVATE ACS AND GUIDANCE ATTITUDE HOLD SOFTWARE	01.05.05	15	1615	
IUS TM DATA MONITOR	01.05.06		1630	

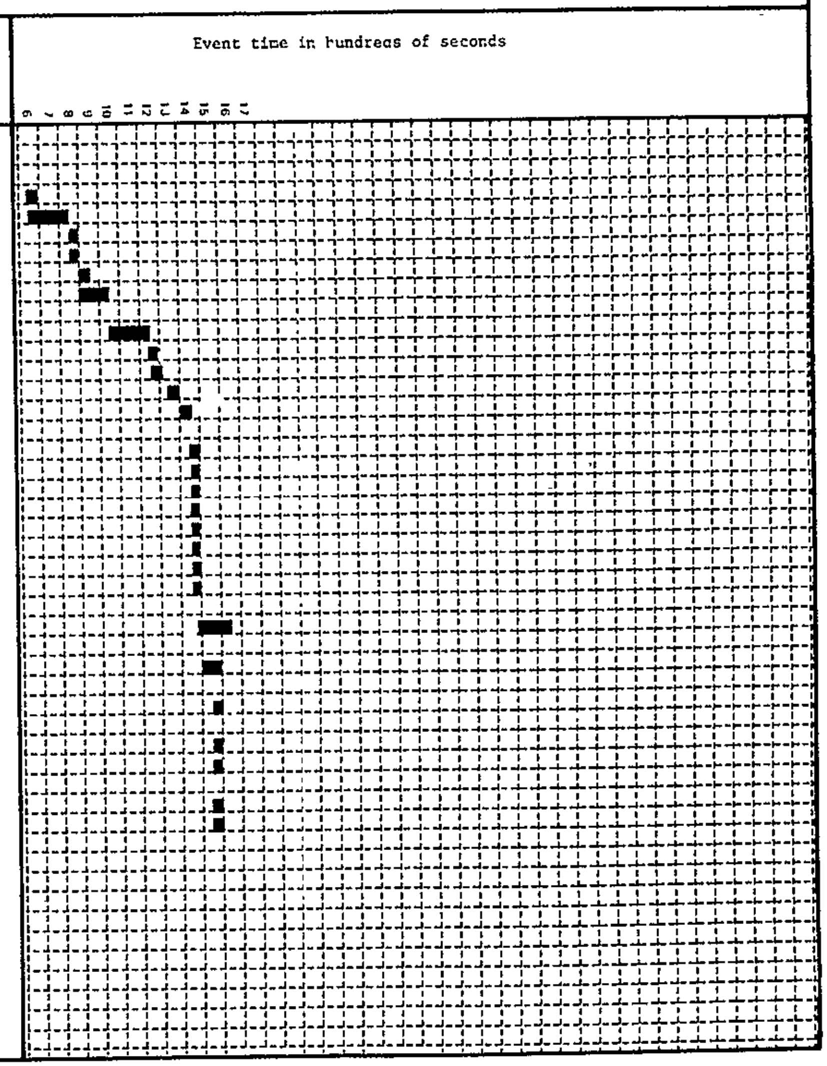

Figure 3.2.2-2. Standard IUS Launch Module Timeline (Continued)

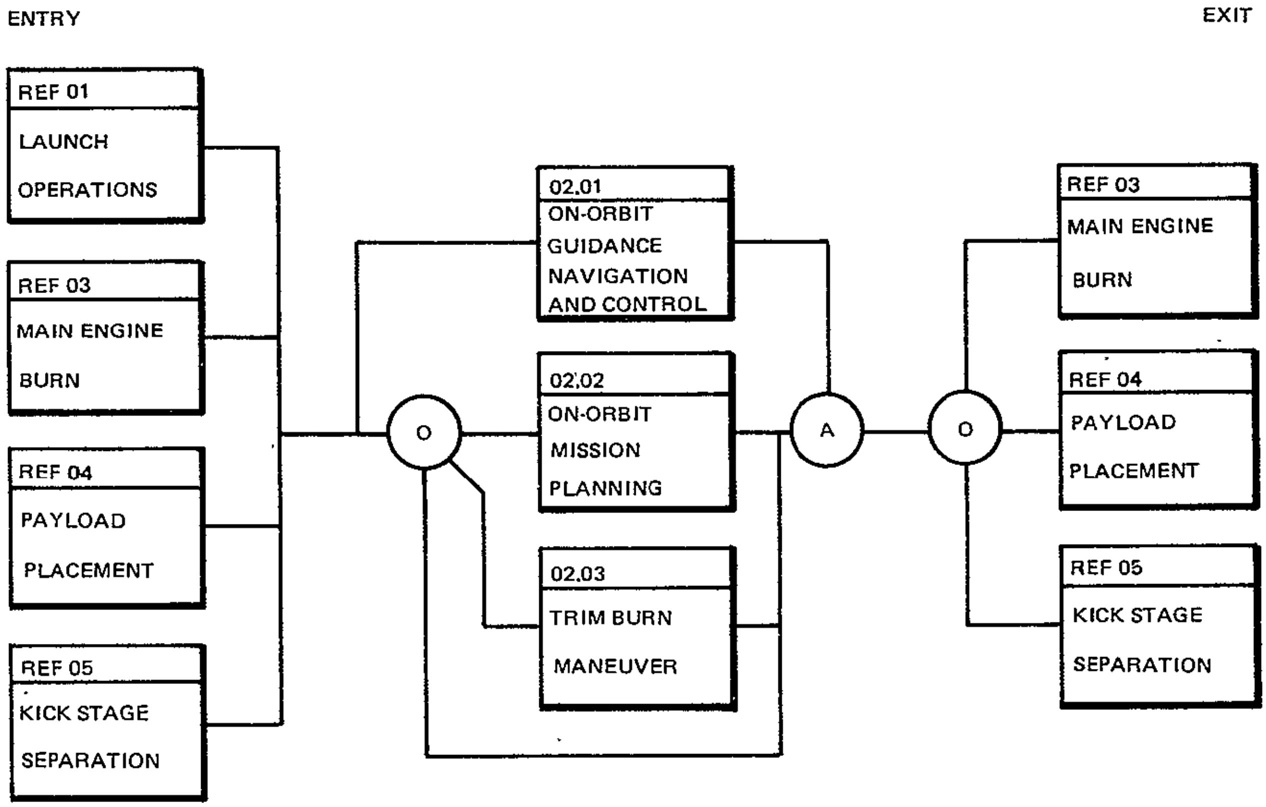

Figure 3.2.3-1. Standard IUS On-Orbit Coast Module Flow

3.2.3.3 On Orbit Mission Planning

The nominal mission will not require any adjustment in the preplanned sequence of events. However, should major perturbations occur, such as missed first mainstage opportunity, early engine cutoff, or anything negating the nominal sequence, then the capability exists through this function to change, by reloading the IUS computer, the mission sequence in a manner best suited to the current realtime conditions.

3.2.3.4 Trim Burn Maneuver

The capability will exist, within the on orbit coast mode, to institute, by ground command, minor trajectory corrections using the attitude control system. This can be done by commanding a vehicle attitude and ACS thrust for a specific duration of time.

3.2.4 <u>Mainstage</u>

3.2.4.1 General

The mainstage module is utilized each time the IUS must make a major maneuver such as a phasing burn, transfer orbit burn, large midcourse correction, and/or circularization. This module is entered with the IUS in the on orbit coast

STANDARD IUS ON ORBIT COAST MODULE (02)

The on orbit coast module provides the interim on orbit navigation guidance and control state between active mission modules. During these awaiting periods the overall mission plan can be reviewed and modified to accomodate realtime mission variations. It is also possible to command addition ΔV utilizing the ACS to improve trajectory parameters.

ENTRY: Launch Operations, Main Engine Burn, Kick Stage Separation, Payload Placement

EXIT: Main Engine Burn, Kick Stage Separation, Payload Placement

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (SEC)	EVENT START TIME IN MODULE (SEC)	EVENT START TIME IN MISSION (HOURS)
ON ORBIT GN&C	02.01.00			
ON ORBIT NAVIGATION	02.01.01			
ON ORBIT ATTITUDE CONTROL	02.01.02			
MONITOR IUS SYSTEMS	02.01.03			
TRACK IUS	02.01.04			
MAINTAIN IUS EPHEMERIS	02.01.05			
MAINTAIN TARGET EPHEMERIS	02.01.06			
MONITOR CONSUMABLES USAGE	02.01.07			
NAVIGATION UPDATE AS REQUIRED	02.01.08	100		
TARGET UPDATE AS REQUIRED	02.01.09	100		
ATTITUDE UPDATE AS REQUIRED	02.01.10	100		
ON ORBIT MISSION PLANNING (CONTINGENCY)	02.02.00	400		
COMPUTE 1ST AND 2ND OPPORTUNITY TARGET PARAMETERS	02.02.01	100		
COMPUTE 1ST AND 2ND OPPORTUNITY BURN PARAMETERS	02.02.02	100		
UPLINK 1ST AND 2ND OPPORTUNITY PARAMETERS AND EVENT SEQUENCE	02.02.03	200		
TRIM BURN MANEUVER (ACS)	02.03.00	515		
CALCULATE TRIM BURN PARAMETERS	02.03.01	200		
UPLINK EVENT SEQUENCE	02.03.02	100		
MANEUVER TO BURN ATTITUDE	02.03.03	200		
INITIATE ACS THRUST	02.03.04	5		
INITIATE TRIM BURN TRACKING	02.03.05			
CALCULATE AND ISSUE ACS CUTOFF	02.03.06	10		
MONITOR CUTOFF AND PROVIDE GROUND CONTROL BACKUP	02.03.07			
	02.03.08			

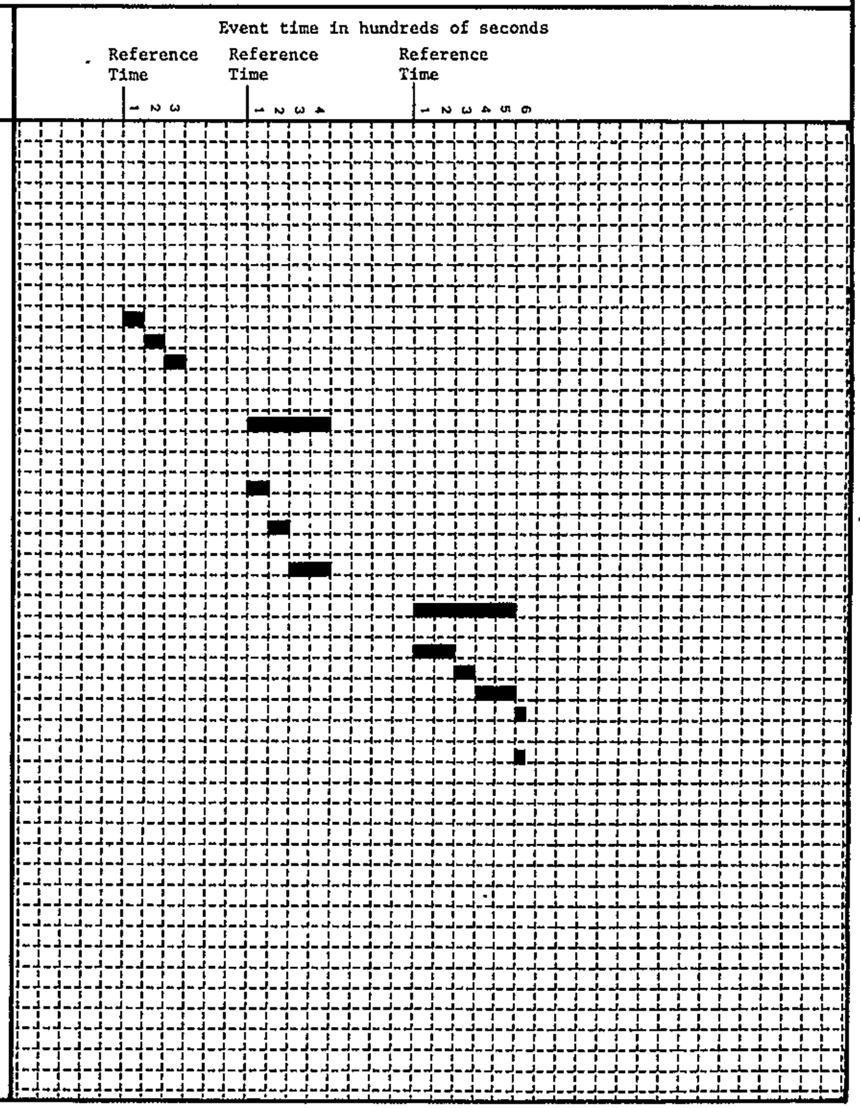

Figure 3.2.3-2. Standard IUS On-Orbit Coast Module Timeline

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mode after accomplishing the desired major thrusting maneuver. Nominal time in the module as currently defined is approximately five minutes for preburn preparations, and three minutes for closing out burn operations. Figure 3.2.4-1 depicts by flow chart the major function sequence within the module. Figure 3.2.4.-2 lists the major IUS and IUS/OC events and their respective times.

3.2.4.2 Main Engine Burn Preparation

This sequence occurs immediately prior to the main engine burn. The IUS is oriented by the ACS to the proper attitude for burn initialization. The main propulsive system is configured for engine ignition.

3.2.4.3 Perform Engine Burn

Immediately prior to engine ignition, the burn sequence is entered and the mainstage GN&C is initiated. If scheduled mainstage ignition should fail to occur, the flight program will terminate the burn sequence and revert to the on orbit coast mode. In the case of the first mainstage burn, a second opportunity sequence will be resident in the flight program and will be automatically implemented.

Prior to mainstage ignition, the IUS/OC will initiate burn tracking if available and will also monitor and verify the onboard events as they occur. During the active mainstage burn, the IUS/OC will monitor the vehicle events and trajectory and provide backup engine cutoff by command. The Orbiter crew will also be in a standby mode for the first mainstage engine burn.

3.2.4.4 Terminate Burn

The main engine cutoff will be calculated and issued by the flight program and the terminal burn parameters telemetered. The IUS/OC will provide backup engine cutoff capability and will terminate burn tracking and evaluate the burn end conditions to determine if burn objectives have been met. The flight program will automatically exit to the on orbit coast mode where mission plans can be modified and an ACS trim burn performed if needed.

3.2.5 Payload Placement

3.2.5.1 General

The payload placement function incorporates those activities required to enable and deploy the IUS payload. Unlike the Tug, the expendable IUS will not engage in placement payload checkout since there is no means to return to the Orbiter. After deployment of the payload, the IUS will re-enter the on orbit coast mode where another mainstage burn could be programmed or commanded to place the expended IUS in another oribt which will not impact spacecraft operations. Figure 3.2.5-1 is a flow chart showing the enable and release sequence and the on orbit coast entry and exit interface. Figure 3.2.5-2 is a listing of the major events and respective event times within the module.

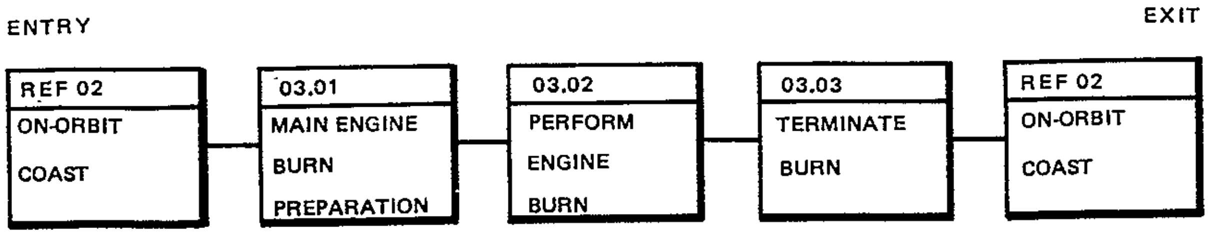

Figure 3.2.4-1. Standard IUS Main Engine Burn Module Flow

3.2.5.2 Placement Preparation

Placement preparation of a Spacecraft will include activating electrical power and any other activation sequencing which can be handled by IUS commands.

3.2.5.3 Release Payload

The process for releasing a spacecraft will include the arming and firing of the release mechanism. The IUS ACS will be temporarily disabled for about two minutes to allow the spacecraft and IUS to drift apart. The IUS ACS will then be automatically activated and the IUS will enter the on orbit coast mode.

3.2.6 <u>Kick Stage Separation</u>

3.2.6.1 General

The Kick Stage separation module describes the activities required to enable and deploy a kick stage. After placement, the IUS enters the on orbit coast mode. Figure 3.2.6-1 is a flow diagram illustrating the separation and separation sequence. Figure 3.2.6-2 lists the major events and event times associated with this operational function. Like all expendable IUS payloads, predeployment checkout is not necessary since the mission is irreversable at this point in time.

3.2.6.2 Kick Stage Separation Preparation

Separation readiness for a Kick Stage will involve activation of the Kick Stage telemetry and an attitude reference update. The IUS will perform any transfer and alignment maneuvers necessary to position the Kick Stage prior to placement. The final preparation steps will involve arming and activations ordinance and transferring the kick stage to its own internal electrical power.

3.2.6.3 Kick Stage Separation

The process for releasing a Kick Stage will include the arming and firing of the separation ordinance. The IUS will perform a separation ACS maneuver and enter the on orbit coast mode.

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STANDARD IUS MAIN ENGINE BURN MODULE (03)

The mainstage module is utilized each time the IUS must make a major maneuver such as a phasing burn, transfer orbit burn, large mid-course correction, circularization, etc. This module is entered with the IUS in the on-orbit coast mode and exits in the on-orbit coast mode after the accomplishment of the desired major thrusting maneuver.

ENTRY: On Orbit Coast

EXIT: On Orbit Coast

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (SEC)	EVENT START TIME IN MODULE (SEC)	EVENT START TIME IN MISSION (HOURS)
MAIN ENGINE BURN PREPARATION	03.01.00	260	- 260	
OPEN PROPELLANT LINE CAVITY VENTS (PLCV) (1ST BURN ONLY)	03.01.01	7	- 260	
PROPELLANT SETTLING - ON	03.01.02	3	- 253	
CLOSE PLCV & OPEN PREVALVES	03.01.03	10	- 250	
PROPELLANT SETTLING - OFF AND OPEN PREVALVES TO POSITION 2 (FULL-OPEN 1ST BURN ONLY)	03.01.04	3	- 240	
ORIENT FOR 1ST BURN	03.01.05	20	- 237	
ORIENTATION COMPLETE	03.01.06	2	- 217	
PROPELLANT SETTLING - ON	03.01.07	202	- 215	
PRESSURIZE PROPELLANT TANKS (2 VALVES)	03.01.08	10	- 14	
START HYDRAULICS PUMP AND PRESSURIZE PROPELLANT TANKS (4 VALVES)	03.01.09	4	- 4	
PERFORM ENGINE BURN	03.02.00		0	
START MAIN ENGINES	03.02.01	0	0	
INITIALIZE DFCS	03.02.02	0	0	
PROPELLANT SETTLING - OFF	03.02.03	0	0	
NO IGNITION (REVERT TO ON ORBIT NAVIGATION AND SELECT 2ND OPPORTUNITY MISSION PLAN)	03.02.04	10	10	
MONITOR EVENT SEQUENCE	03.02.05			
GROUND BACKUP ENGINE CUTOFF COMMAND	03.02.06			
INITIATE AND PERFORM BURN TRACKING	03.02.07			
TERMINATE ENGINE BURN	03.03.00		0	
DISABLE COMMAND SHUTDOWN	03.03.01	9	CO-9	
SHUTDOWN MAIN ENGINE SHUTDOWN HYDRAULICS	03.03.02		CO	
DISABLE PRESSURIZATION (2 VALVES) DISABLE PRESSURIZATION (4 VALVES)	03.03.03	2	CO+2	
TELEMETRY BURN DATA	03.03.04	5	CO+5	
EXIT SEQUENCE TO ON ORBIT NAVIGATION	03.03.05	5	CO+5	
MONITOR CUTOFF AND PROVIDE GROUND BACKUP ENGINE CUTOFF COMMAND	03.03.06	5	CO+5	
COMPARE CALCULATED AND ACTUAL BURN DATA	03.03.07			
INITIATE COAST TRACKING	03.03.08		CO+10	
EXIT TO ON ORBIT COAST	03.03.09		CO+10	

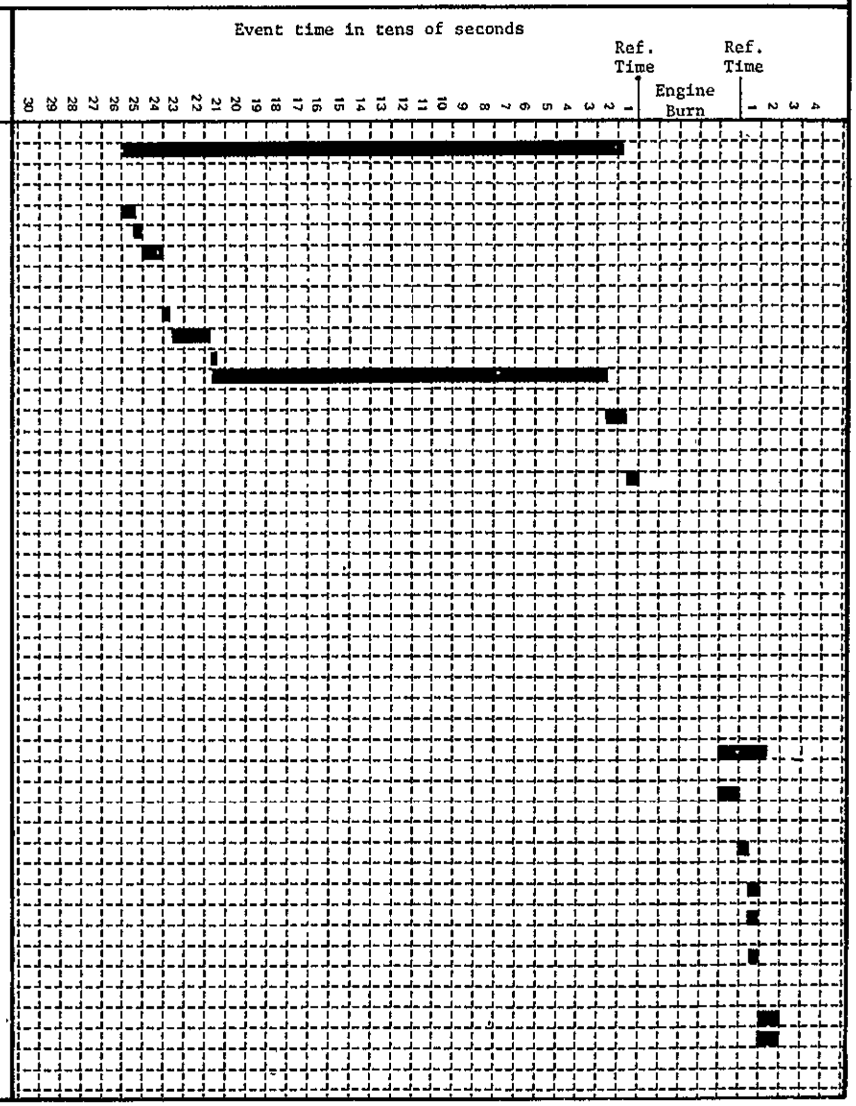

Figure 3.2.4-2. Standard IUS Main Engine Burn Module Timeline

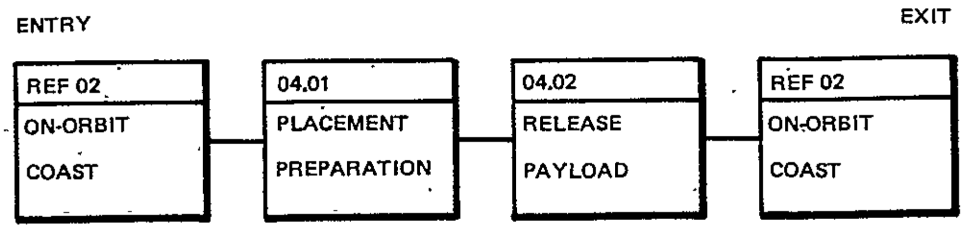

Figure 3.2.5-1. Standard IUS Payload Placement Module Flow

3.2.7 Orbiter Retrieval

3.2.7.1 General

The retrieval of the IUS from orbit by the Orbiter is accomplished after the IUS final main engine burn which places the IUS in a low earth orbit. Retrieval by the Orbiter is applicable only to the reusable IUS. The procedure for retrieval is essentially the reverse of the deployment sequence with the IUS systems being deactivated and safed rather than activated. Figure 3.2.7-1 illustrates the flow of major functions for the retrieval of the IUS from orbit. Figure 3.2.7-2 lists the events associated with this activity.

3.2.7.2 Deactivate IUS Main Propulsion

Prior to deactivation of the IUS main propulsion system, the IUS/OC and Orbiter crew will concur that the IUS will not be required to make a propulsive maneuver to assist in orbiter retrieval. After this decision, the IUS propulsive system will be safed by dumping both oxidizer and fuel. Upon completion of propellant safing, the IUS will assume the retrieval attitude and rendezvous aids will be activated. The IUS/OC will notify the Orbiter crew that the IUS is ready for retrieval.

3.2.7.3 Maneuver Orbiter For Intercept

The orbital intercept maneuver will be the responsibility of the Orbiter crew. The IUS, in a safe condition and in a prescribed attitude with rendezvous aids active, will wait in a fixed low earth orbit. The IUS/OC will continually monitor the IUS status and keep the Orbiter crew posted.

3.2.7.4 Orbiter Acquire IUS Telemetry

When the Orbiter closes within range IUS telemetry will be acquired and command capability of IUS By the crew established.

3.2.7.5 Maneuver Orbiter For Rendezvous

The terminal rendezvous maneuver will be the responsibility of the Orbiter Crew. The IUS will maintain a safe attitude and configuration during this time.

STANDARD IUS PAYLOAD PLACEMENT MODULE (04)

The payload placement module lists the activities required to enable and deploy a payload. The IUS is returned to an on orbit coast mode after payload placement.

ENTRY: On Orbit Coast

EXIT: On Orbit Coast

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (SEC)	EVENT START TIME IN MODULE (SEC)	EVENT START TIME IN MISSION (HOURS)
PLACEMENT PREPARATION	04.01.00	190	0	
INITIALIZE PAYLOAD SYSTEMS	04.01.01	180	0	
ENABLE COMMAND ACCEPT	04.01.02	10	180	
RELEASE PAYLOAD	04.02.00	132	190	
ARM SPACECRAFT SEPARATION	04.02.01	1	190	
FIRE SPACECRAFT SEPARATION	04.02.02	4	191	
DISABLE ACS	04.02.03	125	195	
ENABLE ACS	04.02.04	1	320	
EXIT TO ON ORBIT NAVIGATION	04.02.04	1	321	

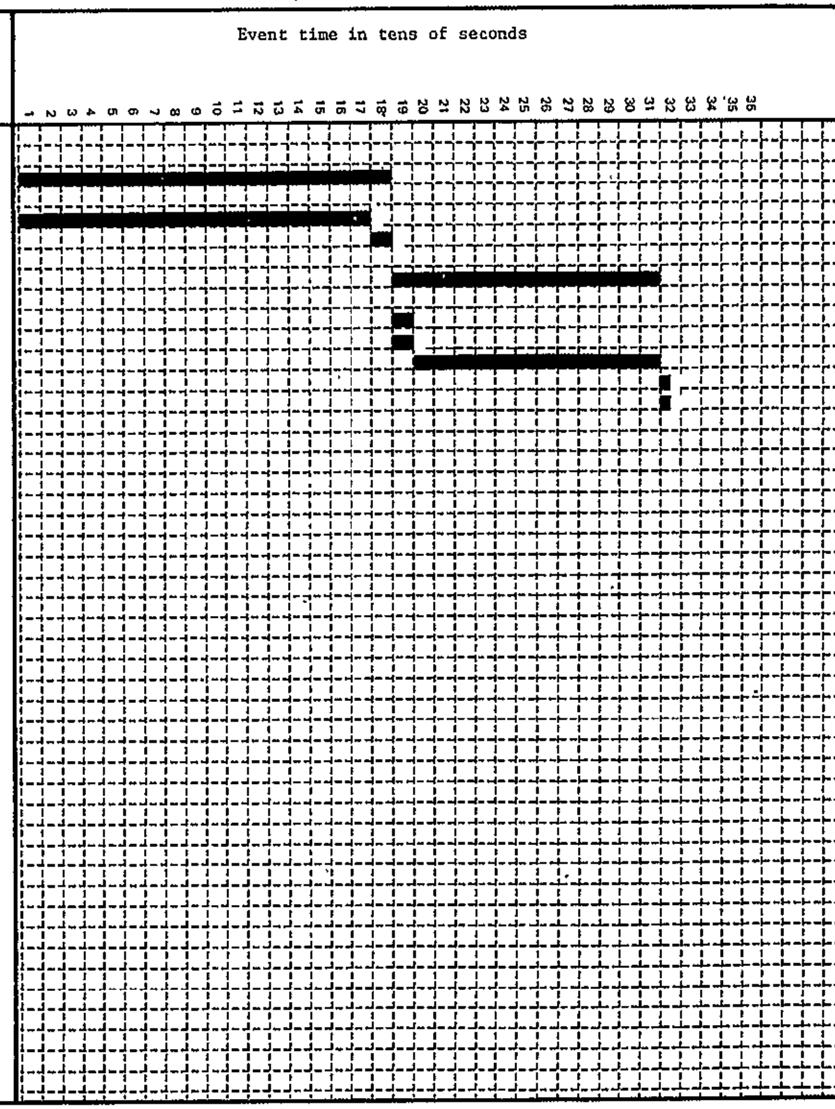

Figure 3.2.5-2. Standard IUS Payload Placement Module Timeline

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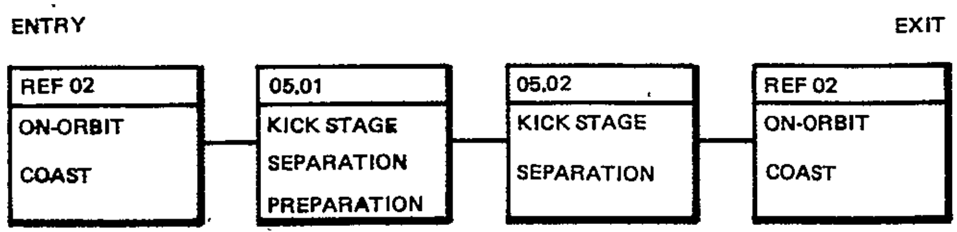


Figure 3.2.6-1. Standard IUS Kick Stage Separation Module Flow

The IUS/OC will continually monitor IUS status and keep the Orbiter crew posted. At the request of the Orbiter crew and with IUS/OC concurrance, command control of the Tug will be transferred from the IUS/OC to the Orbiter crew.

3.2.7.6 Prepare For Retrieval

The Orbiter will have the option of either flying around or commanding an attitude change rate to visually inspect the IUS and payload if desired. The Orbiter will be configured by the crew for retrieval operations. Included in these operations are opening the payload bay doors, assuming the retrieval alignment attitude and activating the RMS and IUS cradle latches. The Orbiter crew will get final concurrence from the IUS/OC that the IUS is ready for retrieval.

3.2.7.7 IUS Retrieval

IUS retrieval begins with the extention of the RMS and the disabling of the IUS attitude control system. When RMS/IUS mate is accomplished, the ACS will be activated. Checks will be made at this time to verify the IUS is safe for retraction into the bay. The Orbiter crew will then retract the IUS into the IUS cradle and secure the latches. The RMS will be disconnected and stored and the IUS/Orbiter umbilicals connected. When hardwire caution and warning data is established IUS RF will be terminated. IUS power will be transfered to the Orbiter and the IUS and Orbiter will be configured for deorbit operations.

3.2.7.8 Deorbit

The deorbit sequence will be accomplished by the Orbiter and crew with the IUS in a passive configuration. The only IUS activity during this period will be the maintenance of the IUS safe condition and the caution and warning data system.

STANDARD IUS KICK STAGE SEPARATION MODULE (05)

The kick stage placement module defines the activities required to activate and deploy a kick stage. After deployment the IUS enters the on orbit coast mode

ENTRY: On Orbit Coast

EXIT: On Orbit Coast

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (SEC)	EVENT START TIME IN MODULE (SEC)	EVENT START TIME IN MISSION (HOURS)
KICK STAGE SEPARATION PREPARATION	05.01.00	633	0	
ACTIVATE KICK STAGE TELEMETRY AND INITIATE ATTITUDE UPDATE	05.01.01	480	0	
PERFORM TRANSFER ALIGN AND MANEUVER TO RELEASE ATTITUDE	05.01.02	120	480	
TRANSFER SC AND KICK STAGE TO INTERNAL POWER AND ENABLE ACS START VALVE	05.01.03	32	600	
ENABLE SEPARATION	05.01.04	1	632	
KICK STAGE SEPARATION	05.02.00	4	633	
INITIALIZE KICK STAGE, UNCAGE GYROS AND FIRE ACS START VALVE	05.02.01	1	633	
FIRE KICK STAGE SEPARATION ORDNANCE	05.02.02	1	634	
ENABLE ACS PULSING	05 02.03	1	635	
EXIT TO ON ORBIT COAST	05 02 04	1	636	

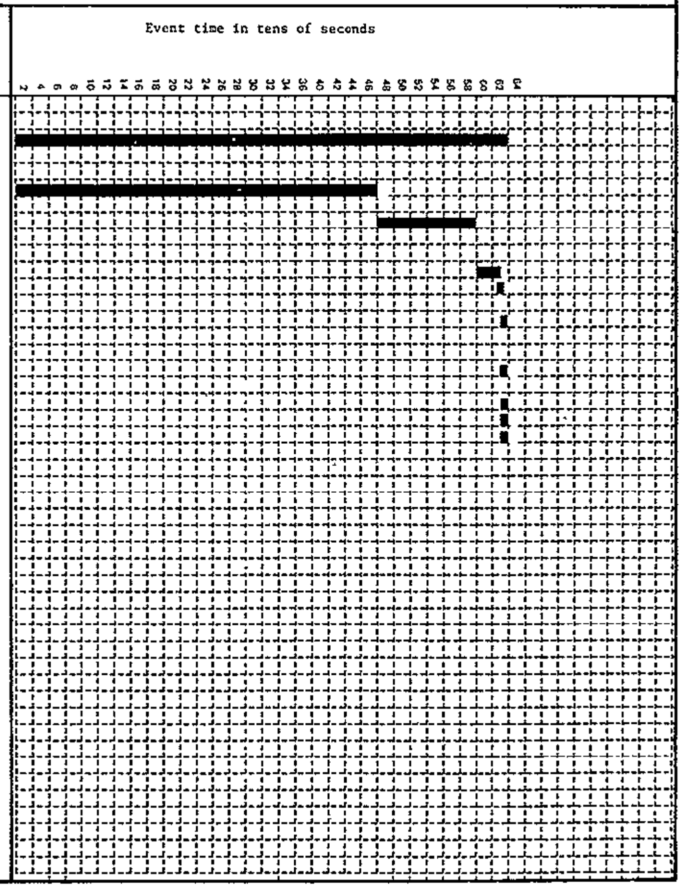


Figure 3.2.6-2. Standard IUS Kick Stage Separation Module Timeline

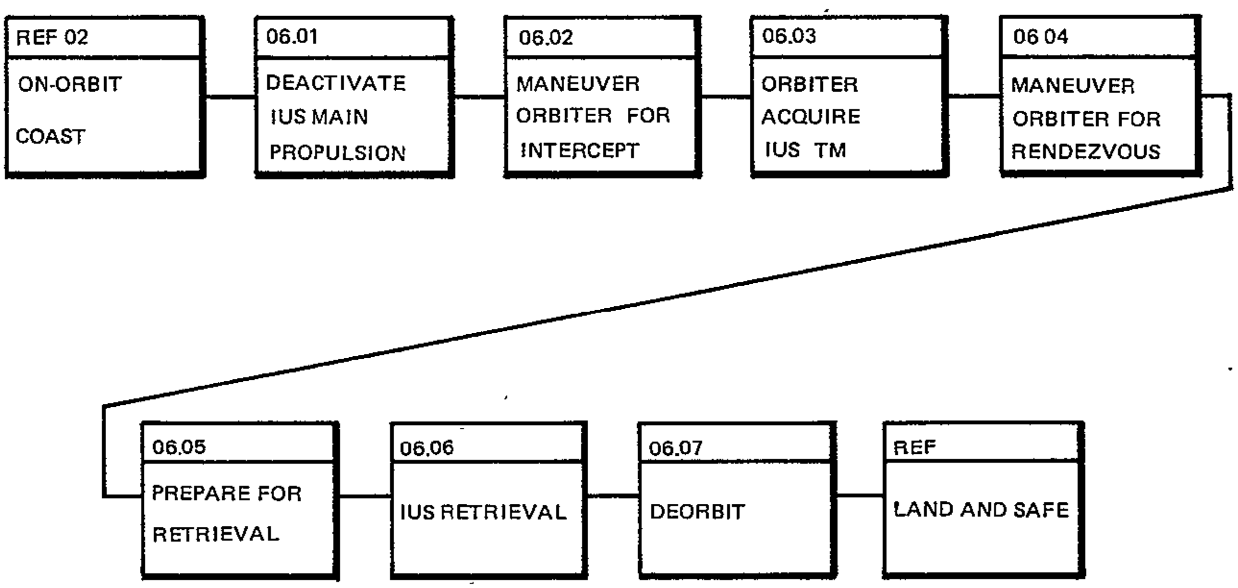


Figure 3.2.7-1. Standard Orbiter Retrieval Module for Reusable IUS

STANDARD ORBITER RETRIEVAL MODULE (06)

Retrieval Operation begins after the IUS final rendezvous main engine burn and terminates with the return of the Orbiter to earth. This module is applicable for Reusable IUS only.

ENTRY. On-Orbit Coast

EXIT. Post Landing Ground Control

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (SEC)	EVENT START TIME IN MODULE (SEC)	EVENT START TIME IN MISSION (HOURS)
DEACTIVATE IUS MAIN PROPULSION	. . . . . 01.00	2230	-2230	
VERIFY TUG PROPULSION SYSTEM NOT NEEDED FOR TUG/ORBITER RENDEZVOUS	. . . . . 01.01	300	-2230	
COMMAND TUG RETRIEVAL SAFING	. . . . . 01.02	10	-1930	
ACS PROPELLANT SETTLING	. . . . . 01.03	10	-1920	
DUMP OXIDIZER AND FUEL	. . . . . 01.04	1500	-1910	
OPTIMIZE PRESSURES	. . . . . 01.05	100	- 410	
DISABLE MAIN PROPULSION ELEC. POWER	. . . . . 01.06	10	- 310	
MONITOR AND VERIFY IUS SAFE	. . . . . 01.07	100	- 300	
COMMAND RETRIEVAL ATTITUDE	. . . . . 01.08	50	- 200	
VERIFY ATTITUDE AND ATTITUDE HOLD	. . . . . 01.09	50	- 150	
ACTIVATE TUG RENDEZVOUS AIDS	. . . . . 01.10	50	- 100	
VERIFY TUG READY FOR RETRIEVAL	. . . . . 01.11	50	- 50	
MANEUVER ORBITER FOR INTERCEPT	. . . . . 02.00	1300	ORBITER FUNCTIONS	
DETERMINE RANGE AND RANGE RATE	. . . . . 02.01	250		
DETERMINE INTERCEPT MANEUVERS	. . . . . 02.02	100		
COMPUTE TPI BURN PARAMETERS	. . . . . 02.03	200		
MANEUVER TO TPI BURN ATTITUDE	. . . . . 02.04	500		
PERFORM TPI BURN (OMS ENGINES)	. . . . . 02.05	50		
PERFORM COURSE CORRECTION OPS.	. . . . . 02.06	200		
ORBITER ACQUIRE IUS TM	. . . . . 03.00	600		
ON-ORBIT NAVIGATION MODE	. . . . 03.01	600		
IUS/ORBITER RF TM AND COMMAND LINK ESTABLISHED	. . . . 03.02	600		
MANEUVER ORBITER FOR RENDEZVOUS	. . . . 04.00	1150		
DETERMINE RANGE AND RANGE RATE	. . . . . 04.10	250		
COMPUTE TPF BURN PARAMETERS	. . . . . 04.02	200		
ORIENT ORBITER FOR TPF BURN	. . . . . 04.03	200		
VERIFY ORBITER READINESS FOR BURNS	. . . . . 04.04	200		
PERFORM TPF BURNS (OMS/APS)	. . . . . 04.05	200		
VERIFY TUG SAFE FOR DOCK	. . . . . 04.06	200		

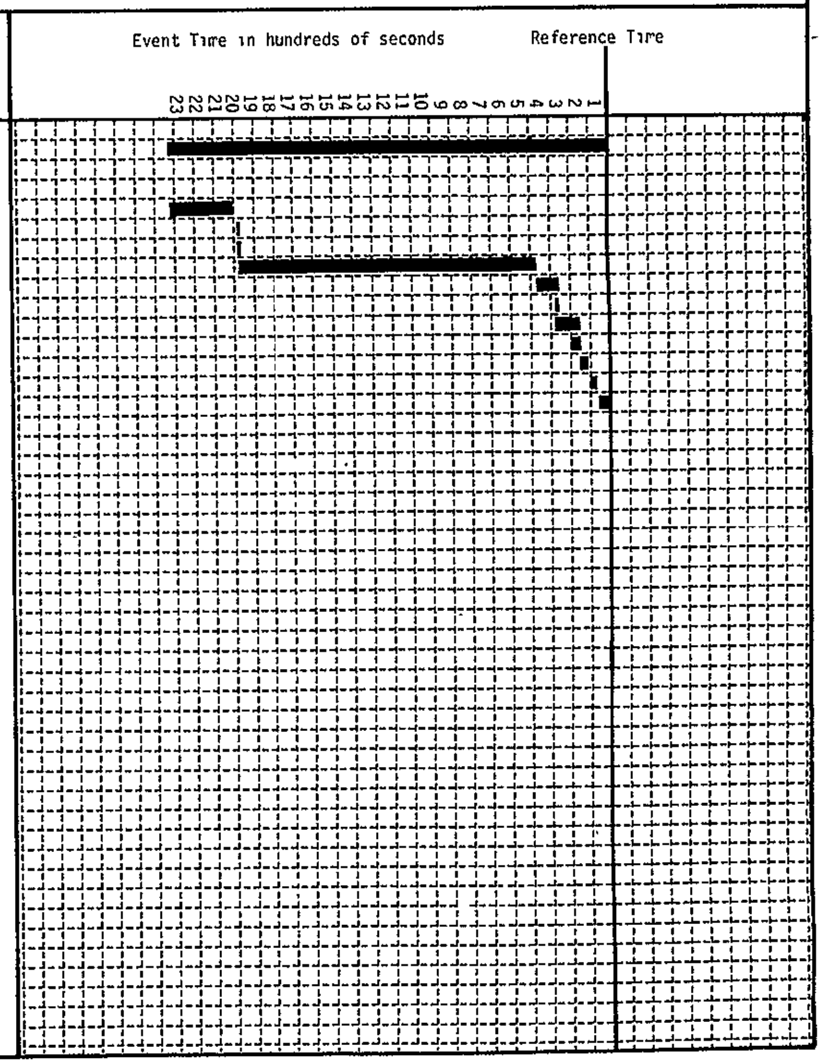


Figure 3.2.7-2. Standard Orbiter Retrieval Module Timeline

STANDARD ORBITER RETRIEVAL MODULE (06) (Continued)

EVENT DESCRIPTION	EVENT NUMBER	EVENT DURATION (SEC)	EVENT START TIME IN MODULE (SEC)	EVENT START TIME IN MISSION (HOURS)
PPEPARE FOR RETRIEVAL	. . . . . 05.00	1000	-1350	
IUS ATTITUDE HOLD MODE	. . . . . 05.01	1000	-1350	
ORBITER INSPECTION OF TUG	. . . . . 05.02	250	-1350	
ORBITER/IUS RETRIEVAL ALIGNMENT .(ORBITER)	. . . . . 05.03	250	-1100	
PAYLOAD BAY DOORS OPEN	. . . . . 05.04	500	- 850	
ORBITER CONFIGURED FOR RETRIEVAL	. . . . . 05.05	250	- 350	
IUS RETRIEVAL	. . . . . 06.00	1110	- 100	
RMS EXTENDED	. . . . . 06.01	100	- 100	
DISABLE IUS ACS	. . . . . 06.02	100	- 100	
RMS/IUS MATE	. . . . . 06.03	50	PFF	
DEACTIVATE IUS ACS	. . . . . 06.04	10	50	
VERIFY IUS SAFE FOR RETRACTION	. . . . . 06.05	100	60	
MOVE IUS INTO BAY/CRADLE	. . . . . 06.06	300	160	
LATCH IUS TO CRADLE	. . . . . 06.07	60	460	
RECONNECT UMBILICALS	. . . . . 06.08	60	520	
VERIFY CAUTION AND WARNING MONITOR	. . . . . 06.09	10	580	
IUS RF OFF	. . . . . 06.10	10	590	
IUS POWER TRANSFER	. . . . . 06.11	10	600	
CONFIGURE IUS FOR RE-ENTRY	. . . . . 06 12	100	610	
CONFIGURE ORBITER BAY FOR RE-ENTRY	. . . . . 06.13	300	710	
DEORBIT	. . . . . 07.00	ORBITER FUNCTIONS		
PERFORM DEORBIT COAST OPERATIONS	. . . . . 07.01			
PERFORM DEORBIT MANEUVERS	. . . . 07.02			
PERFORM ENTRY AND DESCENT MANEUVERS	. . . . 07.03			
PERFORM APPROACH AND LANDING	. . . . . 07.04			

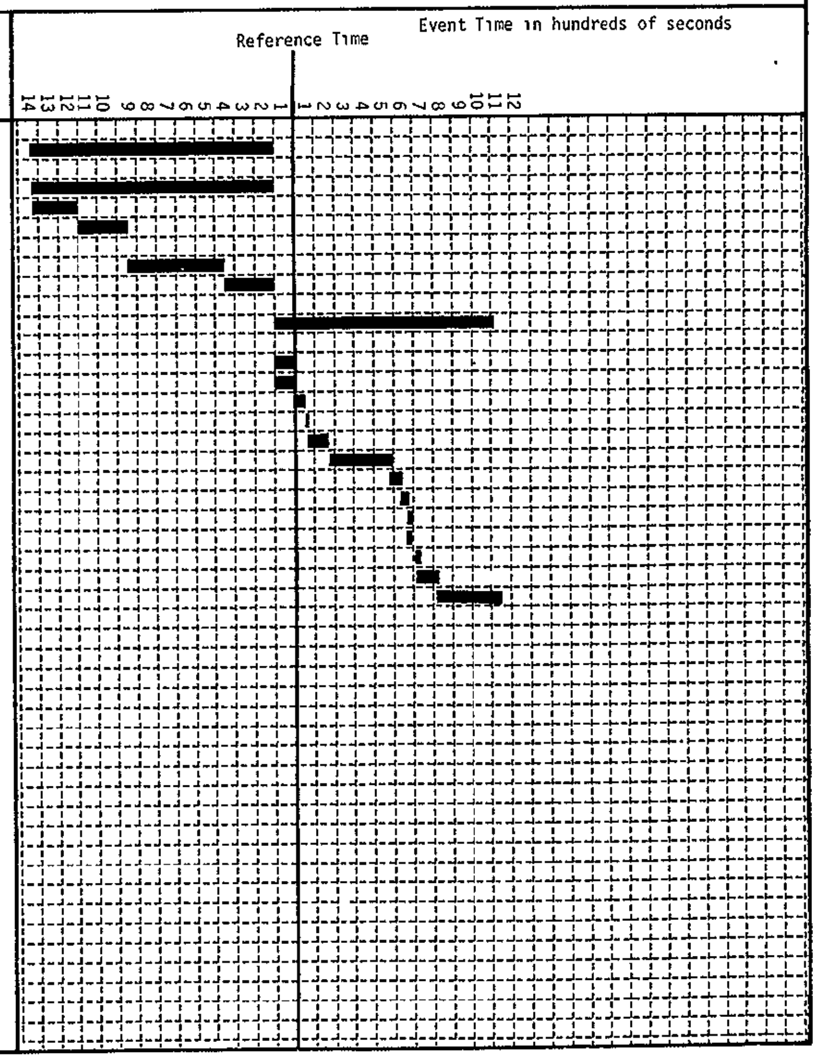


Figure 3.2.7-2. Standard Orbiter Retrieval Module Timeline (Continued)

INTERIM UPPER STAGE CONFIGURATION DESCRIPTION 4

A baseline IUS configuration was established to provide a basis for the operational and costing analyses required in the study effort. Both expendable and reusable configurations were used during the initial study phases, however, the latter part of the study concentrated on the expendable IUS. This section gives an overview of the expendable IUS with deltas shown for the reusable IUS. Unless otherwise specified, IUS discussions assume the same configuration for both EIUS and RIUS. The baseline EIUS and RIUS are derived from information provided by NASA in references 3 through 5.

4.1 OVERALL IUS DESCRIPTION

A modified existing vehicle is baselined for the Orbital Operations Study. The Expendable IUS (EIUS) is ten feet in diameter and approximately 14.3 feet in length. It has a liftoff weight of approximately 27,300 lbs. and a dry stage weight of about 3600 lbs. The EIUS consists of a control module and a propulsion module. The propulsion module houses the liquid propellant tanks, pressurization system and two AJ-10-138 hydraulically-gimballed engines. The Control Module houses the EIUS avionics, and the monopropellant hydrazine Attitude Control System (ACS). The control module can be separated from the propulsion module and remain with the spacecraft to provide attitude control and velocity increments as required. A deployment adapter (or cradle) will be designed for EIUS/Orbiter interface and to support the EIUS and spacecraft while in the Orbiter bay and during deployment.

The Reusable IUS (RIUS) is a modified EIUS with added provisions for Orbiter retrieval. The Reusable stage is 10 feet in diameter and 19.2 feet long with a dry weight of 4400 lbs. and a liftoff weight of approximately 36,800 lbs. The propellant tanks lengths are measured to accomodate the additional fuel requirements, and minor additions or revisions are made to components to allow for longer mission durations and recovery operations.

4.2 PROPULSION SUBSYSTEM

The following is a summary of the IUS propulsion subsystem and its pertinent operational characteristics as baselined for the IUS missions.

4.2.1 Main Engine

The IUS engine is the multiple restart, pressure fed, liquid bipropellant engine utilizing storage propellants. The engine start sequence is initialed by applying a 28 vdc signal to a pilot valve to a cavity behind the bipropellant valve power position. Opening time is controlled by an orifice located between the pilot valve and bipropellant valve. Propellants from the bipropellant valve flow into the fuel and oxidizer manifolds of the injector and are injected into the thrust chamber where hypergolic ignition occurs. Propellant flowrates to maintain the design mixture ratio for the engine system are controlled by balanced orifices located at the bipropellant valve inlets. Termination of the 28 vdc signal to the pilot valve allows the bipropellant valve cavity to be vented through the pilot valve overboard vent tube. The bipropellant valve spring then forces the fuel poppet and oxidizer stem assembly to the closed position terminating fuel and oxidizer flow.

4.2.2 Pressurization

The EIUS pressurization subsystem utilizes helium gas stored in spherical tanks for propellant tank pressurization. The helium gas is regulated by two control valve assemblies with filters and redundant solenoid operated shutoff valves controlled by redundant and propellant tank pressure sensing switch assembly. Check valves in each propellant tank pressurization inlet line prevent vapor backflow and possible vapor mixing during nonflow periods. If propellant vapors leak past the check valves, they are vented overboard through the bleed orifice.

Onboard redundancy is avilable to assure mission success. If any solenoid valve malfunctions, the flow is still controlled by the remaining valves. For example, if a valve fails open, the series arrangements provides a second valve to shut off the flow. If a valve fails closed, the parallel arrangement provides a second flow path. Burst disks are provided on each pressurization leg to provide burst/relief portection.

The pressurization system also includes a propellant utilization system which provides increased vehicle performance by reducing mixture ratio dispersions. Oxidizer and fuel pressurant relief valves prevent tank over pressurization.

4.2.3 Propellant Management

The propellant management subsystem stores, and, when required, distributes the fuel and oxidizer to the main engines. It consists of fuel and oxidizer tanks, propellant tank trap and screen assemblies, propellant utilization sensors, feedlines for propellant fill, drain and dump, and vent and pressurization lines.

The PU system utilizes discrete level sensors located in each propellant tank to sense propellant levels and control propellant utilization. The control system uses pressurant gas to control the flow rates (mixture ratio). The control unit is activated by three switches which increase, decrease, or maintain ullage pressure. The switch selection is determined by the computer based on level sensor error signals.

The propellant isolation is accomplished by motor operated prevalves installed in the feedlines to provide double propellant isolation to prevent accidental engine operation. Dump valves are in the dumpline downstream for the prevalves. For abort dumps, the prevalve and dump valves are commanded open and the propellant dumped through the Orbiter overboard dump system. Pressure switches will close valves and deactivate the pressurization system when the dump is accomplished.

In case of mission abort after IUS deployment, the dump valves will be open, the pressurization system activated, and the propellant dumped. After dumping, the engine feedlines will be purged, the valves closed and the tanks repressurized.

4.2.4 Attitude Control System (ACS)

The IUS ACS is a blowdown, storable hydrazine liquid monopropellant, variable pulse width system which provides attitude and vernier velocity maneuvers. The ACS uses a hydrazine liquid monopropellant and a gaseous nitrogen pressurant. Six rocket engine modules consists of two rocket engine assemblies each. The engine arrangement provides engine-out redundancy in all three control axes.

4.2.5 Hydraulics

The IUS hydraulics system consists of a sealed electric motor-driven pump/reservoir hydraulic lines, fittings, and four electrohydraulic mechanical feedback activators. IUS thrust vector control is accomplished by gimballing the two main engine assemblies. The activator position is sensed by a spring loaded cam follower and mechanically summed with the computer input common on the Servovalve torque motor/flapper assembly.

4.3 AVIONICS SUBSYSTEM

The IUS avionics is a centralized avionics system which consists of the following subsystems:

- Guidance, Navigation and Control
- Electrical Power
- Data Management and Instrumentation
- Communications

The following sections give an avionics overview and a brief summary of the subsystems and their flight operations related characteristics.

4.3.1 Avionics Overview

The Expendable IUS avionics configuration is shown in Figure 4.3.1-1 and the Reusable IUS avionics configuration is shown in Figure 4.3.1-2. The major differences between the two configurations are the additions of an extra 165 amp-hr battery, of computer storage, and of a star tracker for attitude updates for the Reusable IUS.

The baseline EIUS used as a basis for the IBM analyses and costing is an existing vehicle modified to accomplish the basic EIUS mission. The EIUS avionics are basically simplex and designed for a short duration mission.

A digital computer with 16K of 24 bit storage provides the onboard computation capability. The IMU provides an inertial reference system and the computer provides the control signals for the hydraulics and the sequencing of the ACS engines and electrical systems. Two batteries provide the onboard power requirements. Telemetry is collected by the remote multiplex units (RMU) and formatted by the RMIS. The communications provide tracking, telemetry and command interface with the ground and Orbiter.

The interface adapter contains the provisions for making the IUS external interfaces compatible with the Orbiter and GSE. The EIUS command decoders also contain additional provisions for computer inputs, Spacecraft commands and IUS sequencing. Spacecraft telemetry could be integrated with IUS telemetry by inputs to the IUS RMU's.

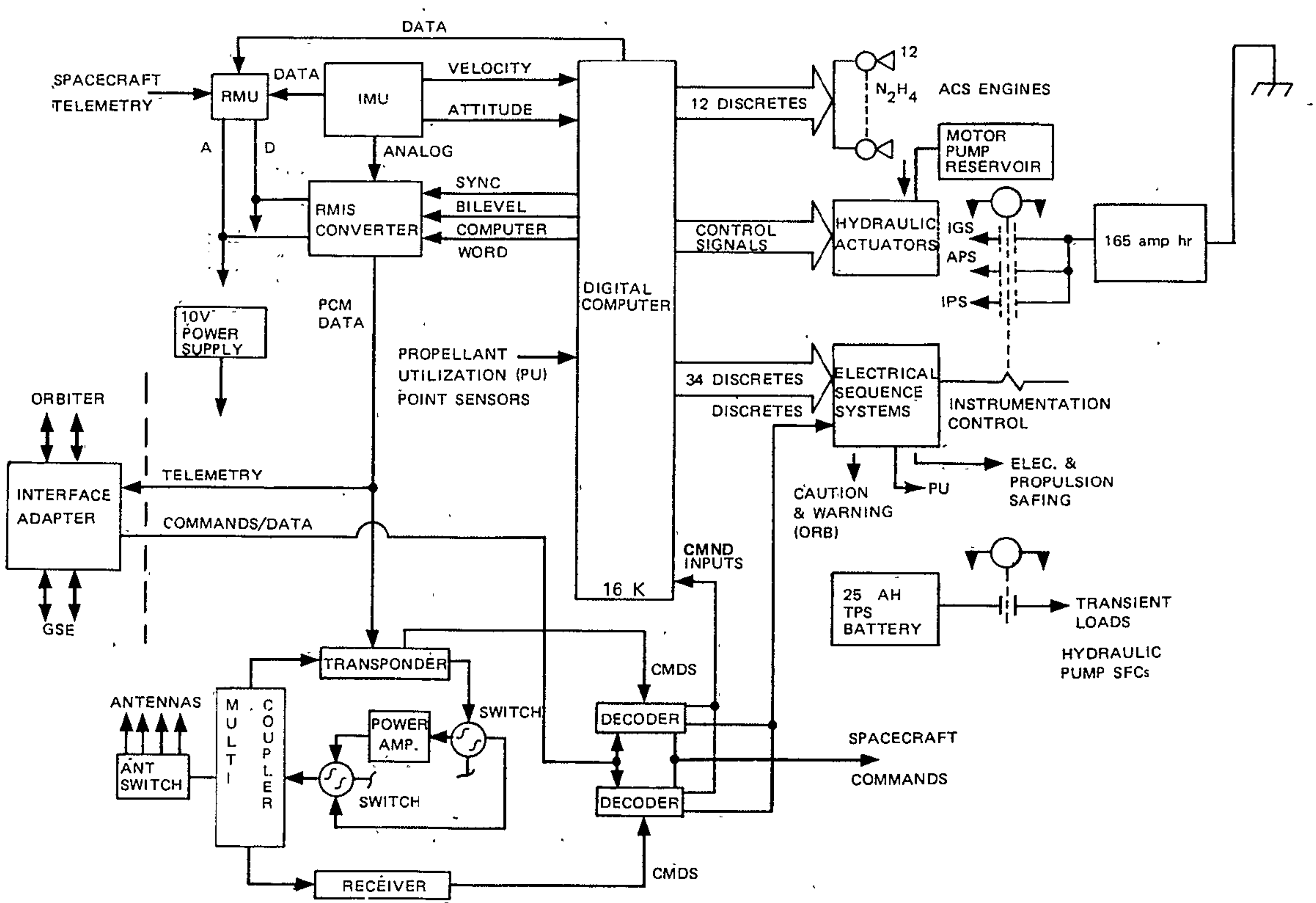


Figure 4.3.1-1. Expendable IUS Avionics Configuration

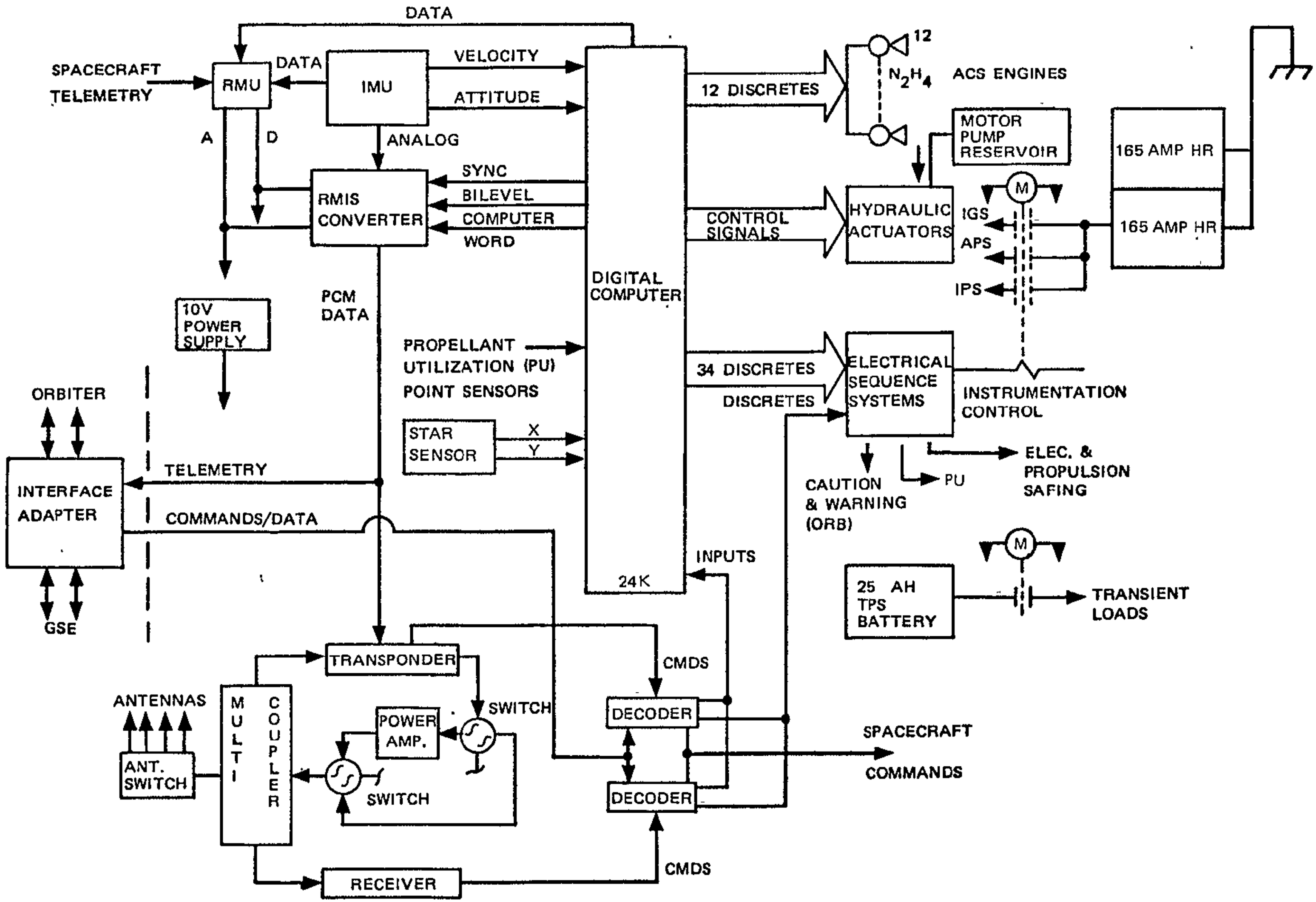


Figure 4.3.1-2. Reusable IUS Avionics Configuration

Table 4.3.1-1 gives a summary of the major IUS subsystems components, a redundancy summary, backup components and functions of the components. An asterisk indicates critical IUS components. As shown, little redundancy exists for the IUS avionics components, no backup capability is available and most components are mission critical.

4.3.2 Guidance, Navigation and Control

The IUS GN&C subsystem shown in Figure 4.3.2-1 consists of an inertial platform which senses vehicle movement, a computer which solves the GN&C equations and provides onboard sequencing and malfunction detection support, and hydraulic activators and attitude control thrusters that control vehicle orientations and maneuvers.

The inertial platform is an IMU which provides delta velocity and delta attitude information to the computer for guidance and navigation processing. The IMU is a four-gimbal all attitude platform stabilized with three single-degree-of-freedom rate integrating gyros and the accelerometers to sense accelerations.

