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

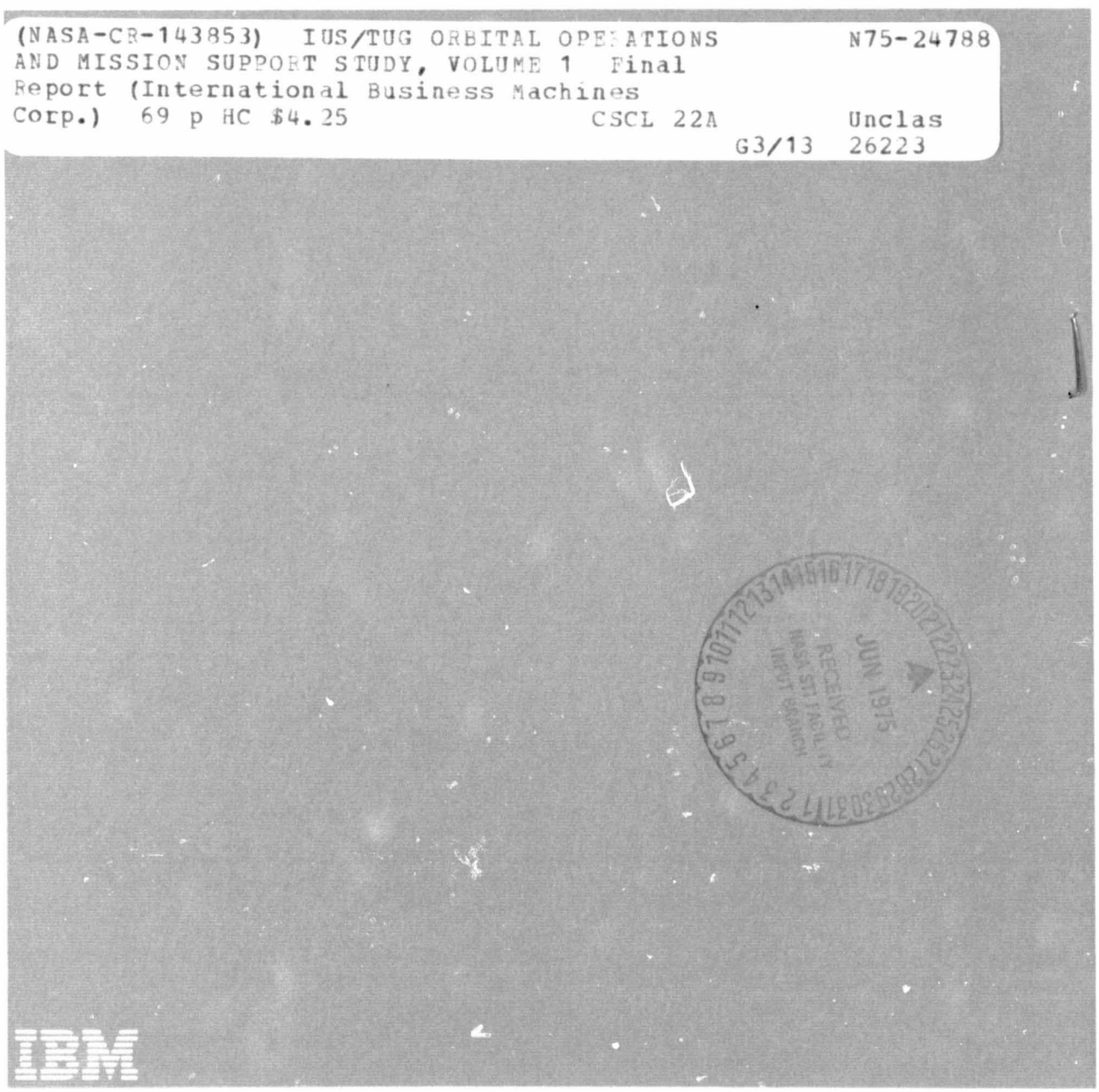
FINAL REPORT

Vol. I of V - Executive Summary

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Classification and Content Approval

Data Manager Approval

Program Office Approval

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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
B/U - Backup

C&D - Control and Display
C&W - Caution and Warning
CCTV - Closed Circuit Television
CMDS - Command
C/O - Checkout
CYI - Canary Island - STDN Ground Station

DFCS - Digital Flight Control System
DMS - Data Management System
DoD - Department of Defense
DSN - Deep Space Network

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
MDM -	Multiplexer/Demultiplexer (Orbiter)
MGC -	Missile Guidance Computer (IUS)
MHz -	Megahertz
MIL -	Merritt Island, Florida - STDN Ground Station
MPS -	Main Propulsion System
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)
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

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
S/C -	Spacecraft
SCF -	Satellite Control Facility
SGLS -	Space Ground Link System
SIRD -	Support Instrumentation Requirements Document
SOC -	Spacecraft 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
Vdc -	Direct Current Voltage
ZOE -	Zones of Exclusion
ΔV -	Delta Velocity

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INTRODUCTION 1

The Space Transportation System (STS) will include a propulsive stage that is carried into low earth orbit by the Space Shuttle. Data have been accumulated from the analyses of various stage concepts, operating modes, and projected missions (Space Tug Systems studies, growth stage studies, engine studies, and critical area studies). The foundation formulated by these studies aided in establishing a tentative two-phase approach for the extension of the STS operating regime beyond the Space Shuttle including plane changes, higher orbits, geosynchronous orbits and beyond.

It is planned that the Interium Upper Stage (IUS) will be developed by the Department of Defense. The IUS will be a modification of an existing expendable stage for use by both NASA and DoD during the transition period from existing launch vehicles to the Space Shuttle operations. This initial vehicle is expected to be operational in 1981. The more capable Space Tug will be introduced into the STS inventory in 1984.

The Space Tug will be developed by NASA and will be a new vehicle designed to fully meet the needs of all Space Shuttle users. It will be a reusable vehicle capable of deployment, retrieval, and on-orbit servicing of payloads to the extent economically effective. The Space Tug is planned to be utilized through 1991 and beyond.

Previous studies have developed systems and operational concepts, and assuming maximum ground mission control of the Space Tug, have sized the hardware, software, facilities and manpower required to support the Space Tug Mission. The results of these early studies emphasize the need for additional in-depth trade studies and the development of a Baseline Operations Plan and Concept incorporating the most feasible, cost effective in-flight operations approach consistent with the flight hardware systems design for both the IUS and Space Tug.

The IUS/Tug Orbital Operations and Mission Study, commonly called the Orbital Operations Study, has been conducted to provide the generation and analysis of operational plans, requirement and concepts for the utilization of these vehicles. Primary emphasis has been placed on methods and techniques to provide a sound technical approach to operations at reduced cost for the STS mission period.

All analysis conducted during the study have resulted in the presentation of sizing and cost estimates for a new development of an operations control center. This new operations control center development was directed to allow the definition of the total set of operational requirements, sizing and cost data. Therefore, assessment of existing facilities and potential of cost-sharing with other space programs have not been included within this study. The analytical cases developed by the study have been structured to allow (1) existing facility assessments and (2) cost-sharing with other space programs assessments with a minimum amount of effort.

For the purpose of this document the term "Operations" is defined as those activities, elements and units required to conduct an IUS or Tug mission from Shuttle launch to flight completion.

STUDY OBJECTIVES 2

The objectives of this study were to develop IUS and Tug orbital operations concepts, plans and requirements to support IUS and Tug missions from Shuttle launch to flight completion. This included the definition of interfaces, ground/airborne crew responsibilities, procedures and documentation required to develop and verify mission flight trajectories, plans and timelines, operations/mission constraints, network communication and processing requirements, airborne and ground software, manpower and facility requirements. The key portion of the study objective is shown in Figure 2.0.0-1 along with the major output products which were developed to meet this objective. These output products have been summarized and are shown to identify major areas contained in other volumes of the final report.

Major efforts of the study concentrated on the definition and analysis of operational concepts for both NASA and DoD utilization of the IUS and Space Tug vehicles. Through this analysis operational elements of various concepts have been sized and cost estimates provided. In addition, specific operational concepts have been recommended with a technical plan for the transition phase between IUS and Space Tug operational periods.

Equally important are the operational requirements which have been generated and analyzed for the Orbiter interface, IUS/Space Tug vehicles and Mission Control Centers. These requirement packages form the initial building blocks for the development of operational capabilities to satisfy IUS and Tug mission requirements.

STUDY OBJECTIVES

"... to develop IUS and Tug orbital operations concepts, plans and requirements to support IUS and Tug missions from Shuttle Launch to flight completion."

- ORBITER INTERFACE REQUIREMENTS
- VEHICLE OPERATIONAL REQUIREMENTS
- CONTROL CENTER OPERATIONAL REQUIREMENTS
- OPERATIONS CONCEPTS
- IUS/TUG BASELINE OPERATIONS PLANS
- COST ESTIMATES FOR OPERATIONS

Figure 2.0.0-1. Study Objectives

RELATIONSHIP TO OTHER NASA EFFORTS 3

The IUS/Tug Orbital Operations and Mission Support Study (NAS8-31009) was one of five concurrent NASA special interest studies. This study defined and analyzed operational requirements and concepts from prelaunch through landing for typical sets of IUS and Tug Missions. As such, the study overlapped portions of the concurrent studies providing continuity of results to NASA. These major relationships are depicted in Figure 3.0.0-1 and illustrate the areas of interface between the studies. The other four special interest contracted studies are listed below.

(1) Space Tug Avionics Definition Study (NAS8-31010)
(2) Space Tug/Shuttle Interface Compatibility Study (NAS8-31012)
(3) IUS/Tug Payload Requirements Compatibility Study (NAS8-31013)
(4) Tug Fleet and Ground Operations Schedules and Controls Study (NAS8-31011)

The major interface with the Space Tug Avionics Definition Study was in the area of rendezvous and docking sensors, redundancy management, system configuration, and on-orbit checkout philosophy. IBM utilized the definition of rendezvous and docking sensors from the Avionics Study. These sensors were used as an input to define the hardware characteristics for the operational analysis which was performed by IBM in the rendezvous and docking area. The system configuration basically was the MSFC Space Tug baseline for avionics; however, during the course of the avionics study an Interfermetric Landmark Tracker (ILT) was added to provide autonomous navigation capability. The Orbital Operations Study used the ILT definition for inclusion in its modes of operations, sizing and cost data.

The major interfaces with the Space Tug/Shuttle Interface Compability Study was in the area of caution and warning analysis, RF compatibility, and Mission Specialist Station functional requirements definition. The caution and warning analysis and Mission Specialist Station functional requirements definition involved the Orbiter interface, the transfer of data from IUS/Tug to the Orbiter and transfer of control commands from the Orbiter to the IUS/Tug. During the time intervals prior to Space Tug deployment and after Space Tug retrieval by the Orbiter, operational requirements were defined in these areas and presented to the Interface Study for implementation.

The major interface with the IUS/Tug Payload Requirements Compatibility Study was in the area of the receipt of Spacecraft operational requirements which were included in the analysis conducted in the Orbital Operations Study. These requirements dealt with functions which the Space Tug performed to support the Spacecraft during ascent, on-orbit checkout, and post-Orbiter mission phases, up to and including Spacecraft deployment and inspection. In addition, the Payload Compatibility Study and the Orbital Operations Study also interfaced in the area of Service Mission requirements. A generic set of servicing requirements were obtained by the Orbital Operations Study and analysis performed in order to better understand this new and unique usage of space.

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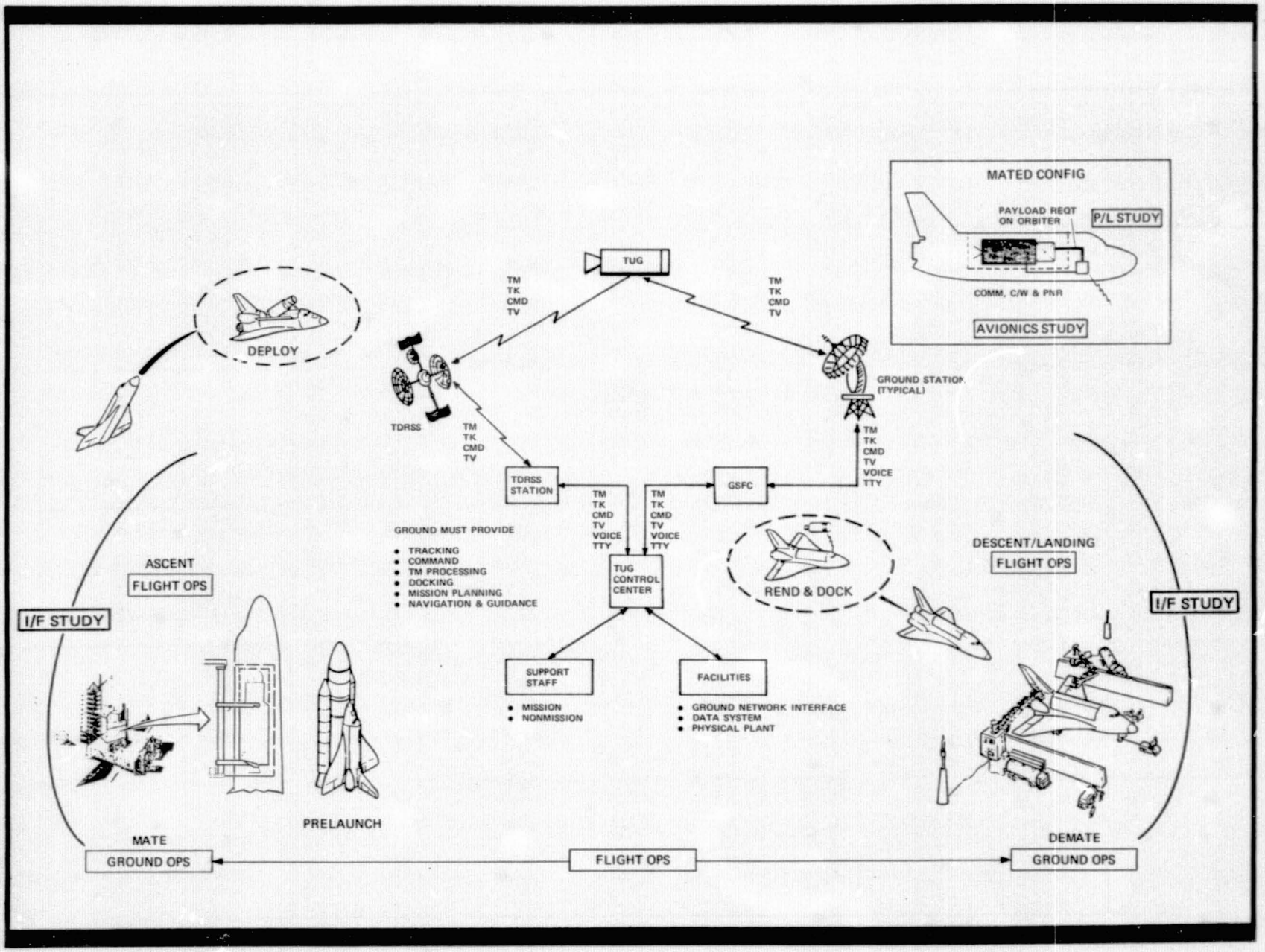


Figure 3.0.0-1. Relationships to Other NASA efforts

The major interface with the Tug Fleet and Ground Operations Schedules and Controls Study was in the area of prelaunch checkout during the last eight hours prior to Orbiter/Tug/Spacecraft liftoff from the launch facility. Requirements were generated by the Orbital Operations Study and transmitted to the Ground Operations Study for inclusion in their overall planning cycle. In addition, these two studies interacted concerning safing of the Space Tug vehicle prior to Orbiter retrieval. The safing philosophy and sequences were defined by the Orbital Operations Study and discussed with ground operations personnel to ensure a compatible and safe Space Tug vehicle during Orbiter landing and the initiation of refurbishment activities at the launch site.

METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS 4

This section presents the overall study approach, major guidelines, major assumptions, and the Space Tug analytical methodology used in the Orbital Operations Study. Space Tug methodology is presented as an example. The IUS methodology, which is similar to the one presented for Tug, is contained and discussed in Volume II of the Final Report. In addition, the Space Tug methodology and the Transition Phase methodology is also presented and discussed in Volume III of the Final Report.

4.1 OVERALL STUDY APPROACH

The IUS/Tug Orbital Operations and Mission Support Study was conducted in five separate phases. These phases were: (1) Compilation and Evaluation Study Phase (Phase 1), (2) IUS Operations Study Phase (Phase 2), (3) NASA Space Tug Operations Study Phase (Phase 3), (4) IUS/Tug Transitional Study Phase (Phase 4), and (5) Trade Issues and Parameter Study Phase (Phase 5). Figure 4.1.0-1 presents each major study phase with the individual tasks being identified whose output fulfills the stated objective of each analytical phase. The detailed definition of each phase and individual task is contained in the IUS/Tug Orbital Operations and Mission Support Study Plan, IBM No. 74W-00211, dated August 15, 1974.

During Phase 1, the baseline documentation used for the study was received, analyzed and formatted for usage during additional analytical phases. In addition, operational requirements against the Orbiter interface were defined. These primarily were caution and warning parameters and an assessment of the data flow path between the Tug vehicle and the Orbiter data bus system. Also during this phase, the mission-model analysis was conducted, which evaluated missions in both NASA and DoD traffic models to determine the operational requirements implicit within the various types of missions indicated. Also, operational concepts were identified and described for usage with the Space Tug/IUS vehicles. These concepts were defined to a level of detail to permit subsequent analysis. Network evaluation was also performed in conjunction with the mission-model analysis. This evaluation considered TDRSS and STDN in NASA missions and SGLS for DoD missions to determine communications compatibilities and station acquisition and loss times. The results of Phase 1 were presented in the first Program Review and documented in IBM No. 74W-00232, dated September 19, 1974.

The Space Tug Operations Phase (Phase III) and the IUS Operations Phase (Phase II) were parallel efforts to determine the operational requirements for each particular program; to allocate the implementation of the requirements to the onboard system, the ground system or the Orbiter; to size the implementation required to satisfy these requirements and to provide cost estimates within an establish DDT&E and Recurring cost structure. Within these phases, the operational concepts were evaluated and trade analysis was performed, such that a recommended operational concept could be presented to NASA.

