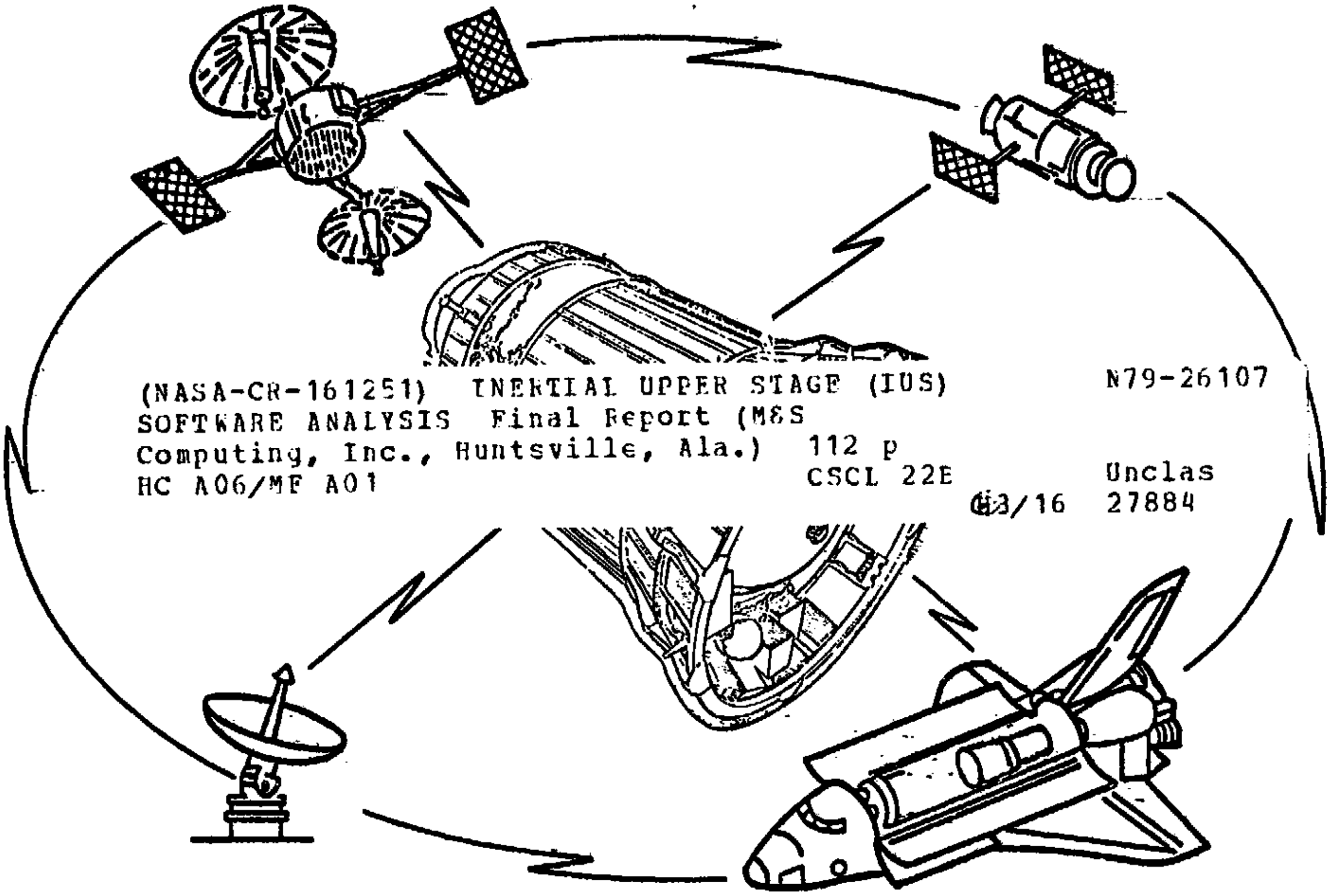

(NASA-CR-161251) INERTIAL UPPER STAGE (IUS) SOFTWARE ANALYSIS Final Report (M&S Computing, Inc., Huntsville, Ala.) 112 p HC A06/MF A01 CSCL 22E G3/16

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INERTIAL UPPER STAGE (IUS)
SOFTWARE ANALYSIS
FINAL REPORT

REPORT NO. 79-020

June 14, 1979

Prepared by:

STS SOFTWARE DEPARTMENT

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MARSHALL SPACE FLIGHT CENTER, AL 35812

Contract NAS8-33072

PREFACE

This report documents results from the IUS Flight Software Analysis Contract. The work was performed by M&S Computing, Inc., under Contract No. NAS8-33072 for the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC). The period of performance for this effort was June 1978 through May 1979.

Technical coordination of this effort was provided by Mr. L. F. Grant (EF23).

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LIST OF ACRONYMS

ADRN	Advance Documentation Revision Notice
BAC	Boeing Aerospace Company
CDR	Critical Design Review
COR	Contracting Officer's Representative
CPC	Computer Program Component
CPDS	Computer Program Development Specification
CPPS	Computer Program Product Specification
DOD	Department of Defense
ECP	Engineering Change Proposal
FOM	Figure of Merit
FQT	Formal Qualification Test
GFSC	Goddard Space Flight Center
GN&C	Guidance, Navigation, and Control
GSTDN	Ground Spaceflight Tracking and Data Network
IMU	Inertial Measurement Unit
IUS	Inertial Upper Stage
LPS	Launch Processing System
MDL	Mission Data Load
MOS	Mission Operations System
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
OFS	Operational Flight Software
PDR	Preliminary Design Review
RCS	Reaction Control Subsystem
RF	Radio Frequency
S/C	Spacecraft
SCN	Specification Change Notice
SCU	Signal Conditioner Unit
SGLS	Space Ground Link System
SPR	Software Problem Report
SRM	Solid Rocket Motor
SS	System Specification
STDN	Spaceflight Tracking and Data Network
STS	Space Transportation System
TBD	To Be Determined
TBS	To Be Supplied

LIST OF ACRONYMS
(Continued)

TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TI	Technical Interchange
TLM	Telemetry
TT&C	Telemetry, Tracking, and Command
V&V	Verification and Validation

1. INTRODUCTION AND SUMMARY

A significant number of Space Transportation System (STS) missions will require that payloads be placed in high energy orbits which cannot be achieved using the Space Shuttle alone. The Department of Defense (DOD) is developing an Inertial Upper Stage (IUS) System to fulfill both NASA and DOD requirements for such missions. The IUS will extend the STS operating regime to include higher orbits, orbital plane changes, geosynchronous orbits, and interplanetary trajectories.

DOD has contracted with The Boeing Company to complete full-scale development of an expendable solid propellant IUS System that will satisfy both the NASA and DOD requirements. Marshall Space Flight Center (MSFC) is designated the NASA Center responsible for IUS Project Management and coordination activities during IUS development. This responsibility includes the definition of NASA-unique mission requirements and analysis to ensure that these requirements are properly implemented. Figure 1-1 shows the relationship among the major IUS milestones and the Boeing schedule for developing the IUS software.

Under a previous contract (see Reference 1) M&S Computing, Inc., defined NASA-unique flight software requirements, evaluated the IUS software preliminary design, analyzed the IUS software interfaces with other systems, and defined a cost-effective level for NASA participation in software verification. This report describes a continuation of the above effort to analyze the IUS software.

1.1 Study Objectives

The objectives of this study were to provide the engineering and data management system analysis necessary to evaluate the detailed design of the IUS software. This effort also was to ensure that the IUS fulfills NASA mission requirements and integrates successfully with the Space Transportation System (STS).

1.2 Scope

Four primary tasks were performed during this contract:

1. Design Analysis.
2. Validation Requirements Analysis.
3. Interface Analysis.
4. Requirements Analysis.

Figure 1-2 shows these four tasks and how they interact with the Boeing software development effort for the IUS flight software. The scope of each task is described in more detail in the following paragraphs.

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SCR NO. SA294

INERTIAL UPPER STAGE (IUS)
SOFTWARE DEVELOPMENT

DISPLAY NO.
SUPPORTS
UPDATE FREQ Quarterly
STATUS AS OF May 31, 1979

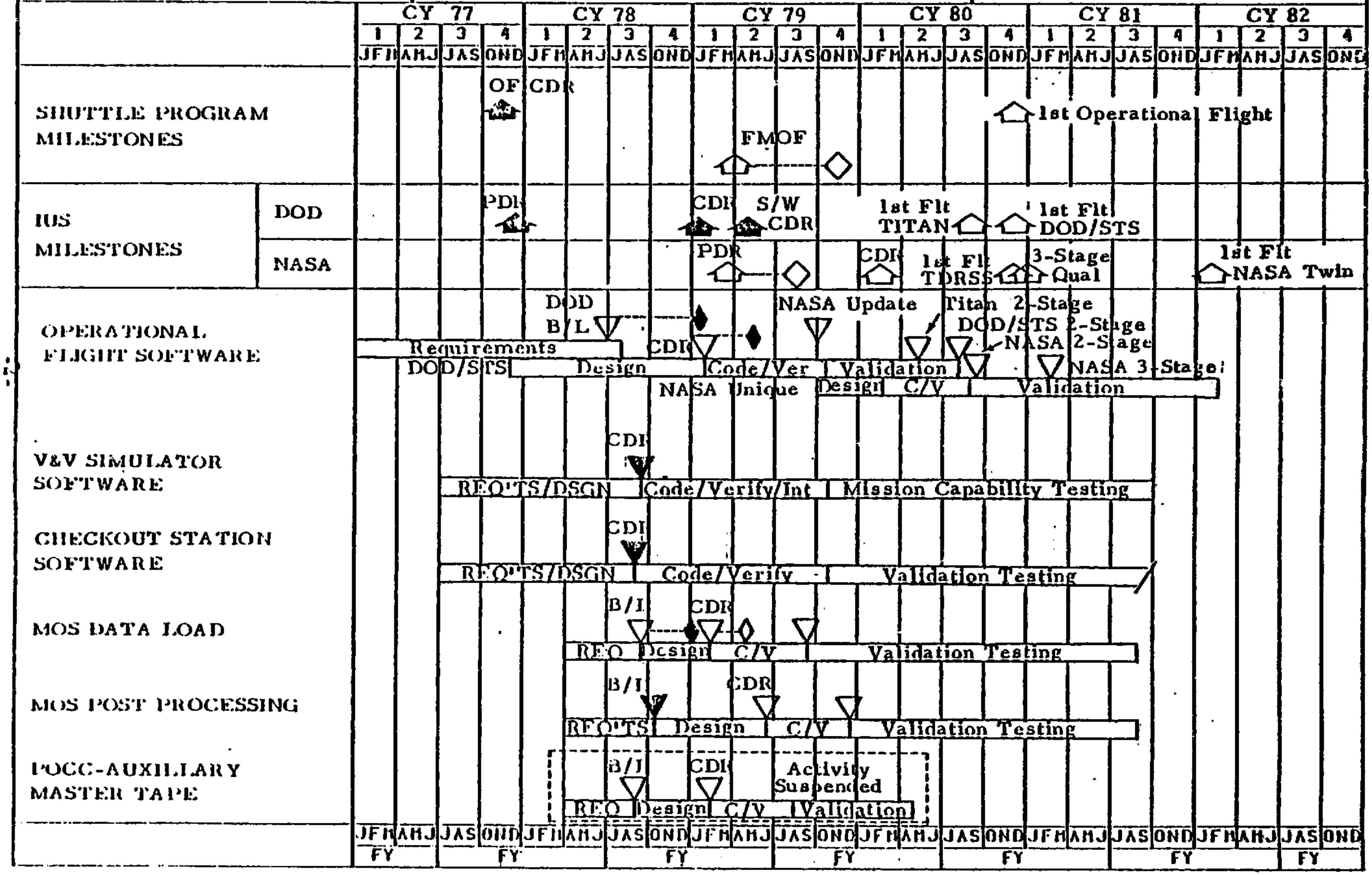


Figure 1-1

STUDY OVERVIEW

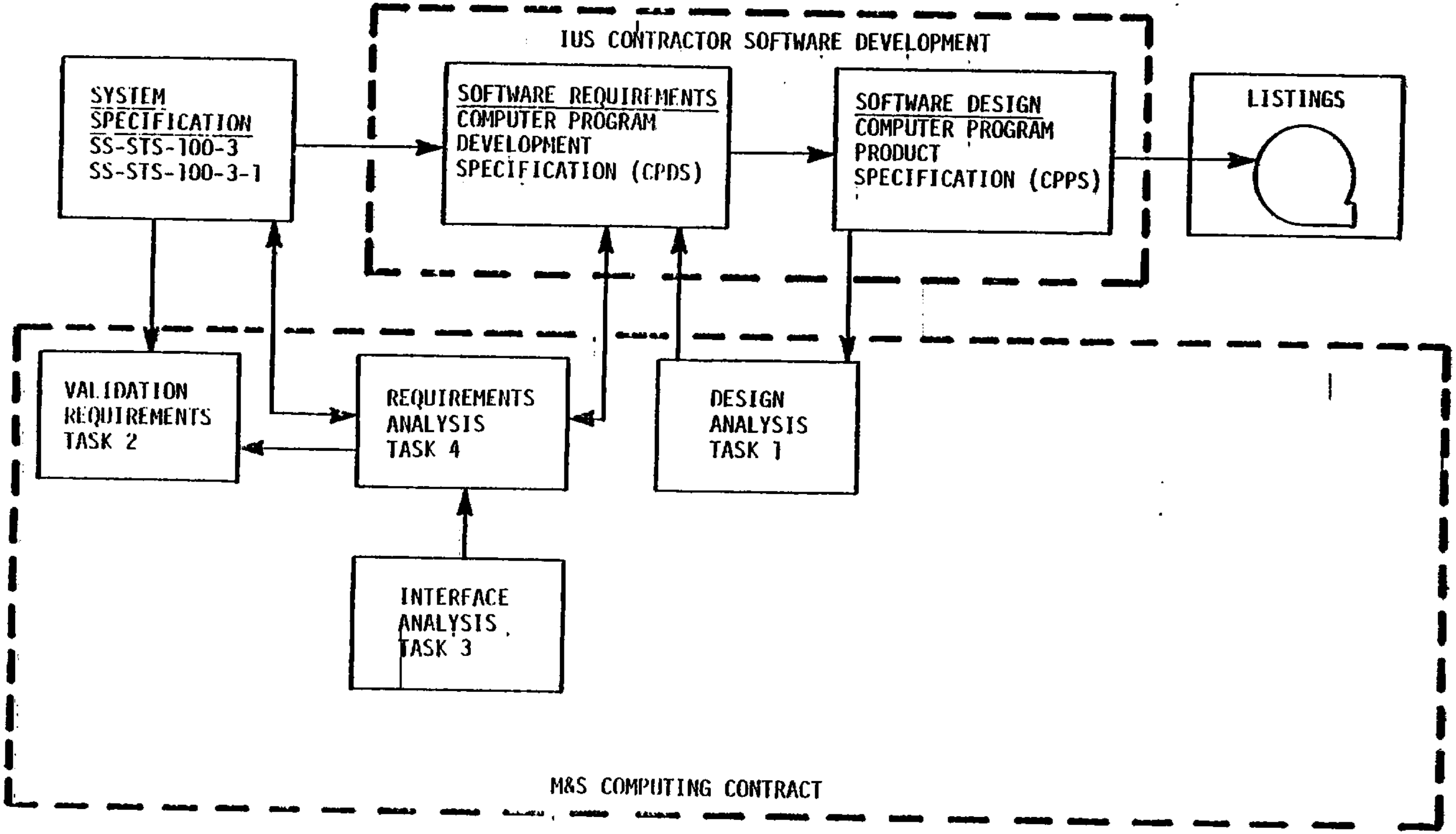


Figure 1-2

1.2.1 Software Detailed Design Analysis

The detailed design of the IUS flight software presented in the Type C5 Computer Program Product Specification (CPPS) was analyzed and evaluated for compliance with the NASA requirements identified in the Type B5 Computer Program Development Specification (CPDS). Analyses included active support for technical interchange (TI) meetings, software working group meetings, the Two-Stage Critical Design Review (CDR), and other meetings with SAMSO, Boeing, TRW, and Martin Marietta. Performance of the task also included evaluating other applicable software documentation. Periodic deliveries of software schedules showing the Boeing activities, the TRW activities, and the M&S Computing activities were accomplished.

1.2.2 Software Test Requirements

Software test plans from Boeing and TRW were evaluated in preparation for the Two-Stage System CDR and Software CDR, respectively. Further definition of the NASA-unique test requirements was postponed until Boeing provides greater detail in the Type B5 NASA Addendum and until the NASA PDR which has been tentatively rescheduled for August 1979.

1.2.3 Interface Analysis and Definition

Current design and proposed changes to the spacecraft and third stage interfaces were analyzed for impact on NASA missions and payloads. Specific requirements for the NASA communications net were also evaluated.

1.2.4 Software Requirements

Each release of the DOD/STS CPDS and the NASA Addendum were evaluated to determine whether NASA-unique requirements were included, modified, or affected. New requirements and an explicit restatement of established NASA requirements were delivered as each new release was evaluated.

1.3 Software Analysis Overview

An overview of the IUS software analysis activities is shown in Figure 1-3 with emphasis in two software areas: Support Software and Operational Flight Software (OFS).

The major areas of emphasis were the OFS requirements (CPDS) and design (CPPS) analysis. Figure 1-4 depicts the events associated with each of the four major M&S Computing tasks. The scheduled events primarily represent analysis activities documented in the IUS memoranda listed in Appendix A.

IUS SOFTWARE ANALYSIS OVERVIEW

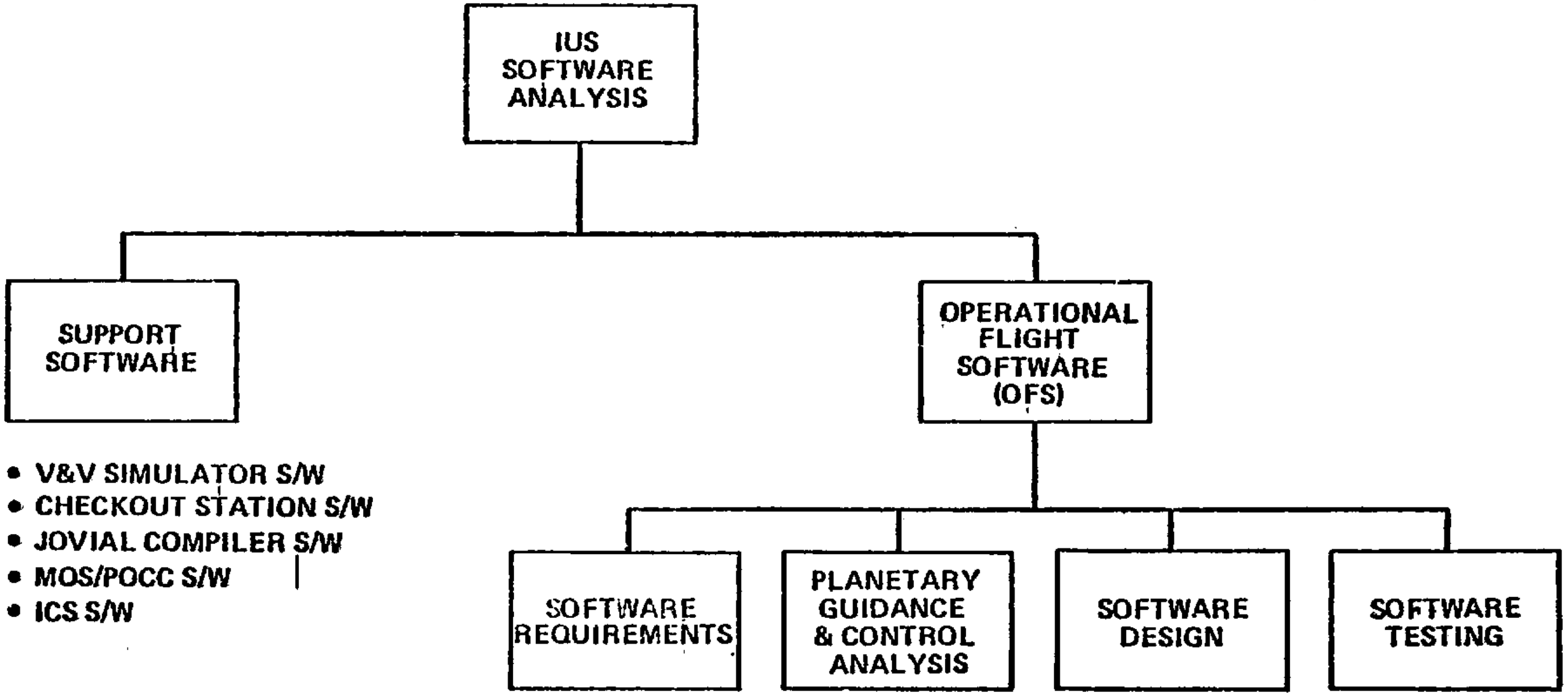
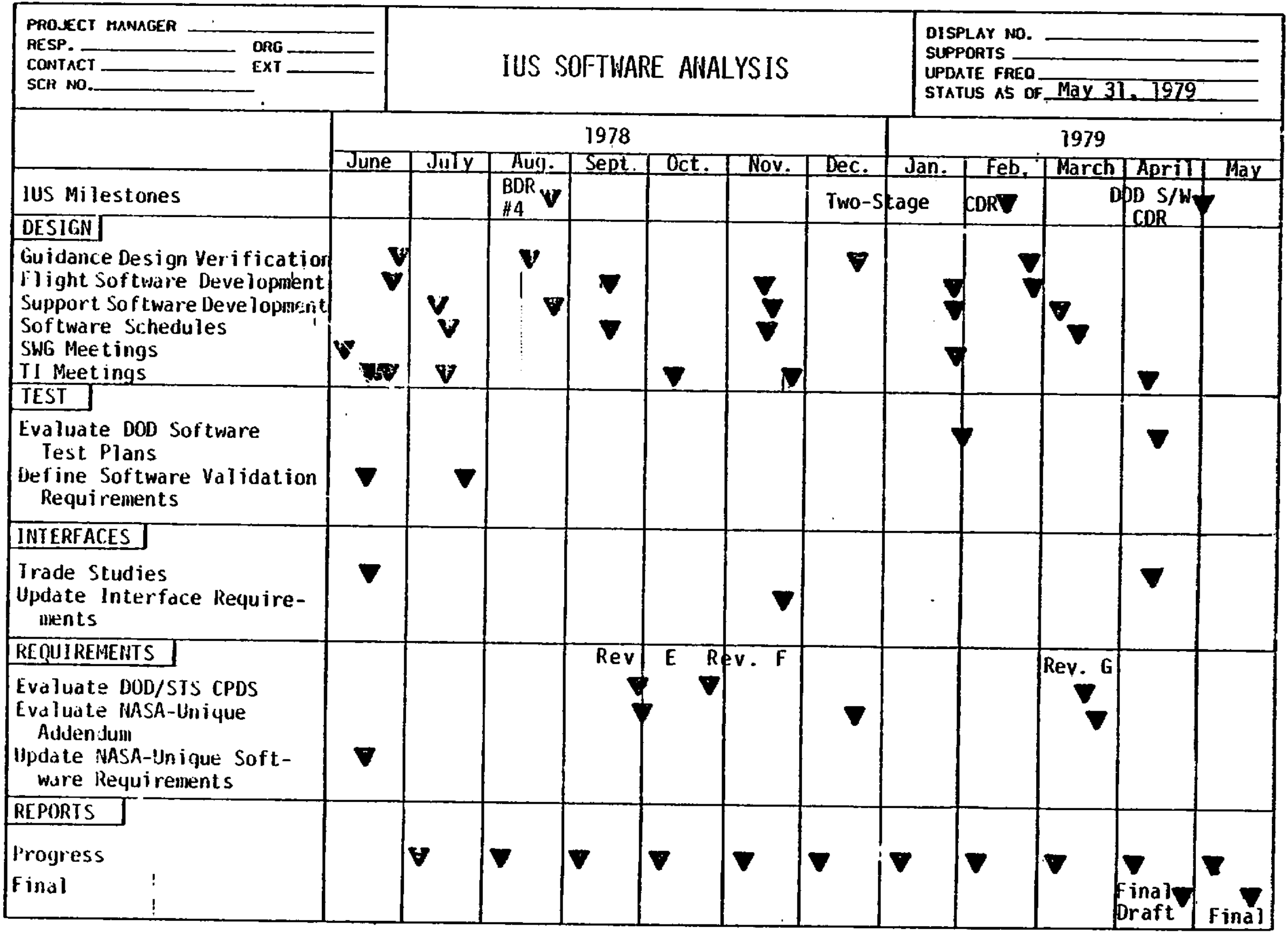


Figure 1-3


PROJECT MANAGER
RESP.
ORG
CONTACT
EXT
SCR NO.
IUS SOFTWARE ANALYSIS
DISPLAY NO.
SUPPORTS
UPDATE FREQ
STATUS AS OF May 31, 1979
1978
1979
June
July
Aug.
Sept.
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Nov.
Dec.
Jan.
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April
May
IUS Milestones
BDR #4
Two-Stage
CDR
DOD S/W CDR
DESIGN
Guidance Design Verification
Flight Software Development
Support Software Development
Software Schedules
SWG Meetings
TI Meetings
TEST
Evaluate DOD Software Test Plans
Define Software Validation Requirements
INTERFACES
Trade Studies
Update Interface Requirements
REQUIREMENTS
Rev E
Rev. F
Rev. G
Evaluate DOD/STS CPDS
Evaluate NASA-Unique Addendum
Update NASA-Unique Software Requirements
REPORTS
Progress
Final
Final Draft
Final

Figure 1-4

Requirements evaluation activites are summarized in Section 2 with an updated status for the NASA-unique requirements. Section 3 identifies the analyses associated with technical interchanges on the preliminary DOD/STS software design and the results of a review of the CPPS for the DOD/STS Software CDR. Analyses associated with the software test documentation is presented in Section 4. A discussion of communications and spacecraft interface evaluation work is found in Section 5. From these basics, a set of conclusions concerning the NASA IUS Software development is presented in Section 6 along with accompanying recommendations for further analyses and evaluation. Appendices B and C provide additional background information on guidance, navigation, and control, and on planning documentation and support software analysis, respectively.