The digital computer is the heart of the IUS avionics. It performs the navigation and guidance processing and generates control commands as well

Table 4.3.1-1. EIUS Operational Redundancy Summary

COMPONENT/SUBSYSTEM	REDUNDANCY	BACKUP	FUNCTION
* IMU	SIMPLEX	-	INERTIAL ATTITUDE REFERENCE
* COMPUTER	SIMPLEX	-	ONBOARD CONTROL AND PROCESSING
RMIS (TELEMETRY)	BASICALLY SIMPLEX	-	TELEMETRY DATA ORGNIZATION
* BATTERIES (2)	SIMPLEX	-	POWER GENERATION
COMMUNICATIONS	BASICALLY DUAL REDUNDANT	-	ORBITER, GROUND INTERFACE
* ATTITUDE CONTROL PROPULSION SYSTEM	BASICALLY DUAL REDUNDANT	-	ATTITUDE CONTROL, LOAD LEVEL THRUST
* MAIN PROPULSION SYSTEM	SOME REDUNDANCY	-	HIGH ENERGY THRUST

* SYSTEMS MANDATORY FOR EIUS OPERATION

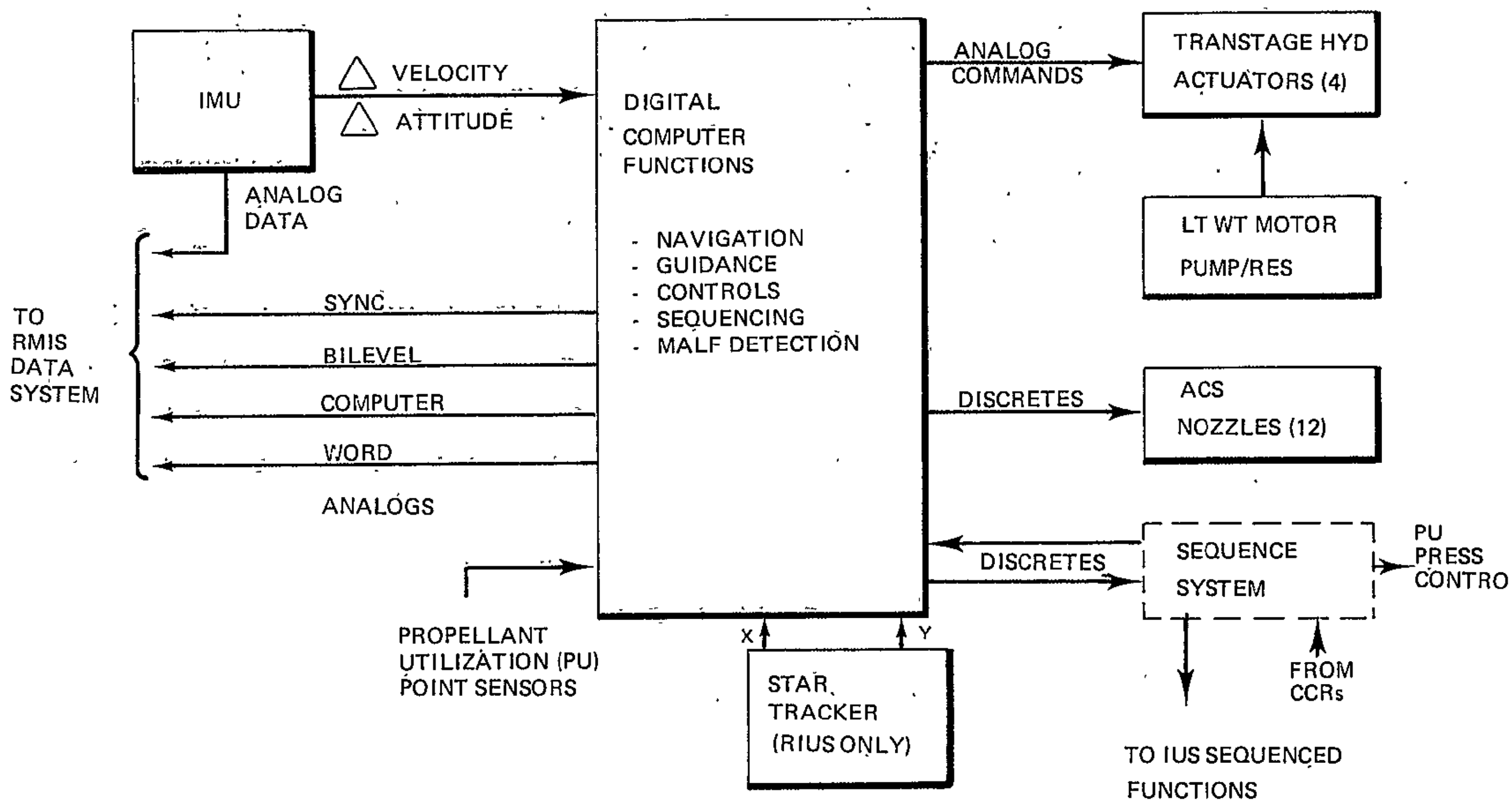


Figure 4.3.2-1. IUS GN&C Subsystem Block Diagram

as performing event sequencing and some malfunction detection. The computer I/O interfaces with six IMU velocity and attitude inputs, four hydraulic activator outputs, and 12 ACS nozzle outputs. Digital flight control equations are used for GN&C processing. Built-in malfunction detection logic performs sum checks and reasonability tests to detect and correct for computer transients.

The computer interfaces with the electrical sequencing system and can issue up to 34 groundleg switching discrete outputs for sequencing of IUS loads, valves or switches. It also accepts discretes from the PU System and controls the switch setting for the helium tank pressurization system. The computer telemetry is routed to the RMIS for insertion into the IUS telemetry stream.

A star tracker interfaces with the computer for altitude update for the Reusable IUS only. The star tracker takes two readings at different RIUS orientations for update computations which are performed by the computer. The angle data from the star tracker is input to the computer.

The EIUS require 16K of 24 bit words and the RIUS 24K of 24 bits words for onboard software storage. As stated, the EIUS performs the basic GN&C computations and sequencing, while additional software is required by the RIUS for star tracker computations and the return and retrieval operations software required for a Reusable vehicle.

4.3.3 Data Management and Instrumentation

The IUS data management and instrumentation subsystem consists of a data bus Remote Multiplexed Instrumentation System (RMIS) with remote terminals, measurement translators, signal conditioning, and a 10 vdc power supply. A schematic of the subsystem is shown in Figure 4.3.3-1. The RMIS converter interrogates six RMU's in a programmed sequence and integrates their response into a 16 or 64 KBPS PCM format along with the bilevels, computer data, and sync pulses. The RMIS is synchronized by the computer to allow insertion of the computer data into the PCM format.

An IUS (both EIUS and RIUS) measurement list summary is given in Table 4.3.3-1 and an uplink command list is given in Table 4.3.3-2.

4.3.4 Communications

The IUS communications, shown in Figure 4.3.4-1, includes the antennas, transmitter, receivers, and decoders for external RF interface. The components are dual redundant except that only one transmitter is baselined for the Expendable IUS. The subsystem includes the capability for telemetry, tracking and command interface and is compatible with the Orbiter and STDN as shown in Figure 4.3.4-2. It provides a 16 or 64 Kbps downlink interface with the ground and a 16 Kbps telemetry link with the Orbiter. It accepts the 2 Kbps command link from both the Orbiter and ground.

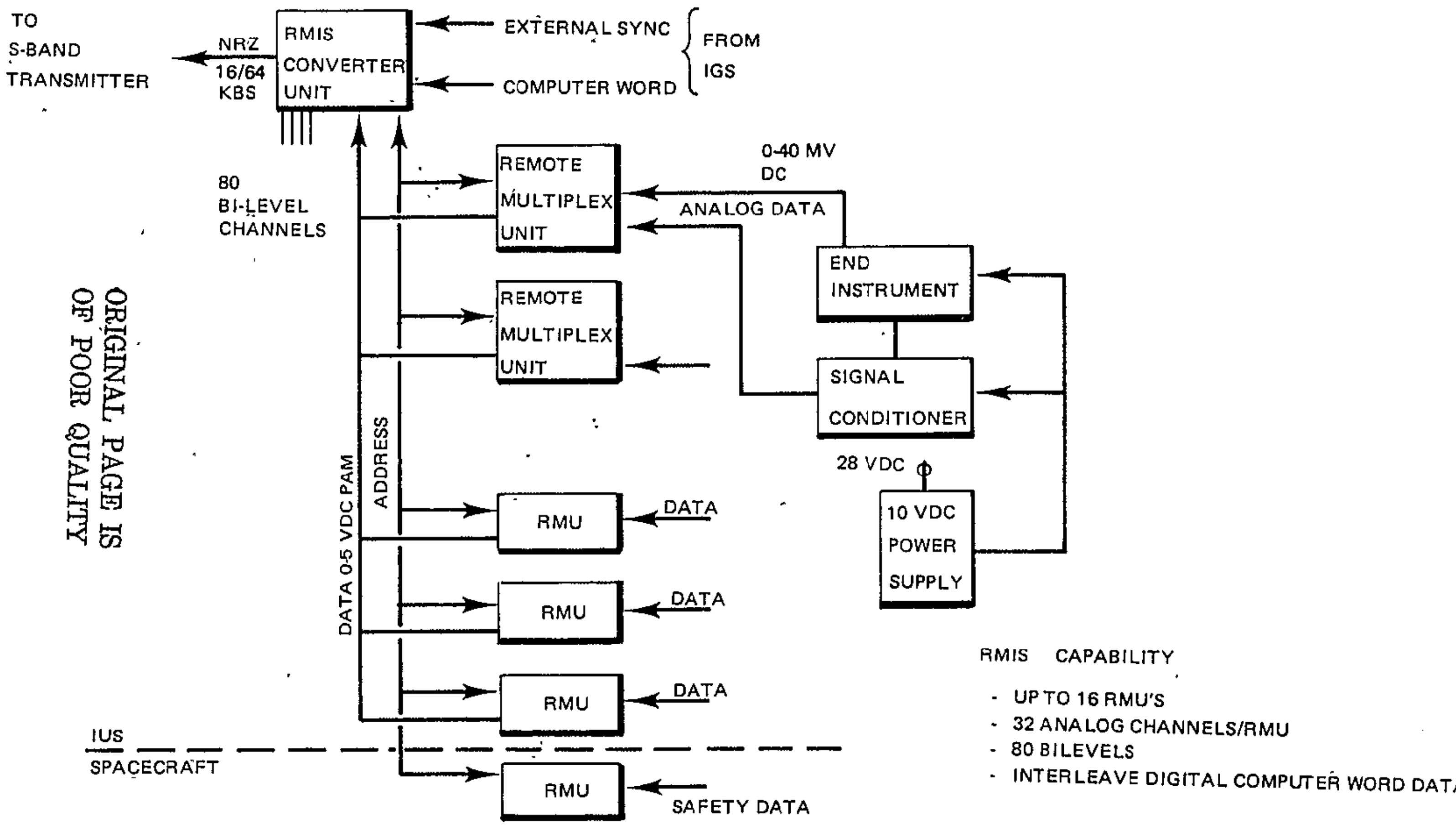


Figure 4.3.3-1. IUS Data Management and Instrumentation Block Diagram

Table 4.3.3-1. IUS Measurement List Summary

MEASUREMENT	DISCRETE	ANALOG
IMU	--	21
COMPUTER	2	12
FLIGHT CONTROL	12	3
HYDRAULICS	--	5
COMMUNICATIONS	21	20
ELECTRICAL	23	18
INSTRUMENTATION	--	6
ENGINES	--	26
PRESSURIZATION/PROPELLANT	12	11
PROPELLANT UTILIZATION	--	6
STRUCTURAL/THERMAL	--	6
CRADLE	5	2
	75	136

The command decoder provides the command interface with the Orbiter while attached. The decoders accept commands and distribute them to the computer, IUS electrical sequencing system, and Spacecraft.

Five antennas are included on the IUS. Three are located 120 degrees apart on the circumference of the vehicle, while two are located pointing towards the front and rear of the vehicle to assure complete spherical coverage.

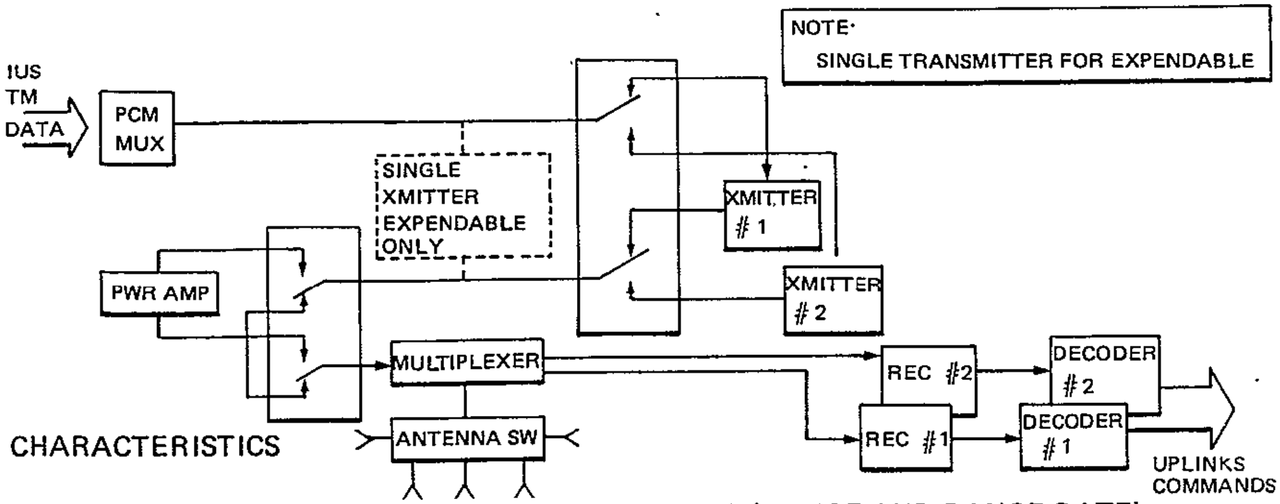
4.3.5 Electrical Power

The IUS electrical power subsystem consists of a 165 amp-hour silver-zinc battery (2 required for RIUS), a 25 amp-hour silver zinc battery and the power distribution and control circuits. An electrical power system schematic is shown in Figure 4.3.5-1. The 165 amp-hour battery (VPS) provides power for the Inertial Guidance System (IGS), ACS, communications equipment and instrumentation. The transient battery system (TPS) provides the power for transient loads such as the hydraulic motor, pyro circuits and solenoids to isolate the noise generating loads from the critical power buses.

While attached, the Orbiter provides power to operate the IUS. The IUS is transferred to internal power just prior to deployment.

Table 4.3.3-2. IUS Uplink Command List Summary

NORMAL ENABLING AND SAFING COMMANDS
Activate Mission Timing
Open/Close TPS MDS
Safe Main Propulsion System
Open Propellant Dump Valves
Close Propellant Prevalve and Dump Valves
Pressurize Tanks to 20 psi
Inhibit ACS
Safe ACS Propulsion System
Remove All IUS Power
Enable Ordnance and Main Engine Buses
Safe Ordnance and Main Engine Buses
Input Guidance Update Data
Open/Close Propellant Line Cavity Vent
OVERRIDE COMMAND FUNCTIONS
Power to RF Amplifier On
Power to RF amplifier Off
Switchover to Backup Transmitter
Switch Back to Primary Transmitter
Turn On Instrumentation/Transmitter
Turn Off Instrumentation/Transmitter
Select Antenna Number 1, 2, 3, 4, 5
Inhibit Antenna Selector Search
Enable Antenna Selector Search
Ranging Channel Enable
Ranging Channel Inhibit
Disable Bang Bang Pressurization
Arm Spacecraft Release
Fire Spacecraft Release Ordnance
Arm Kickstage Release
Fire Kickstage Release Ordnance
Inhibit Spacecraft Release
Inhibit Kickstage Release



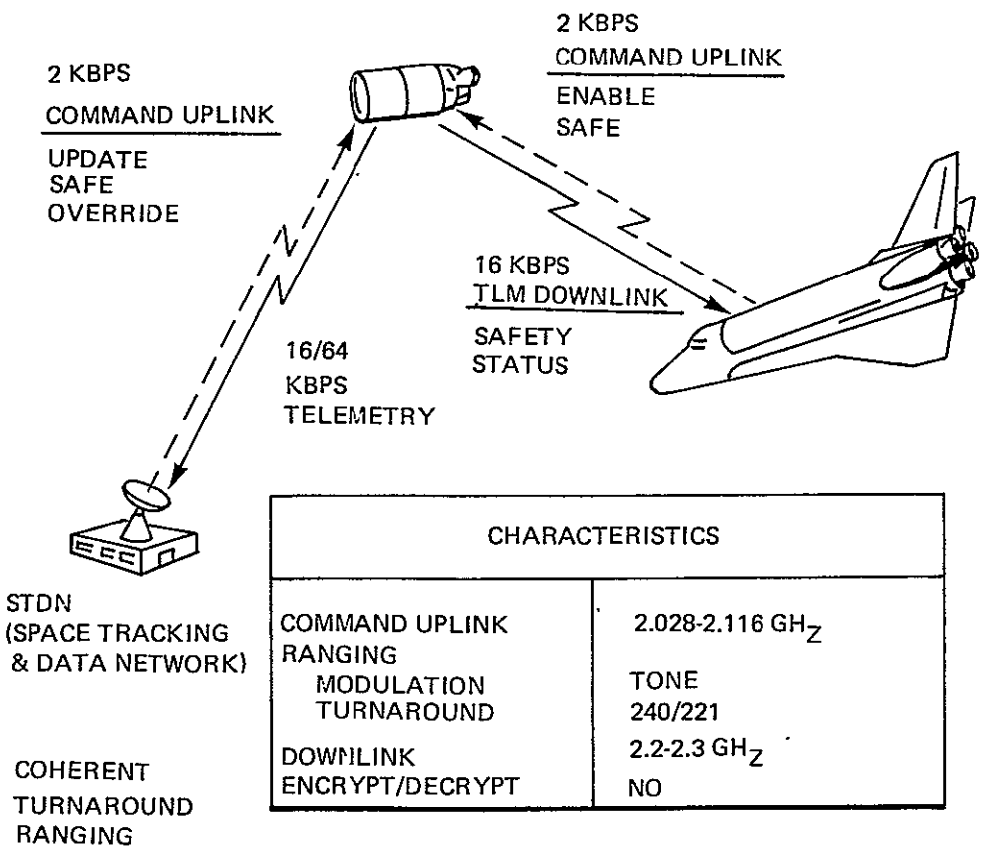
CHARACTERISTICS

TELEMETRY
- XMTR POWER 2/20 WATTS
- MODULATION PCM (BIØ-L)/PM
- BIT RATES 16, 64 KBPS
- BER = 10^{-6}

TRACKING (RANGE AND RANGE RATE)
- COHERENT TURNAROUND
- RANGE TONES ON 1.7 MHZ SUBCARRIER

COMMAND
- MODULATION PCM (BIØ-L), BCH/PM
- COMMAND RATE - 8 KBPS
- BER = 10^{-5}

Figure 4.3.4-1. IUS Communications Diagram and Characteristics



CHARACTERISTICS	
COMMAND UPLINK	2.028-2.116 GHZ
RANGING	
MODULATION	TONE
TURNAROUND	240/221
DOWNLINK	2.2-2.3 GHZ
ENCRYPT/DECRYPT	NO

Figure 4.3.4-2. IUS Communications Interface

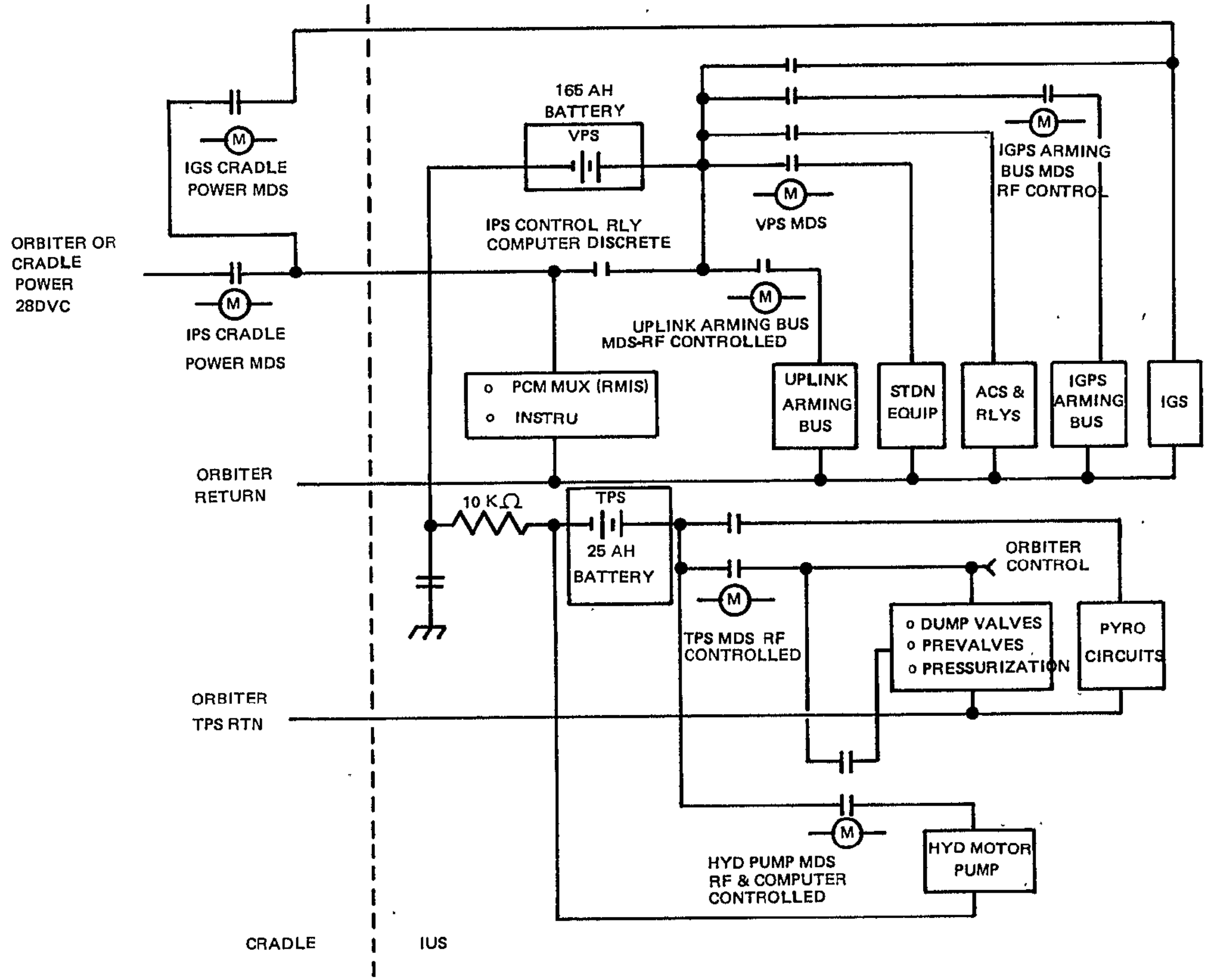


Figure 4.3.5-1. IUS Electrical Power Schematic

IUS OPERATIONAL INTERFACES 5

The IUS interfaces with the Orbiter, ground and Spacecraft during its prelaunch and flight operations. This section will discuss the external flight operations interfaces required by the IUS, with special emphasis on the IUS/Orbiter interfaces and operations.

5.1 IUS/ORBITER INTERFACES

One of the major operational interfaces for the IUS is with the Orbiter during predeployment and deployment operations. Previous sections have given the Orbiter/IUS interface requirements and the IUS baseline configuration. This section discusses the specific Orbiter/IUS interfaces to meet those operational requirements and the interfaces required.

5.1.1 Orbiter Payload Interface Support

The Orbiter provides a wide variety of interface capability for the varying payloads it will be carrying. Figure 5.1.1-1 gives an overview of the avionic interfaces available for payloads, such as the IUS, and the associated paths for the data. As shown, the Orbiter provides interfaces for the following types of data which are useful to the IUS:

- Engineering Data - 16 KBPS to the payload signal processor (PSP) and up to 5 channels of up to 64 KBPS each to the Payload Data Interleaver (PDI).
- Command/Data Input - 8 KBPS (2 KBPS of information) command link from the PSP and GN&C data and discretes from the MDM.
- Caution and Warning - input capability for hardware C&W signals to the C&W Electronics Unit.
- Timing - timing signals from the Orbiter Master Timing Unit (MTU).

In additional, high data rate interfaces are available for scientific data, but these are not required for the IUS. Also, since it is unmanned, no voice interfaces are required.

The Orbiter has allocated approximately 10K of 32 bit words in main storage and approximately 18 KOPS for payload (IUS/Spacecraft) support in its general purpose computer.

The Mission Specialist Station (MSS) and Payload Specialist Station (PSS) also have space available for IUS dedicated interface panels (See Figure 5.1.1-2) which shows potential placement of non-standard avionics to support IUS operations. Figure 5.1.1-3 gives a schematic of the control display panel in the MSS which will support the EIUS operations. As shown, these C&D interfaces include status, deploy operations, IUS commands, abort sequences and manual control of IUS elements.

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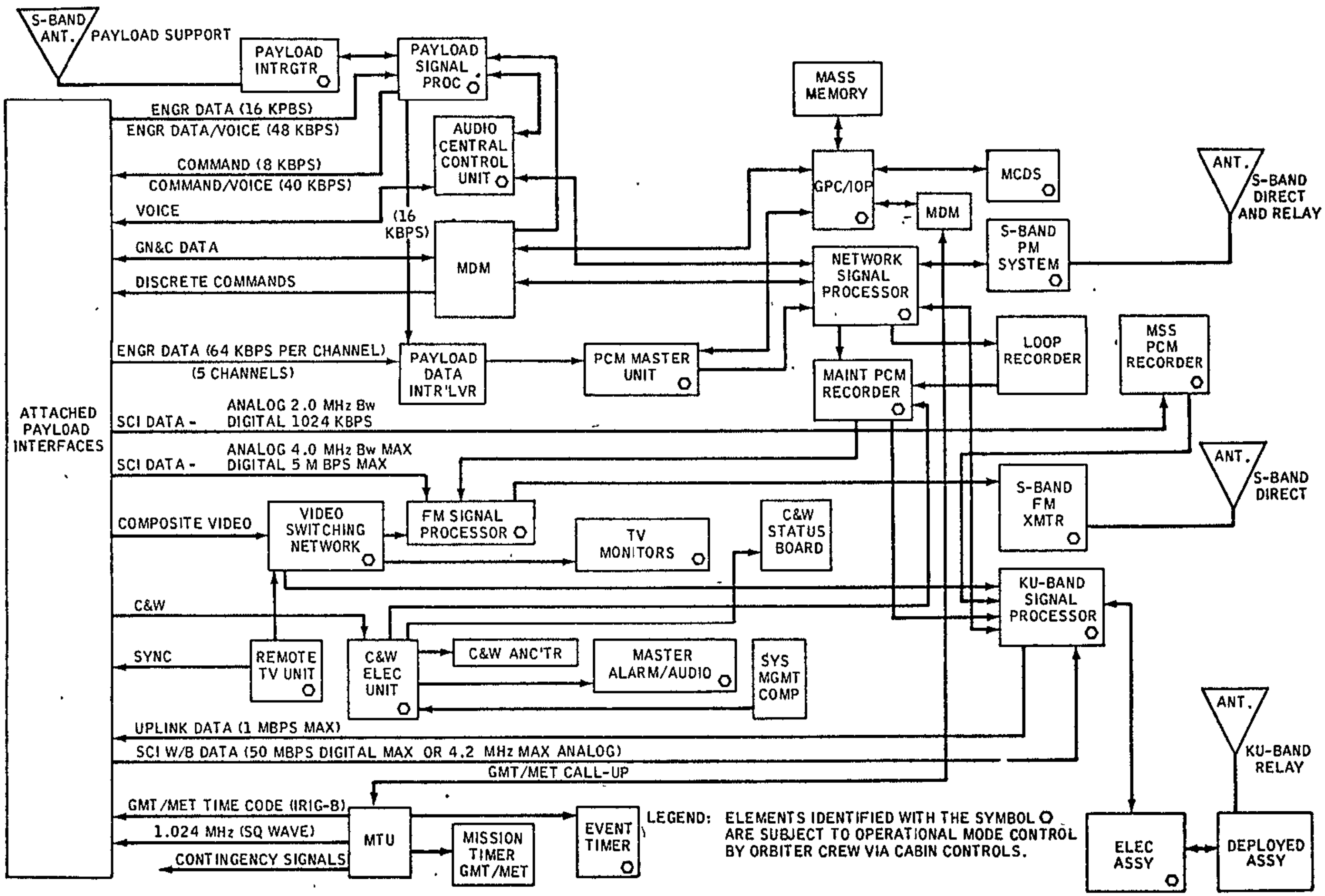

Figure 5.1.1-1. Orbiter Avionics Functional Diagram for Payloads

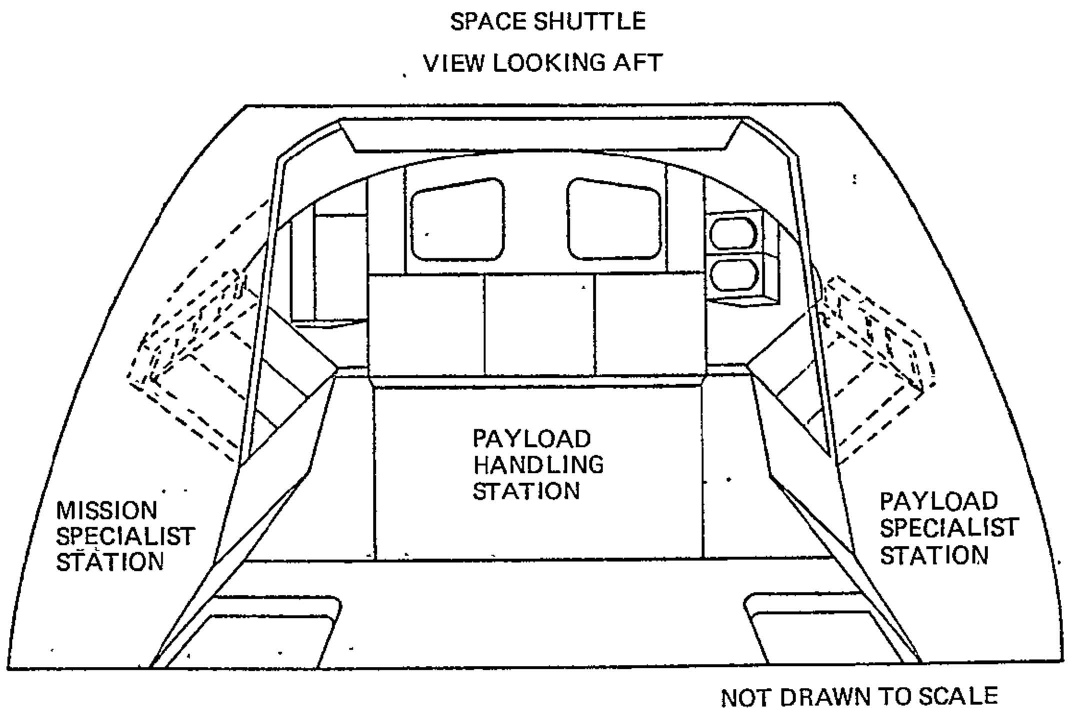

Figure 5.1.1-2. Orbiter MSS/PSS Layout Schematic

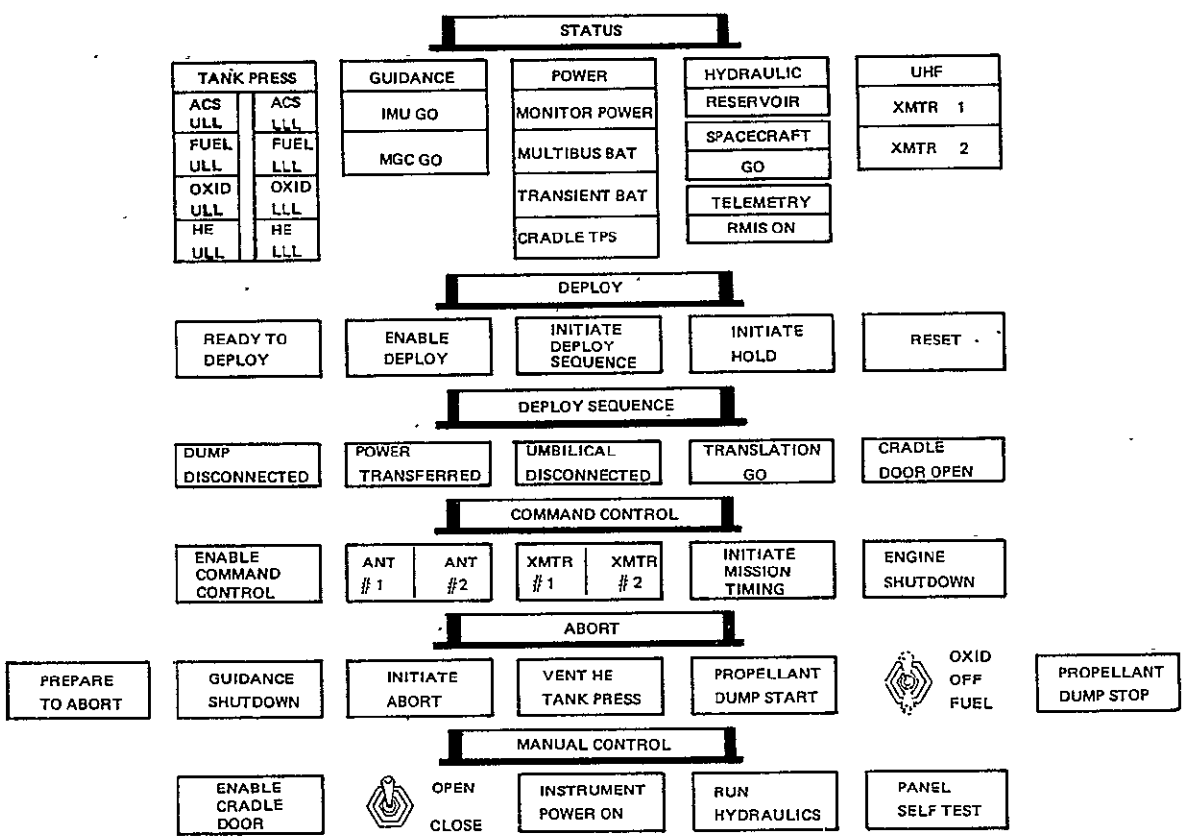

Figure 5.1.1-3. Orbiter MSS Control Display Panel to Support EIUS

5.1.2 EIUS/Orbiter Interface Overview

A top-level EIUS/Orbiter interface schematic is shown in Figure 5.1.2-1. As shown, the interface adapter provides the elements for interface compatibility between the Orbiter and EIUS. The Orbiter provides the same interface capability that will be provided for Tug, but the EIUS is not presently directly compatible with that interface. The interface adapter will eliminate Orbiter grounding problems in addition to providing compatibility element between vehicles.

The EIUS receives data and commands from the Orbiter (or ground) that are routed to the EIUS command decoders for decoding and distribution. Telemetry (16 or 64 KBPS) is routed from the EIUS RMIS to the adapter. C&W parameters are hardwired to the Orbiter.

The Orbiter can receive either 16 KBPS through the Payload Signal Processor (PSP) and/or 0 to 64 KBPS through the Payload Data Interleaver (PDI). Commands are sent from the PSP at 2 KBPS or from the MDM. The Orbiter can also provide GN&C data to the EIUS at rates up to 1 MBPS.

After deployment, the interface between the EIUS and Orbiter is a 2 KBPS command link and a 16 KBPS telemetry link which provides the EIUS safety-related parameter for near-vicinity operations.

A more detailed breakdown at the C&W parameters and discrete command interfaces are shown in Figure 5.1.2-2. As shown, approximately 91 discrete commands have been identified from the data provided by NASA for the IUS and deployment adapter. Thirteen C&W signals were identified and are discussed in the following section.

5.1.3 IUS Caution and Warning Description

The existing definition of the IUS shows caution and warning will consist of the following parameters.

1. Propulsion
   - Oxidizer Tank Overpressures
   - Fuel Tank Overpressures
   - Helium Sphere Overpressure
   - ACS Tank Overpressure

2. Avionics
   - IMU Malfunction
   - Computer Alarm
   - Inadvertent Power On

3. Inadvertent Disconnection
   - Propellant Dump Lines
   - Vehicle Holddown
   - Electrical Umbilical

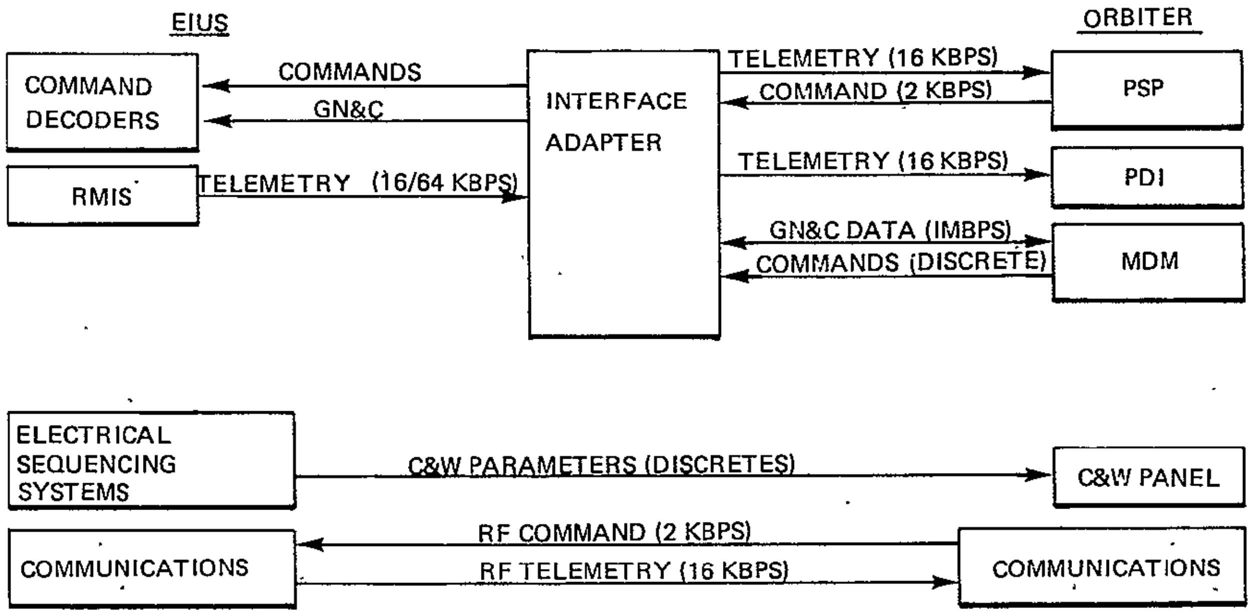

Figure 5.1.2-1. EIUS/Orbiter Operational Data Interfaces

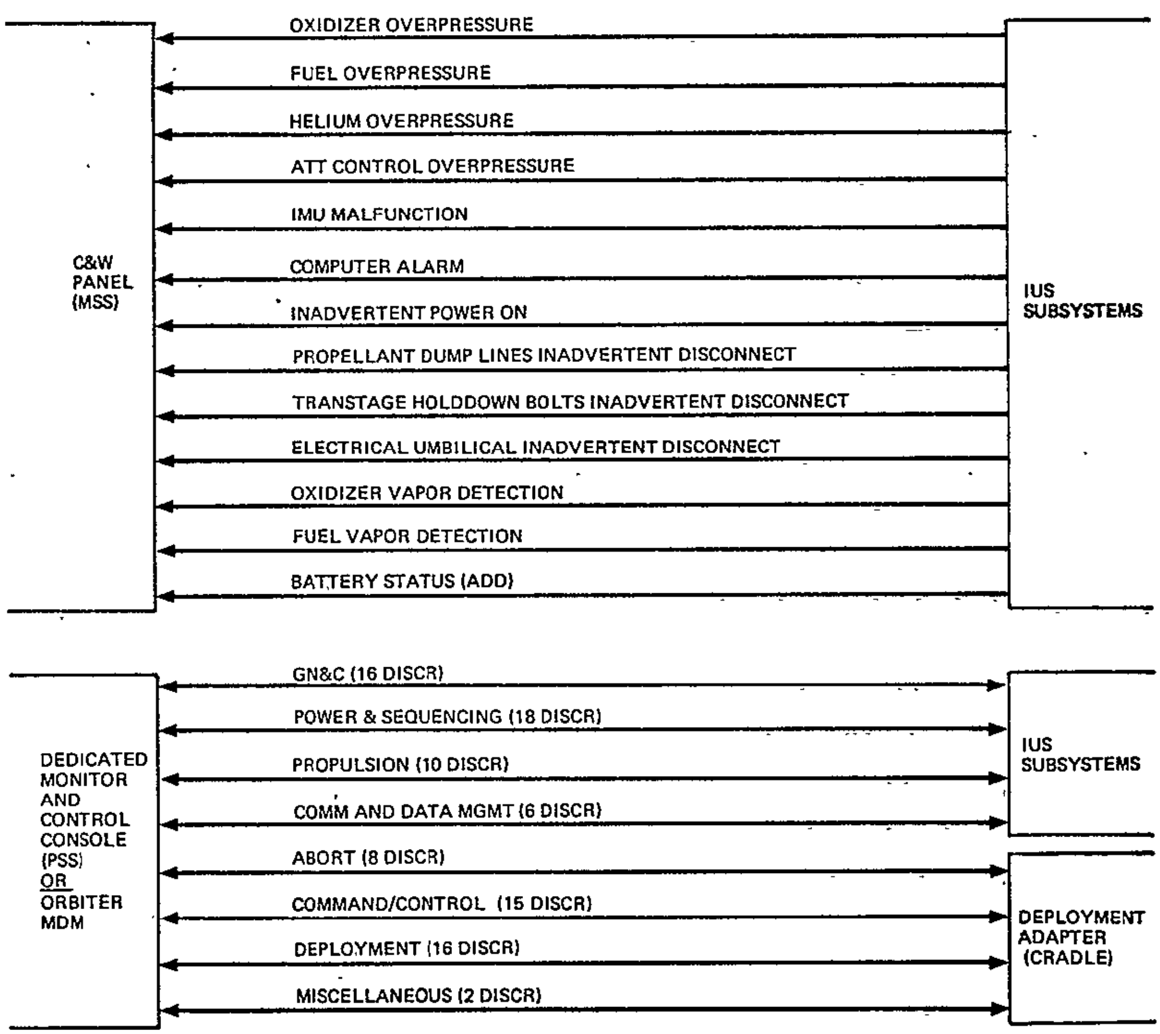

Figure 5.1.2-2. EIUS/Orbiter C&W and Discrete Command Interfaces

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4. Leak Detection
   - Oxidizer Vapor
   - Fuel Vapor

Propulsion - Each of the propellant tanks has an upper limit pressure switch. If the pressure exceeds the switch point, a light will appear on the Orbiter caution and warning panel for the appropriate tank. The first action would be to verify the overpressure condition by calling up the corresponding tank pressure transducer on the vehicle instrumentation system. Once verified the corrective action would be initiated. For the fuel and oxidizer tanks, pressure would be relieved or propellants dumped by opening and closing the appropriate prevalve. This action would be initiated from the Orbiter at the MSS panel. For the helium spheres, pressure would be relieved by Orbiter command through the emergency vent valve. On the ACS tank, the only condition that would be expected to produce a pressure rise is a thermal input, and the ACS tank can withstand a worst-case temperature of 200°F (93°C) and still maintain a safety factor of 1.75. Hydrazine is a very stable monopropellant and contaminants that may produce decomposition would be detected on the ground during the 10-day period after propellant loading.

Avionics - In the avionics system, failure modes exist that would ultimately constitute a safety hazard. The Inertial Measurement Unit (IMU) platform malfunction would be indicated by warning discretes indicating loss of platform. reference. The computer alarm indicates that the computer has failed a hardware especially pyrotechnic power, could constitute a safety hazard during pre-deployment checkout operations. The corrective action for any of the avionics failures is to remove Orbiter power to the IUS by guidance shutdown on the control and display panel. Each system will have redundant monitors to verify the failure prior to aborting the mission.

Inadvertent Disconnection - Inadvertent separation of the propellant dump lines and vehicle IUS from the cradle is monitored by microswitches. These switches will be used to check for inadvertent separation on the electrical umbilical will be monitored by electrical continuity. Spacecraft separation from the IUS could be monitored on the same electrical circuit and in a similar manner to the vehicle separation by an AND/OR gate. The corrective action during the flight could vary from do nothing to EVA, or abort depending on the time of occurrence.

Leak Detection - Leak detection for fuel and oxidizer was divided into two catagories-- (1) Detection during prelaunch when an atmosphere exists and (2) Detection under the vacuum environment of flight.

Leak detection during prelaunch can be accomplished by standard commercial units. These units operate in conjunction with a reference atmosphere and indicate vapor concentrations in parts per million. Separate probes would be used for fuel and oxidizer detection. The probes would be placed at such critical locations as the engine compartment and forward tank dome area or in the exhaust purge ducts on the Orbiter.

It is recommended that a "Battery Temperatury Excessive" measurement be added to cover the possibility that an internal short can cause heating and rupture.

5.1.4 EIUS/Orbiter Operational Interactions

The Orbiter will monitor the EIUS C&W safety related parameters to assure Orbiter crew safety and provides the switching capability to correct any detected malfunctions. These safety parameters are monitored and controlled while the EIUS is in the Orbiter bay or in the near vicinity of the Orbiter.

The Orbiter will provide the capability to initiate safety or deployment critical functions during EIUS deployment, and will monitor the results of those actions to assure the events have been accomplished. The critical activation items include power transfer, communications activation, and ACS activation. The Orbiter will control all mechanisms, such as latches and umbilicals, which relate to deployment.

The Orbiter will monitor the status of safety or mission critical subsystems to assure mission accomplishment; however, the detailed EIUS status will be the prime responsibility of the ground. Corrective commands, which are not safety critical, will be issued by the ground and routed through the Orbiter for EIUS malfunction and contingency operations.

5.2 IUS/GROUND CONTROL INTERFACE

The IUS interfaces with the ground control center both while it is attached to the Orbiter and after deployment. Figure 5.2.0-1 gives an overview of the IUS/ground operations interfaces for both the attached and detached configuration. The IUS interfaces with ground control through either a 16 or 64 KBPS telemetry link which provides the operational and status data required for ground support operations. A 2 KBPS (information) uplink command capability provides any command or updates required for contingency operations. A more detailed discussion of the ground support for IUS is included in later sections.

5.3 IUS/SPACECRAFT INTERFACE

The IUS provides a limited interface with attached spacecraft because limited IUS capability exists to support the Spacecraft, as shown in Figure 5.3.0-1. The IUS provides the capability of routing external commands, (2 KBPS or discretes) through the IUS command decoders to the Spacecraft or by issuing IUS computer generated commands through the electrical sequencing system. Some commands for the Spacecraft, such as IUS/Spacecraft separation and Spacecraft activation, are issued by the IUS. Some capability may exist to monitor parameters and provide commands as required. However, presently the interface capability does not exist in the IUS computer and the Spacecraft philosophy is to minimize these interactive interfaces, so this capability will be minimal or non-existant. Some spacecraft telemetry (10 KBPS maximum spacecraft requirement) can be multiplexed into the IUS 16 or 64 KBPS telemetry stream by using an IUS remote Multiplexer to gather S/C data as inputs to the IUS RMIS.

5.4 IUS/GSE INTERFACE

The IUS interfaces with ground support equipment (GSE) during the prelaunch phase. The GSE interfaces with the IUS interface adapter (See Figure 5.1.2-1) much the same as the Orbiter. The GSE interface is used primarily for data transfer and status evaluation during the time just prior to launch.

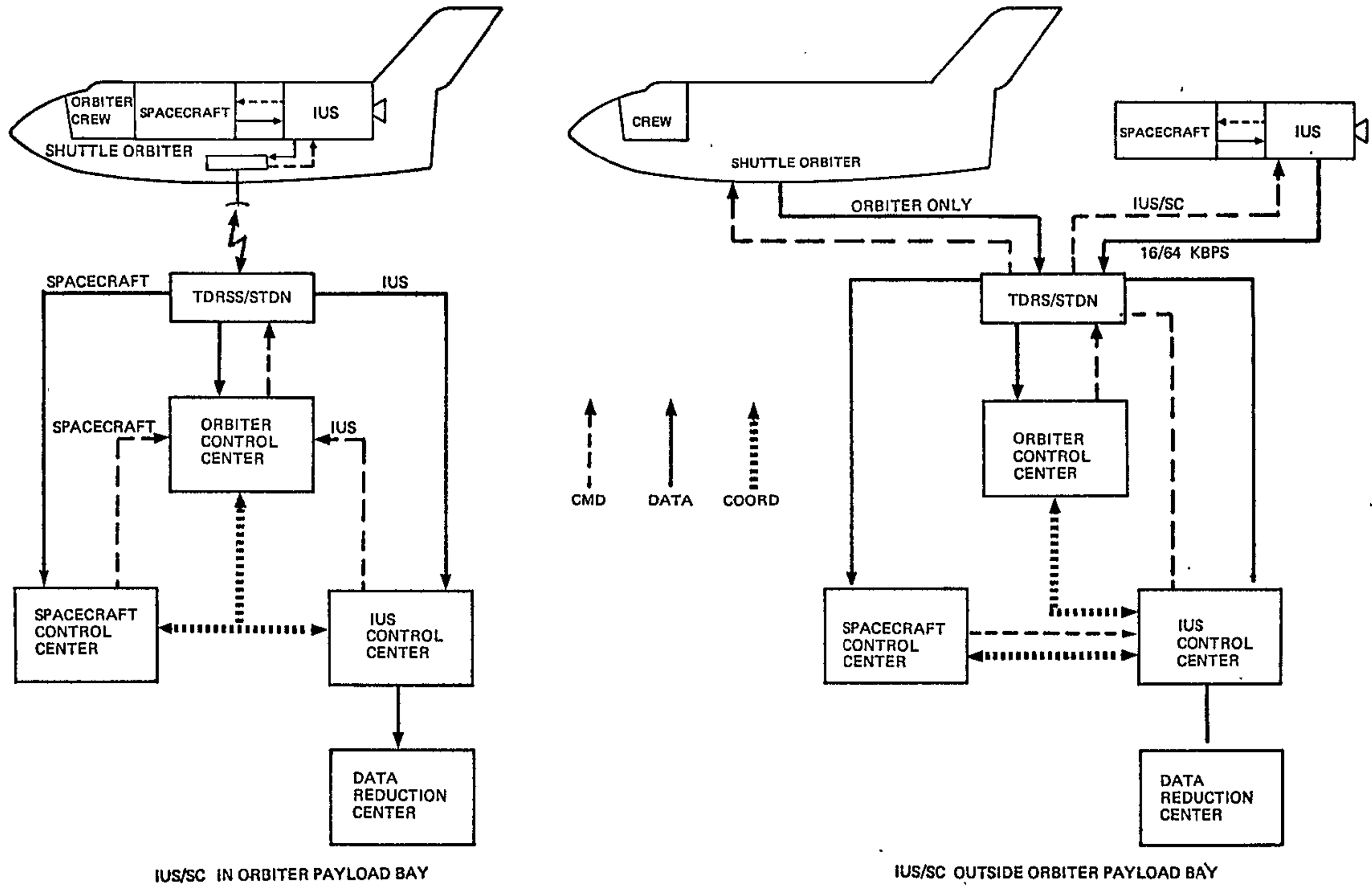

Figure 5.2.0-1. IUS/Ground Interface Schematic

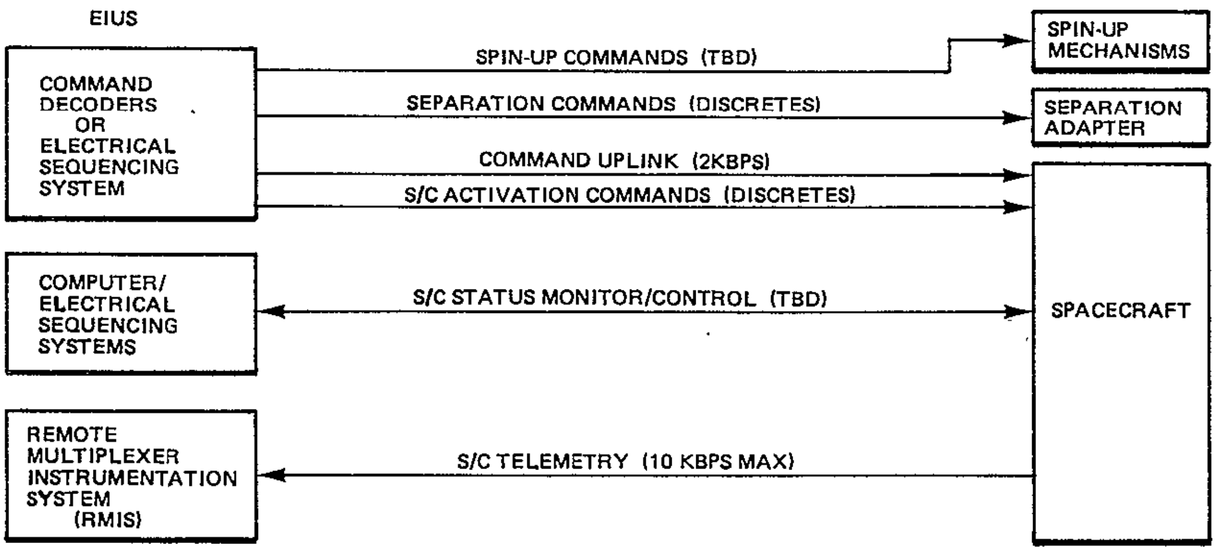

Figure 5.3.0-1. IUS/Spacecraft Avionic Interface

EIUS DEPLOYMENT OPERATIONS 6

An analysis of the EIUS operations between the Orbiter launch and the EIUS initial main engine burn was conducted to evaluate the EIUS predeploy and post-deploy requirements. This section of the report will discuss the EIUS operations during these phases.

6.1 ANALYSIS OVERVIEW

6.1.1 Study Flow

The deployment operations analysis was oriented to the activation and checkout functions to be performed during the phase. The items analyzed were the operational checkout philosophy, the activation and checkout functions and allocations and the impacts of the checkout, specifically for the Orbiter operations and software. The study flow is shown in Figure 6.1.1-1. The EIUS system design, operations and checkout requirements were reviewed, assumptions were made to cover any gaps, and the on-orbit checkout goals were defined.

These items were used as a basis for the development of a recommended checkout philosophy for the EIUS. The functions and operations to be performed for the predeploy and post-deploy operations were analyzed. The activation and checkout sequences were analyzed and allocation of functional tasks during these sequences was performed. The Orbiter functions were defined and software sizing estimates made to determine the Orbiter impacts.

6.1.2 Definitions

The definition of the primary terms used in the EIUS activation and checkout analysis is as follows:

- Predeploy Operations - those operations performed after the Orbiter launch and through the time of release of the EIUS by the Orbiter Remote Manipulator System (RMS).
- Post-deploy Operations - those operations performed after release of the EIUS by the RMS until the EIUS is readied for its initial main engine burn.
- Status Monitor - the routine assessment of the EIUS telemetry stream to determine the health of the EIUS and its subsystems.
- Checkout - the exceptional effort to determine the health of a component or system by issuing a command or stimulus and monitoring the response.
- Operational Monitor - the monitoring of operational data during periods when the system is operating.
- Activation Monitor - the monitoring of parameters or conditions activated or initiated when components or subsystems are being turned-on and readied for operation.

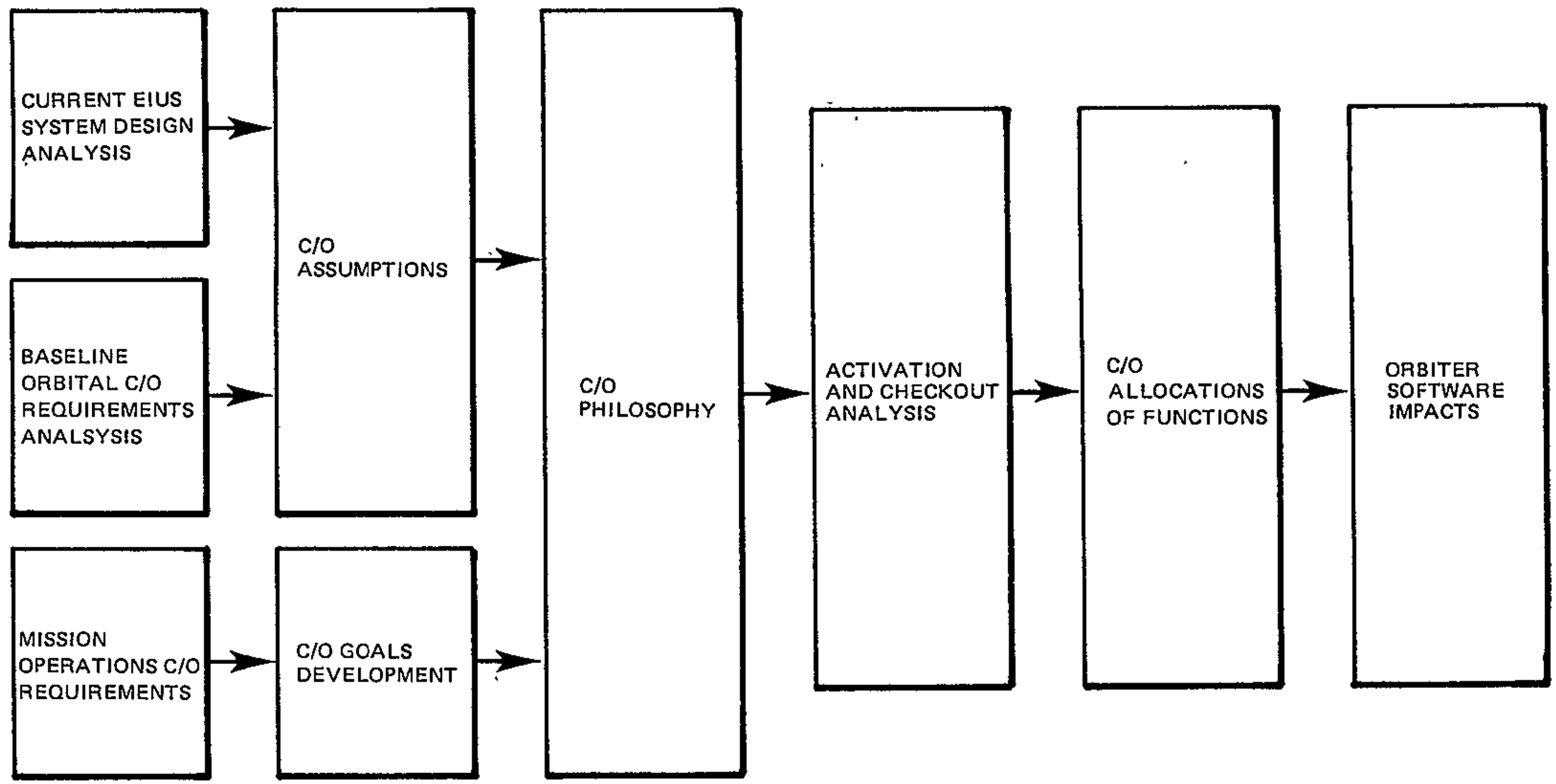

Figure 6.1.1-1. EIUS Orbital Checkout Analysis Study Flow

- Prime Responsibility - denotes the element responsible for initiating or monitoring functions and making decisions involving those functions.

- Backup Responsibility - denotes the element which provides the backup capability to initiate or monitor function and make decisions involving those functions should the primary element become in operative.

6.2 REQUIREMENTS, GROUNDRULES AND ASSUMPTIONS

6.2.1 Requirements

The requirements used as the baseline for this study were the requirements given in Section 2.0, which were derived from those in SR-IUS-100. The requirements which apply to on-orbit operations were used.

The only requirement that did not appear to be met for on-orbit checkout operations is as follows:

> "3.1.9 Systems Verification (SR-IUS-100)
>
> The IUS system shall verify the ability of the IUS to perform its mission at a time after Orbiter ascent, but prior to deployment."

The baselined design of the IUS limits the computer status monitoring to the IMU, computer and flight control subsystems. The IUS only verifies selected IUS elements and either the ground or Orbiter would be required to aid in the total verification of the IUS prior to deployment to perform its mission. No serious operational impacts are defined as a result of this exception.

6.2.2 Groundrules and Assumptions

The following groundrules or assumptions were made to supplement the requirements discussed previously.

- An Expendable IUS was baselined for the study. The Reusable IUS and its associated recovery operations was not addressed.

- The EIUS is baselined to be basically autonomous with command capability available from the ground (or Orbiter) for contingencies.

- From a review of the EIUS design, limited onboard self-test and redundancy management is available.

- The analysis includes on-orbit operations prior to the EIUS initial main engine burn.

- The EIUS is operational in the vicinity of men in the Orbiter, therefore, vehicle safety is imperative.

6.3 EIUS REDUNDANCY AND SELF TEST SUMMARY

The EIUS configuration was analyzed to determine the component redundancy level, component/function capabilities, and self-test capabilities to provide a basis for the operations analysis concept development.

The major EIUS components (or subsystems) are shown in Table 6.3.0-1. The table indicates the redundancy level, backup capability and function for each component or subsystem. The asterisks indicate which EIUS components or subsystems are critical to the success of the EIUS mission. As the chart shows, most of the components are simplex with little redundancy available, and no backup capability exists to support the component or component function. Therefore, little work-around capability exists in the event of an EIUS component or subsystem malfunction.

The EIUS subsystem checkout capability summary is shown in Table 6.3.0-2. The only major subsystem providing self-test is the IMU/computer which uses self-test software to evaluate the GN&C subsystem status. The flight control actuators and ACS provide a capabilityfor a command/response type test, but because of safety considerations, this is practical only after deployment and a safe separation distance is achieved by the Orbiter. Other EIUS subsystems work basically by monitoring status and operational measurement (by Orbiter or ground) and comparison of values with expected values.

There are some conclusions which can be drawn from these charts. First, to enhance mission success probability, the EIUS mission must be performed in as short of a time as possible to decrease the probability of a critical component failure. Secondly, the checkout capability summary indicates that very little capability exists to checkout the EIUS prior to deployment. Since the redundancy is limited, predeployment checkout should be limited to assessing the proper IMU/computer operations and waiting until after separation and the Orbiter is a safe distance from the EIUS to verify the operation readiness of the ACS and main propulsion system.

6.4 CHECKOUT GOALS AND PHILOSOPHY

For the deployment operations, goals were established to provide a basis for the checkout concepts and philosophy. A philosophy was then established which outlined the primary approaches to EIUS on-orbit checkout and the responsibilities for each supporting element.

6.4.1 Goals

The following goals were established as guidelines for the development of the EIUS on-orbit checkout concepts and philosphy:

- The reason for deployment operations was to provide an indication of the EIUS prior to major mission events, specifically, prior to deployment and prior to the initial EIUS main engine burn.
- Since the EIUS was designed for a short duration mission, any increased mission time due to checkout should be minimized or eliminated.

Table 6.3.0-1. EIUS Operational Redundancy Summary

COMPONENT/SUBSYSTEM	REDUNDANCY	BACKUP	FUNCTION
*IMU	SIMPLEX	--	INERTIAL ATTITUDE REFERENCE
*COMPUTER	SIMPLEX	--	ON-BOARD CONTROL AND PROCESSING
RMIS (TELEMETRY)	BASICALLY SIMPLEX	--	TELEMETRY DATA ORGANIZATION
*BATTERIES (2)	SIMPLEX	--	POWER GENERATION
COMMUNICATIONS	BASICALLY DUAL REDUNDANT	--	ORBITER, GROUND INTERFACE
*ATTITUDE CONTROL PROPULSION SYSTEM	BASICALLY DUAL REDUNDANT	--	ATTITUDE CONTROL, LOW LEVEL THRUST
*MAIN PROPULSION SYSTEM	SOME REDUNDANCY	--	HIGH ENERGY THRUST

*SYSTEMS MANDATORY FOR EIUS OPERATION

Table 6.3.0-2. EIUS Subsystem Checkout Capability Summary

COMPONENT/SUBSYSTEM	CHECKOUT CAPABILITY
IMU/COMPUTER	CONSIDERABLE SELF-TEST CAPABILITY IN COMPUTER SOFTWARE
FLIGHT CONTROL SYSTEM	COMMAND ACTUATORS, AND ACS - MONITOR RESPONSE (ORBITER/GROUND)
OTHERS	MONITOR MEASUREMENTS AND COMPARE (ORBITER/GROUND)

- The Orbiter involvement should be minimized to decrease the operational complexity between the EIUS and Orbiter.

- Since the Orbiter is a manned space vehicle, any potential Orbiter safety impacts due to checkout should be minimized or eliminated.

- Effective use of the EIUS onboard capability to support deployment operations should be accomplished. This would reduce external support requirements.

- Any checkout concepts or philosophies considered should be cost-effective approaches.

- The ground control involvement should use cost-effective approaches which enhance mission success probability without undue cost or increased operational complexity.

6.4.2 On-Orbit Checkout Philosophy

Using the goals established above, a philosophy was developed which provides a logical operational solution to the need for verification of the EIUS to perform its mission. A summary of the philosophy is shown in Table 6.4.2-1.

The major emphasis for the EIUS checkout is to minimize the EIUS mission time prior to the EIUS initial main engine burn and to utilize the status, activation and operational data, rather than interactive checkout results to determine the EIUS health. It is assumed that the design of the EIUS involves status and operational parameters which most aptly describe the condition of the EIUS elements. The EIUS will perform as much as the activation and status verification activities as feasible based on an existing design.

Some EIUS components are active for the total EIUS mission, while others are not required until after Orbiter launch. To conserve power and enhance reliability, subsystems and components should be activated only when they are required for operation and it is proposed that only those mission critical component activated after deployment should have any interactive checkout. This minimizes the chances of any hazardous situations developing from activities with potential safety hazards. Since the EIUS is basically autonomous, sequences will be initiated and controlled by the EIUS onboard elements where possible. No nominal command or timeline activity is allocated to the ground for a nominal mission; however, in the event of a malfunction, contingency operations will be supported by the ground.

The Orbiter controls all deployment operations for payloads and thus, for the EIUS deployment and any EIUS related deployment, activities are controlled by the Orbiter. After deployment, the Orbiter will separate to a safe distance from the EIUS and will maintain its station to support contingency operations. No EIUS checkout support will be required after deployment, since the ground will become the prime support element after separation is achieved.

Table 6.4.2-1. EIUS On-Board Checkout Philosophy

- UTILIZE EIUS STATUS, ACTIVATION, AND OPERATIONAL DATA FROM EIUS SUBSYSTEM STATUS
- MINIMIZE MISSION TIME PRIOR TO DEPLOYMENT AND EIUS FIRST BURN
- ACTIVATE SUBSYSTEMS/COMPONENTS ONLY WHEN REQUIRED FOR OPERATION
- LIMIT EIUS CHECKOUT TO MISSION CRITIAL SUBSYSTEMS ACTIVATED AFTER DEPLOYMENT
- NO PREPLANNED COMMAND ACTIVITY ALLOCATED TO GROUND
- NO ORBITER CHECKOUT INVOLVEMENT AFTER DEPLOYMENT
- GROUND INVOLVEMENT
  - MONITORS STATUS, ACTIVATION, CHECKOUT AND OPERATIONAL DATA
  - PROVIDES COMMANDS OR INHIBITS IF ON-BOARD EIUS MALFUNCTIONS OCCUR
- ORBITER INVOLVEMENT
  - MONITORS C&W SAFETY AND CRITICAL SUBSYSTEM PARAMETERS
  - CONTROLS DEPLOYMENT OPERATIONS
  - INITIATES SOME ACTIVATION AND BACKUP SEQUENCE INITIATION COMMANDS
- EIUS COMMANDS ALL NON-C&W/ABORT EIUS SEQUENCING/FUNCTIONS

The EIUS ground control personnel have the responsibility for monitoring the telemetry data generated by the EIUS to evaluate the EIUS health and to make decisions based on that information. However, since the EIUS is basically autonomous, the ground will provide command or inhibit only if EIUS onboard malfunctions occur. The ground will make use of status, operational and activation data and if malfunctions occur while the EIUS is in or near the Orbiter, the ground will report any potential safety impacts to the Orbiter crew and recommend the appropriate remedies.