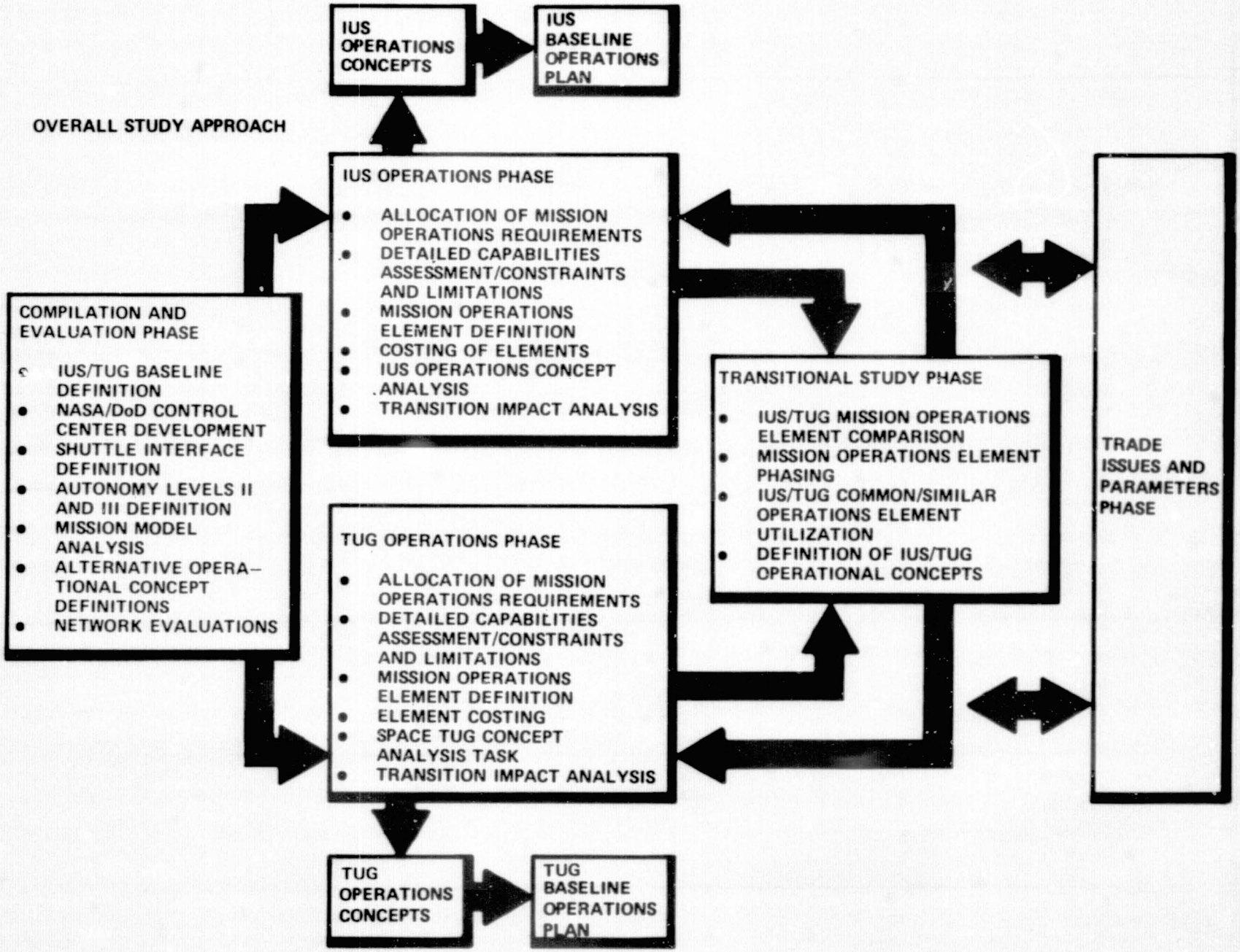


Figure 4.1.0-1. Overall Study Approach

The Space Tug operational analysis, which resulted in a recommended operations concept and a documented baseline operations plan, was presented at the second Program Review and documented in IBM No. 74W-00255, dated November, 1974. The IUS operations analysis, which resulted in a recommended operations concept and a documented operations plan, was presented at the second Program Review and documented in IBM No. 74W-00283, dated December, 1974.

The Transitional Study Phase analyzed the time period between IUS operations and Space Tug operations. This effort defined tasks which were unique to the transitional phase and also provided feedback of information into both the IUS and the Tug phases of analysis such that the recommended operational concepts could be modified if required. The Transitional Study Phase was completed and results presented at the Final Program Review. This analysis was documented in IBM No. 75W-00046, dated April, 1975.

The Trade Issues and Parameters Phase was concerned with special emphasis areas which for this study were: (1) Rendezvous and Docking Analysis, (2) Orbital Checkout Analysis. The results of this study phase were presented at the Final Program Review and documented in IBM No. 75W-00046, dated April, 1975.

4.2 MAJOR GUIDELINES

The major guidelines of the Orbital Operations Study are listed in Table 4.2.0-1. These guidelines reflect the boundaries in which the study was conducted. To properly utilize the results of this study, both data and conclusions should be tempered by the stated guidelines.

The control center location issue has driven the output of this study to provide the total set of operational requirements and cost estimates without considering location or existing facilities or capabilities. Therefore, the sizing and costing data generated by the study has been structured to represent a total estimate of new operational programs. The data have been structured such that existing facilities capabilities may be compared against the study results and new estimates generated with a minimum amount of effort.

4.3 MAJOR ASSUMPTIONS

The major assumptions of the Orbital Operations Study are listed in Table 4.3.0-1. These assumptions reflect the directions which were taken during the course of the study and should be used in assessing both data output and conclusions. The issue of sharing IUS/Tug software and hardware development with other programs has driven the study to present total requirements, total sizing, and total cost estimates without shared-program considerations. Again, the data and study results have been structured such that updates can be easily made when the question of shared program developments are evaluated.

4.4 SPACE TUG METHODOLOGY

The Space Tug methodology used during the Orbital Operations Study is shown in Figure 4.4.0-1. It has been shown as an example. The IUS methodology is similar and is discussed in Volume II of the final report. The methodology begins with the construction of standard operational modules which were defined by analyzing the Space Tug missions contained in the

Table 4.2.0-1. Major Guidelines

MAJOR GUIDELINES

ISSUE	DIRECTION
• SPACE TUG CONFIGURATION	• MSFC BASELINE DOCUMENTS
• IUS REPRESENTATIVE CONFIGURATION	• MSFC PROVIDED DATA PACKAGE (EXPENDABLE AND REUSEABLE)
• IUS AND TUG MISSION MODELS	• MSFC PROVIDED DATA SETS
• ORBITER ACCOMMODATIONS	• JSC ACCOMMODATIONS DOCUMENT - GOAL: MINIMIZE REQUIREMENTS ON ORBITER INTERFACE
• GROUND CONTROL	• GOAL: MINIMIZE GROUND INVOLVEMENT DURING OPERATIONS
• CONTROL CENTER LOCATION	• SPECIFY TOTAL OPERATIONAL REQUIREMENTS AND COST ESTIMATES REGARDLESS OF LOCATION (INDEPENDENT OF EXISTING CAPABILITIES
• COST ESTIMATES	• GENERATE IN FY-74 DOLLARS

Table 4.3.0-1. Major Assumptions

MAJOR ASSUMPTIONS

ISSUE	ASSUMPTION
• NETWORK	• TDRS PLUS SIX GROUND STATIONS FOR NASA; SGLS FOR DOD
• NASA/DOD OPERATIONAL PHILOSOPHY	• SIMILAR EXCEPT FOR SECURITY
• SOFTWARE (FLIGHT & GROUND) DEVELOPMENT LAB	• AVAILABLE FOR IUS/TUG APPLICATIONS
• SHARED IUS/TUG SOFTWARE/HARDWARE WITH OTHER PROGRAMS	• GENERATE REQUIREMENTS, IMPLEMENTATION, AND COST ESTIMATES WITHOUT PROGRAM SHARING CONSIDERATIONS

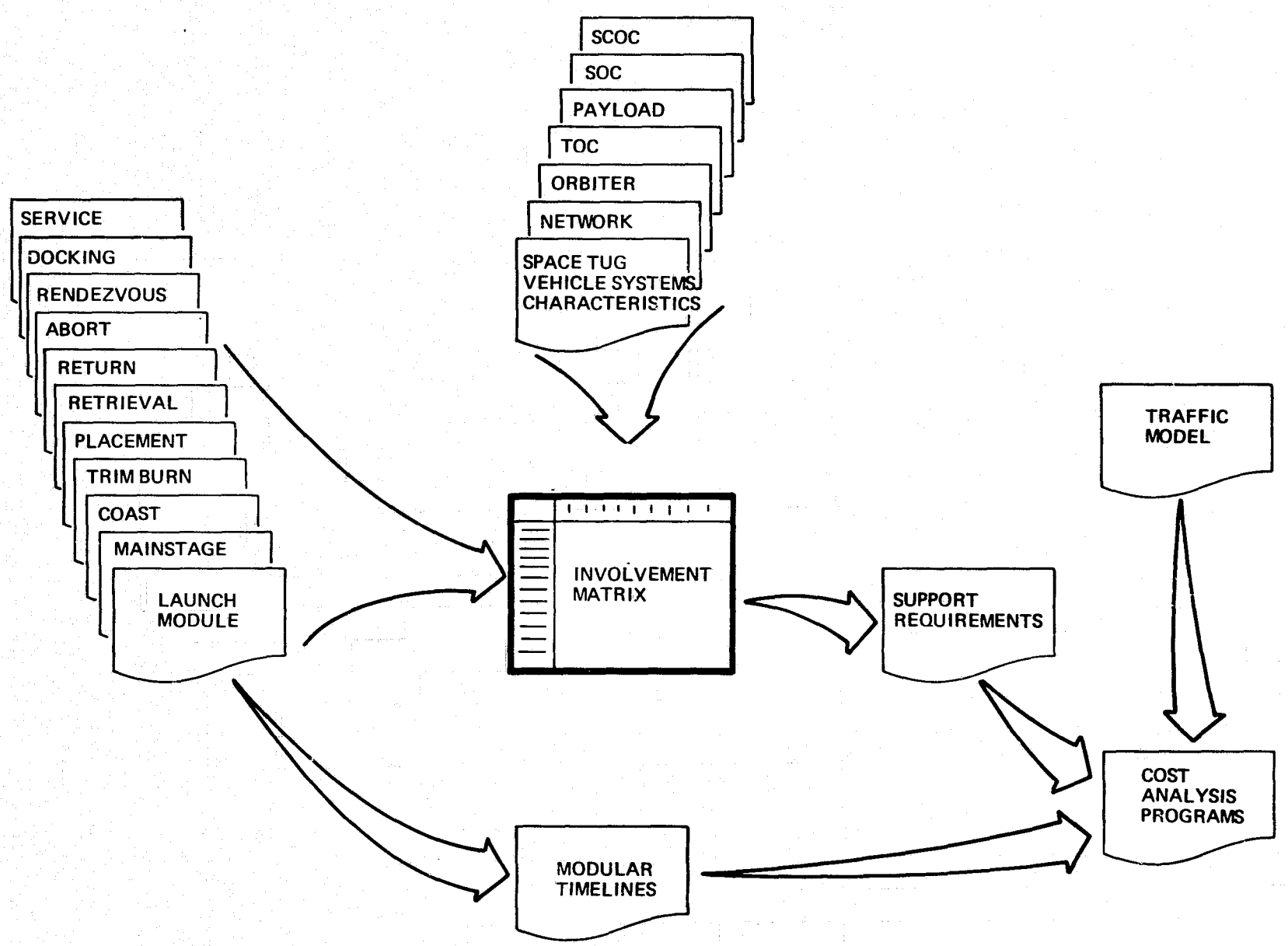


Figure 4.4.0-1. Space Tug Methodology

reference mission models. The modules contain those operational functions required to be performed within a specific phase of the Space Tug mission. These functions or tasks were generated by reviewing the Tug system studies and other prior studies, and were augmented by the mission analysis performed during this current study. The assumption in using standard modules is that the operational functions, tasks or unique events can be defined as occurring in a specific phase of a Space Tug mission. For example, the launch module contains those Space Tug functions performed from T-3 hours at the launch site through Orbiter ascent, checkout, Tug deployment and terminates with the Space Tug vehicle separated from the Orbiter, checked out and waiting to perform its initial burn from low earth orbit. Once these functions or tasks were defined, they were listed on a module-by-module basis along the vertical axis of an analytical tool which has been designated as the Involvement Matrix. The horizontal axis of the Involvement Matrix contains those operational elements which are a part of the flight operational problem associated with the Space Tug program. These operational elements are: the Space Tug vehicle, the network, the Orbiter, the Payload, the Tug Operations Center, the Spacecraft Operations Center, and the Shuttle Operations Center. The characteristics of these operational elements were described and listed on the horizontal axis of the Involvement Matrix. Once the axis of the Involvement Matrix was constructed, each operational function on the vertical axis was analyzed to determine which portion or characteristic of the operational elements was required to perform the indicated operational task. Functions were analyzed on an individual basis with the result being an identification of the interfaces between each operational function and an operational element characteristic. Figure 4.4.0-2 represents the Mainstage Module with the operational functions of the module on the vertical axis and the characteristics of the operational elements on the horizontal axis. The matrix illustrates that each function has been analyzed to identify the operational elements required and is shown as a "1" in the appropriate matrix cell. By this process it was determined which elements were required to support each function, leading to the definition of the operational support requirements. With the definition of support requirements, these statements were then used as an input to the Cost Analysis Programs.

From the standard modules defined for Tug, modular timelines were constructed by selecting different sequences of standard modules. For example, a typical geosynchronous mission can be constructed and represented by a sequence of the standard modules. In many cases, modules were used several times during an operational sequence for a specific mission. For example, the mainstage module was used any time the RL-10 IIB engine was ignited. By constructing modular timelines in this fashion, missions can be represented within a short time interval by the proper selection of the specific standard modules. The modular timelines representing geosynchronous missions, sun synchronous missions and interplanetary missions were also an input to the Cost Analysis Program.

The third input to the cost analysis program was the set of traffic models used in the study. These models were utilized to determine launch densities and overlaps, such that sizing and cost estimates could be provided as a function of the traffic density. The Cost Analysis Programs generated the engineering cost estimates which have been included in this final report.

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Figure 4.4.0-2. Involvement Matrix (Mainstage Module)

BASIC DATA GENERATED AND SIGNIFICANT RESULTS 5

This section contains the basic data generated by the study and the significant conclusions which have been reached. Included within this section are the operational concepts analyzed during the study, and the definition of the operational elements structuring all requirements analysis, sizing and cost estimates. In addition, the flight-operations estimates for the Space Tug analysis, the estimates for IUS operational activities and the results of the Transition Phase analysis have been included.

5.1 OPERATIONAL CONCEPTS

The operational concepts which have been defined and analyzed during this study are shown in Figure 5.1.0-1. These concepts were directed to be studied by NASA and have survived the rigorous analysis involved in IUS and Space Tug flight operations. As indicated in the figure, the application of each concept to the IUS program, to the Space Tug program, or to both, has been shown.

Concept 1, separate NASA and DoD systems, is in accord with the NASA baseline and postulates separate NASA and DoD control center development to satisfy the respective mission requirements. In this concept, control center hardware, software, manpower and facilities are the responsibility of each separate agency; however, it does not preclude the potential of cost savings by sharing the development of similar hardware and software. This concept has defined a stand-alone Tug control center which performs the flight operations activities for either IUS or Tug missions. Minimum interfaces are provided between NASA and DoD during the operational periods for the IUS and Space Tug programs.

Concept 2, shared system, defines a single operations control center for both NASA and DoD missions. Under this concept, each agency is responsible for all aspects of its missions, but would share common operational elements. The common operational elements are the facility, ground hardware, and ground software which a single centralized facility provides. In this concept, it has been assumed that NASA personnel will conduct the flight operations activity for NASA mission, as well as provide NASA unique ground and flight software; DoD would do likewise. Two options under this concept have been analyzed: (1) Concept 2A, which assumes a NASA host role in the shared facility, and (2) Concept 2B, which assumes DoD in the host role. These sub-options were defined and developed to provide additional sizing and costing cases. This concept requires the operations center and its related operational elements to be modified from a secure mission environment to a non-secure mission environment. Concept 2 was analyzed only for the Space Tug program because the required information for the IUS vehicle can be easily extracted by combining the respective elements of Concept 1 (IUS) and Concept 2 (Space Tug).

Concept 3, DoD system, defines an IUS unique concept wherein DoD performs all IUS mssions for both NASA and DoD. NASA activity is limited to the definition of NASA mission requirements, mission planning and post flight evaluation and data dissemination. Under this concept, DoD personnel perform the flight operations functions for both NASA and DoD missions. This concept requires the operations center and its related operational elements to be modified from

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	APPLICATION	
	SPACE TUG	IUS
CONCEPT 1 – SEPARATE NASA/DoD SYSTEM	X	X
CONCEPT 2 – SHARED SYSTEM	X	
A. NASA HOST/DoD TENANT		
B. DoD HOST/NASA TENANT	X	
CONCEPT 3 – DoD SYSTEM (ALL IUS FLIGHTS)		X

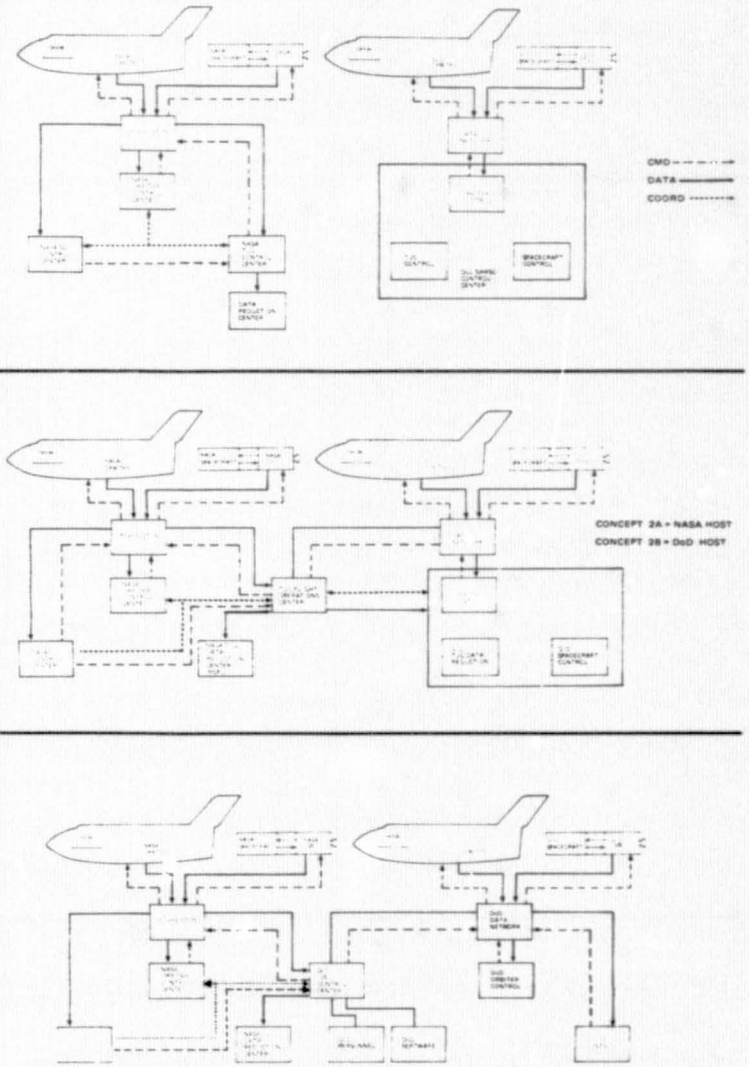


Figure 5.1.0-1. Operational Concepts

a secure mission environment to a non-secure mission environment. Concept 3 was analyzed for only the IUS program because of two factors; (1) the NASA operations personnel contacted did not consider DoD operating NASA Space Tug missions a reasonable case and (2) Concept 1 (Space Tug) analytical case for the DoD system can be modified if the information for Concept 3 were needed.