2. SOFTWARE REQUIREMENTS EVALUATION

The IUS DOD/STS flight software requirements have undergone a major transition during this contract period. In Table 2-1 the first column indicates the four CPDS versions evaluated during the year, and the third column presents the corresponding M&S Computing's evaluation reference. Revision F was rewritten by the Software Working Group and then baselined as Revision G.

The NASA Addendum to the CPDS, however, has remained stagnant since the initial release on July 28, 1978. A draft rewrite designated Revision H was released in April 1979. This version improved some areas and degraded other areas. For example, a NASA data description section was added (data items incomplete); however, a major section on spinup requirements was replaced with a To Be Supplied (TBS) and the Communication section restricts a mission to use either the Tracking and Data Relay Satellite System (TDRSS) or the Spaceflight Tracking and Data Network (STDN), but not both, during the same mission. The NASA-unique requirements are still in the preliminary stages of definition.

NASA-unique requirements stem from three sources:

- Guidance Navigation and Control (GN&C) requirements for planetary missions.
- NASA-unique communication requirements.
- NASA-unique IUS three-stage configuration.

A summary of the NASA requirements previously identified is presented in Table 2-2. These requirements were evaluated against Revision G of the CPDS and the Revision E NASA Addendum to determine the implementation status. Table 2-3 presents a cross-reference matrix between the NASA-unique requirements identified by M&S Computing (Reference 8) and the pertinent (or related) sections of the basic CPDS, Revision G, and the NASA Addendum. A description of the CPDS section content is also included for an easy reference. NASA-unique requirements are discussed in the following overview, paragraph 2.1. Boeing's evaluations of these NASA functional requirements are presented in paragraph 2.2 along with an M&S Computing assessment of current requirement status.

2.1 Overview

Derived requirements for the Executive and Mission Sequencing functions have a relatively minor impact on IUS flight software. No NASA-unique flight software requirements have been identified for the navigation function. Although the utilization of the navigation software function is unique for NASA planetary missions,

IUS SOFTWARE REQUIREMENTS EVALUATIONS

DOD/STS CPDS VERSION	NASA ADDENDUM VERSION	REFERENCE
January 13, 1978		8
September 15, 1978 (Procurement Specification, Revision F)	July 28, 1978 Revision E	9, 10
October 15, 1978 (CPDS, Revision F)	July 28, 1978	11, 12
December 1, 1978 (CPDS, Revision G)	July 28. 1978	Table 2-2 (This report)
	March 23, 1979 (Revision H, Draft)	Section 2 (This report)

Table 2-1

NASA-UNIQUE FLIGHT SOFTWARE REQUIREMENTS SUMMARY

Software Function	Requirements
● Executive	Provide I/O control and formatting of commands to the SCU for selection of the NASA transponder mode (TDRSS or STDN) and NASA antenna switching.
● Mission Sequencing	Provide sequence control and timing functions for planetary missions to support second and third stage ignition timing, third stage spinup, and separation of the second stage.
● Navigation	None. DOD has incorporated essential NASA functions for position and attitute state initialization and updates.
● Guidance	Calculate on-pad and on-orbit launch window targeting parameters for planetary missions, including multiple on-orbit launch opportunities, to meet planetary injection accuracy requirements.
● Attitude Control	Provide the capability to spinup the second stage/third stage/spacecraft configuration to TBD rpm under active attitude control while maintaining the inertial orientation of the spin axis within specified limits.
● Communications	Provide autonomous control of IUS/NASA antenna switching for RF communications with the Orbiter, a selected TDRS, or a selected STDN ground station.
● Redundancy Management	Maintain an antenna status flag as set by ground command for each of 20 IUS/NASA antennas.
● Checkout	No NASA-unique requirements identified.

Table 2-2

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol./Section	B5 Contents and Comments
EXECUTIVE		
• NASA transponder mode control (STDN or TDRSS).	Rev. G-Vol II Page 268 Page 270 Vol. 6/3.2.6.1	Table 10.1-1 Uplinked command list F29 Ground Station Antenna SW F30 Orbiter Antenna SW F78 XMTR to Stdn Mode F79 XMTR to TDRSS Mode No Software Mode Selection for TDRSS Mode
• Downlink NASA antenna switch position indications for four five-position antenna switches.	Vol. II/Table 10.4-1	20 antenna switch positions are allocated in the TM table
• Antenna Switching (to switch to the one antenna selected out of the ten-antenna NASA configuration).	Vol I/Table 3.1.1.2.11-3	Communication Mission Data Load Parameters and Sizing IUS Antenna Data/Antenna-Position-Array/Cosine Beam Width/Number Antenna/Number Ground Station/ Station Location Table/Antenna Index Orbiter Bay/
	Vol 2/3.2.1.3.7.2 3.2.1.3.7.2.1	SCU Command Processing Function Inputs X. (Reserved NASA Addendum)
	Vol. 6/3.2.6.3.3 Page 113	Number Antenna, NA Range 10 NASA, Source: Mission Data Load. Destin: Antenna Selection 3.2.6.3.3

Table 2-3

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol./Section	B5 Contents and Comments
• Antenna switching (Continued)	Vol. 2/3.2.1.3.7.2.2	Processing 1. Antenna Switching Commands (Reserve NASA) a. Comm-Antenna-Switch-Commands (Reserve NASA) 7. Computer commands c. Reserved for NASA addendum 3.2.1.3.7.2.3 Outputs a. Reserved for NASA addendum
	Addendum/3.2.1.3.7.2.2 Page 21	Processing Issue antenna switching commands as soon as the last command duration is up. Save the command in process, to be reissued when the reissue SCU command flag is raised. This function will only execute once each 40 msec frame.
	Vol. II/Page 16	Antenna-Selection-Mode Ground station, orbiter, earth center, or TDRSS Source: command processing Destination: antenna selection and communications and tracking.

Table 2-3
(Continued)

NASA-UNIQUE SOFTWARE REQUIREMENTS
IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol./Section	B5 Contents and Comments
MISSION SEQUENCING		
• The mission sequencing software function shall provide proper second and third stage ignition timing for planetary missions as determined by the guidance software function.	Vol. 3/Figure 3.2.2.2 Page 3	Twin stage (SRM 2) ignition sequencing same as DOD second stage except for event timing.
	NASA Addendum/3.2.2.2 3.2.13 Page 25	NASA second stage separation sequence defines SRM 3 ignition.
• The mission sequencing software shall provide sequence control and timing functions to support third stage spinup, third stage avionics initialization, and separation of the second stage after spinup.	Vol. 3/Table 3.2.2.-1 Page 13	Mission Sequencing Task Number 5. Rotating Reference Frame Mode Reserved NASA Spinup 12. NASA Second Stage Separation 13. NASA Third Stage Sequence
	Vol. 3/3.2.2.2.3.2.10 Page 55	Spacecraft deployment Enable and Arm Command Number — Command M18 — S/C or Spin Stage Separation Enable M19 — S/C or Spin Stage Separation Fire
	Vol. 3/3.2.2.2.3.2.12	NASA Second Stage Separation (processing reserved) REFER ADDENDUM Page 25
	Vol. 3/3.2.2.2.3.2.13 (Page 57)	NASA Third Stage Sequence (processing reserved) REFER ADDENDUM Page 26-27

Table 2-3
(Continued)

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol. /Section	B5 Contents and Comments
• Mission Sequencing (Continued)	Addendum/3. 2. 2. 2. 1 Page 24	Event Scheduling Modify Table 3. 2. 2-1 Coast Mission Sequencing Interface . . . Add 6 Spinup Mode Power and Ordnance Command Function Options Add 12. NASA Second Stage Separation 13. NASA Third Stage Sequence
	Addendum/3. 2. 2. 2. 3. 2. 13	NASA Second Stage Separation A procedure is described in the addendum for the interface (prior to removal of the third stage avionics by ECP 247).
	Addendum/3. 2. 2. 2. 3. 2. 14	NASA Third Stage Sequence A procedure is described in the addendum for the interface prior to removal of the third stage avionics.

Table 2-3

(Continued)

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol./Section	B5 Contents and Comments
GUIDANCE • Calculate the on-pad and on-orbit-launch window targeting parameters.	Vol.4/3.2.4.3 Page 36	"A first estimate for the 24 control parameters and 21 constraint parameters prior to gamma guidance targeting for the coast ARC one prior to SRM Burn one" Also refer to latest two-stage CDR for additional B5 requirements updates.
• Calculate the targeting parameters for multiple on-orbit-launch opportunities.	Vol.4/3.2.4.3 Page 36	After each orbital revolution, the control parameters are adjusted by one orbit period and the guidance algorithm is performed in the nominal parking orbit update mode.
• Meet the TBD planetary accuracy requirements. - This requirement shall be determined for the NASA twin and three-stage vehicles, utilizing the IUS inherent capabilities required to meet the synchronous equatorial accuracy requirements (Table 4-4 on page 84 of Reference 1) and the spin-rate requirements for the NASA third stage.		Not in B5 Spinup information is preliminary for the July 28, 1978, NASA Addendum and TBS in the draft release of Revision II.

Table 2-3
(Continued)

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol./Section	B5 Contents and Comments
ATTITUDE CONTROL Prior to second stage separation, the attitude control software shall provide the capability to spinup the third stage/spacecraft configuration to 70 rpm ±TBD%.		The CPDS has no specific reference to spinup to 70 rpm, nor does it define the duration of the spinup (roll thruster) commands.
• Spinup shall be initiated in the fixed inertial attitude determined by the IUS guidance software for third stage burn. This attitude shall be maintained within TBD attitude and rate deadband limits.	Addendum/3.2.5.2.16.3.2	Processing Prestored rotating reference frame mode processing... prior to NASA third stage spinning
		Note that there is a requirement for unique MOS data load here for attitude pointing and accuracy limits. Probably will need a new flight phase to implement.
• During spinup, the attitude control algorithms shall provide stability in the spinning condition and control of the spin vector orientation within ±TBD degrees in pitch and yaw. Control of the roll attitude is not a requirement.	Vol. 5/3.2.5.2.16.3.2.(d)	Spinup-mode processing - but no ±TBD degrees in pitch and yaw
• Active attitude control shall be maintained during spinup, as long as the IUS attitude reference is available from IMU data. The maximum practical rate ≤70 rpm shall be achieved under active attitude control. Active control shall be terminated prior to loss of the attitude reference.	Addendum/3.2.5.5.2	RCS COMMAND DETERMINATION ...determine commands as necessary to determine spinup in the desired direction...

Table 2-3
(Continued)

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol. /Section	B5 Contents and Comments
• At termination of active attitude control (at spin rates $\leq$ 70 rpm), the software shall provide the capability to implement the following: - Inhibit operation of pitch and yaw thrusters. - Command roll thrusters full on for a time which will provide the remaining rate-to-go to achieve the 70 rpm spin rate.	Addendum/3.2.5.5.2.2	Processing is included to generate roll axis thruster full on commands There is no explicit direction to inhibit operation of pitch and yaw commands and no way to determine completion of spinup
An RCS inhibit shall be implemented at the completion of spinup.		Boeing states that this will be accomplished with a follow-on event command in mission sequencing.

Table 2-3
(Continued)

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol. /Section	B5 Contents and Comments
COMMUNICATIONS: ANTENNA CONTROL FUNCTION IUS Flight Software Requirements An antenna switching algorithm shall be implemented which will provide autonomous control of IUS/NASA antenna switching for RF communications with the Orbiter, a selected TDRS or a selected STDN ground station. The antenna control function shall include autonomous selection of the preferred space or ground station link, and selection of the proper IUS/NASA antenna for that link.	Vol. 6/3.2.6.3.3 Vol. 6/3.2.6.1	- Antenna selection is an autonomous process capable of handling up to 10 antennas. - Mode selection, however, is manual; an uplink command is required to change modes. The B5 does not provide autonomous switching from STDN to TDRSS - Reference 2 indicates STDN and TDRSS are mutually exclusive and only one is active per mission.
• Selection of the preferred space or ground station link shall be made according to the following logic: - If the IUS is less than or equal to 20 nmi from the Orbiter, the Orbiter S-band system is the preferred link.		Not provided in current design
- If the IUS is greater than 20 nmi from the Orbiter, selection of the preferred link shall be between the two TDRSS satellites (the closest RF visible satellite) and the five GSTDN stations (the closest RF visible ground station) whose locations are given in Table 4-9. This station link selection shall be performed in a manner that tends to maximize command uplink signal strength at the IUS antennas.		Not in B5 or addendum
	Requirements	Current Boeing planning is considering changes for Orbiter communications until 75 nmi separation is achieved or for a 15 minute delay. Neither has been approved.
	Vol. 6/3.2.6.3.2.2	Page 38 of B5 has antenna mode selection Does not have a mode for TDRSS
		Maximization of the command uplink signal strength is not done; software simply selects the closest station.

Table 2-3
(Continued)

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol. /Section	B5 Contents and Comments
- When the space or ground station link has been selected, the IUS shall autonomously select and switch the IUS antenna best suited, as defined by antenna cone angles of coverage, for maintaining this link. The selection logic shall be such as to maintain antenna gain within TBD percent of its nominal maximum.	Addendum/3.2.6.3.3.1	NASA unique mission data load values for Number of antenna (NA) and Cosine of Beamwidth (CBW) will satisfy this requirement.
- Overlap between antenna coverage limits shall be utilized to minimize antenna switching and prevent toggling.	Vol. 6/3.2.6.3.3	A 10-degree overlap is provided to prevent toggling when switching from the selected antenna to another antenna.
• It shall be possible, by ground command or prelaunch initialization to remove any space or ground station(s) as a candidate link(s).	Vol. 7/3.2.7	Not in the B5 or the Addendum definition of Redundancy Management.
• Computations and antenna switching shall be performed at sufficient speed to maintain communications up to IUS attitude rates of TBD deg/sec.	Vol. 6/3.2.6.3.3	No mention of third stage spinup communication requirements nor any capability to switch antennas up to a maximum rate.
• Fault detection software shall support proper management of the directional NASA antennas. Autonomous antenna control shall include a test of the antenna status flag and delete bad antennas as candidates for selection. With one or more antennas failed, autonomous antenna switching shall continue to function, with performance degraded only by the availability of coverage from the remaining antennas.	Vol. 7/3.2.7	Redundancy Management does not include antennas.

Table 2-3
(Continued)

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol. /Section	B5 Contents and Comments
• Antenna switching shall be controlled to prevent loss of data during the switching interval.	Vol. 6/3.2.6.3.3	Not addressed in the B5 but Boeing cannot comply due to 600-msec dropout (Reference 17).
• It shall be possible by ground command to override autonomous antenna selections.	Vol. 6/3.2.6.1.2.2 (f)	Time-dependent command - software will switch back in 30 seconds.
- If the IUS is within the field of coverage of more than one station and the preferred station is occulted by the spacecraft, an alternate selection will be made to prevent loss of communication. Antenna coverage limits imposed by spacecraft occultation shall be accounted for, with TBD° reserve, by the antenna switching points set prior to launch. - If the preferred station is occulted by the spacecraft and no alternate station is available, the IUS shall autonomously change attitude to maintain communication. If this condition occurs at or within three minutes prior to RCS vernier burn, SRM burn, or third stage spinup, this autonomous attitude change shall not be initiated and an indication shall be provided to the ground. This provision for autonomous attitude change shall be subject to disable by ground command.		No definitive requirements concerning IUS occultation by the orbiter or spacecraft

Table 2-3
(Continued)

NASA-UNIQUE SOFTWARE REQUIREMENTS IMPLEMENTATION STATUS

NASA-Unique Software Requirements	B5 Specification Vol./Section	B5 Contents and Comments
REDUNDANCY MANAGEMENT • An antenna status flag shall be maintained for each of the 20 NASA IUS antennas to support autonomous antenna switching software of the communications function. These flags shall be set by ground commands.	Vol. 7/3.2.7	Not in B5, the Addendum nor the D290-100864. "Redundacy Management Requirements for the IUS."
CHECKOUT The IUS software shall be compatible with LPS and shall provide the following checkout functions for NASA missions: • Additional checkout functions for common DOD/NASA IUS subsystems as follows: TBD.	Vol. 8/3.2.8.2.3	• Prelaunch checkout command. No failure indicator for TT&C (DOD). • Predeployment-checkout-command. Perform switching check. Select outward facing antenna and activate transmitter.
• Third stage avionics checkout functions as follows: TBD.	Addendum/3.2.8.12	• Twin Stage/Spin Stage Checkout Requirements TBD in the Addendum.

Table 2-3
(Continued)

DOD has incorporated the essential capabilities for initialization and update of the position and attitude state. Areas of concern pertaining to the guidance software function are included in Section 2.3.

NASA-unique attitude control requirements are associated with stabilization and spinup of the third stage. Some details of the attitude control requirements are to be determined from planetary injection accuracy analyses, including spin-stage dynamic performance. Definition of the following attitude control requirements are dependent on completion of these analyses:

- Attitude and attitude rate limits for the inertial attitude at start of spinup.
- Spinup under closed loop control.
    - Attitude and attitude rate limits for pitch and yaw.
    - Spin rate at which spinup under closed-loop control will be terminated.
- Definition of a verified attitude control law for spinup.
- Tolerance on final spin rate.

The Jet Propulsion Laboratory (JPL) requirements for the IUS planetary mission accuracies from the IUS System Specification of March 17, 1978, are presented in paragrah B.3 of Appendix B. The appendix also includes a detailed description of JPL's approach to meeting injection accuracies by calculation of a Figure Of Merit (based on a statistical measure of the spacecraft velocity requirements at midcourse) to control removal of IUS injection errors.

NASA-unique communications requirements have been defined for autonomous antenna switching. The antenna switching algorithm is based on the geometry of the IUS position, IUS attitude (and antenna configuration), Orbiter position, and positions of the TDRSS satellites and STDN ground stations. For NASA three-stage IUS missions, communications requirements after start of spinup are still an area of concern as discussed below.

Currently, the IUS System Specification (SS) and baseline design make no provisions for downlink of the second stage telemetry stream after initiation of "spinning stage operation."

As a result of removing the third stage avionics, no attitude state data from the vehicle will be available to support post-flight evaluation of third stage dynamic performance (including spinup, second stage separation, third stage burn, and spacecraft separation). Also, the above provisions of the IUS/SS and the baseline design prohibit compliance with part (1) of the following paragraph of the IUS/SS for three-stage missions:

> 3.1.5.2.7 Telemetry
>
> The IUS shall be capable of transmitting to the ground: (1) state vector and attitude data immediately prior to spacecraft/IUS separation, (2) verification of IUS vehicle to spacecraft separation events, and (3) verification of received commands.

For three-stage missions under current IUS/SS requirements, the last opportunity to downlink the IUS state vector and vehicle attitude will be just prior to start of third stage spinup.

It is recommended that the second stage radio frequency (RF) system remain active during third stage spinup as long as the IUS attitude reference is available to support autonomous antenna switching. With an adequate software capability for antenna switching, second stage RF communications can be maintained at least through the active attitude control phase of third stage spinup. This additional telemetry will provide data for a period critical to successful third stage performance.

The major NASA impact on redundancy management software is the maintenance of status flags for the NASA antennas. No specific NASA-unique requirements have been identified which affect the onboard checkout software function. However, a potential source of NASA-unique checkout software requirements is that software required to support any NASA-unique tests of common DOD/STS IUS subsystems. A decision to utilize DOD test procedures for common DOD/NASA IUS subsystems could eliminate this potential source.

The following items are recommended for further study:

- Formal coordination of NASA-unique software requirements within the NASA/IUS community prior to incorporation in the Type B5 specification (CPDS).
- Thorough planetary injection accuracy analysis (including spin stage dynamic performance) to support detailed definition of guidance and attitude control requirements for three-stage missions.

- Coordination and definition of a firm timeline for communications requirements during NASA missions including third stage spinup and the resulting impact on the antenna switching algorithm.

- Continued analysis of IUS flight software development activities and products to ensure that NASA-unique requirements are met.

2.2 NASA-unique Functional Requirements

The NASA requirements for the eight baseline software functions defined in Table 2-2 are driven by requirements from IUS-STS-100, Volume 3, and Volume 3-1 (see Reference 14). NASA-unique IUS flight software requirements are either directly driven by the IUS/SS, Volume 3-1, or derived from its provisions.

The state of the NASA-unique requirements to be incorporated in Revision H of the NASA Addendum (Reference 13) is detailed in the following subparagraphs and related tables. There is a subparagraph for each of the eight baseline software functions. The related tables contain the NASA-unique requirements as originally described in Reference 1, the source paragraphs from IUS-STS-100 (Reference 14), and the present status defined by Boeing in Reference 15.

2.2.1 Executive

The executive software function must provide proper management of the NASA-unique software requirements contained in other software functions. At the present time, the executive function capability required by and planned for DOD missions supports NASA requirements with one exception. This exception is related to the communications subsystem which must provide compatibility with STDN ground stations and the TDRSS.

NASA-unique software requirements for the executive function are presented in Table 2-4. The required commands to the Signal Conditioner Unit (SCU) will be determined by the executive from outputs of the command processing and autonomous antenna switching subfunctions of the communication software. In Reference 15 Boeing states that the present transponder system does not distinguish between STDN or TDRSS stations and that a change will be included in the NASA Addendum revision of September 1, 1979. To support the August 1979 Preliminary Design Review (PDR), an Advance Documentation Revision Notice (ADRN) is needed to document this requirement. The other present-status items are acceptable.

EXECUTIVE

LINE NO.	STS-100 PARA.	IUS FLIGHT SOFTWARE REQUIREMENTS	BOEING STATUS (CPDS PARA.)
1-1	3.1.5.2.6 3.1.5.2.7 3.1.5.3.6 3.2.1.7 3.6.1.5	The executive software function shall provide I/O control and formatting of commands to the SCU to implement the following NASA-unique communications functions:	
		• NASA transponder mode control (STDN or TDRSS).	The present system does not distinguish between the two types of stations. A change will be included in the NASA Addendum revision of 9-1
		• Antenna switching (to switch to the one antenna selected out of the ten-antenna NASA configuration).	The algorithm (3.2.6.3.3., 3.2.1.3.7.2) will select one of the ten antennas.
		• Downlink NASA antenna switch position indications for four five-position antenna switches.	(3.2.6.2) This is provided; see Table 10.4-1 SCU measurement data (13th continuation page) in Vol.11 basic CPDS.

Table 2-4

2.2.2 Mission Sequencing

Utilization of the mission sequencing software for NASA planetary missions will be impacted by the longer duration of the three-stage missions, and by launch window and multiple on-orbit injection opportunity requirements. This impact will result in increased size of the event table (additional attitude and rate maneuvers, additional navigation updates, etc.) and may result in increased use of the real-time command capability for sequence changes. The resulting software requirements are presented in Table 2-5. These requirements are derived from guidance, attitude control and communications software functions, and third stage interface requirements.

Boeing states that the mission sequence table is constructed to provide the separation of the second stage after spinup; however, the third-stage spinup sequencing requirements still reference third-stage avionics operations. This section will require an update when the changes identified in ECP 247 are implemented to remove the third-stage avionics.

2.2.3 Guidance

The requirements to support interplanetary missions are, of course, NASA-unique. For these missions, it is necessary to target to a specific hyperbolic escape velocity, V_∞, rather than to an orbital period as in the geosynchronous missions. Computation of the hyperbolic escape velocity is dependent on the relative motion of the target planet. The guidance scheme must also permit targeting on successive orbital opportunities without memory update.

The NASA-unique software requirements for guidance and targeting are presented in Table 2-6. Since the interplanetary injection accuracies are not explicitly defined, the permissible variations in the constraining vector could not be bounded in the software computations.

Boeing states that the planned guidance update in Revision H of the DOD/STS CPDS provides for on-pad and on-orbit launch window targeting parameters; however, this does not answer the question of delay time accommodation: specifically, how well the STS-100 (Volume 1) requirement for retargeting to a dissimilar mission within two hours of launch can be handled. At the DOD/STS Two-Stage System CDR (Reference 16), Boeing deferred applying the Revision H retargeting requirements to planetary missions until further analysis is completed. This leaves the targeting parameters for multiple on-orbit launch opportunities undefined. Finally, Boeing states that planetary accuracy requirements identified in ECP 247 shall be determined during NASA certification.

A detailed discussion on guidance is presented in Appendix B.