The Orbiter crew has the responsibility for monitoring payload safety related parameters and the status of critical payload subsystems, and providing the capability for control of these elements during critical phases, safety related operations and deployment. This includes the activation of selected EIUS components/subsystems during deployment. In addition, to enhance the probability of mission success and to prevent the loss of an EIUS or its mission objectives, the Orbiter will have the capability to initiate selected activation sequences and to provide more detailed backup sequence commands. This Orbiter onboard capability will be a backup to the ground which has prime responsibility for these commands if they cannot be accomplished by the EIUS onboard system.

The EIUS, as mentioned previously, will provide the activation sequencing and checkout evaluation onboard if possible. The Orbiter must be able to control safety related elements and abort situations, but the EIUS is expected to command any non-C&W/abort sequences and/or functions which the EIUS requires. If the EIUS does not have sufficient capability to perform the function, they will be allocated to the ground or Orbiter.

6.5 PRE-DEPLOY OPERATIONS

The EIUS is attached to the Orbiter during prelaunch, launch and on-orbit prior to deployment by the Orbiter. This section discusses the on-orbit flight operations for Orbiter insertion until separation of the EIUS from the Orbiter. The items to be discussed include the EIUS activation sequence, flight operations allocation of functions, the command and monitoring responsibility summary and a general discussion of the operations during the phase. The EIUS timeline and missions flows for this phase are discussed in Section 3.0.

6.5.1 Component Activation

The following EIUS components are active during launch and during the pre-deploy operations:

- Computer
- IMU
- Remote Multiplexer Instrumentation System (RMIS)
- Command Decoders

The computer and IMU are active to maintain an inertial attitude reference for the EIUS and must be activated on the ground. The RMIS provides telemetry data both to the Orbiter and ground to meet safety monitoring and status requirements while the command decoders are required for command interface with the EIUS to accomplish the mission and correct anomalies.

Two EIUS subsystems are activated during this phase. These are:

- Batteries
- Communications

The batteries are activated (or utilization begun) just before Orbiter umbilical disconnections. Since the umbilicals are disconnected prior to being deployed, the batteries must be activated during this phase.

The EIUS communications are required to maintain continuous interface with the Orbiter for Orbiter Safety monitoring and for operational and contingency command interface. The communications are activated and verified just prior to Orbiter umbilicial connections.

Since the ACS and main propulsion system are not required during this phase and since any partial activation could potentially lead to Orbiter safety impacts, they are inactive until after deployment.

6.5.2 Flight Operations Function Allocation

The proposed allocation of EIUS (and Orbiter) functions during the pre-deploy operations is summarized in Table 6.5.2-1. The top level functions are shown and the function is allocated as prime (x) or backup (B/U) to either the EIUS, Orbiter or ground control.

As shown, the EIUS does little but supply data and command certain onboard EIUS sequences such as vents and purges. It is active, however, performing its operational functions, such as navigation, IMU processing, and internal status monitoring.

While the EIUS and Orbiter are attached, the Orbiter is prime for most safety-critical and deployment function, which are the majority of the functions included during this phase. The major Orbiter tasks are C&W monitor and control, EIUS state vector assessment and updates, deployment operations and activation of EIUS batteries and communications. It also provides some backup capability for EIUS subsystem status monitoring and EIUS initiated vents and purges.

The ground control prime responsibility during pre-deploy operations is monitoring the health and status of the EIUS and providing Orbiter crew recommendations or corrective commands for malfunctions. The ground also provides backup capability for data comparisons, navigation updates, and selected sequencings if the Orbiter has problems performing its assigned functions.

6.5.3 Command/Monitoring Summary

The following list gives a summary of the types of data being monitored for major EIUS components during pre-deploy operations, where S = status data monitoring, O = operational data monitoring, C = checkout data, and A = activation data monitoring:

- Computer - S.O
- IMU - S,O
- RMIS - S, O
- Decoders - S,O
- Batteries - S,A,O
- Communications - S,A,O
- ACS and MPS - S

Table 6.5.2-1. EIUS Pre-Deploy Flight Operations Function Allocation

FUNCTION	EIUS	ORBITER	GROUND
	ALLOCATION		
C&W MONITOR		X	B/U
EIUS STATUS MONITOR		B/U	X
SAFETY CONTROL & MONITOR		X	X
VENTS, PURGE	X	B/U	B/U
ORBITER/EIUS IMU COMPARISONS		X	B/U
NAVIGATION, ATTITUDE UPDATE		X	B/U
DEPLOYMENT ADAPTER OPERATIONS		X	
RMS OPERATIONS		X	
BATTERY ACTIVATION/POWER TRANSFER		X	B/U
COMMUNICATIONS ACTIVATION		X	B/U
ORBITER/EIUS RF VERIFICATION		X	

The main types of data being generated are the status parameters and operational data and results and they are the prime means of obtaining and evaluating EIUS health. The activation parameters are useful in assessing the correct operation of the batteries and communications. No interactive checkout is required during this phase.

Table 6.5.3-1 gives an overview of the specific data or task allocated to either the EIUS, Orbiter, or ground control during pre-deploy operations for each of the data types shown above.

The EIUS monitors the status of critical EIUS subsystems, such as the computer and IMU, of selected activation command responses, and of all operational data pertinent to proper EIUS controlled operations. Since EIUS commands and sequences are internally generated, the external command/update list is not applicable.

The Orbiter monitors C&W parameters, critical EIUS status parameters and other safety parameters, during both activation and communications link verification to assure Orbiter safety. In addition, the Orbiter assesses the EIUS state vector and provides updates if required. The Orbiter is required to command the power transfer, any navigation or attitude updates, and communications activation for the EIUS.

The ground monitors all telemetry generated by the EIUS and provides the command capability for target updates or activation sequencing if required.

6.5.4 Operations Description

After Orbiter launch, the EIUS status, C&W and safety parameters are monitored continuously by the ground and/or Orbiter. After any vents or purges are accomplished, the Orbiter will compare the EIUS state vector and attitude with the same Orbiter parameters and will provide navigation or attitude update parameters to the EIUS if the dispersion are above expected tolerances.

After the Orbiter second burn, the Orbiter will begin deployment operations by switching the EIUS from Orbiter to internal batteries and will process with the deployment sequence. Just prior to umbilical disconnection, the EIUS communications will activate and the command link verified. The EIUS will then be disconnected from the Orbiter and released by the Orbiter remote manipulator system.

6.6 POST-DEPLOY OPERATIONS

The pre-deploy operations begin with release of the EIUS by the Orbiter until the EIUS has been activated and readied for its first main engine burn. This section discusses the activation sequence, flight opeations allocation of functions, the command and monitoring responsibility summary and a general discussion of the operations during the phase. The timelines and flows for this phase are discussed in Section 3.0.

6.6.1 Component Activation

All EIUS subsystem or components except the ACS and main propulsion system are activated prior to deployment by the Orbiter since they are required for operation prior to deployment.

Table 6.5.3-1. EIUS Pre-Deployment Command/Monitoring Function Allocation

FUNCTION	DATA/TASK ALLOCATION		
	EIUS	ORBITER	GROUND
STATUS MONITORING	• CRITICAL SUBSYSTEM STATUS	• C&W PARAMETERS • SAFETY PARAMETERS • CRITICAL SUBSYSTEM STATUS PARAMETERS	• ALL PARAMETERS
OPERATIONAL MONITORING	• ALL OPERATIONAL DATA TO COMPUTER	• EIUS/ORBITER IMU COMPARISONS	• ALL TM DATA
ACTIVATION MONITORING	• SELECTED CRITICAL PARAMETERS	• SELECTED SAFETY PARAMETERS	• ALL TM DATA
CHECKOUT MONITORING	---	• SELECTED SAFETY PARAMETERS • COMM LINK VERIFICATION	• ALL TM DATA
EXTERNAL COMMANDS/UPDATES	N/A	• POWER TRANSFER • NAVIGATION, ATTITUDE, UPDATES	• TARGET UPDATE (IF REQUIRED) • BACKUP FOR ACTIVATION SEQUENCING

NOTES: OPERATING DURING PHASE - COMPUTER, IMU, RMIS, DECODERS
BEING ACTIVATED DURING PHASE - BATT. COMM
INACTIVE SYSTEMS MONITORED DURING PHASE - ACS, MPS

The ACS is partially activated just after separation from the Orbiter to allow the EIUS to maintain an attitude hold at its separation attitude to prevent Orbiter recontact until the Orbiter is a safe distance from the EIUS. After the distance is attained, the total EIUS ACS will be activated to allow attitude maneuvers required for proper operation of the EIUS. The main propulsion system (MPS) or main engine is also deactivated, for safety reasons, until after a safe Orbiter separation distance is attained. The MPS is then activated and brought to its operational capability prior to its initial burn.

6.6.2 Flight Operations Function Allocation

The recommended allocation of functions to the EIUS, Orbiter or ground control for post-deploy operational functions are as follows:

	Allocation		
Function	EIUS	Orbiter	Ground
ACS Initial Activation		X	B/U
C&W Monitor		X	B/U
EIUS Status Monitor			X
ACS Final Activation	X		B/U
MPS Activation	X		B/U
Target Update (if required)			X

The prime responsibility is denoted by (X) and the back-up responsibility by (B/U).

As shown, the Orbiter activates the EIUS ACS immediately after separation and monitors the C&W parameters until a safe separation distance is attained. The Orbiter then is on a stand-by status for possible contingency operations. The EIUS has the responsibility of ACS final activation and MPS activation after Orbiter separation.

Ground control monitors the EIUS telemetry for status, safety and operational readiness and provides backup capability as required for contingency sequences or updates, such as target update.

6.6.3 Command/Monitoring Summary

The following list gives a summary of the types of data being monitored for major EIUS components during post-deploy operations, when S = status data monitoring, O = operational data monitoring, C = checkout data, and A = activation data monitoring:

- Computer - S, O
- IMU - S, O
- RMIS - S, O

- Decoders - S, O
- Batteries - S, O
- Communications - S, O
- ACS - S, A, O
- MPS - S, A, O, C

The main types of data being generated are the status parameters and operational data and are the prime means of assessing onboard EIUS health. For instance, if the vehicle performs its maneuvers properly, the computer, IMU and ACS are probably operating properly. The ACS and MPS activation data and results also give an indication of their health and proper operation. The only candidate for checkout is the MPS. Some MPS values could be checked or the MPS hydraulics manipulated, however, since mission time is limited, very little, if any, MPS checkout will be performed.

An overview of the EIUS post-deploy specific data or task allocation of command and monitoring functions is shown in Table 6.6.3-1. These functions were allocated to the EIUS, Orbiter, or ground.

The Orbiter functions begin to decrease after separation. It has the responsibility of commanding ACS activation and is backup for contingency safety related commands. It monitors the EIUS C&W and critical subsystem parameters and the EIUS attitude to avoid collisions with the EIUS. After a safe separation distance is achieved, the Orbiter is no longer responsible for active EIUS operations participation.

The EIUS assumes the prime operational responsibility after separation for monitoring the status and operational data required for effective EIUS operations. The ground monitors the EIUS telemetry and provides the capability for malfunction detection and analysis and corrective command action for contingencies. The EIUS operates autonomously after separation unless inhibited from doing so by the Orbiter or ground.

6.6.4 Operations Description

After release of the EIUS by the Orbiter RMS, the Orbiter activates the EIUS ACS to an attitude hold mode, monitors C&W, safety and EIUS attitude data and maneuvers to a safe separation distance from the EIUS. The EIUS then begins its nominal mission sequence by activating or releasing inhibits from the ACS and MPS controls and by fully activating those subsystems, and performing any required or desired attitude maneuvers. After the operational verification has been established, the EIUS is ready to begin the main engine pre-ignition sequencing required for its initial burn.

6.7 ORBITER IMPACTS SUMMARY

An assessment of the Orbiter impacts based on the results of the deployment operations was made to determine if potential Orbiter support problems exists. This section gives a discussion of the Orbiter operational support functions for the EIUS which would impact Orbiter software and a computer/software sizing estimate to support those functions.

Table 6.6.3-1. EIUS Post-Deployment Command/Monitoring Function Allocation

FUNCTION	DATA/TASK ALLOCATION		
	EIUS	ORBITER	GROUND
STATUS MONITORING	• CRITICAL SUBSYSTEM STATUS	• C&W PARAMETER • SAFETY PARAMETERS	• ALL PARAMETERS
OPERATIONAL MONITORING	• ALL OPERATIONAL DATA TO COMPUTER	• EIUS ATTITUDE	• ALL TM DATA
ACTIVATION MONITORING	• SELECTED CRITICAL PARAMETERS	---	• ALL TM DATA
CHECKOUT MONITORING	• SELECTED STATUS PARAMETERS	---	• ALL TM DATA
EXTERNAL COMMANDS/UPDATES	N/A	• INITIAL ACS ACTIVATION • CONTINGENCY SAFETY RELATED COMMANDS	• BACKUP FOR ACTIVATION SEQUENCES • PROGRAM INHIBITS IF MALFUNCTIONS

NOTES: OPERATING CONTINUOUSLY DURING PHASE - COMPUTER, IMU, RMIS, DECODERS, BATT, COMM
BEING ACTIVATED DURING PHASE - ACS, MPS

6.7.1 Operations Support Functions Description

The Orbiter functions required to support the EIUS on-orbit flight operations are summarized in Table 6.7.1-1. Since the Orbiter is required to monitor selected EIUS safety and status parameters, the Orbiter must process the EIUS telemetry data stream to the Orbiter (16 KPBS) and retrieve the data parameters required for analysis. After the correct C&W, safety and status parameters are selected, the Orbiter will compare those parameters with the expected results or limits and store the data for future display by the Orbiter C&D as required.

The Orbiter will also monitor the operational status of all EIUS mission critical components as a basis for operational impacts. Any anomalies detected by the Orbiter will be evaluated and, if necessary, corrective command control active will be taken to alleviate the anomaly or correct the problem.

The Orbiter is also required to initiate or support selected EIUS activation or operational support sequences while the EIUS is attached or in close proximity to the Orbiter. These functions include power transfer, EIUS communications activation and verification, ACS initial activation, EIUS navigation, attitude or target updates, and the evaluation of the EIUS state vector to determine if updates are required. These support functions are included in the nominal mission timeline.

For the activation initiation, commands would be sent and results obtained and evaluated to determine if satisfactory results were obtained. The EIUS state vector evaluation would be more complex with the comparisons evaluated, and updates initiated if required.

The Orbiter will also provide some capability to support contingency operations associated with the EIUS, such as abort sequencing, subsystem activation activation sequencing, vents and purges. These functions would only be required for contingency operations and could either be hardwired or commanded through the RF link. Except for abort sequencing, which is a prime Orbiter function, most of the contingency activation sequencing is backup to both the EIUS and ground.

The Orbiter also provides operations support for the EIUS when the vehicle or subsystems are not actively involved in the operations. Examples of these types of functions include remote manipulator operations, communication switching and recording of EIUS telemetry and commands, deployment operations and collision avoidance computations. These items may not be charged to the IUS/Spacecraft, but are defined as necessary to support EIUS operations.

6.7.2 Computer/Software Impacts

The basic Orbiter/EIUS on-orbit operations philosophy was to perform as many of the required software functions in the EIUS as possible, which would mean that the Orbiter would only initiate sequences which would be performed by the EIUS. This is especially true for the activation sequencing. This section reviews the Orbiter software functions sized to support the EIUS. Functions to support the Spacecraft were not sized.

Table 6.7.1-1. Orbiter Operations Functions to Support EIUS

- SAFETY/STATUS MONITORING
  - EIUS TELEMETRY PROCESSING (16 KBPS)
  - C&W/SAFETY PARAMETER MONITORING CONTROL
  - SELECTED EIUS SUBSYSTEM STATUS MONITOR/CONTROL
- EIUS ACTIVATION/OPERATION SUPPORT
  - IMU STATE VECTOR COMPARISONS
  - POWER TRANSFER
  - NAVIGATION, ATTITUDE AND TIMING UPDATES
  - COMMUNICATIONS ACTIVATION AND VERIFICATION
  - ACS INITIAL ACTIVATION
- CONTINGENCY SEQUENCING SUPPORT
  - ACTIVATION ACS, MPS, BATT, COMM
  - PROPELLANT DUMP, VENTS AND PURGES
  - ABORT SEQUENCING
- MISCELLANEOUS ORBITER SUPPORT
  - DEPLOYMENT OPERATIONS
  - REMOTE MANIPULATOR OPERATIONS
  - COMMUNICATION SWITCHING/RECORDING MANAGEMENT
  - EIUS ATTITUDE-COLLISION AVOIDANCE MONITORING

6.7.2.1 Sizing Summary

A summary of the Orbiter software storage impacts to support the EIUS operations are given in Table 6.7.2-1. The functions to be sized were discussed in the previous section, and are divided into two groups, Orbiter interactive support for EIUS and Orbiter controlled support for EIUS. The interactive support includes the interactive EIUS/Orbiter interfaces and operations, and include EIUS safety/status monitoring, EIUS subsystem activation and operations support, and backup or contingency sequencing support. The Orbiter controlled support includes overhea to the Orbiter operating system (OS) and EIUS displays and controls in the MSS, and miscellaneous support provided to the EIUS such as remote manipulator, communications and deployment adaptor operations which are done independent of EIUS involvement. Some of the Orbiter controlled support may not be charged to the EIUS.

The sizing assumes that a 75% short and 25% long mix for both instructions and data is used to obtain the total Orbiter storage requirements. The Orbiter is baselined with a 32 bit word length for storage. The summary in Table 6.7.2-1 indicates that approximately 10K of 32 bit words is required in the Orbiter DMS, assuming that both interactive support and Orbiter controlled support are charged to the EIUS. But, since only a portion of the total storage is required at any one time, only about 1.7K of 32 bit words is required in main storage at one time. Therefore, the EIUS required software can be stored in the Orbiter mass storage and called into main memory when required for operations. The major Orbiter storage impacts are for EIUS display formats and data (8 formats assumed) which will be displayed in the Orbiter for safety and status monitoring. The functions sized have extremely low execution rates, and when coupled with low instruction numbers, a minimal speed impact to Orbiter is expected. The Orbiter support requirements appear to be well within the support capability of 10K and 18 KOPS provided to payloads by the Orbiter.

6.7.2.2 Interactive Support

The interactive support sizing details include safety/status monitoring, activations/operations support, and contingency sequencing support, and are shown in Tables 6.7.2-2 through -4.

The safety/status monitoring support (Table 6.7.2-2) lists the items sized. The 16 KPBS telemetry stream from the EIUS is processed by the Orbiter to select the estimated 80 (of about 210 total EIUS) telemetry parameters which would be used by the Orbiter for IUS safety and status monitoring. The parameters requiring limit, status, or go/no-go checks are processed by the Orbiter computer for anomaly reporting. the EIUS data will be grouped into display formats and associated display parameters for display use by the MSS personnel. Eight displays are assumed and the display format (or display background) and the mapping tables, which select the parameters to be displayed on the format, were included in the sizing. As shown, the display images (or formats) are the main storage impacts, with a total storage requirement of a little more than 4K of 32 bit words.

The activation and operations sequencing by the Orbiter to support the EIUS (Table 6.7.2-3) are the power transfer, ACS initial arming, communications activation and verification, and EIUS state vector comparison and update. The commands are in tables which contain the command address, time of issuance, sequence dependency, verification response from the EIUS and error processing

Table 6.7.2-1. Orbiter Software Sizing to Support EIUS

	INST	DATA	*TOTAL (32 BIT WORDS)	MAX MAIN MEMORY (32 BIT WORDS)
• INTERACTIVE SUPPORT FOR EIUS				
- SAFETY/STATUS MONITORING	350	6,195	4,091	1,031
- ACTIVATION/OPERATIONS SUPPORT	900	300	750	219
- CONTINGENCY SEQUENCING SUPPORT	1,900	1,375	2,047	--
SUBTOTALS	3,150	7,870	6,888	1,250
• ORBITER CONTROLLED SUPPORT				
- MSS SUPPORT SOFTWARE (OVERHEAD)	400	280	425	425
- MISCELLANEOUS ORBITER SUPPORT	2,700	1,950	2,907	--
SUBTOTALS	3,100	2,230	3,332	425

*ASSUMES 75% SHORT AND 25% LONG INSTRUCTION AND DATA MIX

Table 6.7.2-2. Safety/Status Monitoring Sizing

FUNCTIONS	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
TELEMETRY STREAM PROCESSING (16 KBPS)*	250	650	563
LIMIT TESTING/STATUS CHECKING	100	25	78
DISPLAY IMAGES (8 IMAGES @600 WORDS/DISPLAY)	---	4,800	3,000
DISPLAY MAPPING TABLES (8 IMAGES X [6 WORDS/IMAGE ENTRY X 15 ENTRIES])	---	720	450
TOTALS	350	6,195	4,091

*BASED ON AN ESTIMATED 80 TELEMETRY PARAMETERS TO BE MONITORED

Table 6.7.2-3. Activation/Operations Support Sizing

FUNCTIONS	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
POWER TRANSFER	200	70	169
ACS ARMING	250	80	206
UPDATE GN&C PARAMETERS(*)	200	50	156
COMMUNICATION ACTIVATION/ VERIFICATION	250	100	219
TOTALS	900	300	750

(*) INCLUDES: (1) COMPARISON OF ORBITER/IUS NAVIGATION/ATTITUDE; (2) NAVIGATION/ATTITUDE UPDATES

Table 6.7.2-4. Contingency Sequencing Support Sizing

FUNCTIONS	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
MISSION SEQUENCE START	50	25	47
ACS ACTIVATE	200	150	219
MPS ACTIVATE	200	150	219
VENTS/PURGES	500	250	468
ABORT SEQUENCING	750	650	875
BATTERY ACTIVATION	200	150	219
TOTALS	1,900	1,375	2,047

indication, if required. The GN&C update capability will provide an evaluation of the EIUS state vector to determine the need for an update and to provide the updates if required. Only about 750 words are required for these items.

The contingency sequencing support (Table 6.7.2-4) provides backup activation or sequencing capability to support the EIUS. The items sized include a more detailed activation/operation sequence than required for normal operations and would be used only if EIUS (or ground) operation were not feasible. The abort sequencing is controlled only by the Orbiter, but was included in the contingency support since it is not required during normal on-orbit operations. Approximately 2K of storage is required for the contingency sequencing support.

6.7.2.3 Orbiter Controlled Support

The functions sized for Orbiter controlled support do not interface with the EIUS, but provide support for EIUS operations. These include MSS support software and miscellaneous Orbiter support. The sizing impacts are shown, respectively, in Tables 6.7.2-5 and 6.7.2-6.

The MSS support software (Table 6.7.2-5) includes function/phase initialization and tables for the Orbiter computer operating system input/output utilization The function/phase initialization sizing includes the selection of displays, responses to keyboard entries, priority assignments and loading data from mass storage. The I/O table includes items the Orbiter OS must support, such as a valid command tables and display linkage tables. The Orbiter storage impact is 425 words.

The miscellaneous support (Table 6.7.2-6) includes remote manipulator operations, deployment sequencing, Orbiter communications management to support EIUS telemetry and commands and collision avoidance computations. The storage impact for these items is about 2.9K.

Table 6.7.2-5. MSS Support Software (Overhead) Sizing

FUNCTIONS	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
FUNCTION/PHASE INITIALIZATION	400	80	300
TABLES FOR FCOS INPUT/OUTPUT UTILIZATION	---	200	125
TOTALS	400	280	425

Table 6.7.2-6. Miscellaneous Orbiter Support Sizing

FUNCTIONS	INSTRUCTIONS	DATA	TOTALS (32 BIT WORDS)
RMS OPERATIONS	1,000	500	938
ATTITUDE/COLLISION AVOIDANCE	250	150	250
DEPLOYMENT SEQUENCE	750	750	938
UMBILICAL MECHANISMS	500	500	625
COMMUNICATIONS MANAGEMENT	200	50	156
TOTALS	2,700	1,950	2,907

7 SPACECRAFT DEPLOYMENT OPERATIONS

The primary responsibility of the IUS is to deliver a spacecraft to its desired location or orbital conditions. Since the IUS is a derivation of an existing vehicle with minimum spacecraft support capability and since the Spacecraft community wishes to minimize the operational interfaces with an IUS, a minimum amount of IUS/Spacecraft operational interface during Spacecraft deployment is anticipated. Some operation interface and interaction does exist, however, and this section will discuss the IUS operational support for the Spacecraft and the ground interactions to support the pre-deploy and post-deploy Spacecraft operations.

7.1 SPACECRAFT PREDEPLOY OPERATIONS

This section discusses the spacecraft predeploy operations which includes the activities from final IUS mainstage or trim burn until physical separation of the Spacecraft from the IUS.

7.1.1 IUS Support

The major IUS functions to support the Spacecraft pre-deploy operations will be to provide an attitude control base for the Spacecraft while it is being activated and checked out, to provide activation and separation sequencing support, and in some cases, to provide the communication link interface with the ground.

During the phases when the Spacecraft is being ferried from low earth orbit to its final destination, the spacecraft may provide its own RF communications links with the ground. For some payloads, however, the Spacecraft RF communication links may be covered or partially covered by shrouds, payloads adapters, appendages, etc., and for those cases, Spacecraft telemetry will be integrated with the IUS RF communications for relay to the ground. The command uplink for the Spacecraft will also be relayed through the IUS. During the Spacecraft predeploy operations, the ground interface would be relayed through the IUS until the Spacecraft antennas were uncovered or until separation of the Spacecraft. In some cases, the ground would use the IUS command decoder interface with the Spacecraft to execute selected functions initiated by Spacecraft ground control.

The IUS provides an attitude control base for the Spacecraft during the pre-deploy operations. The IUS will maintain attitude control for both the IUS and Spacecraft until they are separated. This allows the Spacecraft to be activated, its appendages extended, and the attitude control and RF ground interfaces to be verified prior to separation. If Spacecraft anomalies occur, the IUS can maintain the attitude base for a limited time until work-around corrective action can be taken by the ground.

The IUS is expected to provide direct support for the Spacecraft, even though these services will be minimized to the extent possible. The two main IUS functions are Spacecraft activation sequencing and Spacecraft orientation and spin-up, if required. The activation sequencing may be initiated or performed by the ground, however, the IUS will provide sequencing capability, through the electrical sequence system from the IUS computer, for functions such as shroud deployment, antenna deployment, solar array deployment, and power activation. If required, the IUS will provide the operation base for the orientation and spin-up of a Spacecraft prior to separation.

The capability may eventually be provided for the IUS to monitor critical Spacecraft parameters and react to anomaly situations, but this is not required or particularly desired by the Spacecraft community. Some design modifications would also be required for the baseline IUS to allow additional interface with the IUS computer.

7.1.2 Ground Support

Both the Spacecraft Operations Center (SCOC) and the IUS Operations Center (IUS/OC) will actively participate with each other as well as monitor and control vehicle operations during the pre-deploy operations.

The IUS/OC will be primarily responsible for monitoring the IUS status and operations to assure no operational or anomaly impacts which could endanger the Spacecraft. The emphasis will be on critical subsystem status and hazardous situations, such as over pressurization. There will be extensive interface between the SCOC and the IUS/OC during this phase for status information, for attitude and operations potential conflicts, and to assure the correct procedures are executed in the proper sequence.

The SCOC will have the primary responsibility for Spacecraft activation and operational verification. It will use Spacecraft telemetry and selected event inputs from the IUS via the IUS/OC to determine if the Spacecraft is ready for separation and if all Spacecraft functions are operational. In the event of a malfunction, the SCOC will actively command and control the Spacecraft to eliminate the problem. Any interaction requests for the IUS will be relayed through IUS/OC for their command inputs to the IUS and appropriate feedback to the SCOC.

7.2 SPACECRAFT POST-DEPLOY OPERATIONS

This section discusses the Spacecraft deployment operations from separation of the Spacecraft from the IUS until the IUS is a safe distance from the Spacecraft and can no longer impact the Spacecraft or its mission.

7.2.1 IUS Support

After the Spacecraft separates from the IUS, the IUS can no longer interface with the Spacecraft or provide any additional support. The IUS has no provisions for docking, cannot provide an RF link with the Spacecraft, and has no onboard TV which might be used for a visual inspection of the Spacecraft. Therefore, the responsibility of the IUS is to assure a clean separation from the Spacecraft, to maneuver away from the Spacecraft without recontacting or contaminating the Spacecraft, and to maneuver to some orbit where it can no longer affect Spacecraft operations.

7.2.2 Ground Support

After separation, the SCOC has the prime responsibility for the Spacecraft, while the IUS/OC has the responsibility for evasive maneuvers and disposal of the IUS (if expendable). The primary interaction between the ground centers is to avoid situations where recontact or contamination of the Spacecraft could occur and to identify any IUS problems (by the IUS/OC) which could jeopardize or potentially impact the Spacecraft mission. When the IUS is a safe distance from the Spacecraft, ground center interface is no longer required.

The SCOC will monitor the Spacecraft status and perform any required activation, checkout or operational monitoring or commanding. The SCOC will also react to any potential IUS impacts on the Spacecraft if they occur.

FLIGHT OPERATIONS SUPPORT ANALYSIS 8

During the IUS/Tug time frame, NASA's Spaceflight Tracking and Data Network (STDN) will consist of two subnets: the Tracking and Data Relay Satellite System (TDRSS) subnet and the STDN ground site subnet. The TDRSS will provide two Tracking and Data Relay Satellites (TDRS) plus a TDRSS ground terminal. The post-1979 ground site subnet will be composed of six to eight sites from the STDN. Ground sites are currently planned at the following locations: Goldstone, Madrid, Orroral, Fairbanks, Merritt Island (launch only), Rosman, Bermuda (launch only), and Tananarive (launch only).

The major functions of the STDN are to: (1) track spacecraft and relay launch and trajectory data in real-time from spacecraft to control centers; (2) relay commands from control centers to spacecraft; (3) relay telemetry and TV signals both in real-time and in store-and-forward modes from spacecraft to control center; (4) relay voice communications between control centers and spacecraft; and (5) augment recovery communications, as required.

Although the present network provides sophisticated tracking and data acquisition support to earth-orbiting spacecraft, it does have such limitations as spacecraft access time, geographic coverage, and information bandwidth. These limitations, in turn, impose design and operational constraints on the user spacecraft. To reduce these limitations, as well as to minimize the overall cost of tracking and data acquisition, NASA has been studying the use of a Tracking and Data Relay Satellite System (TDRSS) to augment the STDN.

The TDRSS (see Figure 8.0.0-1) consists of two geosynchronous satellites, approximately 130 degrees apart in longitude, which will relay tracking, telemetry, and command data between low earth-orbiting user spacecraft (<1200 Km), and a ground terminal located in the continental United States. This concept also provides for two spare satellites, one in orbit, and the other in configuration for a rapid launch. A "bent-pipe" concept is used in the design of the telecommunications service system (i.e., all communication signals received at the Tracking and Data Relay Satellite (TDRS) are translated in frequency and retransmitted), making possible almost continuous reception of data in real time.

8.1 STDN/TDRSS DATA FLOW

The data flow from the STDN and TDRSS is illustrated in Figure 8.1.0-1. Several paths are available to the user, dependent on which subnet of the STDN is being utilized. If the user is transmitting data to either of the two TDRSS's, a direct flow is available to the White Sands ground station. The ground station will also function as a bent pipe repeater and process the data only to the extent that it is acceptable to the NASCOM interface. NASCOM in this instance can provide land line capabilities up to 1.3 Mbps. Domestic satellites are also being considered which will provide up to a 50 Mbps/transponder capability from the TDRSS ground station to the user.

If the STDN subnet is used, several possibilities exist. Data acquired by the sites located within the continental United States will be processed to interface with NASCOM. Definition of the NASCOM capabilities for the shuttle era has not been presented; however, a single land line capability will be

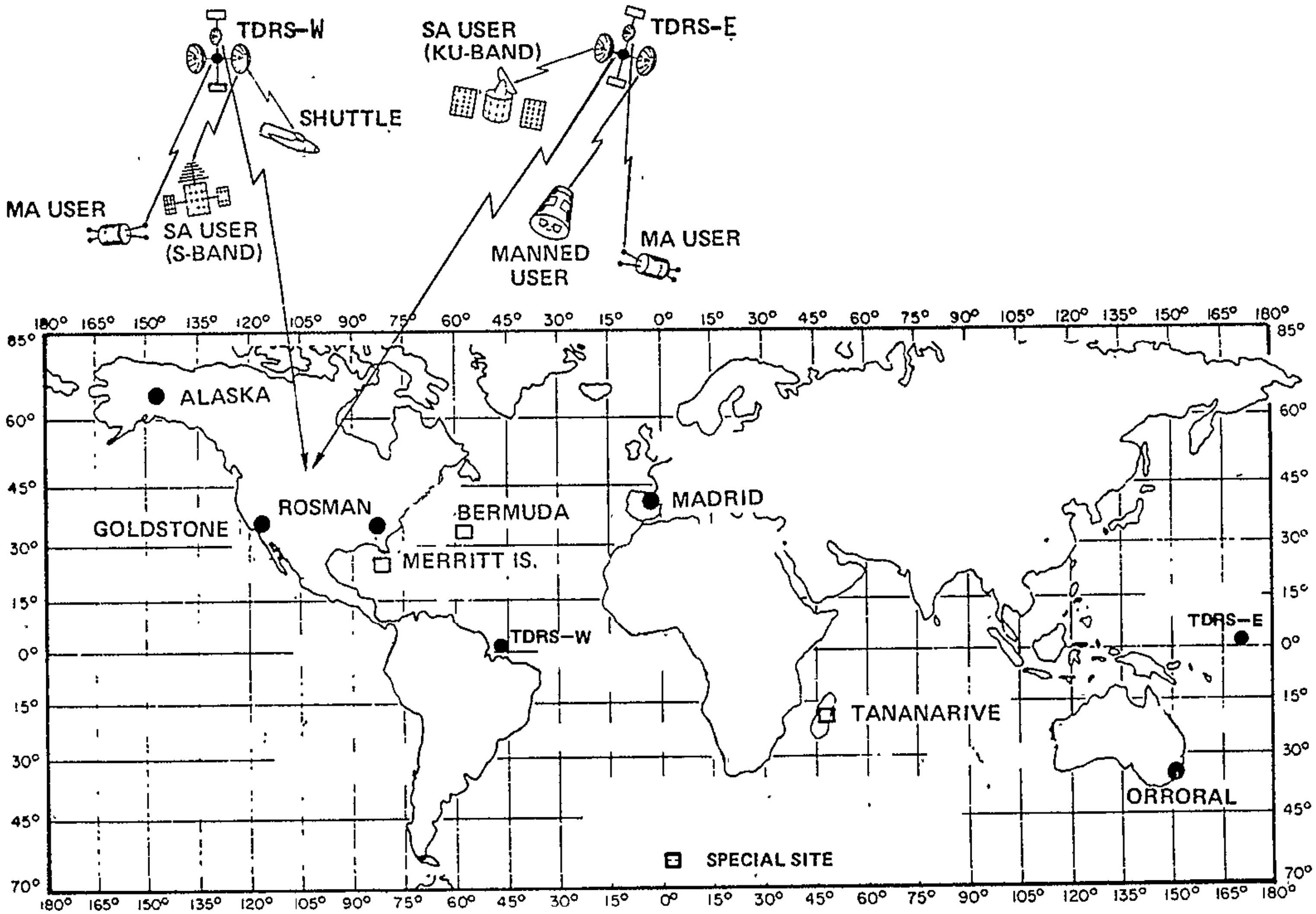

Figure 8.0.0-1. STDN and TDRS Subnets

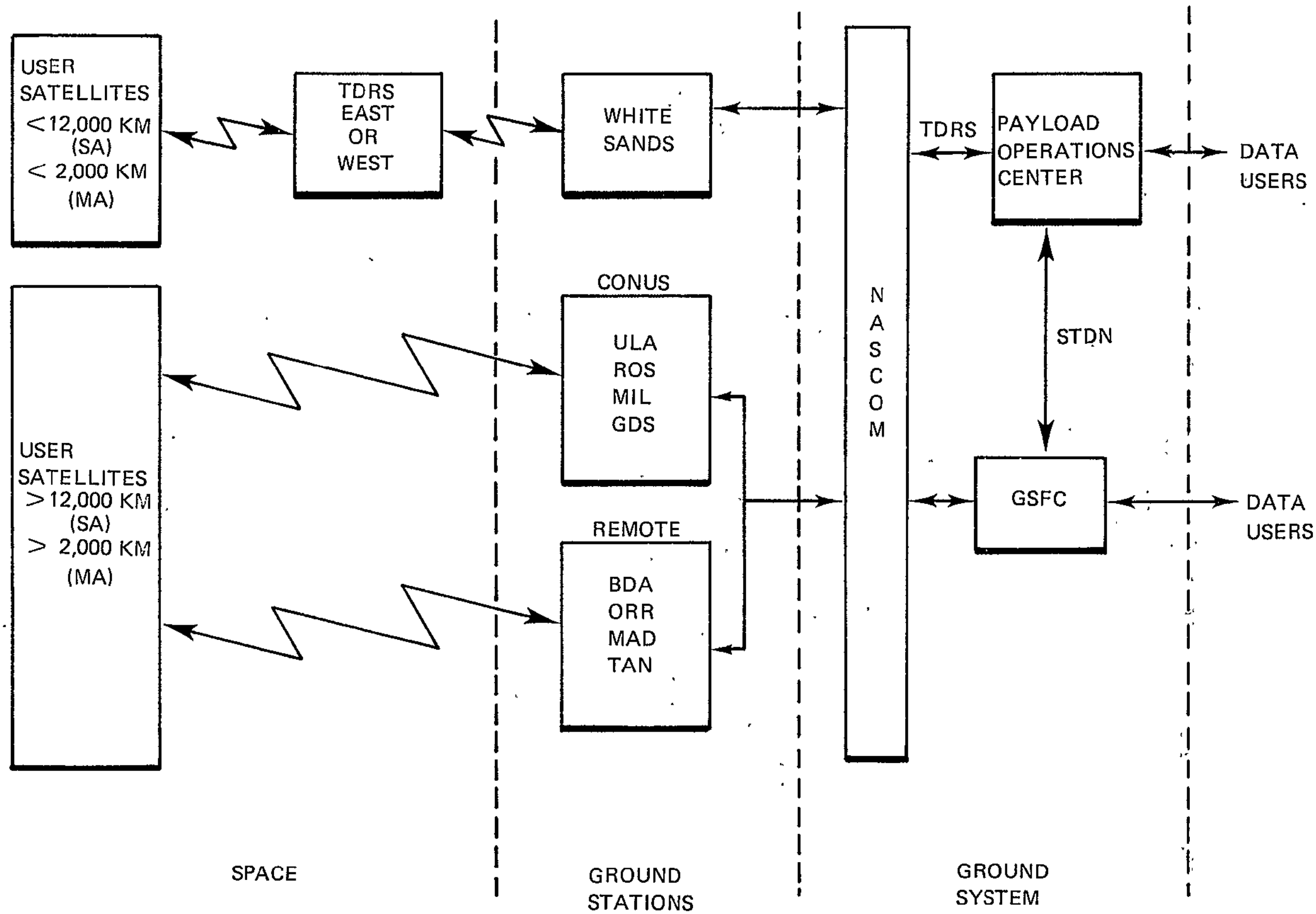

Figure 8.1.0-1. STDN/TDRS Data Flow

available for 1.3 Mbps. NASCOM capability from the remote site is even more loosely defined. Presently, a 21.2 Kbps capability exists at the STDN stations. The Deep Space Network (DSN) and Fairbanks (ULA) have a wideband circuit to GSFC capable of 28.5 Kbps. Rosman has a 1.5 MHz circuit to GSFC. This may be increased by the use of satellite communications or other NASCOM enhancements. It is expected that data from the STDN will be routed to GSFC; GSFC in turn will act as a switching and distribution center to re-route the data to the users.

8.1.1 STDN/TDRSS Telemetry Data FLow and Processing

It is planned that both subnets will present the same interface to the STDN user and both can provide telemetry, command, and tracking to any user. The capabilities planned at the STDN subnet interface have not been defined at this time.

8.1.1.1 TDRS Telecommunications Links

The concept of the TDRS telecommunications links is explained below as a basis for TM data flow and processing (reference Figure 8.1.1-1).

The telecommunications link from the ground terminal to the TDRS to user is called the forward link, and the link from the user to TDRS to the ground is called the return link. The forward links carry user command data, tracking signals, and voice transmissions, and the return links carry user telemetry data, return tracking signals, and voice. Both the forward and return links consist of two segments:

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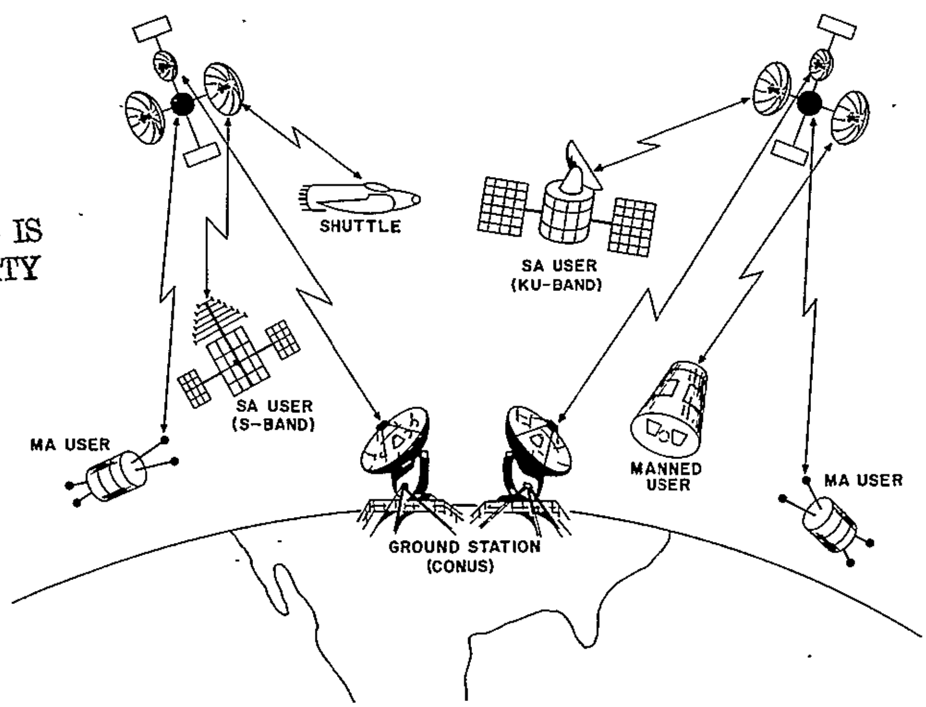

Figure 8.1.1-1. Two-Satellite TDRSS Concept

- Space-to-Space Link - This is defined as the link between the TDRS and the user spacecraft.

- Space-to-Ground Link - This is defined as the link between the TDRS and the TDRSS ground terminal.

Each TDRS contains the following antennas to support the space-to-space communication links and the space-to-ground communication links:

- Space-to-Space Communication Links -

  (1) One 40-element, S-band antenna system: 10 elements are used to support the forward link; the remaining 30 elements are used as an array antenna to support the return (telemetry) link of 20 users simultaneously. This antenna system is called the Multiple-access (MA) system; user spacecraft supported on this system are called MA users.

  (2) Two 3.8-meter parabolic antennas operating at S- and Ku-bands: Each antenna system is called a Single-access (SA) system because each antenna normally will support one user at a time. However, each antenna can support two users simultaneously (one at S-band and one at Ku-band) provided both users are within the beamwidth of the antenna. The user spacecraft supported on these antennas are called S-band Single-access (SSA) users or Ku-band Single-access (KSA) users.

- Space-to-Ground Communication Links - One 1.8 meter, parabolic Ku-band antenna.

8.1.1.2 TDRS Users

The users of the TDRSS are classified by the type of service they require from the system.

- Multiple Access User - The MA user is an S-band user serviced by the TDRS phased array. The maximum return link bit rate under most circumstances is 100 Kbps.

- S-Band Single Access User - The SSA user is serviced by one of the 3.8 meter parabolic antennas on the TDRS. The return link bit rates can vary from 1 Kbps to 6 Mbps.

- Ku-Band Single Access User - The KSA user is serviced by one of the 3.8 meter parabolic antennas on the TDRS. The maximum bandwidth is 225 MHz, thereby providing a 150 Mbps biphase or a 300 Mbps quadriphase bit rate on the return link.

8.1.1.3 TDRS Telemetry Flow

Two of the three user services provided by the TDRS, MA, and SSA are explained in further detail in the following paragraphs. The Single Access Ku-band system capability far exceeds IUS requirements at this time.

Each TDRS will be designed to support a minimum of 20 MA users simultaneously. The multiple access system employs a 30-element S-band phased array antenna to minimize onboard complexity. Adaptive beam forming functions are performed at the ground station. The MA link performance for each user is a function of the number of MA users within view of the TDRS, their data rates, and power outputs.

Each user may have a different data rate. The average user's raw real-time data rate is 11.5 Kbps plus overhead (approximately 10 percent) or approximately 12.7 Kbps. To this, each user spacecraft may add 15 percent for the transmission of data stored onboard during the blind period, thereby yielding an average rate of 14.6 Kbps. The total data rate for 20 users plus overhead is, therefore, approximately 292 Kbps. From time to time, users in the system will change as new spacecraft are launched and old ones are discontinued. Data rates may increase up to 25 percent on the average for the projected system. The total bit rate from the S-band array may, therefore, be projected as high as 365 Kbps through the ground links.

The TDRS SSA return link includes two 3.8 meter antenna steerable by ground command. Autotrack capability does not exist due to weight consideration. The SSA service provides a 10 MHz receive bandwidth and throughput capability of 1 Kbps to 6 Mbps. The 10 MHz bandwidth is sufficient to accommodate video; however, no provisions are made at this time to accommodate video data at the TDRS ground station.

SSA and MA return link data is frequency translated onboard the TDRS for transmission to the ground in the Ku-band frequency range.

8.1.1.4 TDRS Ground Terminal

The TDRS ground terminal provides three primary services: (1) forward user commands to the TDRS for transmission to user spacecraft, (2) receive user TM and provide the NASCOM interface for transmission to the user, and (3) receive Range and Range Rate data as an input to the GSFC orbit determinitation system.

The ground terminal will be capable of receiving and handling downlink data from 20 MA users, 6 KSA users, and 6 SSA users simultaneously. However, for the SA systems only 4 KSA and 4 SSA data streams from the two operational spacecraft will normally be scheduled. The ground terminal will:

a. Receive the return links from the two operational TDRSs. The receiving system is designed to provide a sufficient signal margin for reliable contact between the satellites and the ground terminal.

b. Demultiplex the received signals to recover user spacecraft data and ranging data.

c. Generate the proper PN codes for extracting range information, and, in the case of the MA users, uniquely identifying each of 20 user spacecraft.

d. Demodulate the received user spacecraft telemetry in accordance with the modulation technique used.

e. Bit synchronize, and decode the user telemetry in such a manner to interface with NASCOM for transmission to the appropriate user control center and/or the data processing system at GSFC, or other non-GSFC locations.

The content of user spacecraft telemetry will not be monitored or altered at the ground terminal. It will be routed via NASCOM to the appropriate user control and data processing facility. Presently, all data will be routed to the user as it is acquired by the TDRS ground station in a real time mode. On-site storage capability for store and forward is not being planned. Because users of the TDRSS are divided into primary categories, MA and SA users, the methods of ground data handling will be somewhat different.

The MA user channels are recovered by demultiplexing the converted Ku-band return link from the TDRS. A signal to interference ratio can be established for each MA user by combining signals received from the various elements of the MA antenna array in the proper magnitude and phase. The SSA channels are also recovered from the converted Ku-band signal. Beam forming is not necessary for SSA user signals.

8.1.2 STDN/TDRSS Tracking Modes and Processing

The TDRSS ground terminal is assigned to be furnished with a single tracking data processing system providing both high and low rate sample range and range rate (R&RR) data for all spacecraft tracked via TDRSS in a standard format. The estimated maximum data rate, including transmission overhead, is 4.8 Kbps. This channel will be active almost continuously and at present is considered to be routed through to the GSFC orbit computation center, but also may be bridged to other locations.

The user MA system must be capable of providing PN code coherence so that ranging computations can be performed on the ground. Because PN code modulation is used in both forward and return links, a PN code synchronization must be established before any functions can be performed. After synchronization, data can be transmitted in both directions. Ranging is accomplished by computing the transit time of the signal from TDRS to user to TDRS.

The ranging subsystem accepts digital R&RR data from the RF system MA and SA demodulators and processes it for delivery to the Orbit Determination System (ODS) via the NASCOM interface. It also accepts TDRS R&RR data from the RF system bilateration correlator, or alternatively, from the S-band backup system TDRS demodulator. The ranging subsystem uses this data in two ways.

First, it processes the data for delivery to ODS via the NASCOM interface. Also, it performs some on-site calculations to provide ranging information to the attitude and stationkeeping processor.

TDRSS tracking capability can be summarized in the following manner. User satellite position in near polar orbits can be determined to an uncertainty of 60 meters and accuracy is degraded as the user inclination approaches that of the TDRS. Tracking accuracy is dependent on the length of the data arcs and the number of supporting TDRSs (1 or 2).

The TDRSS is expected to provide three types of user services. The first two services are defined for information; the third for its applicability to IUS.

- Routine Orbit Determination - Necessary only to establish orbits sufficient to predict future satellite position for acquisition by ground station and TDRSS and for network scheduling data.
- Precision Orbit Determination Accuracy - Necessary for satellite systems to properly analyze and evaluate sensor data. Requirements today exist for 100 meters or less. Future requirements may be more stringent.
- Real Time Orbit Determination - Accuracy necessary for those satellite subsystems which must execute maneuvers and guarantee spacecraft and/or shuttle crew safety. Accuracy requirements will vary dependent on mission; however, short data arcs taken in a limited amount of time will be the rule of the day.

8.1.3 STDN/TDRSS Command Flow and Processing

The TDRSS forward link (command) is characteristically described by the type of user - single access or multiple access.

The MA command channel of the TDRS radiates via the 10 element transmit array. The MA uplink is a single frequency time division system with the capability to command only one MA user at a time. The user will interface with the TDRS ground terminal. The ground terminal will provide the proper scheduling and support element selection (antennas, transmitters, carrier modulation, etc.,) to the user. To be consistent with the throughput philosophy of the TDRSS user, commands will be generated, transmitted, executed, and verified by the applicable user control center. The forward link will support MA user requirements up to 10 Kbps. Uplink commands from the user control center will be in a real time mode only, command storage and load capability does not exist at the ground station.

The SSA forward link user can operate in a narrowband or wideband (under consideration) mode. Uplink data rates are variable from 100 bps to 500 Kbps. Operational considerations for the SSA forward link are similar to the MA characteristics of the last paragraphs.

8.2 NETWORK CHARACTERISTICS AND CONFIGURATION

The eight station STDN subnet and single TDRS ground station comprise the STDN. As part of the STDN, operational control of the TDRSS ground terminal will be exercised by the Network Operations Control Center (NOCC). The NOCC will send the ground terminal a weekly user support schedule via NASCOM. The schedule will specify the support times, user spacecraft frequencies, and Acquisition of Signal/Loss of Signal (AOS/LOS) times. This basic support schedule will be used to generate a detailed TDRSS utilization schedule, i.e., an activity plan. Other inputs to the activity plan will include: (a) user and TDRS data; (b) ground terminal status; and (c) other required TDRS commands. The same types of utilization schedules are expected to be provided to the eight STDN stations.

The STDN is configured to provide two types of support: (1) launch support and, (2) high altitude satellite support. The launch support stations will be configured and scheduled for that expressed purpose. Even though the support configuration has not been finalized, it is expected that the launch stations will not have the full capability of the other STDN stations. Fairbanks will provide support to the high inclination orbits, while Orroral, Madrid and Goldstone will be significant to those missions requiring support characteristics of the Deep Space Network (DSN).

The STDN and TDRSS significantly differ in their design and support concepts. It follows then that their operational constraints are different.

8.2.1 STDN Network Operational Constraints

The STDN will function primarily as a high altitude mission support network, and operational support constraints will be described as they relate to these objectives.

Keyhole Considerations - The STDN will probably utilize one or more of the three basic S-band antenna systems; the 9 meter (30'), 12 meter (40'), or 26 meter (85') parabolic dish. These antenna systems utilize an X-Y mount. The X-Y mount application is used because zenith coverage is accomplished which is not possible with the convential Az-EL mount. The X-Y mount is capable of tracking through zenith but has a gimbal restriction keyhole near the horizon. The restriction is generally oriented north to south on the 9 meter systems and east to west on the 26 meter systems (Figure 8.2.1-1). Signal loss is most significant during low altitude missions and becomes less significant as altitude increases. In the past, losses up to a 15 degree antenna elevation angle has occurred. Additional time may be required during a pass to re-acquire phase lock once the vehicle has passed through the keyhole.

Terrain Features - In addition to the keyhole effect, S-band antenna system performance will be degraded by terrain features, i.e., mountainous terrain. Obviously, this is related to station location.

Attitude Considerations - The onboard S-band phased array antenna will have a limited beamwidth. To maintain satisfactory communications with the ground stations at acceptable gains and bit error rates, the attitude and pointing of the vehicle will be restricted.

Handover Considerations - At altitudes above 6500 KM, the STDN should be able to provide continuous coverage of the vehicle. During this time period signal losses during handover should be minimal, since downlink lock can be established

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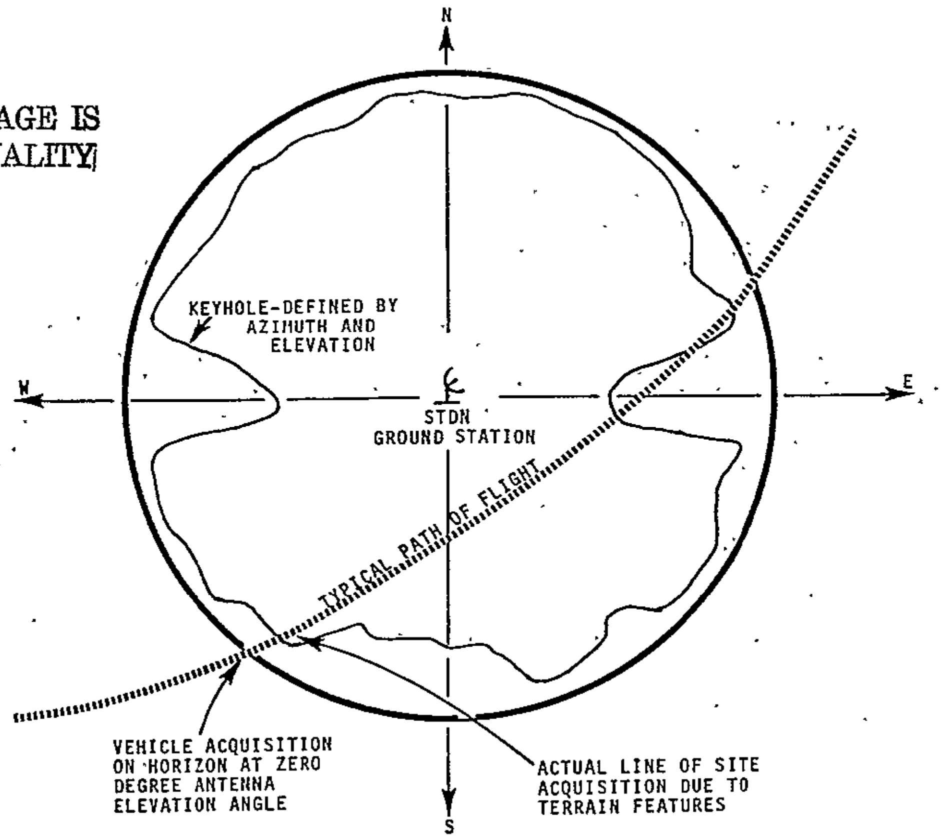

Figure 8.2.1-1. S-Band Antenna Keyholes

by more than one station. Handover becomes primarily procedural. If handover is complicated by vehicle attitude constraints, ground terrain features, or the keyhole effect, then the signal loss may be more significant.

STDN Ground Station Configuration - The STDN will be configured to primarily provide support to high altitude missions. Three stations, MILA, BDA, and TAN are configured for launch support only, and manning levels for these stations will be based on a single shift operation. Four to five stations remain for orbital support. Fairbanks (ULA) will not provide meaningful low earth orbit, low inclination support. Hence, the STDN is reduced primarily to a four station network which is not capable of or designed for significant low altitude support.

8.2.2 TDRSS Network Operational Constaints

The TDRSS will function as the low altitude mission support subnet, and its primary operational constraints are as follows:

Handover Considerations - Assuming the vehicle has only one S-band antenna, three types of handovers must be considered: (1) vehicle to TDRS-E or TDRS-W, (2) TDRSS ground antenna switching, and (3) possible handover to and from the STDN.

Positional location of the vehicle S-band antenna will be signficant because of (1) the need to slew the onboard antenna from one TDRS to another, and the associated antenna slew times, and (2) the possible need for vehicle attitude changes to ensure communications.

Of less significance will be the switching of the data source from one TDRS ground antenna to another as an input to the ground station data handling system.

Handovers from one subnet to another subnet may result in signal losses; again dependent on the geometry involved relative to the vehicle, TDRS and STDN. The following paragraphs will further explain the possible problems:

TDRS Earth Occultation - The TDRS consists of two active geosynchronous satellites 130 degrees apart in longitude on station over the equator. The two active satellites do not provide full orbital coverage of the user vehicle due to earth occultation. Communications interruptions occur in what is termed the "zone of exclusion", with its cause and location illustrated in Figure 8.2.2-1. The zone of exclusion represents the lower altitude coverage limits for the TDRSS users, which is less than 1200 kilometers. The amount of coverage provided to a user spacecraft is a function of the user' altitudes and inclinations. User at low altitudes and inclinations will pass through the zone of exclusion on each orbit and receive the least coverage. However, users at higher altitudes and inclinations will pass through the zone of exclusion only periodically, e.g., a user at 1000 kilometers altitude and 99 degrees inclination will pass through the zone of exclusion once per day or less.

IUS Antenna Occultation Considerations - Vehicle antenna masking could be caused by the vehicle structure occulting the S-band antenna and the TDRS. This situation may occur if the space vehicle is held in an attitude with at least two axis fixed over an extended period of time.

User Coverage Constraints - The user can be provided with 100 percent coverage at altitudes greater than 1200 KM. Twelve hundred kilometers represent the lower coverage limits of the TDRSS. The upper coverage limits for the single and multiple access systems are 12,000 KM and 2000 KM, respectively. A summary of the TDRSS orbital coverage follows:

- Multiple-access

  (1) Minimum coverage at 200 kilometers.
  (2) 100 percent coverage between 1200 and 200 kilometers.
  (3) Coverage decreases towards zero for synchronous altitudes.

- Single-access

  (1) Minimum coverage at 200 kilometers.
  (2) 100 percent coverage between 1200 and 12,000 kilometers.
  (3) Coverage decreases towards zero at synchronous altitudes.

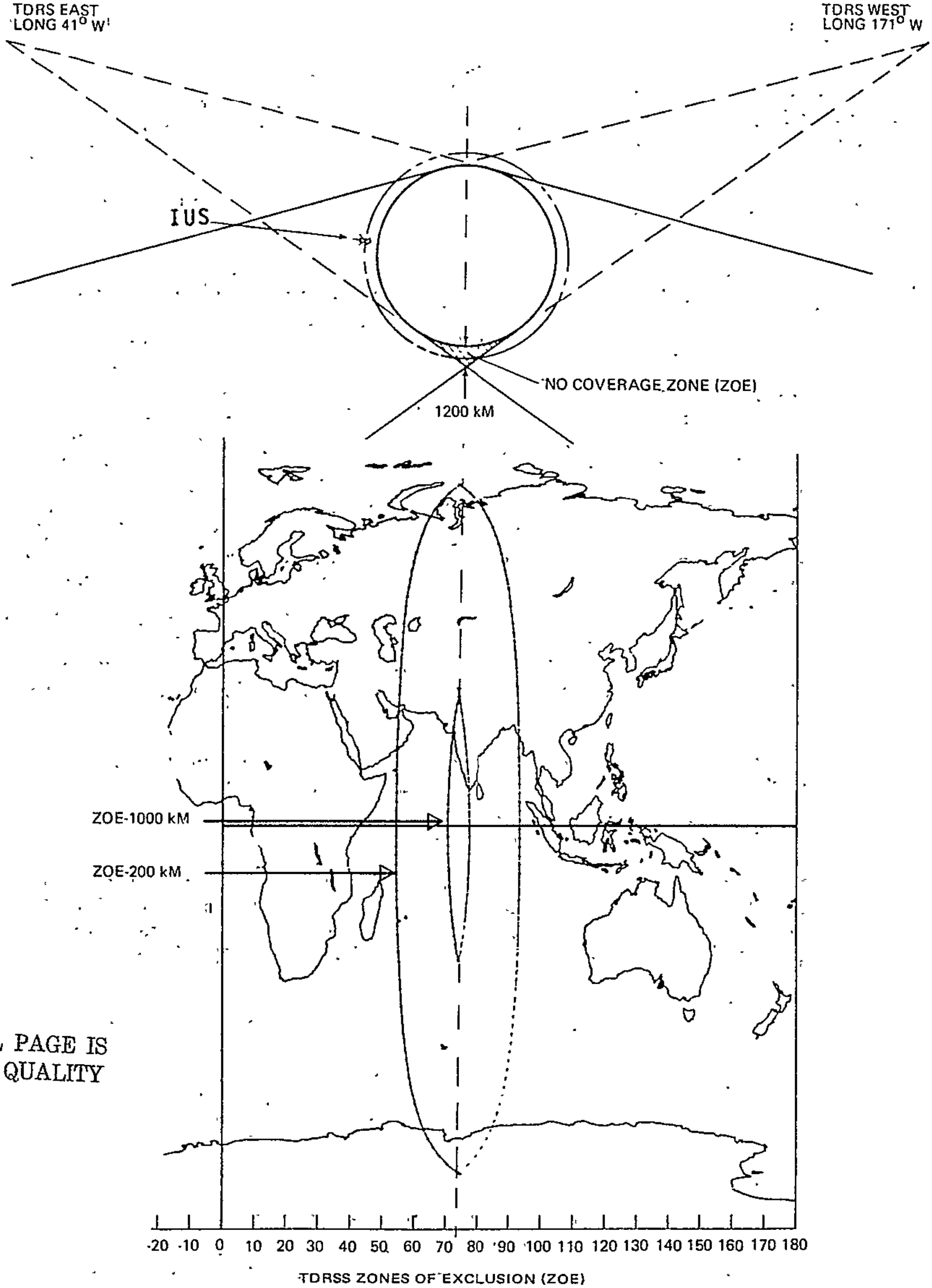

Figure 8.2.2-1. TDRS Zones of Exclusion

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8.3 EIUS MISSIONS COMMUNICATION ANALYSIS

The IUS vehicle data package used for this study is compatible with STDN, and does not presently have the capability to interface with TDRS after separation from the Orbiter; however, NASA requirements do state that the IUS will be compatible with TDRS. Therefore, the study has assumed this capability for the following communications analysis. Three representative EIUS missions were baselined for a network support study. Orbital trajectories were calculated for interplanetary, sun synchronous, and geosynchronous missions, and line of sight geometric support by the STDN and TDRSS was assessed. In the initial assessment, all STDN sites were included, in order to provide a confidence that useful stations were not prematurely disregarded. Table 8.3.0-1 illustrates possible mission support by percentage of mission time. Generalized ground support requirements for each phase of the IUS mission were:

- Launch and Orbiter-Attached Operations (TDRS/STDN)

  TM - 16 or 64 Kbps (Digital)
  CMD - 2 Kbps (Digital)
  Tracking - No Requirement

- Post-Deploy and Coast

  TM - 16 or 64 Kbps (Digital)
  CMD - 2 Kbps (Digital)
  Tracking - STDN for IUS

- EIUS Burns

  TM - 16 or 64 Kbps (Digital)
  CMD - 2 Kbps (Digital)
  Tracking - STDN for IUS

- Payload Deployment (STDN)

  TM - 16 or 64 Kbps (Digital)
  CMD - 2 Kbps (Digital)
  Tracking - STDN for IUS

8.3.1 Sun Synchronous Mission Coverage

The syn synchronous mission was analyzed for 0.50 days in length. The ascent burn delivers the vehicle to an altitude of 920 nautical miles where a circularization burn places the vehicle into a circular orbit. Spacecraft delivery and an orbit change burn completes the EIUS mission. The mission coverage indicated is from TDRS-E, TDRS-W and the three station ground network composed of Goldstone, Orroral and Madrid.