5.2 OPERATIONAL ELEMENTS

For the analysis conducted during the IUS/Tug Orbital Operations and Mission Support Study five operation element structures have been defined. These structures were defined so that requirements analysis, sizing estimates, and cost estimates could be contained within a common frame work to allow comparisons between the various study cases that were analyzed during the study period. The five operational elements defined are: (1) ground software, (2) flight software, (3) IUS/Tug Operations Center support hardware, (4) manpower, and (5) facilities. Within the five operational elements data and conclusions have been structured which will allow the study user the traceability required to follow the analytical cases developed through the study.

5.2.1 GROUND SOFTWARE/FLIGHT SOFTWARE

The ground software structure defines the major modules required for control center operational activities. Top level modules (Figure 5.2.1-1) have been defined for the Executive, Vehicle System, Mission Profile, Control, and Simulation software. This top-level structure has allowed the discussion of ground software to a level of detail where subsequent changes in requirements or programmatic decisions may be reflected into the study results with a minimum amount of effort. Vehicle system software has been subdivided into telemetry and command submodules. The telemetry data is processed in real time and displayed to the flight control personnel for performance evaluation. The command, or uplink, processing controls the formatting and transmitting of commands to either the Space Tug or IUS vehicle and provides verification of the receipt of the command. Mission Profile software has been subdivided into four functional areas: orbital trajectory determination, orbit trajectory computations, mission planning and docking. The orbit trajectory determination software (not required for Space Tug, Level II) processes radar range and range-rate information from the network and performs differential corrections and smoothing functions as required. This information is then formatted into state vectors which are subsequently used in the orbit-trajectory computations. Orbit-trajectory computation software generates trajectory information and maintains current vehicle empherides, computes and formats information relative to current planned maneuvers and estimates ground station contact times. The mission planning software provides the capability to process data for use in evaluation of powered flight performance to satisfy mission objectives. In addition, the mission planning program has the ability to produce and evaluate alternate flight plans both in the pre-mission and real-time environments. The docking software provides the capability for man-in-the-loop rendezvous and docking for Space Tug, Level III Autonomy cases. Control software contains the executive function, data communications and control center support software. The executive software controls all software modules and provides supervisory authority. Data communications provides the capability to transmit high speed data between

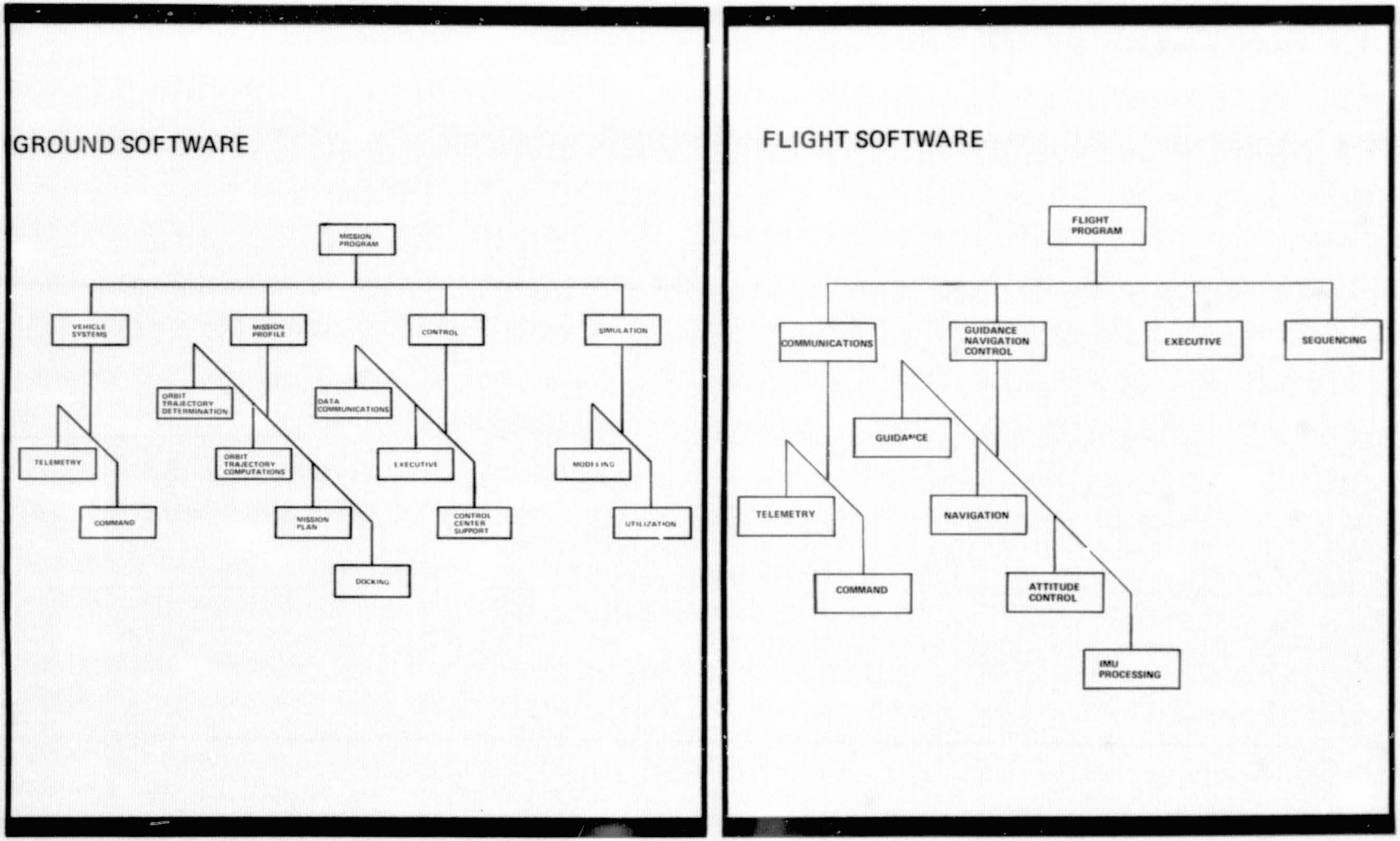


Figure 5.2.1-1. Grand/Flight Software

the IUS/Tug Control Center and other control centers during periods of common operations. The control-center-support software provides for the generation and updating of CRT display formats in the IUS/Tug Control Center. A large software Simulation module has been defined which will simulate vehicle functions and ground network characteristics to be utilized in the training of flight control and flight support personnel. This simulation system will be required to support real-time mission planning and alternate mission design to accommodate degraded mission performance resulting from system malfunction or contingency operations.

The flight software operation element structure defines the major modules required for IUS and Space Tug missions. Top level modules have been defined for executive; communications; guidance, navigation and control; and sequencing. The executive module performs task management functions, interrupt processing, discrete processing, and housekeeping functions. The communications module has been subdivided into telemetry and command processing. Telemetry processing includes formatting, recorder control, and communications-access logic. Command processing provides message validation, acknowledgement and implementation of commands received. The guidance, navigation and control function has been subdivided into four submodules. These modules are: guidance, which incorporates special logic for docking, burn termination and post operations, burn guidance algorithms and targetting; navigation, which performs boost, coast, rendezvous and docking navigational calculations; attitudes control, which includes control laws for burn and coast periods; IMU processing, which accepts the platform output, filters, converts and transforms the data for navigation and guidance computations. The sequencing group issues prestore command tables to the vehicle and processes nominal and alternate mission sequencing updates.

5.2.2 TOC SUPPORT HARDWARE

The TOC support hardware operational element has been structured to contain two major components. The first major component is the data system which contains the interface equipment to the data network, the central computer system which houses the ground software and performs computations required to support both IUS and Tug missions, and the equipment which provides the interface for the display of data to the console areas. The second major component of the support hardware structure is the set of console modules which provides end-item display via CRT's, terminals, and provides the man-machine interface to the data system. This support-hardware structure provides capabilities for flight control personnel in analyzing vehicle information, commanding corrective action and is utilized by flight support personnel in maintaining the control center and performing the required network interface functions. The number of consoles required is dependent upon the mission density factors, especially on the overlap between missions and between modules within a particular mission. During the study, size and cost estimates have been provided which define the capabilities required by the data systems and the console modules to support typical IUS and Space Tug missions. Figure 5.2.2-1 represents the TOC operational elements as defined for the Orbital Operations Study.

5.2.3 MANPOWER/FACILITY

These two operational elements provide the structure to house sizing and cost

estimates for manpower and facility requirements. The manpower structure contains the functional organization and levels required to perform the operational activities for IUS and Tug missions. Within this manpower structure, estimates for flight-control and flight-support personnel have been generated.

The facility structure provides a means for housing the ground computer complex, the consoles, and ground display system required to perform the operational activities of both IUS and Space Tug missions. Within the frame work of the study, cost estimates have been provided based on sizing of standard floors and raised floors to provide NASA with the requirements of the overall cost category (Figure 5.2.3-1).

5.3 SPACE TUG COST ESTIMATES

Table 5.3.0-1 contains the cost estimates results from the Space Tug operational analysis study phase. Each of the operational concepts defined for Space Tug (Figure 5.1.0-1) was used in determining the sizing estimates and cost estimates presented in tabular form. For each operational concept NASA and DoD cost estimates were provided in the DDT&E cost category and Recurring cost categories for two separate autonomy cases utilizing the Space Tug vehicle.

The Level II autonomy Space Tug vehicle can be characterized as follows: (1) MSFC Baseline Tug, (2) autonomous navigation using an Interfermetric Landmark Tracker (ILT), and (3) rendezvous and docking performed autonomously by the onboard system. This Level II autonomy vehicle, consistent with the concurrent Space Tug Avionics Study, presents an analytical case of high onboard autonomy. The operational impacts of the autonomy definition are the deletion of ground tracking and tracking data processing requirements from the Tug Control Center and no TOC involvement in the latter phases of rendezvous and docking with the target Spacecraft.

The Level III autonomy definition for the Space Tug vehicle can be summarized as follows: (1) MSFC Baseline Tug, (2) ground tracking and tracking data processing is required for both navigation and target update capability, and (3) rendezvous and docking features man-in-the-loop control via the onboard TV system. This Level III autonomy definition reflects an increase ground involvement with more TOC software and manpower required to complete the operational activities associated with Tug missions. The Level III autonomy case was defined to provide additional sensitivities to increased operational activities performed at the TOC by structuring the autonomy cases to describe a representative spectrum which can be used in future analysis.

The operational elements contained within the DDT&E cost estimates for Concept 1 have been identified in Figure 5.3.0-1. These elements are the physical plant or facility, TOC software development, data system procurement, operations staff equipment development and Tug flight-software development. The generation of the sizing and cost estimates are discussed in Volumne III of the final report. It can be seen from Figure 5.3.0-1 that the cost driver in the DDT&E category is TOC software development which accounts for approximately 49% of the expenditure. Again, these cost numbers reflect a totally new development program which does not use existing software, hardware or facilities.

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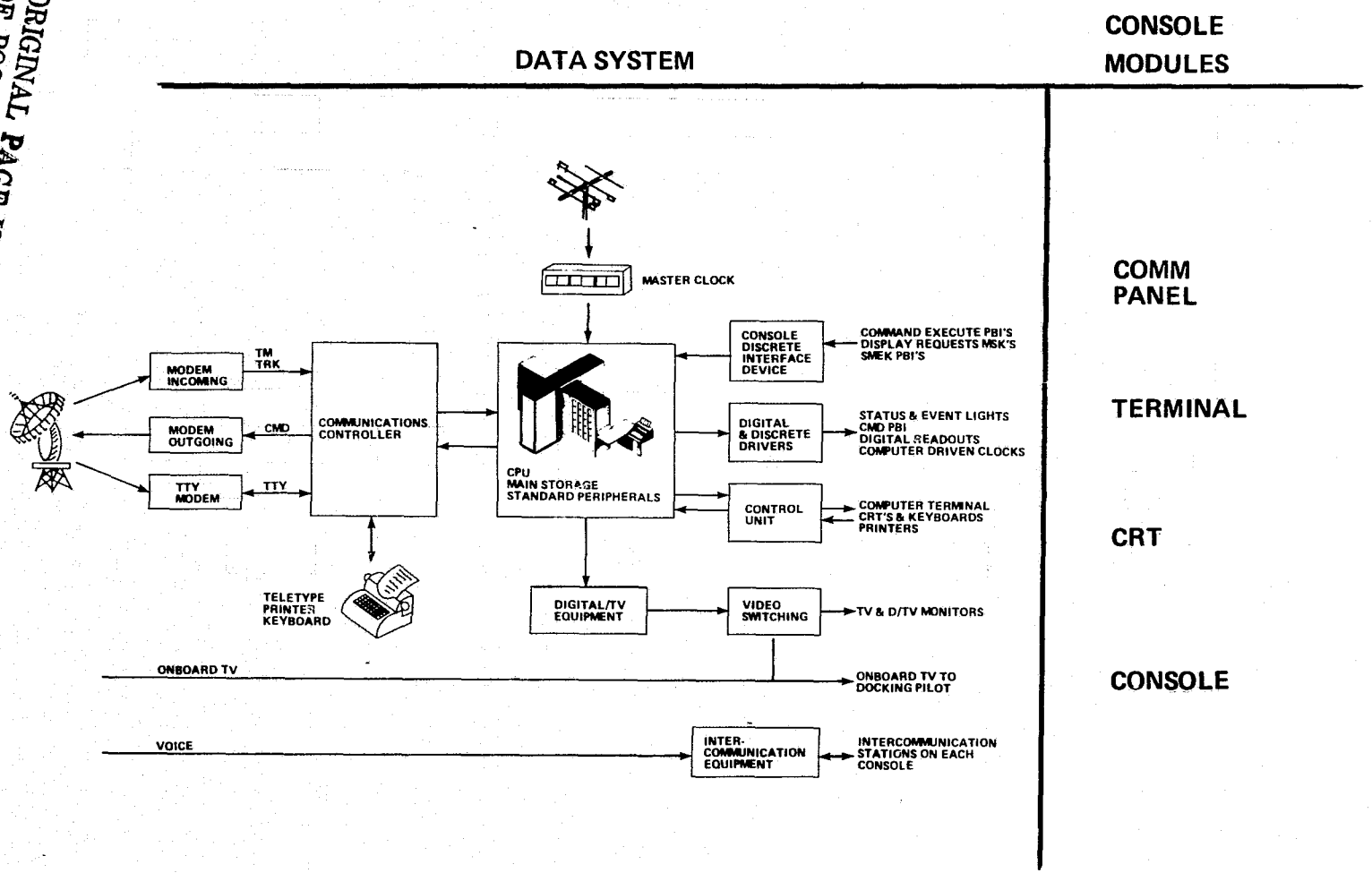


Figure 5.2.2-1. TOC Support Hardware

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OPERATIONAL ELEMENTS

MANPOWER

OPERATIONS DIRECTOR

- VEHICLE SYSTEMS ENGINEER
  - PROPULSION
    - STAGE
    - CONSUMABLES
  - AVIONICS
    - GUIDANCE AND NAVIGATION
    - SEQUENCE
  - NETWORKS
  - COMMUNICATIONS
- FLIGHT DYNAMICS ENGINEER
  - GUIDANCE
  - DYNAMICS
  - DATA SELECT
  - TELEVISION
  - DOCKING

- FACILITIES SUPERVISOR
  - DATA SYSTEM SUPERVISOR
    - COMMAND
    - TELEMETRY
    - SITE SELECT
  - MAINTENANCE AND OPERATIONS
    - COMPUTER OPERATORS
    - DATA FLOW
    - DPS ENGINEER
    - COMPUTER MONITOR
    - VOICE TECH
    - DISPLAY TECH
    - TELEVISION TECH
  - SOFTWARE SUPPORT

FACILITY

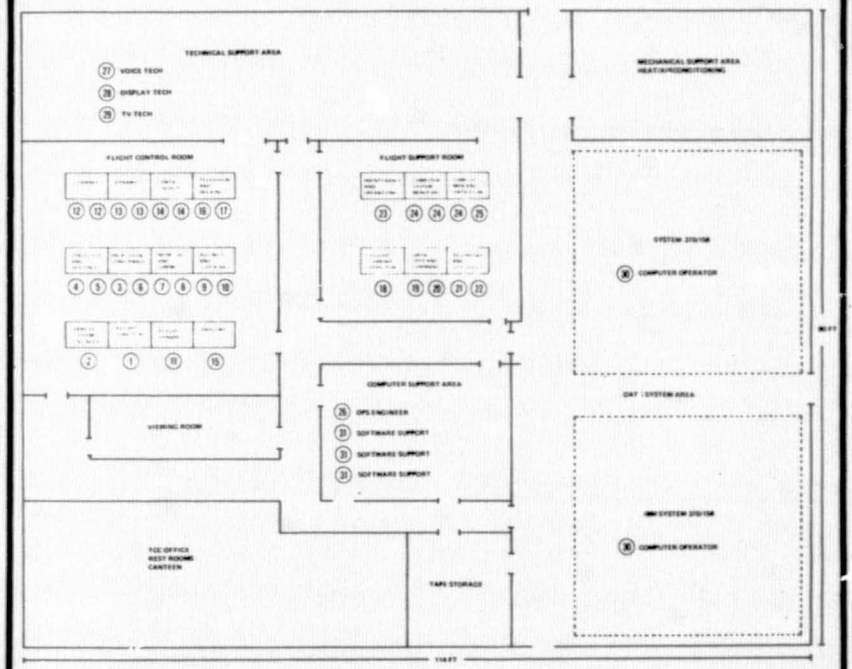


Figure 5.2.3-1. Manpower/Facility

Table 5.3.0-1. Space Tug Cost Estimates

SPACE TUG COST ESTIMATES ($M)

AUTONOMY	CONCEPTS	DDT&E		Recurring	
		NASA	DOD	NASA	DOD
LEVEL II	CONCEPT 1	25.1	25.5	5.49	5.98
	CONCEPT 2A	32.5	5.8	8.53	3.89
	CONCEPT 2B	5.9	32.5	4.08	8.31
LEVEL III	CONCEPT 1	28.9	29.0	6.61	6.18
	CONCEPT 2A	37.3	6.34	8.78	3.96
	CONCEPT 2B	6.54	37.4	4.17	8.56

DDT&E COSTS
(TUG LEVEL II)

ELEMENT	DOLLARS
PHYSICAL PLANT	413620
TOC SOFTWARE DEVELOPMENT	12182167
DATA SYSTEM	6509618
OPERATIONS STAFF EQUIPMENT	1004400
TUG SOFTWARE DEVELOPMENT	5058689
TOTAL	25168494

$25.1 M

Figure 5.3.0-1. Space Tug DDT&E Cost Elements

The operational elements contained within the Recurring Cost Estimates for Concept 1 have been identified in Figure 5.3.0-2. For this study recurring costs are costs per year estimates for operational (non-development) activities. These elements are facility maintenance, ground (TOC) software maintenance, data system maintenance, sustaining TOC (Flight Support) engineering, sustaining TOC FLT. CNTL. (Flight Control) engineering, network rental, and Tug (flight) software maintenance. The generation of the sizing and cost estimates are discussed in Volume III of the final report. It can be seen from Figure 5.3.0-2 that the cost driver in the recurring category is manpower (Flight Control and Flight Support) which accounts for approximately 56% of the recurring costs per year.