MISSION SEQUENCING

LINE NO.	STS-100 PARA.	IUS FLIGHT SOFTWARE REQUIREMENTS	BOEING STATUS (CPDS PARA.)
2-1	3.1.2.6.1 3.1.2.6.2 3.2.1.1. 3.2.1.2	The mission sequencing software function shall provide proper second and third stage ignition timing for planetary missions as determined by the guidance software function.	(3.2.2.2.1.) (3.2.2.2.3.2.12) The mission sequence function will define the two events; the guidance function will determine the proper timing.
2-2	3.6.1.5 3.1.5	The mission sequencing software shall provide sequence control and timing functions to support third-stage spinup, third-stage avionics initialization, and separation of the second stage after spinup.	(3.2.2.2.1.) (3.2.2.2.3.2.13) The mission sequence table is constructed to provide the separation of the second stage after spinup.

Table 2-5

GUIDANCE

LINE NO.	IUS-100 PARA.	IUS FLIGHT SOFTWARE REQUIREMENTS	BOEING STATUS (CPDS PARA.)
4-1	3.1.2.6.1	Calculate the on-pad and on-orbit launch window targeting parameters.	Yes (3.2.4.3) New Rev. H retargeting in basic CPDS provides the capability.
4-2	3.1.2.6.2	Calculate the targeting parameters for multiple on-orbit launch opportunities.	The Rev. H retargeting function provides for the modification only of the control variables (e.g., SRM ignition and burn angles) with multiple on orbit launch opportunities. However, it does not change the mission constraints (e.g., orbital energy, right ascension, and declinatio Future revisions to the retargeting function may be required for this NASA requirement.
4-3	3.2.6.2	Meet the TBD planetary injection accuracy requirements.	Accuracy shall be determined during NASA certification.
4-3.1		• This requirement shall be determined for the NASA twin- and three-stage vehicles, utilizing the IUS inherent capabilities required to meet the synchronous equatorial accuracy requirements (Table 3-4), and the spin-rate requirements for the NASA third stage.	

Table 2-6

2.2.4 Attitude Control

Utilization of the attitude control software is affected by NASA missions in three ways. First, the use of directional antennas for NASA RF communications may call for additional attitude changes to maintain communications. Second, the three-stage missions call for additional attitude and roll maneuvers. The third area is also related to the three-stage missions and involves spinning the entire second stage/third stage/spacecraft configuration using the IUS Reaction Control Subsystem (RCS). Existing DOD software will support the first case if autonomous maneuver capability were enabled. The second area is fully supported by DOD software and the third has unique requirements as defined in Table 2-7.

Table 2-7 reflects the Boeing statement that the attitude control software shall provide the capability to spinup the third stage/spacecraft configuration with gyro saturation occurring at 5 rpm; there is no mention of the 70 rpm requirement. A requirement to terminate spinup at a desired rpm would be preferable to simply commanding the roll thrusters full on until RCS is depleted. For the latter case, the spin rate would not be predictable.

The requirements also state that spinup shall be in the fixed inertial attitude of the IUS software. The NASA Addendum, Revision H replaces this mode with a TBS leaving this requirement undefined. The requirements state that active control shall be terminated prior to loss of the attitude reference; however, RCS pitch and yaw thrusters are not positively inhibited prior to loss of the Inertial Measurement Unit (IMU) at approximately 5 rpm (refer to Line No. 5.1.4.1 of Table 2-7).

2.2.5 Communications: Antenna Control Function

To provide the required TDRSS compatibility, the NASA RF communications baseline uses ten directional antennas for spherical coverage rather than the two omnis used by DOD. Although DOD has implemented an autonomous antenna switching capability, NASA requirements for autonomous antenna switching are unique in two respects:

- The large number of antennas (with narrower beamwidth) demands more frequent antenna switching to maintain spherical coverage as the IUS translates and rotates.
- Autonomous selection of a communication link must consider the two TDRSS satellites and five STDN ground stations instead of the Air Force Space Ground Link System (SGLS) ground stations.

Table 2-8 presents the NASA-unique software requirements for autonomous antenna control.

ATTITUDE CONTROL

LINE NO.	STS-100 PARA.	IUS FLIGHT SOFTWARE REQUIREMENTS	BOEING STATUS (CPDS PARA.)
5-1	3.2.1.5.3	Prior to second-stage separation, the attitude control software shall provide the capability to spin up the third-stage/spacecraft configuration to 70 rpm ±TBD%.	(3.2.2.2.1, 3.2.2.2.3, 3.2.5.1., 3.2.5.4) Provides this capability with navigation degradationgyros saturate at 5 rpm
5.-1.1		• Spinup shall be initiated in the fixed inertial attitude determined by the IUS huidance software for third-stage burn. This attitude shall be maintained within TBD attitude and rate deadband limits.	
5-1.2		• During spinup, the attitude control algorithms shall provide stability in the spinning condition and control of the spin vector orientation within ± TBD degrees in pitch and yaw. Control of the roll attitude is not a requirement.	
5-1.3		• Active attitude control shall be maintained during spinup, as long as the IUS attitude reference is available from IMU data. The maximum practical rate ≤ 70 rpm shall be achieved under active attitude control. Active control shall be terminated prior to loss of the attitude reference.	
5-1.4		• At termination of active control (at spin rates ≤70 rpm), the software shall provide the capability to implement the following:	

Table 2-7

ATTITUDE CONTROL
(CONTINUED)

LINE NO.	STS-100 PARA.	IUS FLIGHT SOFTWARE REQUIREMENTS	BOEING STATUS (CPDS PARA.)
		ATTITUDE CONTROL (CONTINUED)	
5-1.4.1.		- Inhibit operation of pitch and yaw thrusters.	Item addressed in section 3.2.5.4.
5-1.4.2		- Command roll thrusters full on for a time which will provide the remaining rate-to-go to achieve the 70 rpm spin rate.	Item addressed in sections (3.2.2.3.2.13; 3.2.5.4)
5-1.5	●	An RCS inhibit shall be implemented at the completion of spinup.	(3.2.2.1) This is achieved by use of the follow-on event feature of mission sequence.

Table 2-7
(Continued)

COMMUNICATIONS: ANTENNA CONTROL FUNCTION

Line No.	STS-100 PARA.	IUS Flight Software Requirements	BOEING STATUS (CPDS Para.)
6-1	3.1.5.2.6 3.1.5.2.7 3.1.5.3.6 3.2.1.7 3.6.1.5	An antenna switching algorithm shall be implemented which will provide autonomous control of IUS/NASA antenna switching for RF communications with the Orbiter, a selected TDRS or a selected STDN ground station. The antenna control function shall include autonomous selection of the preferred space or ground station link, and selection of the proper IUS/NASA antenna for that link.	(3.2.6.3.1) (3.2.6.3.2) (3.2.6.3.3)
6-1.1		• Selection of the preferred space or ground station link shall be made according to the following logic:	Mode switch available for Orbiter or TDRSS or STDN station communication, except that the station table must be loaded with only one system. Command uplink from Orbiter mode initially.
6-1.1.1		- If the IUS is less than or equal to 20 nmi from the Orbiter, the Orbiter S-band system is the preferred link.	
6-1.1.2		- If the IUS is greater than 20 nmi from the Orbiter, selection of the preferred link shall be between the two TDRSS satellites (the closest RF visible satellite) and the five STDN ground stations (the closest RF visible ground station). This station link selection shall be performed in a manner that tends to maximize command uplink signal strength at the IUS antennas.	Command uplink from Orbiter selects TDRSS or STDN mode (whichever one is loaded). The closest station in the table is selected. Station dropout capability is not provided.

Table 2-8

COMMUNICATIONS: ANTENNA CONTROL FUNCTION
(Continued)

Line No.	STS-100 PARA.	IUS Flight Software Requirements	BOEING STATUS (CPDS Para.)
6-1.1.3		- If the IUS is within the field of coverage of more than one station and the preferred station is occulted by the spacecraft, and alternate selection will be made to prevent loss of communication. Antenna coverage limits imposed by spacecraft occultation shall be accounted for, with TBD reserve, by the antenna switching points set prior to launch.	(3.2.6.3) Not provided. Our design is to provide all attitude coverage.
6-1.1.4		- If the preferred station is occulted by the spacecraft and no alternate station is available, the IUS shall autonomously change attitude to maintain communication. If this condition occurs at or within three minutes prior to RCS vernier burn, SRM burn, or third stage spinup, this autonomous attitude change shall not be initiated and an indication shall be provided to the ground. This provision for autonomous attitude change shall be subject to disable by ground command.	Not provided. See above.
6-1.2		• Selection of the IUS/NASA antenna shall be made according to the following logic:	

Table 2-8
(Continued)

COMMUNICATIONS: ANTENNA CONTROL FUNCTION
(Continued)

Line No.	STS-100 Para.	IUS Flight Software Requirements	BOEING STATUS (CPDS Para.)
6-1.2.1		When the space or ground station link has been selected, the IUS shall autonomously select and switch the IUS antenna best suited, as defined by antenna cone angles of coverage, for maintaining this link. The selection logic shall be such as to maintain antenna gain within TBD percent of its nominal maximum.	(3.2.6.3.2, 3.2.6.3.3) The antenna gain shall be within 3.4.db of maximum.
6-1.2.1		- Overlap between antenna coverage limits shall be utilized to minimize antenna switching and prevent toggling.	(3.2.6.3.3) Antenna cone angle is a mission data load parameter. The overlap is from 5° to 34°.
6-1.2		• It shall be possible, by ground command or pre-launch initialization to remove any space or ground station(s) as a candidate link(s).	Not provided directly: This requires extra software. However, this operation may be accomplished by memory load of the station table prior to launch.
6-1.3		• Computations and antenna switching shall be performed at sufficient speed to maintain communications up to IUS attitude rates of TBD deg/sec.	(3.2.6.3.3) Communications is maintained (with partial data loss to reacquire phase lock) up to 5°/sec. STDN reacquires phase lock in 0.5 sec.
6-1.4		• Fault detection software shall support proper management of the directional NASA antennas. Autonomous antenna control shall include a test of the antenna status flag and delete failed antennas.	Not provided in the IUS redundancy management scheme

Table 2-8
(Continued)

COMMUNICATIONS: ANTENNA CONTROL FUNCTION
(Continued)

Line No.	STS-100 Para.	IUS Flight Software Requirements	BOEING STATUS (CPDS Para.)
		as candidates for selection. With one or more antennas failed, autonomous antenna switching shall continue to function, with performance degraded only by the availability of coverage from the remaining antennas.	
6-1.5	●	Antenna switching shall be controlled to prevent loss of data during the switching interval.	(SCU) Antenna switching is make-before-break to always provide an RF signal.
6-1.6	●	It shall be possible by ground command to override autonomous antenna selections.	(3.2.6.1.2.2f) yes; (3.2.6.3.3) But for only a 30-second period with automatic return to autonomous antenna selection.

Table 2-8
(Continued)

The NASA-unique requirements specify an automatic mode selection algorithm that will autonomously select the best communications link from the available choices: five Spaceflight Tracking and Data Network (STDN) stations, two Tracking and Data Relay Satellite (TDRS) stations, or the Orbiter. The current status of the Boeing design provides only a manual mode selection capability through an uplink command, i.e., without established communications, the mode cannot be switched.

A more severe problem, however, is the lack of any design provision to include the TDRSS communications link. The Boeing status proposes loading the TDRSS coordinates in the table reserved for ground stations on a DOD mission. This solution does not allow loading the STDN coordinates into the flight software for the specified mission. In other words, TDRSS and STDN are mutually exclusive and cannot be used on the same mission. This solution is not acceptable to MSFC and does not meet the requirements of STS-100, Volume 3-1, Sections 3.1.5.2.7 and 3.1.5,3,6.

The requirement to select the communication link in a manner which maximizes command uplink signal strength at the antenna will not be implemented. This algorithm would result is predominate selection of STDN ground stations (whenever available) instead of the TDRSS which is the preferred link.

NASA-unique requirements to compensate for spacecraft occultation are also not provided by Boeing's software design. In a telecon Boeing personnel stated that the current design provides an acceptable ninety percent telemetry coverage and that provisions for occultation have never been established as firm requirements.

Requirements associated with maintaining communications during spinup are not met with the status defined by Boeing. Antenna switching is supported up to a rotational rate of five degrees per second, which is less than 1 rpm, so there is no capability to continue communications throughout spinup. There is an inconsistency in the Boeing status regarding dropout of telemetry (TLM) during antenna switching. Line No. 6-1.3 indicates a 5-second loss of TLM but Line 6-1.5 states that switching is make-before-break. A clarification of status is needed - our understanding is that there is a short loss of TLM signal during antenna switching.

Current implementation of the manual (uplink) override of antenna selection provides a short-term override of 30 seconds with an automatic return to autonomous selection processing. This design accomplishes the intent of an override command. If a longer override period is desired, successive override commands may be issued.

A detailed discussion of communication interface limitations that may result in a loss of telemetry is presented in paragraph 5.1.

2.2.6 Redundancy Management

The Boeing design status in Table 2-9 fails to provide redundancy management for the antennas or the STDN/TDRSS stations. If a bad antenna or station is selected, the IUS telemetry is lost until another switch occurs to a good communications link. Uplink commands could easily remove failed links and antennas from consideration. An antenna failure would have to be uplinked after the IUS has switched back to a good antenna.

2.2.7 Checkout

As shown in Table 2-10, Boeing states that the IUS checkout functions are accomplished within the scope of the contract. No unique checkout requirements are identified for NASA prelaunch and predeployment operations. In previous NASA programs, ground checkout software has been much more comprehensive than the functions provided by the IUS software. Additional checkout functions may be identified as the Boeing design of NASA-unique software matures.

REDUNDANCY MANAGEMENT

Line No.	STS-100 Para.	IUS Flight Software Requirements	BOEING STATUS (CPDS Para.)
7-1	3.1.5.2.6 3.1.5.2.7 3.1.5.3.6 3.2.1.7 3.6.1.5	An antenna status flag shall be maintained for each of the 20 NASA IUS antenna to support autonomous antenna switching software of the communications function. These flags shall be set by ground commands.	(3.2.6.3) (3.2.7.3) Ten antennas are the baseline capability. An available kit will provide an additional 10. Redundancy management is not involved with the autonomous antenna switching. RF switch monitor contacts (flags) indicate which antenna is in use. Flags are not set by ground command.

Table 2-9

CHECKOUT

Line No.	STS-100 Para.	IUS Flight Software Requirements	BOEING STATUS (CPDS Para.)
8-1		The IUS software shall be compatible with LPS and shall provide the following checkout functions for NASA missions:	There is no requirement for IUS to interface with the LPS system.
8-1.1		• Additional checkout functions for common DOD/NASA IUS subsystems as follows: TBD.	(3.2.8) The IUS checkout functions are accomplished within the scope of the IUS contract. No plans for IUS third stage checkout logic currently exist.
8-1.2		• Third-stage avionics checkout functions as follows: TBD.	

Table 2-10

3. SOFTWARE DESIGN ANALYSIS

During the course of this study, M&S Computing performed a thorough engineering and data system analysis of the evolving design of the IUS software and its potential, with respect to fulfillment of the NASA requirements. Three major documents were evaluated in the study effort.

These are:

- IUS Computer Program Development Plan.
- Computer Program Development Specification (Type B-5).
- Computer Program Product Specification (Type C-5).

In addition, M&S Computing supported appropriate technical interchange meetings, software working groups, and preliminary/critical design reviews.

This section describes the results of the design analysis, discusses the status of NASA-unique requirements with respect to the software design, and highlights our concerns with the current design and its likely effect on NASA mission support. This section also provides a review of the latest NASA-Unique Software Schedule and points out inconsistencies developing out of continued schedule compression. The details of support provided to technical interchange, software working group, and design review meetings are contained in Appendix C.

3.1 Detailed Design Analysis

The design analysis activity focused on four consecutive releases of the IUS Operational Software Computer Program Product Specification, TRW Document Number 33332-01, dated:

- September 28, 1978.
- November 16, 1978.
- December 29, 1978.
- March 30, 1979.

These documents were reviewed from three different aspects: (1) compliance with proper software design standards and procedures; (2) faithful implementation of requirements as defined in the appropriate, corresponding level of the IUS Computer Program Development Specification (Type B-5); and (3) compatibility with NASA-unique software requirements.

In addition, as a separate, but closely related effort, the Computer Program Development Specification for "MOS (Mission Operations Segment) Postprocessing Software, Parts I and II," Boeing S290-50010, October 16, 1978, was evaluated to determine the validity and acceptability of the mission data load support software.

3.1.1 Overview

The first (and most lasting) impression gained from this analysis effort is the overwhelming volume of documentation involved. The documentation results from a laudible and conscientious attempt to adhere to modern program practices; however, it also creates new problems. First of all, there are too many releases of complete requirement/design sets. The traceability from design statement to requirement statement (of equivalent release levels) is excellent. Maintaining a library of current equivalent levels of Type B5 and Type C5 specifications is difficult. Identification of changes/differences between release levels is virtually impossible. This problem has been compounded by the lack of an active, current Software Problem Report (SPR) file and timely distribution of Advanced Documentation Revision Notices (ADRN's) and Specification Change Notices (SCN's).

In general, the design adheres to good structured design principles. If anything, it might carry the refinement process too far. Some functions are fractured into quite small modules. The handling of interrupts and lack of software test considerations (e.g., power up, inhibits, etc.) presents some concern; however, these are more of a requirements deficiency than a design flaw.

The major concerns of the DOD/STS IUS software design, as presented in design reviews, center on the timing and sizing overruns. Again, the solution lies as much in tightening of requirements as in design modification. Both the prime contractor, Boeing, and the software developer, TRW, are working toward solutions to these problems and have made significant progress. The open question is whether the gains made in the current design will be of sufficient magnitude to absorb the addition of known or unanticipated NASA requirements.

3.1.2 DOD/STS Design

The specific observations made during the design analysis of each release level of the Type C5 specification were documented as memoranda, placed in the IUS file, and distributed via technical reports to the NASA Contracting Officer's Representative (COR). These detailed memoranda are referenced in Appendix A of this report Tables 3-1 through 3-4 present a summarized/tabularized form of the observations made, deficiencies noted, and corrective actions taken. Each table reflects the concerns evident at a specific Type C-5 specification release level (Note: The paragraph numbers in the B5, C5 columns relate to Revision G and to the March 30, 1979, release respectively); consequently, some concerns are carried forward to subsequent levels awaiting resolution. The tables are structured by Computer Program Component (CPC) and each concern is referenced to the applicable Type C5 and/or Type B5 specification paragraph number (again, note that paragraph numbers reflect the March 30, 1979, release) except in those cases where the concern is of a general generic nature. Not all concerns have been resolved as yet. Satisfactory resolution of all concerns will be ensured only by careful monitoring of future releases of the requirement and design specifications.

IUS CPPS EVALUATION - SEPTEMBER 28, 1978

NO.	CPC's	B5	C5	CONCERN	RESOLUTION
1	Interrupt Processing (INTERUP)	3.1.1.2	3.2.3.8.1	1. The spare interrupts (11, 14, and 15) should be masked and never allowed to cause a reconfiguration.	TRW had noted the problem and has written a Software Problem Report (SPR) against the B5 specification.
		3.1.1.2	3.2.8.1	2. The tight binding of Interrupt Levels 6 and 8 is not a good practice.	Binding is necessary for SCU command processing; TENMSEC (Level 6) issues the first command in the queue and the echo (Level 8) triggers the subsequent commands.
		3.2.1.3.1(A) & 3.2.a.1.3	3.2.3.8.1	3. IMU Data Available (Level 9) should be masked if it has no processing as the C5 states.	The interrupt is now used as a flag to FASTNAV that IMU data is current.
		3.2.1.3.5	3.2.3.8.1	4. What updates IGMT (Level 12) after deployment? Also, this interrupt should be masked after deployment. There is a question as to why this function is needed. Why not do it once at initialization and thereafter with uplink if required?	Navigation and Guidance use GMT on a 10 msec rate after deployment The B5 specification requirement for 1 sec processing will be corrected to 10 msec processing.
		3.2.1.3.6.1 3.2.9.1.3	3.2.3.8.1	5. The description of IMU Channel fault processing and handling of Interrupt Levels 9 and 13 is confusing. What other areas has Level 9 been assigned to perform?	Level 13 is used to indicate a fault in either IMU I/O or Conversation Link I/O. A flag will distinguish between the two. Levels 9 and 13 will occur simultaneously when IMU data is complete 1.5 msec into a minor cycle.
		3.1.1.2.1.2.1	3.2.3.8.1	6. In general, software design should avoid the following: • One interrupt level should not have to depend on the occurrence of another interrupt to identify pointers, furnish data, or whatever. • Interrupts are autonomous events that should not be dependent on the timing of nonpriority functions. • Two different interrupts should not be responsible for performing the same function, i.e., command issuance.	These features are an integral part of DAC's requirements and TRW's design and will probably not change. TRW has added a new CPC DATABUF, to ensure data consistency of routines.

Table 3-1

NO.	CPC's	B5	C5	CONCERN	RESOLUTION
1	Interrupt Processing (Continued)	3.1.1.2 3.2.1.3.6.1	3.2.3.8	7. Hardware failures in firmware, illegal memory addressing (Level 2), EDC memory errors (Level 4), and arithmetic faults (Level 5) should do absolutely nothing except halt the computer. Machine operations would be unpredictable and possibly catastrophic; therefore, current requirements to continue until the next 10 msec period should be modified.	TRW will submit an SPR on this requirements problem.
		3.1.1.2.1.2.2 3.2.1.4.3	TENMSEC TASKKED	8. The interval timer (Level 7) is called by each routine to measure the run time of the routine This is a nice debug feature, but it adds unnecessary overhead for the flight software.	TRW agrees and had written an SPR on the problem, but BAC rejected the SPR and kept the requirement for routine timing.
2	IVECTOR	3.1.1.2.1.2.1	3.2.1.1	During computer status save and restore, are interrupts locked out at any time?	No.
3	Power On and Initial	3.2.1.3.6.3	3.2.1.2 (Poweron)	1. Startup initialization is questionable; the fundamental philosophy should be examined.	TRW is already rewriting this section for the C5 release in November.
		3.1.1.2.1.2.5	3.2.1.6 (Initial)	2. Enabling of interrupts should be the last step of this initialize routine because interrupts are almost sure to be pending.	The rewrite should do this.
4	COMMAND	3.2.6.1	3.2.3.1 (Command)	If maximum uplink rate (NASA) is 50 words per second, why isn't this routine run every 20 msec instead of every 10 msec? Another alternative is to not run the routine at all until an uplink header word is received or a timed command is in process.	Running at a higher rate increases response time and wastes very little time for a routine call and return.

Table 3-1
(Continued)

NO.	CPC's	B5	C5	CONCERN	RESOLUTION
5	SCUPROC	3.2.1.3.7.2(A)	3.2.3.5	Operation of the computer OK command is not clear:	
				1. Is it assured of being issued when it is the lowest priority?	Priority is being changed to first.
				2. Are all nine commands in the queue transmitted consecutively?	Yes, as Echo responses trigger Level 8 interrupts.
				3. Documentation nomenclature is inconsistent (Computer OK, SCU OK, SCU/Computer OK).	Nomenclature will be changed.
6	TASKKED	3.2.1.4.1	3.2.1.4	1. What are the consequences if the assumption in Volume 1, 3.2.29.5, proves wrong and a frame overrun does occur?	Redundancy Management will reconfigure.
		3.2.1.4.1	3.2.1.4	2. Due to software similarities, overrun is likely to occur on both computers if it occurs on one.	Disagree - software timing problems will be resolved and overrun will occur only in case of hardware problems in one machine.
		3.2.1.4.1	3.2.1.4	3. Requirement states, a "goal is to attempt to continue . . ." (Section 3.2.1.2.4.2). This is ambiguous and does not define response to frame overrun.	This statement has been deleted from the requirements.
		3.2.1.4.2	3.2.1.4	4. What are the consequences of an overrun on .5, 1, 5 and 10 second processing?	TRW has not addressed this problem yet. Currently, the routines run until a "done" flag is set.
7	TELMTRY	3.2.1.4.1	3.2.1.4	Why invoke this CPC every 20 msec? TASKKED could check the Hi-Rate Low-Rate flag to reduce overhead.	Desirable for all TM processing to be in one CPC. The overhead incurred is very small.
8	COMTRAK			NASA requirements dictate that this CPC:	TRW was unaware of this requirement; it must be resolved with Boeing.
		None	3.2.3.3	1. Run every 40 msec instead of once per second during spinup of the third stage.	
		None	3.2.3.3	2. Include an additional mode: RCM-Antenna Mode 4 Selection for a TDRSS target vector.	

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Table 3-1
(Continued)

IUS CPPS EVALUATION - NOVEMBER 16, 1978

NO.	CPC's	B5	C5	CONCERN	RESOLUTION
1	General		3.2.1.3	1. The ten millisecond CPC's contain too-many subroutine calls (modules, functions, or routines).	BAC/TRW are withholding changes of this type (along with assembly language code) until the need to relax design guidelines is more urgent.
			3.2.1.7	2. A number of functions which must be accomplished during initialization or predeployment are voided (e.g., GMT update, IUS State Vector initialize, and other flight prerequisites) or required to be repeated in the event of a thermal shutdown. It would seem prudent to have an intermediate mode of a few seconds between predeployment and deployment in which flight readiness parameters could be verified and in which other activities such as update and thermal shutdown monitoring are inhibited. It seems dangerous to have the capability to update (or be in the process of updating) flight-dependent data at the instant of deployment.	A transition state is the subject of Software Problem Report 337.
2	POWERON	3.2.1.3.6.3	3.2.1.2	There is no method to power the computer down and back up, i.e., for test operations, without reloading memory. Initial power up sets a flag which prevents subsequent power up except for a restart after a thermal shutdown. A normal power on/off sequence should be provided.	BAC stated that test requirements had been intentionally omitted from these initial specifications.
3	SCUPROC	3.2.1.3.7.2(A)	3.2.3.5	1. Section 3.2.25.1 mentions two SCU output queues. What are they?	TRW will correct this when Volume 1 is corrected in the December 29 release.
			3.2.1.3 and 3.2.3.5	2. SCUPROC (3.2.25.1) and TEN MSEC (3.2.32) should explain the operation of the computer OK command more thoroughly.	A more thorough explanation will be added when Volume 1 is updated for the December release.