Figure 8.3.1-1 is a timeline of IUS mission events and composite AOS/LOS of the TDRSs and STDN stations. AOS/LOS and mission events are also shown in

Table 8.3.0-1. STDN/TDRSS Station Coverage

NASA MISSION		INTERPLANETARY	SUN SYNCHRONOUS	GEOSYNCHRONOUS DELIVERY
MISSION LENGTH (DAYS)		.66	0.50	1.66
STATION ACQUISITION PERCENTAGE OF TOTAL MISSION TIME	MIL *	8.4	6.6	40.8
	ROS *	4.9	7.8	40.8
	BDA	4.0	6.5	40.8
	MAD *	0.7	1.9	40.8
	CYI	2.6	0	40.8
	ACN	1.4	0	41.1
	TAN	18.3	6.8	8.4
	ORR *	64.9	3.1	17.4
	GWM	52.0	1.3	17.4
	HAW	46.9	2.5	7.1
	ULA *	0	5.7	0
	GDS *	23.8	5.3	40.8
	QUI	19.9	5.9	40.8
	AGO	22.9	4.8	41.1
	TDRS-E	49.7	84.6	15.0
	TDRS-W	44.9	67.4	12.5

*Planned Ground Stations for Tug/IUS Era

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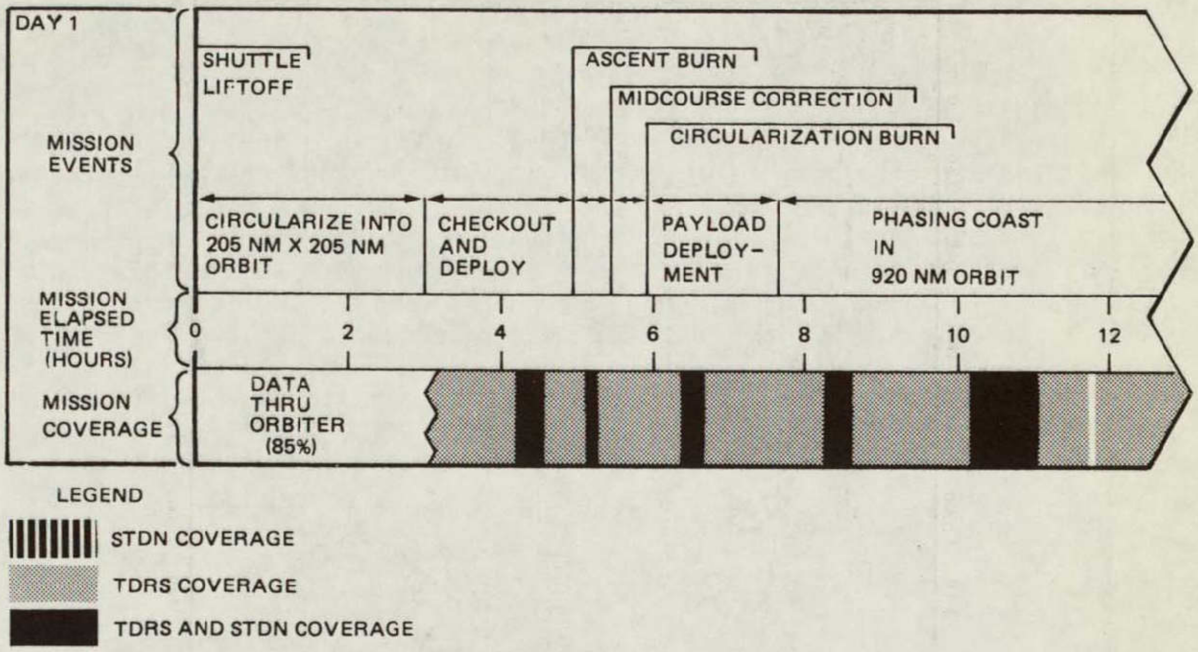

Figure 8.3.1-1. EIUS Sun Synchronous Mission Timeline (TDRS/STDN)

perspective on the mission trajectory traces in Figures 8.3.1-2 and 8.3.1-3. Only pertinent orbits are shown to maintain simplicity and ease of understanding. The following conclusions are based on the known support periods, support station capabilities, and onboard system output rates.

- The STDN does not provide any coverage during two critical mission time periods; the ascent burn and payload deployment. The STDN can support the circularization burn.

- The TDRS can provide support for all burn periods and payload deployment.

- IUS predeploy checkout and deployment will require the Orbiter/TDRS interface for support.

8.3.2 Geosynchronous Delivery Mission Coverage

The geosynchronous delivery mission was analyzed for a mission time of 1.66 days. The ascent burn delivers the vehicle to an altitude of 19,323 nautical miles where a circularization burn places the vehicle in a stationary geosynchronous position at -71^{o} longitude. Payload deployment and an orbit change burn completes the EIUS mission. The mission coverage indicated is from TDRS-E, TDRS-W and the three station ground network composed of Goldstone, Madrid, and Orroral. As with the sun synchronous mission, MIL, ROS, and ULA provided minimum additional coverage.

Figure 8.3.2-1 is a timeline of the geosynchronous delivery mission and summarizes the orbital support of both subnets depicted in Figures 8.3.2-2 and 8.3.2-3. The following conclusions can be drawn from the timelines and the known network capabilities discussed previously in this section.

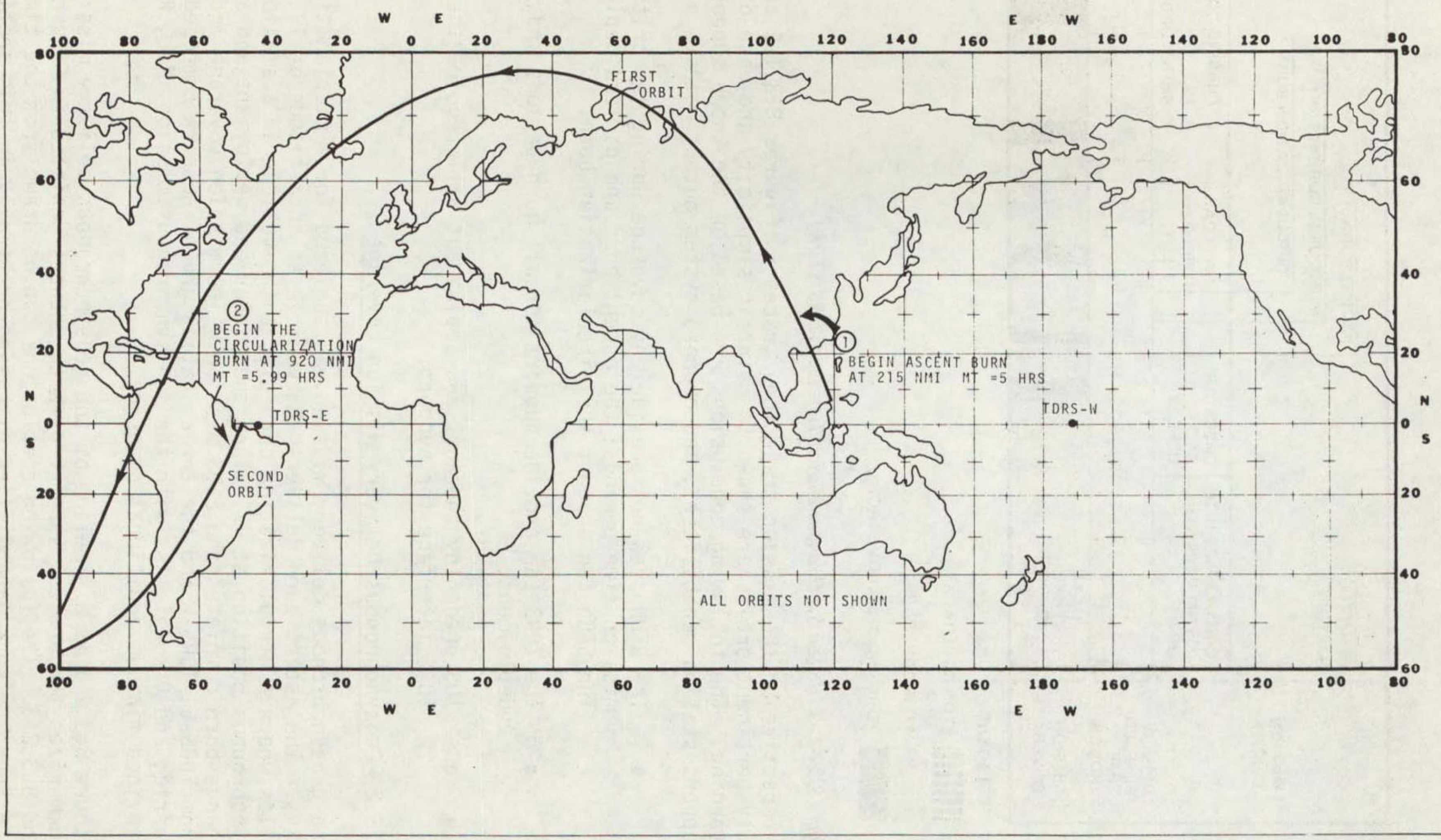

Figure 8.3.1-2. EIUS Sun Synchronous - TDRS Only Case

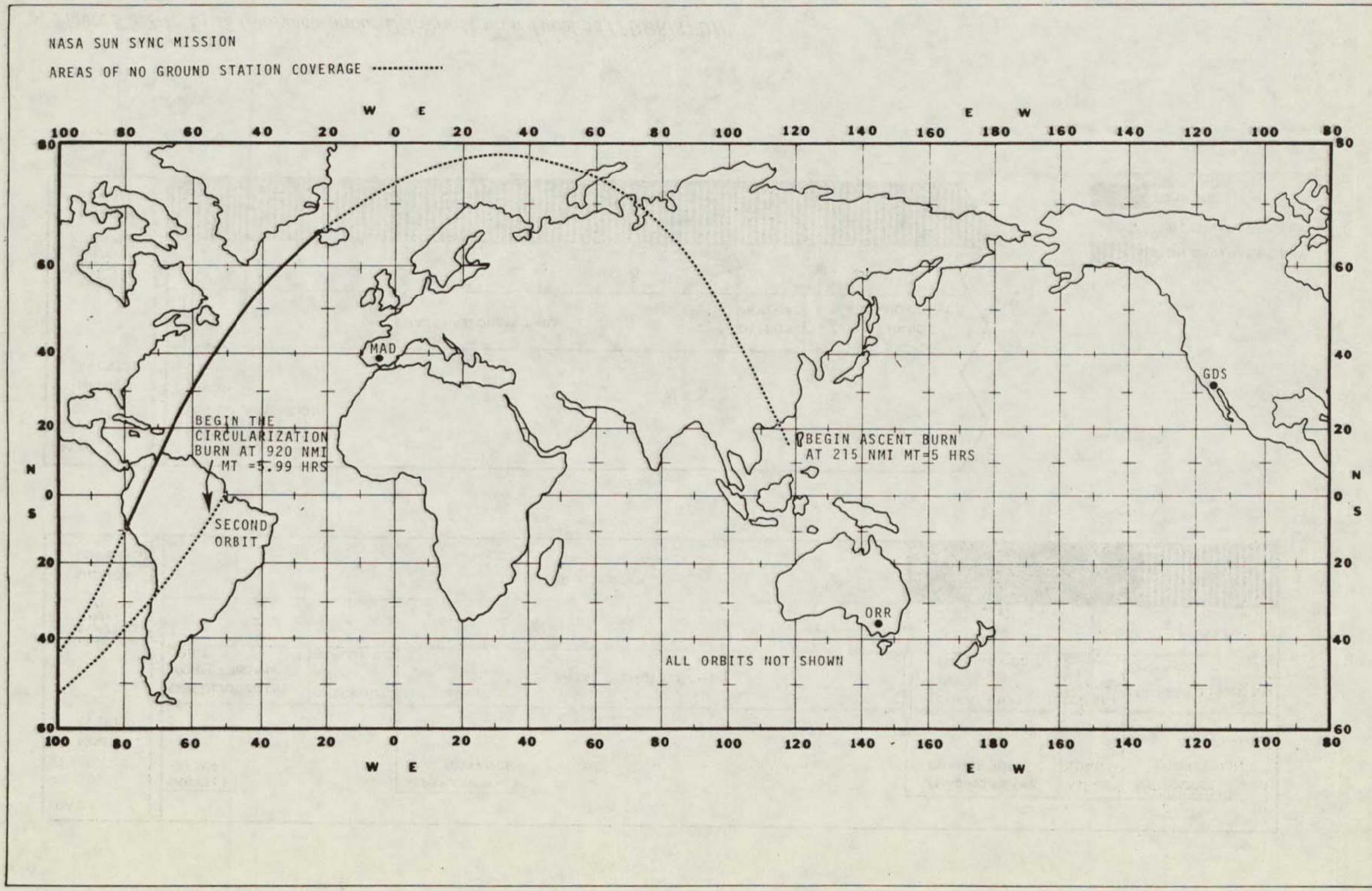

Figure 8.3.1-3. EIUS Sun Synchronous - STDN Only Case

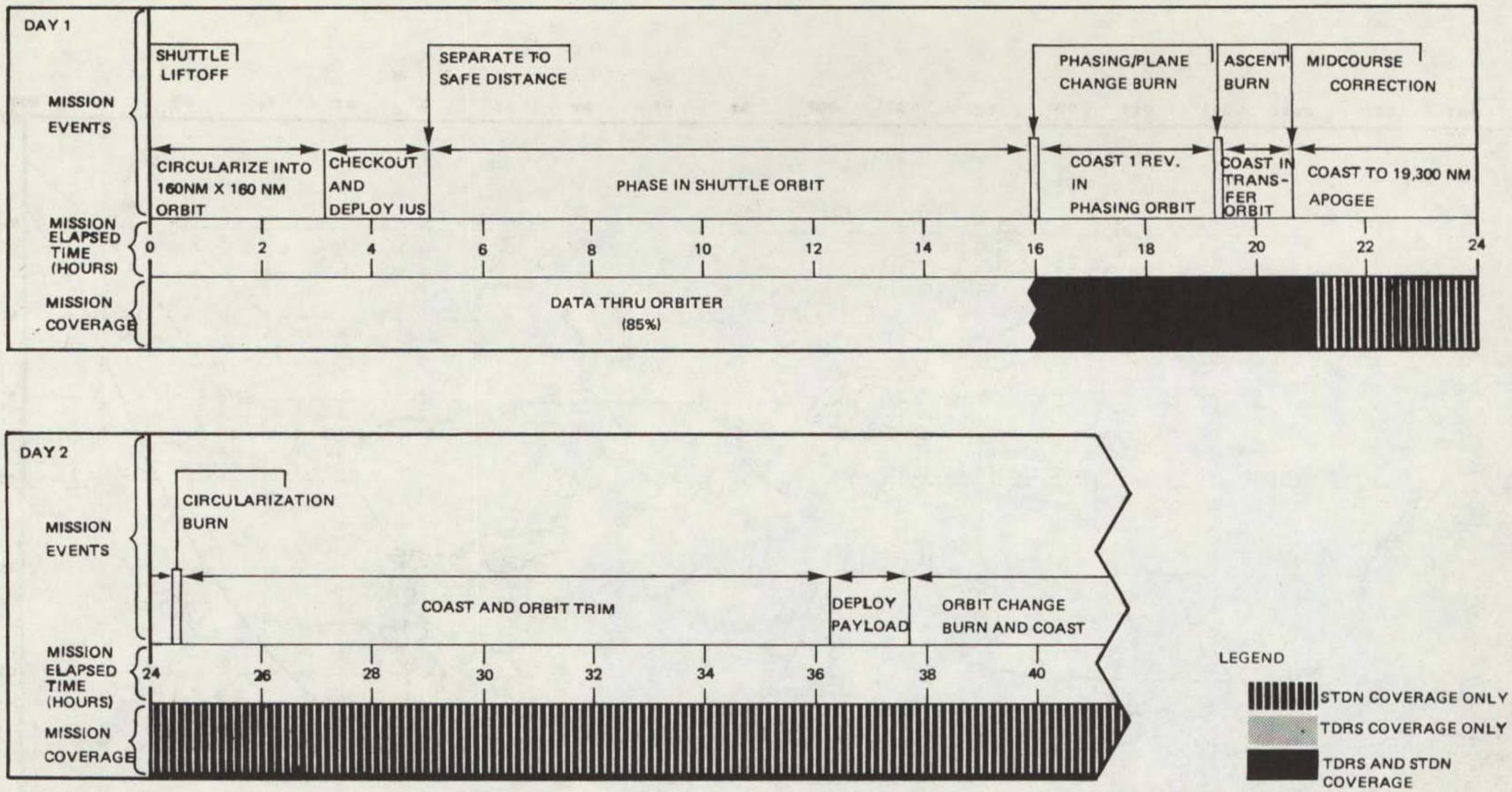

Figure 8.3.2-1. EIUS Geosynchronous Delivery Mission Timeline (TDRS/STDN)

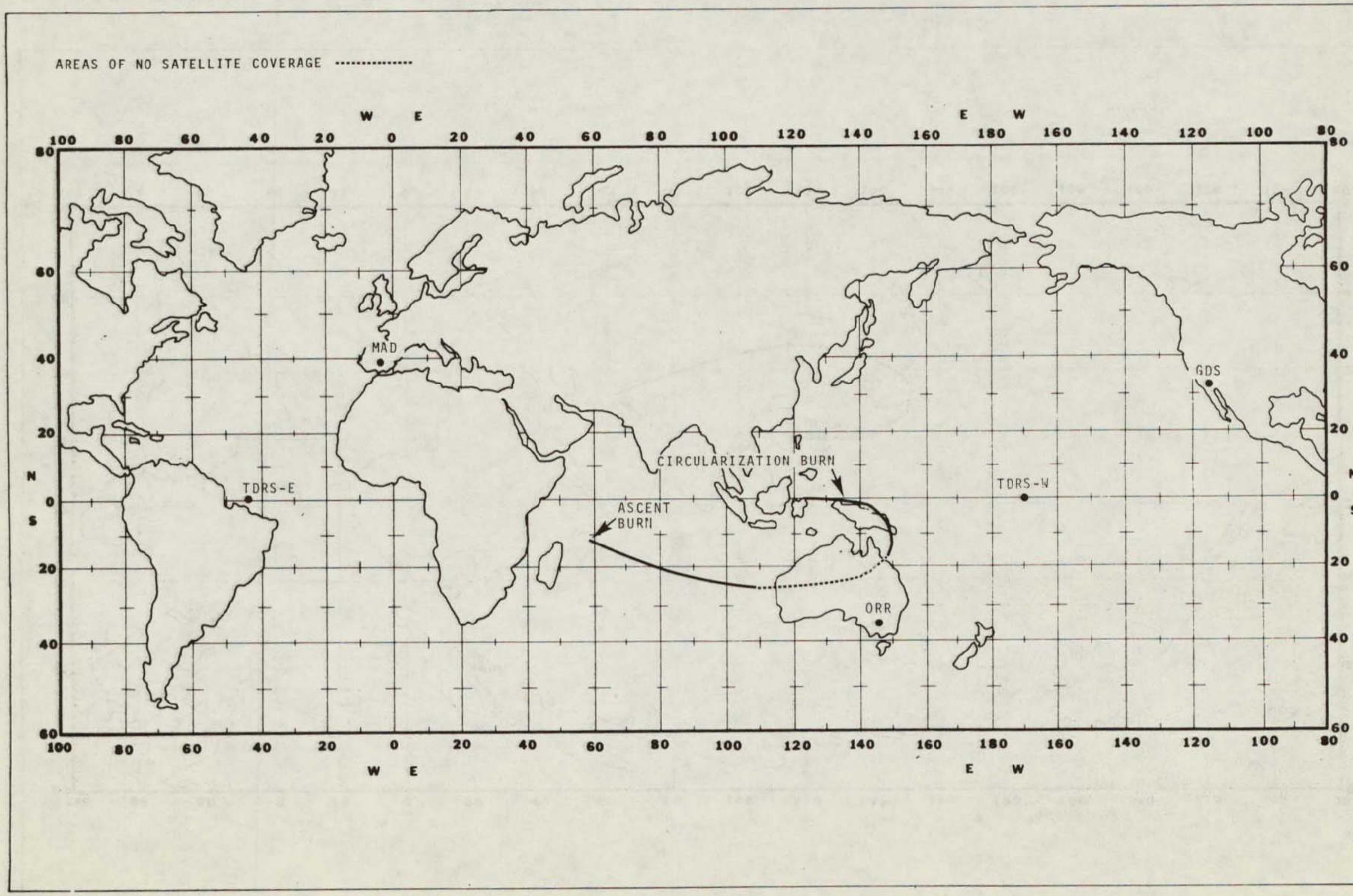

Figure 8.3.2-2. EIUS Geosynchronous - TDRS Only Case

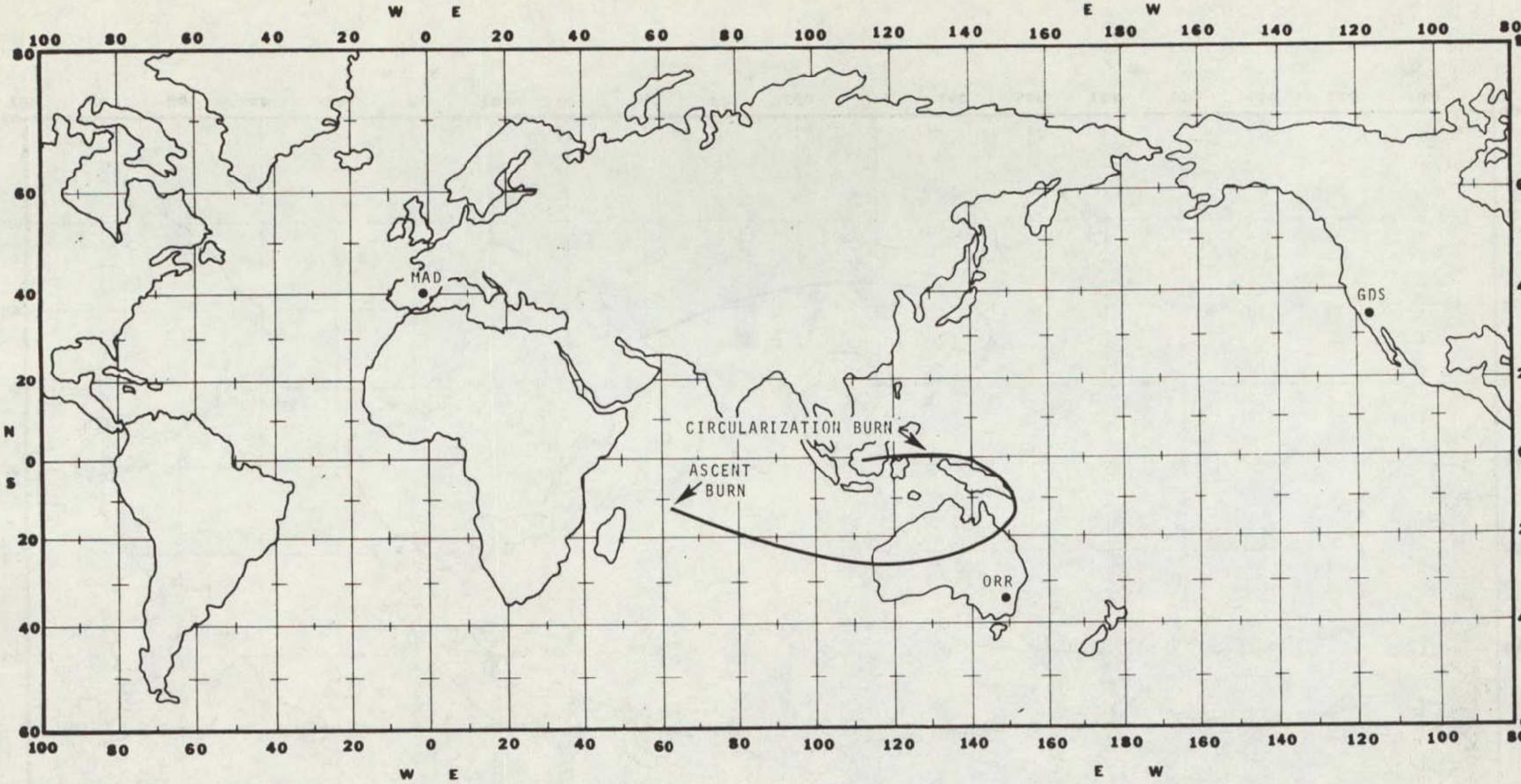

Figure 8.3.2-3. EIUS Geosynchronous - STDN Only Case

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- The STDN subnet can provide support to all major IUS burn periods.

- The STDN will only provide limited support during IUS predeploy checkout and deploy from the Orbiter. Checkout support will be enhanced by IUS utilization of the Orbiter/TDRS interface. The Orbiter SSA or KSA interface will meet all IUS requirements.

- The IUS Geosynchronous Mission does not directly require any capabilities offered by the TDRS except for deployment and on-orbit checkout operations.

8.3.3 Interplanetary Mission Coverage

The interplanetary mission analyzed was .66 days in length. The ascent burn delivers the kick stage/payload to an altitude of 737 nautical miles at 22° latitude and 155° longitude where separation occurs. The hyperbolic burn sends the IUS into a high elliptical orbit with an apogee of approximately 30,000 nautical miles. The mission coverage indicated is from TDRS-E, TDRS-W and the three station ground network composed of Goldstone, Orroral, and Madrid.

Figure 8.3.3-1 is a timeline of the interplanetary mission and summarizes the orbital support provided by the STDN and TDRS subnets. Individual subnet support is projected on Figure 8.3.3-2 and Figure 8.3.3-3. The following conclusions can be drawn from the timelines, known network capabilities, and the onboard systems capabilities.

- The ascent burn is not supported by the STDN; however, the STDN can support the IUS post burn period through the hyperbolic burn and post hyperbolic burn periods.

- The STDN can provide partial support to payload deployment. The TDRS can provide total coverage of payload deployment, however, the SSA user service would be required.

- The addition of the capability of the IUS to directly interface with the TDRS would not be of benefit during the ascent burn. The burn occurs in the TDRS zone of exclusion for the case analyzed.

- TDRS support will be required to the Orbiter for IUS checkout and deployment during low earth orbit.

8.3.4 Summary of Communications Support

In most instances, the STDN does not have the coverage necessary to support IUS checkout and deployment from the Orbiter. However, by IUS utilization of the Orbiter/TDRS interface, the necessary support will be provided without any modifications to the present IUS TM concepts.

There are several cases where an IUS/TDRS interface capability will provide ground interface capability during periods when STDN support is not possible due to orbital geometry such as:

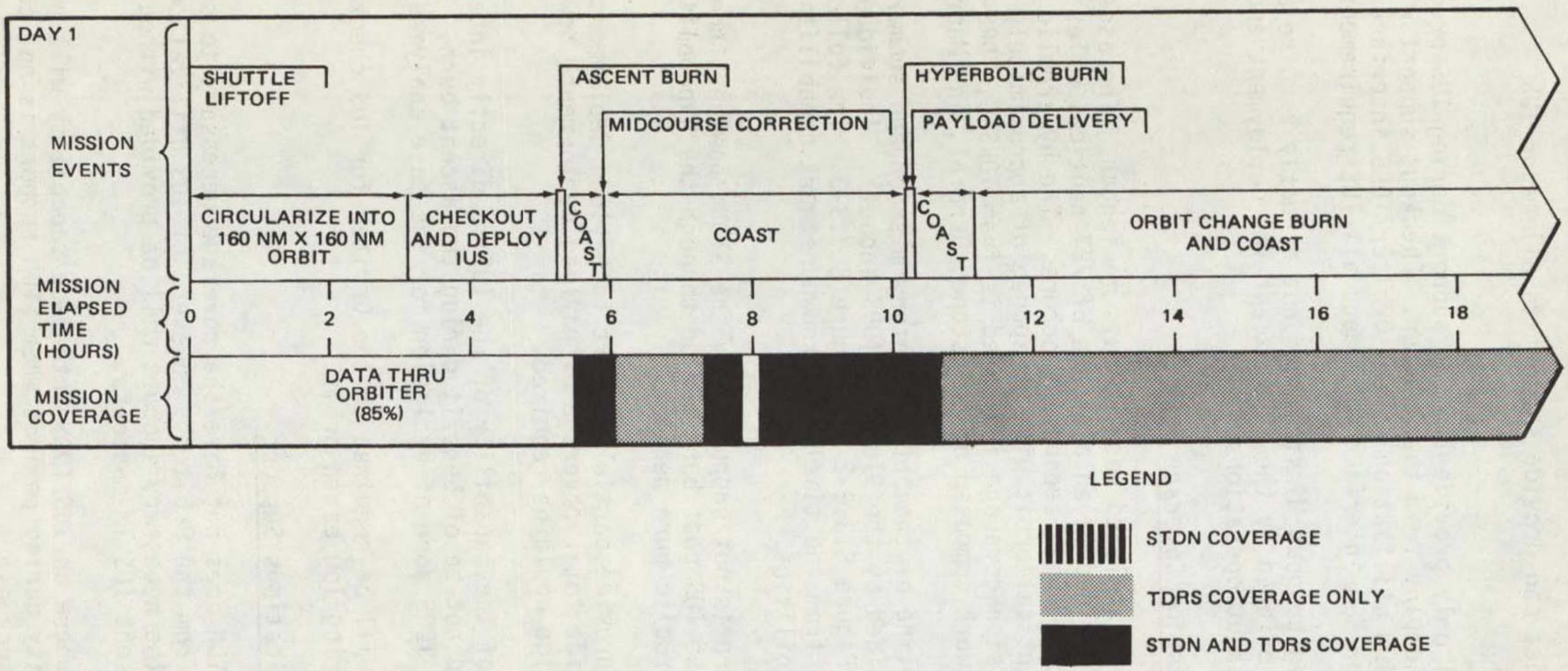

Figure 8.3.3-1. EIUS Interplanetary Mission Timeline (TDRS/STDN)

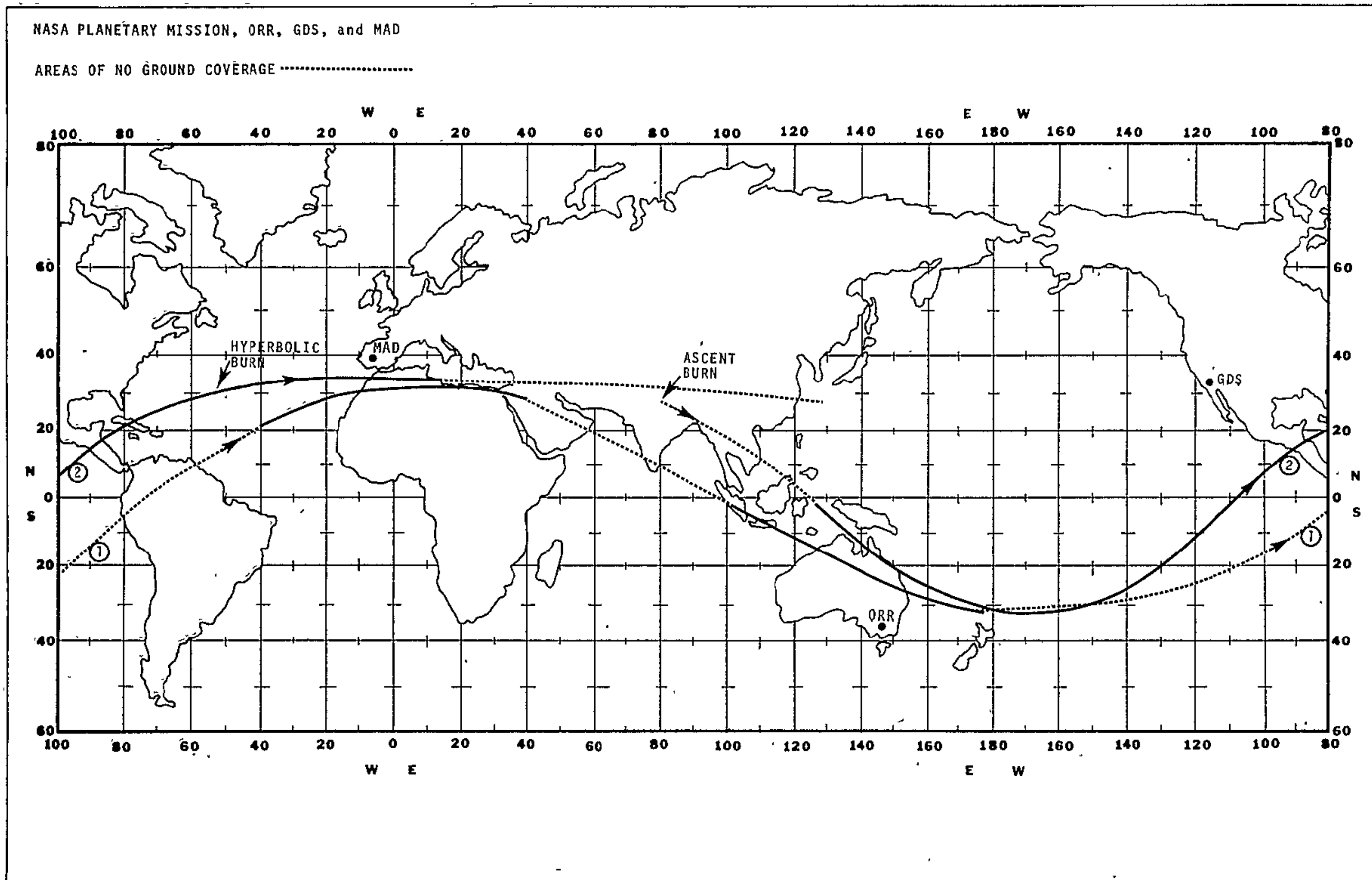

Figure 8.3.3-2. EIUS Interplanetary - STDN Only Case

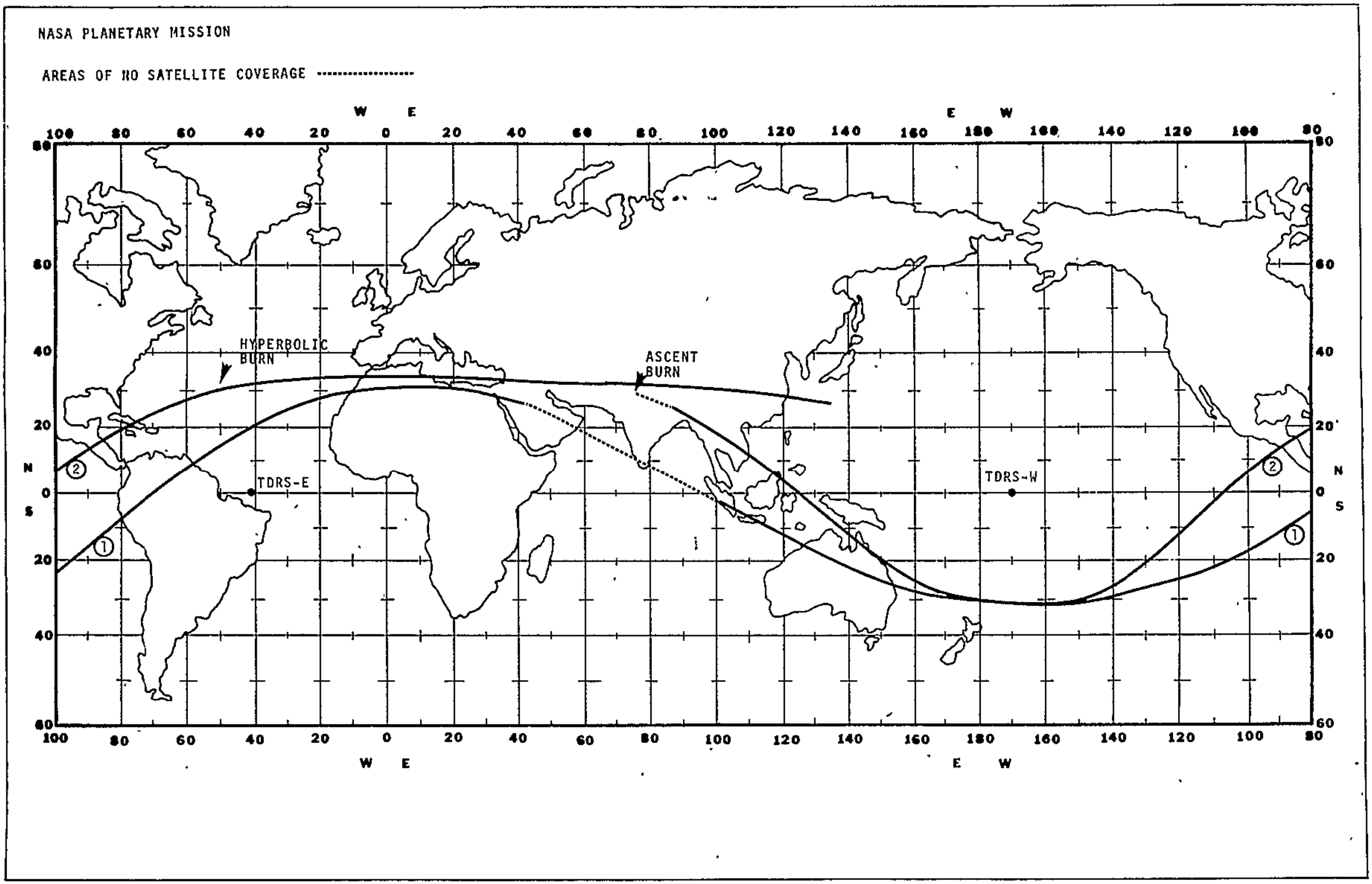

Figure 8.3.3-3. EIUS Interplanetary - TDRS Only Case

- Sun Synchronous Mission - Ascent burn and payload deployment.

- Interplanetary Mission - The payload deployment and orbit change burn.

Payload deployment on the interplanetary mission can be supported by the pointable S-band antenna and single access system. The IUS would exclude other MA users due to bandwidth considerations during the 64 Kbps periods.

It is also recommended that the ground support and RF requirements be written to the next level of detail. This will accomplish two things; (1) impact the requirements against the onboard systems design, and (2) provide a baseline for a more indepth support network analysis. Support requirements should also be prioritized to gauge their impact; mandatory, highly desirable, desirable, and etc.

The study provided network coverage times based on simplistic earth-IUS-STDN geometrical considerations only. Further studies should consider other geometric variables as mentioned in Section 8.2.1.

- Keyholes
- Terrain
- Handovers
- Vehicle Attitudes
- STDN capabilities (must be defined first)
- Vehicle antenna occultations

8.3.5 <u>Representative Network Loading for IUS</u>

The network loading created on the STDN/TDRS was determined based on several assumptions:

- If the ground station was in line of site of the vehicle it supported the mission.

- The IUS mission model presented in the Baseline Space Tug Flight Operation Document is representative of the actual missions flown.

- The Sun Synchronous, Interplanetary, and Geosynchronous missions are representative of these missions.

The typical mission model presented in the Baseline Space Tug Flight Operations document gave total of thirty one missions (deploy and/or retrieve) to be flown in 1984 and was considered to be representative for IUS missions. This total was made up of three categories of missions and is representated in Figure 8.3.5-1.

- Geosynchronous - 14 missions
- Earth orbital - 12 missions
- Earth escape - 5 missions

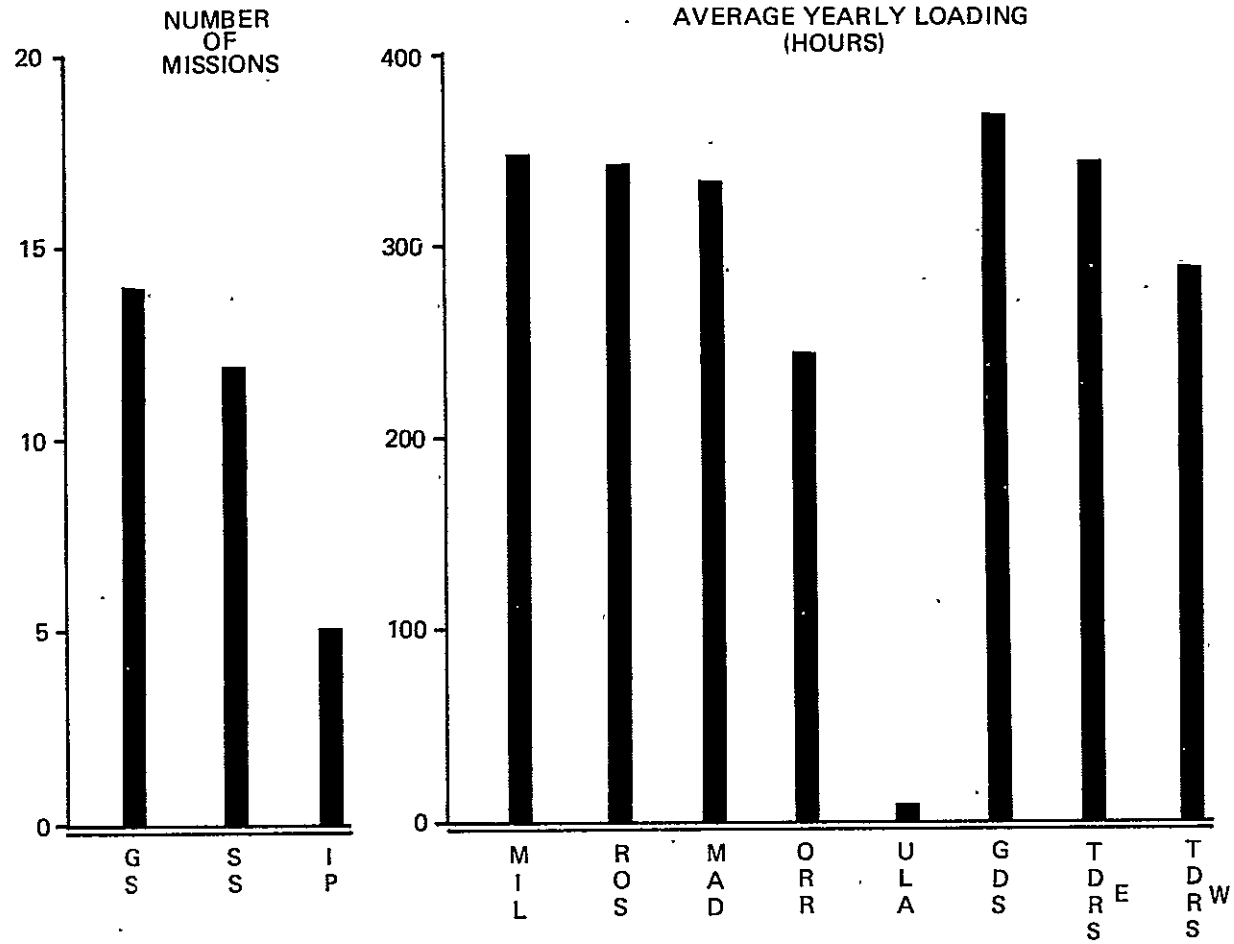

Figure 8.3.5-1. Network Loading for 1984 Missions (Typical for IUS)

The three missions analyzed to obtain network loading data were assumed to provide average loading data for all other missions within their respective category. The missions analyzed were:

- Geosynchronous (GS)/geosynchronous
- Sun-synchronous (SS)/earth orbital
- Interplanetary (IP)/earth escape

The resulting average yearly loadings per station were a total of the hours required per station for support of the three missions analyzed. Roseman (ROS) and Merritt Island (MIL) had nearly duplicate coverage, while Alaska (ULA) provided minimum coverage. The minimum station network configuration that can provide economical coverage for the three different types of missions consist of Madrid (MAD), Orroral (ORR), Goldstone (GDS), TDRS-East, and TDRS-West. Additional analysis of the EIUS missions would be required to identify the optimum network configuration for IUS.

8.4 OPERATING MODES OF MISSION CONTROL

The Space Transportation System is a vast integrated operation within which is embedded a facility for the real-time control of the EIUS operations. Figure 8.4.0-1 illustrates the five fundamental elements which must act together in order to effect the maximum efficiency of operations and their associated interfaces.

Each of the designated facilities has its own particular requirements. The Spacecraft Operations Center (SCOC) is responsible for the monitoring, commanding and controlling of the Spacecraft ephemeris. The Spacecraft Operations Center is also responsible for the control, processing and analyzing of the scientific data derived from the experiments carried by the Spacecraft. The type of data coming into the Spacecraft Operations Center relates to the trajectory, a limited amount of systems performance data and a large quantity of scientific data. The outgoing information from the Spacecraft Operations Center consists fundamentally of commands to the Spacecraft and voice coordination with other centers within the operational complex.

The Space Shuttle Operations Center (SOC) will be responsible for the monitoring, command and control of the Space Shuttle Orbiter vehicle and the attached payloads, with primary emphasis being placed upon crew safety operational requirements. The information supplied to the Shuttle Operations Center consists of trajectory measurement data, some system performance information and scientific data from those experiments which are carried onboard the Shuttle. During early phases of the flight, the Shuttle Orbiter trajectory will be utilized to provide initial phasing for the EIUS trajectory, therefore, it is required that this trajectory information be provided to the EIUS Operations Center.

The EIUS is designed to operate a Level B autonomy, which requires a high level of ground involvement. The EIUS Operations Center operation is equivalent to the combined control of the S4B/Instrument Unit in the unmanned configuration.

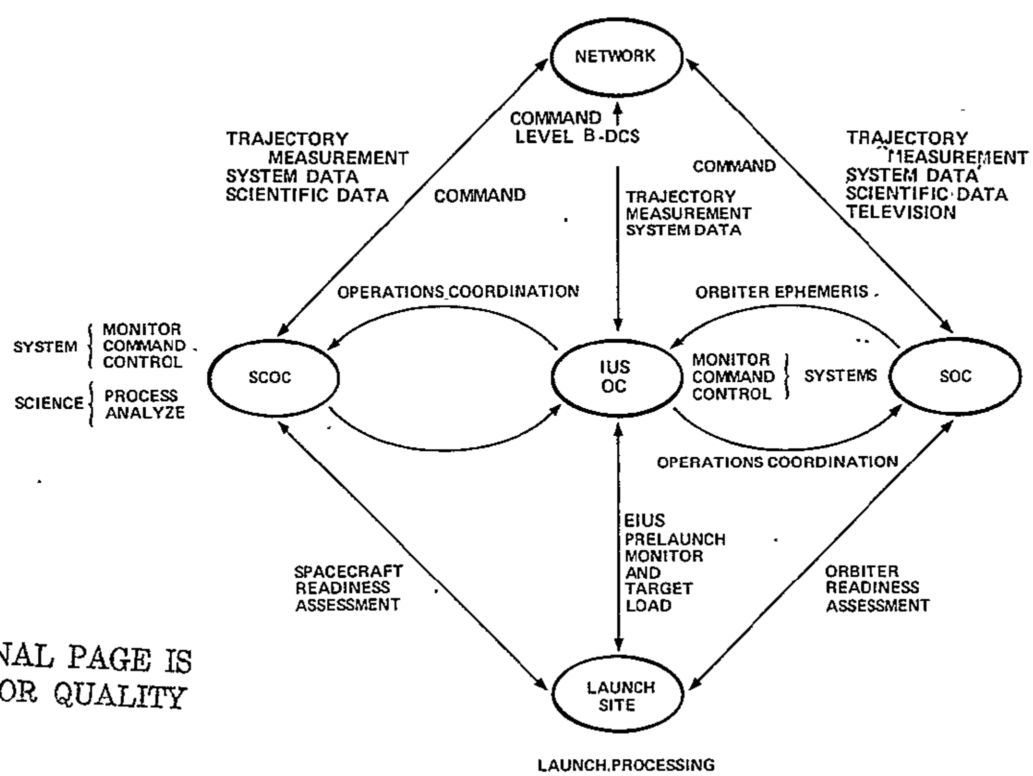

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Figure 8.4.0-1. Space Transportation Control Center Interfaces

Since there are no astronauts to assist in the control of the vehicle, complete system information and analytical capability must be maintained on the ground or integrated into the onboard data management system.

The network, consisting of the TDRS and the STDN for NASA missions, is charged with the responsibility of routing data to the appropriate control center in usable format. At some point the downlink data stream must be split apart and segregated into scientific data routed to the Spacecraft Operations Center, scientific and system data is routed to the Shuttle Orbiter Control Center and detailed systems data routed to the EIUS Control Center. The network must also provide tracking information to all three centers.

8.4.1 Prelaunch Operations

The prelaunch operations element interfaces are illustrated in Figure 8.4.0-1 and are discussed in the following sections.

8.4.1.1 IUS Operations Center/Launch Site Interface

The IUS operations control center maintains a prelaunch interface with the Launch site. In the prelaunch period, the IUS operations center will monitor prelaunch systems testing from an informational and backup standpoint. In some tests, such as command checkout and target loads, the IUS Operations Control Center will provide an active role. The EIUS Control Center will not act in other than an advisory capacity to the launch operations center during most prelaunch testing. There is not post-launch interface with the launch site.

The primary purpose of the launch site is preparation of the Spacecraft, IUS and Orbiter for launch operations. The interface with the IUS Operations Center can include any and all aspects of systems readiness, verification and preparation. The launch operations center will acquire, process, and analyze prelaunch data, and will provide the data either in real-time or near-real-time to the IUS Operations Control Center for analysis and concurrence. The countdown will be conducted at the launch site.

8.4.1.2 IUS Operations Center/Shuttle Operations Center Prelaunch Interface

The IUS Operations Center will interface with the Shuttle Control Center (SOC) during prelaunch for systems coordination purposes. The IUS requires all systems be monitored at the Control Center. There will be minimum dependence upon the Orbiter crew for any functions other than caution and warning monitoring. No prelaunch tests or system performance will be conducted by the Orbiter crew.

Since the Orbiter crew will be in contact only with the SOC, any system functions of the IUS which change the status of any parameter displayed to the astronauts must be pre-coordinated through the SOC air-to-ground voice loop. There will be no direct voice contact between the IUS Operations Center and the Orbiter crew.

The Shuttle Orbiter Control Center functions are devoted primarily to the control and monitoring of the Orbiter vehicle, with major effort being devoted to the Spacecraft and EIUS Caution and Warning function. Primary responsibilities will center around crew safety involvement of the Space Transportation System. Primarily the Shuttle Orbiter Control Center will monitor the Orbiter launch, provide voice communication with the crew and real-time data analysis during the boost phases.

Following insertion into low earth orbit, the Space Shuttle Control Center will be responsible for managing the Orbiter trajectory, not only during the time period for shaping the EIUS phasing, but also during the subsequent phases of the mission during which Shuttle onboard particular experiments are being conducted.

During all phases, the Orbiter system will be monitored for proper performance and voice communication established with the crew for the purpose of coordinating system condition information. The Shuttle Orbiter Control Center will also be deeply involved in alternate missions and contingency operations and support, including recovery, landing and rescue operations.

8.4.1.3 IUS Operations Center/Spacecraft Operations Center Prelaunch Interface.

During prelaunch operations, the focus of activity is on the launch site, Orbiter and Orbiter Control Center. The IUS Operations Center and Spacecraft Operations Center (SCOC) perform backup and monitoring functions only. The Spacecraft Operations Center is primarily concerned with Spacecraft readiness, while the IUS Operations Center performs the same assessment. There are some potential spacecraft/IUS physical interfaces which acquire operations coordination in order to ascertain the systems operability.

8.4.1.4 IUS Operations Center/Network Prelaunch Interface

The Network will acquire real-time telemetry and provide a command interface during prelaunch operations through a ground site located near the Launch Operations. The IUS Control Center will generate commands through the network to the IUS, and will monitor feedback from the IUS over the RF links. All operational interfaces between the IUS Control Center and Network will be verified during the prelaunch phase. Any anamoly will be cause to hold the launch count, since the network is essential to the conduct of post launch IUS operations.

8.4.2 Predeploy Operations

The predeploy operations interfaces between the operations elements are illustrated in Figure 8.4.0-1. This section briefly discusses the element interfaces and interactions during the predeploy phase.

8.4.2.1 IUS Operations Center/Shuttle Operations Center Predeployment Interface

The IUS Operations Center must maintain knowledge of the Space Shuttle Trajectory in the predeployment period, since the Orbiter trajectory is integral to the IUS mission trajectory plan. A low-speed state vector interface will be communicated from the Orbiter Control Center to the IUS Control Center during the predeployment period.

The IUS Operations Center monitors all downlink data from the IUS, and acts as backup analyst to support Orbiter-derived IUS concerns. Any communication with the Orbiter crew will be through the IUS Operations Center/Shuttle Orbiter Operations Center coordination loop. There will be no direct astronaut/IUS Operations Center communication.

The Shuttle Orbiter Control Center functions are devoted primarily to the control and monitoring of the Orbiter vehicle, with major effort being devoted to the Spacecraft and EIUS Caution and Warning functions. Primarily the Shuttle Orbiter Control Center will monitor the Orbiter launch, provide voice communication with the crew and real-time data anaysis during the boost phases. Following insertion into low earth orbit, the Space Shuttle Control Center will be responsible for managing the Orbiter trajectory, not only during the time period for shaping the EIUS phasing, but also during the subsequent phases of the mission during which Shuttle onboard particular experiments are being conducted. During all phases, the Orbiter system will be monitored for proper performance and voice communication established with the crew for the purpose of coordinating system condition information. The Shuttle Orbiter Control Center will be deeply involved in alterate missions and contingency operations and support, including recovery, landing and rescue operations. Primary responsibilities will center around crew safety involvements of the Space Transportation System.

8.4.2.2 IUS Operations Center/Spacecraft Operations Center Predeployment Interface

The IUS Operations Center and Spacecraft Operations Center interface during the predeployment phase. At this time, the IUS and the spacecraft are still secured within the Shuttle Orbiter cargo bay. There is no significant difference in the operations in the prelaunch and predeployment periods as regards the interface between the Spacecraft Operations Center and the IUS Operations Center. Operations coordination is required in order to advise the Centers of onboard events which may change the status of their displays.

8.4.2.3 IUS Operations Center/Network Predeployment Interface

The ground network provides support to all control center operations. The network acquires, processes and distributes data to the control centers. The primary functions of network data support are to schedule the network facility to meet the particular program, experiment, and vehicle support requirement.

The network interface with the IUS has been verified in the prelaunch period. The interface between the network and the IUS Operations Center in the predeployment period provides the information to the IUS Control Center which was provided by the launch site in the prelaunch period. The primary function is to monitor system data and provide backup information through the Spacecraft Operations Center to the astronauts in the event of operational coordination requirements.

8.4.3 Post-Deploy Operations

The Orbiter crew will monitor and control the IUS systems performance during all cargo bay manipulator arm and near-in operations where there is a crew safety involvement. After deployment, however, the operational interface become somewhat more complex. The post-deploy interfaces are shown in Figure 8.4.0-1.

8.4.3.1 IUS Operations Center/Shuttle Operations Center Post-Deploy Interface

During post-deploy operations, data is provided to the Shuttle Orbiter Control Center, the IUS Operations Center and the Orbiter crew relative to the IUS systems condition. Any command action undertaken by the IUS Operations Center must be pre-coordinated through the Shuttle Operations Center to the Orbiter crew so that any change in system status indications will not be unexpected. The immediate post-deploy time frame is critical to mission success and will require close team work and coordination activities. Trajectory measurement information will be supplied to the IUS Operations Center simultaneously with the supply of trajectory measurement informationto the Shuttle Operations Center. During the immediate post-deploy period, there exists an opportunity to compare IUS and Shuttle state vector information.

8.4.3.2 IUS Operations Center/Spacecraft Operations Center Post-Deployment Interface

During the post-deployment phase, the spacecraft is still a passenger aboard the IUS vehicle. System data from the spacecraft will be provided to the network through the IUS downlink and, in the network, will be distributed to the Spacecraft Operations Center, where it will be assessed and analyzed. There exists the potential that a command uplink will be required to use corrective actions to the spacecraft systems. No command action may be taken to the spacecraft without pre-coordination with the IUS Operations Center. The IUS Operations Center will be monitoring IUS parameters and a selected set of spacecraft parameters. The IUS trajectory measurement and system data will be processed through the network through the IUS Control Center.

8.4.3.3 IUS Operations Center/Network Post-Deploy Interface

In the post-deploy operations, the ground network will receive and process systems data and trajectory measurement data for the IUS Operations Center, and will provide a command uplink capability between the IUS Operations Center and the IUS vehicle. Command two-way lock is required during all mission phases other than while the IUS is in the Orbiter cargo bay. Many of the IUS functions require a command initiation or a command backup capability. Ground tracking, range and range-rate data will be acquired by the network and processed to the IUS Control Center at all times following separation from the Shuttle Orbiter. Remote-site data processors will perform special calculations to support consumables analysis and delta velocity computations as established by the network data handling requirements. The network receiving site will record and process data for retransmission, preserving the historical in the process. The network will provide real-time data routing and distribution to all user agencies. The network will also provide special processing support, such as the re-packing of data, logical operations, and special processing as required by the particular program and established in pre-mission period. The network will also provide a catalog of, and maintain, historical data archieves for all programs.

8.4.4 Spacecraft Deploy Operations

Figure 8.4.0-1 illustrates the spacecraft deploy operations coordination loops. The IUS mission will have carried the spacecraft to the planned deployment location. Since there exists no capability for communicating with the spacecraft after separation, the only IUS function is to provide a stable attitude and establish predeployment conditions for the spacecraft prior to totally losing contact with it.

The spacecraft systems will be activated by the IUS either automatically or through ground command prior to separation. Upon activation, the spacecraft will begin communicating trajectory, system data, and scientific data to the Spacecraft Operations Center. The spacecraft will also be prepared to accept command uplink data through the network, if that capability has not existed previously during its role as passenger on the IUS. The primary coordination problem is in ascertaining that the correct predeployment conditions have been reached by the IUS. This requires operational coordination between the Spacecraft Operations Center and the IUS Operations Center, particularly in the comparison of ephemeris achieved versus ephemeris desired.

Once separated, the IUS will phase away from the deployed spacecraft. Following a successful phasing maneuver, the IUS will be retargeted to insure no interference with spacecraft operations.

8.5 CONSIDERATIONS FOR "NEW BUILD" CONTROL CENTER DESIGN

The objective of this task was to identify development concerns incurred during the establishment of NASA/DoD Mission Control Centers. All elements of the Mission Control Center development activity were addressed, with existing approaches identified, so that developmental problems could be avoided in defining the IUS/Tug operations concepts, functions, and plans. Several center/programs were assessed for requirements; such as, staffing, computer capability, software, hardware and facility. Those centers included are JPL-Deep Space, AMES-Pioneer, JSC-Apollo and Gemini, GSFC-Unmanned Satellites and the Air Force Satellite Test Center (AFSTC).

8.5.1 NASA/JSC Development Concerns

8.5.1.1 Operational Philosophy

Prior to discussing any development activities, it is benefical to understand the operational objectives and environment of each center. JSC is currently configured (as in the past) to support missions of relatively short durations on an infrequent launch basis.

The JSC Mission Control Center and associated tracking stations are set up as a system rather than project oriented; therefore, it is reconfigured from project to project. Occasionally part of the system (i.e., control console, displays, memory systems) are updated or upgraded, however, an attempt is made to normally have the resources required to support a project, rather than modify the MCC into a project specific configuration. When equipment is acquired to support a project, a growth factor is added whenever possible to accommodate future requirements.

8.5.1.2 Systems Configurations

The basic MCC consists of the Real Time Computer Complex (RTCC) composed of five IBM S360/75's on parallel input and output busses, console areas for flight controllers, network controllers (STDN), and instrumentation controllers. Real time processing is a major MCC effort. The second largest effort is system validation and training. The RTCC is used 99 percent of the time in these roles, with one percent of the total utilization spent on actual flight support. The third largest effort is the off-line data processing by other computers, Univac 1108; however, the RTCC computers provide the interface for this data as input to JSC from the remote sites.

To alleviate scheduling problems, NASA writes a development plan for each major MCC change. This plan assures a close coordination of the contractors and government and is closely followed and reviewed to identify problems at an early stage. A need was developed for extensive software configuration planning and development control.

Some development concerns were created outside the realm of the MCC; however, a direct relationship exists from data acquisition by the onboard sensor to data processing at the MCC. This resulted in a major problem in ground telemetry processing caused by the non-uniformity of onboard data communication systems. An indexing counter in the main frame would simplify the ground decommutation process in many cases, however, it was not provided because it is not required for onboard commutation. NASA should coordinate the commutation and decommutation developments to reduce the total cost of data processing.

8.5.1.3 Roles and Responsibilities

There are about 160 NASA people and 900 contractor personnel active in the JSC MCC operation. IBM is the software contractor and integrator for the RTCC, and Philco Houston Operation (PHO) is the hardware integrator and system Maintenance and Operations contractor for all except the RTCC. Various manufacturers provide contracted maintenance on their data processing equipment. NASA retains the system integrator and system engineer roles, and additionally supplies facilities and precision measurements and equipment laboratories.

8.5.1.4 Identified Design/Development Concerns

Further evidence of the end to end impact of processing on the data flow system occurred during the Gemini mission. It was found that the command uplink had been designed to give a very low error rate (redundant commands, encoding, high gain antennas, etc.) while command verification was based on a two watt transmitter in a high error rate link. The result was that errors in the downlink caused the MCC to transmit many commands unnecessarily.

JSC committed early in the development stage to reconfigure the RTCC by software changes when signal sources varied between missions. In some instances, where there was a minimum time between launch centers and significant requirement for support, simulation, or training, software changes were not possible and wiring changes proved more feasible. Software freezes caused subsequent reconfigurations to be made by rewiring the data inputs to the RTCC's. Wiring changes were selected because of simpler validation and less man hours.

The MCC/User interface needs attention to assure that anomalies in the experiment are understood by the personnel creating the telemetry reduction software. In essence, the software was designed to operate with less than perfect data. Rather than requiring simple software changes, such as change coefficients, software required more extensive programming efforts, revalidation, etc. If software were more flexible, the software quality assurance effort could then identify immediate products in the processing needed to assure that discrete steps are properly implemented. In many other cases, the user stated his requirements without considering the processing load involved (color imagery vs. black and white), which resulted in a reduced utilization of the MCC resources.

8.5.2 NASA/JPL Development Concerns

8.5.2.1 Operational Philosophy

The JPL Mission Command and Control Center (MCCC) is viewed as a support service to the various deep probe programs offices. "Institutional Software" at JPL performs the actual communications functions with the Deep Space Network (DSN) sites in Spain, Australia and Goldstone, California. Other "institutional" routines for orbit planning, video and telemetry reduction, and command generation, are available for use by the probe program. Mariner (JPL) is controlled in the JPL Mission Test Control Facility (MTCF, Univac 1218, 1230 and 116 computers). Pioneer is controlled at NASA Ames (Xerox Sigma 5s and PDP 11s). Viking (NASA Langley) will be controlled at JPL, and Helios at Munich, Geormany. As a result JPL builds some spacecraft, e.g., Mariner, and functions as the data gathering and communications center for the probe controllers, wherever they are located. It also provides institutional software and computer resources to the requesting Project Offices, but spacecraft control resides with the builder, not the DSN.

8.5.2.2 System Configuration

The MCCC consists of three computer complexes, the Mission Computing Center Facility, (MCCF, three IBM 360/75), the General Purpose Control Facility (GPCF, a Univac 1108), and the MTCF used for Mariner. The DSN has 210 feet and 85 feet dishes at each of three locations, with high (117 Kbps), medium (51.2 and 22.05 Kbps), and low (2.4 and 4.8 Kbps) rate data lines connected to an IBM 360/75 in the MCCF. During operations, two 360/75s share the data lines and computing, although only one set of outputs is used (hot switching to backup is possible). The MCCF handles command bit structure generation and data packing/unpacking in real time, with up to six data lines simultaneously. The unpacked telemetry may be routed to the GPCF, MTCF or other operations control centers. The 1108 computer performs orbital planning and control, while the 360s are primarily real time processing machines, with resident software freezes before operational contacts to assure software integrity. The long time-line in JPL missions allows development of operational software after spacecraft launch, so that 360 software development, testing and validation is a continuous process at the MCCF, generally on the third (offline) machine. Attached to the DSN before the data enters the MCCF is a network control computer, which continuously monitors data quality and constructs a Master Data Record, to duplicate the Original Data Record at the site.

8.5.2.3 Roles and Responsibilities

Jet Propulsion Labs of California Institute of Technology is a NASA contractor, and other NASA, government and JPL contractors reside at JPL. Philco-Ford is the JPL subcontractor operating in the data services division for manning and operating the Goldstone Complex with 1000 people. The 4000 total JPL employment includes spacecraft designers, builders and system engineers for the DSN. The role of JPL is different from probe to probe, as is the utilization of the JPL/DSN resources. The different probe efforts utilize the MCCF and JPL data services to different extents, depending on the size and talents of the probe program office and their support contractors. As an example, Pioneer 6 through 9 installed telemetry processors at the DSN sites to reduce telemetry and transmit it via TTY to NASA Ames, where analysts could telephone the MCCF to have commands transmitted. For Pioneers 10 and 11, the telephone has been replaced by a data link from the Ames Sigma 5 through its PDP 11 to the JPL 360/75. This link also carries the Pioneer telemetry. The DSN sites operate as a "bent pipe" and no longer perform telemetry reduction.

8.5.2.4 Identified Design/Development Concerns

The software freeze on the 360/75 for an operation impacts software development/testing for the programs. The Support Instrumentation Requirements Document (SIRD), which levies support requirements on JPL and the DSN, should be expanded to show expected freezes in the timeline of each probe's associated software development cycle. JPL allocates resources by committing themselves to the SIRD requirements.

Software testing has expanded from five men to 30 to reflect the intricate software relations in the 360/75 computers and to give more confidence in software development.

Scheduling is accomplished by resource - DSN, MCCF, GPCF and MTCF, so that a space probe office must schedule each resource weekly, rather than put the input into a network scheduling office which would combine all requests for all resources. High priorities are allocated to operations and state of health problems, so that the remaining operational problems are of a low level nature, but can impact software development.

8.5.3 Pioneer Mission Operations Control Center Development Concerns

8.5.3.1 Operational Philosophy

The Pioneer Mission Operations Control Center (PMOCC) capabilities have been developed to control two spacecraft (SC), Pioneers 10 and 11. Because the Pioneers are nearly fly-by-wire, most changes in the SC are commanded from the ground. Only a few emergency shutdowns are accomplished automatically by the SC. This imposes real-time state of health monitoring of every SC subsystem on the MCC. To meet this requirement, pre-programmed command sequences to shut down a subsystem are stored at the MCC and at each Deep Space Network (DSN) station. Extensive DSN loss of communications procedures are necessary to preserve the SC in the event of MCC-DSN communication outages. With a one way RF delay of 50-60 minutes, there is time for the MCC to call

SC subsystem specialists in to help on equipment problems while pre-programmed commands are being set. The large round trip delay and fly-by-wire nature of the SC have caused the MCC to be designed around real time state of health checks and having/updating elaborate contingency command plans to "safe" the SC until a subsystem specialist can perform detailed evaluation of the subsystem. "Quick look" telemetry reduction is performed in the MCC for functional command verification. This includes gain changes, telemetry mode changes, attitude and control system configuration changes, etc.

The MCC was designed from the start (it is a converted conference room) for the Pioneer Mission, and for budgetary reasons maximum use of prelaunch ground test computers for flight support is a driving concept. The same office that operates the PMOCC also acquired the spacecraft; therefore, the systems contractors were responsive to developing the ground test fixtures for their dual roles.