5.3.1 RENDEZVOUS AND DOCKING OPERATIONAL ANALYSIS

The rendezvous and docking operational analysis comprised three tasks: operational submodule description, parameter definition and parametric relation identification. The submodules were selected so that they were functionally discrete and different so that each function be accomplished during rendezvous and docking was in only one module and each module contained only a limited number of functions.

The definition of parameters was influenced by the baseline operational requirements as well as the functional description. An assessment of the total Tug mission and the generics problems to be solved in automated rendezvous and docking verified that these requirements were valid. Those which affected parametric definitions are included in the following list.

- The Tug will be located on a coplunar constant differential height (CDH) orbit relative to the target spacecraft.
- The Tug rendezvous sensor will acquire the target and track it sufficiently to identify Tug navigation error before the Tug terminal-phase-initiation (TPI) burn.
- The TPI burn starting the Lambert transfer to the target will be accomplished with the main engine but the terminal-phase-finalization (TPF) burn will be accomplished with the APS.
- The Tug will stop at a stationkeeping position before beginning docking operations.

Emphasis was placed on identifying the relations affecting those parameters associated with significant problems such as rendezvous acquisition range. Docking parametric relation descriptions such as those involving control policy and the dynamical effects of varying the docking tracker range were not evaluated because a suitable Tug model including a detailed slosh model was unavailable.

The relations between rendezvous tracker acquisition range and the APS impulse required for TPF are shown in Figure 5.3.1-1. The example impulse budgets are the same orders of magnitude as the expected final budgets and point out the requirement for acquisition ranges significantly greater than the baseline range of approximately 45 UNI. If the one-sigma navigation error of 8 NMI were all in a radial, or altitude, direction, the height differential would probably be in the range of 10 to 30 NMI. For the transfers possible with the given impulse budgets, a significant portion of the low and middle-altitude transfers

RECURRING COSTS
(TUG LEVEL II)

ELEMENT	DOLLARS
FACILITY MAINTENANCE	19672
TOC SOFTWARE MAINTENANCE	1104000
DATA SYSTEM MAINTENANCE	134458
SUSTAINING TOC ENGINEERING	1584000
SUSTAINING TOC FLT. CNTL. ENGINEERING	1440000
NETWORK RENTAL	204755
TUG SOFTWARE MAINTENANCE	1008000
TOTAL	5494885

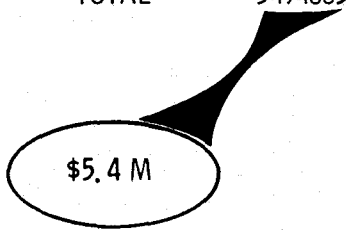


Figure 5.3.0-2. Space Tug Recurring Cost Elements

EXAMPLE SUMMARY

TARGET ALTITUDE (NM)	EXAMPLE TPF ΔV BUDGET (M/S)	DIFFERENTIAL HEIGHT (NM)	TRANSFER ANGLE (DCG)	MINIMUM ACQUISITION RANGE (NM)
900	15	-10	58-170	15-24.5
		-20	103-170	33-49
		-30	140-170	62-73
7000	10	-20	48-170	25-49
		-40	87-150	60-87 *
		-60	119-150	110-132
19365	5	-10	20-90	10.5-15
		-20	31-90	20.5-31
		-30	45-90	35-46
		-40	58-90	50-62
		-50	70-90	67-78

* EXTRAPOLATED

Figure 5.3.1-1. Significant Rendezvous and Docking Parameters

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could not be attempted. The purpose of this chart and the more detailed supporting graphs in the referenced section, is to point out the relation between acquisition range and impulse budget. The effect of one parameter on the requirements for the other must be assessed in arriving at a rendezvous and docking implementation scheme.

The relations between the orbital parameters of differential height and transfer angle are related to the target-referenced parameters of side and closing speed in complex ways (Figure 5.3.1-2). The example is keyed to the table by the shaded portions of the curves. This braking gate is located 10 KM from the target spacecraft. The change in side speed as well as closing speed as a function of transfer angle indicates that braking the Tug for some transfers at the range is more complex than for others - the best braking being accomplished when side speed is low. This observation led to the hypothesis that the range of the initial braking gate should vary according to the transfer angle. The relationships illustrating the effect of range on the side speed for various transfer angles are shown in the referenced section and verify the hypothesis. No braking policy was developed but the parametric relations are presented in that section so that they might be used in developing such a policy.

5.3.2 TUG/ORBITER INTERFACE OVERVIEW

The Tug/Orbiter interfaces are summarized in the right half of Figure 5.3.2-1 and include all mission phases when the Tug and Orbiter are physically attached. The Orbiter provides IRIG B timing signals to the Tug from its master timing unit. Ground commands (2 KBPS) to either the Tug or Spacecraft are routed through the Orbiter Payload Signal Processor (PSP) and relayed to the Tug command decoder. Tug commands are processed by the Tug and Spacecraft commands are routed to the Spacecraft.

The Tug and Spacecraft telemetry, for Orbiter and/or ground use, is routed from the Tug through a multiplexer in the Tug Deployment Adapter (D/A) to the Orbiter or Payload Data Interleaver (PDI). This link contains the housekeeping/status data required to monitor the general health of the Tug and Spacecraft.

The hardwire data links between the Tug and Orbiter provide the Tug and Deployment Adapter Caution and Warning (C&W) signals to the Orbiter displays through the C&W system and provide a means of issuing time-critical safety commands. The 1 MBPS command/monitor link is routed through the D/A to the Orbiter and provides a means of obtaining the Tug C&W (backup) and safety critical parameter (primary) as well as the command capability to execute safety related commands as required. In addition, this 1 MBPS link provides the Orbiter/Tug data link (through the D/A) to provide data required by the Tug, such as a Navigation Update, and to receive status and verification data required by the Orbiter to monitor Tug activities, such as IMU activation.

The Tug/Orbiter post-deployment data interfaces are shown in the upper right of Figure 5.3.2-2 and includes the deployment and retrieval phases when the Tug and Orbiter are detached and within 20 NM. As shown, the only data interfaces between the Tug and Orbiter are the telemetry and command interfaces which include both Tug and Spacecraft data.

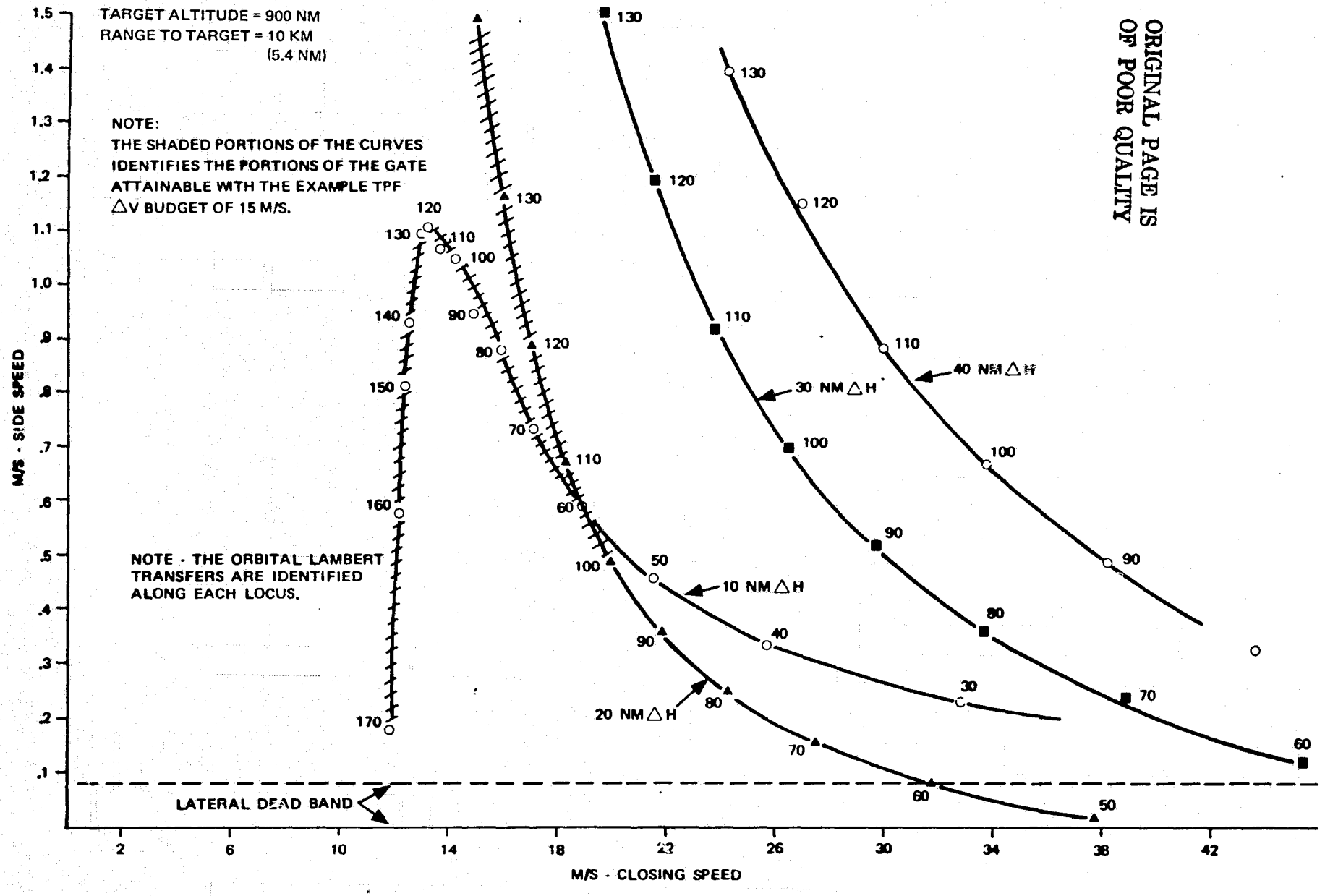


Figure 5.3.1-2. Parametric Relation Between Transfer Angle, Closing and Side Speeds at 10 KM Braking Gate

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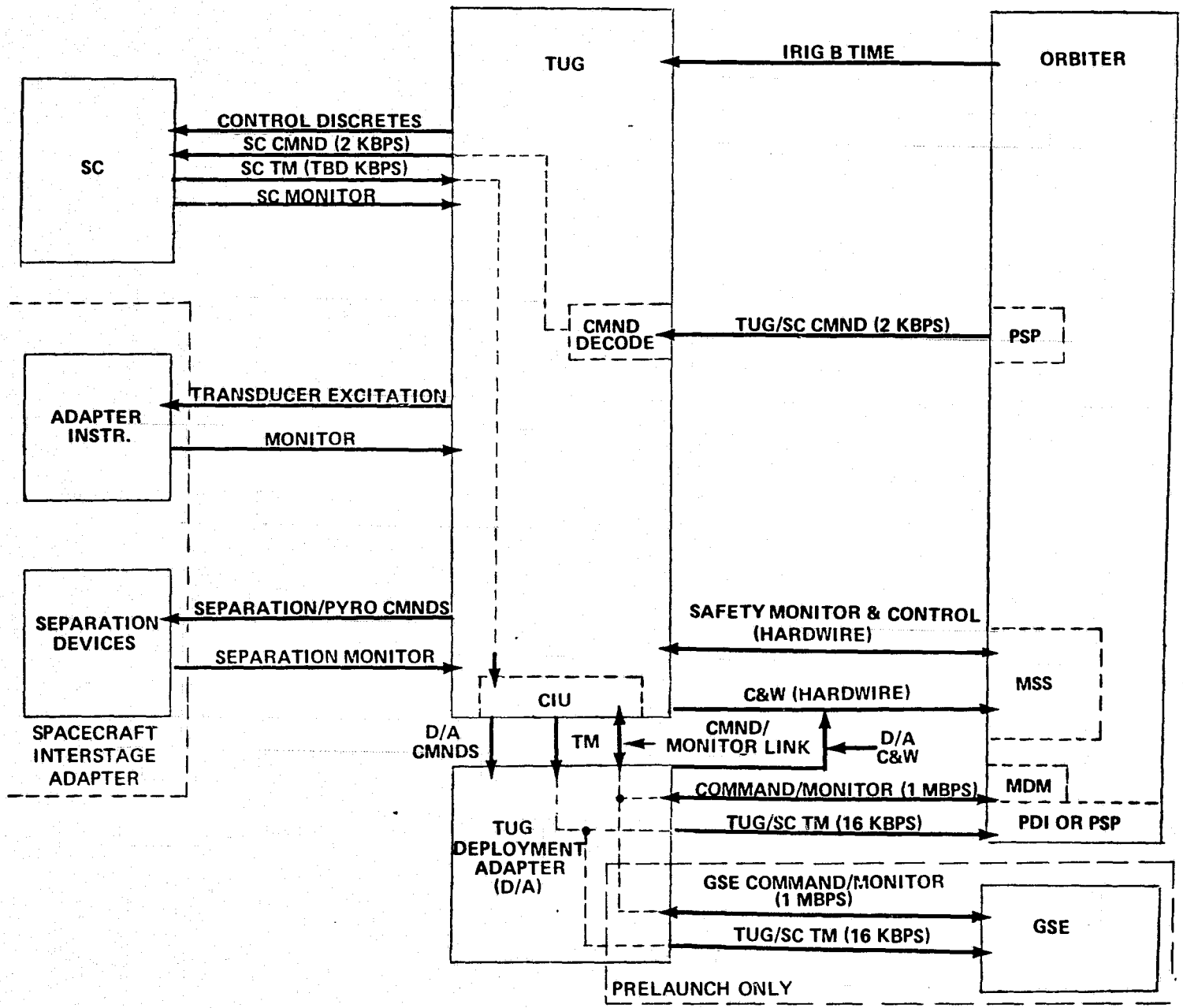


Figure 5.3.2-1. Tug/Orbiter Interfaces (Attached)

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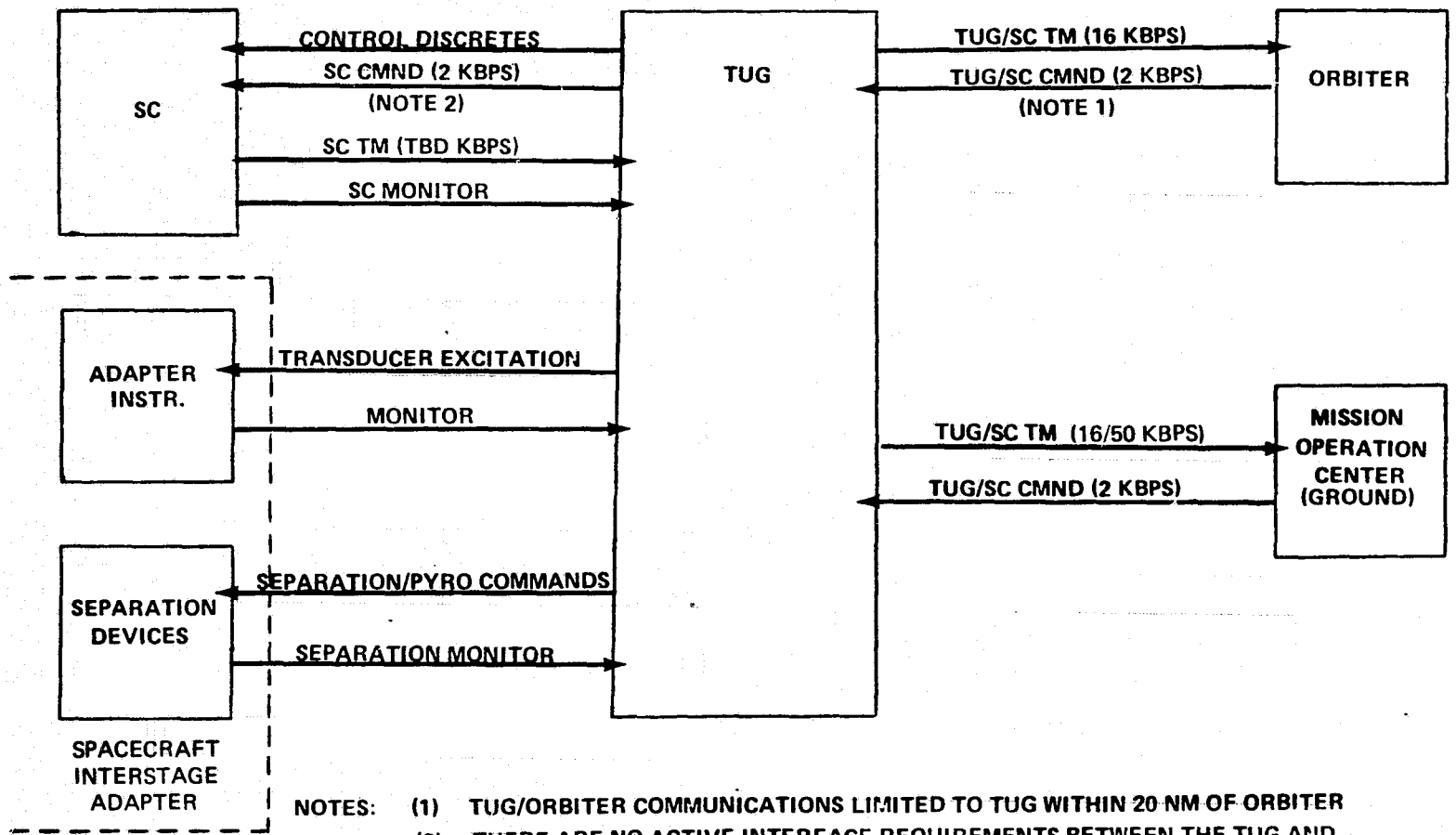


Figure 5.3.2-2. Tug/Orbiter Interfaces (Detached)

The telemetry link is required to provide Tug and Spacecraft C&W, safety related and status data to the Orbiter to determine their health during deployment and retrieval operations. The 16 KBPS RF data link is provided to the Orbiter PSP. The command link allows the Orbiter to control safety critical Tug/SC functions during near orbit operations and to provide backup capability for critical activation signals as required. The following are the Tug operational recommendations for status measurements and C&W annunicators resulting from safety requirements, subsystem and mission analysis.