Table 3-2

NO.	CPC's	B5	C5	CONCERN	RESOLUTION
4	INTERUP		3.2.3.8.1	1. The last sentence of Section 3.2.19.1 is not exactly correct. The inhibit on RIP SCU DATA does not apply to Echo data.	TRW will reword the sentence.
				2. INTERUP PDL states that no processing is required for the Level 10 Interrupt, Conversation Link. Volume I does not reflect this in Section 3.2.19.	The PDL and Volume I will both change as a result of a recent change - Level 10 will be used for a Conversation Link inhibit calculation.
				3. Since the PDL shows that Level 12 (RPGMT) is not active after Initialization, it should be masked after Initialization.	TRW intends to mask unused interrupts.
5	COMMAND		3.2.3.1	1. Section 3.2.6 states that Initialization is performed by the INTERUP CPC, but the PDL does not contain it.	The reference in Volume I will be deleted.
				2. Section 3.2.6.1 references three subroutines; it should reference seven subroutines.	This will be corrected.
6	DATABUF		3.2.1.5	The routine expects a "done" flag to be set by 1 and 2 Hz processes. Will it respond sanely if the flag is not set?	The routine will simply wait until the next test period.
		3.2.1.4.1	3.2.1.4	The assumption in Section 3.2.29.5 implies that the system does not switch computers upon a frame overrun. Is this current design?	A requirement to switch for frame overrun was just recently added to the B5 - TRW will incorporate it.

Table 3-2
(Continued)

IUC CPPS EVALUATION - DECEMBER 29, 1978

NO.	CPC's	B5	C5	CONCERN	RESOLUTION
1	ATTIMAN		3.2.3.1	The description for ATTIMAN does not define the differences for NASA-unique software. Implementing the spinup mode should be explained	These comments have not been resolved and are not incorporated in the March 30, 1979, C5 release.
2	COMMAND		3.2.6 3.2.6	COMMAND CPC initialization is performed by the subroutine RCDINIT. What initialization function is performed by INTERUP as defined in paragraph 3.2.6?	
3	COMMAND		3.2.6.1	COMMAND CPC hierarchy consists of an initialization routine, CCR and ten subroutines instead of the three subroutines referenced in the first paragraph.	
4	CONTRAK		3.2.7	The method and changes necessary to accommodate NASA antenna switching should be identified.	
5	(TBD)		3.2.2.5.1	The number of buffers and sources for NASA antenna switching commands are TBD. Has this area been resolved by ADRN Number 4?	
6	TASKED		3.2.2.9.5	Still assumes that CPC's will complete within their allotted time instead of specifying a re-configuration for a frame overrun.	
7	(TBD)		Vol. II Page 571	The VGAMMAX/MAT parameter is not identified in this portion of the data base. What are the source/destination CPC's for this data element?	
8	POWER ON		Vol. III Page 31	The software contains no provision for a power on after a commanded power off. Currently, a software reload would be necessary before another power on would be executed (except after thermal shutdown). A fourth power-on condition is needed for software testing and prelaunch operations. In the power-on mode after a power failure (VSTRST not set and LKPOFLAG set), the software just enters a wait loop. Some error messages should be output to indicate the status of the failed computer. A capability to process uplink commands during the wait loop would provide a desirable recovery capability during pre-launch and predeployment operations	

Table 3-3

IUS CPPS EVALUATION - DECEMBER 29, 1978

NO.	CPC's	B5	C5	CONCERN	RESOLUTION
9	SEQUENC		Vol. III Page 295	Processing is TBD for the following: • RSQ NASA Second Stage separation. • RSQ NASA Third Stage sequence. NOTE: The sequence defined for B5 Section 3.2.2.2.3.2.14, NASA Third Stage Sequence, is not applicable once ECP 247 is implemented to remove third stage avionics.	These comments have not been resolved and are not incorporated in the March 30, 1979, C5 release.
10	COMTRAK		Vol. III Page 750	The beam width cosine (CBW) value in the data base (Vol. II A, Page 445) gives the DOD nominal cone of 95 degrees but does not mention the NASA cone.	
11	COMTRAK		Vol. III Page 755	The description of RCMCCR states that the response to SPR 089 will determine what software will do if no antenna selection mode is specified by COMMAND. According to Section 3.0, Table 3.1-1, this SPR should be included in the C5 since ADRN 14 is part of the baseline documentation. RCM-INIT sets V ≠ ASM = 1 during initialization so this problem is evidently just a description problem.	
12	COMTRAK		Vol. III Page 756	Antenna mode Selection does not include TDRSS or STDN (unless Ground Station Pointing includes it). NOTE: V≠ASM is used by COMTRAK but it is set by COMMAND. This will be impacted, perhaps serverely, in order to implement an autonomous switching system for NASA.	
13	COMTRAK		Vol. III Page 770	COMTRAK defines a Station Location Table (M/SLT) which is an array of earth-centered fixed geographic coordinates for ten ground stations. Will this table be used for both DOD SGLS stations and NASA GSTDN stations?	
14	COMTRAK		Vol. III Page 780	How is the Antenna Position Array (M/APA) utilized for NASA antenna switching? Are any additional unit vectors needed?	
15	SCDPROC		Vol. III Page 858	In the Command/Buffer table, the source for the NASA antenna switching commands is TBD. When will this be resolved?	
16	SCDPROC		Vol. III Page 466	Is the VANTSW/CMND≠ in PROC≠PLG data item the same as the VASNPROC data item (p. 869)? The first item is not identified in the data base, Volume II A.	
17	INTERUP		Vol. III Page 1043	The description of RIP GMTINR states that the routine is only active during initialization. Where is the processing which prohibits the interrupt response?	

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Table 3-3
(Continued)

IUC CPPS EVALUATION - DECEMBER 29, 1978

NO.	CPC's	B5	C5	CONCERN	RESOLUTION
18	ATTIMAN		Vol. V Page 40	The command-quaternion-source-indicator (CQSI) is not processed in the ATTIMAN Rotating Reference Frame Mode as specified in the NASA Addendum paragraph 3.2.5.2.16.3.2, Item C. This mode is used to position the IUS prior to a third stage spinup.	These comments have not been resolved and are not incorporated in the March 30, 1979, C5 release.

Table 3-3
(Continued)

IUS CPPS EVALUATION - MARCH 30, 1979

NO.	CPC's	B5	C5	CONCERN
1	COMTRAK		3. 2. 3. 3	REVIEW ITEM: Communications Tracking: This section does not include the capability to determine line-of-site communications with TDRSS. RECOMMENDED ACTION: Communications Tracking: Add provision to establish line-of-site communications via TDRSS.
2	COMMAND	3. 2. 6. 1. 2. 2. c(6	3. 2. 3. 1. 1. 15	REVIEW ITEM: RCD-13: A local flag in this routine prevents Orbiter state vector update after initialization (and first update) except for thermal shutdown This is an unnecessary restriction on flight operations and provides no allowance for Orbiter maneuvers after IUS deployment RECOMMENDED ACTION: Eliminate the local inhibit flag on Orbiter state vector update.
3	UTILITY		3. 2. 2. 3	REVIEW ITEM: Utility: A number of utility descriptions (RUTACOS, RUTEXP, RUTLOG, RUTMXV, RUTUNV, etc.) lack calling sequences. The RUTFLT description is not complete in that calling functions and levels are not specified. RECOMMENDED ACTION: Utility: Use standard form for a complete, consistent description of each utility routine.
4	CHECKOUT AND SELFTEST	3. 2. 6. 1. 2.	3. 2. 2	REVIEW ITEM: Checkout and Selftest: There is a legitimate question as to the advisability of unrestrained exercise of flight hardware (actuators, relays etc). The number of cycles of hardware during testing should be controlled and specified. RECOMMENDED ACTION: Checkout: Add to the checkout commands a finite count of cycles to be performed. Eliminate the command to stop checkout.

Table 3-4

NO.	CPC's	B5	C5	CONCERN
5	GENERAL		1.2	REVIEW ITEM: Functional Summary: Third paragraph incomplete. RECOMMENDED ACTION: Functional Summary, third paragraph, second sentence should read: "...into a desired orbit or planetary injection trajectory."
			1.1	REVIEW ITEM: Identification: This document does not establish requirements. It establishes a design description to satisfy requirements. RECOMMENDED ACTION: Identification, first sentence: Replace "Requirements" with "design description" or "design specification."
				REVIEW ITEM: The Addendum Requirements are not reflected in the C5 specification design. RECOMMENDED ACTION: Develop preliminary design for review at the NASA PDR.

ble 4
Continued

3.1.3 NASA-Unique Requirements

Throughout the evolution of the IUS operating software requirements/design process, there has been an ambivalent approach to the incorporation of NASA requirements. As a result, the current version of the Type C5 specification (March 1979) does not contain a thorough design for the NASA-unique requirements, as specified in the October 15, 1978, version of the NASA Addendum, S290-51002. This is an ongoing problem, caused by the failure to successfully convey NASA requirements through the DOD/prime contractor as Type B5 specifications to the software development contractor. In other words, NASA has developed the NASA software requirements, but the software developer has not received them in a usable form (i.e., a concise set of requirements statements).

In general, the major deficiencies in terms of implementation of NASA-unique requirements are:

- Antenna selection, switching, and line-of-sight computation for TDRSS, Orbiter, and ground stations.
- Processing of NASA second stage separation and third stage sequence.
- Attitude control and third stage spinup processing.
- Figure-of-merit (FOM) calculation and achievement of FOM design requirements.
- Variable data update (command uplink) after deployment, such as state vector update, initial conditions, etc.

Guidance software routines are the most thorough in implementing NASA requirements. A more detailed description of the communications interface and Guidance, Navigation & Control Requirements analysis can be found in paragraph 5.1 and Appendix B, respectively.

3.2 Design Concerns

There are three major concerns requiring close NASA scrutiny during the remaining development cycle of the DOD/STS IUS system software. First, unless full consideration is given to the NASA requirements during baseline implementation, the impact of additional resources to support NASA requirements may exceed timing and sizing constraints of the baseline system, resulting in extensive system software modification. Second, the current software design may not be flexible enough to conform to effective NASA Mission Operations control of the IUS during deployment and flight (i.e., command update of variable mission parameters such as Orbiter state vector, initial conditions, etc.). Third, the lack of compatible software support tools for NASA in-house verification, validation, and test - particularly in the case of mission load data - may significantly increase software testing costs to NASA on a per-mission basis.

3.3 NASA-Unique Software Schedule

Figure 3-1 depicts the most recent schedule for NASA-unique IUS software. Several points are worthy of mention. Most obvious is the fact that the schedule is rapidly becoming compressed. For example, Preliminary Design Review (PDR) is shown with an approximate six-month slip. Any additional slippage will certainly begin to affect the Critical Design Review (CDR) and, consequently, the final Planetary Navigation and Control Equation Certification. Although NASA planetary software delivery is scheduled for October 1981, it should be noted that this software is required by the fourth quarter of 1980 -- less than a year from CDR.

The next apparent anomaly is the fact that the requirements development is now running in parallel with design. This is an unusual situation which ordinarily becomes expensive because of the continual false starts and rework. In fact, coding is in process before the requirements are firm.

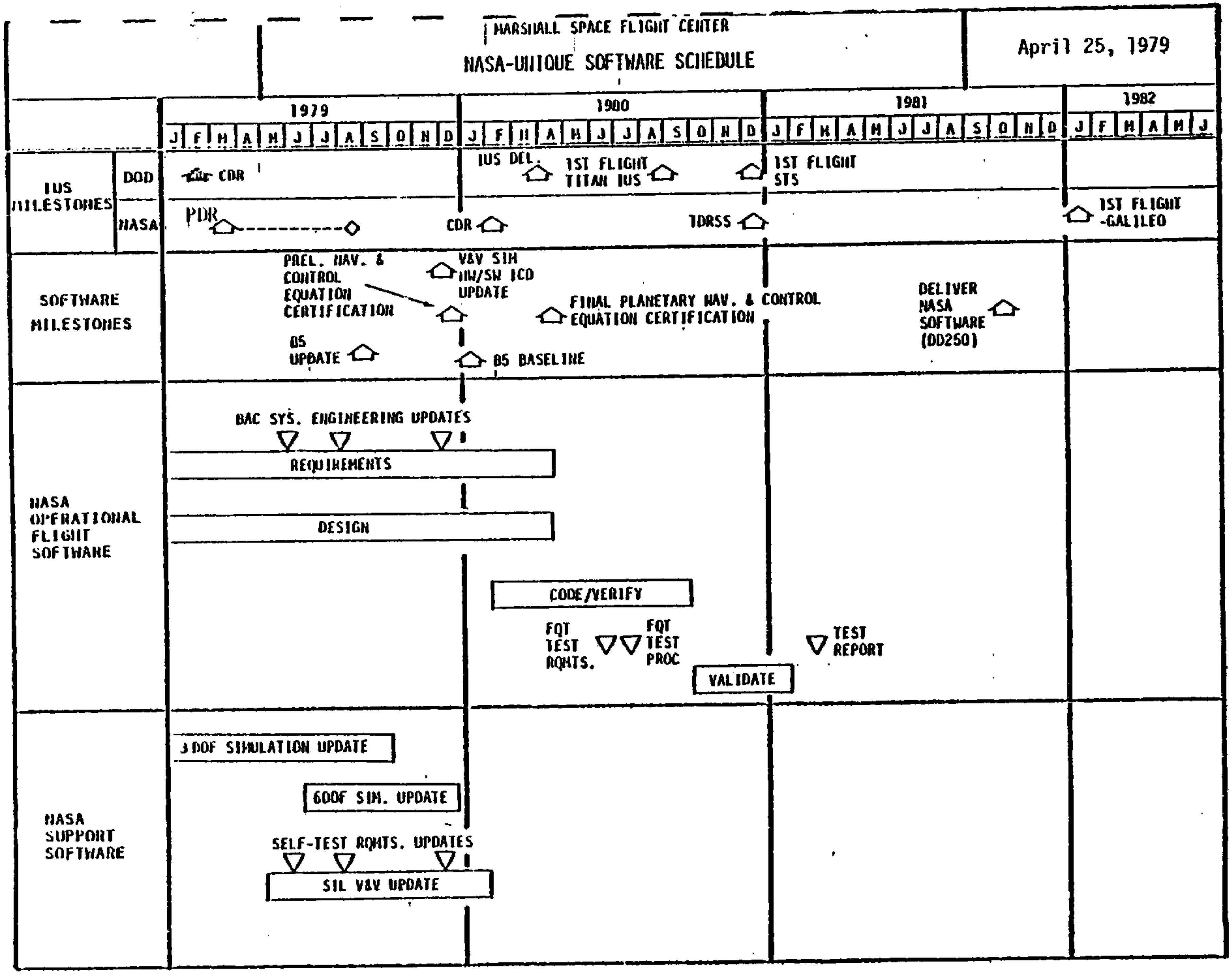
MARSHALL SPACE FLIGHT CENTER
NASA-UNIQUE SOFTWARE SCHEDULE
April 25, 1979
1979
1900
1981
1982
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
IUS MILESTONES
DOD
NASA
CDR
IUS DEL.
1ST FLIGHT TITAN IUS
1ST FLIGHT STS
PDR
CDR
TDRSS
1ST FLIGHT -GALILEO
SOFTWARE MILESTONES
PREL. NAV. & CONTROL EQUATION CERTIFICATION
V&V SIM HW/SW ICD UPDATE
FINAL PLANETARY NAV. & CONTROL EQUATION CERTIFICATION
DELIVER NASA SOFTWARE (DD250)
B5 UPDATE
B5 BASELINE
NASA OPERATIONAL FLIGHT SOFTWARE
BAC SYS. ENGINEERING UPDATES
REQUIREMENTS
DESIGN
CODE/VERIFY
FQT TEST RQMTS.
FQT TEST PROC
VALIDATE
TEST REPORT
NASA SUPPORT SOFTWARE
3 DOF SIMULATION UPDATE
6DOF SIM. UPDATE
SELF-TEST RQMTS. UPDATES
SIL V&V UPDATE

Figure 3-1

4. SOFTWARE TESTING

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Test considerations for the NASA MSFC encompass both the NASA-unique software and the DOD/STS OFS test programs. MSFC must remain involved in the DOD software testing because the common portion of the software represents more than 90 percent of the software used for NASA missions. NASA-unique requirements will comprise less than 10 percent of the flight software. Figure 4-1 presents the major NASA activities during software development: NASA-unique requirements definition, design evaluation, design verification (of NASA-unique requirements), and IV&V for NASA missions. Testing for NASA-unique software is based upon the assumption that the DOD software is thoroughly tested; therefore, test plans, procedures, and results of the DOD software testing must be evaluated to verify that the NASA mission requirements are satisfied. Any problems noted during the design or test evaluations will be forwarded to SAMSO for corrective action.

4.1 DOD/STS OFS Testing

4.1.1 Test Scheduling

Rescheduling the first operational flight of DOD/STS rearranged the priorities in the IUS software development and test schedules. When the first launch slipped almost six months, the Titan launch in September 1980 became the first IUS mission. This has forced Boeing to accelerate development of the Titan software and this reorientation is reflected in the test documentation.

4.1.2 Test Documentation

Detailed test documentation released for the DOD Software CDR is devoted exclusively to DOD/STS and Titan software. Boeing's detailed test requirements document (Reference 2) has the framework to include all three software configurations but the CDR version does not contain any NASA-unique software test requirements.

The TRW Verification Test Plan (Reference 3) contains two entries for NASA antenna command verification but does not include any other references to NASA-unique software testing. This document does not address the various software configurations, so no plan is identified for testing the NASA software which will be identified and incorporated into the test program at a later date.

The Boeing Computer Program Test Plan (Reference 4) is a more generic document that includes provisions for NASA testing. This document thoroughly presents the test philosophy for IUS software verification, preliminary qualification testing (PQT), and final qualification testing (FQT) with schedules for the three software configurations. The only shortcoming from a NASA standpoint was an out-of-date software development schedule.

IUS FLIGHT SOFTWARE DEVELOPMENT - OVERVIEW

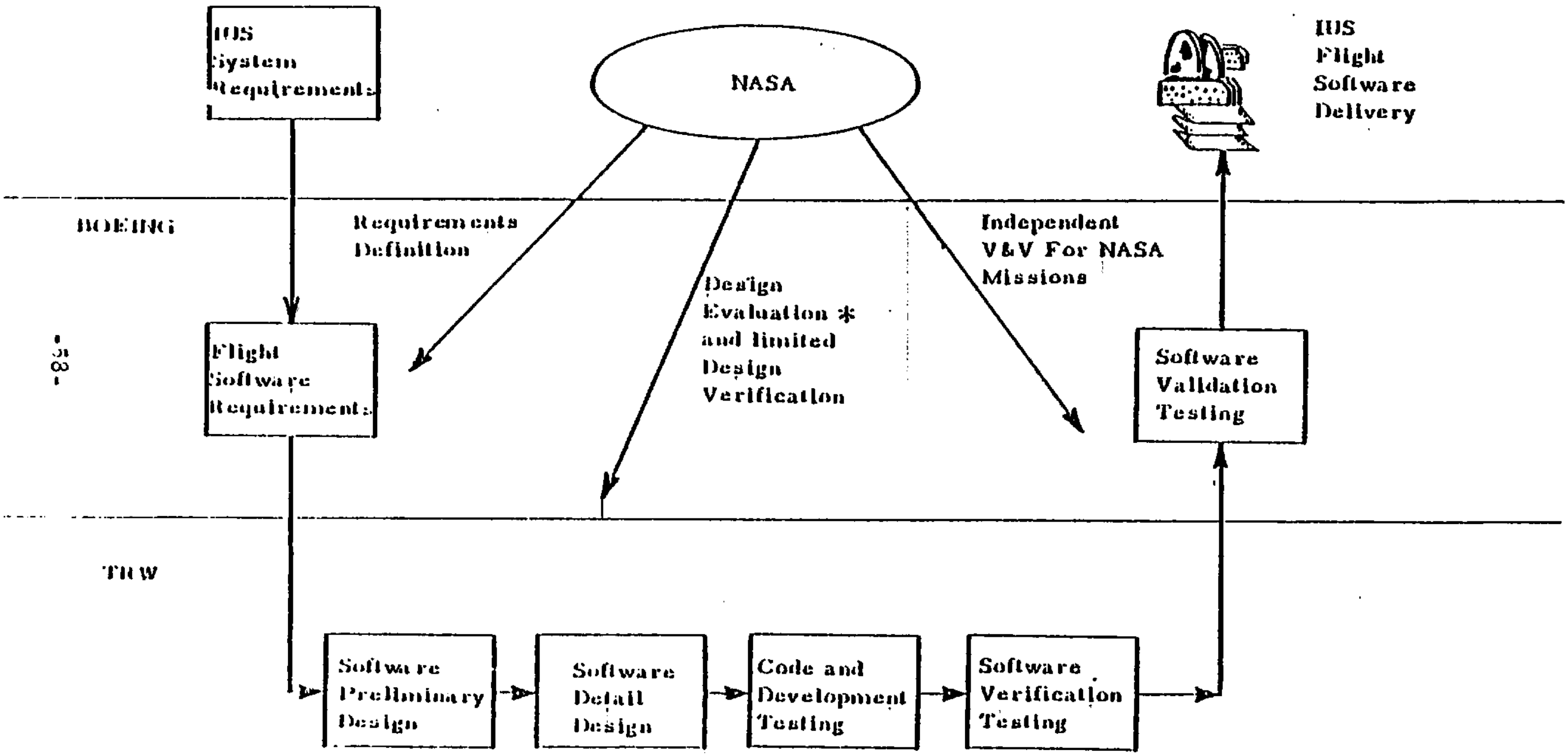


Figure 4-1

* NASA-Unique Functions Only

4.1.3 Test Facilities

The Titan Verification and Validation (V&V) Simulator in the System Integration Laboratory (SIL) is nearing completion (July 1979 for Titan) and is beginning to support preliminary OFS integration tests. Phasing the OFS integration allows testing to begin before the V&V simulator is fully checked out. This V&V simulator will implement the breakpoint/restart capability proposed in Reference 5 and at the V&V software CDR by MSFC personnel.

4.2 NASA-Unique Software Testing

4.2.1 Test Scheduling

Any impact of the slip in DOD/STS IUS software delivery on the NASA-unique software development schedule has not yet been reflected in Boeing schedules. Figure 1-1 shows that the completion of DOD/STS two-stage validation is within three months of the beginning of NASA Twin Stage validation. During this period, NASA-unique software coding and testing competes with the DOD package for facility and manpower resources. NASA personnel must remain closely involved in the TRW verification, BAC validation, and IV&V testing to ensure that the final software design satisfies the NASA mission requirements.

4.2.2 Test Documentation

Boeing and TRW test documentation should be updated prior to the NASA CDR. Therefore, the FQT Requirements delivery two months after the CDR (see Figure 3-1) should be rescheduled for a release in early January of 1980 to support the NASA CDR.

The NASA-unique software test requirements document scheduled for release by M&S Computing during this contract period was postponed. Test requirements must be based upon a good set of design requirements, and, as Section 2 pointed out, the NASA Addendum is not mature enough to write even a preliminary set of test requirements. A reasonable target date for a preliminary test requirements definition is in October of 1979 following the NASA PDR (slipped from March to August 1979) and the subsequent CPDS NASA-Addendum update on September 1, 1979 (see Figure 3-1).