8.5.3.2 System Configuration

The PMOCC has three Xerox Sigma 5 computers, two of which were used for spacecraft checkout, and two PDP II communications concentrators. A Sigma 5 and PDP II are dedicated to each Pioneer, with the third Sigma 5 performing offline processing, with the capability to be switched to online real-time support. The system has evolved from heavy reliance on JPL 360/75 computers for DSN site support to performing all real time functions in the PMOCC, with JPL providing metric orbit reduction and calculations for course changes. This change was made to reduce the effects of software freezes on the JPL 360/75 caused by a critical phase of any of the spacecraft sharing the DSN. The JPL 360/75 has resident routines supporting each of the spacecraft, and it has been necessary at times to freeze all software development in order to prevent changes on the program's software from disrupting the computer during a critical portion of another program's flight. Moving this application software to the PDP II and Sigma 5 has minimized the impact of these freezes on PMOCC software development. The real time support positions are a controller for each Pioneer and a technical assistant for both. These personnel command, read telemetry, and assure state of health of the SC. Offline processing of Master Data Records for the DSN sites is performed around the clock. Experimenters and subsystem specialists are on call, and perform other functions while the spacecraft are in the cruise mode. The manning jumps during contact periods, and the offline processing changes to provide "quick looks" at subsystem data. The intent in the PMOCC design is to provide the minimum resources necessary to do the job, with a large cross-pollenization among the center personnel.

8.5.3.3 Roles and Responsibilities

The Pioneer mission is a typical case where the Space Project Office (SPO) procures both the spacecraft and the ground data processing system, with JPL and the DSN providing the data collection resources. Present NASA mission operations personnel number 20, with 52 Bendix support people in four groups: Flight Operations, Data, Mission Analysis, and Launch Operations. Flight Operations are the controllers and technical assistants, performing SC control, real time telemetry readout of the science and SC equipments, and real time interfacing with JPL and the DSN. The Data group operates the computers, and accomplishes hardware and software development to support the mission. The Mission Analysis and Launch Operation groups have various roles that change with the mission phase. Both NASA and Bendix are flexible in the roles that the offline personnel perform as the mission progresses. The software is unique to PMOCC, and has been developed by the SPO, including the launch support software. The hardware has been salvaged, rented and contracted for, with manufacturer maintenance wherever possible. The maintenance contractor performs all modifications to his equipment. Bendix performs system maintenance mods, interconnects, etc., to the equipment otherwise unsupported. These include the consoles, bit syncs, and telemetry station.

JPL's role is that of data gatherer and DSN interface, and also provides the use of high cost resources, such as the orbit determination and some image processing equipment.

The trend has been to concentrate the real time functions at PMOCC, minimizing dependence on the JPL computers for DSN support. A major problem is DSN resource allocation, with several programs requesting maximum data receipt, and the many programs competing for the same resources. Weekly scheduling meetings handle normal conflicts, with real time changes when a spacecraft's health is threatened. This forces the Pioneer Mission Office to gather weekly requests from the scientists as inputs to the scheduling process. There is a DSN operations control center at JPL in voice contact with the stations, but normally PMOCC is in voice contact with JPL, and not the sites.

8.5.3.4 Identified Design/Development Concerns

Resource allocation at JPL has caused PMOCC to become self-reliant wherever possible. Although duplicating existing capabilities, by having them at PMOCC, the SPO has gained development resources that would normally be shared if at JPL.

The flexibility of the NASA staff is a response to the shifting workload in PMOCC and is an effort to broaden in-house capabilities.

8.5.4 <u>NASA/GSFC Development Concerns</u>

8.5.4.1 Operational Philosophy

NASA GSFC has been developed to support satellite payloads. Current design objectives are to standardize the Multisatellite Control Center (MCC), and to automate configuration changes from one satellite pass to the next. Another goal is to have standardized software and operator interfaces so that modular improvements can be made. The prime mission of the MCC is the health and safety of the SC, with other Goddard divisions handling software, data analysis, orbit reduction, and data reduction.

8.5.4.2 System Configuration

The MCC is built around a digital switch, SCADI, which is really three PDP 11-20s. These provide connections between the computers (XEROX 930s and Sigma 5s), PCM converter decoders, strip chart decoders, CRTs and consoles, and the data lines from the sites. Up to 10 simultaneous satellite supports are possible. In the past, each console and computer group was custom built for a particular satellite, but the movement to grouping common functions and providing standard consoles is underway. The three SCADI computers function as executive, online and backup, with real time switching possible. Simple format conversions are also performed in the SCADI, with an emphasis on automatic reconfiguration of the system as the support load changes. The SCADI also monitors the data blocks from site and performs real time corrections and diagnostics on the data.

8.5.4.3 Roles and Responsibilities

RCA is the Maintenance and Operations contractor at the MCC, in a ratio of seven RCA to each NASA person in flight operations. The NASA MCC design staff numbers 15. Goddard requires standard interfaces from the SC builder, with a Support Instrumentation Requirements Document detailing the agreement. This formal document is regularly reviewed and is the vehicle for handling conflicts between SC builder desires and ground capabilities. The level of normal support is herein defined, and requests for more than this must be approved by higher NASA offices.

Wherever possible the SC contractor is asked to develop test software on compatible machines, in a structure so that it can later be used in flight operations. Structurally, NASA designates a member of the MCC project staff as user interface, where the definition of ground system processing of SC data is performed in real time. This man is also the responsible person for MCC operations in support of the SC. To assure hardware/software compatibility, the Control Center Systems Managers have complimentary backgrounds, and both must initial design reviews of all hardware and software developed for the MCC. No new software development is allowed until the specifications for the changes are approved, and the interfaces defined.

8.5.4.4 Identified Design/Development Concerns

The GSFC MCC has become conservative in technology utilization, reflecting a small budget.

A Digital Data Processing System, a minicomputer with large disk storage, is being procured to allow post pass playback of the entire pass over low quality voice lines. This system will eliminate the shipping of range tapes in most cases.

Unplanned MCC processing changes are handled with software changes wherever possible, reflecting the shorter development cycle of minor program changes.

The MCC design is frozen about 3 to 4 months before launch to allow 30-45 days for operator training and another 30-60 days for simulation and rehearsals. This early freeze has become necessary to confidently assess MCC readiness. Changes are allowed only at times agreed to by the M&O and NASA staffs. This freeze provides a system baseline early enough to make the necessary changes.

Two basic questions in MCC development are "What are the real requirements?" and "When is it really ready?". The designated member of the project staff to interface with the user, and the MCC design freeze are the GSFC responses to these questions, along with the regular reviews of the Support Instrumentation Requirements Document.

8.5.5 DoD/SGLS Development Concerns

This section does not include the operational philosophy and systems descriptions as previously defined at the other centers due to sensitivity of the data. However, a summary of the concerns is described below in general terms.

Identified Design/Development Concerns - Several problem areas can be related to other centers as well as the Satellite Control Facility (SFC). Once software tradeoffs had been performed a software freeze was initiated. The premature freeze impacted developmental program design as well as changes, integration among contractors, and the relationship of the contractor and his role in the facility.

The network does not have the resources to satisfy all support requirements levied by users, primarily due to computer, communications and tracking-station limitations. For months at a time, a Remote Tracking Station (RTS) will have no unscheduled periods if it has the capability to service both polar and equatorial high energy orbit satellites. The small on-line computers have been so heavily loaded in recent years that an emulator system having a five-fold increase in throughput is being procured. Eventually the existing software will be replaced by a new software system. The number of hours spent in real time support has increased each year, and currently saturates the computer resources. The wideband data system, where data rates to 1.024 Mbps are supplied directly from an RTS to a Systems Project Office (SPO) telemetry reduction center, is expected to offload some of the Satellite Test Center (STC) computer requirements.

System rehearsals are not as extensive as NASA's, because the missions tend to be evolutionary, with evolutionary software changes to accommodate them. The melding of contractor telemetry reduction facilities into the real time loop will be a problem in future rehearsals.

In the Advanced Data System era (1967 - 1969), large scale concurrent development of new computers, buffers and software, caused many problems, and an interim software system with minimal changes became the standard system (Model A). Since then, Model A has gradually evolved into the dual computer processor system originally requested in the ADS era. This gradual evolution is now preferred for meeting new requirements.

8.5.6 New Control Center Development Approach

The assessment of the mission control centers in the previous paragraphs was based on the particular role of that center and the specific types of missions they supported. Several items appear significant in determining the development philosophy for a new control center.

Planning and close coordination has been a key to the development of new MCC's. Problems were solved more easily in the past by utilization of a detailed development plan and close coordination and review with the developers and implementators. Close coordination provided early identification of problem areas and allowed flexibility for long lead time changes.

The development plan should specify a system that has growth potential to meet future requirements. The upgrading of a system is preferred by a gradual evolutionary process rather than by drastic changes.

The MCC should have the capability to restructure its systems on its own timeline. Or the MCC should thoroughly understand the ramifications of utilizing institutional resources (hardware/software) that may be in contention by other programs. In the same vein, the MCC should not contend for its own resources, i.e., software development on a machine that is providing mission support.

The MCC development should be streamlined, deleting redundant operations and development cycles. For instance, test software should be developed on MCC compatible machines, such that the software can later be used in flight operations.

The MCC should establish a definite interface with other facets of the data flow; NASCOM, GSFC and the STDN/TDRSS·subnets. The MCC should realize a continued increase in support requirements from other programs may negate those services once supplied by NASCOM or GSFC (Orbit determination), etc.

The MCC should also establish a definite interface with its users, defining the capabilities it can provide and the requirements the user systems must meet to utilize these capabilities. This will prevent the user from overloading MCC systems.

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INTERIUM UPPER STAGE (IUS) BASELINE OPERATIONS PLAN

IBM

INTERIM UPPER STAGE BASELINE OPERATIONS PLAN 9

A significant number of missions in the Space Transportation System model set cannot be achieved by the Earth Orbiting Shuttle Vehicle. This is because its performance capabilities limit it to near-earth missions. To extend the capabilities of the System, an additional stage has been added to the basic shuttle vehicle. The Interim Upper Stage (IUS) performs this service in the 1981-1983 time frame.

Implicit in the addition of the IUS is the necessity for a ground network and control center for monitoring and/or control of the IUS vehicle during its mission. The complexity and, therefore, the development costs of the IUS Control Center, is a function of the requirements resulting from the mission profile and the autonomous capabilities of the onboard avionics of the IUS vehicle.

IUS vehicle avionics have the greatest influence on operational autonomy. Onboard autonomy establishes the required degree of ground control and monitoring. Allocation of functions, such as navigation, influence the avionics requirements. From a mission standpoint, this function must be performed, and if not accomplished onboard, it must be done by the ground. It follows that the more autonomous IUS operation permits a decrease in ground operations. The following are characteristics of the two autonomy levels:

- Level A Autonomy
  - Existing Vehicle
  - Tone command system
  - No interface with onboard computer
  - No navigation or target update capabilities
- Level B Autonomy
  - Modified vehicle
  - Digital command system
  - Interface with onboard computer
  - Navigation and target update capabilities

This section presents the baseline operations plan for an IUS vehicle designed for operation at Level B autonomy. The Baseline Operations Plan includes the ground support functional organization, mission controller functional requirements, and operations support requirements. Cost estimates are presented for software (ground and airborne), hardware, facilities and services which are directly chargeable to the support of IUS mission operations.

9.1 MISSION PLAN DESCRIPTION

This section defines the reference missions, which is structured to include the covering set of mission requirements (required mission functions), which provide a basis for selecting and sizing operational support elements.

9.1.1 Covering Set of Mission Requirements

Modular timelines were developed which capture the scope of operational activities surrounding trajectory based events. Section 3.2 presents and discusses the modules making up the modular timelines. It is sufficient for the purposes of this section to note that the reference mission includes all unique operational activities of an IUS mission.

The modules are: the Orbiter Launch Operations module, which covers the period from launch preparations through IUS deployment, enable and first coast period; the On-Orbit Coast module, which covers the interim on-orbit navigation, guidance and control state between active mission modules; the Main Engine Burn module, which is utilized each time a major manevery is required; the Payload placement module, which covers the payload (Spacecraft) enable and deployment functions; and the Kick Stage Separation module, which defines the functions required to activate and deploy a kick stage.

9.1.2 Single Spacecraft Deploy Mission Timeline

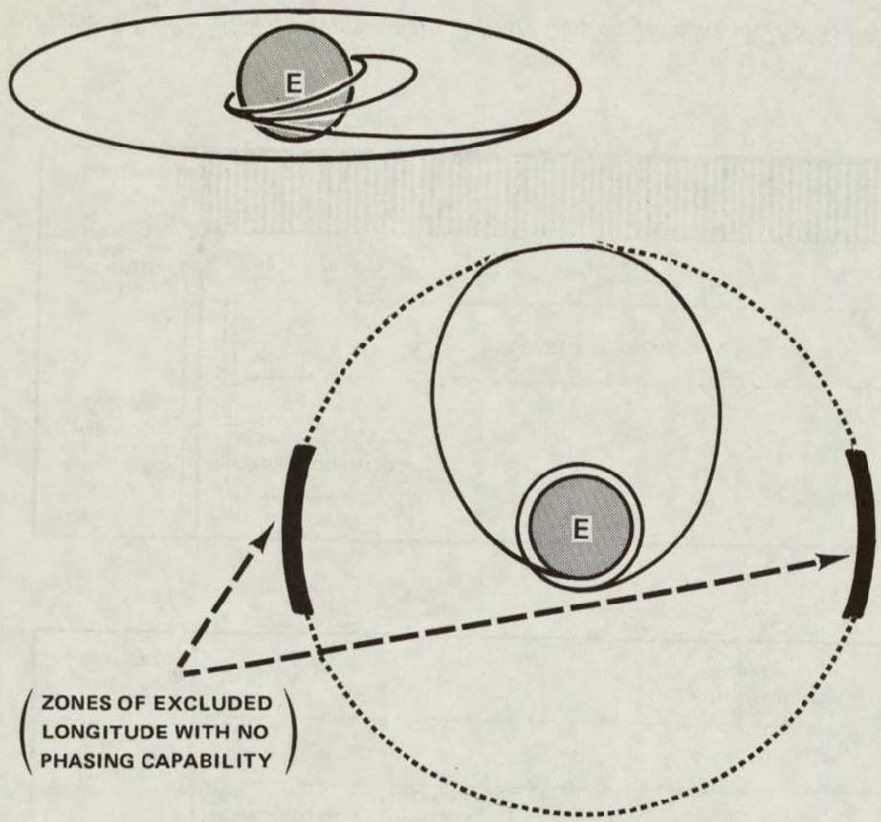
The mission chosen as the reference for determining control center requirements, deploys a Spacecraft at geosynchronous altitude. Figure 9.1.2-1 illustrates the mission geometry and Figure 9.1.2-2 illustrates the combined STDN/TDRS converage. Figures 9.1.2-3 and 9.1.2-4 illustrate the TDRS-only and STDN-only ground tracks and coverage.

9.2 FUNCTIONAL ORGANIZATION

Figure 9.2.0-1 presents an overview of the recommended mission control organization. The basic line structure for mission control organization will begin with Mission Director at the apex to whom reports the Orbiter Operations Director, the IUS Operations Director and the Spacecraft Operations Director. Coordination between the three involved control agencies will be direct, with the decision authority vested in the Mission Director to resolve conflicting subordinate level requirements. The chart as drawn is relevant to on-orbit operations and does not include the launch operations involvement.

The IUS Operations Director is responsible for all aspects of control of the IUS including the facilities maintenance and operations, vehicle systems, flight dynamics, mission planning and special function organization.

Reporting to the IUS Operations Director are a Facilities Management group, a Vehicle Systems group, a Flight Dynamics and Mission Planning group devoted to real-time analysis of flight dynamics, real-time retargetting and restructuring of the mission and the preparation of the initial mission plans, and a Special Functions group. The Special Function operation will be Spacecraft particular or experiment related function.



MODULE	START	STOP
1	-64800	3476
2	3476	3956
3	3956	4792
3	23156	23992
7	23992	27692

MISSION : SPACECRAFT DELIVERY

MISSION MODULE	TIME →	START	STOP	START	STOP	START	STOP	START	STOP	START	STOP
LAUNCH		–64800	3476								
ACTIVATION		3476	3956								
BURN		3956	4792	23156	23992						
PAYLOAD PLACEMENT		23992	27692								

Figure 9.1.2-1. EIUS Spacecraft Delivery Mission Profile

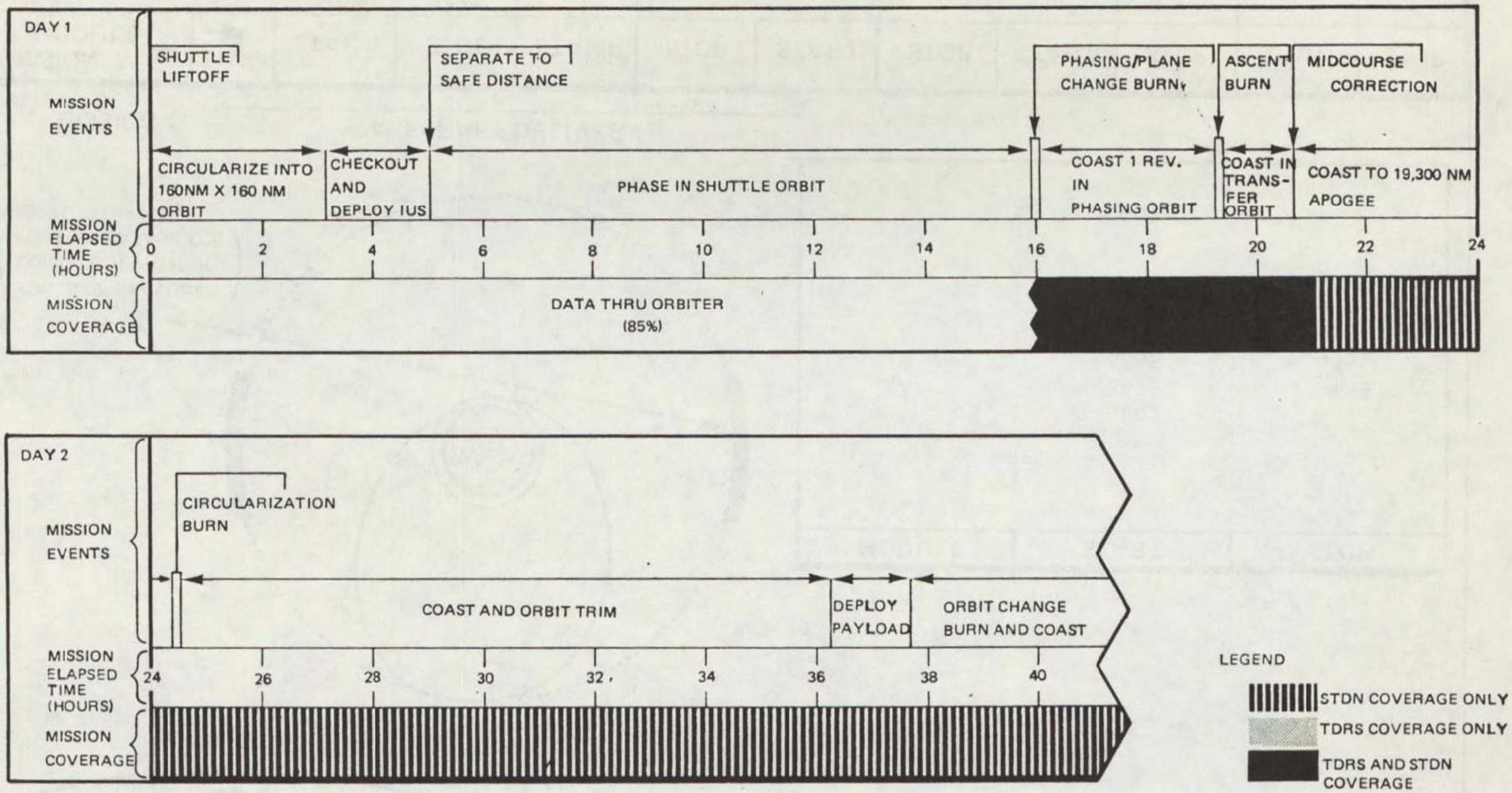


Figure 9.1.2-2. EIUS Geosynchronous Delivery Mission Timeline (TDRS/STDN)

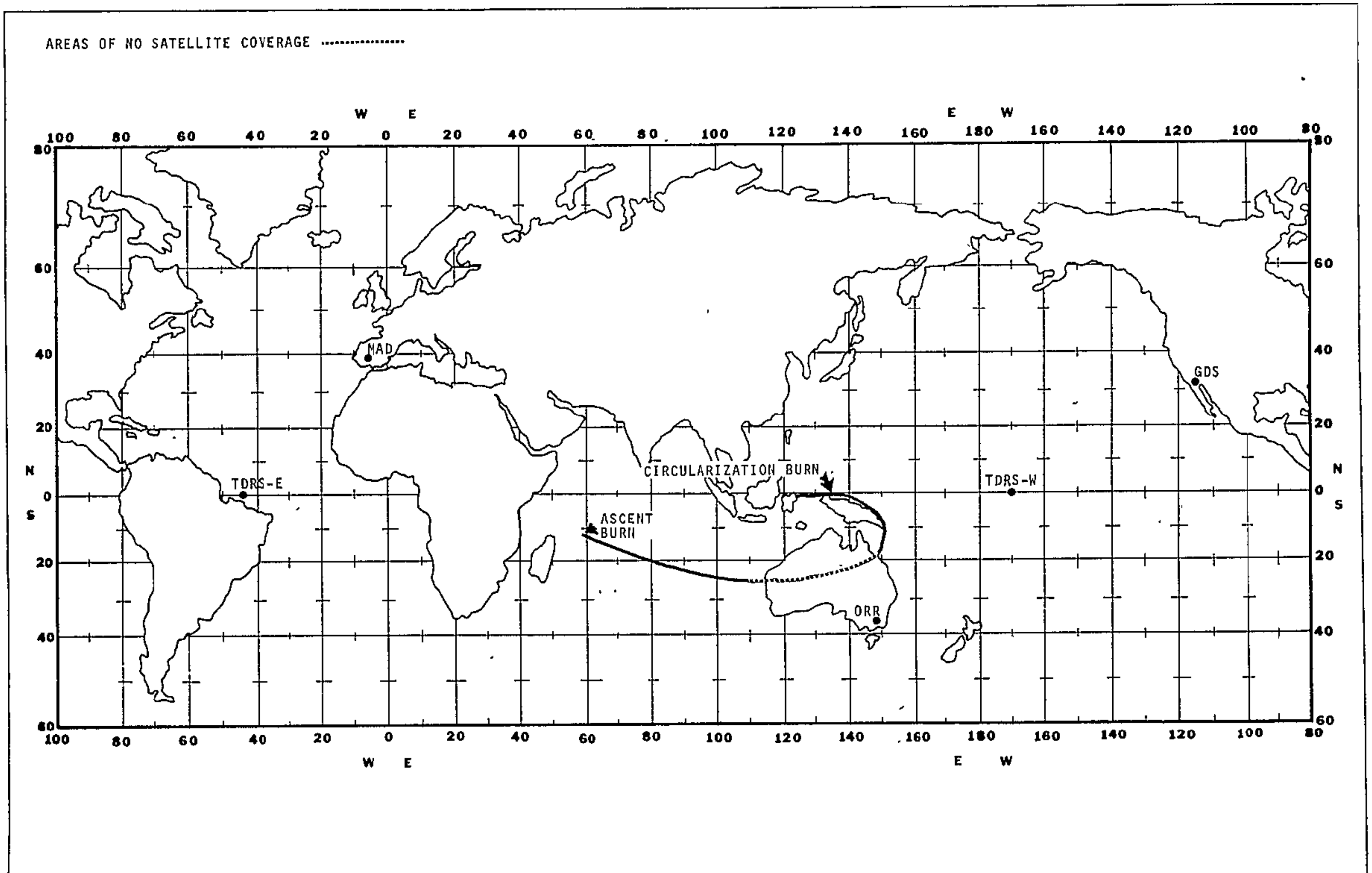


Figure 9.1.2-3. EIUS Geosynchronous - TDRS Only Case

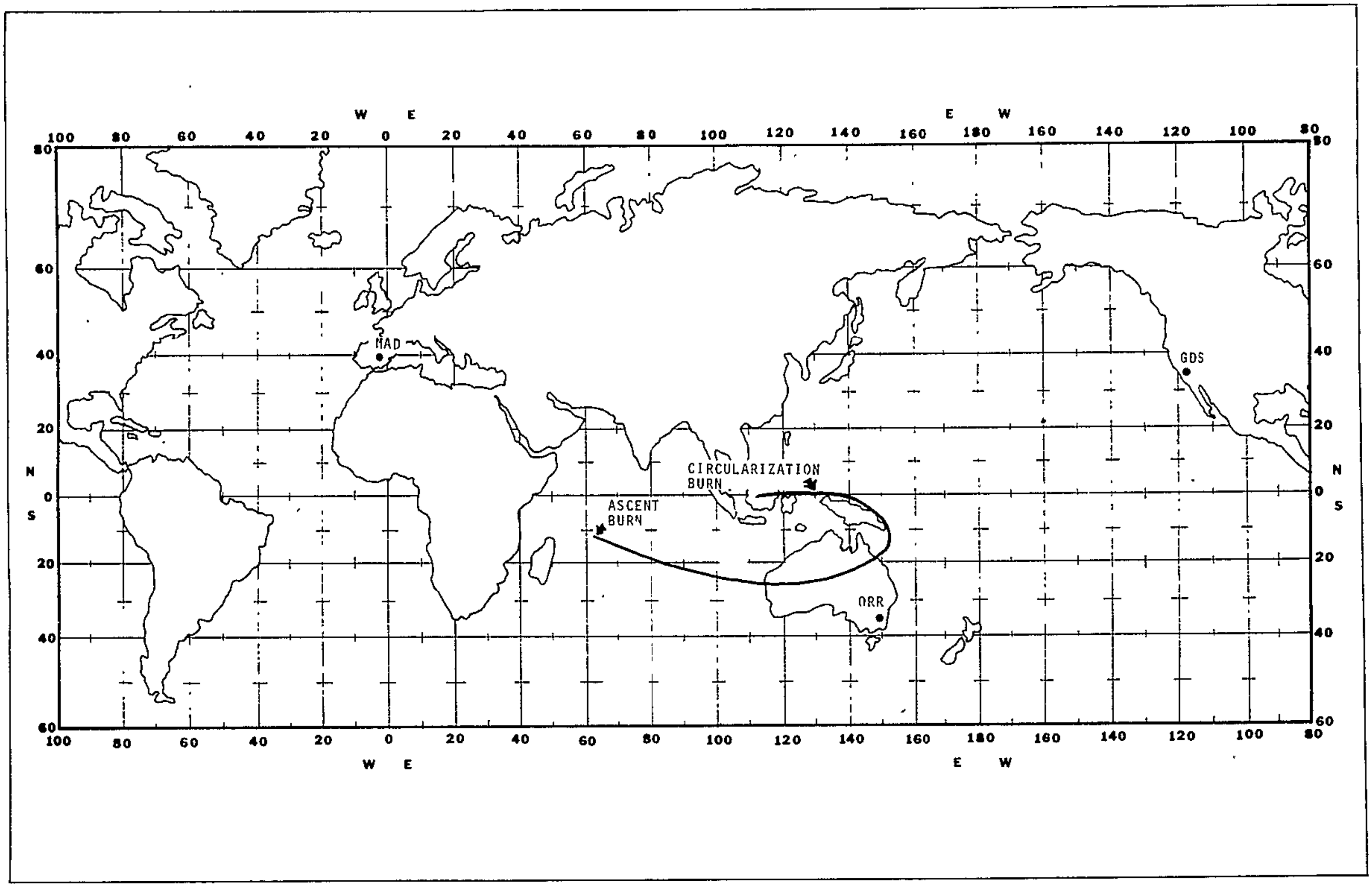


Figure 9.1.2-4. EIUS Geosynchronous - STDN Only Case

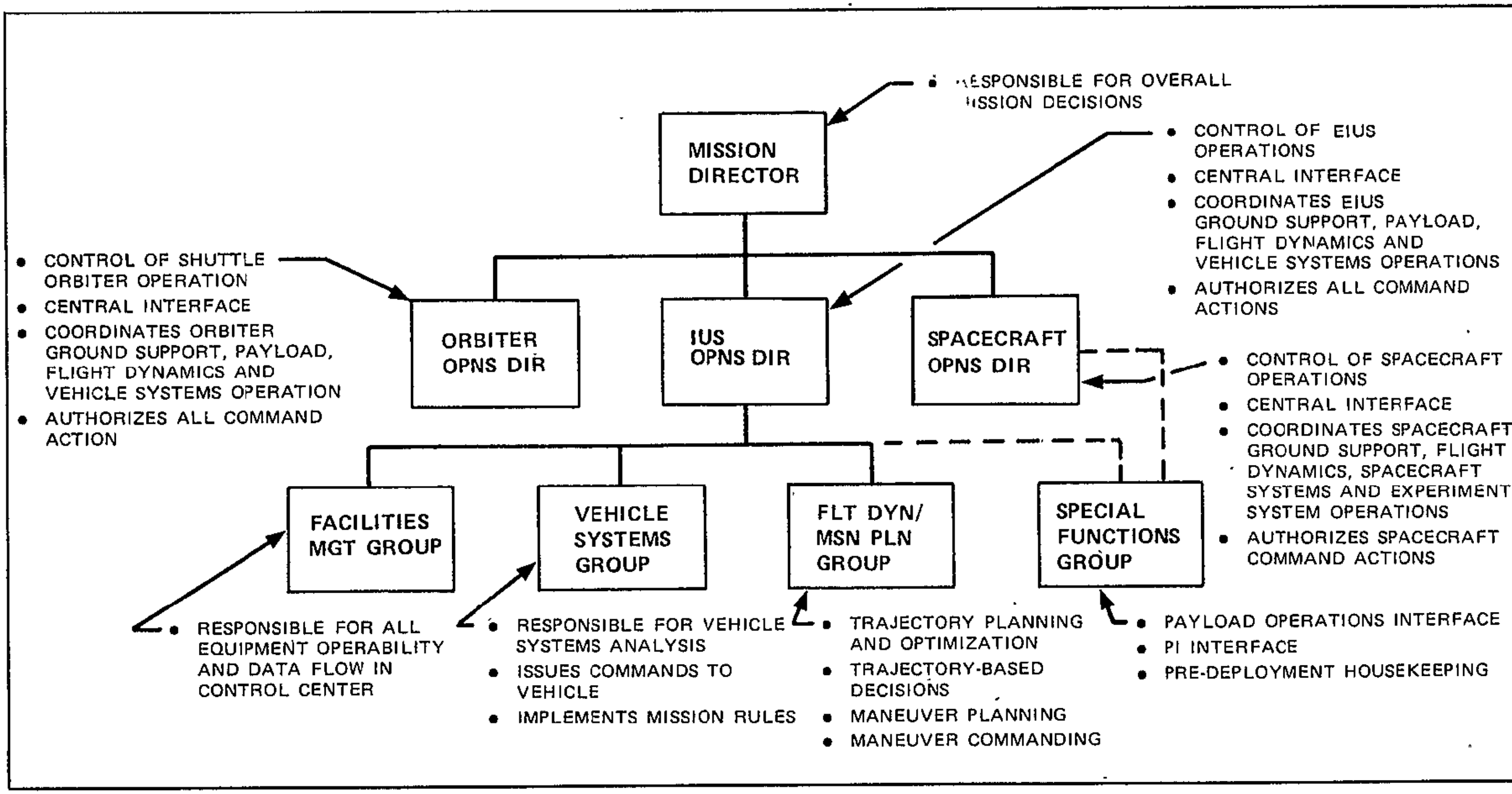


Figure 9.2.0-1. IUS Mission Control Organization

9.2.1 Flight Control Organization

The flight control organization begins at the second tier of the mission control organization.

During operational periods the IUS Operations Director assumes total authority over all control center functions, including the Facilities Management group. During non-operational times, the Facilities Supervisor directs the support personnel. This report is concerned only with the operational relationships.

The Flight Control Group is responsible for the IUS vehicle and the successful accomplishment of its mission. It is divided into three teams: Vehicle Systems, Flight Dynamics, and Special Functions. The Facilities Management group operationally reports to the IUS Operations Director but assumes a support, not control activity. Personnel manning the positions in the Flight Control Group will be experienced engineering personnel with corresponding design and test responsibility for the IUS system which they monitor and control.

Flight Control personnel are responsible for the real-time control of the IUS. Preparation for these responsibilities requires extensive study and Control Center "on-console" traning for each mission. Backup personnel must also be equally prepared to assure timely and qualified flight support continuation in contingency situations. Flight controllers must be completely abreast of IUS vehicle systems, the IUS Control Center data display, command system and all details concerning the specific mission being flown.

The basic responsibilities of each team position are listed below:

Vehicle Systems Group - The Vehicle Systems Group, reporting to the Vehicle Systems Engineer, monitors real-time IUS data and maintains cognizance of the IUS operational status. The team is functionally divided into four areas of vehicle responsibility: propulsion, avionics, networks, and communications.

Flight Dynamics/Mission Planning Group - The Flight Dynamics Group, reporting to the Flight Dynamics Engineer, is responsible for IUS vehicle trajectory management. This entails the continual comparison of predicted, actual and desired vehicle trajectory and the generation of corrective maneuver seq-ences. Functional divisions of the group are Guidance, Dynamics and Data Selection.

Special Functions Group - The Special Functions Group is responsible for monitoring Spacecraft status and most activity during deployment operations. It is probable that Special Functions Group personnel will vary with the type of Spacecraft being serviced.

9.2.2 Facilities Management Organization

The Facilities Management Group is composed of three teams, Data Systems, Maintenance and Operations and Software Support. These teams insure and are responsible for control center readiness and operational integrity. These teams report directly to the Facilities Supervisor during mission operations.

The Facilities Management Group assists the Flight Control Group with commands, communications, and displays, and maintains and operates all equipment within the facility. This team also provides logistic support for continuous control center operation. The Software Support Team operational responsibility requires a continual availability of personnel capable of explaining and/or handling software related problems.

9.2.2.1 Organization and Reporting Responsibility

Figure 9.2.2-1 presents the Facilities Management Group organization. The organization is functionally divided into three groups: Data Systems, Maintenance and Operations, and Software Support. Division is along functional lines, although there is overlap between all three groups.

The leader of the Facilities Management group is known by two titles, used interchangeably; as the Flight Support Director or as the Facilities Supervisor. This is indicative of the dual role he has in mission operations. During the real-time period, he reports to the Flight Director and is responsible for overall support to the Flight Control personnel. During non-real-time operations, he supervises the maintenance and checkout of the facility equipment. In both roles, the Data Systems, Maintenance and Operations and Software Support teams report administratively to him.

The Data System Supervisor oversees the activities of the Command, Telemetry and Site Select Technicians.

The Maintenance and Operations Supervisor oversees the activities of the computer operators, computer monitors, data flow technician, data processing engineer, voice technician and display technician.

The Software Support Supervisor heads a team of specialists who are knowledgeable in the mission profile, vehicle systems, executive/control center, and simulation software. These personnel provide expertise during real-time operations to resolve software-related problems, and provide update and mission-peculiar software modifications during non-real-time periods.

9.2.2.2 Data System Support Group Responsibilities

The Data Systems Group is composed of personnel who are actively involved in operating the support systems in real-time. These personnel interface between the flight control personnel and the support equipment, acting as aides and assistants to the flight control personnel. They occupy the same functional relationship to the flight controllers as an aircrew does to a pilot. They are operators, as opposed to maintenance personnel, who interpret data in support of flight controllers.

There are three subdivisions under Data Systems: telemetry, command and site select.

It is the responsibility of the telemetry technician to monitor telemetry data flow status and to initiate any corrective actions required to maintain telemetry data flow throughput to the flight control consoles. The telemetry technicians will operationally respond to any flight controller's request for telemetry readouts (e.g., bit circuit, calibration data, bit-error rate, etc.), and to the Facilities Supervisor through the Data Systems Supervisor.

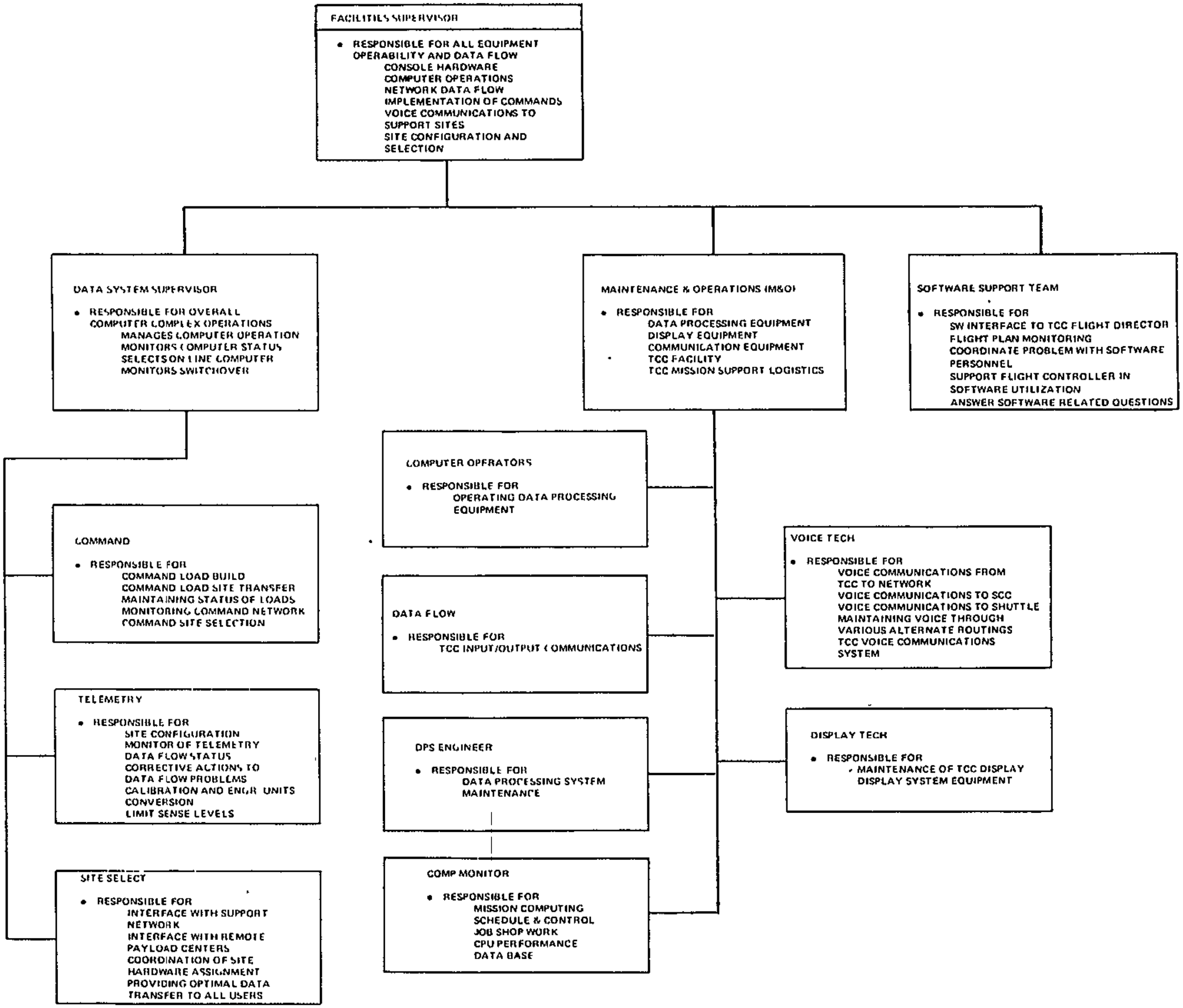


Figure 9.2.2-1. Facilities Management Group Organization

The command technician is responsible for the construction of command loads in the appropriate format for uplink, the transfer of that load into an uplink data buffer, and monitoring the uplink and verification-of-receipt of the command. The command technician also must track down the sources of errors in the command data flow system, and cause corrective action to be initiated. The command technician responds to any flight controller having a command panel and to the Facilities Supervisor through the Data Systems Supervisor.

The site select technician is responsible for interface between the IUS Control Center and the support network (TDRS and STDN). He will coordinate the selection of the appropriate site to receive telemetry or to uplink commands to the IUS. He is further responsible for checking the operational status at each site and for planning backup or alternate routings for the data connections with the IUS. He is responsible for providing optimum data transfer between the IUS and the Mission Control Center. The site select technician reports to the Data Systems Supervisor, and has no direct contact with the flight controllers.

The Data Systems Supervisor is responsible for overall operation of the data systems supporting the flight controllers. He manages the computer operation, monitors computer status, selects the on-line CPU and monitors switchover. In addition, he has organizational responsibility for the performance of the telemetry technician, command technician and site select technician.

9.2.2.3 Maintenance and Operations Group Responsibilities

The Maintenance and Operations (M&O) Group is composed primarily of equipment maintenance specialists who are responsible for the operability of all Mission Control Center support equipment.

The M&O personnel have no direct interface with the flight controllers in the operational sense, but must be responsive in real-time to requests to fix the equipment. In the pre-mission non-operational phases, the M&O technicians must perform periodic maintenance on the equipment and conduct proof-of-performmance tests of equipment operation. During operational periods, the M&O technicians monitor equipment operation, and are alert to malfunction indications. They will notify the M&O Supervisor when equipment must come off-line for repair, and will coordinate equipment configuration with the Data Systems Technicians.

Computer operators operate the data processing equipment associated with real-time flight control operations, and are responsive to requests from the Data System technicians. They are administratively responsible to the Maintenance and Operations Supervisor.

The computer monitors are responsible for mission computing, scheduling and control of non-mission job-shop work, CPU performance and maintaining of the system data base. Computer monitors and computer operators function interactively to maintain the data processing equipment configuration at peak efficiency. The computer monitors report administratively to the M&O Supervisor.

The Data Processing System Engineer is responsible for the maintenance of the data system CPU and peripherals. This function is best performed by a maintenance contractor which will provide a DPS engineer to NASA who will respond as a member of the Flight Support Team, Maintenance and Operations group. This function requires highly specialized skills and training normally available only from the Data Processing System manufacturer. During operational periods, the DPS engineer reports functionally to the M&O Supervisor. During non-mission periods, he executes the requirements of a Data System Maintenance Contract.

The Data Flow Technician is responsible for all equipment interfacing between the data system and the outside world. This will include all MODEMS and line termination equipment which interface with the network. During operational periods, he will monitor the equipment performance and select the terminals having best operational characteristics. During non-operational periods, he will perform periodic maintenance and conduct proof-of-performance tests on the equipment. He reports administratively to the M&O Supervisor.

The Display Technician is responsible for maintaining the equipment which interfaces with the flight control personnel; consoles, console displays and group displays. During operational periods he monitors the operation of the equipment and stands-by to execute immediate replacement or repair of the equipment. During non-operational periods, he will perform periodic maintenance and conduct proof-of-performance tests. The Display Technician directly interfaces with and is responsive to direction from the flight control personnel in real-time, and reports administratively to the M&O Supervisor.

The Voice Technician is responsible for all voice communications internal to the control center, and for all voice communication with external operational entities. He is the primary interface with the common commercial carriers which provide communications service to the Mission Control Center. The Voice Technician maintains all communications loops in operational configuration, and reports both functionally and administratively to the M&O Supervisor.

9.2.2.4 Software Support Group Responsibilities

The software support team will consist of high-level software personnel who are functionally familiar with the overall software and its capabilities. Because the software is the critical element in achieving the Mission objectives, the software support team must be able to respond rapidly to software-related questions and actively participate with flight support group team members in the effective utilization of the software capabilities.

The software support supervisor will be responsible for the continuous software support and development activities after intial delivery of the software system. He will provide the interfaces with NASA and contractor personnel for all software-related functions. To provide the necessary interfaces, he will have a staff of software/hardware systems personnel to perform the following functions:

- Software Reviews
- Configuration Control
- Software Audits
- Continuing Customer Interfaces
- Project Status Reporting (Costs and Schedules)
- Document Control

A software development section will be responsible for the control updating of the software to support changing requirements. Previous space programs of long duration, such as Apollo, have shown that the software within the control center will continue to evolve throughout the lifetime of the program. The RTCC software, for instance, grew in size by a factor of 50 percent over the lifetime of the Apollo program. This growth was distributed among all the elements of the software.

To address the requirements for continual software change, the software development activity has been organized according to the functional software requirement areas:

- Mission Profile
- Vehicle Systems
- Executive/Control Center Support
- Simulation and Training

Mission Profiles - The mission profile group will be responsible for maintenance and support of the software which addresses the mission profile function. These software elements are:

- Orbit Trajectory Determination
- Orbit Trajectory Computations
- Mission Planning

Vehicle Systems - The vehicle systems group will be responsible for maintenance and support of the uplink and downlink processing software.

Executive/Control Center Support - The executive/control center support areas of the control center software will be highly volatile because of the changing display requirements and response time changes as a result of mission changes and vehicle changes. This support group will maintain and support all changes to these areas.

Simulation and Training - The simulation and training software group will be responsible for modifications of the simulation software system which reflect changes in mission profiles and vehicle configuration. In addition, this group will conduct training sessions in software capabilities for the flight support group and will support the use of the simulation system during ground controller training.

The central computers of the control center will be utilized for real-time mission support, training of flight support personnel, software development, and normal jobshop operations. It is assumed that for cost effectiveness, the computer operations will be three shift/day, seven day a week operations.

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9.2.3 Recommended Manning Level

The following paragraphs describe the recommended manning levels for IUS operations. Major divisions in manning are (1) Facilities Maintenance or Flight Support Staff and (2) Flight Control Staff.

9.2.3.1 Facilities Maintenance or Flight Support Staff

There are 30 personnel required to staff the Facilities Maintenance or Flight Support organization on a continuing basis. Table 9.2.3-1 presents a breakdown of the staff requirements.

The size of the staff is established by the real-time support requirements. However, the staff, during non-mission and non-training periods, is to be utilized to perform mission preparations and maintenance jobs. This multiplexing of personnel is cost-effective in that it spreads the productive work load of the permanently assigned personnel more evenly across the operational periods.

Table 9.2.3-1. Flight Support Staff Requirements

POSITION	MAX MANNING	NUM OF CONSOLES	SHIFT DENSITY	TOTAL REQ.
FLIGHT SUPPORT GROUP				
FLIGHT SUPPORT DIRECTOR	1	1	2	2
DATA SYSTEM SUPERVISOR	1	1	2	2
COMMAND	1	0	2	2
TELEMETRY	1	1	2	2
SITE SELECT	1	0	2	2
MAINTENANCE AND OPERATIONS	1	1	2	2
DATA FLOW	1	1	2	2
DPS ENGINEER	1	0	2	2
VOICE TECH	1	0	2	2
DISPLAY TECH	1	0	2	2
COMPUTER SYSTEM MONITORS	2	1	2	4
COMPUTER OPERATIONS	2	0	2	4
COMPUTER SUPPORT	2	0	1	2
TOTALS	16	6	25	30

9.2.3.2 Flight Control Staff

There is a specific minimum staff required to control the IUS vehicle during mission operational periods. For the IUS program, that staff requirement is 30 flight control engineers. The flight control organization is a required sustaining engineering staff which may be utilized during non-mission periods in performing preparation tasks, such as training, scheduling, and interface type operations. As with the flight support staff, the spreading of effort across the period of operations is a cost-effective utilization of the flight control staff. Table 9.2.3-2 presents the flight control staff requirements.

Table 9.2.3-2. Flight Control Staff Requirements

POSITION	MAX MANNING	NUM OF CONSOLES	SHIFT DENSITY	TOTAL REQ.
FLIGHT CONTROL GROUP				
TUG OPERATIONS DIRECTOR	1	1	2	2
VEHICLE SYSTEMS ENGINEER	1	1	2	2
PROPULSION	1	1	2	2
STAGE SYSTEMS	1	1	2	2
CONSUMABLES	1	0	2	2
NETWORKS	1	1	2	2
COMMUNICATIONS	1	0	2	2
AVIONICS	1	1	2	2
GUID. AND NAV.	1	0	2	2
SEQUENCE	1	0	2	2
GUIDANCE	1	1	2	2
DYNAMICS	1	1	2	2
DATA SELECTION	1	1	2	2
FLIGHT DYNAMICS OFFICER	1	1	2	2
SPECIAL FUNCTIONS	1	1	2	2
TOTALS	15	11	30	30

9.2.3.3 Derivation of Manning Requirements

Before arriving at an estimate of recurring cost, it was necessary to investigate the impact of simultaneous missions and mission module overlaps on the level of support required.

To accomplish this impact analysis, IBM developed a mission density factor program. This program creates a launch schedule and mission module timing schedule for which the overlap of missions and mission modules is developed. At the same time, gaps in the schedule are identified which can be used for training and simulation tasks.

Outputs from the mission density factor drive the following dependent cost relationships.

- Computer Support Personnel - Establishes the hours the computer is committed.
- Sustaining Flight Control - Establishes the number of shifts required and the number of personnel required.
- Flight Support Personnel - Establishes the number of shifts required and the number of personnel required.
- Flight Control Consoles - Establishes the number of consoles required by type.
- Network Rental - Establishes the number of hours required in one year of TM, Command and Tracking Service

9.2.3.4 Sustaining Support Personnel

The mission density function establishes the computer commit hours per year, which then is converted to equivalent men required to provide computer support.

The mission density function also establishes the shift density factor for flight support personnel. The level of effort established for flight support is constant. No provision has been made to assign other duties to the flight support staff.

The mission density function provides a shift density factor and console multiplier which are combined to create a manpower requirement estimate. The level of effort established for flight control support is constant. No provision has been made to assign other duties to the flight control staff.

9.2.3.5 Ground Software Maintenance

Since software problems will be identified throughout the entire software module set, it is necessary to provide resident personnel familiar with every area. The number of personnel required is dependent upon the size, complexity, criticality and level of mission-to-mission changes for the program. Twenty-five programmers have been estimated as required to perform the ground software maintenance.

9.2.3.6 Flight Software Maintenance

Flight software maintenance is similar to ground software maintenance in concept. It is necessary to maintain a staff of personnel who are familiar with each of the four basic programs, and to maintain capability to define, code and verify the flight programs. Twenty-one programmers are required to supply mission modifications, coding and verification for the four baseline programs.

9.3 FLIGHT CONTROL FUNCTIONAL REQUIREMENTS

The following paragraphs define the nominal and contingency functions of the Flight Control Organization.

9.3.1 Vehicle Systems Group

The vehicle systems group is required for EIUS mission control. The vehicle system group is formed of a leader and four subordinate organizations. The leader, the Vehicle System Engineer, is responsible for all vehicle systems, and will coordinate the analysis of vehicle systems and issues all commands to the vehicle which are directly related to hardware functions, as opposed to trajectory shaping functions. The vehicle systems engineer is a primary consultant and recommends implementation of mission rules based upon the state of affairs at a given time during the mission.

Reporting to the Vehicle System Engineer is the propulsion group, which is responsible for the main propulsion system, the attitude control propulsion system, pneumatics, propellant tank management, main engine performance and main engine support devices, maintaining knowledge of consumables utilization, structures and thermal control considerations.

The second major division under the vehicle systems group is the avionics support team. The avionics support team is responsible for the analysis of all hardware relevant to the guidance, navigation and control system and the attitude and thrust vector control systems. Two suborganizations beneath the avionics organization are the Guidance and Navigation Engineer and the Sequential Systems Engineer with the primary division between those two being between sensor hardware and computational hardware analysis.

The third breakdown beneath the vehicle system engineer is the network responsibility. All functions relevant to the electrical power capability, battery charge, and electrical loads are the responsibility of the Networks System Engineer.

The fourth subdivision is the Communications System Engineer. This engineer is responsible for maintaining cognizance of the status of the communications systems for uplink, downlink, and tracking functions. Additionally, he is responsible for the generation of commands and the coordination of uplink requirements with the network. He maintains cognizance over the signal conditioning, multiplexers, transducers, and RF components of the telemetry systems.

Figure 9.3.1-1 presents the vehicle systems group organization.

9.3.2 Flight Dynamics and Mission Planning Group

The flight dynamics and mission planning organization is concerned, in the pre-mission period, with the structure and generation of the optimum mission trajectory based upon the Payload, Orbiter and EIUS operational constraints. In real-time the flight dynamics organization is responsible for trajectory planning and shapeing, all decisions based upon trajectory considerations, planning of maneuvers, commanding maneuvers, plus maintaining knowledge of the Orbiter and EIUS ephemerides.

Figure 9.3.2-1 presents the Flight Dynamics and Mission Planning Organization. There are three basic subdivisions beneath the flight dynamics organization: Guidance, Dynamics and Data Selection. The Guidance engineer is responsible for monitoring vehicle performance during guidance phases, the analysis of drift in references, the optimization of corrective maneuver, the recommendation of command action to accomplish those maneuvers, and the selection of the optimum guidance scheme for a particular mission maneuver. The Dynamics engineer is responsible for maintaining knowledge of vehicle mass characteristics, the monitoring of the trajectory, and the overseeing of the trajectory computations which result in the ephemeris tables for the EIUS and Orbiter. The Data Select engineer is responsible for insuring the validity of tracking information, monitoring the smoothing, differential corrections and weighting factors pertinent to the construction of the trajectory, the selection of a tracking site and/or the monitoring of the TDRS range and range rate information, coordination of site hand-over and providing assistance to the network in assuring that the appropriate tracking information is available to the EIUS Operations Control Center as needed.

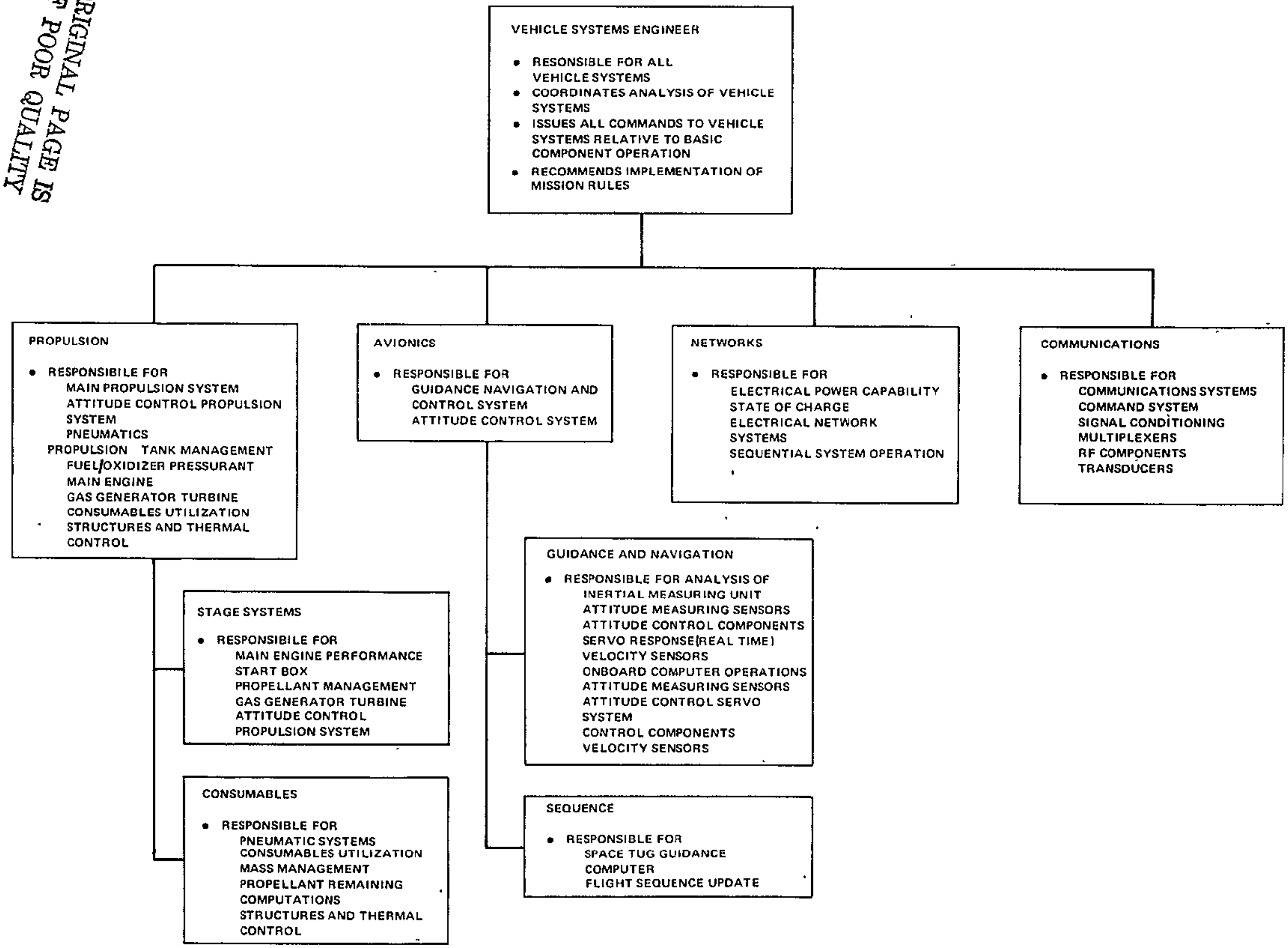

Figure 9.3.1-1. Vehicle Systems Group Organization

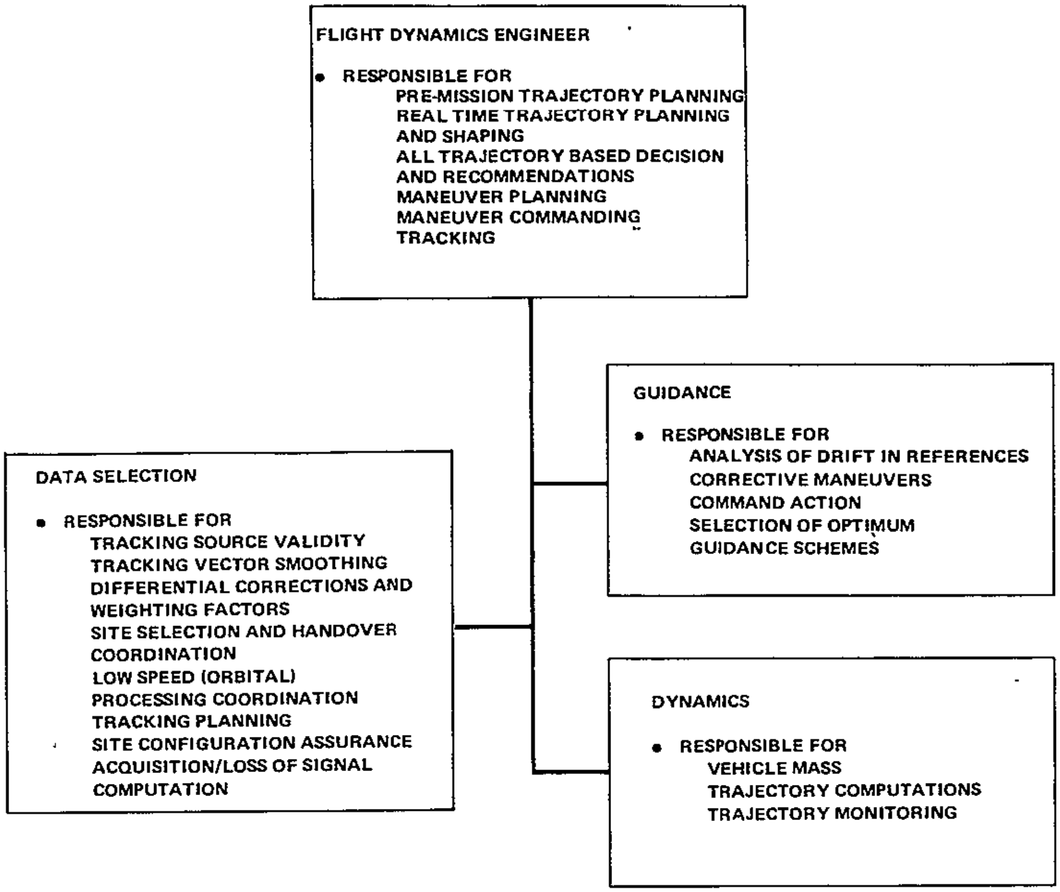

Figure 9.3.2-1. Flight Dynamics and Mission Planning Organization

9.3.3 Special Functions Group

Provision has been made for a "Special Function" group to be incorporated into the basic IUS operations organization in order to accommodate experiment packages or unique Spacecraft missions that may require additional specialists for specific functions. Figure 9.3.3-1 shows the Special Functions group organization.

The one permanent member of the Special Function group is the Special Functions engineer who will be responsible for all payload operations from predeployment monitoring and housekeeping through interface with the principal investigator.

9.3.4 Facilities Management Group

The Facilities Management Group (reference Figure 9.2.2-1) is responsible for providing the necessary data, command and network configuration coordination required to support the EIUS mission. All scheduling interfaces with the network operations will be conducted by this team. Additionally, all hardware and software maintenance required in the EIUS control center will be provided by the facility management group.

There are three basic organizational entities reporting to the facilities management supervisor. Those organizations are the data system subgroup, the maintenance and operations subgroup and the software support team.

The data system supervisor has three groups reporting to him; a command group, a telemetry group, and a site select group. The data system supervisor collectively has responsibility for overall operation of the computer complex and is responsible for telemetry, tracking and command interface with the support network.

The maintenance and operations organization is responsible for the operability of the data processing and display equipment, communications equipment, the overall facility capabilities and the mission support logistics. The maintenance and operations supervisor has reporting to him seven specialists: computer operators, a data flow specialist, a data processing system maintenance engineer, a computer monitor, display technician, and voice technician.

The software support team is responsible for maintaining the support software in an operable condition, coordinating the problems with the flight director as required and for answering of all software related questions, including operational utilization of the software by the flight controllers.

9.3.5 Ground Software Support Group

It is reasonable to assume that there will be changes from mission to mission in the IUS Control Center software. To effect these changes, a Software Support Group will be required. This organization is depicted in Figure 9.3.5-1 and will be discussed in the following paragraphs.

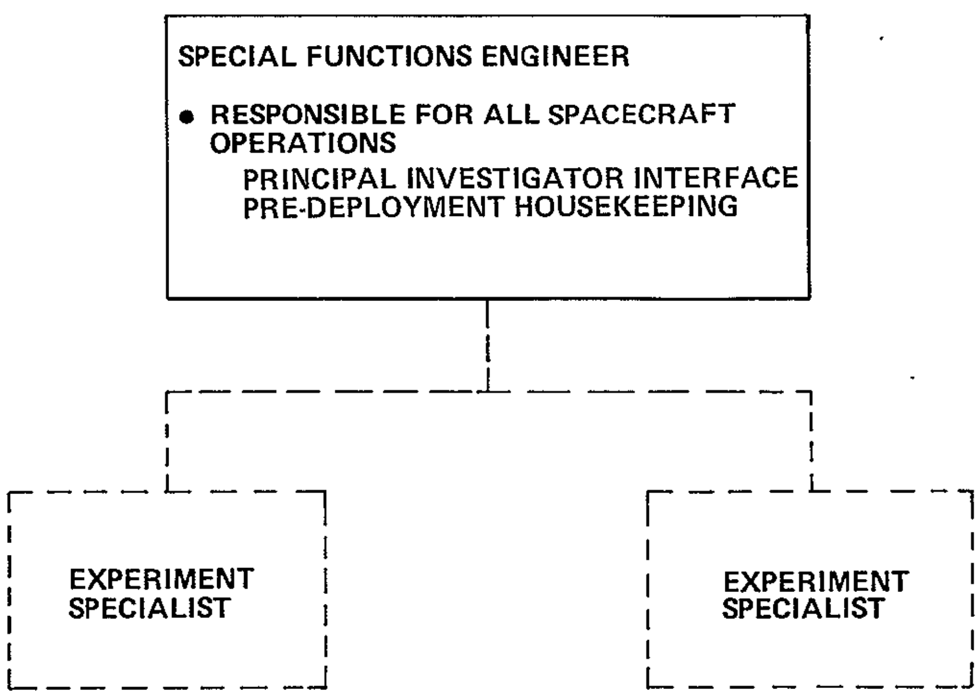

Figure 9.3.3-1. Special Functions Group

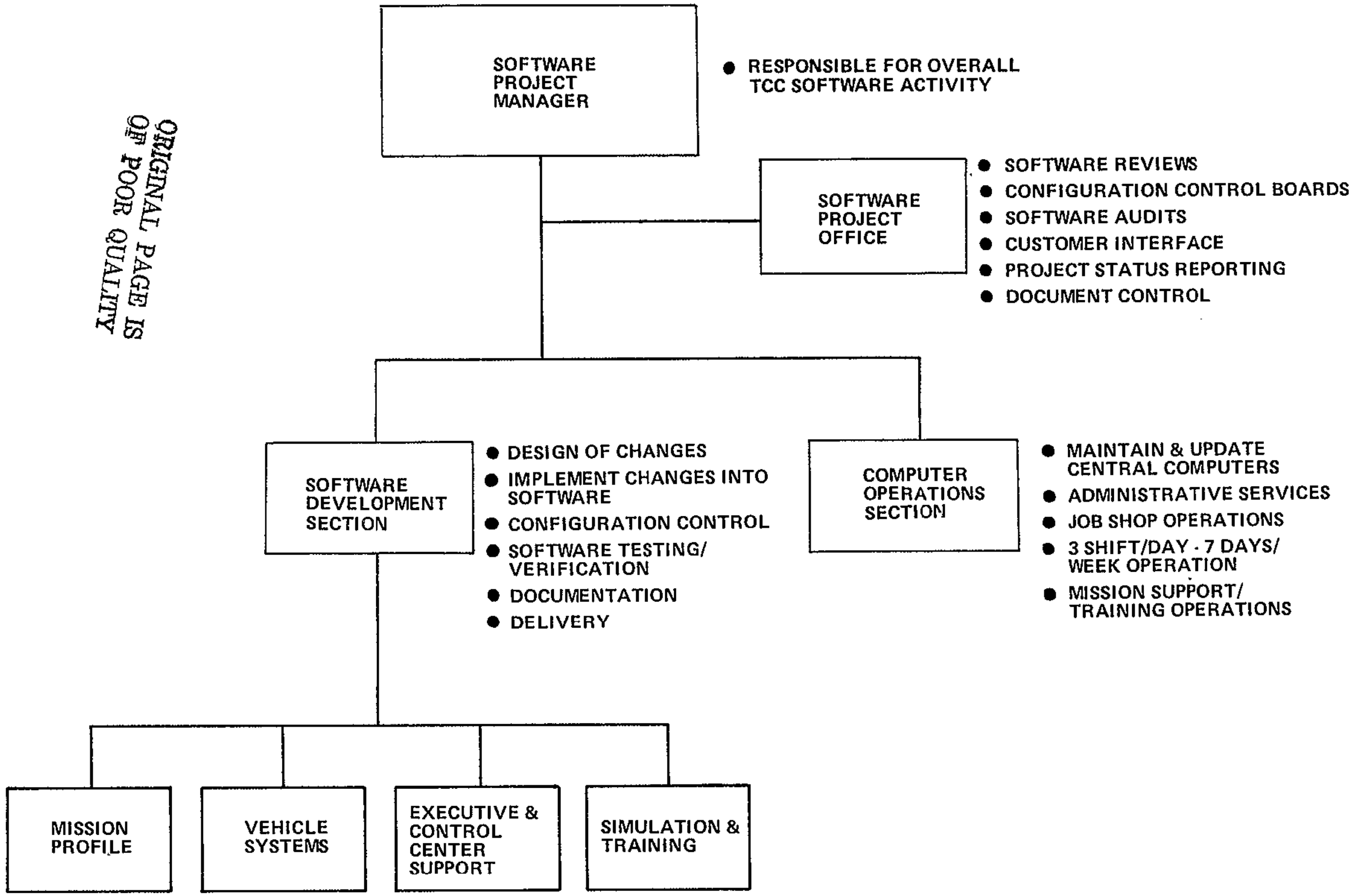

Figure 9.3.5-1. Software Support Group

9.3.5.1 Project Manager/Project Office

The software project manager will be responsible for the continuous software support and development activities after initial delivery of the software system. He will provide the interfaces with NASA and other contractor personnel within the control center for all control center software-related functions. To provide the necessary interfaces, he will have a project office staff of five software/hardware systems personnel to perform the following functions:

- Software Review
- Configuration Control
- Software Audits
- Continuing Customer Interfaces
- Project Status Reporting (Costs and Schedules)
- Document Control

9.3.5.2 Software Development Section

The software development section will be responsible for the continual updating of the software to support changing requirements. Previous space programs of long duration, such as Apollo, have shown that the software within the control center will continue to evolve throughout the lifetime of the program. The RTCC software, for instance, grew in size by a factor of 50 percent over the lifetime of the Apollo program. This growth was distributed among all the elements of the software.