TUG SYSTEM STATUS TO C&W	ANNUNCIATORS
LH_2 TANK PRESSURE	MAIN TANK LH_2 PRESS
LO_2 TANK PRESSURE	MAIN TANK LO_2 PRESS
N_2H_4 TANK TEMP 1	N_2H_4 TANK TEMP
N_2H_4 TANK TEMP 2	
N_2H_4 TANK TEMP 3	
FUEL CELL LO_2 PRESSURE	FUEL CELL LO_2 PRESS
FUEL CELL LH_2 PRESSURE	FUEL CELL LH_2 PRESS
DEPL. ADAPT. ARMED	DEPL. ADAPT. ARM SAFE
APS ARMED	TUG APS ARM SAFE
TUG MAIN PROPL. ARMED	TUG MAIN PROPL. ARM SAFE
AUX. BATTERY TEMP.	AUX. BATTERY
SPACECRAFT DEPL. ARM SAFE	SPACECRAFT ARM SAFE
H_E BOTTLE PRESS. 1	H_E BOTTLE PRESS
H_E BOTTLE PRESS. 2	
H_E BOTTLE PRESS. 3	
FUEL CELL TEMP. 1	FUEL CELL TEMP.
+28 VDC BUS 1	TUG CRITICAL BUS VOLTAGE
+28 VDC BUS 2	

5.3.3 TUG MISSION COMMUNICATION ANALYSIS

Three representative Tug mission types were defined for communication analysis. 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 confidence that useful stations were not prematurely disregarded.

Volume III of the final report contains the details of the communication analysis conducted. To illustrate the type of analysis performed the following paragraphs present data for the geosynchronous mission cases.

The geosynchronous delivery mission was analyzed for a mission time of 2.39 days. The ascent burn delivered the vehicle to an altitude of 19,323 nautical miles where a circularization burn placed the vehicle in a stationary geosynchronous position at -71^{0} longitude. The mission coverage indicated is from TDRS-E, TDRS-W and the three station ground network composed of Goldstone, Madrid, and Orroral.

Figure 5.3.3-1 is a timeline of the geosynchronous mission and summarizes the orbital support of both STDN and TDRS depicted in Figures 5.3.3-2 and 5.3.3-3. 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 can provide support to all major burn periods; however, during rendezvous with the Orbiter, support is limited.
- Because of the altitudes involved, the TDRS cannot support the first circularization burn nor the retro burn for return. TDRS can support the rendezvous phase with the Orbiter.
- The geosynchronous mission will require the coordinated support from both the STDN and TDRS.

5.3.4 ORBITAL CHECKOUT

The items analyzed during the Orbital Checkout task 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 Tug 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 Tug. The functions and operations to be performed

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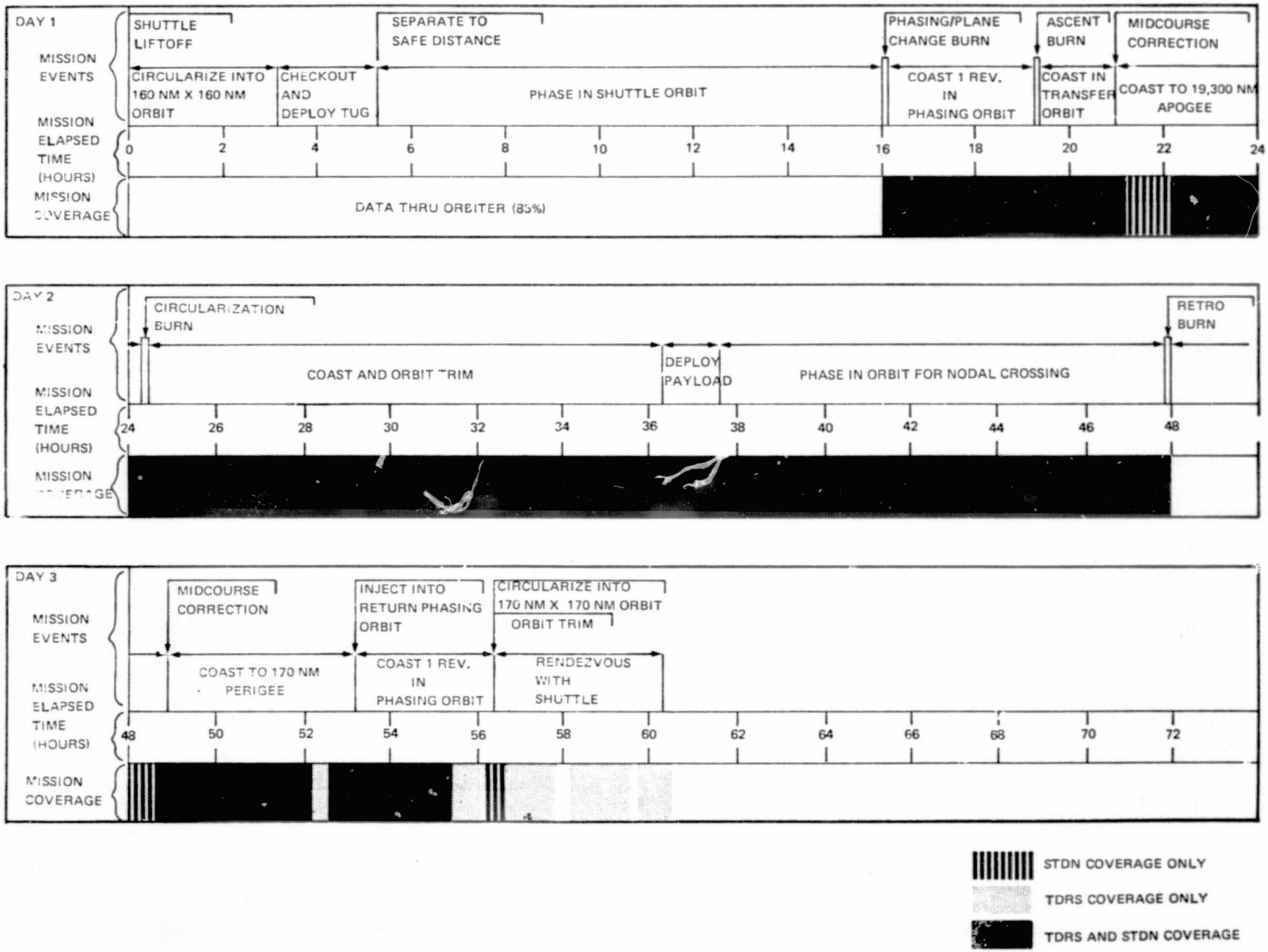


Figure 5.3.3-1. Space Tug Geosynchronous Mission Timeline

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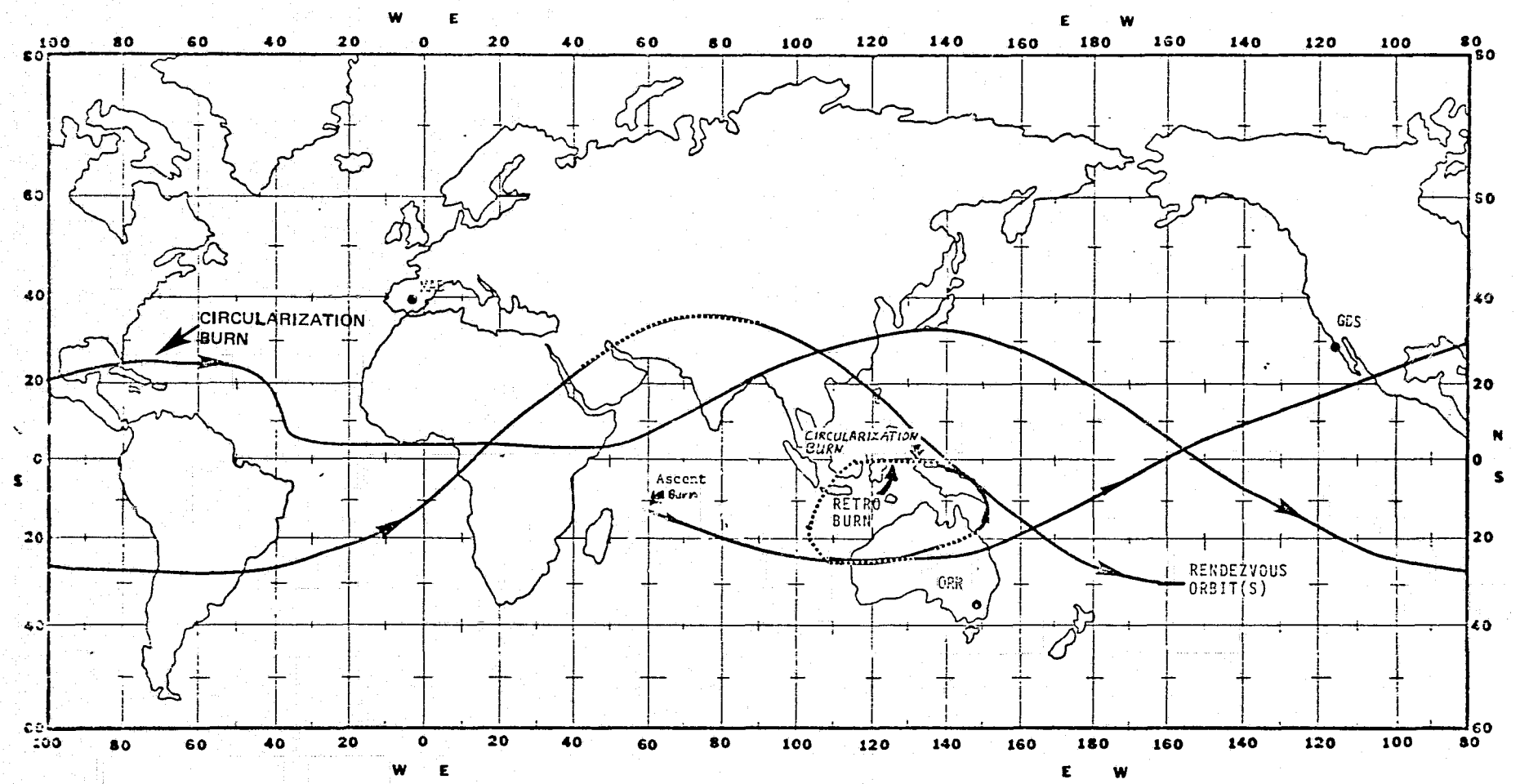


Figure 5.3.3-2. Geosynchronous Mission (TDRS Support)

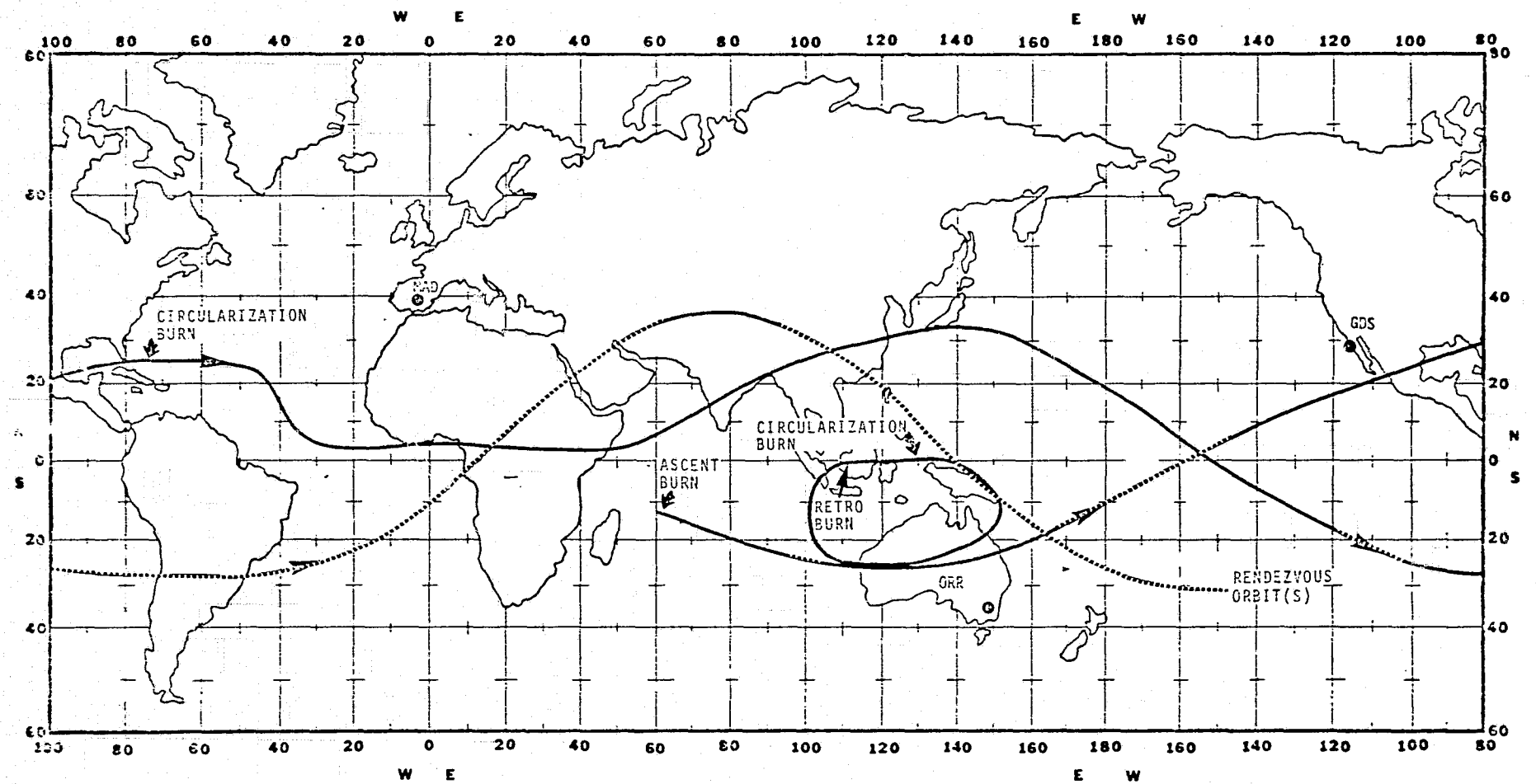


Figure 5.3.3-3. Geosynchronous Mission (STDN Support)

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.

The basic Orbiter/Tug on-orbit operations philosophy was to perform as many of the required software functions in the Tug as possible, which would mean that the Orbiter would only initiate sequences which would be performed by the Tug. This is especially true for the activation sequencing. The following paragraphs define the Orbiter software functions sized to support the Tug.

A summary of the Orbiter software storage impacts to support the Tug operations are given in Table 5.3.4-1. The functions to be sized were divided into two groups, Orbiter interactive support for Tug and Orbiter controlled support for Tug. The interactive support includes the interactive Tug/Orbiter interfaces and operations, and include Tug safety/status monitoring, Tug subsystem activation and operations support, and backup or contingency sequencing support. The Orbiter controlled support includes overhead to the operating system, Tug displays and controls in the MSS, and miscellaneous support provided to the Tug such as remote manipulator, communications and deployment adapter operations which are done independent of Tug involvement. The Orbiter controlled support may not be charged to the Tug.

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 5.3.4-1 indicates that approximately 16K of 32 bit words is required in the Orbiter DMS, assuming that both interactive support and Orbiter controlled support are charged to the Tug. But, since only a portion of the total storage is required at any one time, only about 2.5K of 32 bit words is required in main storage at one time. Therefore, the Tug 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 Tug display formats and data (12 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 18KOPS provided to payloads by the Orbiter.

5.4 IUS COST ESTIMATES

Table 5.4.0-1 contains the cost estimate results of the operational analysis conducted for various IUS stages and operational concepts. The structure of this table is similar to Space Tug, that is, containing DDT&E and recurring cost items as a function of individual analytical case.

Two separate cases of autonomy were analyzed during the IUS operational study phase. These two cases have been identified as Level A autonomy and Level B autonomy. Level A autonomy can be summarized as follows: (1) an existing vehicle constrained to a tone command system, (2) no operational interface with the onboard computer subsystem, (3) no navigation or target update capability. This autonomy case assumes a sightly modified existing stage with the same operational characteristics of stages currently used on expendable launch vehicles. The Level B, more capable vehicle, autonomy case can be summarized as follows: (1) a digital command system, (2) operational interface

Table 5.3.4-1. Orbiter Software Sizing to Support Tug

	INST	DATA	*TOTAL (32 BIT WORDS)	MAX MAIN MEMORY (32 BIT WORDS)
• INTERACTIVE SUPPORT FOR TUG				
- SAFETY/STATUS MONITORING	350	9,055	5,878	1,031
- INITIALIZATION, ACTIVATION AND DEACTIVATION	2,450	1,030	2,175	938
- CONTINGENCY SEQUENCING SUPPORT	3,800	2,675	4,047	-
SUBTOTALS	6,600	12,760	12,100	1,969
• ORBITER CONTROLLED SUPPORT				
- MSS SUPPORT SOFTWARE (OVERHEAD)	500	350	531	531
- MISCELLANEOUS ORBITER SUPPORT	3,200	2,450	3,532	-
	3,700	2,800	4,063	531

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

Table 5.4.0-1. IUS Cost Estimates

IUS COST ESTIMATES ($M)

AUTONOMY	STAGE	CONCEPTS	DDT&E		RECURRING	
			NASA	DOD	NASA	DOD
LEVEL A	EXPENDABLE	CONCEPT 1	20.3	20.4	4.5	4.5
		CONCEPT 3	2.69	26.5	3.87	5.98
	REUSABLE	CONCEPT 1	22.7	22.8	5.65	5.66
		CONCEPT 3	3.83	29.5	4.48	7.7
LEVEL B	EXPENDABLE	CONCEPT 1	24.6	24.8	5.27	5.66
		CONCEPT 3	3.8	32.4	4.54	7.68
	REUSABLE	CONCEPT 1	25.9	26.1	5.8	5.8
		CONCEPT 3	4.35	34.1	4.61	7.88

with the onboard computer subsystem, (3) navigation and target update capabilities. The Level B autonomy case reflects increased ground involvement, more ground software and manpower, and approximates current capabilities of the candidate IUS vehicles being studied under DoD contracts.