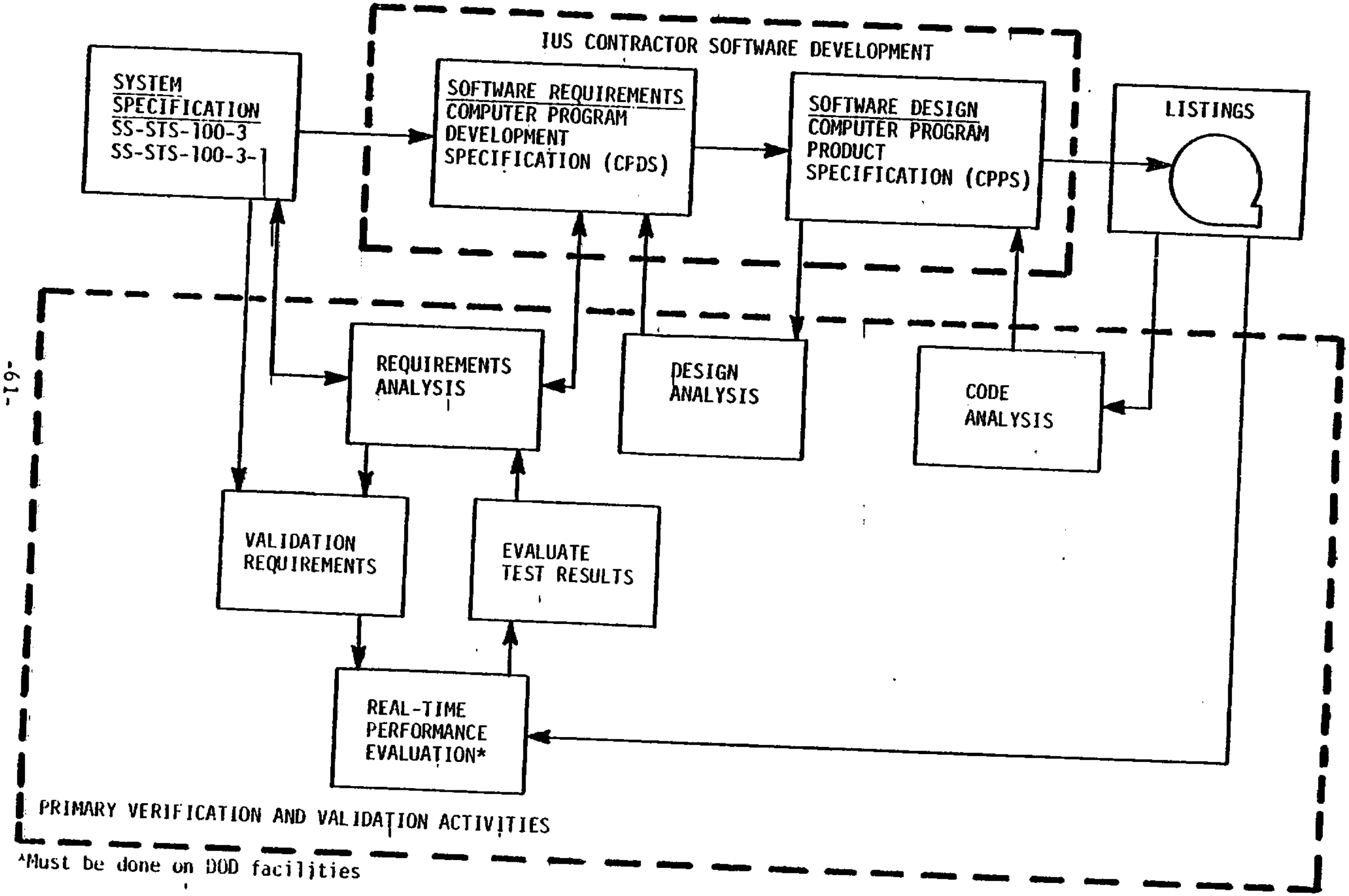
This delay will allow the Boeing system engineering analysis to be reflected in the NASA Addendum and still allow the release of meaningful test requirements prior to the NASA CDR in February 1980.

4.2.3 Test Facilities

In past programs, NASA MSFC developed in-house software test facilities to verify that the software product satisfied the overall system or mission requirements. The conclusion of the IUS Software Requirements Definition Study (Reference 6) is that such a real-time test facility would be too costly. However, this does not preclude an independent NASA verification and validation program. Figure 4-2 presents the independent verification and validation (IV&V) activities MSFC may still undertake. The requirements, design, and code analysis activities can be accomplished without a real-time simulation facility. Two facilities are available for evaluation of real-time software performance: the Boeing DOD/STS V&V simulator or the Martin Marietta IV&V facility. The Boeing facility would not provide an independent test facility, but careful coordination of the test requirements and procedures could avoid performing duplicate tests and still fully validate the NASA-unique software. The in-house IV&V effort would require the following tasks from test facility personnel:

- Review the test requirements document to ensure that the tests are within IV&V facility capabilities.
- Prepare a test plan to define test milestones, the procedures required (general outline, not specific content), the schedules for IV&V test facility usage for NASA tests, and a test requirement/test procedure cross-reference matrix. This plan should reflect the procedures used for DOD/STS software testing and the corresponding test results.
- Write detailed test procedures for each test requirement and submit to NASA for review and approval.
- Arrange for software test facilities suitable for performing the software validation tests.
- Perform IV&V tests on the IUS software released to support the NASA missions.
- Record and submit Software Problem Reports (SPR's) to MSFC for review and submittal to SAMSO.
- Evaluate the test results against the test requirements to ensure proper software behavior.
  - A "Quick-look" evaluation report should be delivered within 10 days after completing each test milestone.
  - Final test report would be required 30 days after completing each test milestone.
  - Data packages containing reduced test data, "as-run" procedures, SPR's, and copies of test conductor logs would be delivered to NASA.
  - Data recorded during final (demonstration) test runs would be preserved until 30 days after the associated NASA IUS launch.

PRIMARY NASA/MSFC VERIFICATION AND VALIDATION ACTIVITIES



*Must be done on DOD facilities

Figure 4-2

- SPR's would be retested upon resolution and a closeout disposition submitted to NASA.

NASA would analyze the test results to determine whether the IUS software meets requirements for launch.

The primary mode of software testing should use a real-time simulation to drive the flight software as it executes on an IUS flight computer (Delco M362S). A secondary testing mode using an interpretive computer simulation (ICS) may be used to supplement the above real-time testing.

It is anticipated that some modification of the Boeing V&V simulation used to test the basic DOD/STS flight software package will be required for NASA software testing. The extent of these modifications is largely dependent on the requirements for attitude control during third stage spinup and on the design of the guidance software. MSFC expressed these concerns at the V&V Simulator Software CDR by submitting two Review Item Discrepancies (RID's) - see Reference 7. Boeing stated that specific V&V Simulator modifications for NASA testing would be addressed at a later date. A subsequent schedule release included the update (see Figure 3-1), but specific modifications have not been identified.

5. INTERFACE ANALYSIS

The IUS interfaces with the NASA communications network, the third stage, and the spacecraft were analyzed. M&S Computing activities associated with each of these interfaces are outlined in the following paragraphs.

5.1 NASA Communications Requirements Evaluation

In-flight Telemetry, Tracking, and Command (TT&C) requirements for the IUS have been collected from References 14 and 17 and depicted in Figure 5-1. It can be seen from 5-1 that all NASA missions require continuous tracking from the STDN system (Reference 18) or TDRSS (Reference 19) from IUS/Shuttle separation to spacecraft (S/C) separation for twin stage missions, or spinup for spin-stabilized missions.

Telemetry of state vector and attitude data is required at all solid rocket motor (SRM) burns. Commands to arm the SRM's are required for all burns and also to arm the S/C pyrotechnics.

The actual TT&C space-to-ground linkage is controlled by the IUS software. This software selects one antenna of the onboard antenna array that points to the closest ground station (see Reference 20) relative to the IUS. This selection process includes the TDRSS satellites which are loaded as ground stations having geosynchronous altitude. The reliance on the onboard software to select and maintain continuity of RF transmission for telemetry and command data is subject to various physical limitations on the STDN and TDRS systems that could, under many conditions, result in short or long term losses of communication; herein referred to as dropouts. The following paragraphs describe some of the limitations on the STDN and TDRS systems and should lead to the conclusion that the TDRS system cannot be handled as just another set of ground stations. The major system limitations to be considered are listed below and collected in Table 5-1 along with system impact predictions.

- IUS antenna switching dropout.
- TDRSS - Zone of exclusion.
- TDRSS - Antenna steering angle limitations.
- TDRSS - Earth grazing angles.
- TDRSS - RF earth impingement limitation.
- TDRSS - Handled as ground station (signal strength).
- STDN - Ground effects (low elevation angles).
- STDN - Station masking (keyhole and terrain limitations).
- TDRSS and STDN - Thermal noise due to sun-IUS orientation.

IN-FLIGHT TT&C REQUIREMENTS

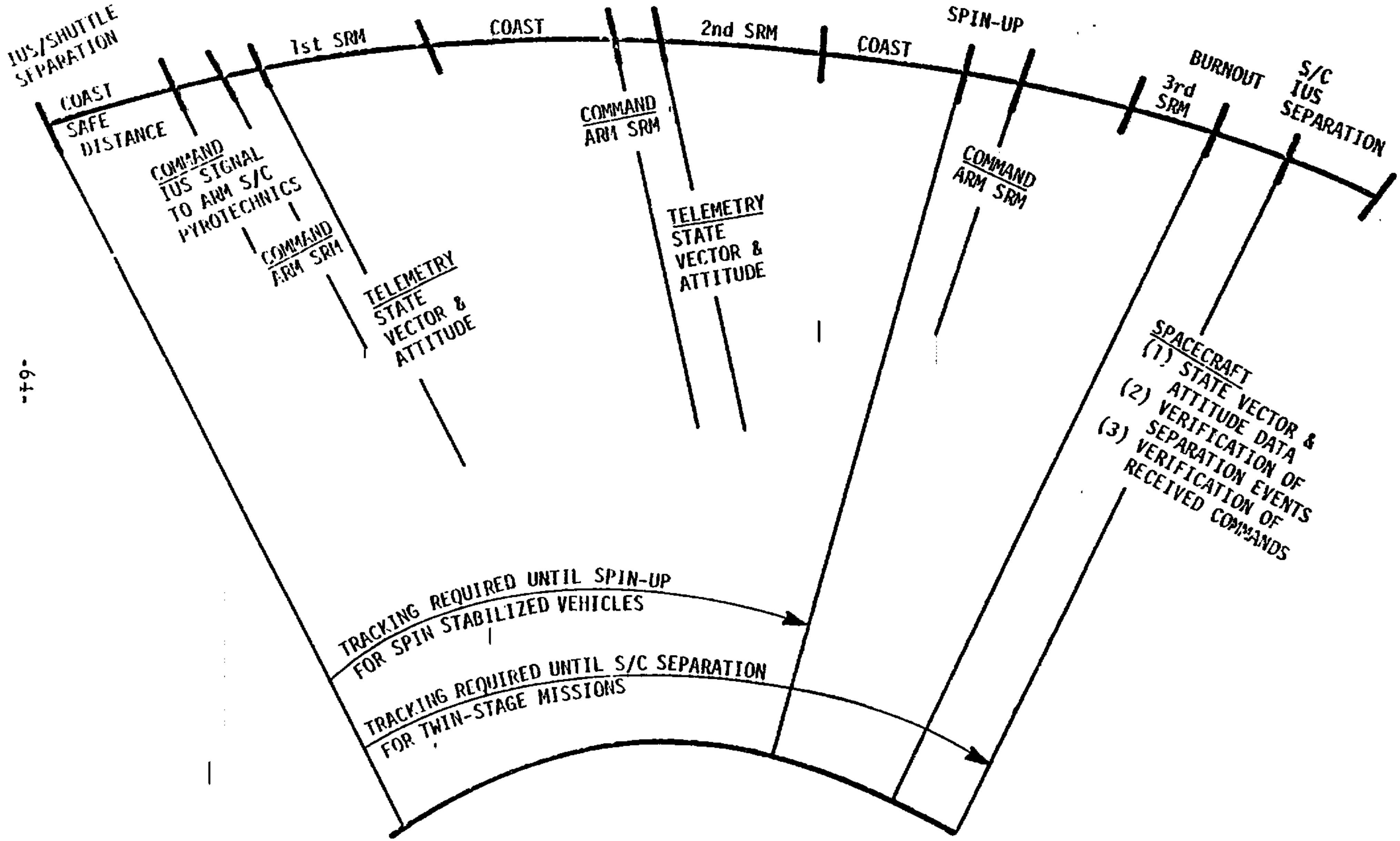


Figure 5-1

The last paragraphs of this section describe a combination of these system limitations as they act upon a typical Galileo mission (Reference 4) to dropout communication prior to second SRM ignition.

5.1.1 Antenna Switching Dropout

IUS telemetry and command dropout due to antenna switching is discussed first for command reception and second for telemetry transmission.

- Command reception when switching between antennas in the STDN mode.
  - May lose phase lock for 2 to 20 milliseconds during switching period.
  - Reestablishment could take 500 milliseconds.
  - Each antenna switchover could result in 520 milliseconds of command or ranging loss.
  - Commands may require repeating.
  - Ranging may be disrupted.
  - Operation in the TDRSS mode will be similarly affected.
  - The command reception design meets the IUS requirements for NASA compatibility of STDN or TDRSS signals.
- Telemetry Transmission
  - Telemetry data utilizes two STDN compatible subcarriers, one for pulse code modulation (PCM) and one for analog vibration data (frequency modulation (FM)). Both are compatible with STDN or Orbiter.
  - FM vibration data is not transmitted through TDRSS due to format incompatibility and insufficient signal margin.
  - An RF command can override onboard computer software antenna selection for 30 seconds. After 30 seconds, the onboard algorithm again gains control of antenna selection. This prevents an inadvertent lockout due to an incorrect selection.
  - While switching between antennas the receiving site may lose phase lock and PCM decommutate lock due to the switching transient. This period is estimated to be less than 2 3/4 seconds for STDN and TBD for TDRSS.
  - The telemetry transmission design meets the operating requirements for STDN or TDRSS compatibility.

March 29, 1979

IUS TT&C DROPOUTS

Problem	Systems Involved	Duration of Dropout	Impact
Telemetry and command dropout due to antenna switching	STDN and TDRS	1/2 sec commands 2 1/2 sec telemetry	Repeat commands, ranging disrupted 2 1/2 sec. STDN, TBD TDRS - possible loss of data (TBD)
Lack of continuous TT&C coverage (geometrical)	STDN and TDRS	Mission dependent	Durations of no uplink (command) or downlink (telemetry) capability
Lack of TT&C due to sun alignment	STDN and TDRS	Mission dependent	TBD - Thermal noise levels
Lack of communications during third stage spinup	STDN and TDRS	Mission dependent	No TT&C thru TDRS or STDN
TDRS (zone of exclusion)	TDRS	Mission dependent	Loss of communication
Occultation of IUS by spacecraft (no Orbiter update vector)	TDRS	Mission dependent	Intermittent or loss of communication
Antenna steering angle limitations (sectors of no communication)	TDRS	Mission dependent	Intermittent or loss of communication
Earth grazing angle limitation	TDRS	Mission dependent	Loss of communication
TDRS handled in software as a ground station	TDRS	Mission dependent	No compensation for Occultation grazing angles, sector limitations, or transmission power (uplink)*
International limitation on RF power density impinging on the earth	TDRS	TBD	Possible loss coverage of 5% to 20% per orbit

Table 5-1

IUS TT&C DROPOUTS

(Continued)

Problem	Systems Involved	Duration of Dropout	Impact
STDN ground reflection (low elevation angles)	STDN	TBD	Loss of communication
STDN station masking (keyhole and terrain limits)	STDN	TBD	Intermittent communication
STDN no ground station available	STDN	TBD	No TT&C thru STDN

*Uplink signal strength will differ for TDRS and STDN. Cannot use "closest distance" as switching criteria for ground versus TDRS.

Table 5-1
(Continued)

5.1.2 Limitations of the TDRSS

Zone of Exclusion

The fixed positions, relative to the earth, of the two geosynchronous tracking satellites result in a "zone of exclusion." This zone is a region where TT&C cannot be conducted by TDRSS as neither of the satellites can see into this zone. The zone is formed by the intersection of two cones of visibility (with respect to each satellite) and the sphere of the earth. Details of the location of the zone are given in Figure 5-2 and Figure 5-3.

Steering Angle Limitation

The maximum single access antenna steering angle results in three regions of no TT&C capability with respect to TDRSS at various ranges of latitude and longitude above altitudes of 12000 kilometers. Details of these regions are contained in Figure 5-2.

Earth Grazing Angles

TT&C signal attenuation due to earth grazing angles (angles less than six degrees). The angle formed by the tangent to the earth's surface through TDRSS and the line through the TDRSS and the point being observed. Refer to Figure 5-4.

RF Earth Impingement Limitation (Flux Density Limits)

International limitations on the power level of an RF signal impinging on the earth may result in a potential coverage loss due to reduced power levels of transmission (Reference 4).

TDRSS Simulated as a Ground Station

The signal strength of an STDN station will exceed that of a TDRSS. Optimal signal strength will be a function of transmission power and is not defined by the closest station concept as outlined in the IUS software requirements.

5.1.3 STDN

The STDN station locations are described in Figure 5-5.

Station Masking (Keyhole and Terrain Limitations)

Ground stations are subject to restrictions in elevation and azimuth due to local terrain such as hills and buildings. Additionally, hardware mountings (keyhole limitations) further restrict their overall movement. Examples of these azimuth and elevation restrictions (called station masking) are described in the following paragraphs for the Goldstone and Madrid stations.

From Figure 5-6, there exists a loss of communications with respect to the Goldstone Tracking Station for an azimuth near 272 degrees from 0 degrees to 28 degrees in elevation. Similarly,