To address the requirements for continual software change, the software development activity has been organized according to the functional software requirement areas. As shown in Figure 9.3.5-1, these areas are:

- Mission Profile
- Vehicle Systems
- Executive/Control Center Support
- Simulation and Training

9.3.5.3 Mission Profile

The mission profile area will be responsible for maintenance and support of the software which addresses the mission profile function. These software elements are:

- Orbit Trajectory Determination
- Orbit Trajectory Computations
- Mission Planning

9.3.5.4 Vehicle Systems

The vehicle systems group will be responsible for maintenance and support of the uplink and downlink processing software of the IUS Control Center.

9.3.5.5 Executive/Control Center Support

The executive/control center support areas of the software will be highly volatile because of the changing display requirements and response time changes as a result of mission changes and vehicle changes. This support group will maintain and support all changes to these areas.

9.3.5.6 Simulation and Training

The simulation and training software group will be responsible for modifications of the simulation software system which reflect changes in mission profiles and IUS vehicle configuration. In addition, this group will conduct training sessions in software capabilities for the flight support group and will support the use of the simulation system during flight controller training.

9.3.5.7 Computer Operations Section

The central computers of the control center will be utilized for real-time mission support, training of flight support personnel, software development, and normal jobshop operations. It is assumed that for cost effectiveness, the computer operations will be three shift/day, seven day a week operations, and is staffed accordingly. Included within this section are keypunch services, tape librarians, administration personnel, management personnel, customer engineers, as well as the computer operations personnel.

9.4 ORBITER CREW FUNCTIONAL REQUIREMENTS

There is minimal IUS operations interface with the Orbiter Crew. What interaction exists, is, for the most part, monitoring of caution and warning parameters, and stand-by to back-up critical sequences in the event of contingency situations.

9.5 OPERATIONS SUPPORT REQUIREMENTS

This section summarizes the hardware, software, and data system required to support real-time IUS flight operations.

9.5.1 Airborne Operations Support Hardware

The IUS Avionics System has the dominant impact upon mission operations. The implementation of control decisions can be shifted between the onboard avionics and the ground based electronics. This shift is a function of the level of autonomy to which the IUS is designed.

In general, the shift of control authority to the onboard system is desirable, since the implementation of any control of the ground carries with it a heavy overhead for transfer of data from the vehicle relative to its physical conditions to a ground based information assimilator. This overhead (tracking, telemetry, command, etc.) contributes nothing to the decision processes.

Figure 9.5.1-1 presents the IUS level B avionics system, which houses the airborne operations support hardware.

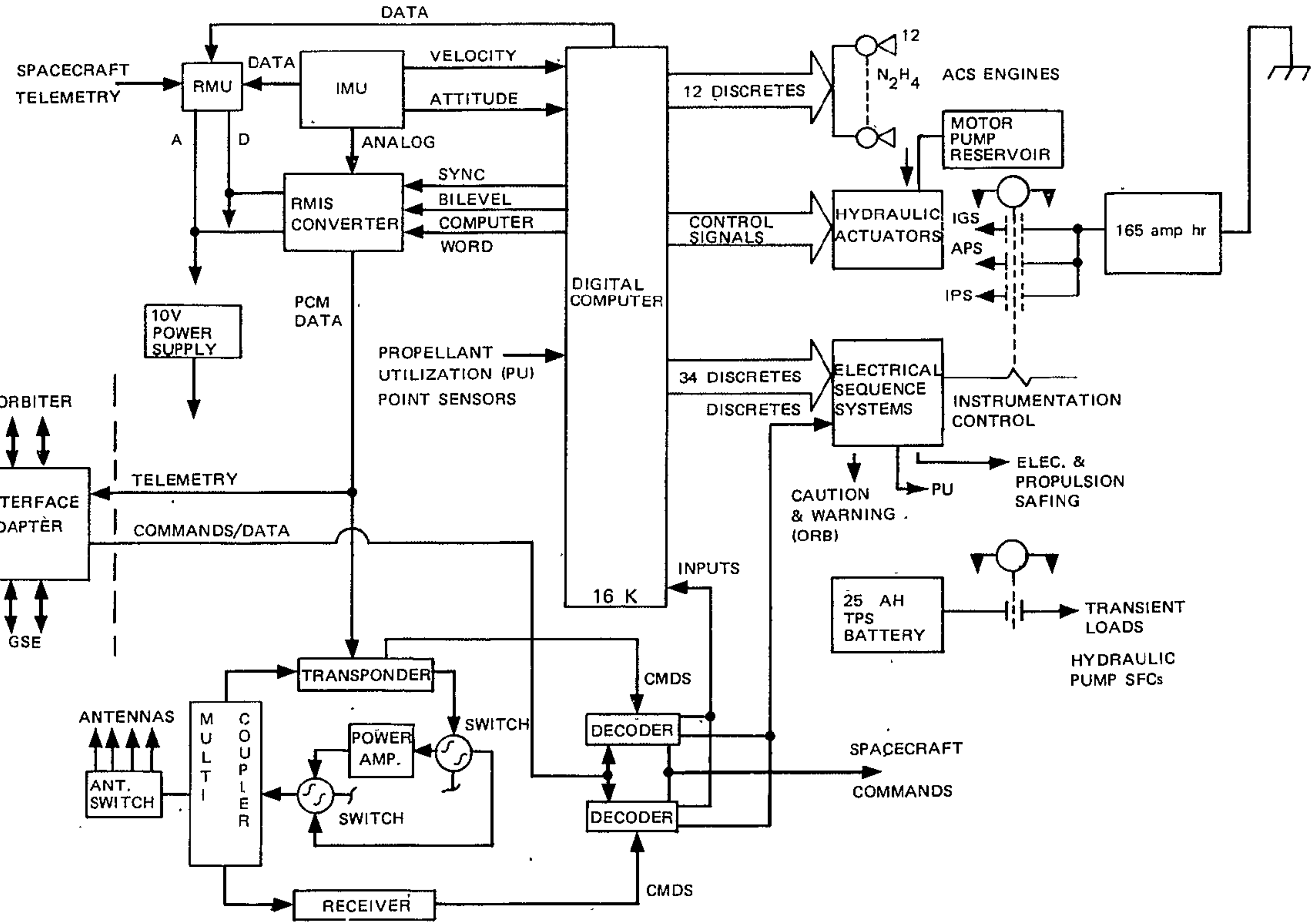

Figure 9.5.1-1. Expendable IUS Level B Avionics Configuration

The baseline EIUS used for the IBM analysis and costing is a representative vehicle modified to accomplish the EIUS mission. The EIUS avionics are basically simple and designed for a short duration mission. The major addition is the STDN/Orbiter compatible communications, with minor mods for the sequencing, RMIS converter, and software. Interface provisions for the Orbiter have also been provided.

The digital computer with a 16K, 24 bit storage provides the onboard computation capability. The IMU provides an inertial reference system and the computer provides the control signals for the hydralics and the sequencing for the ACS engines and electrical systems. Two batteries provide the onboard power requirements. Telemetry is collected by the remote multiplex unit (RMU) and formatted by the RMIS. The communications provide tracking, telemetry and command interface with the ground and Orbiter.

The interface adapter contains the provisions for making the EIUS external interface compatible with the Orbiter and GSE. The EIUS command decoders also contain additional provisions for computer inputs, Spacecraft commands and EIUS sequencing. Spacecraft telemetry could be integrated with EIUS telemetry by inputs to the EIUS RMU's.

9.5.2 Ground Operations Support Hardware

The hardware analysis is divided into two parts; i.e., that utilized by the mission support staff (consoles, communication panels, etc.) and that required for the IUS Control Center Data System.

9.5.2.1 Data System

The data system in the IUS Control Center is the system by which incoming, outgoing, and intercenter intelligence is processed, routed and managed. The data system is depicted in Figure 9.5.2-1. The computer is the central element of the system, and because of its significance, it has been addressed separately. The remaining elements of the system are discussed in the following paragraphs.

Communications Controller - The communications controller is a device required for buffering and routing input and output data between the central computer and the data line terminations (MODEMS). Incoming telemetry and tracking data is checked for transmission errors, error encoding removed and then formatted for transfer to the central computer. Outgoing command data is received from the central computer, encoded into proper format and then transferred to outgoing transmission facilities. The unit is essentially a switch and storage facility for incoming and outgoing data.

Modulator/Demodulators (MODEM's) -MODEMS are devices required for interfacing with IUS Control Center transmission lines. These devices serve the function of modulation conversion between transmission line format and the computer system format for both incoming and outgoing information.

Master Clock - The master clock is an independent time source supplying master time (GMT) to the central computer system. The central computer will then generate the differential times needed for mission control. The master clock will also contain a receiver for synchronization of the master clock to the National Bureau of Standards master clock.

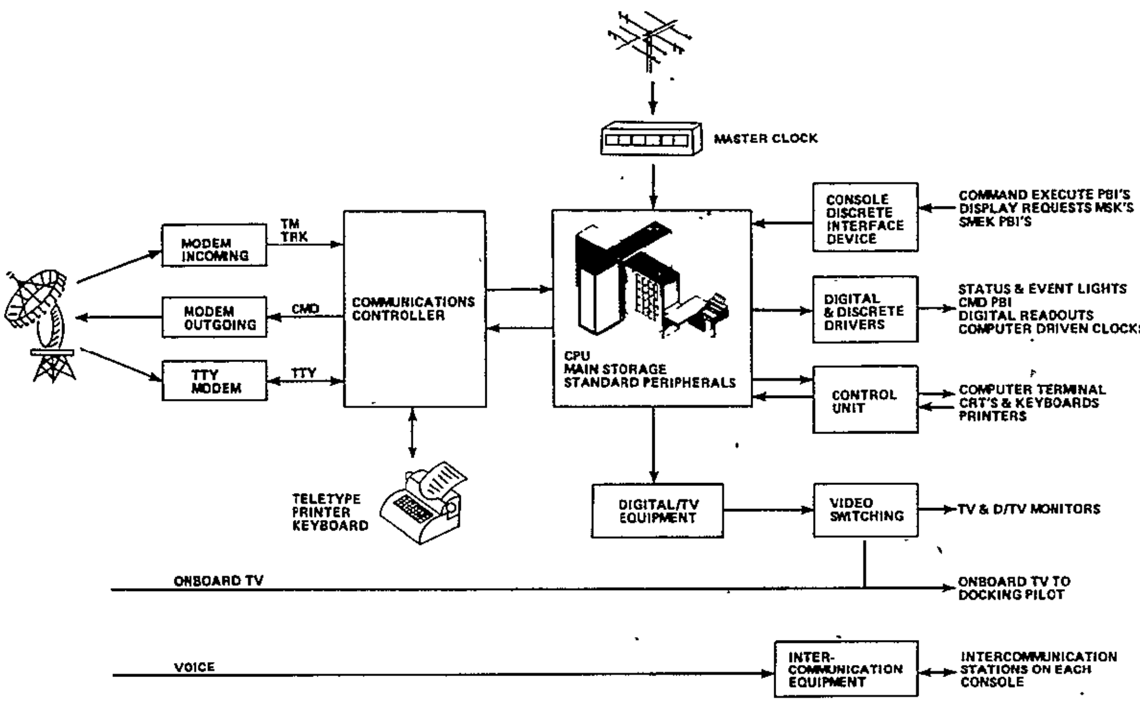

Figure 9.5.2-1. IUS.Control Center Data System Block Diagram

Console Discrete Interface Device - This unit serves as an interface between the central computer and the support staff consoles. It compiles discrete and digital signals into formats acceptable for use by the central computer. These signals include command execute pushbuttons, display request signals, computer control pushbuttons and miscellaneous computer control discretes. For IUS Control Center usage, this unit will be capable of processing approximately 1200 individual signals.

Digital and Discrete Drivers - The digital and discrete drivers are interface devices between the central computer and console displays which receive digital and discrete word outputs, de-multiplex these words and then drive individual lamps, readouts, etc. These drivers are required for all status and event lites, command pushbotton indication lites, digital readouts, and clock read-outs. For Control Center usage, the system will handle approximately 2000 individual discretes.

Digital TV Equipment - Digital TV Equipment (DTE) is required to convert computer generated display data into video and video associated signals compatible with the support staff console TV monitors. The DTE combines static background format data stored by the computer with the dynamic data being processed by the computer in real-time and formats the information for display on the TV monitors. Display refresh is performed by the DTE. Only updated information, that is, information which has changed since the last refresh cycle, is transferred from the computer to the DTE.

Video Switching Equipment - The Video Switching Equipment distributes Digital TV data from the computer to individual console TV monitors.

Computer Terminal Equipment - During an IUS mission, some of the communications between the support staff (particularly flight controllers) and the central computer can be conducted most efficiently using standard terminal equipment. These terminals consist of a Manual Entry Device (MED) and a CRT display. Nominally, one display control unit (interfacing unit to the computer) will be required for each combination of six of these terminals.

Teletype Printer/Keyboard (TTY) - A TTY Printer/Keyboard will be required in the Control Center for general administrative message receipt and generation.

Communication Equipment - This equipment provides voice communications throughout the Control Center and interfaces with external commercial/common carrier lines. For IUS/OC operation, a central switchboard will be required to provide the following:

- 30 internal loops
- 15 external connections
- 10 PABX stations

The PABX will be configured such that no more than five positions will have the same rotary number.

Computer Peripheral Equipment - The central computer will require standard peripheral equipment in addition to the Central Processor Unit (CPU) and memory. Standard peripheral devices such as tape drives, disc storage, channel control, line printer, card reader and interface adapters will be configured for Control Center support.

9.5.2.2 Support Staff Hardware Requirements

The mission support analysis discussed in this document delineates various positions and their responsibilities to support an IUS mission. To effect the support from these personnel will require a means whereby information can be made available to them for decision and action.

Dissemination of this information is achieved by displaying the information to the support staff in the form of TV displays, discrete light indicators, meters, etc. For convenience, pertinent indicators and computer driven TV displays are lodged in operator consoles according to the requirements of that position.

Table 9.5.2-1 summarizes the equipment necessary for each position to perform the required duties assigned to it.

9.5.3 Ground Operations Support Software

The IUS Control Center Software, which resides in the central computer, provides centralized processing of telemetry and radar inputs received from the ground network and performs other complex mathematical and logical functions in support of flight controllers. In addition, software will exit to: (1) provide a normal computer center jobshop environment when not supporting

Table 9.5.2-1. Flight Support and Flight Control Staff Equipment Allocation

POS NO	POSITION	MAXIMUM MANNING	CONSOLES	COMM PANEL	TV MONITORS	EVENT MODULES	SUMMARY MESSAGE KEYBOARD	COMMAND PANEL	TV DISPLAY CONTROL
	FLIGHT DIRECTOR	1	1	1	2	4	1		1
	VEHICLE SYSTEMS ENGINEER	1	1	1	2	4	1	1	1
	PROPULSION	1	1/2	1	1	2	1	1	1
	STAGE SYSTEMS	1	1/2	1	1	2			1
	SEQUENCE	1	1/2	1	1	2	1		
	CONSUMABLES	1	1/2	1	1	2			1
	NETWORKS	1	1/2	1	1	2	1		
	COMMUNICATIONS	1	1/2	1	1	2	1	1	
	AVIONICS	1	1/2	1	1	2	1		1
	GUIDANCE & NAVIGATION	1	1/2	1	1	2		1	
	FLIGHT DYNAMICS	1	1	1	2	4	1	1	1
	GUIDANCE	1	1	2	2	4	1		1
	DYNAMICS	1	1	2	2	4	1		1
	DATA SELECTION	1	1	2	2	4	1		1
	SPECIAL FUNCTIONS	1	1	1	2	4	1	1	1
								1	
	FLIGHT SUPPORT DIRECTOR	1	1	1	2	4	1	1	1
	DATA SYSTEM SUPERVISOR	1	1/2	1	1	2	1		1
	COMMAND	1	1/2	1	1	2		1	
	TELEMETRY	1	1/2	1	1	2	1		1
	SITE SELECT	1	1/2	1	1	2			
	MAINTENANCE & OPERATIONS	1	1	1	2	4	1		1
	COMPUTER SYSTEM MONITORS	2	1 1/2	3	3	6	1		1
	DATA FLOW	1	1/2	1	1	2	1		1
	DPS ENGINEER	1							
	VOICE TECH	1							
	DISPLAY TECH	1							
	TELEVISION TECH	1							
	COMPUTER OPERATIONS	2							
	SOFTWARE SUPPORT TEAM	2							
	TOTAL	31	17	28	34	68	18	8	17

the real-time IUS mission, and (2) to provide simulation capability in support of software development, ground controller training, and procedure verification. The principal emphasis within this discussion of the IUS Control Center Software will be on the IUS mission support areas of real-time processing and simulation activity prior to actual flight.

The mission support software consists of several interdependent application subsystems operating in real-time to satisfy the overall support requirements of the control center. The interrelationships of the control center hardware and software required to satisfy the support role are shown in Figure 9.5.3-1.

In addition to defining the Control Center functional software specification, the establishment of the overall size of the software is required. This sizing information will be later used in costing of software development and in establishing the specific central computer size required to support the Control Center. Because of costing differences, the software size will be presented in the form of computer words for instruction utilization and those used for data allocation. The differentiation between data and instruction definitions is shown in Table 9.5.3-1. With each of the paragraphs which discuss the Control Center software requirements, the corresponding size information will be provided.

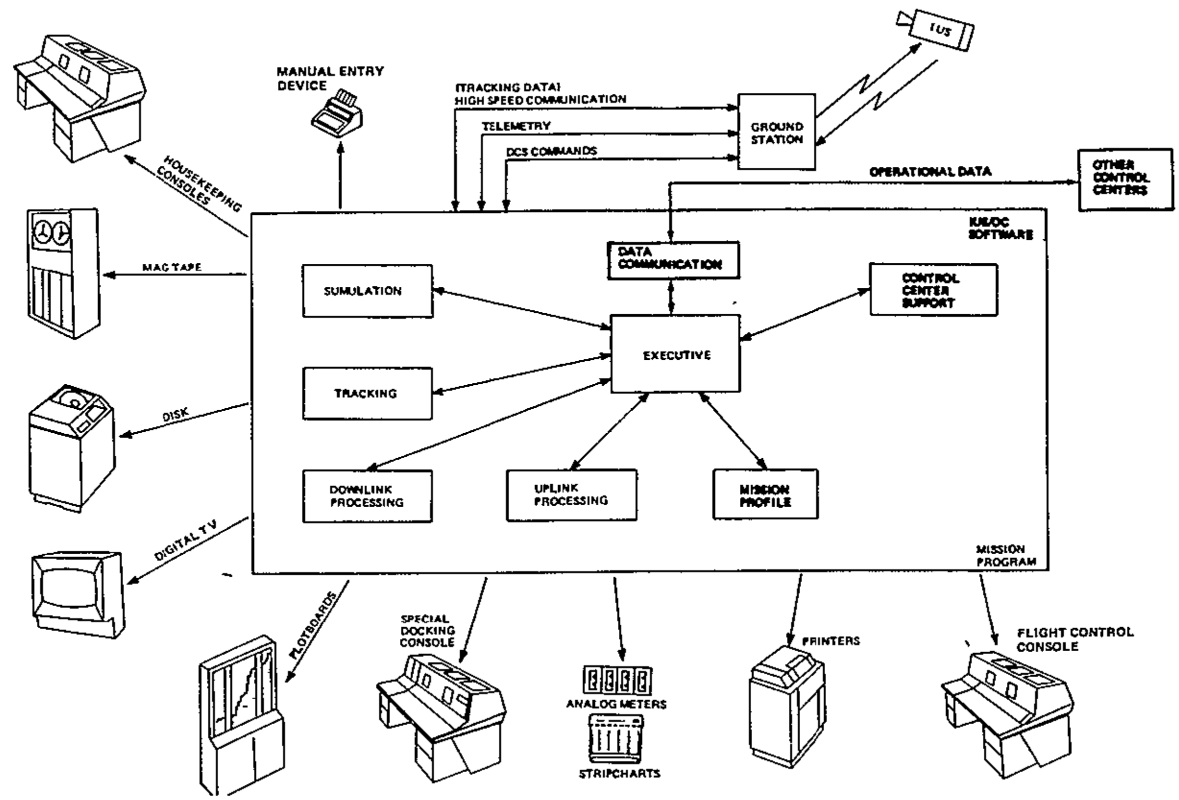

Figure 9.5.3-1. IUS Control Center Software Functional Interfaces

Table 9.5.3-1. Instruction/Data Definition

INSTRUCTION/DATA EXAMPLE

PROBLEM: Evaluate y as a function of time (t) according to the following expression:

$$y = A + Bt + Ct^2 + Dt^2$$

Where: A, B, C, and D are coefficients which determine the particular relationship between y and t.

PROGRAMMING:

INSTRUCTIONS are the sequence of machine operations required to evaluate the expression for y.

DATA consists of the coefficients A, B, C, and D.

DISCUSSION:

Once the instructions for the evaluation have been tested, data can be changed without retesting of the instruction logic. This reduces the cost of changing data words; whereas selection of a new evaluation technique will require complete redevelopment.

The Control Center mission support software has been subdivided into four major functional areas for discussion in this report. These areas are: (1) vehicle systems, (2) mission profile, (3) control, and (4) simulation. These four subdivisions have been further divided, as shown in Figure 9.5.3-2, and will be discussed in the order shown.

9.5.3.1 Vehicle System Software

To provide monitoring and control functions, the Control Center is required to maintain interface with the IUS vehicle through the telemetry downlink system and the digital command uplink system. The application software systems which provide these interface capabilities are the downlink processing and uplink processing software. These critical subsystems are discussed in the following paragraphs.

9.5.3.1.1 Downlink Processing

The downlink processing subsystem processes telemetry data received via the STDN (or TDRSS) from the IUS vehicle. The data is processed in real-time and the results displayed to Flight Control personnel for system evaluation. The downlink processing capability is comprised of real-time processing, telemetry support processing, and special processing each of which will be discussed in subsequent paragraphs. This process is depicted in Figure 9.5.3-3. Size of the downlink processing software is shown in Table 9.5.3-2.

Table 9.5.3-2. Downlink Processing Summary

FUNCTION	NO. OF INSTRUCTION WORDS	NO. OF DATA WORDS	TOTAL
REAL-TIME TELEMETRY PROCESSING			
DECOMMUTATION	5,300	2,600	7,900
DATA CONVERSION	10,900	10,100	21,000
TELEMETRY SUPPORT			
DATA REDUCTION	33,300	4,200	37,500
DATA ANALYSIS	30,100	4,000	34,100
SPECIAL PROCESSING	3,200	1,000	4,200
TOTALS	82,800	21,900	104,700

Real-Time Telemetry Processing

The real-time processing capability consists of software to perform decommutation and conversion of input telemetry parameters utilized in real-time support of mission controllers and in performing analysis on telemetry parameters to provide system status data regarding the IUS vehicle. This process is shown in Figure 9.5.3-4. The major processing performed is discussed in the following paragraphs.

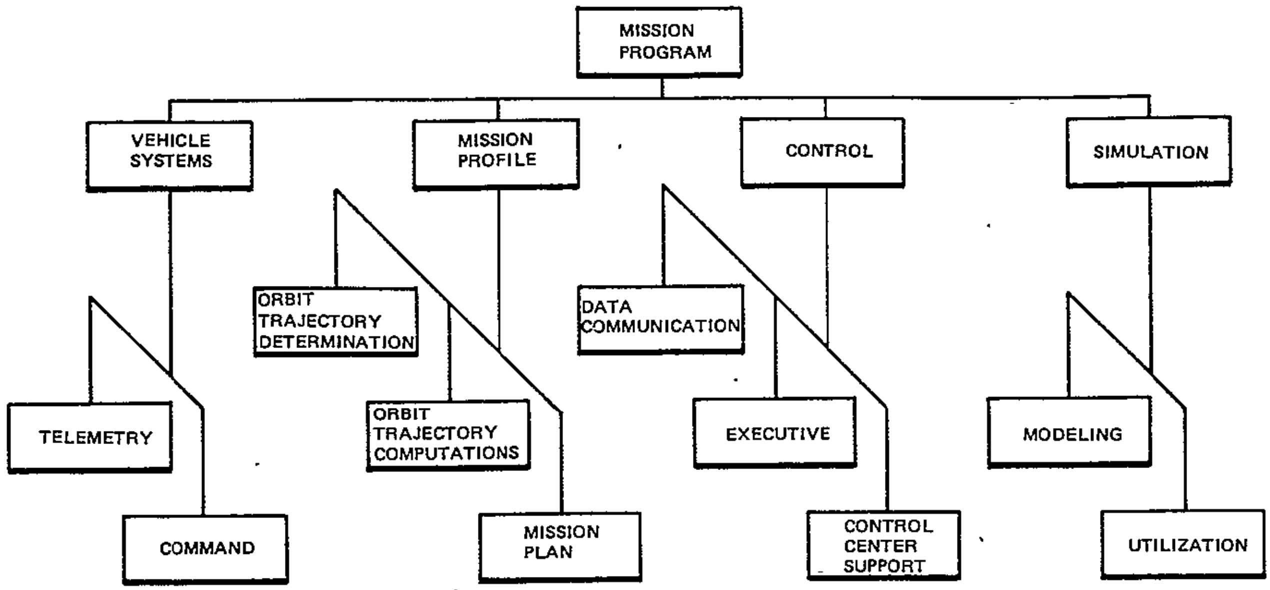

Figure 9.5.3-2. IUS Control Center Mission Software Structure

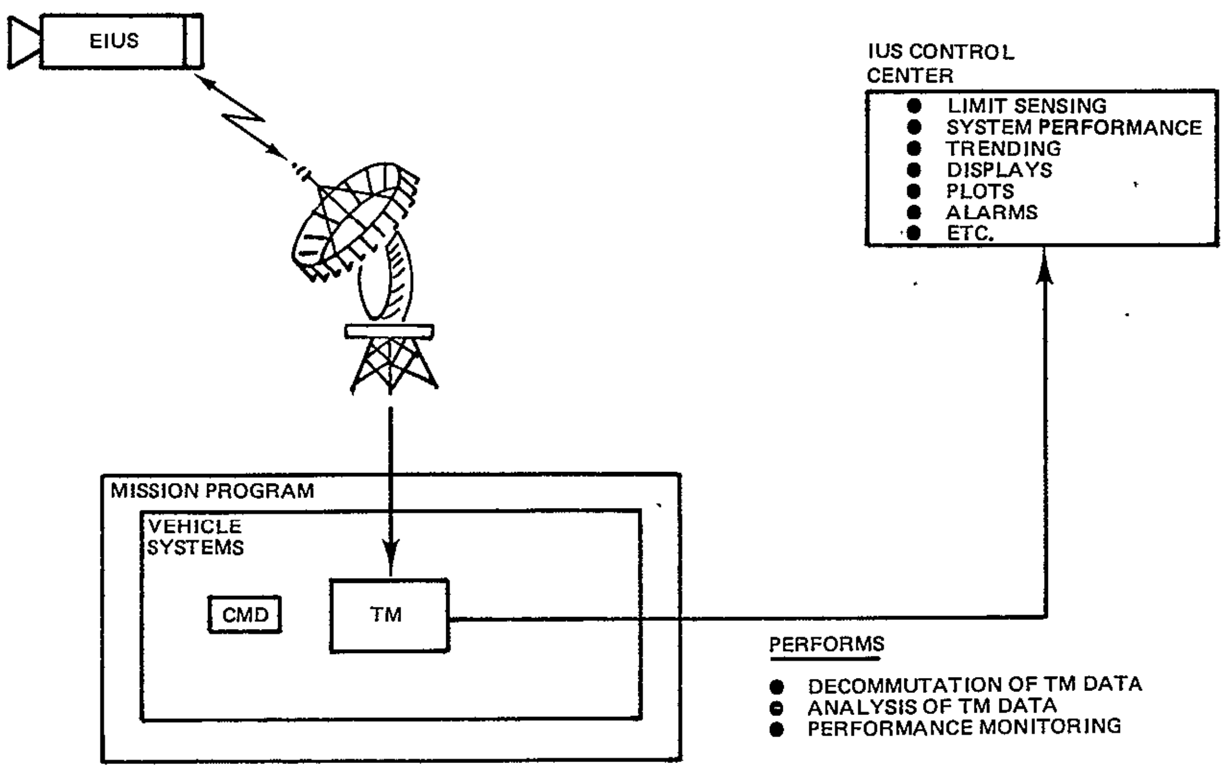

Figure 9.5.3-3. Downlink Telemetry Processing

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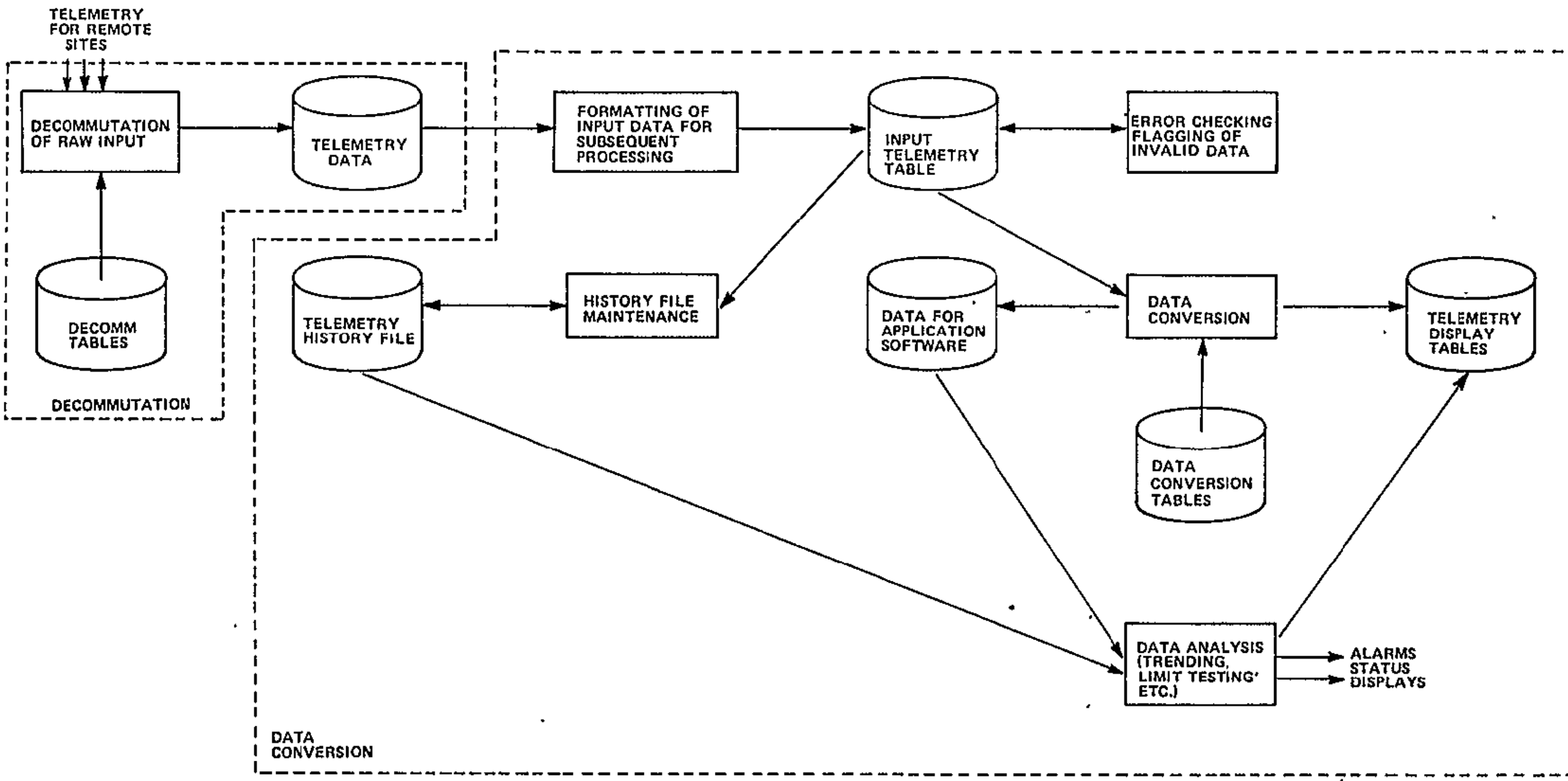

Figure 9.5.3-4. Real-Time Telemetry Processing

Decommutation - The decommutation module of the downlink processor processes real-time telemetry data at the input message level. Each message is validated for proper sequence by the ground site. Formats of input messages are also validated.

Through the use of a decommutation table, generated offline and loaded upon receipt of an input message, the decommutation module will unpack data from the input stream into data buffers utilized by telemetry conversion software. In addition, information pertaining to the location within the buffer of data is provided to user programs.

Data Conversion - For use within the software subsystems and for display to mission controllers and other mission support personnel, the raw input telemetry data must be converted into a meaningful format. This function is performed by the data conversion modules of the downlink processor through the following steps:

- Data formatting
- Check for error conditions and set appropriate status indicators
- Maintenance of history buffers of input data
- Perform data conversions
- Store converted data into appropriate data areas
- Limit-sensing of converted data

Telemetry Support Processing

The telemetry support processing software is designed to operate in a non-real-time environment and is largely dedicted to the data reduction and data analysis of all parameters received via the downlink system. The input to the telemetry support system is the telemetry history data gathered in real-time and saved on auxiliary storage devices for offline analysis. Outputs of the analysis are reports for use by flight controllers in evaluating overall system performance.

Another function performed by the telemetry support software is the generation of tables to be utilized for real-time telemetry processing. These tables contain the attributes required in processing each telemetered parameter and include such characteristics as scaling, calibration information, and limits on range. Also included are critical event tables for use in monitoring correct IUS operation in real-time and display format tables for defining console support requirements.

9.5.3.1.2 Uplink Processing

Uplink processing involves the formatting and transmission of commands to the IUS vehicle via the STDN (or TDRS) and the verification of network responses to those commands. The uplink processing software is comprised of three major functional areas whose responsibilities are: (1) format and transmit all commands; (2) validate the transmitted commands and update command status displays; and (3) perform site and data management. The overall functioning of the uplink processing software is discussed in the following paragraphs. A functional diagram of the uplink processing is shown in Figure 9.5.3-5 and the size of the software is shown in Table 9.5.3-3.

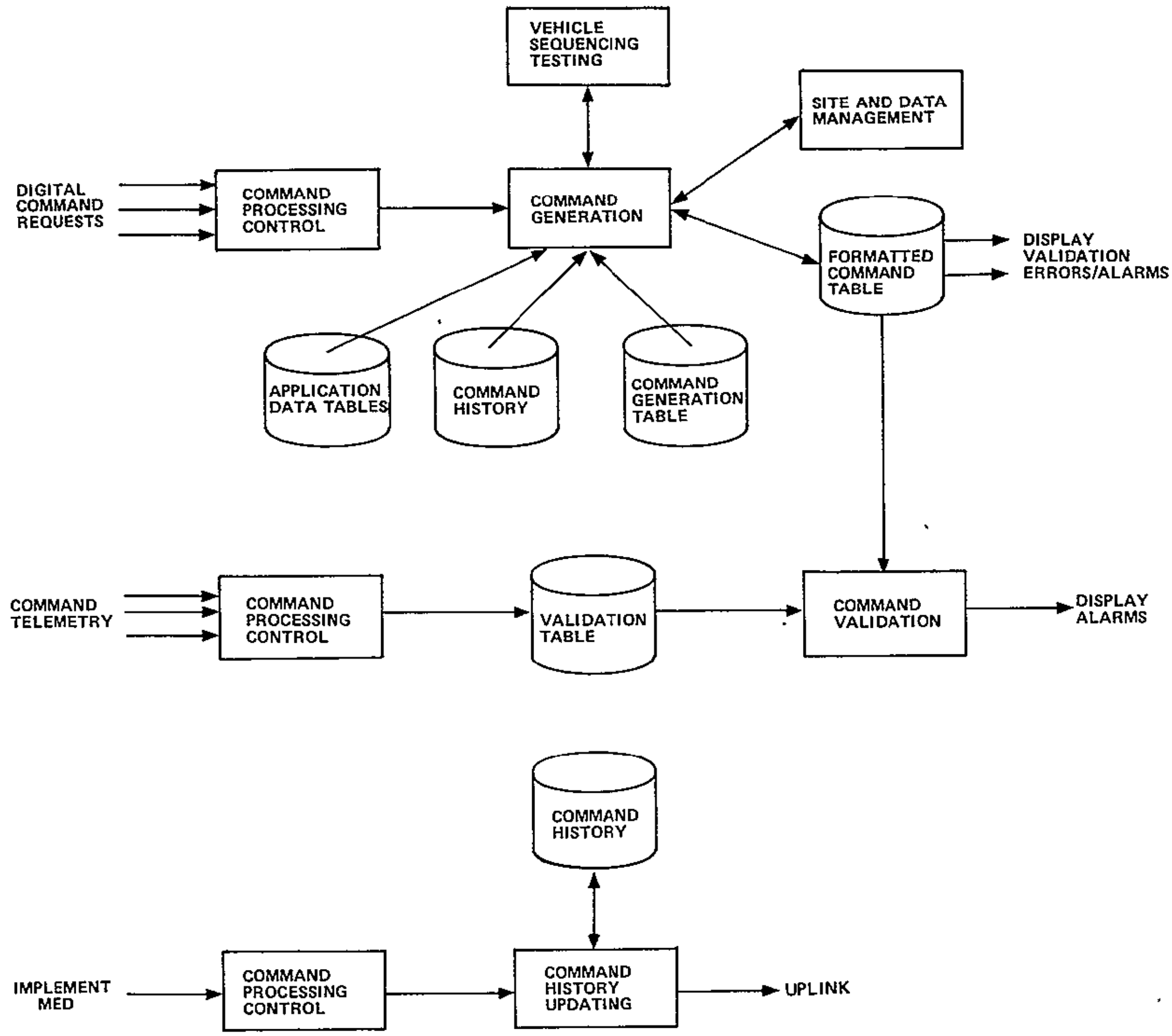

Figure 9.5.3-5. IUS Control Center Uplink Processing

Table 9.5.3-3. Uplink Processing Sizing

FUNCTION	NO. OF INSTRUCTION WORDS	NO. OF DATA WORDS	TOTAL
SITE MANAGEMENT	6,800	13,000	19,800
DIGITAL COMMAND PROCESSING	32,000	11,400	43,400
TOTALS	38,800	24,400	63,200

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Command Processing Control Program - The command processing control program is active in all aspects of uplink processing and performs the following functions:

- Responds to requests for uplink processing
- Retrieves and initializes tables
- Handles communications among program modules utilized in uplink processing

Its overall prime function is to control the operations required in response to requests for uplink processing functions.

Command Generation Program - The command generation program examines the input request and determines the command which is required. Using data from the command processing data table and data acquired from other ground center software, the command is then formatted for transmission. Prior to transmission, appropriate display tables are updated for mission controller verification of correct command format. The command is then transmitted to the appropriate remote site ground station for uplink to the IUS vehicle.

Command Validation Program - All commands transmitted to remote sites are 'echoed' back to the ground control center with status information indicating whether the command was accepted or not. In addition, the command validation program has a "time-out" feature in the event that no response is obtained from the remote site within the specified interval.

The command validation program processes the 'echo' messages and will print messages for those commands flagged as invalid. These print message will indicate the command as well as the reason for invalidity. Command messages successfully received by remote sites and verified are logged into command history tables.

Site and Data Management - The site and data management program updates the command-related displays for use by mission controllers. The displays are only updated upon request for command processing and contain the following types of information:

- Site management command history
- Overall command history
- Critical parameter changes executed through the uplink system
- Failure analysis history

9.5.3.2 Mission Profile Software

The mission profile software of the ground control center is primarily concerned with trajectory-associated functions. The functional requirements satisfied within the mission profile software are listed below and are discussed in more detail in subsequent paragraphs.

- Orbit trajectory determination
- Orbit trajectory computations

The overall estimated size of the mission profile software is shown in Table 9.5.3-4. In addition, major subdivisions of the software are shown.

Table 9.5.3-4. Mission Profile Software Sizing

FUNCTION	NO. OF INSTRUCTION WORDS	NO. OF DATA WORDS	TOTAL
TRAJECTORY DETERMINATION	63,500	62,300	125,800
LOW-SPEED RADAR PROCESSING	17,700	8,000	25,700
HIGH-SPEED RADAR PROCESSING	4,600	1,000	5,600
ORBIT TRAJECTORY COMPUTATIONS			
EPHEMERIS GENERATION AND CONTROL	24,000	5,500	29,500
MANEUVER COMPUTATIONS AND CONTROL	21,500	1,200	22,700
STATION CONTACTS	10,800	1,000	11,800
TOTALS	142,100	79,000	221,100

9.5.3.2.1 Orbit Trajectory Determination

In maintaining current trajectory information on the IUS vehicle, two types of radar input measurements are utilized. High-speed radar input measurements are utilized during mainstage burn phases, and low-speed radar measurements are received from remote radar tracking stations, batched, edited, and processed within the orbit trajectory determination software to provide refined IUS state vectors for use in orbital trajectory computations. A functional diagram of the orbit trajectory determination software is shown in Figure 9.5.3-6.

High-Speed Radar Processing

The high-speed radar input processing is used during mainstage burn phases and provides the ability to display the vehicle trajectory status in near-real-time. The high-speed input processor utilizes radar inputs transmitted from remote radar sites or range and range rate data transmitted thru TDRS. Each message rceived will be tested against a prescribed set of error limits before being accepted for subsequent processing.

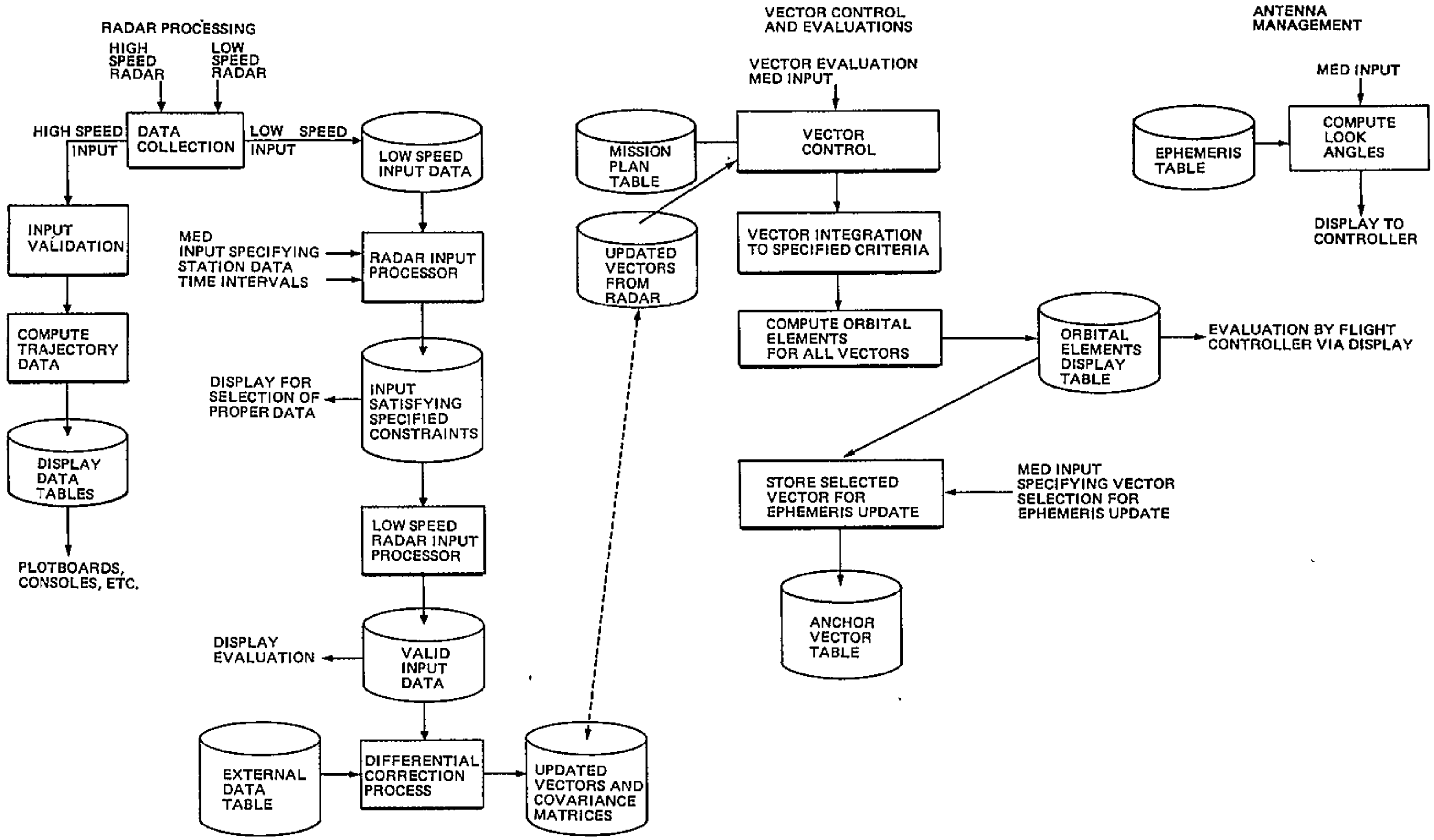

Figure 9.5.3-6. Orbit Trajectory Determination

The high-speed processing software will execute at a rate of twice per second and will provide the following parameters for display:

- IUS vehicle velocity
- IUS vehicle altitude
- IUS vehicle flight path angle
- Latitude of present position
- Longitude of present position

Low-Speed Radar Processing

Since the coast phases of the mission consititue the majority of the mission timeline and the environment is more predictable, the majority of orbit trajectory determination calculations are performed on low-speed radar inputs. The software elements required to satisfy the processing of low-speed radar inputs are discussed in the following paragraphs.

Data Collection - The data collection processor is responsible for receiving, retaining, or discarding of low-speed radar inputs. Input data is routed to the real-time input program for validity and quality testing. Control over validity and quality testing is provided through manual entry devices.

Radar Input Processor - The function of the radar input processor is to read, from a defined tape drive, low-speed radar data within specified time limits and pass the data to low-speed radar input processor for possible inclusion in data batches.

The input processor is under control of manual entry devices. The processing is initiated after specifying the tape drive, start time, end time, operating priority, and stations from which data are to be retrieved. A history tape is read until the begin time is found. The data is then checked against data type and transmitting station. Acceptable data is collected and passed to the low-speed data input processor.

Low-Speed Radar Input Processor - The function of the low-speed radar input processor is to form batches of data, according to radar station and vehicle, for possible differential correction (DC) computations. Data is routed based on validity/quality checks and batch requirements.

The following types of quality checks are performed on input data:

- Each teletype character and total message length must be valid.

- Data frame must contain frame identification character.

- Message must be from valid station.

- Elevation angle must be greater than or equal to the acceptable minimum.

- Time difference between observations must be greater than or equal to a minimum specified via manual entry device.

- Quality indicators set by remote sites must be set to 'GOOD'.

- Range and angle data must be within specified limits.

Failure to pass these tests will result in the input being discarded; whereas, acceptance will result in the input being passed for further processing.

Prior to differential correction processing, all low-speed batched radar data are retained in the low-speed collection table and formatted for evaluation and viewing by the appropriate mission controller.

Differential Correction - The differential correction (DC) process uses low-speed radar data, an initial estimate of the state vector, and an initial covariance. DC is performed thru the execution of the following programs.

DC Control - The DC control programs contain the logic required to perform the following basic steps:

- Select the DC inputs, which include the radar data to be used, the input vector, the input covariance matrix, and the appropriate K-factor.
- Control the propagation function, which consists of integrating the input vector and propagating the covariance matrix to the start time.
- Present the result of the DC to the user in the form of displays.

DC Propagation - This process requires that the input vector and covariance be updated to the time of the first observation in the set of data upon which a correction is to be performed. The DC propagation program provides the capability of integrating the input vector and propagating the covariance matrix to the desired time. Integration and propagation through both non-powered maneuvers is provided.

DC Convergence - The inputs to the convergence program are a list of up to 80 input batches with an initial estimate of the state vector and covariance matrix. The convergence processor is the basis of the DC function, containing the logic and mathematical formulation necessary to compute the updated state vector and associated covariance matrix.

To accomplish DC convergence, the following steps are executed:

- For each observation, compute its residual, weight, and partial with respect to the current state vector.
- Solve the equations for the vector correction, update covariance, and bias terms.
- Calculate the new vector and bias estimate by adding the corrections computed above.

Vector Control and Evaluation

The function of the vector control and evaluation software is to provide the flight controller the capability to compare the current IUS vehicle trajectory data with those predicted previously and, if required, to select a new anchor vector for ephermeris generation. The vector control and evaluation software is under complete control of the mission controller and will be executed only upon receipt of a manual entry device (MED) request.

The vector control portion of the software collects specified vectors from the current ephemeris table and updated vectors from the radar processing software and places them into data tables for subsequent processing. In addition, the MED input data is also placed into the data tables.

The vector evaluation portion of the software integrated all vectors to the conditions specified via the MED input and computes the display data for use in the evaluation process. If a new anchor vector is required for subsequent ephemeris generation calculations, the new vector is placed into the anchor vector table.

9.5.3.2.2 Orbit Trajectory Computations

The orbit trajectory computations software is responsible for generation of current trajectory information. In particular, it:

- Maintains current orbital ephemerides which describe IUS vehicle trajectory containing periods of free-flight and/or powered flight.
- Maintains detailed information for currently planned maneuvers.
- Computes and formats information relevant to radar station time and duration of track for transmission to the tracking network.
- Computes numerous parameters for definition and evaluation of predicted IUS trajectories.

The software to accomplish the above functions is discussed in the following paragraphs. A functional description of the trajectory computation process is shown in Figure 9.5.3-7.

Ephemeris Generation and Control

The ephemeris generation and control software generates, maintains, and references ephemerides for the IUS vehicle, the Space Shuttle, and the target vehicle. The ephemerides provide rapid access and/or computation of tracjectory dependent data for mission planning and real-time flight monitoring.

The ephemerides are of two types, live or static. A "LIVE" ephemeris describes the current trajectory of a vehicle. It is considered live because the trajectory is computed and output on trajectory evaluation displays for monitoring purposes. In addition, the live ephemeris is advanced as current time processes. A "STATIC" ephemeris describes the predicted trajectory from an anchor vector whose time is anywhere within the mission profile. The anchor vector is either specified by the user or defaults to the times of the

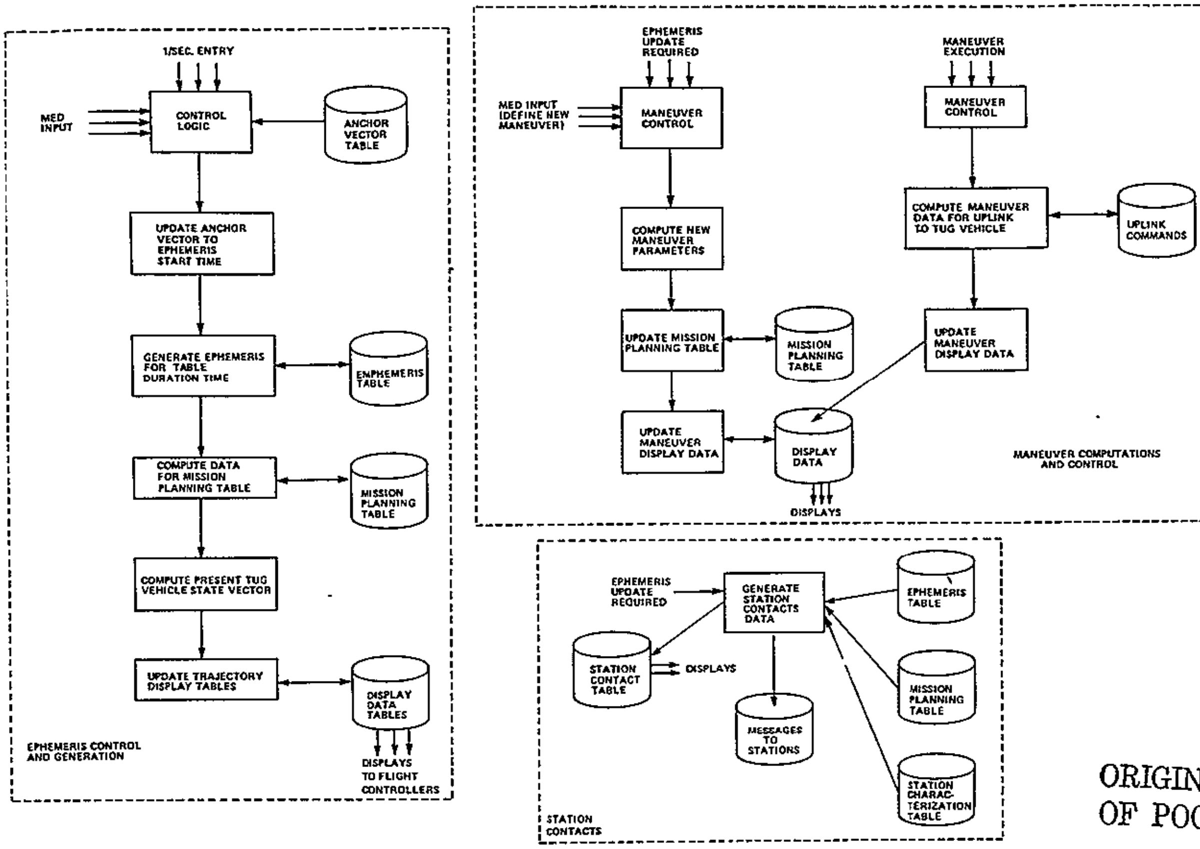

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Figure 9.5.3-7. Trajectory Computation Process

last anchor vector specified. The "STATIC" ephemeris, therefore, does not advance with time but instead remains fixed at the defined base state.

Ephemerides have the following additional characteristics:

- Each can contain periods of free flight and/or powered flight.
- Density of each ephemeris is three minutes for free flight periods and 10 seconds of powered flight periods.

The ephemeris generation and control software is subdivided into three major areas: (1) control logic, (2) ephemeris generation logic, and (3) display requirements. These areas are addressed in the following paragraphs.

Control Logic - The control logic performs initialization and supervisory functions necessary in maintaining and referencing vehicle ephemerides. There are five categories of processing within the control logic: (1) input processing, (2) anchor vector table maintenance, (3) vector routines, (4) trajectory update supervision, and (5) miscellaneous vector processing. The following steps are executed in performing these functions:

- Vector for a specified vehicle ephemeris is entered via manual entry device.

- Vector is stored in anchor vector table.
- Ephemeris vector is generated.
- A trajectory update is performed utilizing new anchor vector.
- Miscellaneous vector routines are used to perform trajectory computations.

Ephemeris Generation - The ephemeris generation software performs the actual generation of a vehicle ephemeris and updates the necessary tables to reflect the current trajectory. Since each ephemeris can contain periods of free-flight and powered flight, the software updates the ephemeris table with both types of vectors.

Display Requirements - This portion of the ephemeris generation and control software provides the capability to display ephemeris associated data to flight controller personnel. These displays contain the following types of data:

- Vehicle state vector at specified time
- Earth-referenced position at specified time
- Arrival time and orientation at specified point
- Current vehicle state vector
- Time-to-go to specified position

Maneuver Computations and Control

The maneuver computations and control software are responsible for processing inputs related to the computation and insertion of maneuvers into the appropriate vehicle ephemeris and inputs related to all trajectory updates that involve maneuvers. The primary function of this software is to control the generation and maintenance of maneuver information in the mission planning table. To accomplish these functions, the maneuver computations and control software are comprised of three subsystems - control logic, maneuver definition unit, and display requirements.

Control Logic Unit - The control logic supervises the processing of inputs that affect and/or update the mission plan table for a specified vehicle ephemeris. The primary function of this processing is to guarantee the accuracy and consistency of maneuver definitions in the mission planning table. The following functions are performed by the software:

- Input processing
- Maneuver update to the mission planning table due to a maneuver definition
- Freeze, unfreeze, deletion of a maneuver being input and changed

- Change weights, areas, fuels, K-factor, and/or initial configuration codes

- Execute a maneuver in the mission planning table

Maneuver Definition Unit - The purpose of this program is to process and/or compute the maneuver targets which properly define a desired finite burn in the mission plan table.

There are two ways in which maneuvers can be defined. The desired finite burn targets plus ignition time can be specified, or an impulsive maneuver time plus the specified orbits before and after the burn can be specified.

Overall, the maneuver definition unit is responsible for generating or accumulating all data which must be stored into the mission planning table. The types of maneuvers supported for the IUS vehicle are:

- Mainstage burn maneuvers
- Midcourse ΔV maneuver
- Venting maneuvers
- Non-propulsive maneuvers

Display Requirements - The purpose of the maneuver display software is to provide maneuver- associated data for use in display to flight controllers. For each maneuver, the following data will be provided:

- GMT of maneuver initiation
- Incremental velocity required to accomplish maneuver
- Height of apogee after maneuver
- Height of perigee after maneuver

In addition, maneuver information for evaluation by flight controllers will be provided. Example of this data are:

- Maneuver definition and targetting parameters
- Maneuver execution parameters
- Resultant trajectory information
- Maneuver update information

Station Contacts

The station contacts software determines when the IUS vehicle and radar ground stations are in contact with each other, displays this data, and informs the remote station of upcoming contact periods. To accomplish these functions, the software has been divided into the following areas:

- Station contact generation
- Station contact displays
- Remote site acquisition

Station Contact Generation - The programs in this unit generate orbit station contact information based on specified ephemeris. The mathematical models required to determine horizon crossing times, terrain masking effects, and keyhole loss of signal times are maintained. When given site definitions and ephemeris data, the program will generate a chronological list of station contacts.

Station Contact Displays - The station contact displays software produces information about present and future station acquisition and parameters associated with those contacts.

Remote Site Acquisition - The transmission of acquisition messages to the remote tracking stations is the function of this software. Information contained within the messages is as follows:

- Slant range, receiver frequency, transmitter frequency, bias doppler, and one way doppler to S-Band stations

- Pointing data for tropospheric refraction

9.5.3.3 Control Software

The Control Software provides the capabilities to control overall software execution and interface with Flight Support Facilities. A diagram of the functioning of the Control Software is shown in Figure 9.5.3-8.

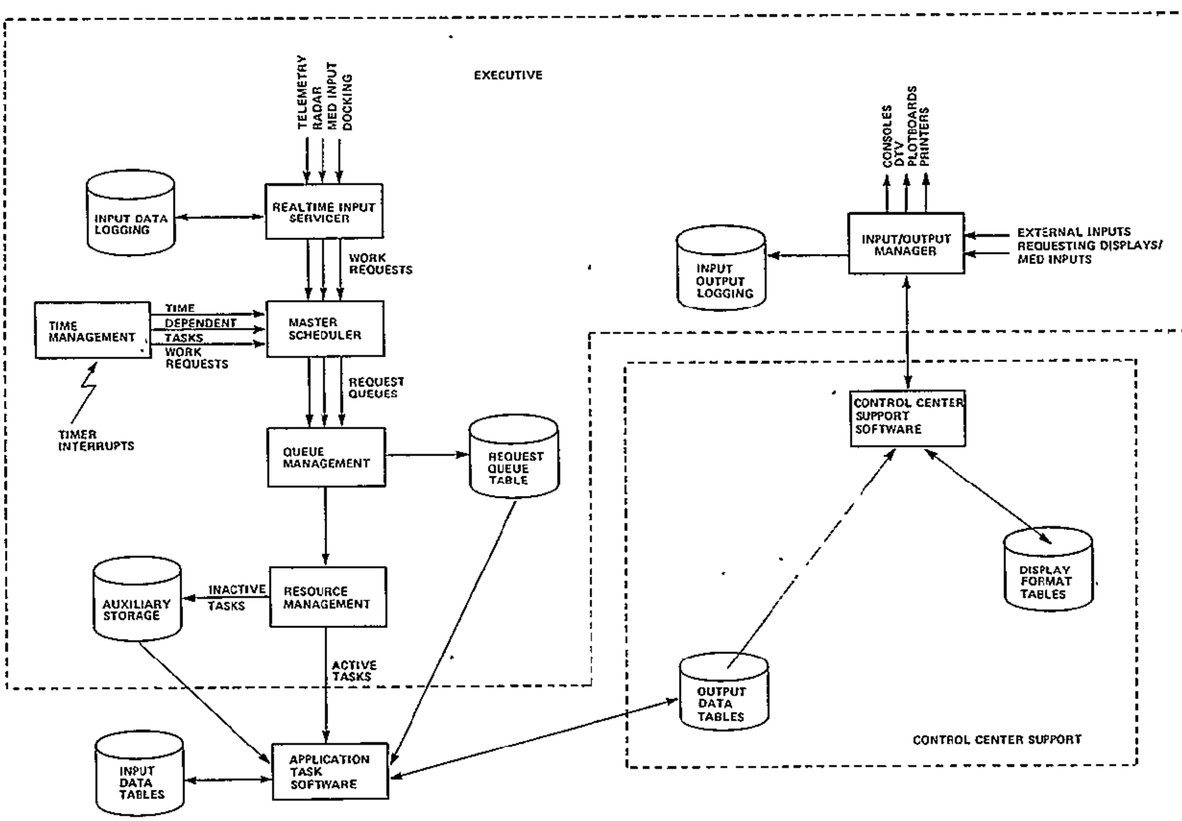

Figure 9.5.3-8. IUS Control Center Control Software

9.5.3.3.1 Executive

The executive program functions as the supervisor of the application software within the central computer and controls and sequences all input/output activity. In addition, the software within the executive will provide the capability to recover from component failures within the control center without degrading system integrity. The subelements which comprise the executive and the size of the executive software are shown in Table 9.5.3-5.

Table 9.5.3-5. Executive Software Summary

FUNCTION	NO. OF INSTRUCTION WORDS	NO. OF DATA WORDS	TOTAL
TASK MANAGEMENT	78,600	6,100	84,700
APPLICATION TASK CONTROL INITIALIZATION ERROR RECOVERY QUEUE MANAGEMENT MASTER SCHEDULER OPERATING SYSTEM UTILITIES			
DATA MANAGEMENT	78,600	8,600	87,200
RESOURCE MANAGEMENT DATA LOGGING STATISTICS GATHERING AUXILIARY STORAGE OPERATING SYSTEM UTILITIES			
INPUT/OUTPUT MANAGEMENT	31,800	5,100	36,900
I/O CONTROL INTERRUPT HANDLING OPERATING SYSTEM UTILITIES			
SYSTEM INITIALIZATION	33,000	13,500	46,500
TOTALS	222,000	33,300	255,300

The executive program is designed to:

- Minimize the application system hardware dependence
- Ensure fast response to system activity
- Provide simplicity to application program development
- Provide the support to application software in handling large amounts of real-time data

- Provide a flexible base for future expansion

The major functions provided for application software are task management, data management, input/output management, system initialization and simulation support. These major functions are discussed in the following paragraphs. Reference should be made to Figure 9.5.3-8 to follow the interfacing of the subelements discussed following.

Task Management

The task management capability of the executive is built upon the independent task concept. In this concept, an independent task is able to receive work at all times regardless of the input data rate. When data is received by the system for a task, it is sent in the form of a request. Each request has its own priority which in turn becomes the priority of the task. If a task is processing a request and a new request is received from the task, the new request is held according to its priority and processed upon completion of the request in progress.