Two distinct IUS vehicle stages have been used during the analytical portion of the Orbital Operations Study. These two vehicle stages have been defined as the Expendable IUS (EIUS) and Reusable IUS (RIUS). The Expendable IUS case assumes a throw-away vehicle which is not retrieved by the Orbiter for earth return. The Reusable IUS case utilizes a vehicle which does have capability to be returned to and is retrieved by the Orbiter for earth return. Both IUS stage configurations have Spacecraft delivery capability but do not have capability for the return of satellites via the Orbiter transportation system.

The operational concepts evaluated during the IUS analysis phase were Concept 1, NASA and DoD separate facility and Concept 3, which reflects the operational case where DoD would perform all operational activities for both NASA and DoD missions. These operational concepts have been described and are shown in Figure 5.1.0-1. The engineering details and data associated with the IUS operational analysis phase is contained in Volume II of the final report.

The operational elements contained within the DDT&E cost estimates for Concept 1 have been identified in Figure 5.4.0-1. These elements are the physical plant or facility, ground (TOC) software development, data system procurement, operations staff equipment development and IUS (flight) software development. The generation of the sizing and cost estimates are discussed in Volume II of the final report. It can be seen from Figure 5.4.0-1 that the cost driver in the DDT&E category is ground (TOC) software development which accounts for approximately 55% of the expenditure. Again, these cost numbers reflect a totally new development program which does not use existing software, hardware or facilities.

The operational elements contained within the recurring cost estimates for Concept 2 have been identified in Figure 5.4.0-2. For this study recurring costs are costs per year estimates for operational (non-development) activities. These elements are facility maintenance, ground (TOC) software maintenance, data system maintenance, sustaining TOC (Flight Support) engineering, sustaining TOC FLT. CNTL. (Flight Control) engineering, network rental and IUS (flight) software maintenance. The generation of the sizing and cost estimates are discussed in Volume II of the final report. It can be seen from Figure 5.4.0-2 that the cost driver in the recurring category is manpower (Flight Control and Flight Support) which accounts for approximately 54% of the recurring costs per year.

5.4.1 EIUS/ORBITER INTERFACE OVERVIEW

A top-level EIUS/Orbiter interface schematic is shown in Figure 5.4.1-1. 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 data package used for the study 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

DDT&E COSTS
(EIUS LEVEL B)

ELEMENT	DOLLARS
PLHYSICAL PLANT	418620
TOC SOFTWARE DEVELOPMENT	13513129
DATA SYSTEM	7010008
OPERATIONS STAFF EQUIPMENT	1052400
IUS SOFTWARE DEVELOPMENT	2729197
TOTAL	24723354

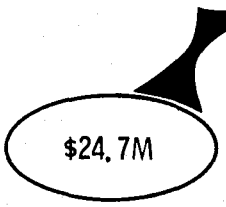


Figure 5.4.0-1. EIUS DDT&E Cost Elements

RECURRING COSTS
(EIUS LEVEL B)

ELEMENT	DOLLARS
FACILITY MAINTENANCE	19872
TOC SOFTWARE MAINTENANCE	1200000
DATA SYSTEM MAINTENANCE	138795
SUSTAINING TOC ENGINEERING	1440000
SUSTAINING TOC FLT. CNTL. ENGINFERING	1440000
NETWORK RENTAL	26233
IUS SOFTWARE MAINTENANCE	1008000
TOTAL	5272900

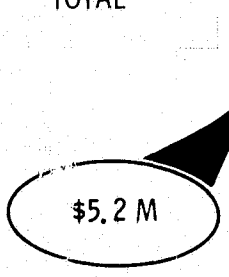


Figure 5.4.0-2. EIUS Recurring Cost Elements

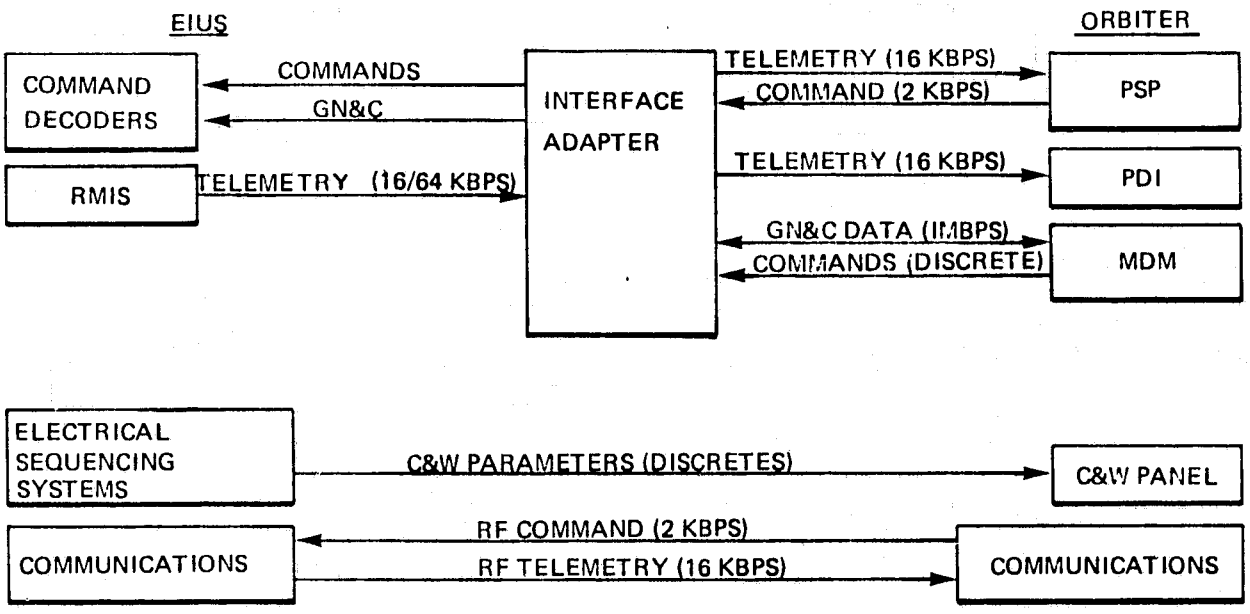


Figure 5.4.1-1. EIUS/Orbiter Operational Data Interfaces

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 CN&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 parameters for near-vicinity operations.

A more detailed breakdown of the C&W parameters and discrete command interfaces are shown in Figure 5.4.1-2. As shown, approximately 91 discrete commands are required for the IUS and deployment adapter. Thirteen C&W signals are required and are discussed below.

- Propulsion
  - Oxidizer Tank Overpressures
  - Fuel Tank Overpressures
  - Helium Sphere Overpressure
  - ACS Tank Overpressure
- Avionics
  - IMU Malfunction
  - Computer Alarm
  - Inadvertent Power On
- Inadvertent Disconnection
  - Propellant Dump Lines
  - Vehicle Holddown
  - Electrical Umbilical
- Leak Detection
  - Oxidizer Vapor
  - Fuel Vapor

5.4.2 EIUS MISSION COMMUNICATION ANALYSIS

Three representative EIUS mission types were defined for communication analysis. 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 confidence that useful stations were not prematurely disregarded.

Volume II of the final report contains the details of the communication analysis conducted. To illustrate the type of analysis performed, the following paragraphs present data for the sun synchronous mission cases.

The sun synchronous mission was analyzed for 0.50 days in length. The ascent burn delivered the vehicle to an altitude of 920 nautical miles where a circularization burn is initiated. Spacecraft deployment completes the EIUS mission sequence. The mission coverage indicated is from TDRS-E, TDRS-W and three station

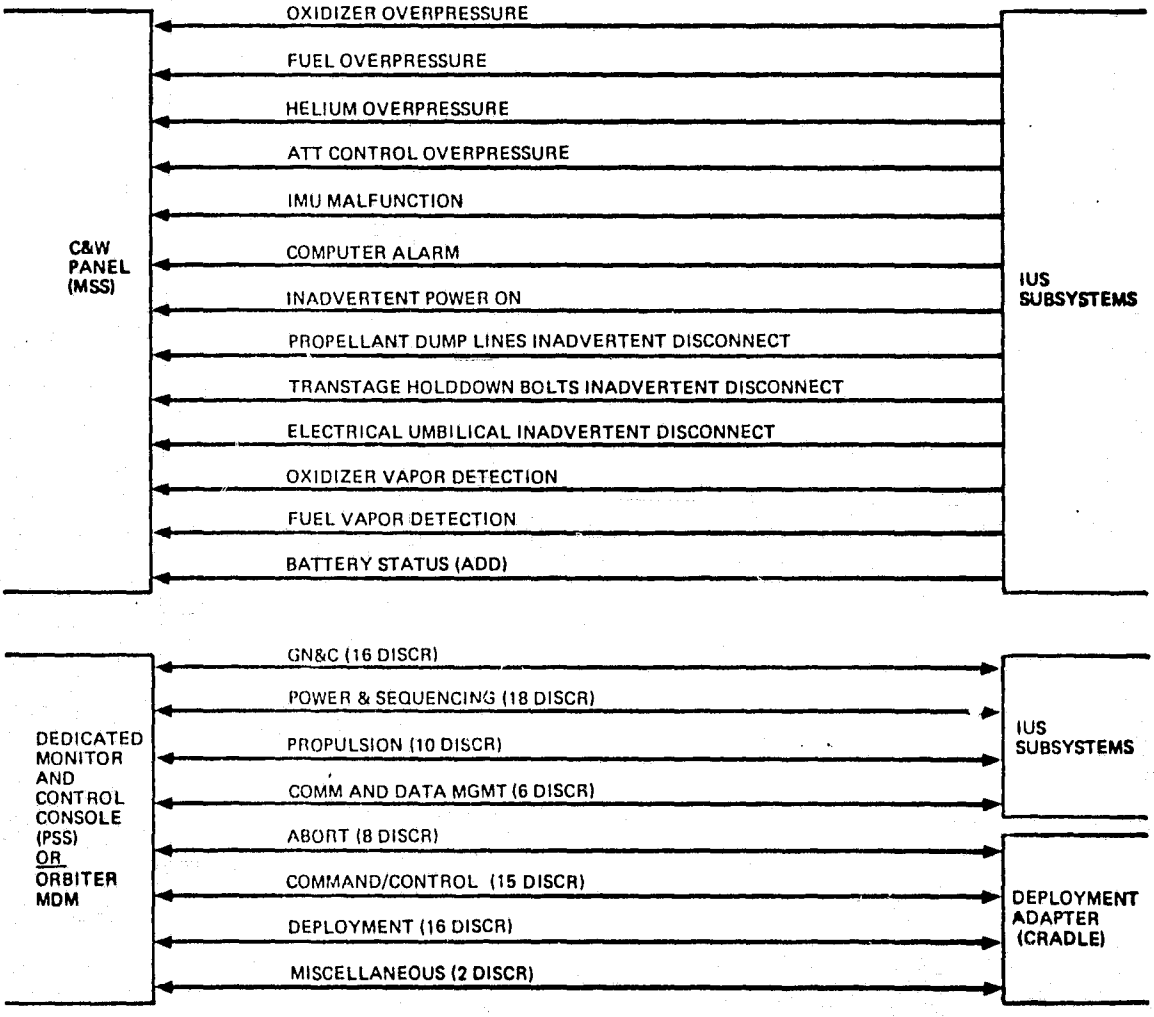


Figure 5.4.1-2. EIUS/Orbiter C&W and Discrete Command Interfaces

ground network composed of Goldstone, Orroral and Madrid.

Figure 5.4.2-1 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 perspective on the mission trajectory traces in Figures 5.4.2-2 and 5.4.2-3. 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 coverage during the critical mission time periods; the ascent burn, the orbit circularization burn, and payload deployment.
- The TDRS, on the other hand, can support all burn periods.
- IUS checkout and deployment requires the Orbiter/TDRS interface for communication support.

5.4.3 ORBITAL CHECKOUT

The items analyzed during the Orbital Checkout task 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 IUS 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 IUS. 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.

The basic Orbiter/IUS on-orbit operations philosophy was to perform as many of the required software functions in the IUS as possible, which would mean that the Orbiter would only initiate sequences which would be performed by the IUS. This is especially true for the activation sequencing. The following paragraphs define the Orbiter software functions sized to support the IUS.

A summary of the Orbiter software storage impacts to support the IUS operations are given in Table 5.4.3-1. The functions to be sized were divided into two groups, Orbiter interactive support for IUS and Orbiter controlled support for IUS. The interactive support includes the interactive IUS/Orbiter interfaces and operations, and include IUS safety/status monitoring, IUS subsystem activation and operations support, and backup or contingency sequencing support. The Orbiter controlled support includes overhead to the operating system, IUS displays and controls in the MSS, and miscellaneous support provided to the IUS such as remote manipulator, communications and deployment adapter operations which are done independent of IUS involvement. The Orbiter controlled support may not be charged to the IUS.

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 5.4.3-1 indicates that approximately 10K of 32 bit words is required in the Orbiter DMS,

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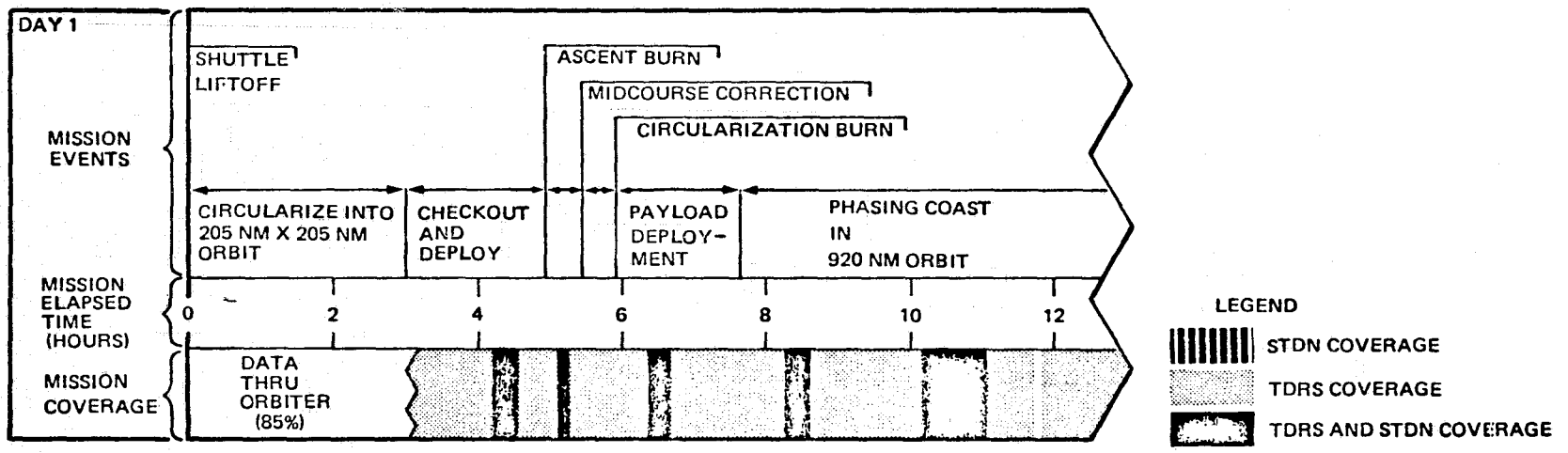


Figure 5.4.2-1. IUS Sun Synchronous Mission Timeline

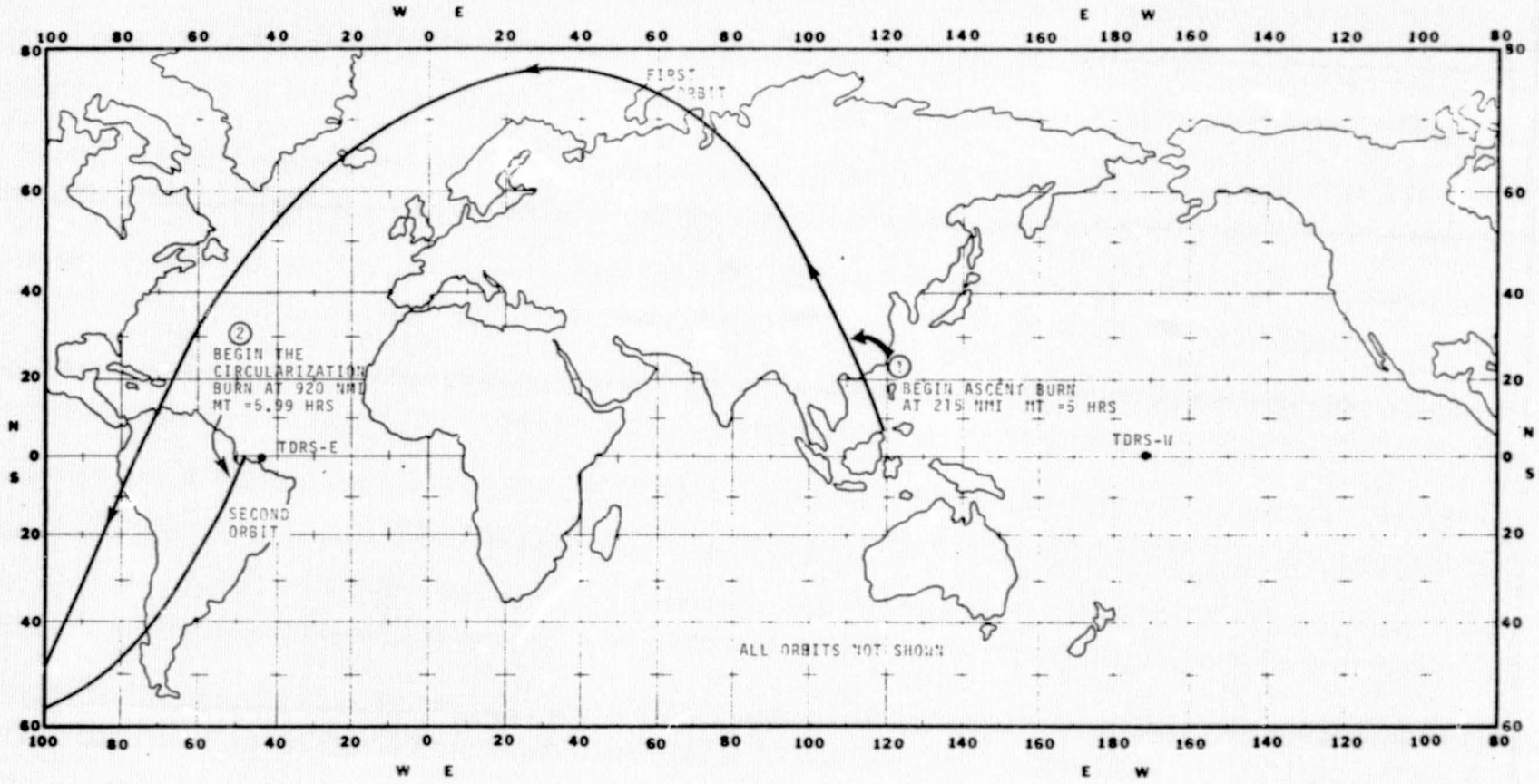


Figure 5.4.2-2. Sun Synchronous (TDRS Support)