UPPER ALTITUDE COVERAGE GEOMETRY

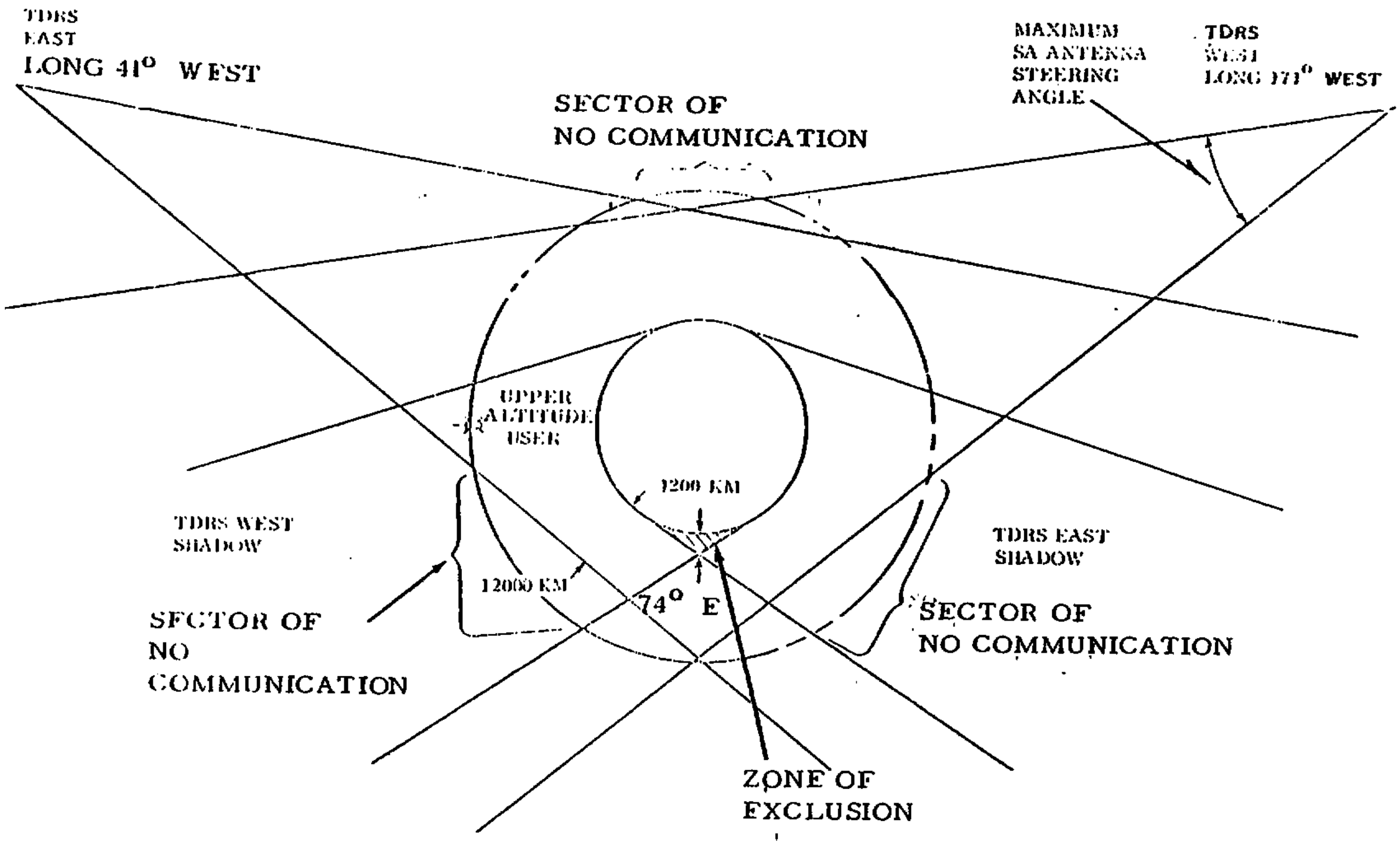


Figure 5-2

GROUND PRINT OF ZONE OF EXCLUSION

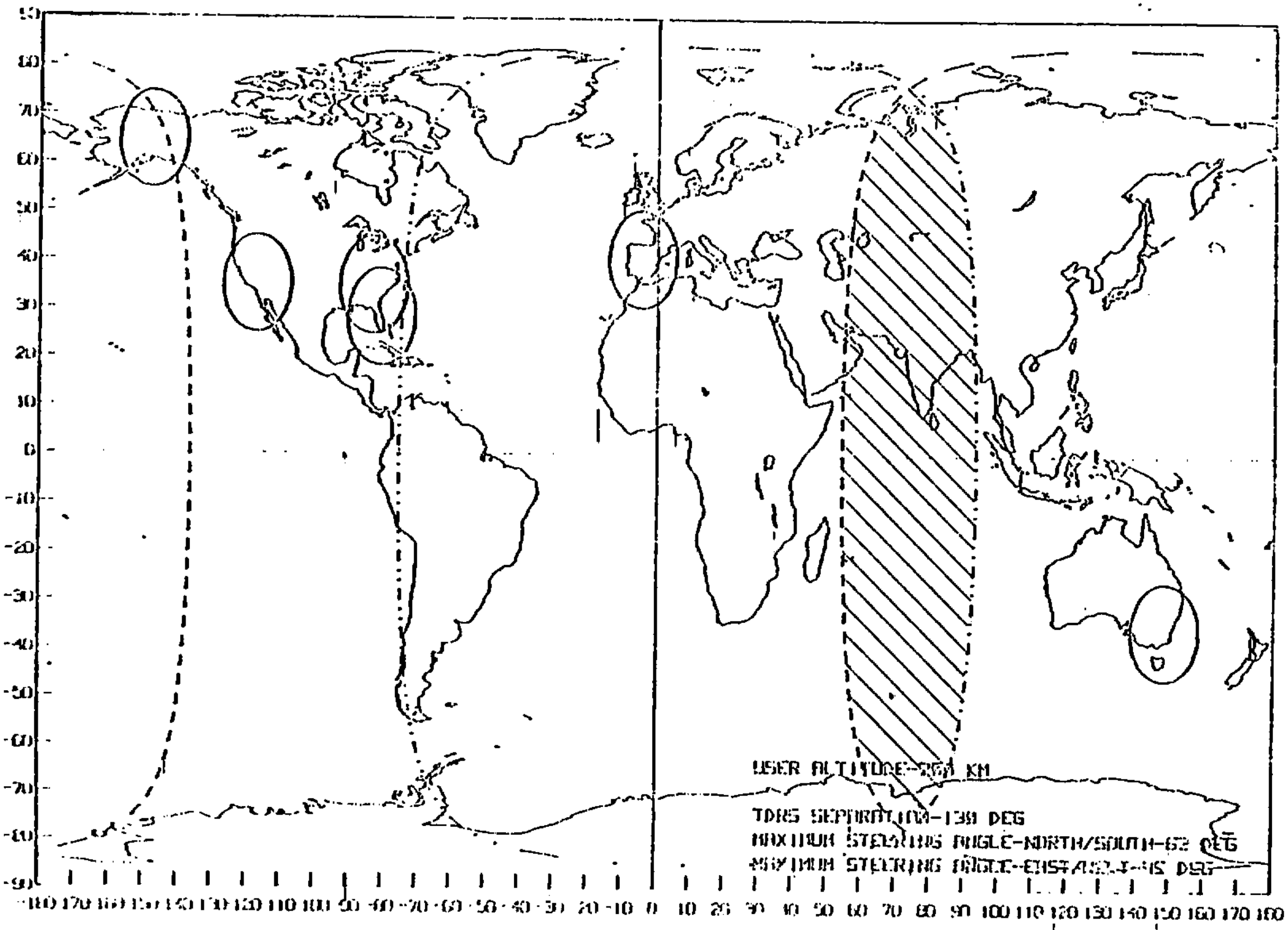


Figure 5-3

DEFINITION OF EARTH GRAZING ANGLES

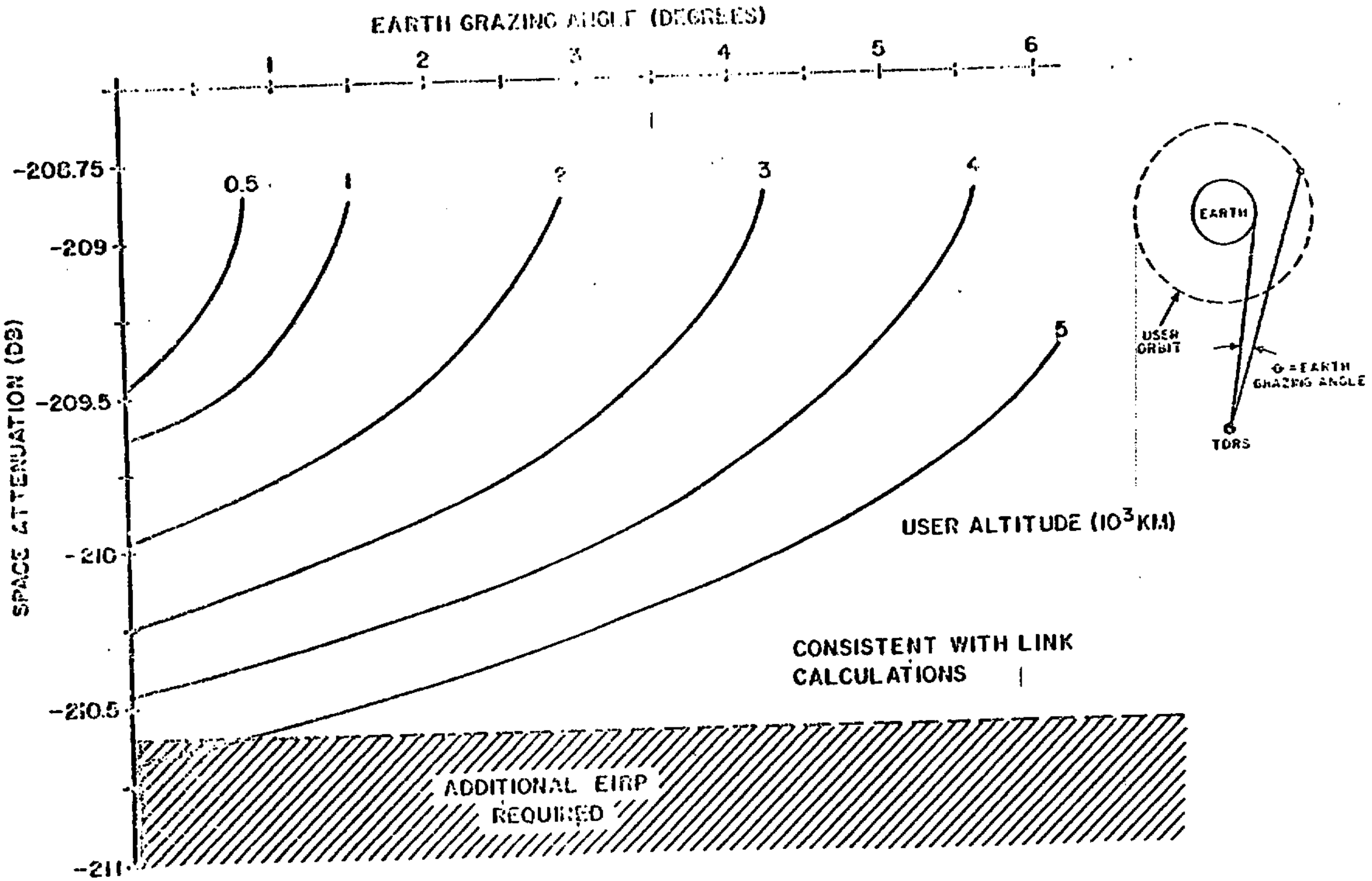


Figure 5-4

SPACEFLIGHT TRACKING AND DATA NETWORK

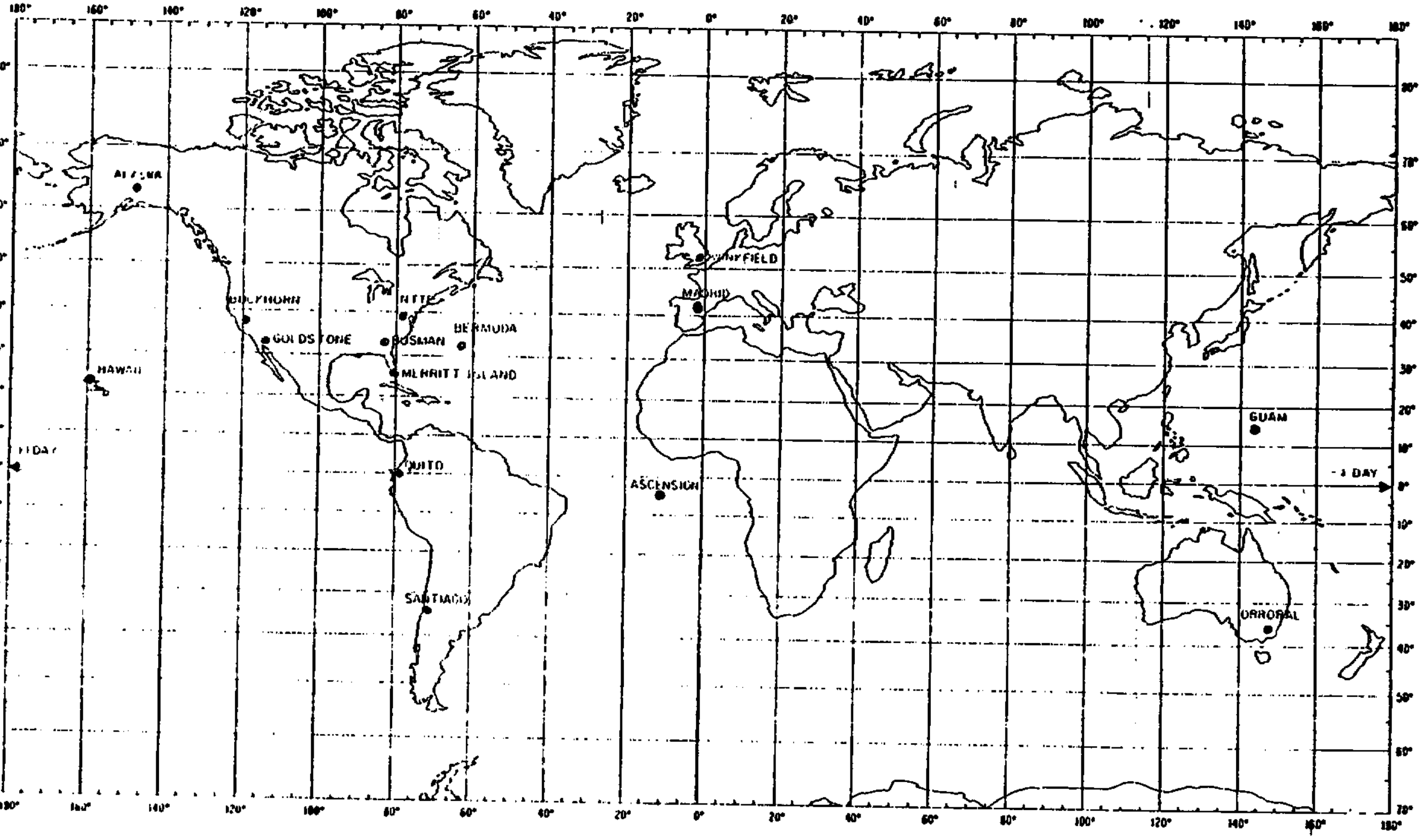


Figure 5-5

TRACKING STATION MASKING DATA

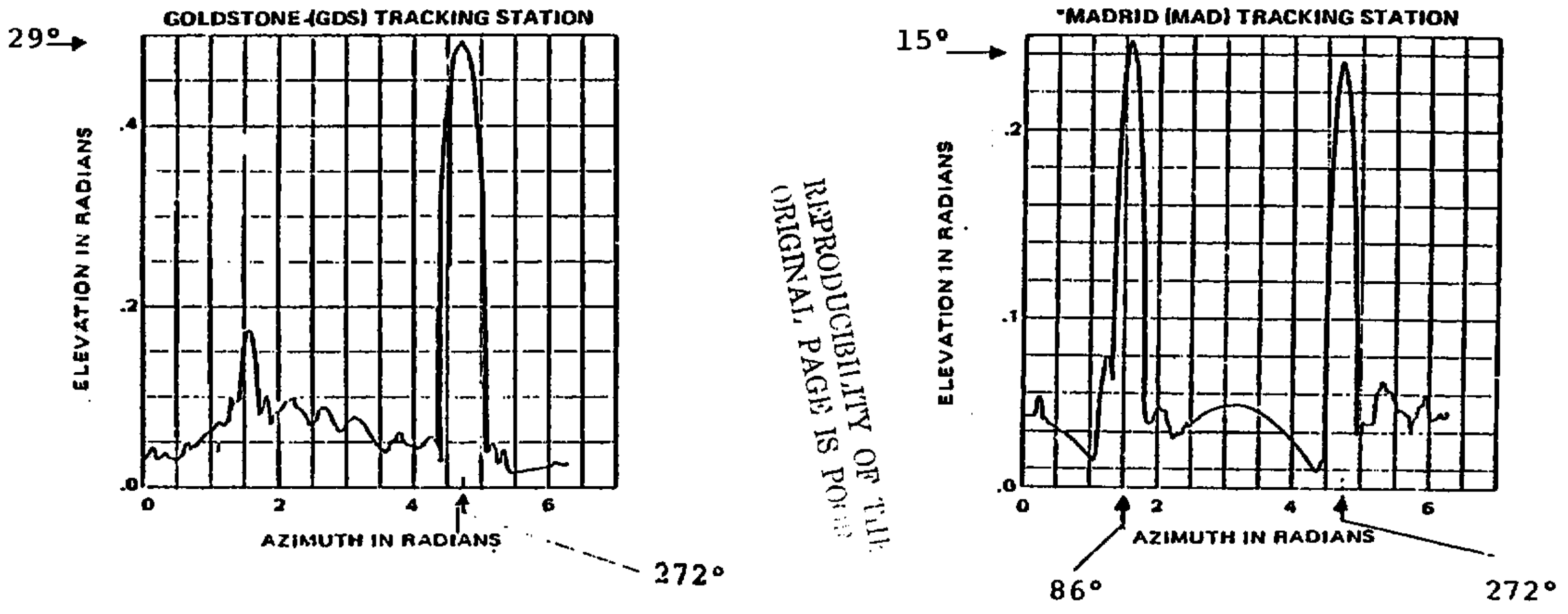


Figure 5-6

losses would occur for Madrid tracking station near azimuths of 86 degrees and 272 degrees from 0 degrees to 14.9 degrees in elevation.

The duration of losses in communication due to masking are dependent on the motion of the IUS relative to each tracking station.

Ground Effects

Low elevation angles of a target (less than 5 degrees) with respect to a ground tracking station usually results in unreliable TT&C due to various distortions of signals as they react with the ground and interfere with either incoming or outgoing wave patterns.

Cumulative Effect

A typical cumulative effect of limitations acting on the TDRSS is shown in Figure 5-7 for the Planetary Mission Profile (NASA Galileo). During this preliminary reference mission second stage ignition occurs at the outer edge of the zone of exclusion. Thus, any time delay in orbit would result in loss of TT&C through the TDRSS. In addition, this ignition is at a small grazing angle with respect to TDRS and could also result in signal attenuation. This location is also outside the ground station visibility for the STDN system. See References 18 and 19 for further discussion of Figures 5-2 through 5-7.

5.2 Third Stage Interface Analysis

Interfaces between the IUS second and third stages are in a transitory state. ECP 247 is in the final approval cycle to remove the third stage avionics so this NASA-unique interface will soon disappear. The solid rocket motor (SRM) interfaces will remain essentially the same except that the spacecraft will issue the SRM ignition command after second and third stage separation. The IUS will still issue the enabling commands which prepare SRM 3 for firing. A summary of the interface changes associated with the engineering change proposal (ECP) is listed in Table 5-2. These interfaces are still being negotiated and may change before implementation.

Analysis of the third stage interface also encompasses the evaluation of the FOM performance capabilities and the dynamic effects (with control and without control) of third stage/spacecraft spinup. Some of the spin dynamics parameters to be analyzed are:

- M, I, RCS thrust uncertainty.
- Spin rate at which active control is terminated.
- Final spin rate uncertainty.
- Second stage separation effects.

PLANETARY MISSION PROFILE (NASA GALILEO)

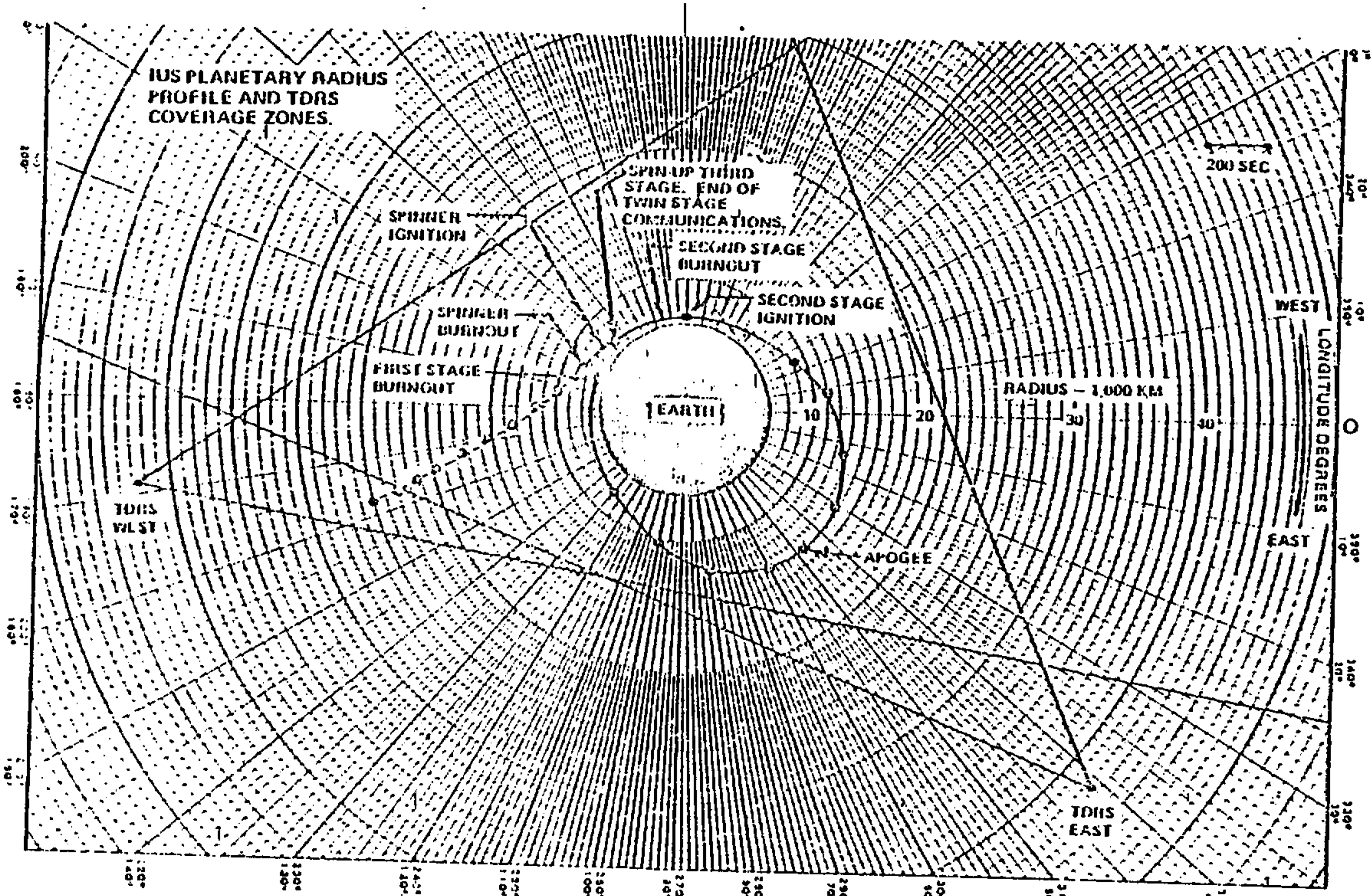


Figure 5-7

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IMPACT OF REMOVING THIRD STAGE AVIONICS

Interfaces	With Spin Stage Avionics	Without Spin Stage Avionics
IUS Twin Stage to Spin Stage	8 Spacecraft Discrete Commands	2 Spacecraft Discrete Commands
IUS Twin Stage to Spacecraft	N/A	≤ 6 Spacecraft Discrete Commands
Spacecraft to Spin Stage	S/C Measurement (for 100 bps telemetry)	*SRM Arm (4 circuits) *SRM fire (4 circuits)
Spin Stage to Spacecraft	Payload Separation (2 circuits)	*Analogs/discretes (hard-wired ignition measurements)
Spin Stage and Spacecraft Telemetry	256 bps: Spin Stage transmission	256 bps: Spacecraft transmission

*New interfaces

Table 5-2

- SRM 3 burn.
  - ISP, thrust alignment uncertainty.
  - M, I uncertainty.
- Flexibility effects.
- S/C separation effects.

These factors and other error sources contributing to the FOM performance are covered in more detail in Appendix A.

A related short study was conducted during the contract period to determine whether the IUS would accept an IUS State Vector Update command after an SRM 1 burn. Analysis by JPL and MSFC indicated that this ground update would significantly improve the FOM performance for planetary missions. The flight software analysis revealed that the IUS state vector command was inoperative after IUS deployment. Subsequently, the command was deleted from the CPDS. Boeing considers the IUS state vector update to be an improvement in FOM performance; and, therefore, they do not plan to incorporate the capabilities.

5.3 Spacecraft Interface

The changes noted in the previous section for removal of the third stage avionics are the only modifications to the spacecraft interfaces for NASA vehicles (twin and three-stage). NASA MSFC and Goddard Space Flight Center (GSFC) will be heavily involved in the IUS DOD/STS software modifications due to the requirement for continuing attitude control during deployment of the TDRS appendages. Boeing ECP ZS-0222 indicates that a new CPDS addendum will be released and modifications made to the 6DOF simulation, V&V simulation and checkout station. Analysis associated with these activities will occur during late 1979 and early 1980.

6. CONCLUSIONS AND RECOMMENDATIONS

This section presents the study conclusions from the four basic contract tasks and recommended actions to ensure successful development of the IUS software for NASA missions.

6.1 Conclusions

The primary concerns associated with the NASA-unique software development are listed below:

- NASA-unique software requirements as documented in the CPDS Addendum are incomplete.
- Preliminary and detailed design specification development for the NASA-unique software will be adversely affected by delays in requirements baselining.
- Cumulative attitude control and guidance errors may prevent the IUS from meeting the JPL FOM requirements.
- Manual certification of 20 to 30 mission data load (MDL) tapes as currently required for planetary missions will be very difficult in a short time period (i.e., a reissue shortly before launch).
- Development of the TDRS Addendum to the CPDS will be on a very tight schedule with initial requirements release only eight months prior to launch.

Two major software concerns were alleviated during the reporting period by the following actions:

1. The DOD/STS CPDS was baselined.
2. Boeing and TRW brought the sizing and timing estimates within computer capabilities.

The DOD/STS CPDS was baselined in January 1979, and placed under DOD configuration control. Delays in an acceptable baseline did, however, cause a slip in the software subsystem CDR schedule such that a delta software CDR was held May 1 through 3, 1979 (2.5 months after the IUS System CDR).

As TRW began the preliminary design of the IUS software in the fall of 1978, their estimate for software sizing and timing exceeded computer capabilities. A joint SAMSO contractor task team was formed to address the problems. The Titan software sizing estimate has now been reduced from a high of 63,500 words to 57,600 and DOD/STS software from 60,800 words to 55,200 words. With currently proposed design changes, Boeing projects a futher reduction to 53,145 for Titan and 50,995 for DOD/STS. These latest estimates do not include an allocation for NASA-unique software. However, preliminary NASA-unique requirements definitions do not indicate any significant affect on software sizing if the Boeing projections on DOD/STS software are accurate.

The current sizing estimates still remain above Boeing's reaction limits which were set to reserve a comfortable growth margin for the test phase. Traditionally, problems during test cause memory increases. Sizing must continue to be monitored as the NASA software design matures to ensure that the Boeing estimate of 50,995 words for DOD/STS is realized. Software-sizing, however, is no longer an overriding concern.

Timing estimates for the eight flight software timing slots (10 msec, 20 msec, 40 msec, 0.5 sec, 1 sec, 5 sec, 10 sec, and 200 sec) all exceeded 100 percent of the allocation for worst-case timing paths in October 1978. By March 1979 timing estimates had been reduced to a worst case of 84 percent utilization for the 10 millisecond (msec) slot. All timing slot estimates are below reaction limits. Again, the NASA-unique software specification is not included in the TRW estimates.

6.2 Recommendations

To ensure successful development of the NASA-unique software, MSFC should remain deeply involved in all phases of the software production. Involvement should follow the activities outlined in Figure 4-1 which are reiterated below:

- Requirements analysis.
- Design analysis.
- Software testing.

Specific recommendations for these activities are presented in the following paragraphs.

6.2.1 Requirements Analysis

The most urgent concern for NASA-unique IUS flight software is the development of a comprehensive set of requirements that will accomplish NASA missions. NASA-unique requirements stem from five sources:

- Guidance, Navigation, and Control (GN&C) requirements for planetary missions.
- Unique communications requirements.
- Three-stage configuration requirements.
- TDRS software requirements.

Guidance, Navigation, and Control Analysis

The IUS attitude control system must provide stable attitude control for all flight phases. For powered flight attitude control during first and second SRM burns and corresponding RCS vernier burns, the DOD IUS provisions have been accepted by NASA.

For the three-stage spinner missions, the IUS must provide the capability to spin the third stage/spacecraft up to 70 rpm for a spin-stabilized third stage burn. There are no specific requirements placed on spacecraft separation attitude. Since the three-stage spinner IUS vehicle is unique to NASA missions, the demands placed on the attitude control for spinup are NASA-unique.

Recently, the design reference mission and planetary injection accuracy requirements have been changed (see Section B.3 of Appendix B).

At present the FOM (see Reference 21) is the only requirement placed on the guidance, navigation, and control accuracies. Further analysis of the IUS capability to meet this requirement is recommended.

Boeing, for the design analyses of the coast attitude control system, has employed a digital computer simulation (Reference 22) which inludes the following:

- Simplified rigid body.
- Blow-down thrust level.
- Detailed control algorithm.

This anlaysis tool is being used for detailed spot checks of performance. This simulation does not have the capability to account for the wide range of parameters (as stated in the error sources Section B.4 of Appendix B), or to fully determine statistical injection errors that the spacecraft will be required to correct.

To determine correctly the injection errors due explicitly to the control law (and navigation implicitly), we recommend that a detailed computer simulation be developed. This simulation must include all of the attitude control error sources (see Section B.4, Appendix B), in describing the dynamics of the IUS/SC and should also incorporate the control law as proposed by Boeing. The simulation results will have the following utility:

- Evaluate Boeing's control law for spinup.
- Quantify the control software's contribution to injection errors.
- Define the inherent capability of the IUS to initialize for third stage SRM burn.

Communication Analysis

TT&C operations represent a major portion of the NASA-unique software requirements. None of the communications have been fully addressed in the CPDS NASA Addendum; however, current Boeing requirements (CPDS Addendum Revision H) specify that STDN and TDRSS cannot be used simultaneously on a single mission. During the MDL tape load, either one network or the other is loaded, but not both. By using this scheme, Boeing avoids changing the DOD/STS software. Unfortunately, this design will not provide the coverage specified in SS-STS-100 (Reference 14). The following related STDN/TDRSS requirements must also be resolved.

- Autonomous on-board selection of the communications mode (Orbiter, STDN, or TDRSS).
- Removal of failed antennas, TDRSS stations, or STDN stations as candidate communications links.
- Maintaining communications of telemetry during spinup to obtain final attitude prior to third stage ignition (prior to loss of RIMU reference).

Three-Stage Configuration Analysis

In addition to GN&C performance analysis, the third stage hardware interface requirements affect the software. Software modifications associated with ECP 247 should be tracked to ensure that SRM3 ignition sequence events are coordinated properly with the spacecraft.

TDRSS Requirements Analysis

Implementation of the DOD/STS software changes associated with the TDRSS appendage deployment will be on a tight schedule - eight months between TDRSS CPDS Addendum release in April 1980 and the launch in December 1980. During this period, the adequacy of the design must be verified with all analytical tools (6DOF simulator, V&V simulator, checkout stations, etc.).

Ideally, the software design for the TDRSS would not only provide IUS support for TDRSS, but, also, provide a flexible control process that will support other mission-unique spacecraft operations for DOD two-stage and NASA twin-stage vehicle configurations. Analysis of the requirements and design should attempt to remove unnecessarily restrictive specifications.