Each task is assigned an area in main storage called a resource table. This is a private area that can be used by the program running under the task. In addition, each task is assigned a unique protect key which protects it from all programs controlled by other tasks.

Master Scheduler - The master scheduler examines all input data and acts as an interface between the hardware interrupt servicing function and the task management function. When the master scheduler receives an input message, it compares the message with the current data definitions. If a compare exists, the message is routed to the task which will process it. If no compare exists, the message is discarded. The master scheduler can also accumulate a number of messages for the same task and generate a request for the task after the specified number of messages have been received. In this case, all the accumulated messages will be sent to the task as one request.

Within the Control Center, work requests will also be generated according to elapsed time. For example, a task may be created to control a load module which updates the position of the vehicle every second. The only data necessary to perform this operation is the previous position and the orbital parameters. Since this data exists within the software system, no external signal will occur to request execution of the task. In a case such as this, the request will be generated through a timer interrupt under control of the software. This technique for task requests is known as time routing.

Time Routing - Time routing is used within the Control Center software to generate work requests on specified time intervals. It functions as the interface between the time management function of the executive and the task management function. When an application program requests a series of time dependent activations, the time routing program sends the request to time managment specifying the time when the next request should be generated. When the timer interrupt associated with the request is received, time management will call the time routing function which, in turn, will call the required task.

Queue Management - As mentioned previously, if a task is processing a work request, all other requests for that task must be held by the system until the task is available for further processing. To support this operation, the executive must build and maintain a queue of work requests waiting to be processed by each active task. Information concerning each request is held in a real-time queue element.

Each active task will be processing one work request and that request is represented by the active queue element. All other requests for the tasks will be placed in the queue of 'waiting' elements. Requests from the 'waiting' elements are ordered according to priority; in the case of equal priority, first-in first-out (FIFO) is the order of processing. When the task completes, the request of high priority is made active and passed to the task for processing. If no 'waiting' requests exist, the task becomes dormant awaiting new data for processing.

If queue management is not provided, the queue elements can accumulate indefinitely unless the tasks can process their work requests faster than they are generated. Queue management provides the capability to control requests by limiting their number. It can also be used to control system load by not giving requests to a task until other tasks are complete.

Time Management - The computer to be utilized within the IUS Control Center will be equipped with a special high resolution GMT clock and interval timer. To provide support for these timer devices, a time management supervisor will be required within the executive. The supervisor maintains system time and controls the setting and interrupt handling functions resulting from the timer hardware.

System Recovery - It is of prime importance that the software continue to function in the presence of errors or failure conditions. Three areas of software are required to address: switchover, high-speed restart, and error recovery.

For system reliability considerations, a backup main computer system will exist within the ground control center. The ability to select the backup computer system without interruption to the input/output processing of real-time data or degradation of mission output will be performed within the executive program.

In the event of computer failure, the backup computer system must be brought online within a minimum specified time interval. An initial load program will exist within the executive to transfer all required data from the operational system to the selected backup system.

The error recovery function of the executive pertains to errors resulting from program checks, hardware malfunctions, or abnormal conditions arising within the software system itself. In effect, error recovery capability is restricted to those errors recognizable within the software for which software action can be taken. The error recovery programs will print appropriate messages and recommendations regarding system status.

Operating System Utilities - The executive program for the IUS Control Center will be built around the capabilities of the operating system provided with the computer. This approach will allow utilization of existing system software and will provide a standard base for development of application software. In addition, the utilization of the computer's operating system will allow one control center computer to be used for normal job processing when not being used for real-time mission support.

Input/Output Management

Because of the real-time nature of input/output processing, special techniques must be provided to handle this activity efficiently and rapidly. These techniques are included in the following functional areas of the input/output management software:

- Real-time access method
- Real-time interrupt servicer and start-stop input routing
- Digital/TV display control
- Shared device support

Real-Time Access Method - The real-time access method performs device dependent data manipulation and output messages to special real-time devices within the IUS Control Center. It also is used to control the reading of information from the display hardware used by flight controllers. Output to all display hardware is also controlled by the real-time access method.

Real-Time Interrupt Servicer and Start/Stop Input - The real-time interrupt servicer and start/stop routines provide control over the input from real-time input devices within the control center. The servicer passes the request information to the master scheduler for use in scheduling the execution of the appropriate task. The start/stop input routine controls the initiation and transfer of data from the input device and can stop the transfer in the event of failure.

Digital Display Device Control - The digital display device control software centralizes and simplifies the control of digital displays. The control program is entered when user request-change in display information. The control routine updates the display format and passes the new data to the real-time access method for output.

Shared Device Support - The shared device support program acts as an interface for computer jobs which may share devices. Inputs for use of shared devices are received and routed to the appropriate task; outputs to the shared devices are controlled through this program.

Data Management

The data management portion of the ground control center executive performs the functions of:

- Data logging
- Data table maintenance
- Auxiliary storage control
- Background utilities

The functional discussions of these elements are contained in the following paragraphs.

Data Logging - In a real-time environment, it is essential that a technique be provided which saves the data received, transmitted, and processed by the system. Within the control center, all such data is recorded on magnetic tape. In addition to system inputs/outputs, application program data can be recorded for program checkout purposes.

Data Table Maintenance - Because of the large amounts of data which must be accessed and manipulated during support of an IUS mission, a series of control programs will be utilized to support data table handling.

Data tables are blocks or arrays of data maintained on direct access devices. Through use of data table control software, tables can be 'logged' to ensure data integrity and consistency during a read operation. This will delay any tasks attempting to write into the table until the data has been 'unlocked'.

Each data table is identified by a name field and is defined by its block size and number of blocks. A data table generation program uses these parameters in allocating space for each table and providing the controls required to access it.

Auxiliary Storage Control - Because the overall software size for the control center will exceed the capacity of the computer's main memory, direct access devices will be used to store all programs not required to reside in memory at all times. The retrieval of these programs from auxiliary storage in real-time and the dynamic loading into main memory are functions performed by the auxuiliary storage control software.

Background Utilities - Numerous capabilities have been included in the executive for use in background operations which can be initiated or terminated by console operation. These background utilities execute asynchronously with normal operation and provide the following capabilities:

- Dump auxiliary memory to tape
- Restore auxiliary memory from tape
- Clear auxiliary storage device
- Copy a tape
- Compare tapes
- Print magnetic tape

Statistics Gathering System - The statistics gathering system provides timing information and execution frequency statistics useful in accessing overall system performance. Example of the types of statistics are given below:

- CPU Performance - shows the amount of CPU utilization, the time spent waiting on I/O, or time spent in gathering statistics

- Load Module Performance - shows the execution frequency, average execution time, percent of CPU utilization, and number of requests for each task

- Task Performance - shows the number of task executions per specified time interval and the execution time for task

- Executive Performance - shows the percent of CPU utilization spent in performing executive functions

System Initialization

Prior to initiation of the application software to support an IUS mission, the executive will perform the necessary diagnostics on system hardware, configure the hardware in accordance with input specification, and initialize the application software to accept task requests.

The system initialization software will reside on auxiliary storage devices and will be loaded into main memory under control of the computer's operating system. The initialization software then controls the loading of remaining software into main memory and will pass control to the task management function when all initialization tasks have been completed. The main memory utilized by system initialization then becomes available for system use.

Simulation Support

To assist in development of the application software, the executive program has two features which provide significant testing capability. These features, discussed below, are simulated input control (SIC) and fast time.

Fast Time - Fast time is a capability of the executive to stop the time reference if no software activity is scheduled. In this way, many hours of computer time and programmer time can be saved. Using this capability, the input messages are processed as rapidly as the tasks can be run.

Simulated Input Control (SIC) - Simulated input control provides the capability to send simulated input data into the application software for test purposes. This input data can be in the form of cards or tape or both. All data has the time of receipt associated with each message and SIC routes each data message to the master scheduler for scheduling of the required task. For convenience, SIC will allow data log magnetic tapes to be used as source for simulated input. In this manner, actual data obtained from previous flights or simulations can be used as a test bed for software change verification.

9.5.3.3.2 Control Center Support Software

As was discussed previously, the executive program provides the input/output capability to interface with the hardware devices within the control center. In addition to the software existing for input/output, significant software is required to format data properly for output, to provide the data requested, and to maintain the data base required for display purposes. A functional description of the control center support software's relationship to the executive and hardware external to the computer system is shown in Figure 9.5.3-8. Sizing data is shown in Table 9.5.3-6.

Table 9.5.3-6. Control Room/Display Management

FUNCTION	NO. OF INSTRUCTION WORDS	NO. OF DATA WORDS	TOTAL
DISPLAY DEVICE INPUT SERVICING	3,800	400	4,200
DISPLAY DEVICE OUTPUT	10,000	4,800	14,800
TOTALS	13,800	5,200	19,000

9.5.3.4 Simulation System Software

In the development and qualification of the control center, data from external sources such as remote sites, IUS vehicle, etc., will not be available on a continuing basis. In addition, certain hardware systems within the control center may not be available when needed to support testing. To provide an environment to assure the capability to perform testing at all times, development of a simulation capability will be required. This simulation capability will be performed through software modelling of the control center environment. The simulator will provide simulated real-time inputs, under control of simulation personnel, to test both the nominal and contingency capabilities of the control center.

Simulations have been utilized in both the Mission Control Room at JSC and at the Deep-Space Control Center at JPL with significant results. For the IUS Control Center, the simulation system will be used to address testing requirements associated with hardware checkout, software development, procedural verification, and ground controller training.

The subelements which comprise the simulation system are shown, with corresponding sizing information, in Table 9.5.3-7.

Table 9.5.3-7. Simulation System Size

FUNCTION	NO. OF INSTRUCTION WORDS	NO. OF DATA WORDS	TOTAL
IUS VEHICLE SIMULATION	43,200	12,700	55,900
GROUND STATION SIMULATION	55,000	12,500	67,500
CONTROL CENTER SUBSYSTEMS SIMULATION			
DISPLAYS	11,500	16,900	28,400
MED ENTRIES	15,000	9,000	24,000
SIMULATED INPUT CONTROL	7,500	11,300	18,800
TOTALS	132,200	62,400	194,600

9.5.3.4.1 Simulation Description/Operation

The overall functional description of the simulation system and its relationships with the operational software and hardware of the control center are shown in Figure 9.5.3-9. The simulation system contains models of the following operational components:

- IUS vehicle
- Ground station
- Radar tracking sites
- Subsystems within the control center, such as displays, consoles, and panels

To provide a near real-time environment, the simulation system software will be executed within the backup central computer system. The primary central computer will contain the operational software of the control center. The simulation software will perform all modelling, as requested by the simulation controller, and provide inputs to the operational software. Outputs of the operational software will be directed to the control center hardware or simulated models. Uplink commands will be routed to the simulation system rather than to remote sites. Through this operation, a closed-loop simulation is achieved which will provide significant flexibility in the overall testing plan for the control center.

The elements of the simulation system are discussed in the following paragraphs.

IUS Vehicle Model - The model of the IUS vehicle is a detailed mathematical model which includes the following onboard systems:

- Onboard computer (includes onboard computer software)
- Guidance
- Telemetry
- Stabilization and control
- Reaction control
- Propulsion
- Sequential events
- Attitude sensors
- Uplink command
- Power
- Payload

Ground Station Model - The ground station model will accept as input the telemetry data generated by the veicle module and will generate telemetry data in the format acceptable to the IUS Control Center software.

Radar Tracking Station - A simulated vehicle trajectory will be used to generate low-speed and high-speed radar input data for use in the control center's operational software. The trajectory will be updateable during the simulation to provide off-nominal IUS vehicle perturbations.

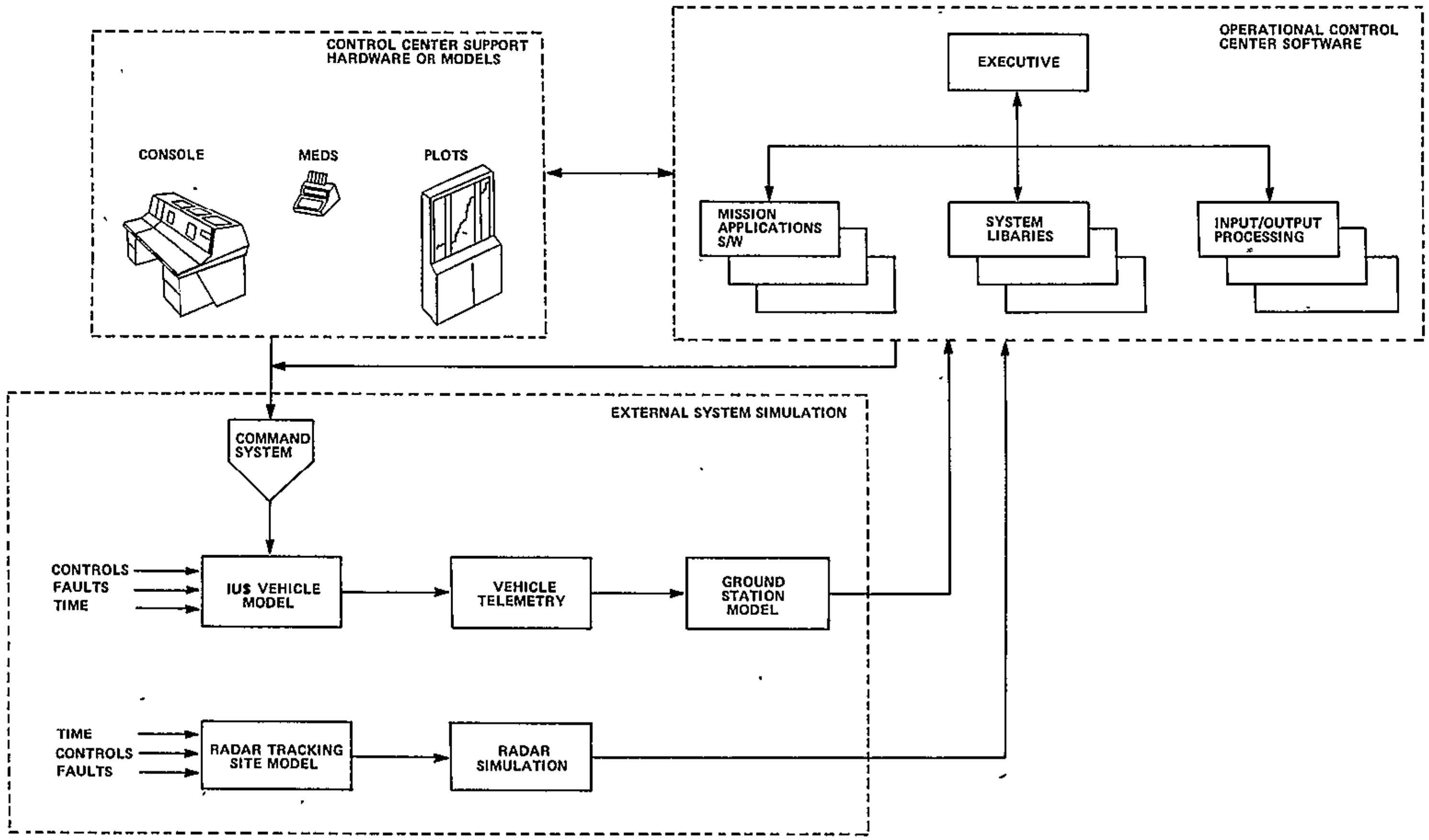

Figure 9.5.3-9. IUS Control Center Simulation Software Interfaces

Control Center Hardware - Since a signficant portion of the simulation will be controlled from flight consoles and manual entry device inputs, this control center hardware will be modelled within the simulation system.

For MED inputs, tables of input data to be executed as a function of mission time will be established prior to the mission simulation. As the mission is simulated, these inputs will be issued at the appropriate time. Each issuance will be logged for post-simulation analysis, and, in addition, tests will be conducted, during the simulation, on response of the operational software to the stimuli issued through the MED simulation.

Display simulation will test the capability of the operational software to properly respond to display requests and display properly formatted data. The display data will be logged for post-simulation analysis. Correlation between the data generated by the simulation and that calculated and displayed will be accomplished during the simulation and logged for analysis.

Simulated Input Control - The simulated input control, although a subset of the simulation system, is a 'stand alone' simulation tool for selective entry of data into the operational software. This capability provides a means of performing software checkout without the overall simulation system being involved. The input is largely manual and provides a tightly controll testing environment.

9.5.3.4.2 Simulation System Utilization

As was stated previously, the prime uses of the simulation system are:

- Hardware checkout
- Software development
- Procedural verification
- Flight controller training

Hardware Checkout - Through use of the hardware simulation capability, a dat base can be provided for comparison between actual hardware and modeling tes cases. Replacing software models with actual hardware also provides verification of system interfaces prior to overall system testing.

Software Development - The simulation system will be utilized to provide inputs, during software development, for program checkout purposes. Because of the input control features of the simulation system, predictable test cases can be generated and conducted. This use of the simulation system wil provide a base for systematically testing the operational software in a real tic environment and will allow testing to proceed at the overall system leve before requiring the participation of outside activities.

Procedure Verification - Prior to each IUS mission, a flight plan will be generated. This flight plan will detail the procedures to be followed to en that the IUS mission achieves all objectives. The simulation system will pr vide the test bed to verify that the procedures are correct.

Flight Controller Training - Flight controllers must be trained to handle all contingency situations. In view of the criticality of flight controller expertise, a thorough training program prior to the actual mission must be provided.

The simulation system is ideally suited to provide the training needed by flight controllers. The simulation system in conjunction with the control center software can reproduce all nominal events and non-nominal contingencies which may occur during a mission. The active participation of flight controllers in overall system simulation will ensure that the controller is thoroughly familiar with available mission support tools, data and will provide training in a real-time environment.

9.5.3.5 Software Summary

This section of the IUS study report has identified the functional software requirements which must be satisfied in order to control the IUS vehicle from a control center. The overall size of the software has also been addressed and is summarized in Table 9.5.3-8.

The primary emphasis has been placed on ensuring that all the functional requirements have been addressed. The software size, which has been developed, is based on a study of similar software at the JSC-RTCC and JPL-DSC. As can be seen in Figure 9.5.3-10, the IUS software size is less than previous ground control center software for other space programs; however, as the IUS control center requirements are more clearly defined, the software may grow.

Table 9.5.3-8. IUS Control Center Software Summary Size

FUNCTION	NO. OF INSTRUCTION WORDS	NO. OF DATA WORDS	TOTAL
DOWNLINK PROCESSING	82,800	21,900	105,700
UPLINK PROCESSING	38,800	24,400	63,200
MISSION PROFILE	142,100	79,000	221,100
EXECUTIVE SYSTEM	222,000	33,300	255,300
CONTROL CENTER SUPPORT	13,800	5,200	19,000
DATA COMMUNICATIONS	3,800	2,500	6,300
SIMULATION SYSTEM	132,200	62,400	194,600
TOTALS	635,500	228,700	865,200

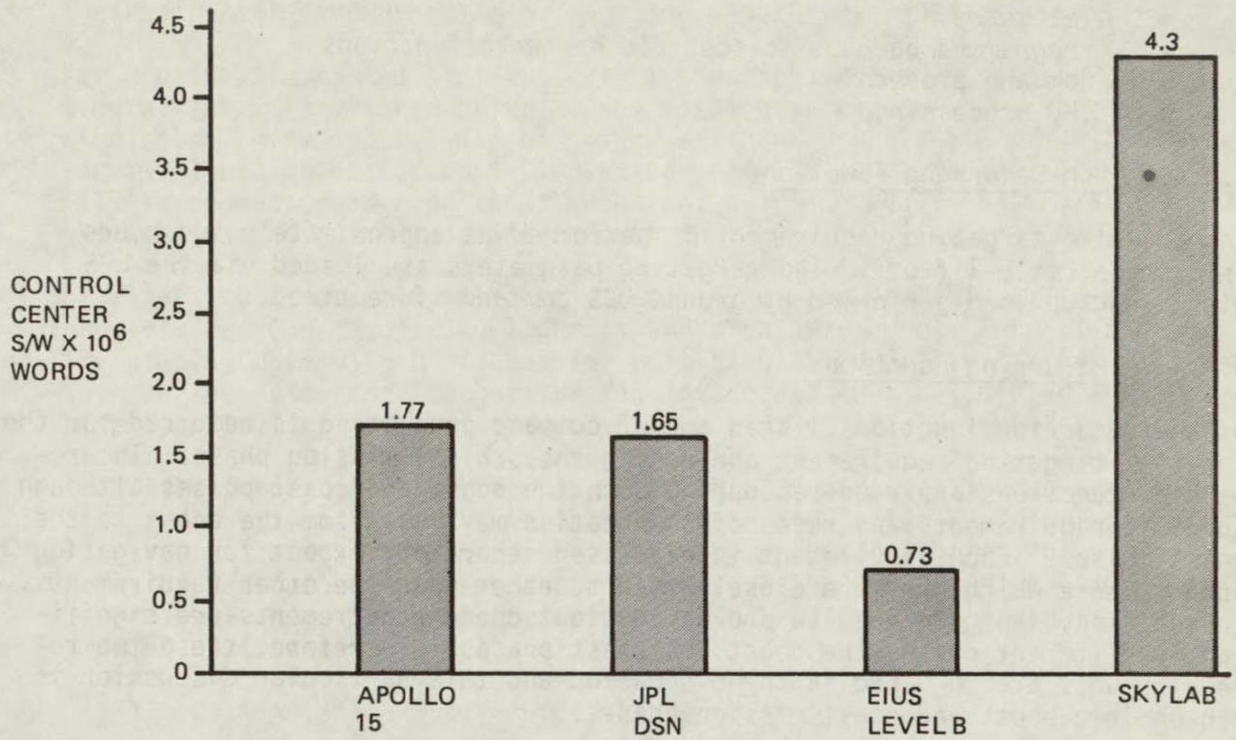

Figure 9.5.3-10. Space Programs Mission Software Size

9.5.4 AIRBORNE OPERATIONS SUPPORT SOFTWARE

The Flight Software requirements for a Level B EIUS vehicle are estimated, based upon the anticipated share of the mission operations decision requirements. Four baseline flight programs have been postulated, and the specific mission implementation is to be a modular adaptation of one of the baseline programs. The following paragraphs discuss the general approach to the IUS Flight Program.

The flight program is an integral part of: (1) the guidance and control system comprising the central computer, IMU and the flight control electronics; and (2) the IUS sequencing system comprising the discrete input, discrete output, and interrupt processing of the central computer.

The integration of these systems is accomplished through the flight program. It provides a flexible mechanism by which the system functional and detailed specifications may be altered, within wide limits, to accomplish a wide variety of missions without changes to the vehicle hardware.

Although specific requirements will vary with mission phase, the flight program is required to provide for the following recurring functions.

- Navigation
- Guidance
- Attitude Control
- Sequencing

- Telemetry
- Programmed backups to specific hardware functions
- Command processing
- IMU processing

9.5.4.1 Non-Recurring Functions

The one-time targeting requirement is performed at approximately two hours prior to shuttle liftoff. The targeting parameters are loaded via the LPS with a backup load performed by ground DCS command if required.

9.5.4.2 Recurring Functions

Of the recurring functions listed above, command processing is required for the one-time targeting requirement and during the orbital mission phase. The remaining functions are required during both the boost and coast phases although specific requirements and rates of computation may vary from the boost to the coast phases. Each requirement is discussed separately except for navigation and guidance which are more closely tied together than the other requirements. In addition, the guidance law and navigation scheme requirements are significantly different during the boost and coast phases. Therefore, these two rerequirements are combined in the discussion and this particular discussion is broken into boost and coast mission phases.

The following definitions of navigation, guidance and control apply in this document.

Navigation: The calculation of vehicle position and velocity at any time with respect to a specified reference frame.

Guidance: The computation, according to a specified law, of instantaneous vehicle attitude, with respect to a specified reference frame, necessary to achieve a specified state vector and/or vehicle attitude at some future time.

9.5.4.2.1 Boost Navigation and Guidance

Since variations in acceleration are large during boost, the computation rate for navigation must be higher than during coast. In determining position and velocity relative to the desired reference frame, gravitational effects are computed as part of the navigation scheme since the sensors cannot measure gravitational acceleration. A mathematical model of the earth's gravitational field, which was empirically derived from satellite measurements, will be used in the gravitational computations. Position and velocity in the desired reference frame are obtained by differencing the integrated measured and gravitational accelerations. The computation rate, or integration interval will be variable. With these rates, and the smoothed acceleration function, a simple trapezoidal integration routine yields sufficient accuracy. A single navigation scheme is adequate through the boost phase.

In order to achieve the correct orbital inclination and longitude of descending node, active guidance is required in both the pitch and yaw planes. Compensation in the guidance law is required for abrupt transients in vehicle performance and for subtle off-nominal vehicle characteristics such as center of gravity offsets. In general, active guidance laws, including IGM, tend to become unstable as the end conditions are approached. In order to maintain a stable vehicle at cutoff, certain of the guidance constraints will be dropped shortly before cutoff. In particular, the position constraints, and the lateral and vertical position rate constraints are dropped as the time-to-go approaches zero. The component velocity-to-be-gained constraints are maintained slightly longer and the commands "frozen" just before cutoff to ensure zero angular rates and a stable vehicle. The time of cutoff is computed as a function of total velocity-to-be-gained and the cutoff command issued to the IUS at the proper time. The primary constraints on the orbit are inclination and longitude of descending node. The constrained insertion conditions are radius, path angle, and velocity.

9.5.4.2.2 Orbital Navigation and Guidance

Orbital navigation and guidance requirements are relatively simple when compared to boost requirements. Orbital navigation consists primarily of integrating the orbital equations of motion. The required gravitational model is constructed by adding the third and fourth zonal harmonics to the model used during boost.

The only external force of consequence acting on the vehicle and tending to alter its orbit is drag. A mathematical model of drag force is used instead of using the inertial platform sensors. Therefore, pre-stored equations are used in the computation of vehicle drag accelerations.

If navigation errors are large enough to require correction, the navigation state vectors may be updated by ground command. The new state vectors and time are transmitted to the flight program via the command system.

Orbital guidance consists primarily of following a pre-determined attitude timeline. In addition, variations to the timeline may be made from the ground via the digital command system.

Attitude Control

The primary stabilization loop of the IUS vehicle is the attitude control loop which is closed by the flight program in the Central Computer. The control law requires vehicle turning rates and accelerations and commanded and actual vehicle attitudes, with respect to the prescribed reference frame, as inputs. Attitude error commands are issued to the engine actuators through the vehicle control system to effect the control function.

Limits are applied to the rate of change of the commanded attitude, the commanded attitude error magnitude, and the rate at which the commanded attitude error may change. Vehicle angular rates are thereby maintained within safe limits. The control function is required throughout the mission although the frequency of control computations is higher during boost than during orbit.

During the boost period, when control is provided by the main engine, significant control authority with relatively fast vehicle response is available. Therefore, a high iteration rate for the control computations is required. During the orbital phase, control is maintained by a reaction jet system with limited control authority. Thus since the response of this system is slow, a relatively slow iteration rate for control computations is adequate.

Sequencing

The flight program functional requirements include sequencing of the discrete vehicle events. A limited number of discrete sequencing requirements are satisfied by use of the discrete outputs of the Central Computer. The flight program itself must sequence into the different phases in response to interrupts and discrete inputs from the vehicle. These vehicle interrupts and discrete inputs signal the occurrence of specific mission events.

The vehicle sequencing requirements are based on the occurrence of specific mission events. Therefore, the vehicle sequencing requirements are divided into several distinct series of commands. Each series is referenced to a specified event. In this manner, vehicle sequencing is correct in spite of perturbations during previous mission phases.

Telemetry

Data are required from the flight program during its operation for real time monitoring of guidance system performance and for detailed post flight evaluation. Real time data generally consists of the state vector, error or backup indications, vehicle attitude, and program/vehicle status, mode, sequencing, and timing information. Detailed data generally consist of intermediate guidance calculations and hardware information. These data are transmitted to the ground stations through the IUS telemetry system.

Command Processing

The Digital Command System (DCS) provides the capability to alter certain specified flight program functions and data upon receipt by the flight program of the proper commands and data from the ground. Some commands will require only a valid mode command for execution while others, such as Navigation Update, require a valid mode command and appropriate data for execution. Through use of the command capability, several preplanned alternate modes can be entered or corrections can be made for certain predefined off-nominal performance situations or vehicle failures through the update and generalized sequencing commands.

The flight program first validates the mode and data sequence upon receipt of the command. Appropriate data are telemetered to the ground to indicate acceptance and validation of the command. If any of several non-allowable conditions exist upon receipt of a command; such as invalid command, out of sequence mode or data, or valid command at a wrong time; the flight program transmits the proper error message to the ground to inform flight controllers of the conditions so that appropriate action may be taken.

With the exception of the Targeting Load command and the other commands required to support it, the command capability is only required during the coast phase of the mission.

Table 9.5.4-1 presents the IUS Flight Software size and complexity summary.

Table 9.5.4-1. Expendable IUS Flight Software Sizing Summary

FUNCTION	INSTRUCTIONS (WORDS)	DATA (WORDS)	COMPLEXITY
EXECUTIVE			
• TASK MANAGEMENT	225	345	.1
• INTERRUPT PROCESSING	120	50	.1
• DISCRETE PROCESSING	45	26	.1
• TIMEKEEPING	94	45	.3
• I/O CONTROL	100	650	.3
• INITIALIZATION/TERMINATION	900	83	.2
• MATH UTILITIES	864	---	.3
• COMMAND DATA POOL	---	1200	---
NAVIGATION			
• NAVIGATION EXECUTIVE	125	45	.8
• BOOST NAVIGATION	178	69	.8
• COAST NAVIGATION	1238	192	.5
• NAVIGATION UPDATE	591	282	.4
• IMU ALIGNMENT	2452	822	.4
• NAVIGATION UTILITIES	578	125	.3
GUIDANCE			
• GUIDANCE EXECUTIVE	83	38	.8
• BURN TERMINAL GUIDANCE	105	37	.5
• COAST GUIDANCE	254	53	.75
• BURN GUIDANCE (IGM)	1645	280	.25
ATTITUDE CONTROL			
• INITIALIZATION	64	30	.75
• UPDATE ATTITUDE	15	3	.9
• COMPUTE, TRANSFORM ERRORS	43	11	.9
• BURN CONTROL LAW	233	32	.5
• COAST CONTROL LAW	64	23	.6
• CONTROL OUTPUTS	106	23	1.0
SEQUENCING			
• NORMAL COMMAND ISSUANCE	224	21	.6
• ERROR PROCESSING	195	28	.4
• NOMINAL PROCESSING TABLE	51	9	.4
• ALTERNATE TABLE PROCESSING	47	11	.4
• DATA TABLES	---	1000	---
TELEMETRY			
• BLOCK MAINTENANCE	169	30	.5
• RECORDER CONTROL	161	34	.75
• STATION VECTORS (10)	---	30	---

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Table 9.5.4-1. Expendable IUS Flight Software Sizing Summary (Continued)

FUNCTION	INSTRUCTIONS (WORDS)	DATA (WORDS)	COMPLEXITY
UPLINK PROCESSING			
• READ INPUT	211	34	.4
• MESSAGE PROCESSING	154	35	.6
• MESSAGE ACKNOWLEDGEMENT	53	6	.9
• ERROR PROCESSOR	66	10	.75
• DATA OUTPUT	38	6	1.0
• DATA BUFFER	---	100	---
• FUNCTION PROCESSING	1100	100	.25
IMU PROCESSING			
• READ INPUT DATA	50	12	1.0
• RESOLVE AND CONVERT DATA	100	108	.5
• BODY-TO-INERTIAL TRANSFORMATION	50	9	.4
• IMU FAULT DETECTION	600	30	.2

9.5.5 GROUND DATA SYSTEM

The Central Computer within the IUS control center, through its software, is the focal point for the entire mission support operation. The computer must support a myriad of capabilities - examples of which are listed below:

- Mission Program Development and Test
- System Simulation
- Scientific Computation
- Training of Flight Controllers
- Real-Time Support of IUS Mission
- Schedule and Control Jobshop Work

Because of the criticality of the Central Computer to the overall operation, it is essential that the computer selected be capable of handling all planned functions in an orderly fashion and also provide sufficient growth capability to support changing requirements as the IUS program matures. The growth factor is particularly significant in view of the fact that the RTCC software required for support of the Apollo Program expanded by approximately 50 percent during that program. As a result, the Central Computer became marginal, in some instances, in its ability to perform the burden of work placed on it.

9.5.5.1 Computer Selection Considerations

The principal driving factors in the selection of a computer system are the memory capacity of the computer and its Central Processing Unit (CPU) capabilities. Additional factors to be considered are peripheral device capabilities and the ability to interface with special devices required in the IUS control center. The following paragraphs discuss the primary factors of memory capacity and CPU capabilities as they relate to the IUS control center central computer.

9.5.5.1.1 Memory Capacity

The total size of the system software required to support the IUS Mission is 864,200 words. However, it is not necessary for the entire program to continuously reside in main memory. Through a proper structuring of the software system, a significant amount of the program can be placed on auxiliary storage devices to be read into main memory when required. This technique will reduce the demand for core-resident programs and, therefore, reduce the main memory capacity requirements; however, the use of auxiliary storage will require significant input/output operations which may affect the ability of the system to satisfy response time requirements.

In selection of the computer, a maximum case main memory requirement must be established. Through analysis of the software functional requirements, it was determined that the maximum memory utilization case for the IUS control center would occur when the executive, vehicle system, and mission profile modules of the mission program software were required simultaneously.

As shown in Table 9.5.5-1, such a combination of software would require approximately 415,497 words of main memory. Vehicle system software consists of the downlink processing module and the uplink processing model, which collectively require 167,900 words of storage, if all vehicle system software were simultaneously in main memory. Worst case analysis has shown that the maximum simultaneous requirement, however, is only 65 percent of the total vehicle software. This reduces the actual storage load to 109,135 words.

The mission profile module total word requirement is 221,100 words, as shown on Table 9.5.3-8, of which 34.8 percent is the maximum simultaneous requirement. This adds 76,943 words to the total simultaneous memory requirement.

The control software consists of the executive system module and the control center support module, which collectively require 280,600 words of storage. The maximum simultaneous requirement is 81.76 percent of the total control software. This adds 229,419 words to the total simultaneous memory requirements.

Table 9.5.5-1. Co-Resident Summary Requirements

FUNCTION	WORDS
CONTROL	229419
VEHICLE SYSTEM	109135
MISSION PROFILE	76943
TOTAL	415497
TOTAL + GROWTH FACTOR	830994

9.5.5.1.2 CPU Utilization

CPU capability is defined to be the number of operations a computer can perform within a one second interval. In selection of the central computer, it is required that the computer have sufficient computational capability to perform all defined functions within the specified time constraints. As in the case of memory capacity, CPU growth capability must also exist for additional computational requirements as the IUS Program matures.

Within the Tug control center, the principal factors which directly affect the CPU requirements are:

- Software execution rates
- Input/output requirements
- Response times to user requests

The determination of CPU execution rates for a proposed computer system is a detailed effort requiring the use of extensive modeling techniques. These modeling techniques require a detailed knolwedge of software module content and frequency of operation. The preliminary nature of software module definition contained in this study precludes the use of such techniques and, therefore, an alternate approach was taken.

The functional similarities between the RTCC, JPL, and IUS/OC requirements provide a means whereby an analysis of extending system CPU utilization can establish a baseline for CPU requirements. Because the RTCC is a "man rated", real-time system, its CPU utilization was selected as an upper bound. A minimum bound was established from the JPL operation, which is a non-man rated, non-real-time system.

Control Center Computer execution rates were then assumed to be greater than the JPL operation and less than the RTCC. Through comparative statistics, it was established that the maximum case CPU utilization would require 20 percent less than the RTCC maximum. Table 9.5.5-2 documents the statistics for the subject control centers.

The 75 percent maximum utilization for the IUS/OC when applied to the 360/75 Model J, results in a maximum CPU utilization of 3.85 x 10^6 operations/second required of the Control Center central computer.

Table 9.5.5-2. Control Center CPU Utilization

CONTROL CENTER*	% CPU UTILIZATION		
	MIN	MAX	AVG
RTCC (APOLLO)	40	95	50
JPL	10	60	12-15
IUS/OC (PROJECTED)	30	75	40

* Computer System IBM 360/75, Model J
Cycle Time - 195 Nanoseconds, 5.128 x 10^6 Operations/Second

9.5.5.1.3 Growth Considerations

As has been stated previously, growth capability in both memory capacity and CPU capability must be considered in computer selection. IBM's previous experience on similar ground control centers (RTCC and JPL) indicate that growth potential in both areas should be approximately 50 percent to satisfy requirements. Failure to provide for this growth can severely restrict the ability of the IUS control center to expand with the increasing requirements placed upon it. A major objective in selecting the central computer should be to provide for orderly growth in capability throughout the lifetime of the center.

9.5.5.2 Candidate Computers and Selection

As was developed previously, the main memory capacity must be a minimum of 415,496 words to handle maximum case memory requirements, and the CPU capability must provide 3.85 x 10^6 operations/second. An additional 100 percent increase in these capabilities to provide the desired growth capacity yields the following characteristics the candidate computers must satisfy:

- Memory capacity - 830,993 words
- CPU capability - 7.7 million operations/second

The candidate computers, within the IBM/370 line, which should be considered for the ground control center application with the growth capability provided, are shown in Table 9.5.5-3.

Table 9.5.5-3. Candidate Computers

THE LIST OF CANDIDATE COMPUTER SYSTEMS (IN ASCENDING ORDER OF INSTALLED COST) MEETING OR EXCEEDING THE MAIN MEMORY AND CPU CRITERIA IS:

	SYSTEM	MODEL	INSTALLED COST	YEARLY MAINTENANCE	REQ'D AREA	MEMORY (MEGA WORDS)	CPU SPEED (MEGA OPS/SEC)
1	3158	MP6	6711376	138795	3024	1.05	8.70
2	3168	MP4	10317601	281730	3024	1.05	12.50
3	3168	MP5	10931201	291071	3024	1.31	12.50
4	3168	MP6	11437201	295408	3024	1.57	12.50
5	3168	MP7	11943201	299745	3024	1.84	12.50
6	3168	MP8	12449201	204081	3024	2.10	12.50

From the preliminary analysis conducted in this study, the 370/158-MP6 appears to be the minimum cost computer which provides the desired growth potential.

Prior to actual selection of a computer for the ground control center for the IUS missions, an extensive modeling study should be conducted. This study should utilize the system requirements and software definition and develop a detailed model of the control center computer system. From this model, detailed statistics can be gathered regarding such items as main memory requirements, CPU utilization, auxiliary storage utilization, and system response times. All of these data can then be utilized to determine the most cost-effective computer system for the control center.

9.6 PHYSICAL PLANT

It has been assumed for the purposes of this study that no existing facilities will be utilized. This requires that a separate physical plant be designed to house the flight control, flight support, data system, and staff equipment areas required to support the operation functions.

The only variable which controls a portion of the physical plant design is the number of consoles required by the flight control personnel and the flight support personnel. This parameter varies as a function of the operational philosophy and data display requirements.

Figure 9.6.0-1 presents a representative floor plan for a typical concrete block, slab foundation structure, 114 feet by 90 feet, to house the flight control functions. It is assumed that the government will contract the construction of the physical plant and therefore, cost to the government will be in two phases: (1) those costs involved in administering and overseeing the contract during the period of its execution and (2) the procurement cost of the completed building.

Procurement costs are estimated on the following basis:

> Raised floor construction - areas requiring subfloor cabling, air conditioning, etc., will cost $50.00 per square foot to construct.
>
> Ordinary floor construction cost $35.00 per square foot to construct.

Figure 9.6.0-1 depicts a representative floor plan with sufficient capacity for the personnel and equipment specified in this study. Total area for this particular IUS/OC layout is 9,936 square feet of which the following allocation of space is tabularized in Table 9.6.0-1.

Table 9.6.0-1. IUS/OC Area Space Allocation

TCC AREA	SQUARE FEET
Flight Control Room	1100
Viewing Room	243
Flight Support Room	600
Computer Support Area	594
Tape Storage	255
Office, Restrooms, Canteen	1080
Technical Support Area	1296
Mechanical Support Area	612
Data System Area	3024
Hall/Lobby	1132
TOTAL	9936

The prime considerations in developing this configuration were separation of functions, equipment space requirements, and operations staff positions locations.

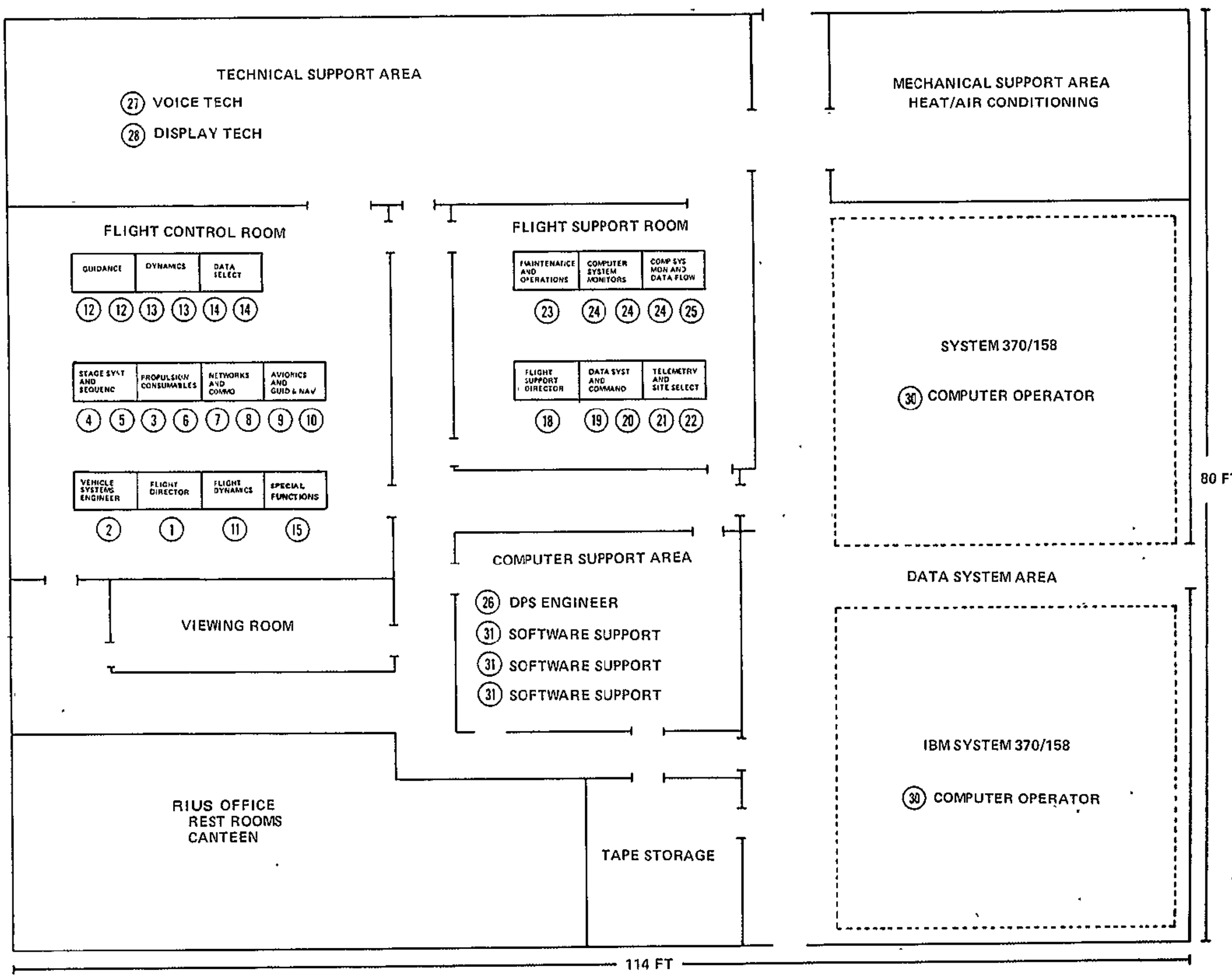

Figure 9.6.0-1. IUS/OC Representative Floor Plan and Support Staff Stations

Space allocation for display consoles in the Flight Control Room and Flight Support Room are based on a standard 6 x 4 foot console with a six foot separation between console rows for chair, bookcase and passage. Console arrangement is based on operational function and console operator duty. This orderly arrangement of consoles groups teams with similar responsibilities and consoles with supervisory and summary displays. This provides efficient mission support during high and low mission phase activity. It is of particular significance during low activity phases where manning is minimal. Operational positions that are manned are adjacent permitting efficient monitoring all of active IUS vehicle systems during this period. Consoles in the Flight Control and Support Rooms face the Technical Support Area. This arrangement accommodates the utilization of special large screen displays should this be desired. The space allocated in the Data Systems Area is comparable to current space requirements for all equipment associated with a dual IBM System 370/158.

9.7 COST ESTIMATES

The two key elements to the IUS costing methodology are the involvement matrix and the cost analysis programs. The IUS involvement matrix is constructed by utilizing the Space Tug involvement matrices as a baseline and subtracting from the matrix those functions and elements which are not relevant to the IUS mission model or support configuration.

Two involvement matrices were prepared on the Space Tug program, one for the Level II autonomy interactions and the other for Level III autonomy. In the IUS program, no concise definition of autonomy is available; and, at the time the study was first entered, the Reusable IUS and the Expendable IUS were competing concepts.

In order to accommodate the Reusable and Expendable IUS configurations and to provide a spread between the higher and lower levels of autonomy, four involvement matrices were prepared. Level A autonomy is analogous to Level II autonomy in the Space Tug, Level B autonomy is analogous to Level III autonomy in Space Tug. Mission functions and sub-functions were necessarily different not only from Space Tug but between the Expendable and Reusable versions of the IUS. However, it was found possible to adjust the two basic Space Tug involvement matrices to accommodate Expendable and Reusable IUS cases operating at Level A and Level B autonomy. The involvement matrices thus established formed a relationship between IUS missions and the support required by the IUS missions. These matrices were then used as a data base for investigating these relationships.

The major output from the involvement matrices are support requirements. This is a summary of the impact the mission structure has upon the ground support structure.

In parallel with the manipulation of the involvement matrices, reference missions were constructed by sequencing mission modules into modular timelines. These modular timelines are utilized in the cost analysis programs to establish shift density, overlap of modules and overlap of missions when compared to the associated traffic model in the cost analysis programs. The cost analysis programs accepts inputs from the traffic model, support requirements, and the modular timelines, then produce a detail printout of DDT&E expenses and recurring cost expenses. Figure 9.7.0-1 illustrates the IUS methodology.

9.7.1 Involvement Matrix

The involvement matrix is a 277 row by 137 column matrix which defines the involvement of the operational elements with the operational functions in the covering set of mission operations requirements. The involvement matrix provides a method of quantifying the effects of variations in support technique and variations in mission operations functions. The difference between the number of relations involved in Level A autonomy support and in Level B autonomy support provides a direct process of quantifying the support element requirements. The involvement matrices for the IUS were derived from the involvement matrices constructed for Space Tug by "zeroing" those support elements and mission functions (columns and rows) which are not relevant to the IUS design or covering set of mission requirements. Figure 9.7.1-1 presents the involvement matrix. The 137 operational elements are listed across the top of the matrix. The 277 mission operational functions and sub-functions are listed vertically.

9.7.1.1 Autonomy Level Differential

Figure 9.7.1-2 shows a typical set of Involvement Matrices; one for Level B autonomy, one for Level A autonomy; with the involvements indicated by a "1" entry in the matrix cells and no involvement by a "0" in the matrix cells. By analysis of the differences in involvement, the support requirements may be ascertained. It will be noted that the involvement matrix is merely a convenient organization tool for the exploration of inter-related factors. The validity of the matrix lies in the effort expended by knowledgeable flight control systems engineers in analyzing the operations.

9.7.1.2 Autonomy Level Differentiation Example

Figure 9.7.1-3 highlights one line of entries for control center involvement. That line is relative to the initialization of guidance, navigation and control systems and the alignment of the inertial measuring unit prior to a main stage burn. It will be noted that there are four differences (additions) between Level A and Level B implementations. Those four differences are: in the requirement for 1) command process, 2) command generation, 3) command validation, and 4) data transfer outside the IUS operations center. All of the foregoing are required to provide a ground command interface with the IUS vehicle. The significance in that partial row (Level A) is that the onboard system is not entirely responsible for functions required to initialize the guidance, navigation and control system and can thus rely upon the ground for some level of assistance in accomplishing those funcions. In turn, flight software may be reduced, at the expense of increasing ground software and ground manning requirements. Costs can then be associated with each of the two related functions and the cost optimal implementation selected.

9.7.1.3 Cost Analysis Programs

Fifteen cost analysis programs have been used to investigate various aspects of the support element cost. Figure 9.7.1-4 presents the flow of logic as

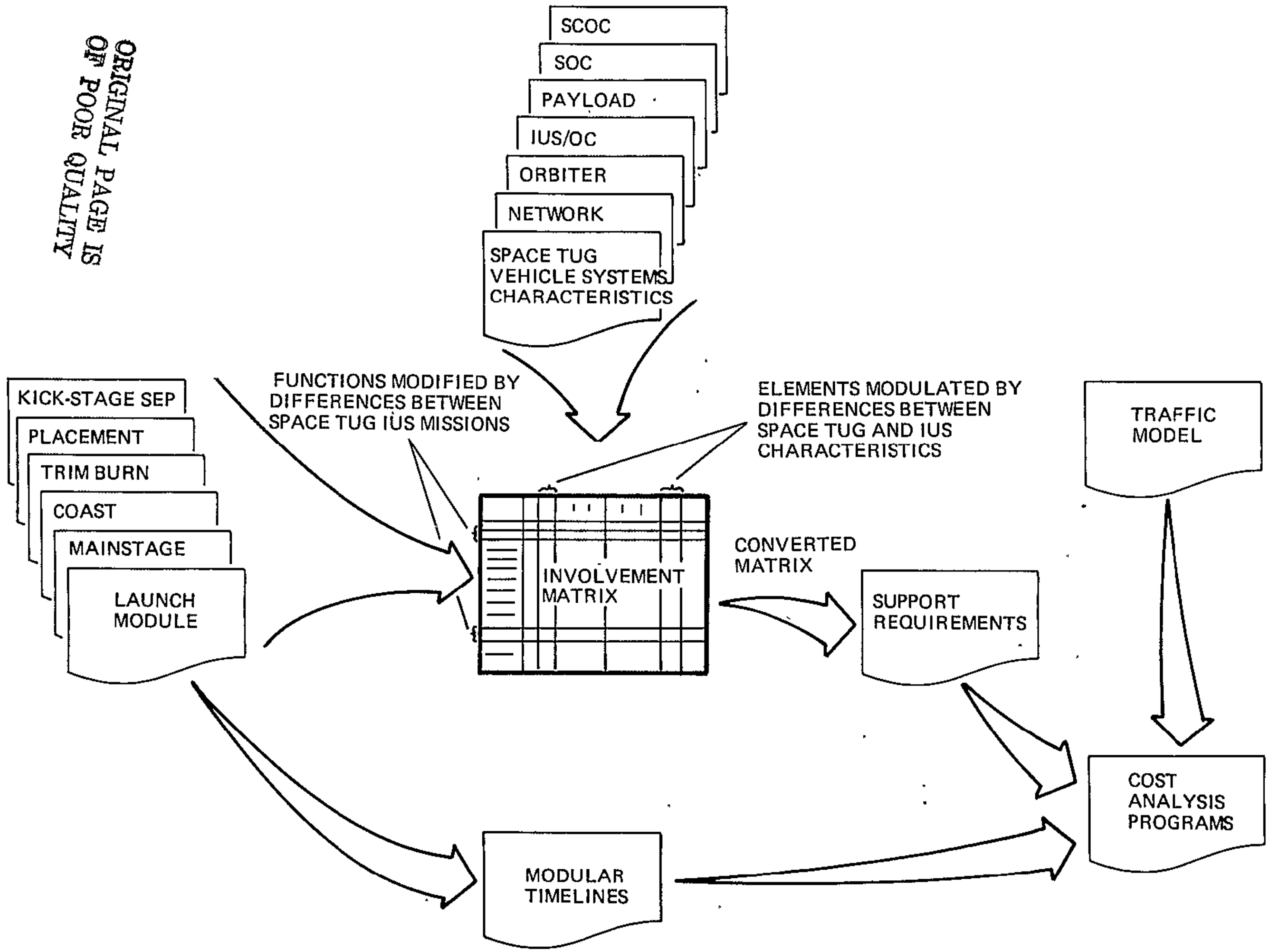

Figure 9.7.0-1. IUS Methodology

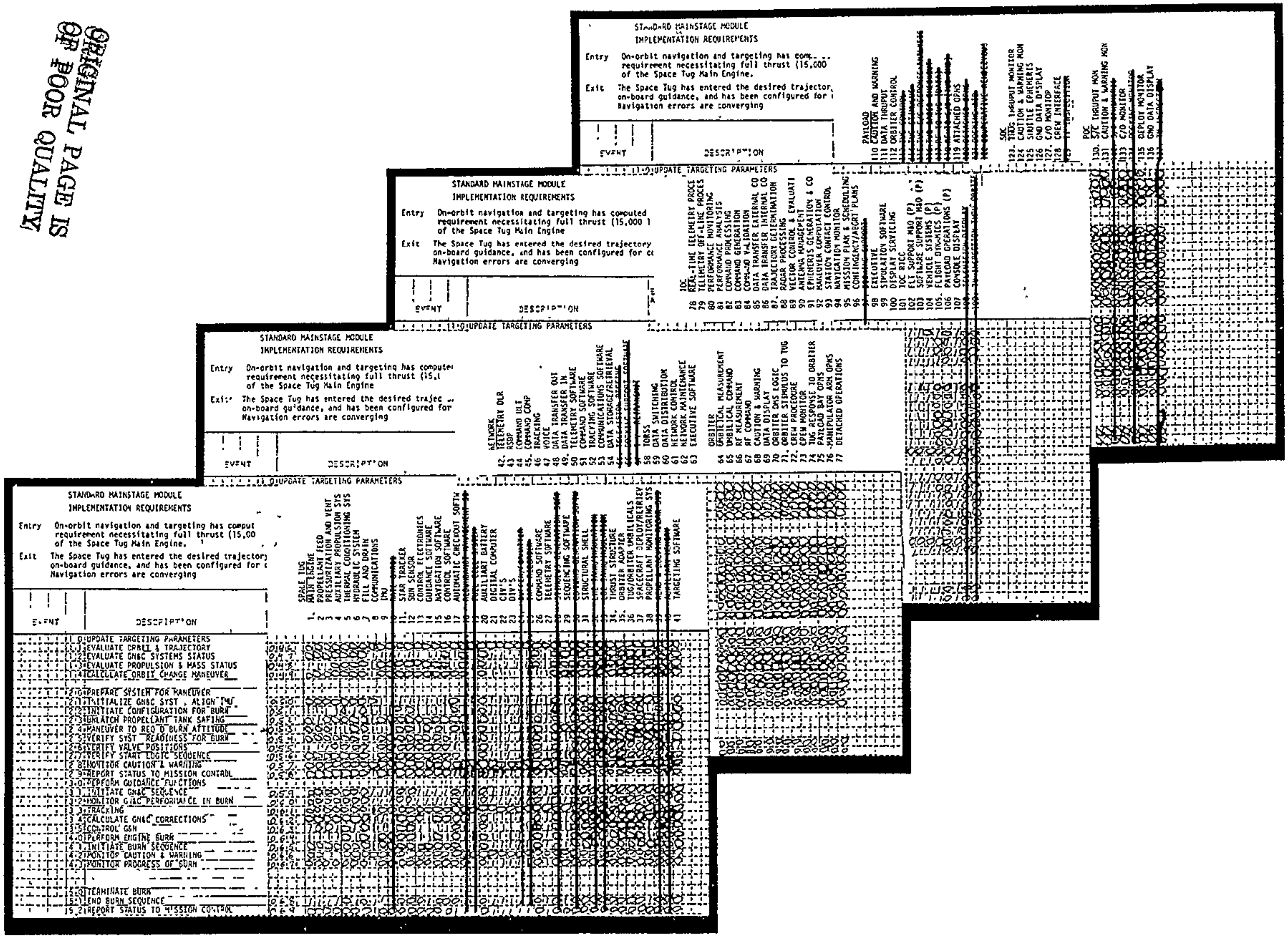

Figure 9.7.1-1. IUS Involvement Matrix

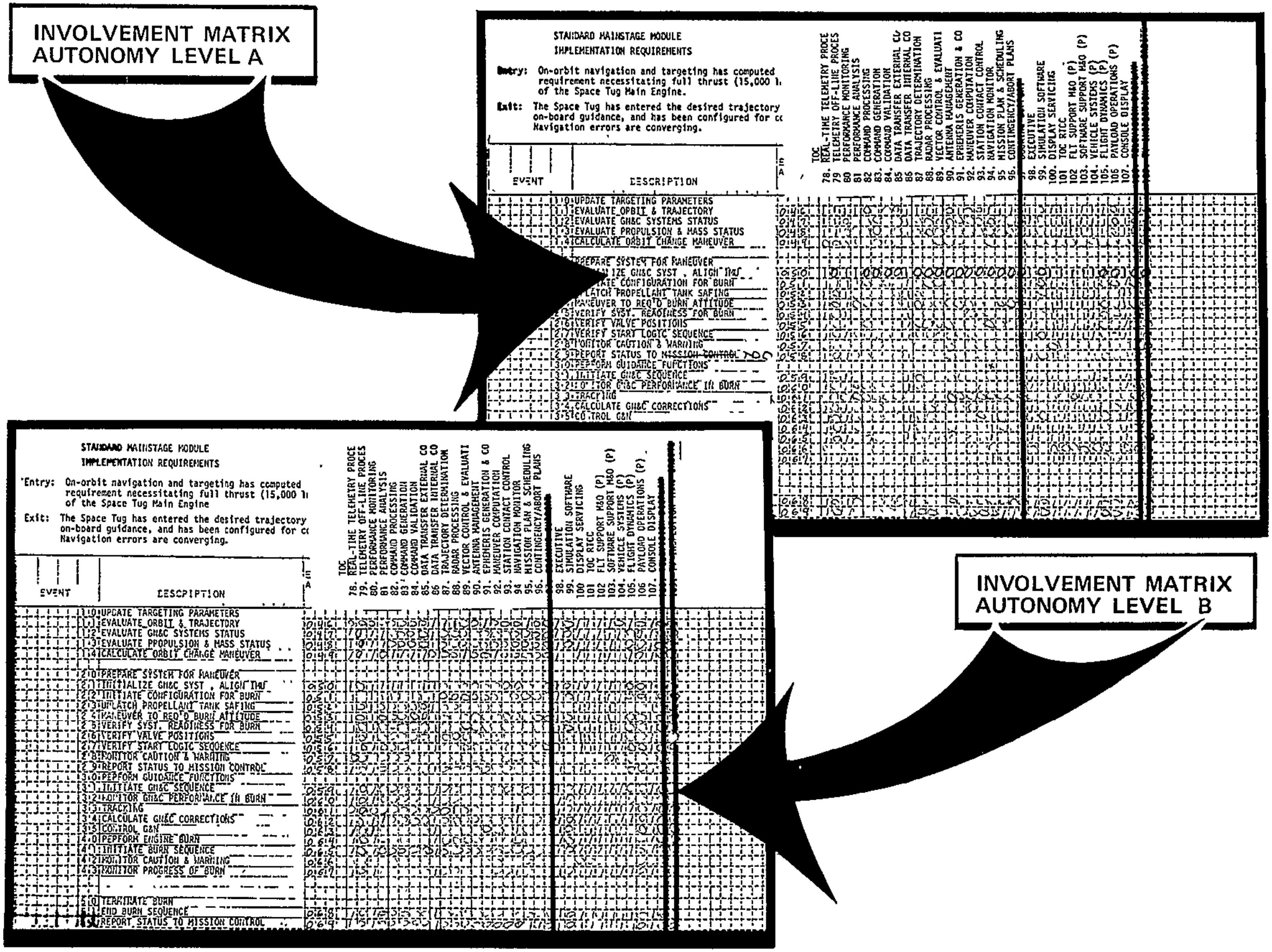

Figure 9.7.1-2. IUS Autonomy Level Differentation

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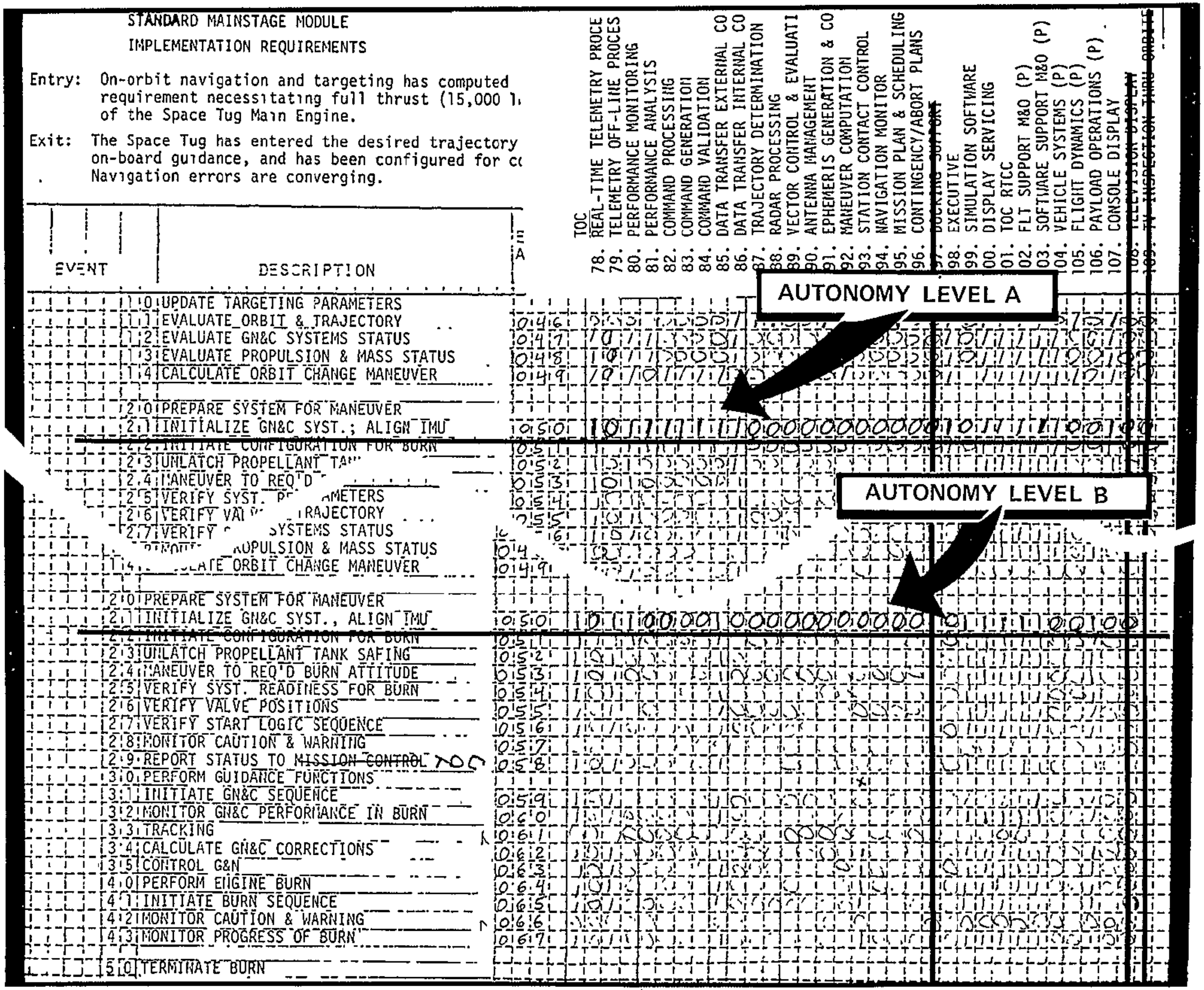


Figure 9.7.1-3. Autonomy Level Differentation

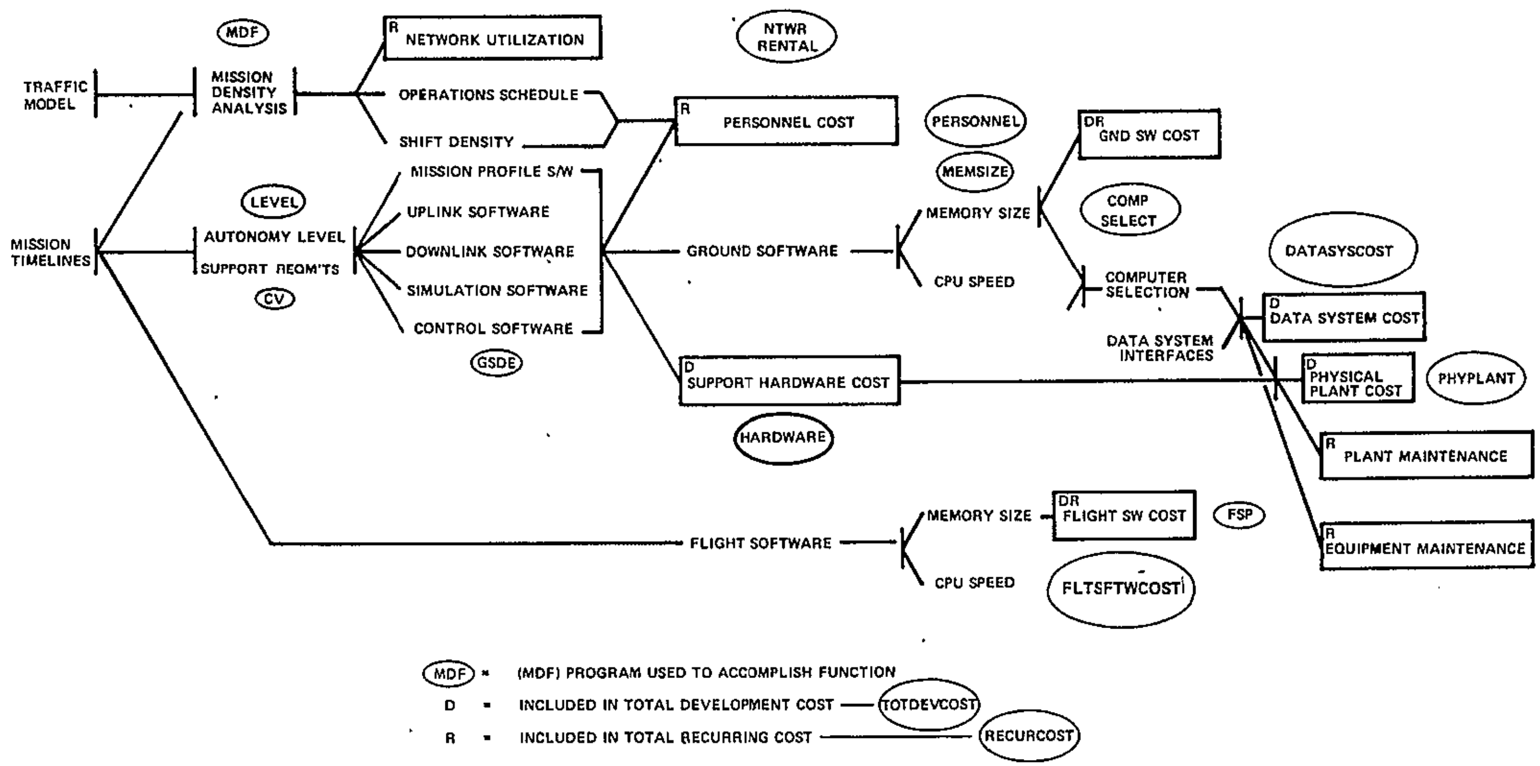


Figure 9.7.1-4. Cost Analysis Programs

implemented in the analytical software which creates the total development costs and total recurring costs for an operational concept. The inputs to and the outputs from the operations are illustrated. The software active during the various processes are displayed by their mnemonic designators placed in the elliptical bubbles near the operations. Cost output information, that is, printouts available of the programs, are enclosed in rectangular boxes with either the letter D or the letter R entered in the box, indicating the final utilization of the derived cost in either the DDT&E summation or the recurring cost summation, or both. A sixteenth program, which analyzes the alternate concepts of mission operations, was utilized in the generation of prior study results.