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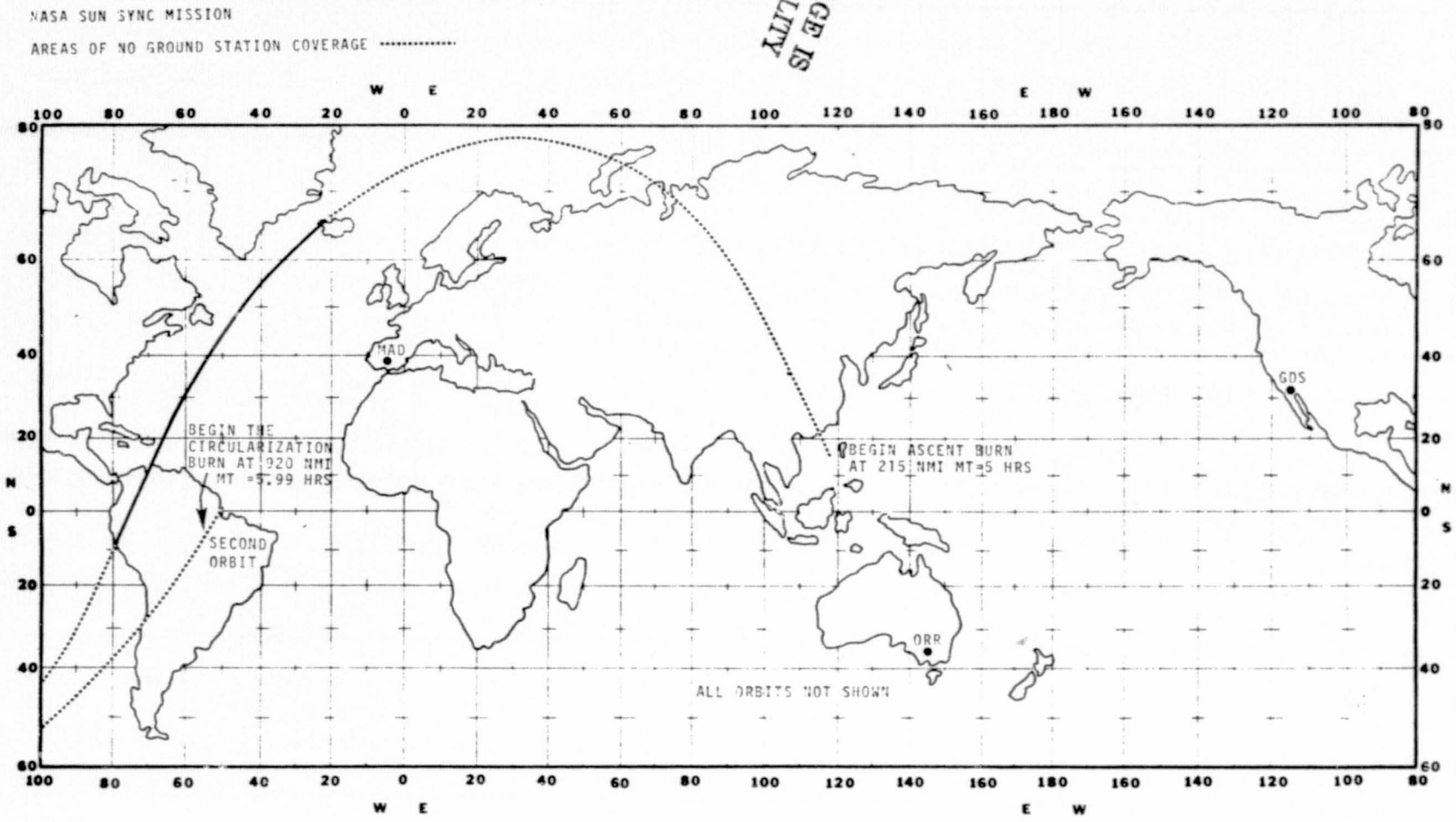


Figure 5.4.2-3. Sun Synchronous (STDN Support)

Table 5.4.3-1. Orbiter Software Sizing to Support IUS

	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

assuming that both interactive support and Orbiter controlled support are charged to the IUS. But, since only a portion of the total storage is required at any one time, only about 1.1K of 32 bit words is required in main storage at one time. Therefore, the IUS 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 IUS 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.

5.5 TRANSITION PHASE

The transition phase study activities analyzed the operational activities and techniques for transition from the IUS program to the Space Tug program. This study phase compared IUS tasks and Space Tug tasks and resulted in operational activities being divided into three distinct categories. These categories, as shown in Figure 5.5.0-1, were (1) common tasks which were common to both programs, (2) IUS unique tasks, and (3) Space Tug unique tasks. Having performed this initial separation, the tasks were then merged into a unified program which took the common tasks grouping and added to that the IUS unique and Space Tug unique tasks required for operations. In the analysis conducted during the study, the Expendable IUS (EIUS) Level B vehicle and Space Tug Level II autonomy vehicle were used to evaluate the transition phase. These two vehicles were selected at the completion of the Phase II and III analysis because of reduced orbital operations support requirements for the ground control centers. The results of this phase of analysis identified no major operational technical challenges during the transition phase from EIUS Level B to Space Tug Level II activity. Although no major technical challenges were identified, the need for early planning was evident in attempting to reduce overall DDT&E expenditures when considering operational requirements for the two programs. Figure 5.5.0-2 contains a summary of the major activities of the generated IUS/Tug composite program. These operational activities have been structured using PERT analysis techniques with the goal of minimizing yearly expenditures for the development of IUS and Tug operational capabilities. As the figure indicates, this particular summary plan for the transition phase indicates an initial start in first quarter of 1977. The initial task would be the requirement analysis and planning of ground software development. The tasks which have been waterfalled throughout the six year development program includes both IUS and Tug operational development activities. The Space Tug ground software development tasks have been split into three distinct phases. Phase 1, the requirements analysis task for ground software is recommended to begin second quarter of 1977. The timing of this task would allow both IUS and Space Tug software requirement analysis to be conducted simultaneous, to ensure the design structure for IUS would also include features which could be utilized for Space Tug operational capability. The combined requirements analysis thus could be used for the sizing of the ground data system to ensure compatibility between the IUS and the Space Tug programs. The PERT analysis and transition plan which has been developed is discussed in Volume III of the final report. The transition study phase has indicated that the IUS and Space Tug should be approached as one operational problem. In so doing, this presents opportunities for significant cost savings, especially in the DDT&E cost areas. As shown in Figure 5.5.0-2, if the two programs are approached as one unified operational program, DDT&E costs may

- AFTER MERGING IUS WBS AND SPACE TUG WBS
  - SOME TASKS ARE COMMON
  - SOME TASKS ARE UNIQUE TO IUS
  - SOME TASKS ARE UNIQUE TO SPACE TUG
  - SOME TASKS START WITH IUS AND ARE PHASED INTO SPACE TUG
- TABLE FORMAT

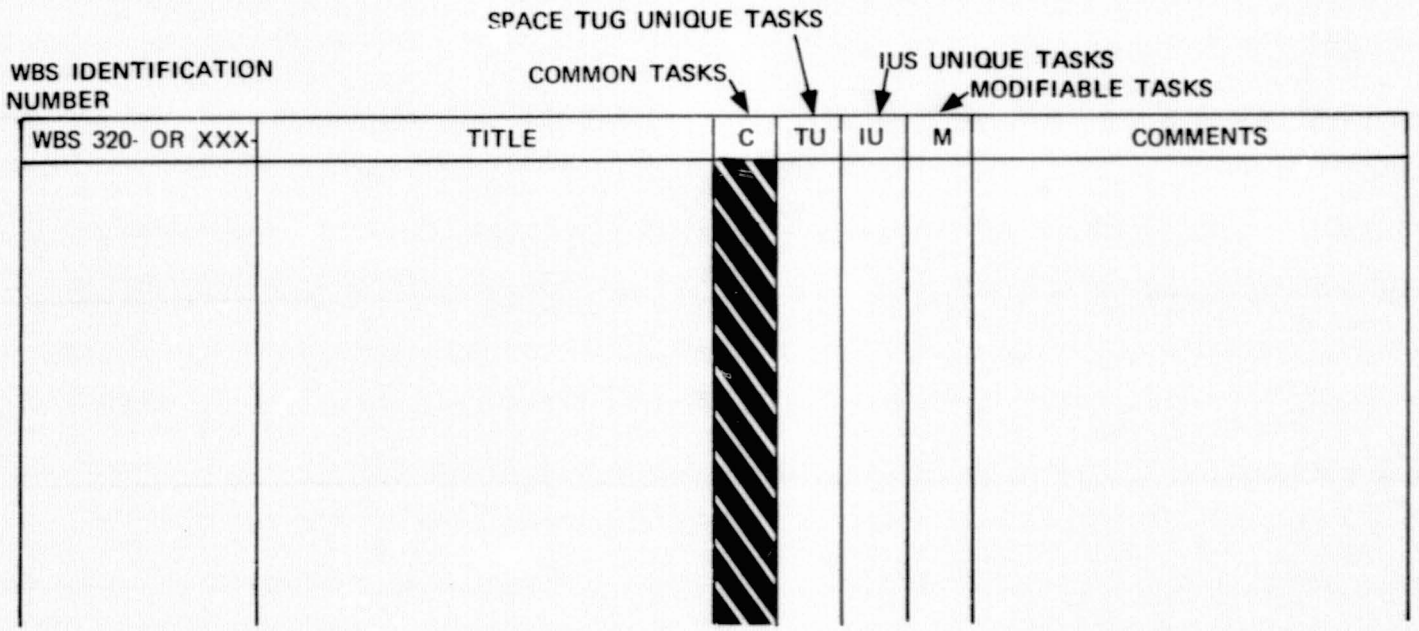


Figure 5.5.0-1. Categories of Tasks

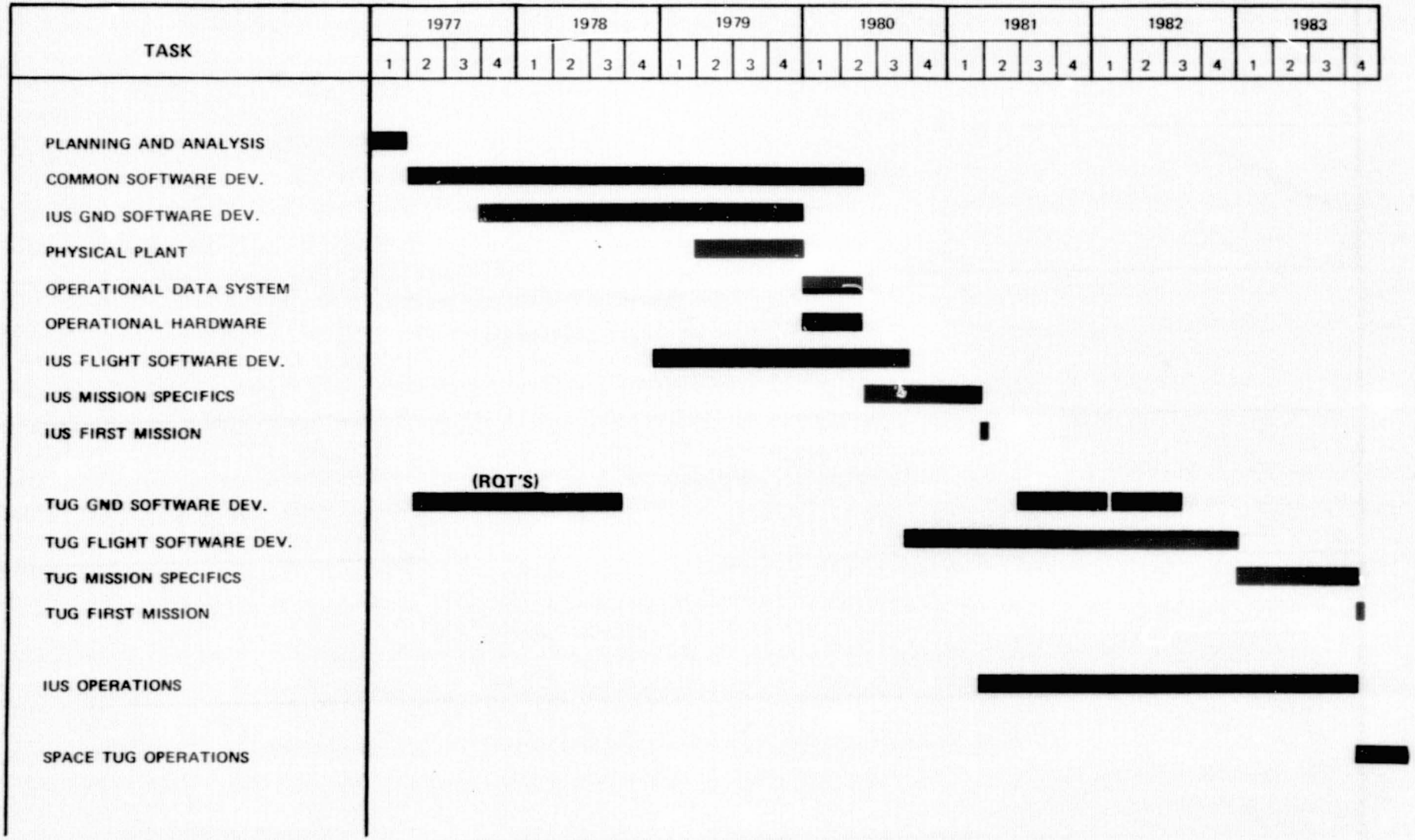


Figure 5.5.0-2. Major Activities IUS/Space Tug Composite Program

be reduced by approximately 14 million dollars. This potential savings can be seen in Figure 5.5.0-3 which represents the Tug program as a stand-alone operational entity, the IUS program as a parallel entity, an estimate of the two programs viewed serially and finally the result of the IUS and Tug programs being viewed as one unified operational program. As noted in the figure, control center software development still remains the cost driver in DDT&E expenditures. Under the unified operational program concept potential savings can be obtained by co-locating IUS and Tug operational activities, and developing ground software commonality for the two programs. Additional DDT&E reductions are possible through utilization of existing facilities, data systems and software. These assessments have not been conducted during this study but should be performed in the near future. Due to the time phasing of the two programs, major recurring cost savings are not available through the unified operational program approach.

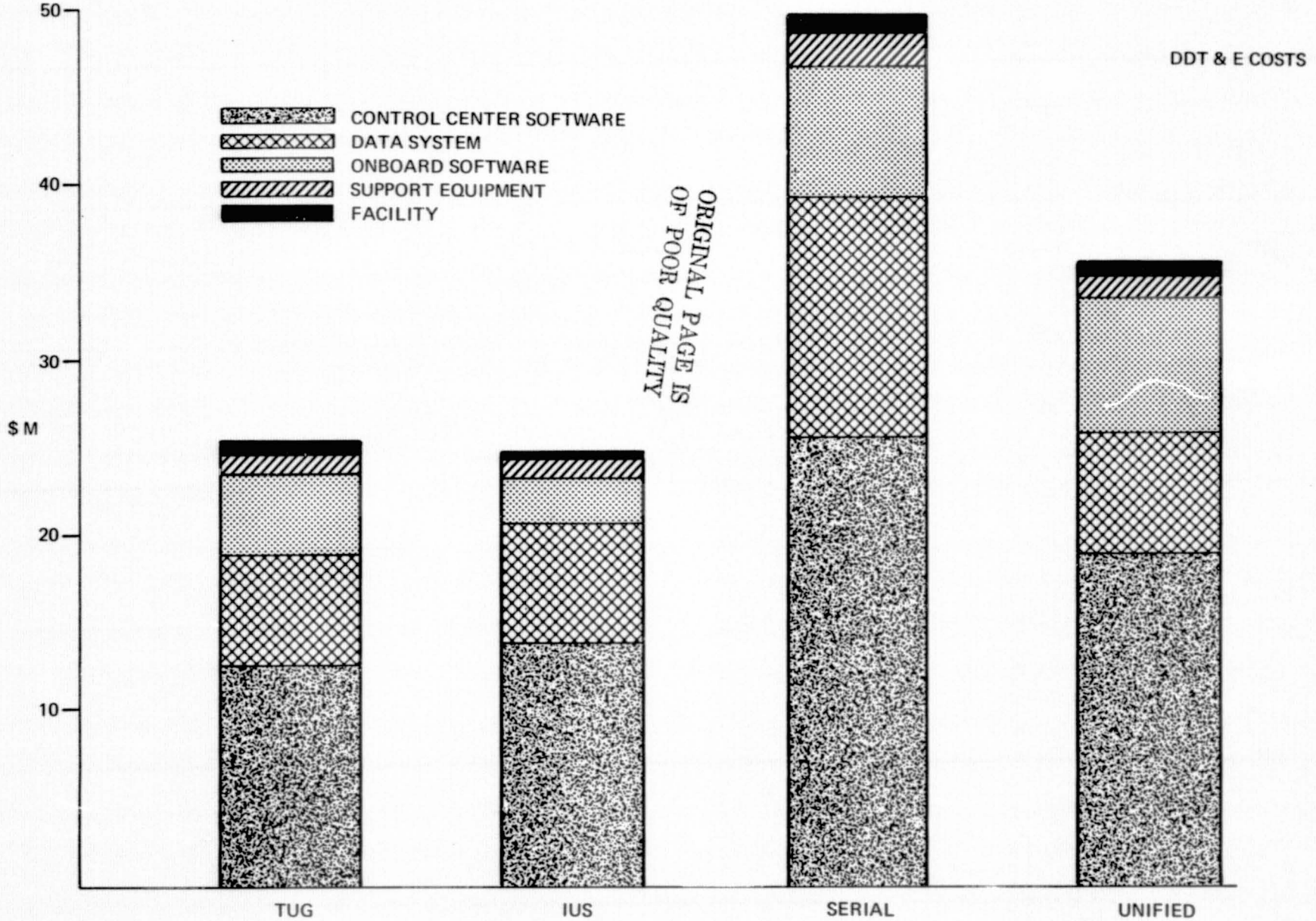
5.6 SIGNIFICANT CONCLUSIONS

The major conclusions from the IUS/Tug Orbital Operations and Mission Support Study have been listed in Table 5.6.0-1. These conclusions have been reached following the completion of the various analytical phases of the study. The detail data and backup information for these conclusions has been provided in the remaining volumes of the final report.