6.2.2 Design Analysis

Analysis of the NASA-unique software preliminary design is dependent upon developing a concise requirements document. For this reason, the software design presented at the NASA CDR will be adversely affected by the parallel requirements development shown in the schedule in Figure 6-1. Since the requirements will not be completely certified until after CDR, the design presented at CDR

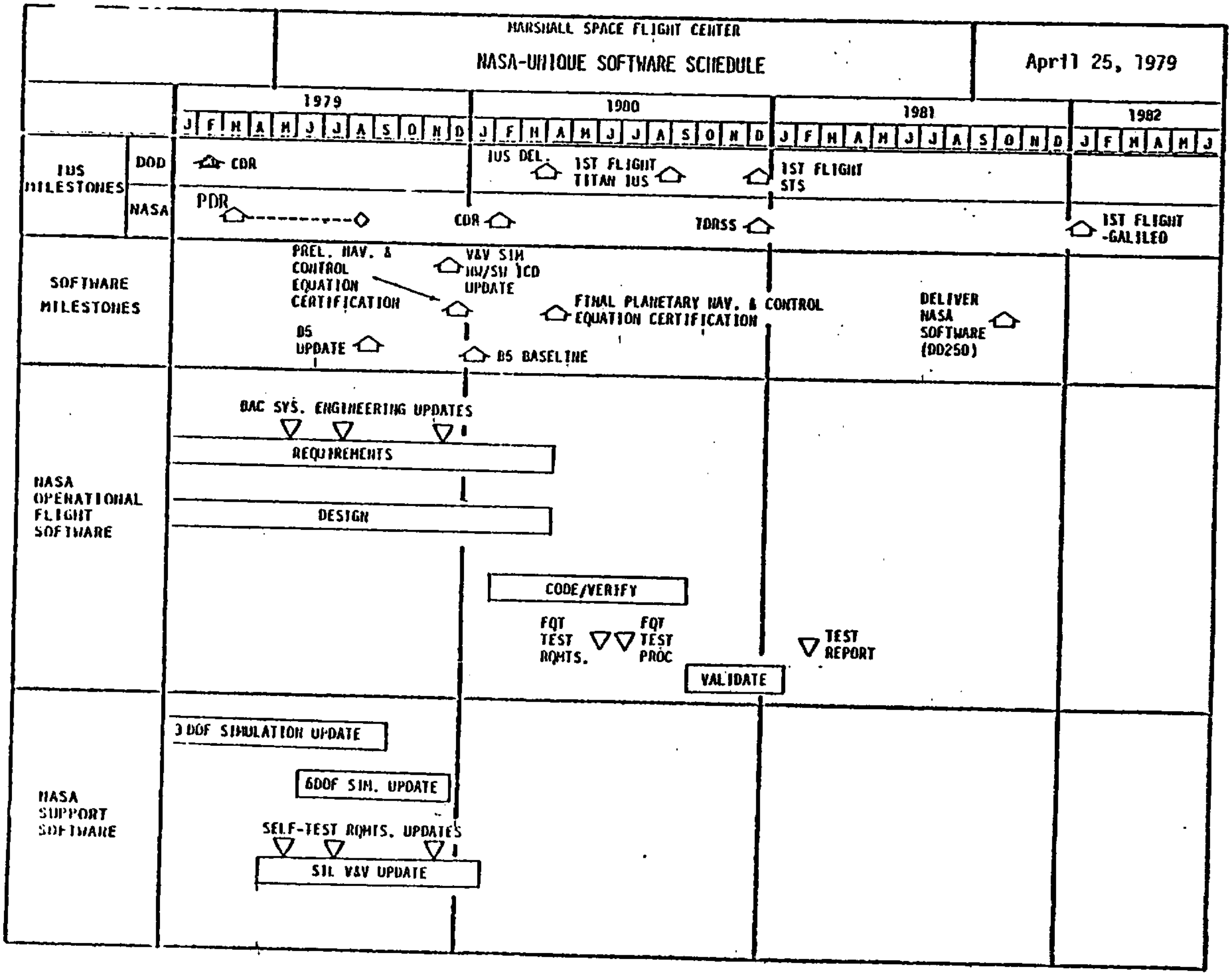
MARSHALL SPACE FLIGHT CENTER
NASA-UNIQUE SOFTWARE SCHEDULE
April 25, 1979
1979
1980
1981
1982
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J
IUS MILESTONES
DOD
NASA
CDR
IUS DEL.
1ST FLIGHT TITAN IUS
1ST FLIGHT STS
PDR
CDR
TDRSS
1ST FLIGHT -GALILEO
SOFTWARE MILESTONES
PREL. NAV. & CONTROL EQUATION CERTIFICATION
V&V SIM HW/SW ICD UPDATE
FINAL PLANETARY NAV. & CONTROL EQUATION CERTIFICATION
DELIVER NASA SOFTWARE (DD250)
B5 UPDATE
B5 BASELINE
NASA OPERATIONAL FLIGHT SOFTWARE
BAC SYS. ENGINEERING UPDATES
REQUIREMENTS
DESIGN
CODE/VERIFY
FQT TEST RQMTS.
FQT TEST PROC
TEST REPORT
VALIDATE
NASA SUPPORT SOFTWARE
3 DOF SIMULATION UPDATE
6DOF SIM. UPDATE
SELF-TEST RQMTS. UPDATES
SIL V&V UPDATE

Figure 6-1

must be considered incomplete. A similar situation during DOD/STS software development has resulted in a delta software CDR slipped until two months after the sytem CDR. An update of the CPPS after completing planetary equation certification in April of 1980 could easily slip the NASA software CDR until June of 1980. MSFC needs a detailed software development schedule from Boeing that indicates its planning to meet the PDR, CDR, and delivery milestones.

6.2.3 Software Testing

Verification and Validation (V&V) of the IUS flight software for NASA missions should be directed by NASA. Design analysis tasks should be performed by NASA to identify not only that the CPDS and the CPPS meet NASA mission requirements, but also that Boeing tests thoroughly verify the basic DOD/STS software package. Independent software testing will be performed against test requirements developed by NASA which specify the types of software tests needed and the success criteria for each requirement. Since NASA has no IUS software development facility, the tests will be performed on a DOD facility - either the Boeing Company facility or the Martin Marietta facility. These independent tests of the NASA-unique software should attempt to avoid direct duplication of Boeing validation tests. This independent test effort will attempt to supplement, not duplicate, Boeing testing.

MDL tapes released for NASA TDRSS or planetary missions must be certified before flight. This certification could become a problem for final changes close to a launch date. With 20 to 30 MDL tapes per mission, certification will become a time-consuming process. Therefore, we recommend developing an MDL tape certification program at MSFC to automatically provide the following capabilities:

- Limit comparison tests.
- Tape sum check.
- Validation of day-to-day retargeting (from one tape to the next).
- File builder to provide data parameters for a 6DOF simulation test of the mission.
- Plot routine to display the daily launch variations.

This program will provide a quick assurance that the MDL tape updates are accurate.

7. REFERENCES

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APPENDIX A

M&S COMPUTING MEMORANDA
FOR THE IUS CONTRACT

M&S COMPUTING MEMORANDA FOR THE IUS CONTRACT

Memo No.	Title	Date
IUS-78-013	Monthly Progress Report for May 1978	June 8, 1978
IUS-78-014	IUS Software Working Group Meeting, June 5, 1978	June 7, 1978
IUS-78-015	NASA Unique IUS Flight Software Requirements	June 20, 1978
IUS-78-016	Evaluation of the IUS Computer Program Development Plan Revision A dated February 28, 1978	June 23, 1978
IUS-78-017	IUS File Subject: Proposed Changes to SS-STS-100, Volumes 3 and 3-1	June 28, 1978
IUS-78-018	Monthly Progress Report for June 1978, Contract No. NAS8-33072	July 10, 1978
IUS-78-019	Evaluation of IUS Support Software Requirements	July 11, 1978
IUS-78-020	IUS Software Development Schedules	July 21, 1978
IUS-78-021	Software Impact on Planetary Mission Accuracy	July 31, 1978
IUS-78-022	Monthly Progress Report for July 1978, Contract NAS8-33072	August 8, 1978
IUS-78-023	Evaluation of the Redundancy Management Requirements for Inertial Upper Stage (D290-10086-1, Revision B)	August 8, 1978
IUS-78-024	Evaluation of the Interpretive Computer Simulators (ICS) CPDS, CPCI No. ICS 0001.	August 25, 1978
IUS-78-025	Trip Report - IUS Baseline Design Review No. 4 and Guidance Technical Interchange	August 29, 1978
IUS-78-026	Monthly Progress Report for August 1978, Contract NAS8-33072	September 8, 1978
IUS-78-027	Evaluation of the NASA Addenda to the Prime Item Development Specification (PIDS) for DOD Two-Stage Vehicle Inertial Upper Stage, S290-70001.	September 14, 1978

Memo No.	Title	Date
IUS-78-028	September Update of the IUS Software Development Schedules	September 14, 1978
IUS-78-029	Evaluation of the IUS CPDS NASA Addendum S290-51002, July 28, 1978	September 26, 1978
IUS-78-030	Gamma Guidance Trajectory Dependence on Initial Guess for SRM Steering Angles	September 29, 1978
IUS-78-031	Monthly Program Report for September 1978, Contract NAS8-33072	October 10, 1978
IUS-78-032	Trip Report for the IUS Software Computer Product Specification (C5) Technical Interchange Meeting, October 10-11, 1978	October 17, 1978
IUS-78-033	Evaluation of the IUS Computer Program Procurement Specification S-290-51003, dated September 15, 1978	October 25, 1978
IUS-78-034	Evaluation of the IUS Computer Resource Integrated Support Plan (CRISP), D290-10151-1, September 28, 1978 (Draft)	November 6, 1978
IUS-78-035	Monthly Progress Report for October 1978, Contract No. NAS8-33072	November 9, 1978
IUS-78-036	November Update of the IUS Software Development Schedules	November 16, 1978
IUS-78-037	IUS Spin Stage Equations of Motion	November 20, 1978
IUS-78-038	Trip Report for the IUS Software MOS Postprocessing PDR and OFS C5 Specification Technical Interchange Meeting - November 29-30, 1978	December 11, 1978
IUS-78-039	VOID	
IUS-78-040	Monthly Progress Report for November 1978, Contract No. NAS8-33072	December 8, 1978
IUS-78-041	IUS Technical Project Review (TPR) Software Splinter Session	December 13, 1978

Memo No.	Title	Date
IUS-78-042	Gamma Guidance Trajectory Dependence on Initial Guess for SRM Steering Angles (Galileo Mission)	December 21, 1978
IUS-78-043	Explicit Definition of the NASA-Unique Requirements	December 27, 1978
IUS-79-001	Monthly Progress Report for December 1978, Contract No. NAS8-33072	January 10, 1979
IUS-79-002	Evaluation of the IUS Software Computer Program Product Specification (C5), December 29, 1978, Release	January 31, 1979
IUS-79-003	Monthly Progress Report for January 1979, Contract No. NAS8-33072	February 8, 1979
IUS-79-004	Trip Report - Software Working Group Meeting and MOS Data Formatting PDR, January 31 and February 1, 1979	February 13, 1979
IUS-79-005	Evaluation of Boeing Response to NASA V&V Simulation CDR RID'S	February 28, 1979
IUS-79-006	Trip Report - Guidance Subsystem CDR, February 21, 1979	February 26, 1979
IUS-79-007	Monthly Progress Report for February 1979, Contract No. NAS8-33072	March 9, 1979
IUS-79-008	Software Problem Reports for the NASA B5 Addendum, S290-51002	March 21, 1979
IUS-79-009	Update of the IUS Software Development Schedules	March 19, 1979
IUS-79-010	Evaluation of the Boeing Software Development Schedule for NASA	March 30, 1979
IUS-79-011	Monthly Progress Report for March 1979, Contract No. NAS8-33072	April 9, 1979
IUS-79-012	Contract NAS8-33072, Final Report (Draft)	May 2, 1979
IUS-79-013	Monthly Progress Report for April 1979, Contract No. NAS8-33072	May 10, 1979
IUS-79-014	Monthly Progress Report for May 1979, Contract No. 33072	June 11, 1979

APPENDIX B

GUIDANCE, NAVIGATION, AND CONTROL (GN&C)

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B.1 GN&C Software Implementation for Three-stage NASA Missions

The baseline guidance scheme for IUS is Boeing's Gamma Guidance. This scheme solves the guidance problem for performing orbit transfers with a space vehicle having a fixed velocity impulse Solid Rocket Motor (SRM). Gamma Guidance permits onboard targeting, orbital maneuvers, and interplanetary injection. This scheme is based on matching the required set of velocity impulses with the impulses available from the IUS.

The transfer orbit is subdivided, from a guidance standpoint, into a series of arcs and phases. Arcs define all the potential coast and powered-flight sectors. Each flight phase identifies a portion of the transfer orbit where the guidance philosophy is constant. A phase comprises a pair of coast/powered flight arcs. Figure B.1-1 shows how the vehicle configuration, guidance phase, and guidance, navigation and control (GN&C) software activities for a three-stage NASA mission vary with time. The arcs/phases and different guidance modes are shown in Figure B.1-2. Phase 5 in Figures B.1-1 and B.1-2 shows the third stage, which will be spun up for stability by the IUS Reaction Control System (RCS) prior to SRM_3 ignition. For this phase, Gamma Guidance will provide phase initialization, midcourse guidance, and preignition, but will not provide the closed loop guidance mode. Figure B.1-3 shows the events associated with the third stage.

The operational flight software controls the IUS in achieving the placement of an attached payload into a desired orbit, following deployment from the orbiter. Software functions provide calculation and control capability for the following operations: mission sequencing, guidance, attitude control, communications, redundancy management, checkout, and navigation. Here, attention will be restricted to the part of the software which consists of guidance, attitude control, and navigation.

The purpose of the guidance function is to command orientation of the thrust vector and to command the SRM/RCS ignition times required to change the current vehicle state to an injection state that satisfies the mission requirements. The guidance is active during both coast and powered flight modes. In the coast mode, guidance command changes result from attitude control maneuvers and environmental perturbations. During powered flight, the changes arise from off-nominal propulsion system performance and hardware anomalies.

Attitude control software provides commands to the reaction control system and thrust vector control (TVC) actuators to achieve and maintain various vehicle attitudes during the IUS mission. Control will be provided during powered flight as well as during mission coast phases. During powered flight, attitude control software provides pitch and yaw commands to thrust vector control actuators and roll commands to the RCS to maintain IUS attitude in an orientation defined by guidance software. During coast phases, attitude control software provides roll, pitch, and yaw commands to the RCS to accomplish required attitude reorientations, thermal, and other attitude maneuvers required to maintain defined inertial attitudes.

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GUIDANCE NAVIGATION AND CONTROL SOFTWARE ACTIVITIES

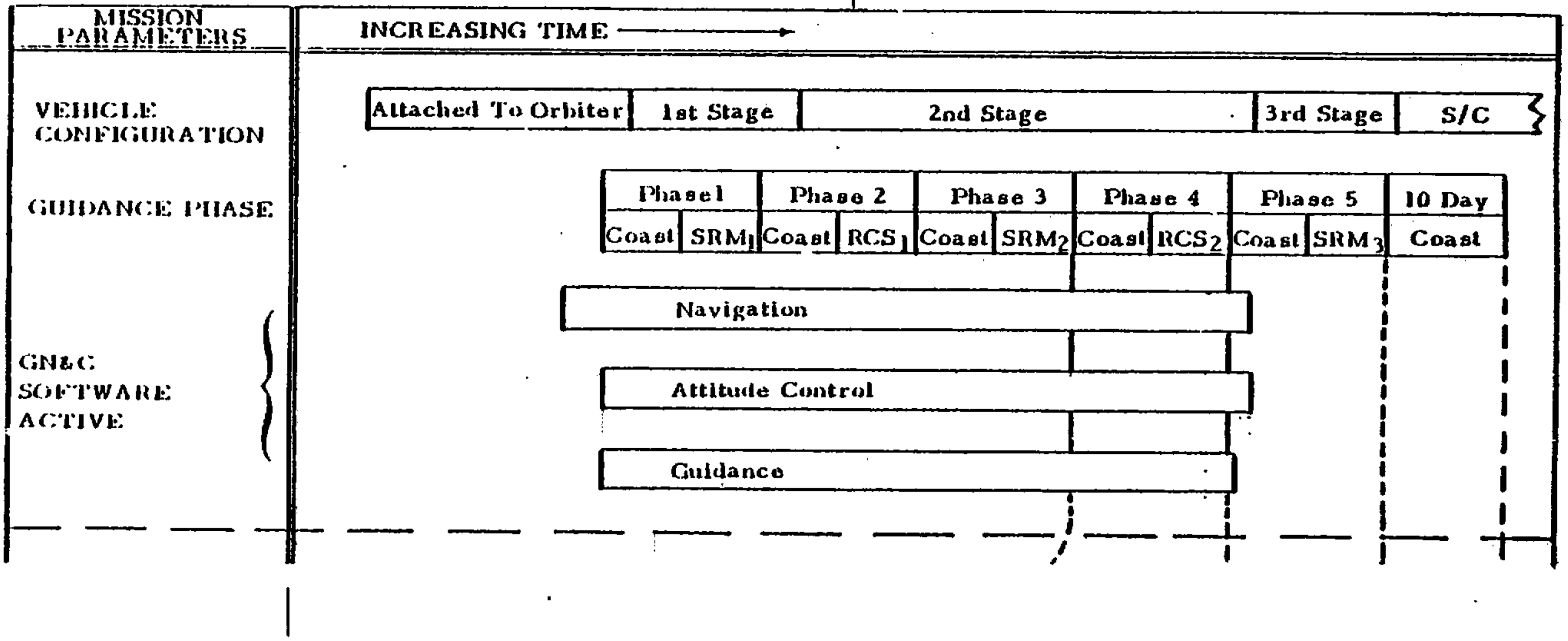


Figure B-1.1

GAMMA GUIDANCE ARCS AND PHASES

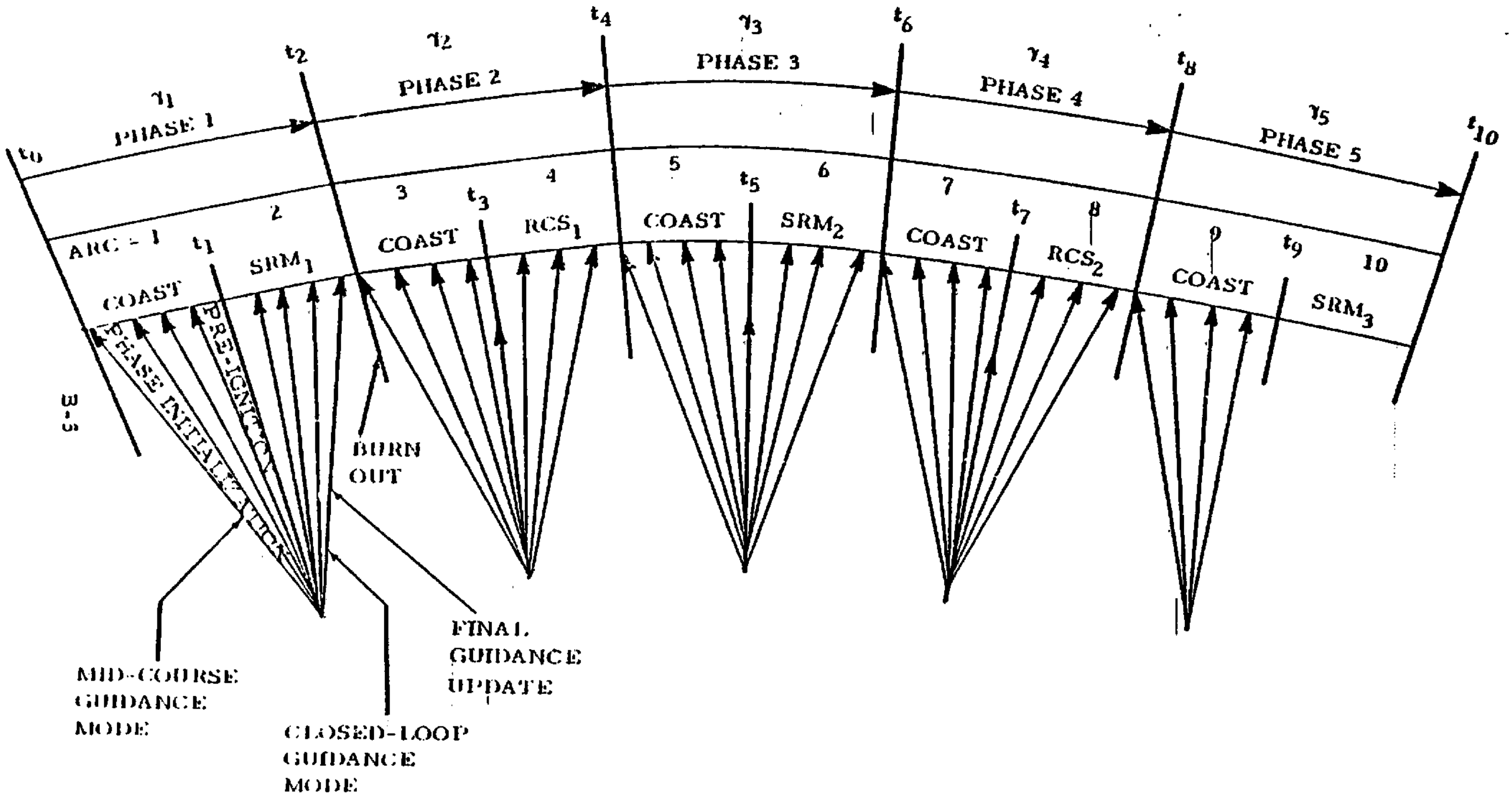


Figure B-1.2

THIRD STAGE OPERATIONS

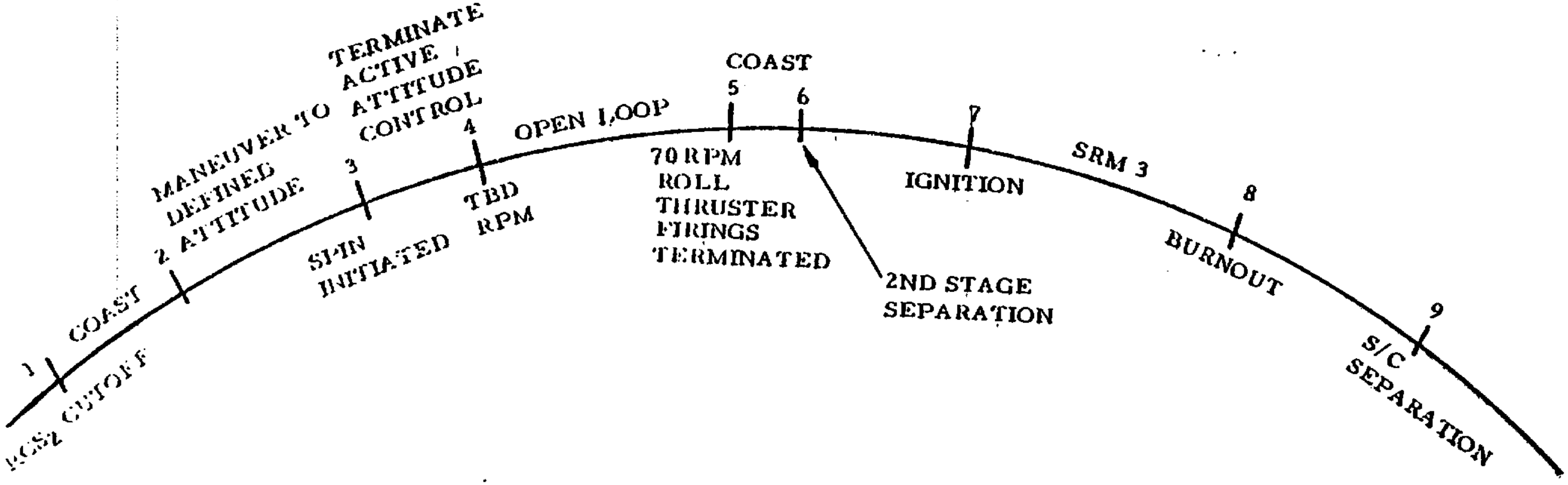


Figure B:1-3

The purpose of the navigation software is to provide current values of IUS position, velocity, and attitude with respect to inertial space, given raw Inertial Measurement Unit (IMU) accelerations and attitude rates as input. This software employs two modes of operation, alignment mode and space navigation mode. Alignment mode is entered and exited on command prior to flight. Certain functions are sequenced to effect mathematical alignment of the attitude quaternion. Position and velocity are maintained by direct computation. When in the space navigation mode, attitude reference is maintained by solution of a quaternion differential equation. Position and velocity are maintained by integration of acceleration and velocity.

The above description of the guidance, attitude control, and navigation software is generic in nature, i.e., applicable to both the DOD and NASA. The NASA three-stage missions introduce several areas of uniqueness. The guidance software, which uses a gamma guidance algorithm, has several more control variables for the three-stage missions. Unlike two-stage missions, the guidance computations terminate prior to the initiation of the spinup (point 3 of Figure B.1-3). The guidance software is inactive beyond that point as shown in Figure B.1-1. The attitude control software also has NASA-unique requirements. The three-stage missions call for spinning the entire second stage/third stage/spacecraft configuration using the IUS RCS (second stage). However, the attitude control software activities cease prior to the termination of the spinup phase (point 4 of Figure B.1-3). There are no NASA-unique requirements for the navigation software. The only impact on this software arises from the longer duration of the planetary missions. This software becomes inactive during the spinup phase (point 4 of Figure B.1-3).

B.2 Potential Numerical Instability in the Gamma Guidance Iteration

In Reference 1, concerns regarding the potential numerical instability in the Gamma Guidance iteration scheme were expressed. M&S Computing conducted a study to examine the Gamma Guidance convergence criteria by exercising Boeing's Gamma Guidance Analysis Program. The preliminary investigation was limited to examining the effect of deviations in the initial guesses of the control steering angles with respect to a Boeing-supplied solution. Two missions were examined: (1) a two-stage Geosynchronous Mission, (2) a three-stage Galileo Mission. The results of the study were reported in References 23 and 24. The study procedure, results and conclusion for a Galileo Mission are given below.