9.7.2 DDT&E Costs - Level B EIUS

First estimates of DDT&E costs have been derived for the Level B EIUS, by using the cost analysis programs presented in a previous section. These estimates encompass all "deliverable" end items in the EIUS program, but do not contain cost elements which have intermediate, or planning type outputs. The cost analysis programs account for 90% of the DDT&E expenses. A detailed examination of the Work Breakdown Structure (WBS) presented in Volume V will identify the elements not priced by the cost analysis programs.

Figure 9.7.2-1 presents the Ground Software DDT&E cost estimate.

Figure 9.7.2-2 presents the Flight Software DDT&E cost estimate for the flight software.

Figure 9.7.2-3 presents the Data System DDT&E costs.

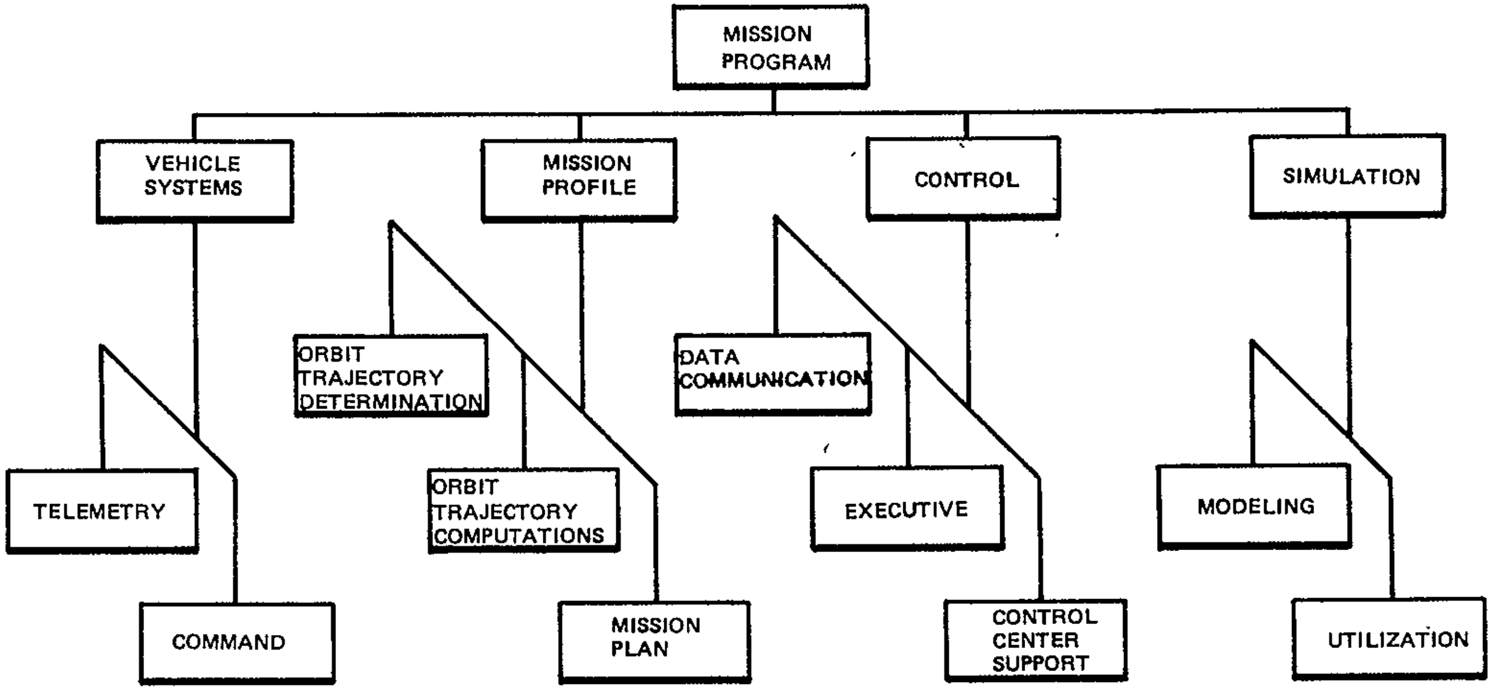
The operational console hardware is tabulated in Table 9.7.2-1.

Figure 9.7.2-4 represents the physical plant DDT&E costs.

Table 9.7.2-1. Consoles and Hardware Costs

Equipment Item	Quantity	Unit Cost	Total Cost
Console	17	4,800	81,600
Communication Panel	28	6,000	168,000
TV Monitor	34	2,000	68,000
Event Monitor	66	8,000	528,000
MED	18	6,400	115,200
Command Panel	8	7,200	57,600
Display Control Panel	17	2,000	34,000
TOTAL			1,052,400

Table 9.7.2-2 summarizes the total DDT&E costs output by the cost analysis programs.

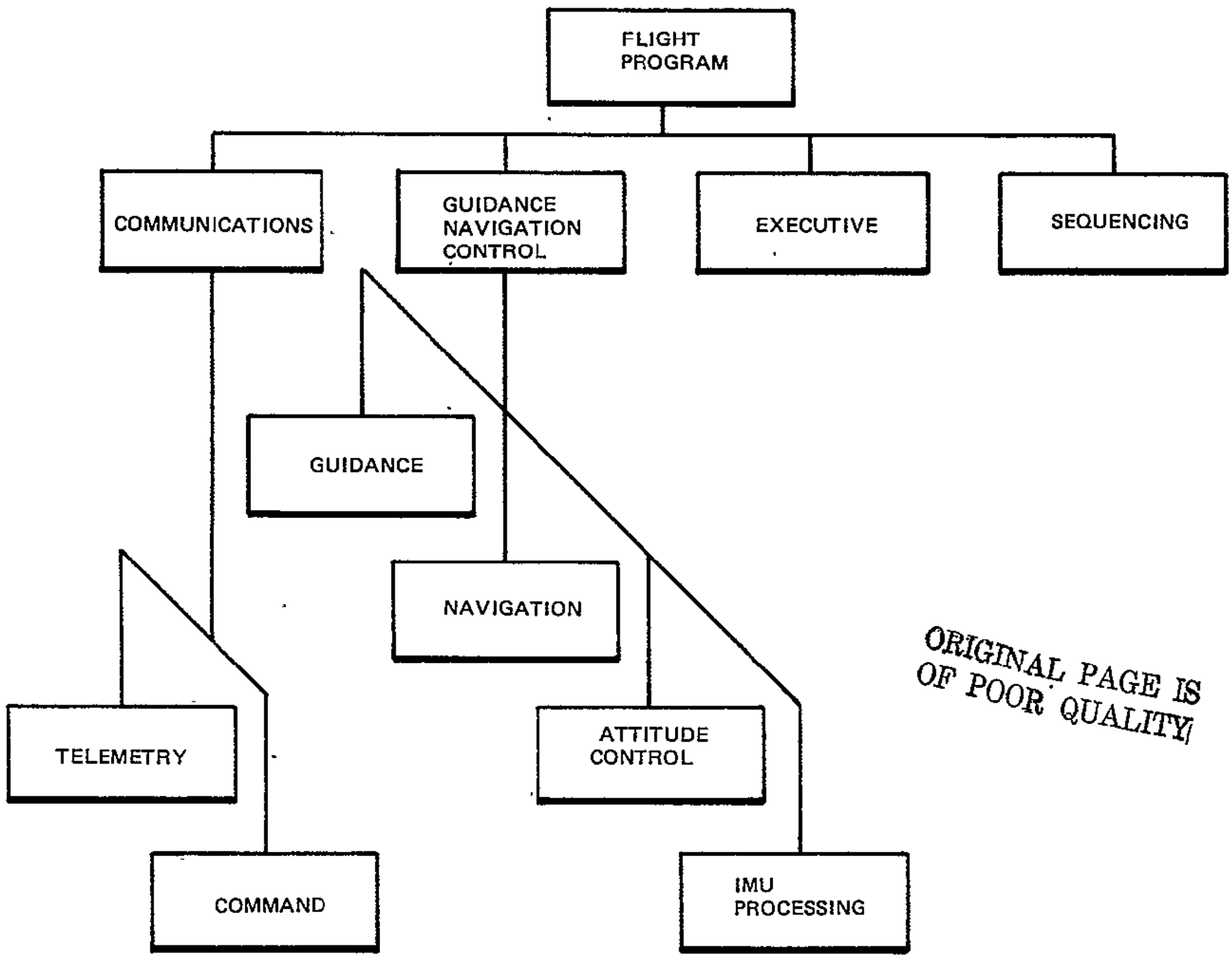


THE CONSTANTS USED IN COMPUTING GND SFTWR COSTS BY THIS FUNCTION ARE:

1) *WORKING DAYS/MONTHS* = 21
2) *COMPUTER WORDS/INSTRUCTION* = 1
3) *PROGRAMMER PRODUCTIVITY (INST. LINES/DAY)* = 14
4) *COMPUTER WORDS/DATA* = 4
5) *PROGRAMMER PRODUCTIVITY (DATA LINES/DAY)* = 30

PROGRAM	*INSTRUCTION SIZE (WORDS)*	*INSTRUCTION COST (DOLLARS)*	*DATA SIZE (WORDS)*	*DATA COST (D)*	*COMPLEXITY FACTOR*	*TOTAL (D)*
DOWNLINK PROCESSING	82800	1126531	21900	34762	1.00	1161293
UPLINK PROCESSING	38800	527891	24400	38730	1.00	566621
MISSION PROFILE	142100	2577778	79000	125397	.75	2703175
EXECUTIVE	222000	6040816	33300	52857	.50	6093673
CONTROL CENTER SUPPORT	13800	375510	5200	8254	.50	383764
DATA COMMUNICATIONS	3800	103401	2500	3968	.50	107370
SIMULATION SYSTEM	132200	2398186	62400	99048	.75	2497234
TOTALS		13150113		363016		13513129

Figure 9.7.2-1. Ground Software DDT&E Costs

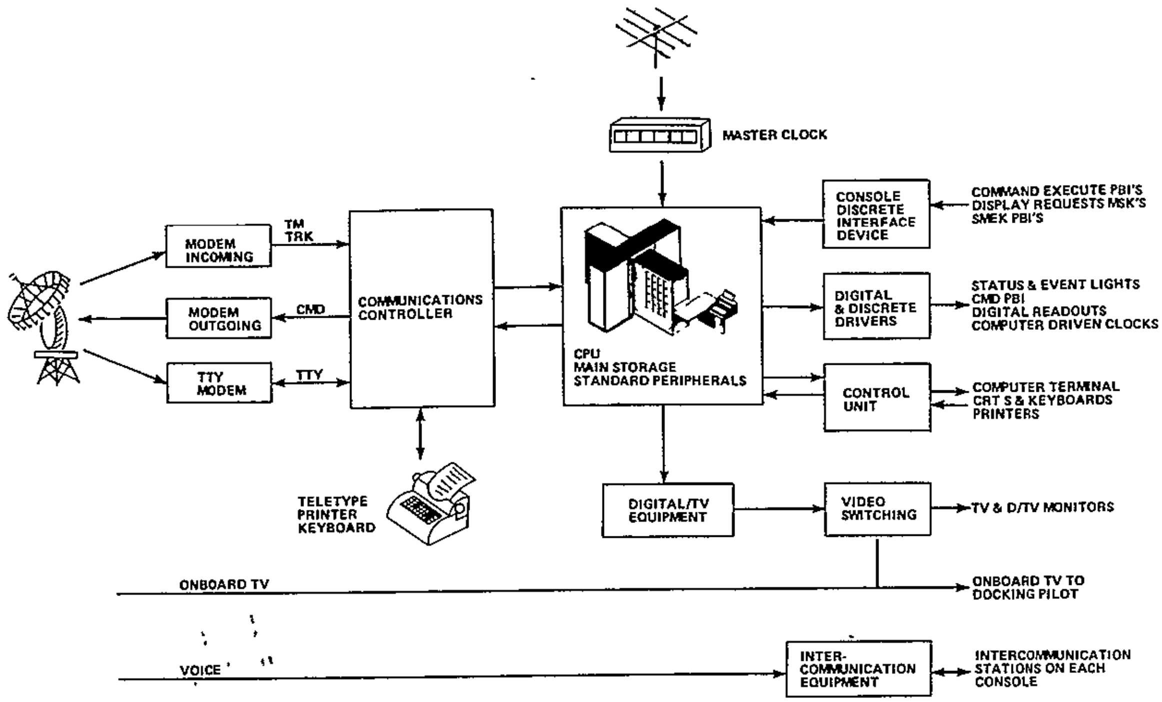


THE CONSTANTS USED IN COMPUTING FLT SFTWR COSTS BY THIS FUNCTION ARE:

1) *WORKING DAYS/MONTH* = 21
2) *COMPUTER WORDS/INSTRUCTION* = 1
3) *PROGRAMMER PRODUCTIVITY (INST. LINES/DAY)* = 6.9
4) *COMPUTER WORDS/DATA* = 4
5) *PROGRAMMER PRODUCTIVITY (DATA LINES/DAY)* = 30

PROGRAM	*INSTRUCTION SIZE (WORDS)*	*INSTRUCTION COST (DOLLARS)*	*DATA SIZE (WORDS)*	*DATA COST (D)*	*TOTAL (D)*
DOWNLINK PROCESSING	330	34632	94	339	34971
UPLINK PROCESSING	1622	336446	291	1049	337495
EXECUTIVE	2348	728572	2399	8644	737216
SEQUENCING	517	69296	1069	3852	73148
GUID.,NAV. AND CNTL.	8574	1538354	2224	8013	1546367
TOTALS		2707300		21896	2729197

Figure 9.7.2-2. Flight Software DDT&E Costs

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ENTER THE UNIT COST (IN DOLLARS) FOR EACH
OF THE FOLLOWING ELEMENTS
          MASTER  CLOCK
          ⎕:
                44560
          NTWK. TERMINAL EQUIP.
          ⎕:
                20900
          TTY PRINTER KEYBOARD
          ⎕:
                3172
          INTERCOM. EUIP.
          ⎕:
                230000
          DATA SYSTEM  COST
                ITEM                       COST
          3158 MP6                      6711376
          MASTER  CLOCK                   44560
          NTWK. TERMINAL EQUIP.           20900
          TTY PRINTER KEYBOARD             3172
          INTERCOM. EUIP.                230000
                          TOTAL         7010008
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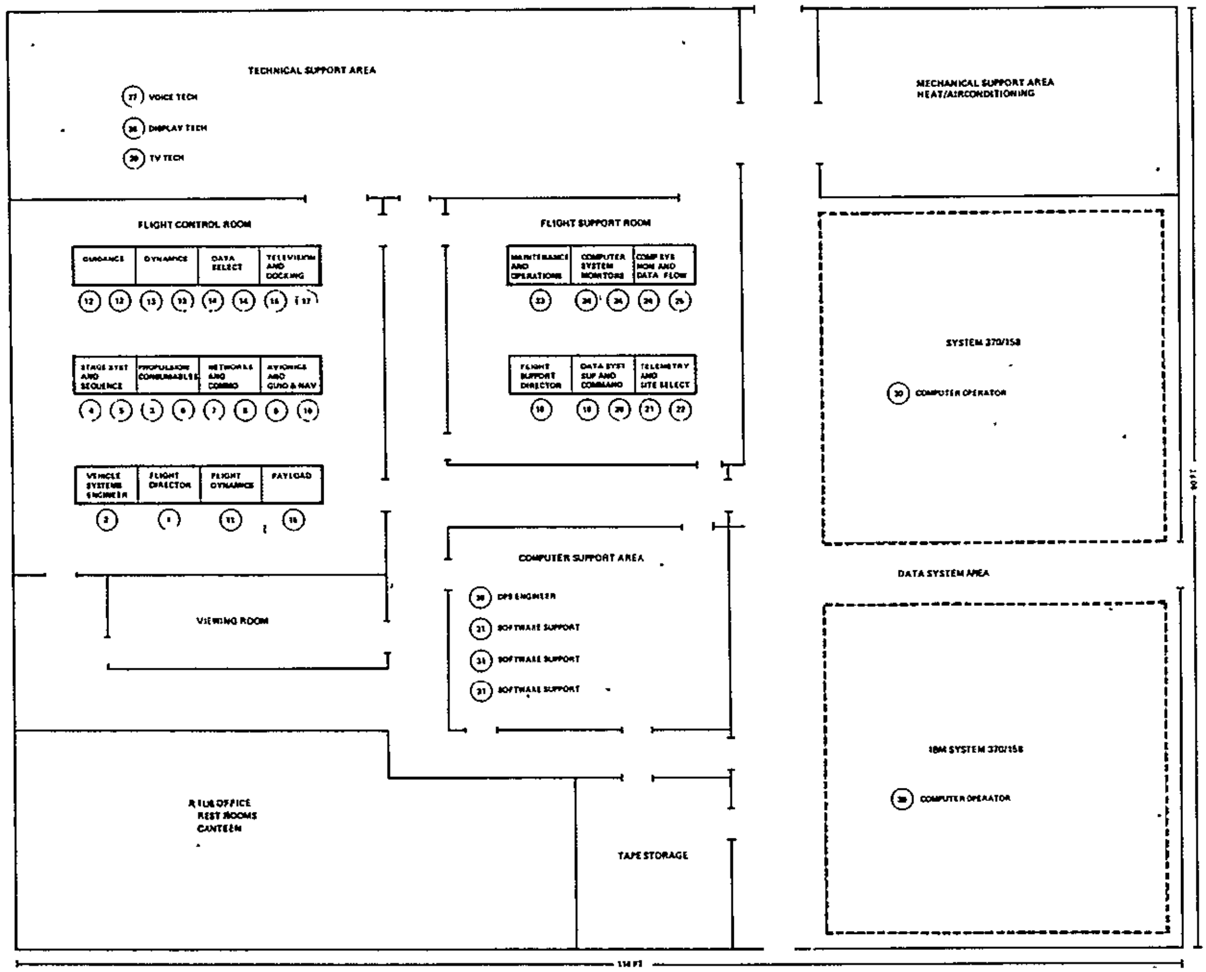
Figure 9.7.2-3. IUS/OC Support Hardware DDT&E Costs



IUS OC AREA	SQ. FT.	D/SQ. FT.	COST (D)
FLIGHT CONTROL ROOM	1100	50	55000
FLIGHT SUPPORT ROOM	600	50	30000
DATA SYSTEM AREA	3024	50	151200
VIEWING ROOM	243	28	8505
COMPUTER SUPPORT AREA	594	28	20790
TAPE STORAGE	255	28	8925
OFFICES,RESTROOMS,CANTEEN	1080	28	37800
TECHNICAL SUPPORT AREA	1296	28	45360
MECHANICAL SUPPORT AREA	612	28	21420
HALL/LOBBY	1132	28	39620
TOTAL	9936		418620

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ENTER THE AREAS (IN SQ. FT.
VIEWING ROOM
⎕:
      243
COMPUTER SUPPORT AREA
⎕:
      594
TAPE STORAGE
⎕:
      255
OFFICES, RESTROOMS, CANTEEN
⎕:
      1080
TECH. SUPPORT AREA
⎕:
      1296
MECH. SUPPORT AREA
⎕:
      612
HALL/LOBBY
⎕:
      1132
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Figure 9.7.2-4. Physical Plant DDT&E Costs

Table 9.7.2-2. Total EIUS DDT&E Cost Summary

Element	Dollars
Physical Plant	418,620
IUS/OC Software Development	13,513,129
Data System	7,010,008
Operations Staff Equipment	1,052,400
IUS Software Development	2,729,197
TOTAL	24,723,354

9.7.3 Recurring Costs - Level B IUS

The recurring costs incurred in orbital operations and mission support are in the main service type costs, since there are no major hardware refurbishments involved. The types of costs included are: facility maintenance, ground software update and maintenance, data system maintenance, IUS flight software maintenance, sustaining facilities engineering, sustaining flight control engineering and network rental expenses. Of these tasks, facility maintenance and data system maintenance will be contracted to outside agencies. Ground software update and maintenance will be accomplished by the permanently assigned software support team. The sustaining facilities engineering and sustaining flight control engineering personnel will perform all pre-mission preparations, training and conduct of mission operations. Network rental will be charged to the Operations organization on the basis of the number of hours utilized and the type of service rendered. The IUS flight software maintenance tasks are those tasks involved in defining, programming and verifying mission specific deviations from the basic four flight programs. This is largely a manpower expense. Computer time will be provided by the control center computer at no cost.

9.7.3.1 Facility Maintenance

Facility maintenance includes refuse disposal, janitorial services, internal electrical maintenance, internal power and heating maintenance, internal painting, air-conditioning costs, exterior painting, roofing, and parking lot maintenance. Facility maintenance costs commonly are based upon a constant of approximately $1.32 for government installations and $2.00 for industrial installations. The cost of facility maintenance is computed from the estimated number of square feet required by the operations and support areas multiplied by $2.00 per square foot. This expense is approximately $20,000 per year.

9.7.3.2 Ground Software Update and Maintenance

The approach chosen to develop this algorithm divides the software maintenance task into two subtasks. The first subtask consists of finding and fixing software problems, supporting system operation, and installing nominal mission-to-mission program enhancements. The second subtask consists of adding new functions and performing major modifications to the existing software system.

The cost of the former can best be sized as a "level of effort" task. Since software problems will probably be discovered throughout the software system, a level of expertise must be maintained through the availability of personnel familiar with every software area. The number of personnel required for each area is dependent on the size, complexity, criticality, and level of mission-to-mission changes for the programs therein.

The level of effort will decrease as a function of time. Saturn Launch Computer Complex data indicates that the number of software problems decreased by more then 50% during the first year of system operation. After the first year, the number of problems should continue to decrease but at a much slower rate.

The cost of the second subtask is similar to that of new software development. Two offsetting attributes of modification/extension work affect this cost. The first is that adding new functions to an existing working system is easier than new work due to the existence of well defined, operational interfaces and system services. The second attribute applies to modifications.

Modifications usually require a significantly greater degree of design and system testing than the number of instructions involved would indicate. Modifications in inter-program interfaces can spread through larger parts of the system causing subtle problems which require extensive system testing.

Given these offsetting factors and assuming a reasonable mixture of the two, we can approximate these costs by using the same cost algorithm as used for new development work.

9.7.3.3 Data System Maintenance

Standard rate schedules exist for the maintenance of large-scale computer systems and the associated peripheral gear. For the data systems chosen, the data system maintenance costs are approximately $139,000 per year for the IUS program. Maintenance of all other equipment will be a responsibility of the sustaining flight support engineering organization.

9.7.3.4 Sustaining IUS/OC Engineering

A certain minimum staff is required to control and support the control of an IUS vehicle. That staff is divided into two major groupings--the flight support group (Sustaining Engineering) and the flight control group. There are 30 personnel required to staff the flight support organization on a continuing basis. These people have been costed at $48,000 per man per year.

The size of the staff is established by the real-time support requirements. However, the staff, during non-mission and non-training periods, is to be utilized to perform mission preparations and maintenance jobs. This multiplexing of personnel is cost-effecitve in that it spreads the productive work load of the permanently assigned personnel more evenly across the operational periods.

9.7.3.5 Sustaining Flight Control Engineering

There is a specific minimum staff required to control the IUS vehicle during mission operational periods. For the IUS program, that staff requirement is 30 flight control engineers. The flight control organization is a required sustaining engineering staff which may be utilized during non-mission periods in performing preparation tasks, such as training, scheduling, and interface type operations. As with the flight support staff, the spreading of effort across the period of operations is a cost-effective utilization of the flight control staff.

9.7.3.6 Network Rental

In order to arrive at a minimum network rental cost, Philco-Ford designed a system for the transmission of telemetry, command, tracking and television data from six STDN remote sites to the IUS operations control center. This network utilized commercial carrier satelite transmission directly from the ground station to the operations control center. Figure 9.7.3-1 presents the network and terminal cost data derived by Philco-Ford.

To implement the network, each of the remote stations requires a line terminal installation, which creates a recurrring cost of $31,700 per month. The line terminal equipment at the remote stations feed commercially available common carrier single-sideband data links at a composite leased cost of $284,830 per month. The leased lines are demultiplexed at the operations center by three line-terminal stations.

It is assumed that no costs will be incurred to rent the ground station equipment itself; that is, the data being fed to the line terminals at the STND sites are supplied free of charge to the IUS program by GSFC. It is also assumed that the terminal stations within the operations center are costed as a portion of the network terminal fees and are not part of the network rental computation. The summation of the recurring costs of network leasing per month and the STDN site stations per month are $475,030. To arrive at a minimum cost, the operation of the TDRS system was assumed. This reduced the monthly cost of ground station terminal equipment from $190,200 to $31,700. This was arrived at by assuming the TDRS ground station would be provided with the terminal equipment and a fee equivalent to the leased line cost from the 6 STDN stations would be imposed.

The summation of a single-station line terminal installation and the leased line costs is $316,530. Since these are leased costs, it is assumed that the hourly cost would be equivalent to dividing the summation of leased line cost and ground station recurring cost by the number of hours of operation in a month. This gives an hourly rate of $430. Now, the network rental charges will be further based upon the type of service required, since all phases of the missions do not require the entire capability of the leased lines. A further division of the $430 per hour fee was made on the basis of bandwidth requirements. The television signal requires 51 kilobits per second, the telemetry signals require 16 kilobits per second, the tracking and command signals require 2 kilobits per second each. It was estimated that if a charge were made on the basis of service provided, that charge would be approximately proportional to the bandwidth requirements of the type of signal being processed. On that basis, television was rated at $290 per hour, telemetry was rated at $90 per hour, and command and tracking were each rated at $25 per hour. Those constants were utilized in arriving at the network rental calculations.

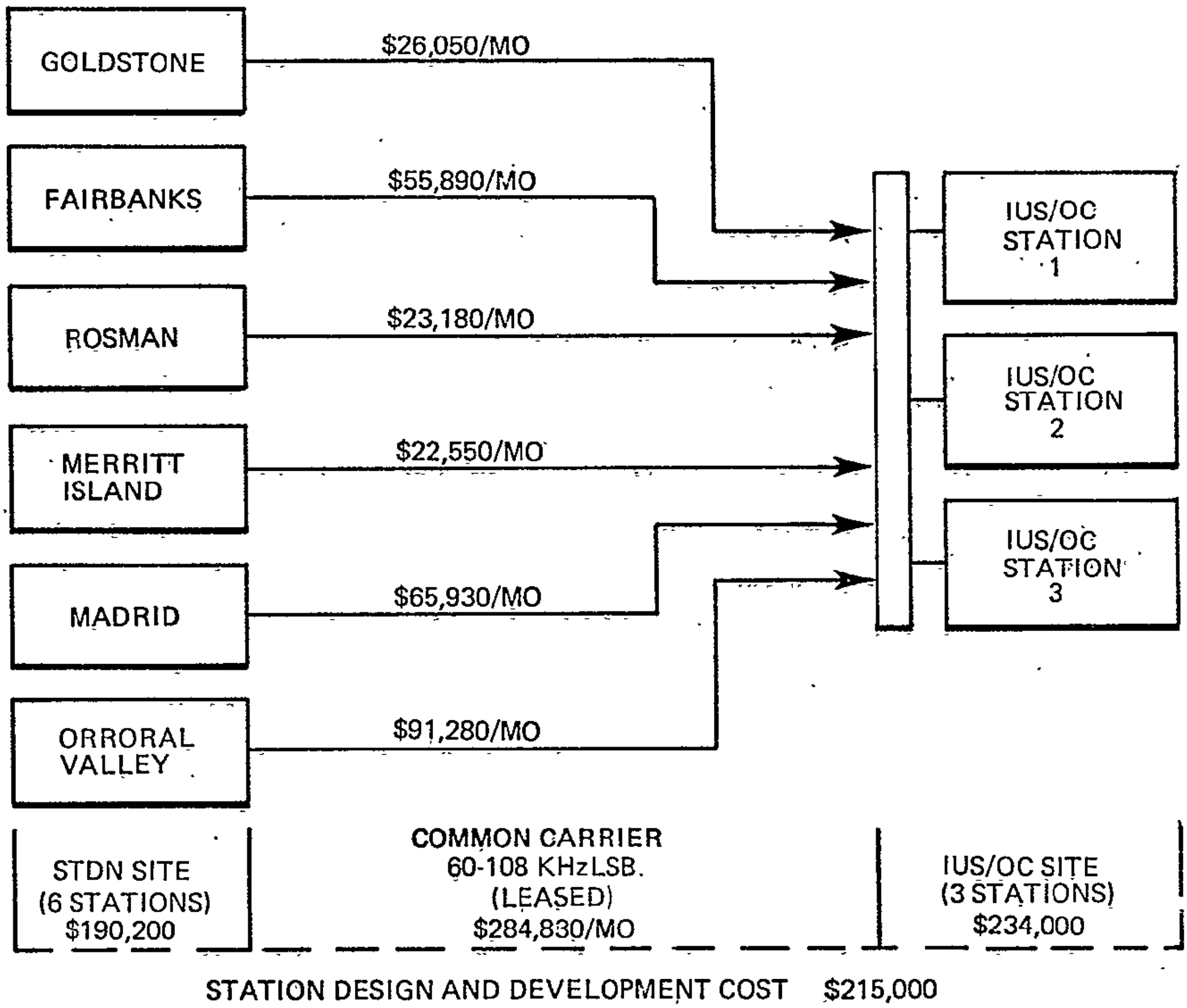


Figure 9.7.3-1. Network and Terminal Cost Data

The mission density function program within the cost analysis programs calculates the number of hours per year that each of the communications services are required, based upon the launch schedule and mission type established for that year. The baseline year chosen for IUS was 1983.

9.7.3.7 IUS Software Maintenance

A maintenance and support cost algorithm has been developed for flight software. This algorithm assumes that the four baseline programs generated in the DDT&E phase will not be subject to major modifications. A major modification, should one be required, is to be costed in accordance with the initial software development algorithm.

The maintenance and support cost algorithm divides the level of effort requirements into manpower required to design the changes, manpower required to program the changes, and manpower required for flight program verification. For programs less than 64,000 words (instructions and data) the level of effort is a function of the number of programs being maintained. The annual recurring cost for this service is $1.008 million per year for both the IUS flight program maintenance efforts.

9.7.3.8 Off-Peak Manpower Utilization

Flight control and flight support are full-time employment for those personnel assigned flight control and flight support duties. There will be no multiplexing between operational and non-operational assignments. The time during which operations are not in progress will be utilized by the assigned flight control and flight support personnel in preparation, maintenance and other operations related activities. The frequency and complexity of Space Tug missions dictate the assignment of a dedicated staff.

9.7.3.9 Summary of Recurring Costs

Table 9.7.3-1 presents a summary recurring costs.

Table 9.7.3-1. Recurring Cost Summary

Element	Dollars
Facility Maintenance	19,872
IUS/OC Software Maintenance	1,200,000
Data System Maintenance	138,795
Sustaining IUS/OC Engineering	1,440,000
Sustaining IUS Flt. Control	1,440,000
TL. Engineering	
Network Rental	26,233
IUS Software Maintenance	1,008,000
TOTAL	5,272,900

9.7.4 Alternative Concepts Cost Data

Figure 9.7.4-1 defines the operational concepts analyzed during the study and the application of the concepts to the IUS and Space Tug Programs.

Concept 1, Separate NASA/DoD System, is in accord with the NASA baseline concept and depicts separate NASA and DoD control center development to satisfy their respective requirements. In this concept control center hardware, software, manpower and facilities will be the responsibility of each separate agency; however, it does not preclude the potential of cost savings through the development of similar hardware and software.

Concept 3, DoD System, defines an IUS unique concept where DoD performs all IUS missions for both agency traffic models. NASA activity would be limited to the definition of NASA mission requirements, mission planning and post flight evaluation/data dissemination.

9.7.4.1 Level A Autonomy - Concept Development Cost Comparison

Figure 9.7.4-2 presents a comparison of NASA and DoD expenses for a Level A autonomy IUS design under the concepts:

1) Separate and equal NASA and DoD operation

3) Single facility, DoD owned, NASA tenant

Similarity of Concept 1 costs derives from the assumption that NASA and DoD operate in similar modes, and the DoD costs are comparable to NASA costs for similar functions.

The shift in costs to increase the host's net outlay in Concept 3 does not preclude recovery of some portion from the tenant, but does assume the host will retain all program assets.

The costs presented update and supercede the figures presented in the December IUS Baseline Operations Plan (IBM No. 74W-00283). Cost increases in operational hardware and flight software have been included.

9.7.4.2 Level A Autonomy - Concept Annual Recurring Cost Comparison

Figure 9.7.4-3 presents a comparison of NASA and DoD expenses for a Level A autonomy IUS design under the concepts:

1) Separate and equal NASA and DoD operation

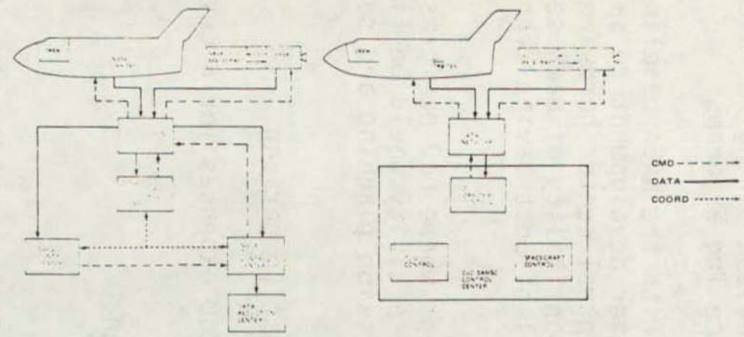
3) Single facility, DoD owned, NASA tenant

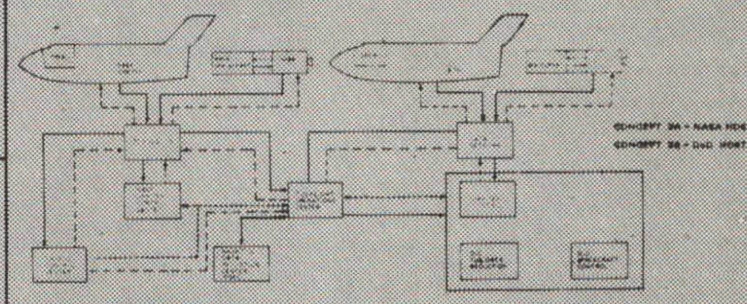
Similarity of Concept 1 costs derives from the assumption that NASA and DoD operate in similar modes, and the DoD costs are comparable to NASA costs for similar functions.

The shift in costs to increase the host's net outlay in Concept 3 does not preclude recovery of some portion from the tenant, but does assume the host will retain all program assets.

OPERATIONAL CONCEPTS

	APPLICATION	
	SPACE TUG	IUS
CONCEPT 1 – SEPARATE NASA/DoD SYSTEM	X	X
CONCEPT 2 – SHARED SYSTEM A. NASA HOST/DoD TENANT	X	
B. DoD HOST/NASA TENANT	X	
CONCEPT 3 – DoD SYSTEM (ALL IUS FLIGHTS)		X





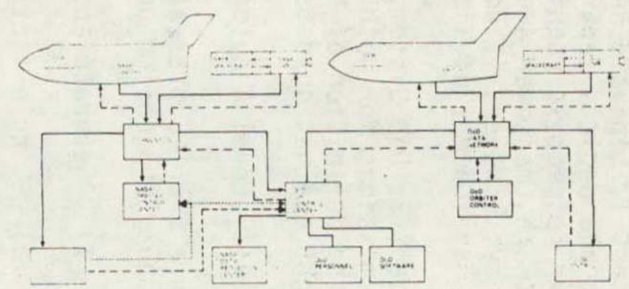
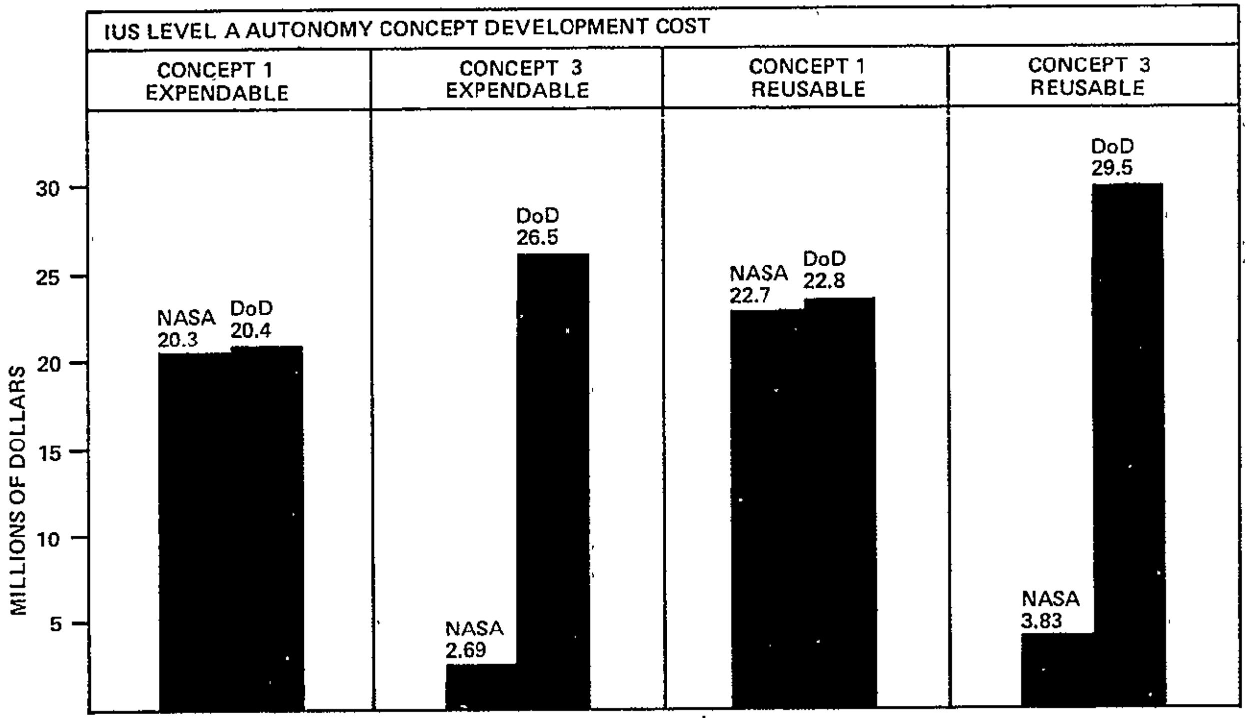


Figure 9.7.4-1. IUS/OC Operational Concepts



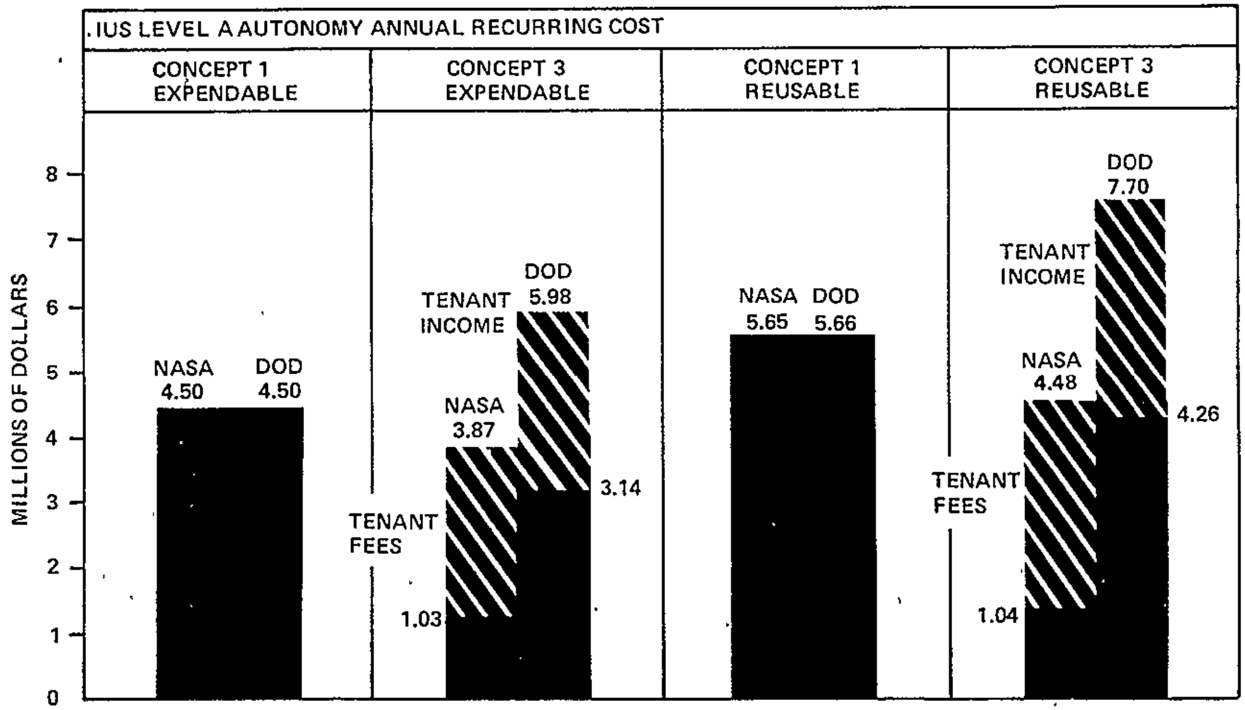
TOTAL ALTERNATIVE DEVELOPMENT COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 3 NASA	ALTERNATIVE 3 DOD
PHYSICAL PLANT	372136	409350	0	520990
TOC SOFTWARE DEVELOPMENT	10112000	10112000	299347	12143040
DATA SYSTEM	6504008	6504008	0	9756012
OPERATIONS STAFF EQUIPMENT	884400	972840	0	1680360
IUS SOFTWARE DEVELOPMENT	2391702	2391702	2391702	2391702
TOTALS	20264245	20389899	2691049	26492104

TOTAL ALTERNATIVE DEVELOPMENT COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 3 NASA	ALTERNATIVE 3 DOD
PHYSICAL PLANT	382136	420350	0	534990
TOC SOFTWARE DEVELOPMENT	11515093	11515093	624062	14041256
DATA SYSTEM	6504008	6504008	0	9756012
OPERATIONS STAFF EQUIPMENT	1052400	1157640	0	1999560
IUS SOFTWARE DEVELOPMENT	3203274	3203274	3203274	3203274
TOTALS	22656910	22800364	3827336	29535093

Figure 9.7.4-2. Level A Autonomy Development Cost Summaries



TOTAL ALTERNATIVE RECURRING COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 3 NASA	ALTERNATIVE 3 DOD
FACILITY MAINTENANCE	19472	21419	0	27261
TOC SOFTWARE MAINTENANCE	1008000	1008000	0	1270080
DATA SYSTEM MAINTENANCE	134458	134458	0	201687
SUSTAINING TOC ENGINEERING	1440000	1440000	0	2160000
SUSTAINING TOC FLT. CNTL. ENGINEERING	864000	864000	0	1296000
NETWORK RENTAL	21510	21510	21510	21510
IUS SOFTWARE MAINTENANCE	1008000	1008000	1008000	1008000
TOTALS	4495440	4497387	1029510	5984538

NASA TENANT COSTS-ALTERNATIVE 3

ELEMENT	COST PER YEAR
SERVICE FEES	
FACILITY MAINTENANCE	5842
TOC SOFTWARE MAINTENANCE	262080
DATA SYSTEM MAINTENANCE	67229
SUSTAINING TOC ENGINEERING	720000
SUSTAINING TOC FLT. CNTL. ENGINEERING	432000
NETWORK RENTAL	0
IUS SOFTWARE MAINTENANCE	0
RENTAL FEES	
PHYSICAL PLANT	37214
DATA SYSTEM	1084001
OPERATIONS STAFF EQUIPMENT	235640
TOTAL	2844205

TOTAL ALTERNATIVE RECURRING COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 3 NASA	ALTERNATIVE 3 DOD
FACILITY MAINTENANCE	19872	21859	0	27821
TOC SOFTWARE MAINTENANCE	1104000	1104000	0	1391040
DATA SYSTEM MAINTENANCE	134458	134458	0	201687
SUSTAINING TOC ENGINEERING	1632000	1632000	0	2448000
SUSTAINING TOC FLT. CNTL. ENGINEERING	1728000	1728000	0	2592000
NETWORK RENTAL	27953	27953	27953	27953
IUS SOFTWARE MAINTENANCE	1008000	1008000	1008000	1008000
TOTALS	5654283	5656270	1035953	7696501

NASA TENANT COSTS-ALTERNATIVE 3

ELEMENT	COST PER YEAR
SERVICE FEES	
FACILITY MAINTENANCE	5962
TOC SOFTWARE MAINTENANCE	287040
DATA SYSTEM MAINTENANCE	67229
SUSTAINING TOC ENGINEERING	816000
SUSTAINING TOC FLT. CNTL. ENGINEERING	864000
NETWORK RENTAL	0
IUS SOFTWARE MAINTENANCE	0
RENTAL FEES	
PHYSICAL PLANT	38214
DATA SYSTEM	1084001
OPERATIONS STAFF EQUIPMENT	280640
TOTAL	3443085

Figure 9.7.4-3. Level A Concepts Annual Recurring Cost Summaries

The costs presented update and supercede the figures presented in the December IUS Baseline Operations Plan (IBM No. 74W-00382). Cost increases in operational hardware and flight software have been included.

9.7.4.3 Level B Autonomy - Concept Development Cost Comparison

Figure 9.7.4-4 presents a comparison of NASA and DoD expenses for a Level B autonomy IUS design under the concepts:

1) Separate and equal NASA and DoD operation

3) Single facility, DoD owned, NASA tenant

Similarity of Concept 1 costs derives from the assumption that NASA and DoD operate in similar modes, and the DoD costs are comparable to NASA costs for similar functions.

The shift in costs to increase the host's net outlay in Concept 3 does not preclude recovery of some portion from the tenant, but does assume the host will retain all program assets.

The costs presented update and supercede the figures presented in the December IUS Baseline Operations Plan (IBM No. 74W-00283). Cost increases in operational hardware and software have been included.

9.7.4.4 Level B Autonomy - Concept Recurring Cost Comparison

Figure 9.7.4-5 presents a comparison of NASA and DoD expenses for a Level B autonomy IUS design under the concepts:

1) Separate and equal NASA and DoD operation

3) Single facility, DoD owned, NASA tenant

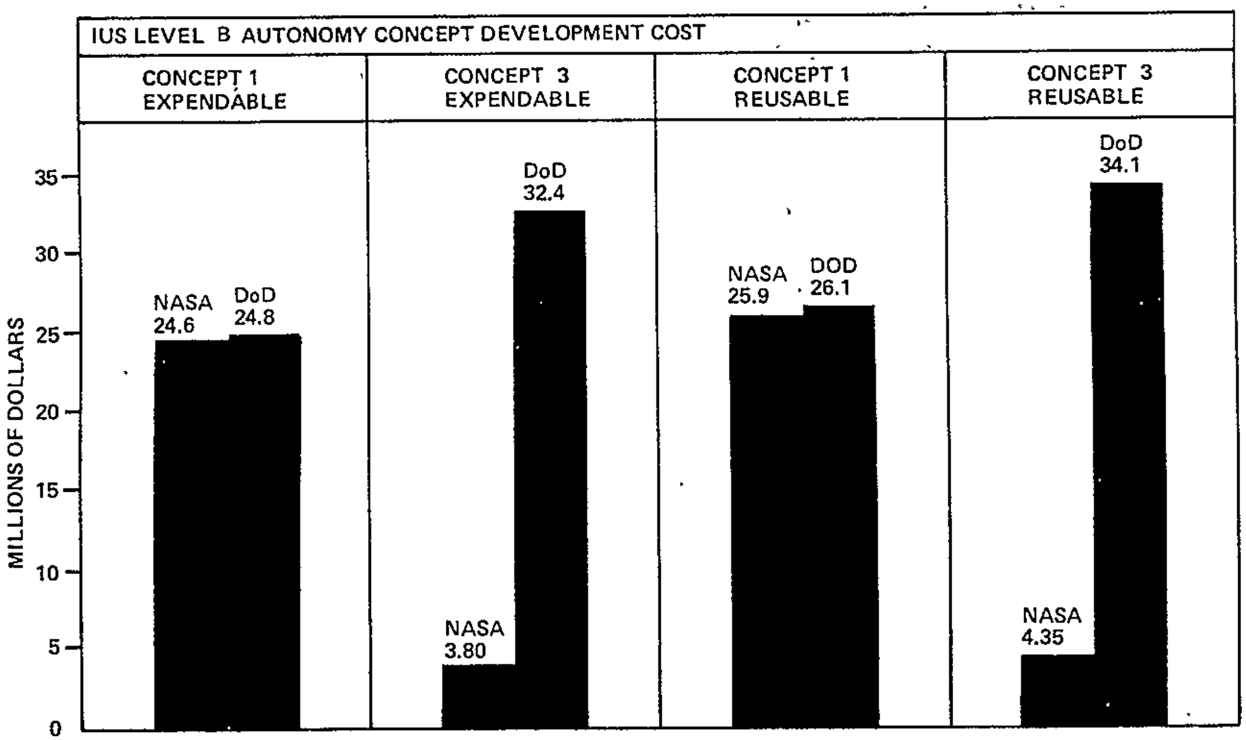
Similarity of Concept 1 cost derives from the assumption that NASA and DoD operate in similar modes, and the DoD costs are comparable to NASA costs for similar functions.

The shift in costs to increase the host's net outlay in Concept 3 does not preclude recovery of some portion from the tenant, but does assume the host will retain all program assets.

The cost presented update and supercede the figures presented in the December IUS Baseline Operations Plan (IBM No. 74W-00283). Cost increases in operational hardware and flight software have been included.

9.7.5 <u>Rationale for the Selection of Concept 1 Level B Expendable IUS</u>

The Expendable version of the IUS was selected over the Reusable version of the IUS because the Reusable version was approximated by the Space Tug analytical cases. This allowed more study effort to be directed toward the expendable case.



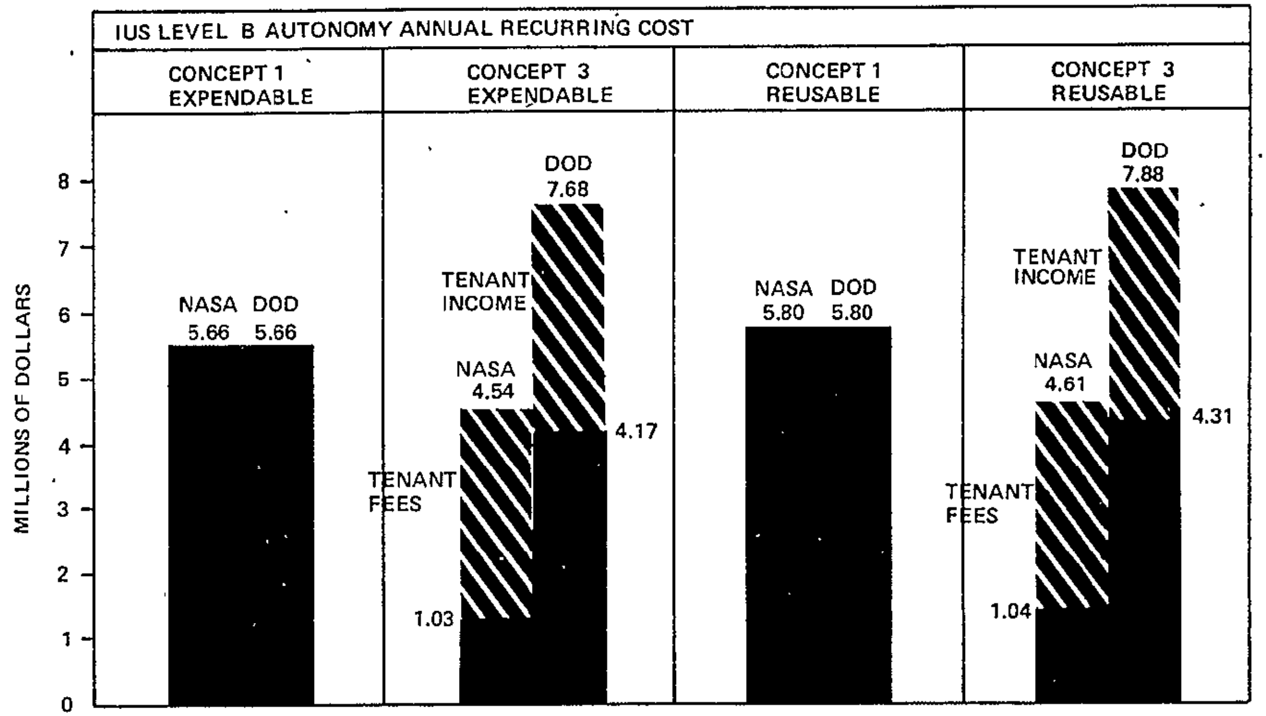
TOTAL ALTERNATIVE DEVELOPMENT COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 3 NASA	ALTERNATIVE 3 DOD
PHYSICAL PLANT	382136	420350	0	534990
TOC SOFTWARE DEVELOPMENT	13513129	13513129	1072753	16627057
DATA SYSTEM	7010008	7010008	0	10515012
OPERATIONS STAFF EQUIPMENT	1052400	1157640	0	1999560
IUS SOFTWARE DEVELOPMENT	2729197	2729197	2729197	2729197
TOTALS	24686870	24830323	3801950	32405816

TOTAL ALTERNATIVE DEVELOPMENT COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 3 NASA	ALTERNATIVE 3 DOD
PHYSICAL PLANT	382136	420350	0	534990
TOC SOFTWARE DEVELOPMENT	14605147	14605147	1454023	18100747
DATA SYSTEM	7010008	7010008	0	10515012
OPERATIONS STAFF EQUIPMENT	1052400	1157640	0	1999560
IUS SOFTWARE DEVELOPMENT	2902487	2902487	2902487	2902487
TOTALS	25952178	26095632	4356510	34052796

Figure 9.7.4-4. Level B Develop Cost Comparison



TOTAL ALTERNATIVE RECURRING COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 3 NASA	ALTERNATIVE 3 DOD
FACILITY MAINTENANCE	19972	21859	0	27[illegible]
TCC SOFTWARE MAINTENANCE	1200000	1200000	0	1512000
DATA SYSTEM MAINTENANCE	138795	138795	0	208192
SUSTAINING TCC ENGINEERING	1536000	1536000	0	2304000
SUSTAINING TCC FLT CNTL ENGINEERING	1724000	1724000	0	2592000
NETWORK RENTAL	26233	26233	26233	[illegible]
IUS SOFTWARE MAINTENANCE	1008000	1008000	1008000	[illegible]
TOTALS	5656900	5653987	1034233	[illegible]

NASA TENANT COSTS-ALTERANTIVE 3

ELEMENT	COST PER YEAR
SERVICE FEES	
FACILITY MAINTENANCE	5962
TCC SOFTWARE MAINTENANCE	312000
DATA SYSTEM MAINTENANCE	69397
SUSTAINING TCC ENGINEERING	764000
SUSTAINING TCC FLT CNTL ENGINEERING	864000
NETWORK RENTAL	0
IUS SOFTWARE MAINTENANCE	0
RENTAL FEES	
PHYSICAL PLANT	38214
DATA SYSTEM	1165335
OPERATIONS STAFF EQUIPMENT	260640
TOTAL	3506547

TOTAL ALTERNATIVE RECURRING COSTS

ELEMENT	ALTERNATIVE 1 NASA	ALTERNATIVE 1 DOD	ALTERNATIVE 3 NASA	ALTERNATIVE 3 DOD
FACILITY MAINTENANCE	19972	21859	0	27501
TCC SOFTWARE MAINTENANCE	1248000	1248000	0	1572480
DATA SYSTEM MAINTENANCE	138795	138795	0	208192
SUSTAINING TCC ENGINEERING	1632000	1632000	0	2448000
SUSTAINING TCC FLT CNTL ENGINEERING	1728000	1728000	0	2592000
NETWORK RENTAL	27953	27953	27953	27953
IUS SOFTWARE MAINTENANCE	1008000	1008000	1008000	1008000
TOTALS	5802520	5804607	1035953	[illegible]

NASA TENANT COSTS-ALTERNATIVE 3

ELEMENT	COST PER YEAR
SERVICE FEES	
FACILITY MAINTENANCE	5962
TCC SOFTWARE MAINTENANCE	324480
DATA SYSTEM MAINTENANCE	69397
SUSTAINING TCC ENGINEERING	816000
SUSTAINING TCC FLT CNTL ENGINEERING	864000
NETWORK RENTAL	0
IUS SOFTWARE MAINTENANCE	0
RENTAL FEES	
PHYSICAL PLANT	38214
DATA SYSTEM	1165335
OPERATIONS STAFF EQUIPMENT	260640
TOTAL	3567027

Figure 9.7.4-5. Level B Recurring Cost Summaries

Level B version of the Expendable IUS was chosen because the Level A version was unable to meet NASSA placement accuracy constraints within the performance envelope and had a command system which was limited to only two on/off commands. There was, therefore, no capability for real time alternate mission completion or timeline adjustment other than to terminate the mission. The conversion from Expendable Level A to Expendable Level B involves the addition of a digital command system and the associated interfaces to the onboard computer. It was thus possible to achieve the economic advantages of Level A Expendable IUS with the operational complexity required by NASA for minimum design change and cost.

Concept 1 was selected because Concept 3 involves NASA tenancy on a DoD facility with all of the attendant operational and access difficulties. DoD, due to the nature of their mission, must maintain a more rigid security than NASA. The probability of successfully operating a joint facility with dissimilar security requirements is low.

The technique used to establish the above conclusions is an adaptation of the Kepner-Tregoe Decision Analysis methodology to the parameters of the IUS program.

Six objectives were established. An objective, in Kepner-Tregoe context, is a factor or consideration to be optimized. Differing implementations, or "Alternatives" have differing impacts upon the objectives. In order to quantity these impacts and place the values of the objectives into perspective, each objective is given a "Rank", which is a numerical weight between 1 and 10 establishing the relative importance of the objective.

The impact of each alternative is established by analysis of the alternative and the estimation of the effect on the objective; a number between 0 and 10. In assessing the impact of alternatives, the sense of the assessing is that numerical value increases as "desirability" increases. For example, cost is an objective which is inversely related to desirability. Thus, higher cost results in a lower numerical value.

Once the impact of each alternative on each objective is established, a computer program performs the computations required to establish a final relative ranking of the alternatives.

The process is identical for establishing the undesirable attributes of each alternative. The final results are obtained by weighting the finishing order of desirable and undesirable alternatives and selecting the best composite alternative.

Three experienced mission operations engineers were given the task of establishing the impact of the Space Tug alternatives on a fixed set of objectives and adverse consequences. Figure 9.7.5-1 illustrates the Kepner-Tregoe input sheet.

Table 9.7.5-1 (a) presents the summary results of the three inputs after computation and rank-ordering.

The first column of Table 9.7.5-1 (a) is the weighting factor for rank-order. This is used to further drive apart the finishing position of each alternative.

IUS CONCEPT TRADE

INPUT DATA SHEET

		REUSABLE				EXPENDABLE			
		ALT 1		ALT 3		ALT 1		ALT 3	
OBJECTIVE	RANK	A	B	A	B	A	B	A	B
		CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
COST	10								
SUCCESS	9								
OPERABILITY	8								
MOD. ABILITY	5								
ACCESS	5								
ADVERSE CONSEQUENCES									
PRE—EMPTION	10								
HUMAN ERROR	9								
CHANGE CONTROL	6								
MOTIVATION	5								

- INPUT DATA FROM 3 EXPERIENCED ENGINEERS
- WEIGHTED (+5 TO −5) INDIVIDUAL SELECTIONS
- NUMERICAL SUM OF FACTORS/CONCEPT
- SELECTED "BEST SCORE" CANDIDATE

Figure 9.7.5-1. Kepner-Treqoe Input Sheet

Table 9.7.5-1 (b) is the final weighting matrix. The weighting factor of Table 9.7.5-1 (a) is multiplied by the number of times the alternative appears in the row having a weighting factor of 5, it is given a score of 10 in column one of Table 9.7.5-1 (b). When that operation is completed the columns are summed to give the final selection.

The IUS alternative scoring highest was expendable Level B autonomy - Concept 1, with Reusable Level B/Concept 1 ranked second. This leads to the conclusion that, based upon the objectives and adverse factors analyzed, expendable Level B Autonomy - Concept 1 implementation is the best selection for IUS operations.

Table 9.7.5-1. Kepner-Tregoe Results

(a)							(b)							
WEIGHT VALUES	MAN-A		MAN-B		MAN-C		CASE NUMBERS							
	A	0	A	0	A	0	1	2	3	4	5	6	7	8
5	6	2	6	3	5	7	0	5	5	0	5	10	5	0
3	2	4	5	7	6	5	0	3	0	3	6	3	3	0
1	1	1	2	8	1	3	3	1	1	0	0	0	0	1
0	5	6	1	4	2	8	0	0	0	0	0	0	0	0
0	4	8	8	2	7	1	0	0	0	0	0	0	0	0
-1	8	3	7	6	8	6	0	0	-1	0	0	-2	-1	-2
-3	7	7	4	1	3	4	-3	0	-3	-6	0	0	-6	0
-5	3	5	3	5	4	2	0	-5	-10	-5	-10	0	0	0
			CASE NUMBERS				0	4	-8	-8	1	11	1	-1

POTENTIAL PROBLEM AREAS SUMMARY 10

The IBM study defined items which appear to be potential problem areas for IUS operations while other areas require further consideration or analysis. A summary of these items are included in this section:

- IUS Activation Sequence - The timeline inputs from the IUS studies indicate that the IUS will be transferred to internal power and the communications activated prior to the Orbiter circularization burn. The deployment analysis by IBM indicates these subsystems should be activated just prior to umbilical disconnection, which is after the Orbiter circularization burn. Further analysis of these conflicts is needed.

- IUS Post-Deploy Activation - The IUS timelines indicate the IUS ACS is activated approximately 90 seconds after RMS separation. Further analysis is required to determine the time from RMS release to ACS attitude hold initiation.

- IUS/TDRS Interface Capability - The present baseline IUS data provided by NASA does not include the capability for IUS/TDRS communications interface. The NASA requirement exists for the IUS to provide the onboard capability for TDRS interface. This should be pursued to assure the capability is included on the IUS.

- STDN/TDRS Support For IUS Missions - In the event the IUS/TDRS interface is not feasible, STDN support after IUS deployment from the Orbiter is limited, and for some missions, no STDN support is available for post-deploy activation or main engine burn phases. Without TDRS interface, limited ground support is available for IUS critical events. Consideration should be given to performing more detailed timeline analyses for a variety of IUS missions.

- TDRS support for 64 KBPS TM Link - The use of the 64 KBPS IUS output requires a single access channel, wherein, use of the 16 KBPS requires only a multiple access channel. The requirements for the 64 KBPS link interface prior to deployment (when the IUS is attached to the Orbiter) and after deployment should be assessed.

- IUS Checkout - As discussed in Section 6.2, the IUS does not have the capability for complete self-checkout. The requirements for this capability should be reassessed.

- Retrieval of a Disabled EIUS - This study did not include the analysis for retrieval of a disabled EIUS (or Spacecraft) if it is in an Orbit which is accessable to the Orbiter. An example would be the failure of the EIUS prior to its first mainstage burn. This area should be studied to determine if a retrieval capability for the EIUS is justified.

- Spacecraft Orbiter Impacts - The EIUS Orbiter software impacts were investigated, but the Spacecraft software impacts on the Orbiter were not. The Spacecraft impacts should be assessed to determine the total EIUS and Spacecraft impacts on the Orbiter.

- EIUS Deployment Adapter (Cradle) Definition - A dated cradle definition was used by IBM for the deployment sequence and operations analysis. An updated deployment adapter definition from the current DoD studies should be assessed for potential impacts on flight and timeline operations.

REFERENCES 11

1. "Basic IUS System Requirements - Part I," SR-IUS-100.

2. "IUS System Detail Safety Requirements," - Appendix IV to SR-IUS-100.

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