Operational Concept - Operational Concept 1, separate NASA and DoD facilities, has been recommended from the results of a Kepner-Tregoe trade, the long term program (IUS/Tug) involvement, and security complications. The trade was performed using the Kepner-Tregoe decision analysis technique with weighted factors on nine independent variables. Individual scores from control center personnel were again weighted to arrive at the "best score" candidate. Separate facilities between the two agencies will reduce agency interfaces and when viewed as a 10-year operational program would simplify operations and provide for greatest flexibility within each agency. Conversion of a secure operations facility for non-secure activities and the inverse conversion would add complexity to a 10-year operational program. Concept 2A and 2B, as analyzed during the course of the study, both involve shared operational elements with DoD. In addition, the potential for non-USA payloads on both the IUS and the Space Tug vehicles increase the concerns of sharing DoD/NASA facilities. Therefore, Operational Concept 1 has been recommended by the study, although it is the most costly.

Autonomy Level - EIUS (Level B) and Space Tug (Level II) autonomy are recommended by the study. Both represent reduced ground involvement in the cases analyzed and present a greater mission capability to address a 10 year operational program. Technology trends in the area of rendezvous and docking sensors and autonomous navigation devices appear to be reasonable operational tools for the Space Tug Level II vehicle. The Level B EIUS vehicle provides for greater capability than expendable stages flown today in the areas of digital command system and onboard computer system interfaces. These factors, from an operational standpoint, allow for reductions in ground software development and manpower requirements. Therefore, these two vehicle recommendations have been made from the analysis conducted with the study.

Orbiter Accommodations - Orbiter accommodations for both the IUS and Space Tug appear adequate based on (1) caution and warning analysis, (2) orbital checkout analysis, (3) deployment analysis and (4) retrieval analysis. The



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Figure 5.5.0-3. Transition Phase

CONCLUSIONS

- OPERATIONAL CONCEPT 1 (SEPARATE NASA AND DOD FACILITIES) IS RECOMMENDED FOR THE CASES STUDIED
  - KEPNER-TREGOE RESULTS
  - DOD HAS SECURITY RESTRICTIONS ON IUS/TUG
  - POTENTIAL NON-USA PAYLOADS ON IUS/TUG
- SPACE TUG (LEVEL II) AND EIUS (LEVEL B) ARE RECOMMENDED
  - TECHNOLOGICAL TRENDS MAKES HIGH AUTONOMY FEASIBLE
  - GROUND SOFTWARE/MANPOWER COSTS ARE REDUCED
- ORBITER ACCOMMODATIONS ARE ADEQUATE FOR IUS/TUG OPERATIONAL INTERFACE REQUIREMENTS
- IUS AND SPACE TUG SHOULD BE CONSIDERED A SINGLE OPERATIONAL PROGRAM
  - DEVELOPMENT SHOULD BEGIN JANUARY, 1977
  - SOFTWARE DEVELOPMENT LAB IS REQUIRED TO ENABLE PARALLEL DEVELOPMENT
  - PROVIDES REDUCTION IN OVERALL DDT&E ($\simeq$ \$14M)
- OPERATIONAL COST DRIVERS
  - GROUND SOFTWARE (DDT&E)
  - MANPOWER (RECURRING)
- FLIGHT SOFTWARE AND GROUND SOFTWARE SHOULD BE APPROACHED AS ONE TECHNICAL PROBLEM

Table 5.6.0-1. Conclusions

accommodations as described in JSC07700 Volume XIV, Change 7, will adequately meet the operational requirements identified during this study. Specific requirement statements and analysis have been documented in Volumes II and III of the final report.

Unified Operational Program - One of the strongest conclusions of the study is that the IUS and Tug programs should be approached as one operational problem. During the transition study phase analyzing these two programs as one operational problem has identified a potential DDT&E savings of approximately 14 million dollars and will allow an orderly operations development beginning with the IUS program. When viewed as one unified operational program and using the current transition plan from this study, the ground software development analysis should begin in January, 1977, assuming a total development program. The results of the analysis have indicated a need for a software development lab to provide the capability for both ground and flight software development, implementation, and verification.

Cost Drivers - The operational cost drivers identified in all analytical cases conducted during the study were the same. In the DDT&E cost category, ground software development required the largest expenditure of funds. In the Space Tug Level II autonomy case, ground software development resulted in 49% of the DDT&E expenditures. In the EIUS Level B analytical case ground software development received approximately 54% of the DDT&E expenditures. These development cost drivers can provide potential DDT&E savings if the IUS/Tug is considered a single unified operational program. Through development sharing and structuring of software in the design phase for both IUS and Tug requirements potential savings can be achieved. Additional potential major cost savings may be realized by utilizing existing software rather than developing totally new packages.

In the recurring cost catagory the cost drivers in all analytical cases studied was manpower. Manpower as defined in this study consists of flight control and flight support personnel who perform real-time evaluation and support within the control center. In the Space Tug Level II autonomy case manpower was approximately 56% of the total recurring costs per annum. In the EIUS Level B autonomy case manpower contributed approximately 54% of the total recurring costs per annum. As can be seen, manpower continues to be the cost driver in the recurring cost category. Additional analytical effort needs to be expended to determine techniques to reduce manpower requirements.

Flight/Ground Software - During the performance of the Orbital Operations Study it became apparent that flight software and ground software should be approached as one technical problem. Software is the element which makes an EIUS or a Tug mission unique. In allocating operational functions between the ground and onboard systems, the allocation process requires that both sets of software be evaluated and analyzed as one problem. As conclusions were reached where a functional task should be performed and for example it was added to the ground software, it could be assured that this same function would not also be duplicated in the flight software. Through this functional analysis process both sets of software maintained a sense of commonality with the end result being a minimum amount of overlap of redundant requirements between the two software sets. By approaching flight software and ground software as one technical problem, change activities during the 10 year operational program could be minimized.

STUDY LIMITATIONS 6

The limitations of the IUS/Tug Orbital Operations and Mission Support Study can be summarized in three specific areas. These areas are control center location, DoD cost assumptions, and shared program considerations. The following paragraphs discuss each of these areas and provide basic information as to the limitations of the study.

6.1 CONTROL CENTER LOCATION

One of the major guidelines of the study dealt with the control center location issue for both the IUS and Space Tug programs. The guidance and direction received was to specify the total operational requirements, sizing, and cost estimates regardless of location or existing capabilities. This guideline was implemented throughout the study and therefore is reflected in all requirements, sizing, and cost estimates provided. The net effect of the control center location issue resulted in the generation of the maximum operational estimates for sizing and cost during the IUS and Tug programs. It did not provide an assessment of existing facilities against the operational requirements derived for IUS and Tug and therefore presents the high boundary of both DDT&E and recurring costs which can be anticipated during operatonal development phases of these two programs. In summary the control center location guideline has resulted in the generation of data for a "build from scratch" development activity. However, the data within the study has been structured to allow existing facility assessments at a later date.

6.2 DoD COST ASSUMPTION

The DoD cost assumptions used during the study to generate estimates for DDT&E and recurring costs as associated with the IUS and Tug programs, have been generated by the study contractor. These assumptions have not been agreed to by DoD and therefore represent an operational cost comparison as estimated by the study contractor. The analytical methods used and the total study results have been structured to allow rapid update. Therefore, by providing new cost assumptions if required in the area of DoD estimates the study data can be utilized to generate new data sets with a minimum amount of effort.

6.3 SHARED PROGRAMS

The third major limitation of the Orbital Operations Study deals with the issue of sharing IUS/Tug development costs with other programs. The results of the study do not consider sharing hardware or software developments with other programs but provide the total requirements set, the total sizing set and the total cost estimate set without program sharing considerations. The data in all cases has been structured to reflect a separate development program; however, the study results can be easily modified by shared program considerations. These shared program considerations offer high savings potential in both DDT&E and recurring cost categories.

IMPLICATIONS FOR RESEARCH 7

This section contains the candidate areas for research which have been identified during the IUS/Tug Orbital Operations and Mission Support Study. The detailed description of each candidate area is contained in Volume IV as a recommended SR&T item. The areas are (1) Rendezvous Targeting Onboard Software, (2) Automatic Docking Feasibility Demonstrations, (3) Level I Autonomy Flight Software Development, (4) Minimization of Ground Control Interaction, (5) Flight Software Modularization, and (6) Orbital Navigation. Each candidate research area is discussed in the following paragraphs.

7.1 RENDEZVOUS TARGETING ONBOARD SOFTWARE

The feasibility of automatically targeting a rendezvous sequence based on inflight navigation and externally derived target information has been theoretically determined. The limiting factor in prior investigations has been the available CPU speed of airborne digital computers. The current state of the art in airborne digital computer design indicates that CPU speeds approaching 500,000 equivalent adds per second will be available in the Space Tug time frame.

Previous studies have estimated the requirements for rendezvous targeting to be on the order of 480,000 equivalent adds per second. It is, therefore, technically feasible to implement the theoretically derived rendezvous targeting capability. Needed is the development of new schemes to minimize onboard computation time and to optimize the rendezvous targeting algorithms.

A period of development should precede demonstration of the rendezvous targeting in a flight-type computer. Algorithms should be designed, optimized, and coded. The resulting software can then be demonstrated in both hardware and software simulators.

7.2 AUTOMATIC DOCKING FEASIBILITY DEMONSTRATION

All docking operations undertaken by previous Space Programs have been manually guided corrections between a stabilized target vehicle and a manually controlled pursuing vehicle. Schemes based upon slow scan television interrogation of the target and ground man-in-the-loop control of docking are expensive in docking support software required and contain time delays involved in supporting transfer of information from the physical condition in orbit to the ground controller.

The problem of rendezvous and docking requires, necessarily, a simulation of the target and a simulation of the pursuit vehicle. Each of the simulators must provide six degrees of freedom for each element of the rendezvous problem.

The software developed to support docking should be implemented in a computer of the type planned for Space Tug, which will control the motion of the pursuit vehicle. A second computer source will drive the target vehicle in the motions which may be encountered during docking. The long range simulator may be to scale; however, it must be augmented with a short range docking assembly in order to simulate the final closure and physical dock.

7.3 LEVEL I AUTONOMY FLIGHT SOFTWARE DEVELOPMENT

Until recently, autonomous space missions were not feasible on the basis of qualified avionics computer CPU speeds and navigation uncertainties derived from hardware error sources and other uncertainties. Recent programs sponsored by the Department of Defense have shown autonomous navigation to be feasible based upon ILT and star tracker hardware implementations coupled with a high speed onboard computer. Existing autonomous software schemes such as MASCOT and OPGUIDE have been developed and coded in PL1 and FORTRAN languages for demonstration purposes on high speed, ground based digital computers. The technical approach suggested is to begin with the existing software coding and modify that coding for implementation in an airborne digital computer having the computational speed and memory size necessary to implement the autonomous flight software. The resulting coded program will be tested in simulated flight conditions in a flight computer, with the test being monitored by a large, highspeed ground computer, which will simulate the external inputs to the onboard computer. A further test program involving the utilization of autonomous flight software in a passenger mode or in a switchin/switchout mode during actual flight is recommended.

7.4 MINIMIZATION OF GROUND CONTROL INTERACTION

The Mercury, Gemini, Apollo and the Skylab programs relied heavily upon ground interaction and augmentation of inflight decisions. For the most part, these decisions were analyzed during the pre-mission phase and were implemented by ground based personnel following a "mission rules" document. It necessarily follows that many decisions which can be analyzed in advance may also be programmed into a ground based digital computer. It is therefore feasible to utilize ground interaction only when that interaction involves pattern recognition, and to implement the routine decisions in a ground based computer.

These decision types, should be analyzed and software written to implement the decisions through interaction of the Space Tug vehicle and the communications systems. This demonstration will be followed by a simulated mission during which the adequacy of the ground software to respond to contingency situations inflight will be judged. Upon completion of a simulation demonstration, the decision software will be implemented in the ground computer complex supporting the Space Tug mission and utilized in parallel to manual observers. After confidence has been gained in the efficiency of computer based mission decisions, the operation of Space Tug flights through automatic decision processes should be implemented.

7.5 FLIGHT SOFTWARE MODULARIZATION

The Apollo program demonstrated the efficiency of modular programming. However, there is considerable room for improvement in the techniques of relating equation definition to program implementation. The problems in modular flight software development have been primarily in the translation of requirements from the equation level into practical implementation of flight software.

The technical plan to be followed is to investigate existing bodies of theory for mechanisms which segregate interrelations and to demonstrate a software based system which will decouple input requirements into logical relationships at the equation level. This will permit the programmer to efficiently code modules and ensure that the modules being coded will not be destroyed by changes in the input. This will involve some form of a constraint or relation matrix, some form of control matrix, and an adaptation of mapping techniques. This task is primarily to develop a theoretical base for flight software modularization.

7.6 ORBITAL NAVIGATION

Orbital navigation was performed in the Saturn/Apollo program by integrating the equations of motion and performing minor corrections due to gravity anomalies and atmospheric drag. Orbital navigation over an extended period resulted in an accumulation of state errors which, since the system was open loop, were not corrected, and propagated into the translunar burn phases. With the development of ILT technology and the coupling of ILT landmark navigation and stellar sensed attitude update information, it is now theoretically possible to navigate in a closed loop sense. This will require the development of a detailed gravity model, a detailed atmospheric model, and techniques for servicing the star tracker and ILT input information to a central computer onboard the vehicle.

Development of a detailed gravity model based on empirical satellite observations should be initiated along with a detailed atmospheric model based on empirically derived drag coefficients. ILT servicing software should be adapted from DoD implementations to NASA Space Tug applications. All inputs should be combined into a high speed airborne-type digital computer having 500,000 equiavlent adds per second (or higher speed) with the resulting software package demonstrated in simulations.

Following a demonstration in the simulation mode, the system can be flown aboard a Space Shuttle or Space Tug as a passenger and demonstrate, under actual flight conditions, precision orbital navigation.

SUGGESTED ADDITIONAL EFFORTS 8

This section presents suggested additional efforts which have been defined during the study and warrant consideration for the near future. The four major areas of additional efforts which have been defined are discussed in the following paragraphs, they are, (1) Rendezvous and docking, (2) Software (flight/ground), (3) Operational concept and (4) Orbiter interface.

8.1 RENDEZVOUS AND DOCKING

Rendezvous and docking issues have been bounded by the current NASA studies but require more concentrated efforts. In particular sensor development (SLR or equivalent) needs attention because sensor range and delta-velocity budgets have driven the operational analysis conducted during this study. The key component in the Space Tug Level II autonomy configuration is the rendezvous and docking sensor; therefore, a technology program needs to be established and work continued in the development of unmanned rendezvous docking sensors. In parallel with sensor development, additional effort needs to be expended in simulator development activities associated with rendezvous and docking. The parametric work performed during the Orbital Operations Study has bounded the rendezvous and docking problem from an operational standpoint. However, a simulator development program needs to be undertaken to allow design analysis to coninue which would include such parameters as slosh, and docking dynamics which would provide a capability to evaluate rendezvous and docking techniques prior to a sensor commitment.

8.2 SOFTWARE (FLIGHT/GROUND)

Software, both flight and ground, requires effort for (1) requirements analysis, (2) to evaluate the transferability issue and (3) to provide data for a software development plan. Also included in this analytical effort would be a requirements definition for a software development lab. The results of this study has shown that the largest DDT&E expenditure is ground software development. In order to minimize expenditures during development programs it is recommended that both IUS and Tug software requirements analysis be conducted now in order to generate and formulate a detailed software development plan in preparation for the IUS operational development cycle. A general tendency during programs of the past has been to minimize the early planning and analysis activities with respect to both ground and flight software. This delay in the front end portion of the software task has resulted in large and expensive software development cycles for major space programs. The Space Transportation System with its IOC date of 1981 for the IUS provides the unique opportunity to ensure early planning and analysis with the ultimate goal being reduced software development costs.

8.3 OPERATIONAL CONCEPT

Operational concepts require additional analytical efforts in the near future. The existing facility (or location) issue has not been addressed and the program sharing options need to be evaluated. These two issues present attractive options for reducing DDT&E costs expenditures estimated by this study. Sharing

of IUS/Tug operational development tasks with programs such as Space Lab or the Orbiter present attractive cost saving alternates which need to be analyzed. These alternates should be evaluated and data generated in the near future so that the major programmatic decisions which must be made within the next twelve months will be based on the best engineering data available.

8.4 ORBITER INTERFACE

Orbiter interface accommodations are adequate for the operational requirements of IUS and Tug; however, two areas appear to need additional effort. They are (1) a technical re-evaluation of the onboard Bose-Chaudhuri-Hocquenghem (BCH) coding scheme used by the Orbiter, which places a decode requirement on every payload in the cargo bay, and (2) the determination of the need/no need of an Orbiter/IUS/Tug interface lab. The BCH coding scheme used in the Orbiter is an error protection scheme to ensure the reliability of information received by and processed through the Orbiter subsystems. The impact to the IUS and Tug vehicles, and all payloads which reside in the cargo bay, is that this coding scheme must be decoded on the IUS/Tug side of the interface. A technical re-evaluation of the error protection rates associated with the BCH code should be evaluated such that payload related recommendations could be made. The need of an interface development lab requires assessment by the IUS/Tug program. This issue is not unique to IUS and Tug but shares commonality with all payloads which reside in the Orbiter cargo bay. The basic issue to be resolved is the need/no need of an interface development lab and a requirements definition/development plan if the lab is required.