A reference trajectory (refer to Table B.2-1) was generated by exercising the Boeing Gamma Guidance Analysis Program for a three-stage Galileo Mission (Reference 23) utilizing MSFC-supplied guidance parameters that include values for all control variable initial guesses. These parameters yielded a trajectory with a C_3 of 65000 $(Km/sec)^2$ at final insertion from an earth parking orbit of 100 by 350 nautical miles.

The guidance prediction uses the steering angles α and β (Table B.2-2) to determine the direction of the impulse vectors for SRM_1, SRM_2, and SRM_3 burns. The initial guesses of these angles were varied for each different simulation run while all other MSFC-supplied parameters were unchanged. Resulting trajectories were compared with the reference trajectory based upon a nominal performance vehicle.

For purposes of study, a single nonconverging Gamma Guidance Analysis Program simulation is compared with the reference trajectory. Table B.2-2 describes the variation in initial guesses with respect to the nominal guesses that resulted in a nonconverging trajectory. Figure B.2-1 is a comparison of the reference trajectory with the nonconverging trajectory. The number of guidance iterations per computation cycle shows a maximum number of eight for the perturbed case. The lower left-hand table describes the converged values for the constraint differences at the start of the SRM3 burn and the large values of the nonconverged perturbed case which resulted in a very low final C_3 value. The final C_3 value is given in the lower right-hand table.

The nonconvergence of the perturbed case indicates potential similar nonconvergence in the flight computations. It is pointed out here that the engineering simulation exercised for this study does not duplicate the update intervals required by the operational flight software. Future studies should incorporate realistic computation frequencies of once every 200 seconds during coast arcs and once every 5 seconds during powered arcs. This incorporation of realistic computation frequencies may improve the guidance convergence.

NOMINAL MISSION
PL-13A

DEPLOYMENT POINT ($\underline{X}_0$) AND TERMINAL POINT ($\underline{X}_F$) ARE EXPRESSED IN TERMS OF ORBITAL ELEMENTS

	$\underline{X}_0$	$\underline{X}_F$
a [FT] SEMI-MAJOR AXIS	22,294,840.	-20,119,240.
e [ND] ECCENTRICITY	.03487656	2.081845
i [°] INCLINATION	28.41414	28.29862
ω [°] ARGUMENT OF PERIGEE	68.70946	69.75375
Ω [°] INERTIAL LONG OF ASCENDING NODE	-90.36991	-91.98525
θ [°] TRUE ANOMOLY	-3.764526	104.2503

MISSION CONSTRAINTS

$C_3 = 65 \text{ KM}^2/\text{S}^2$

$= 6.993 \times 10^9 \text{ FT}^2/\text{S}^2$

HOUR ANGLE = 95.43°

DEC = -4.00°

Table B.2-1

VARIATION IN INITIAL GUESSES

	SRM1		SRM2		SRM3	
	α	β	α	β	α	β
MSFC NOMINAL	67.9	10.1	65.7	11.6	75.3	4.7
PERTURBED	63.9	6.1	69.7	15.6	71.3	.7

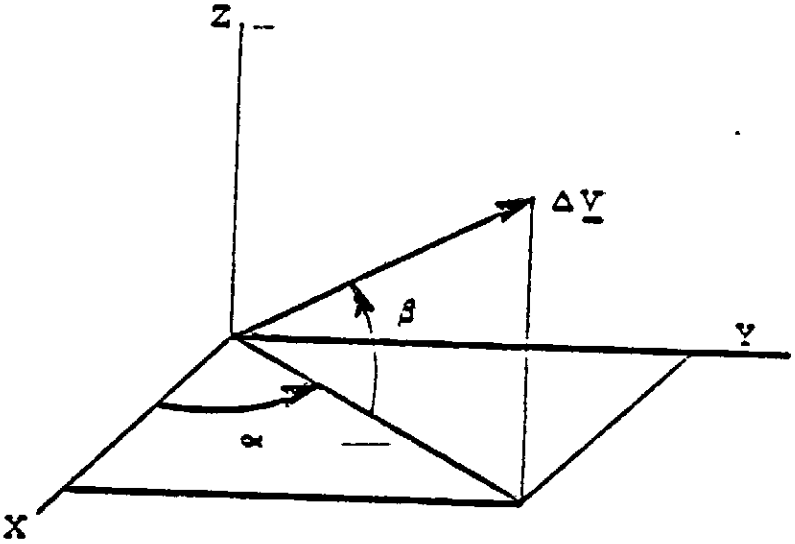
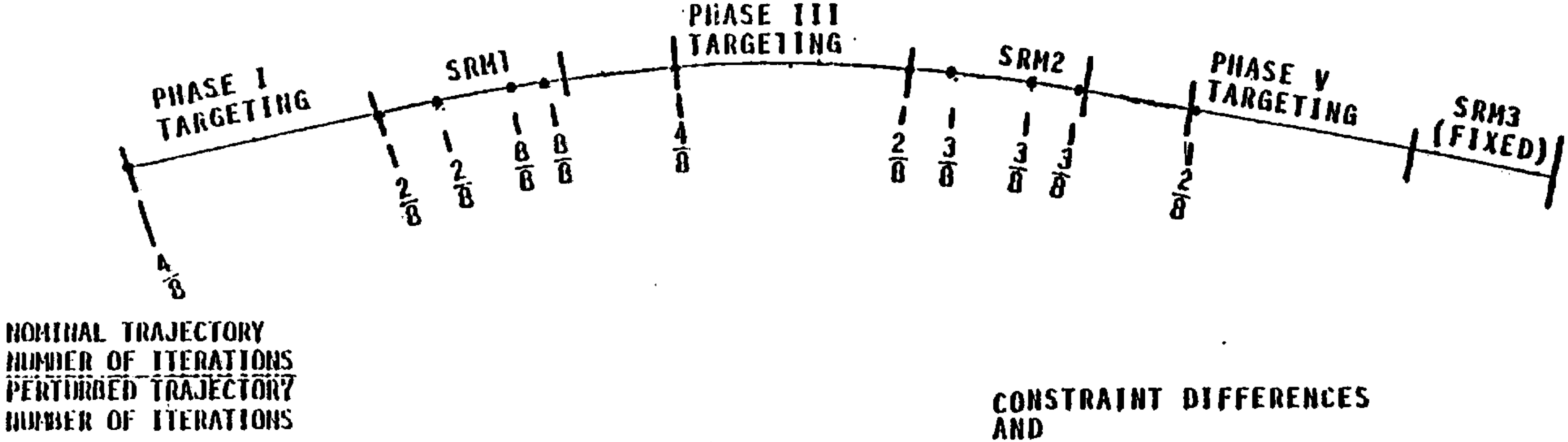


Table 3.2-2

NUMBER OF ITERATIONS NOMINAL VS 4° PERTURBED CASE

(-4°, +4°, -4°)



CONSTRAINT DIFFERENCES
AT START OF SRM3 BURN

	NOMINAL	PERTURBED
ΔC3*S1	7.	425,869.
ΔC3*S2	132.	553,273.
ΔC3*S3	-56.	271,747.

CONSTRAINT DIFFERENCES
AND
SPECIFIC ENERGY
AT END OF SRM3 BURN $[FT/SEC]^2$

	NOMINAL	PERTURBED
C3	.6996 09	.6991 09
ΔC3*S1	53500.	378000.
ΔC3*S2	-1400.	560400.
ΔC3*S3	203140.	588000.

Figure B.2-1

In addition, error models should be incorporated in the guidance scheme to simulate the effects of (1) anomalies resulting from integrating the guidance gravity model during coast arcs, (2) IMU errors propagated during coast arcs, (3) off-nominal engine performance during powered arcs, and (4) IMU errors propagated during powered arcs.

B.3 Reference Missions and Performance Requirements

The current Inertial Upper Stage (IUS) System Specification (SS-STS-100, dated March 17, 1978) covers the following NASA Design Reference Missions:

- Jupiter Orbiter Probe '82.
- Mars '84
- Saturn - Uranus Probe '85

For these NASA planetary missions, the guidance and navigation accuracies are specified by the following paragraph in the system specification:

> 3.2.1.2 IUS Planetary Injection Accuracy. The IUS planetary and non-synchronous mission injection accuracies shall be determined utilizing the IUS inherent capabilities required to meet the synchronous equatorial accuracy requirements of 3.2.1.2 of SS-STS-100 Volume 3 and the spin rate requirements of 3.6.1.5. The computational procedures for determining the spacecraft delta variance shall be in accordance with JPL document "Determination of IUS Planetary Injection Accuracy" dated October 1977.

The design reference missions and the planetary injection accuracy requirements have been changed recently (by ECP 247). The current design reference missions are:

- Galileo (GLL) '82
- International Solar Polar Mission (ISPM) '83
- Venus Orbiting Imaging Radar (VOIR) '83

The mass and injection energy requirements have also been changed, to be consistent with these new missions. The paragraph (3.2.1.2) specifying the planetary injection accuracies has been deleted and replaced with the following:

> Injection accuracies required for Deep Space Missions are shown in Table B.3-1. For the purpose of evaluating planetary injection accuracies, the figure of merit (FOM) is to be calculated as follows:

$$A_V = A\,A_{INJ}\,A^T$$

where; A_V is the midcourse velocity correction covariance matrix (3 x 3).

NASA DESIGN REFERENCE MISSIONS

REF MISSION (1)	S/C MASS KG(2)	C_3 KM^2/S^2	INJECTION ACCURACY FOM(5) M/S	C.G. M(3)	ASE MASS KG(4)
PL-13A GALILEO	2060 (6)	65	30	1.21	300
SO-09A ISPM	885 (6)	115	35	1.5	300
PL-07A VOIR	5700 (6)	7	5	2.5	100

(1) ALL MISSIONS FROM ORBITER PARK ORBIT = 150 N. MI.
(2) S/C MASS INCLUDES ADAPTER AND ATTACH. HARDWARE.
(3) C.G. LOCATION IS MEASURED FROM S/C-IUS INTERFACE PLANE.
(4) ASE MASS INCLUDES CABLING AND RTG COOLING EQUIPMENT.
(5) FOM = STATISTICAL MEASURE OF THE VELOCITY REQUIREMENTS AT [-1-]0 DAYS TO REMOVE L/V INJECTION ERRORS.
(6) S/C MASS REQUIREMENT PRESUMES ASSOCIATED INJECTION ACCURACY.

Table B.3-1

A_{INJ} is the IUS injection covariance matrix (6 x 6) provided by BAC.

A is the matrix of trajectory sensitivities (3 x 6) provided by JPL.

A^T is the A matrix transposed.

FOM is the square root of the sum of the diagonal elements of A_V.

The above specified FOM is a statistical measure of the velocity requirements (spacecraft ΔV) at midcourse to remove IUS injection errors. Six error components of the injection state are mapped to the single constraining mission parameter, midcourse ΔV magnitude. No specific requirements are placed on the individual components of the injection state (i.e., local position and velocity are not specifically constrained). Therefore, to determine acceptability of any IUS injection state, an FOM computation (a function of all six components of the injection state) is required.

The computational scheme for FOM involves a matrix A_{INJ}. This matrix is the covariance matrix of the IUS injection state error. The generation of this matrix requires analyses of all sources which contribute to the error in the terminal state.

B.4 Identification of Error Sources and Analysis Required

The accuracy requirements for the planetary missions are expressed in terms of FOM. A brief description of FOM is given below. Most planetary missions are targeted utilizing the so-called aiming plane defined by the R, S, T encounter planet coordinate system. S is parallel to the incoming asymptote of the spacecraft's orbit, T is defined to be parallel to the ecliptic and orthogonal to S. R lies in the southern celestial hemisphere and completes the orthogonal right-handed system. A convenient method for describing the spatial miss at target in this system is to consider where the spacecraft would penetrate the R-T plane for a massless planet. The distance from the target planet center to this point is referred to as the impact parameter B. B in turn is characterized by B·T, and B·R. Frequently, the deviation of the flight time from the nominal is desired, and is readily expressed in this coordinate system by knowledge of the spatial miss in the S direction and the approach velocity (i.e., $\partial S = V_\infty \partial t_F$). For high-energy planetary missions with long flight times, simple velocity corrections applied early in the mission will produce large changes at encounter. This fact merits mapping injection errors to encounter and then determining the early maneuver (nominally ten days post launch) required to null the effects of these errors. The FOM is a measure of the cost of maneuver required to null injection errors mapped to encounter rather than to maneuver time (midcourse correction time).

Whether IUS injection accuracy is expressed in terms of FOM or IUS inherent capabilities, they both reflect the injection state errors. The FOM computations or quantitative measures of the IUS inherent capabilities require identification and analysis of the sources which contribute to the error in the injection state. Listed below are the probable error sources:

- Navigation.
    - IMU hardware.
    - Computational effects from navigation equations.
- Guidance.
    - Software errors representing off-nominal performance.
        - Guidance constants.
        - Quantization on cut-off prediction.
        - Targeting errors due to approximation in guidance equation.

- Attitude control.
  - Transport delays.
  - Dead zones.
  - Dynamic cross-coupling.
- Third-stage spin dynamics.
  - Mass uncertainty.
  - Inertia uncertainty.
  - RCS thrust imbalance.
  - Spin rate at which active control is terminated.
  - Final spin rate uncertainty.
  - Flexibility effects.
- Second stage separation.
- SRM_3 burn.
  - I_{sp} tolerance.
  - Thrust misalignment.
  - Center of mass uncertainty.
  - Rate of change of moments of inertia.
- Third stage separation.

Figure B.4-1 shows the software impact on planetary mission accuracy. NASA-unique software testing is required for guidance, navigation, and control tasks. A large portion of the third stage is uncontrolled and software ceases to function (as shown in Figure B.4-1) several minutes prior to injection. For software testing, the point showing software injection in Figure B.4-1 should be well-defined. To this end, an analysis of the third-stage dynamics becomes essential.

A preliminary analysis of the performance (of system and/or software) could be accomplished by accounting for only the errors encountered due to:

- Initial IUS state dispersion (at deployment).
- IMU hardware.
- Third stage dynamics and SRM_3 burn.

An analysis of these errors will help define the test requirements for the software when superimposed on the nominal performance.

SOFTWARE IMPACT ON PLANETARY MISSION ACCURACY

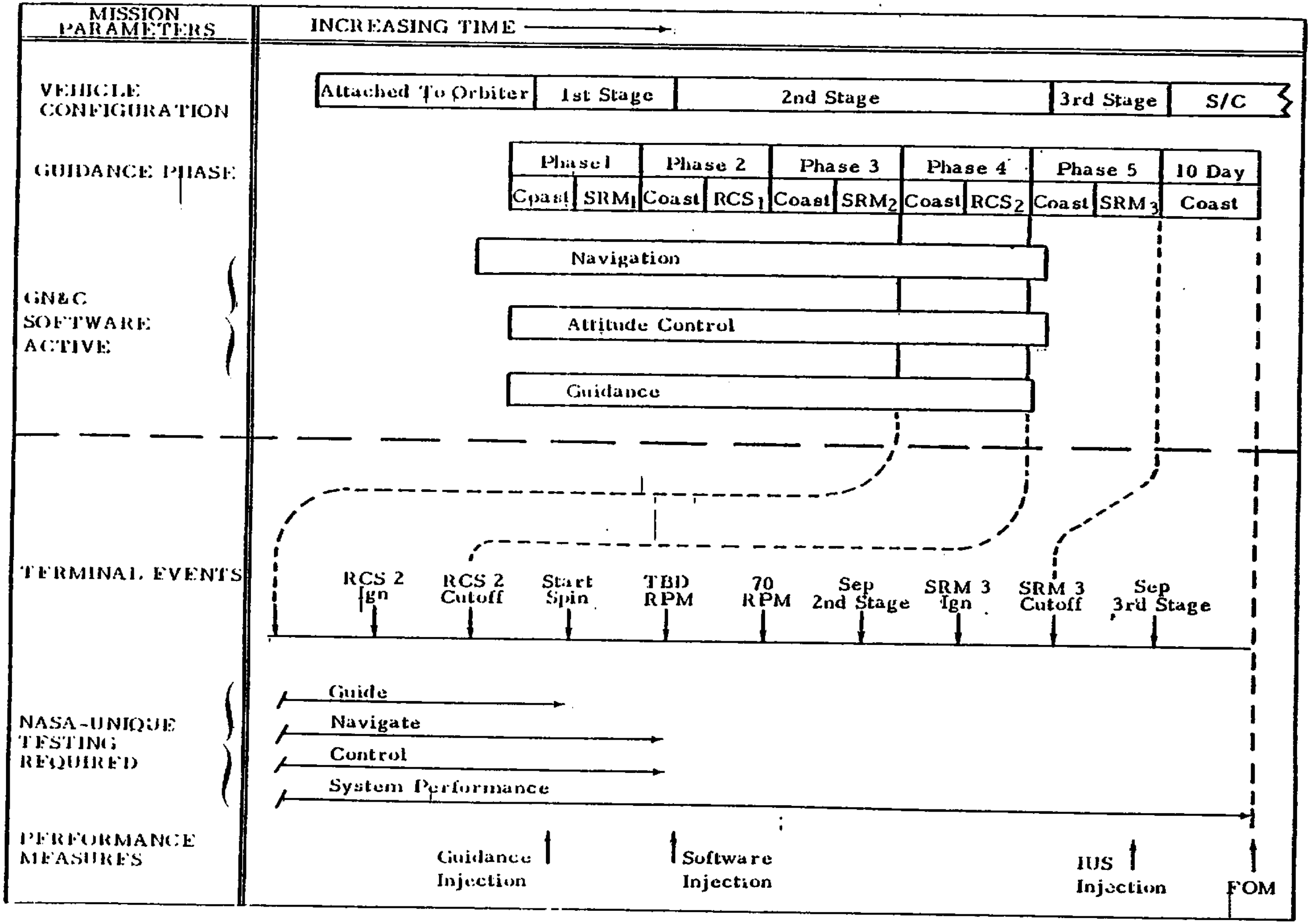


Figure B.4-1

B.5 Analysis Tools

The analysis of the third-stage dynamics is of utmost importance at this time. This analysis should include the period beginning just prior to the start of the spin and ending with spacecraft separation (Figure B.1-3, terminal events). The mathematical model must have the inherent capability to implement the actual control shemes that are proposed as the design evolves. The simulation of the mathematical model can be subdivided into three segments:

- Thrusters firing with active control and thrusters firing without active control.
- Stage separations.
- SRM_3 burn.

An ideal third-stage dynamics model should represent "general motion of a spinning body with varying configuration and mass." This will describe a body under translation and rotation, with relative motion leading to varying configuration, undergoing changes in mass with time.

There are two operational computer programs which can be used for preliminary analysis: SAMBO and the Boeing Gamma-Guidance simulation. SAMBO utilizes linear programming (Simplex Algorithm) to determine quasi optimum exoatmospheric trajectory for multistage rockets in the earth's gravity field. This algorithm allows three degrees-of-freedom (Newton's equations of motion) for the vehicle. SAMBO can provide an initial reference trajectory that achieves the missions planetary injection constraints. The third-stage trajectory can also be ideally generated by SAMBO. However, it should be noted that these reference trajectories generated by SAMBO are based upon optimization of certain cost functions. Thus, the validity of SAMBO-generated reference trajectories are dependent on the choice of the cost functions.

The Boeing Gamma Guidance Simulation makes use of a state space formulation to solve a two-point boundary value problem for the set of nonlinear ordinary differential equations that describe the IUS trajectory. The algorithm is an explicit guidance scheme that generates thrust steering angles for both SRM and RCS based on the knowledge of the current state and the desired mission orbit conditions. Gamma Guidance solves for combinations of SRM and RCS control variables (steering angles and ignition times) depending on the stage of the trajectory to which the IUS has progressed. The simulation requires an initial guess of the control variables. Different constraint solutions exist for different control variable initial guesses. The initial values of the control variables could be obtained from SAMBO-generated trajectories for preliminary analysis.

Boeing's reference trajectories (nominal trajectories) and trajectory generator computer program will be essential for analysis and software testing.

APPENDIX C

PLANNING DOCUMENTATION AND SUPPORT SOFTWARE ANALYSIS

PLANNING DOCUMENTATION AND SUPPORT SOFTWARE ANALYSIS

As ancillary tasks to the flight software analysis, M&S Computing evaluated IUS software planning documentation and the support software development documentation. The technical planning effort included maintenance of a set of software schedules.

C.1 Software Technical Planning Analysis

The most current IUS software development plan (Reference 25) does not adequately reflect the phased approach to IUS software development where the Titan, DOD/STS, and NASA versions are developed sequentially instead of simultaneously. Schedule and configuration management impacts of phased development were not specified for any flight or support software package.

Recommendations for the plan (see Reference 26) emphasized the importance of customer insight into software through formal detailed schedules and a well-defined configuration control plan. These recommendations were never implemented because the Air Force decided that the development plan was needed only for preliminary planning purposes and allowed the document to lapse. As a result, the software development schedules are not formally released, and the top level schedules are only updated for major reviews. The last release of the IUS Program Milestones Document (D290-10052-11) is dated January 17, 1979. During a critical phase when the software development program is switching emphasis from DOD/STS to Titan, a set of formally controlled schedules should be made available for review and information. In order to plan for manpower loads and schedules, NASA should have a set of detailed schedules depicting the flight and support software development and facility utilization.

Another deficiency in the development plan was the lack of explicit configuration control planning. Boeing and TRW subsequently identified their basic configuration management practices in technical presentations and in the test documentation: IUS Software Test Plan (BAC) and verification test plan (TRW). These documents cover the internal contractor configuration management practices very well, but they do not adequately address the formal control process required once the government takes control of a baselined document or delivered software package.

To provide management information in the MSFC Software Projects Schedules and Status Report (Reference 27), M&S Computing prepared a set of schedules tracking items important to NASA software. Updates to these schedules were based upon the best available information from review presentations and Boeing schedules. Schedule updates were provided quarterly throughout the contract (References 28, 29, 30, and 31).

C.2 Support Software Analysis

Evaluation of the support software complements the IUS flight software analysis by providing insight into all phases of flight software production. Familiarity with the compiler and MOS data formatting software facilitates understanding the flight software structure and the format for the program load tapes. Knowledge of the interpretive computer simulator (ICS), V&V Simulator and checkout station (COS) helps ensure that these test tools will adequately verify all facets of the flight software design. Finally, the post-processing software is the key to assessing vehicle and flight software performance. Capabilities must be coordinated with flight software design to provide adequate information for mission performance analysis.

C.2.1 MOS Data Formatting

This software will create a mission data load (MDL) tape which will be merged with the operational flight software (OFS) for a unified flight software load tape. The program is a straightforward translator that creates a MDL tape from unique requirements specified for a mission. At the MOS Data Formatting PDR (Reference 32), two requirements modifications were proposed: first, an output tape range test was proposed to augment the input parameter range test Boeing has already specified; and secondly, a more positive identification scheme was proposed to ensure compatible MDL tape and OFS tape merges. A software identification cross-check was suggested to replace the manual tape label verification. The major concern for NASA at this PDR was the announcement that Boeing plans to accommodate the day-to-day launch slip retargeting requirements by delivering 25-30 MDL tapes; one tape for each day during the launch window. Multiple software load tape deliveries dictates extensive testing and more complex tape handling procedures for configuration management.

C.2.2 Test Support Software

In July 1978, Reference 5 noted deficiencies in the V&V Simulator software requirements. NASA requirements for third stage spinup and the third stage command interface were not scheduled; and the simulator breakpoint/restart capability did not contain a feature that would allow the operator to suspend a test, dump flight computer memory, and resume testing. These deficiencies were written up as RID's at the V&V Simulator CDR. Boeing's answer to the RID's was to incorporate full breakpoint/restart capability but to defer the NASA requirements until more specific OFS requirements are available. Prior to the NASA PDR, Boeing should define the NASA requirements for a V&V Simulator update and a schedule for its development (see Reference 7).

An analysis of the JOVIAL (J73)/M362S Cross Compiler in Reference 5 pointed out several restrictions on compiler design that were not related to developing efficient software and therefore were unproductive. Restrictions included percent of compiler source code in assembly language, memory limitations, and the number of instructions per statement. These constraints remain in the current compiler specification dated January 31, 1979.

The review of COS software (Reference 32) revealed that there are no unique NASA requirements for this system. Under the IUS checkout concept, any NASA-unique checkout procedures will be a part of the test scenarios written by test engineers and incorporated into the COS software.

Several software improvements were proposed for an ICS design proposed by the IV&V contractor (see Reference 33). Recommendations were included for performance improvement for interactive testing of the IUS flight software instead of complete reliance on batch processing. Another concern was that the ICS had been originally proposed as the primary software test tool. Subsequently, the IV&V contractor was authorized to procure a real-time V&V Simulation facility with flight hardware (or equivalent) from the Boeing Company.

C.2.3 MOS Post-processing Software

The MOS Post-processing CPDS defines a good, general-purpose data processing package for analyzing IUS flight data. Our only comments were that the software should be programmed in an ANSII standard high-order language for transportability to other computers and that the format of an IUS memory dump should present the contents referenced to the specific memory address. BAC had deleted the references to FORTRAN in the CPDS and is currently planning to program in JOVIAL J73/I which is not an ANSII standard language. Therefore, a RID was submitted on the proposed language. BAC agreed to the memory-dump format suggestion. A summary of the MOS PDR discussions is presented in Reference 34.

During the MOS PDR, the BAC presented an ICD for Mission Operations Segment Post Processing Software Input Mission Data (ICS-290-80036). This ICD specifies the format for IUS data tapes delivered to BAC for post-processing.