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REVISION B



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PROJECT/SPACE SHUTTLE

SPACE SHUTTLE GUIDANCE,
NAVIGATION AND CONTROL
DESIGN EQUATIONS

VOLUME I

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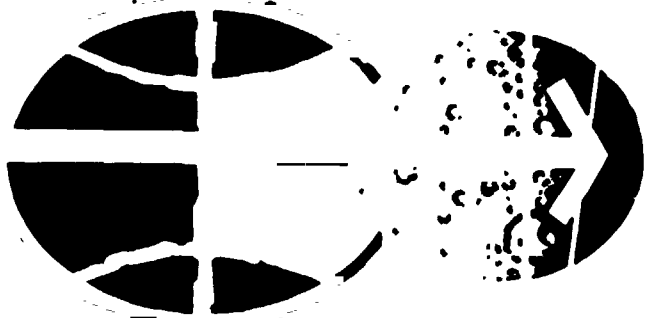
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SYSTEMS ANALYSIS BRANCH
GUIDANCE AND CONTROL DIVISION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS



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NASA SPACE SHUTTLE PROGRAM WORKING PAPER

SPACE SHUTTLE GUIDANCE, NAVIGATION
AND CONTROL
DESIGN EQUATIONS

VOLUME I

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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This second publication of the Space Shuttle GN&C Design Equation Document contains baseline equations for approximately fifty percent of the GN&C computation requirements as specified in the GN&C S/W Functional Requirements Document (MSC-03690 Rev. B). This document supercedes the original MSC-04217 and the subsequently published revision. Additions or corrections to this document since its original publication are indicated in the Table of Contents by asterisks in the margin.

It is planned to republish this document in a new revision in approximately four months time. At that time it is anticipated that equations will be available for virtually all requirements. The new revision will be issued with format changes intended to stress interdependency of related submittals and to eliminate duplication to the greatest degree practicable.

This issue has been modified to reflect the shuttle-structure and avionics-configuration changes which have occurred subsequent to the first issue. A significant change is that orbiter control of the booster has been added as a requirement. Decentralization of the computations and allocation to sub-systems is the current trend with the MARK I & MARK II shuttle configurations. The computation requirements for shuttle vehicles and missions may be much less than those allowed for in this document. However, since the configurations are very fluid at this state in the shuttle development, the approach adopted in this document is to include as complete a set of design equations as possible to cover reasonable possibilities. Therefore, subsets of equations may be extracted from this document to form specifications for specific vehicles, computers and missions.

The GN&C Design Equations document is the result of the efforts of many people from NASA and support contractors. The list is too long to credit all contributors; however, contractors which made direct contributions to the document are as follows:

- a. TRW Systems Group, Inc., Houston Operations
- b. MIT/Charles Stark Draper Laboratory
- c. Lockheed Electronics Co., Inc., Houston Aerospace Systems Division
- d. The Boeing Co., Houston, Texas

The equations are reviewed by the GN&C Formulation and Implementation Panel and their comments included on submittal forms where appropriate. The names of equation submitters are included on the submittal sheet in each section. Comments on the submittals should be referred to the individual submitter or to the responsible NASA engineer. General comments on the document or proposed submittals should be referred to the System Analysis Branch, Guidance and Control Division.

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1. PURPOSE

The purpose of this document is to specify the equations necessary to perform the guidance, navigation and control onboard computation functions for the space shuttle orbiter vehicle. This equations document will provide as comprehensive a set of equations as possible from which modules may be chosen to develop Part I Specifications for particular vehicles, computers and missions. This document is expected to be the source of any equations used to develop software for hardware/software feasibility testing, for ground-based simulations or flight test demonstrations.

2. SCOPE

This document defines a baseline set of equations which fulfill the computation requirements for guidance, navigation and control of the space shuttle orbiter vehicle. All shuttle mission phases are covered from Prelaunch through Landing/Rollout. The spacecraft flight mode and the aircraft flight mode are addressed. Equations are included for the Mark I systems and Mark II systems through the all-up shuttle configuration. Control of the booster during launch is covered. The baseline equations may be implemented in a single GN&C computer or may be distributed among several subsystem computers, depending upon the outcome of centralization/decentralization deliberations currently in progress.

3. APPLICABILITY

This document is applicable to the guidance, navigation and control (GN&C) computation functions for the space shuttle orbiter vehicle. It specifies a set of baseline design equations which may be used for the shuttle program software specification and hardware sizing. It defines the baseline equations for MSC G&CD hardware/software simulation.

4. DEFINITION OF TERMS

Because of the large number of abbreviations and terms contained within this document, the abbreviations and terms used in the equations are listed in Section 9 with the applicable equations.

5. REFERENCE DOCUMENTS

The reference sources from which data are compiled include the following:

- a. MSC-03690 Rev. B, "Project/Space Shuttle, Space Shuttle Guidance, Navigation and Control Software Functional Requirements - Vertical Flight Operations," 15 November 1971. (Also previous releases.)
- b. Minutes of GN&C Shuttle Mechanization Panel Meetings.
- c. Minutes of Guidance and Control Division Panel III Meetings - GN&C Software Equation Formulation and Implementation Panel.
- d. MSC-03439, "Space Shuttle Orbiter GN&C Design Data Book," 6 October 1970. (Also unpublished updates.)
- e. MSC Memorandum EG7-71-149 "Baseline GN&C System for O4OA Shuttle," 3 December 1971. (Also previous baseline releases.)
- f. MSC-02542, "Typical Shuttle Mission Profiles and Attitude Timelines,
Vol. I Space Station Resupply Missions," 23 June 1970
Vol. II Four Scientific Support Missions," 28 Sept. 1970
Vol. III First Ten Shuttle Missions," 11 Dec. 1970
Vol. IV Four Shuttle Mission Profiles," 1 March 1971
- g. MSC Briefing Charts LAll2971, Space Shuttle Program Avionics Systems Recommendations, 29 November 1971.
- h. NR Document DB2.1.5-13000-10, "NR Space Shuttle Program Aerodynamic Design Data Book - Vol. II - Delta Wing Orbiter," May 1971.
- i. MSC Document EX24/7110-334B, "Aerodynamic Data for MSCO4OA Baseline Orbiter Configuration," September 1971.
- j. General Information from Phase B and B' Space Shuttle contractors.
- k. Derivations of GN&C equations, as referenced on submittal forms for equations contained in this document.

6. GN&C SYSTEM DESCRIPTION

The GN&C system description included herein is the baseline hardware configuration assumed in the definition of GN&C software functional requirements (MSC-03690 Rev. B). The description is not intended to specify the defined GN&C system baseline. This is defined by MSC Memorandum EG7-71-149 (Ref. e). The assumed baseline is categorized be a spacecraft GN&C system (Figure 6-1) and an aircraft GN&C system (Figure 6-2).

At this time, the baseline remains general and software requirements have been defined in as all-inclusive a manner as possible. Therefore, the functional requirements addressed in this Design Equations document are broader in scope than the requirments implied by the baseline definition.

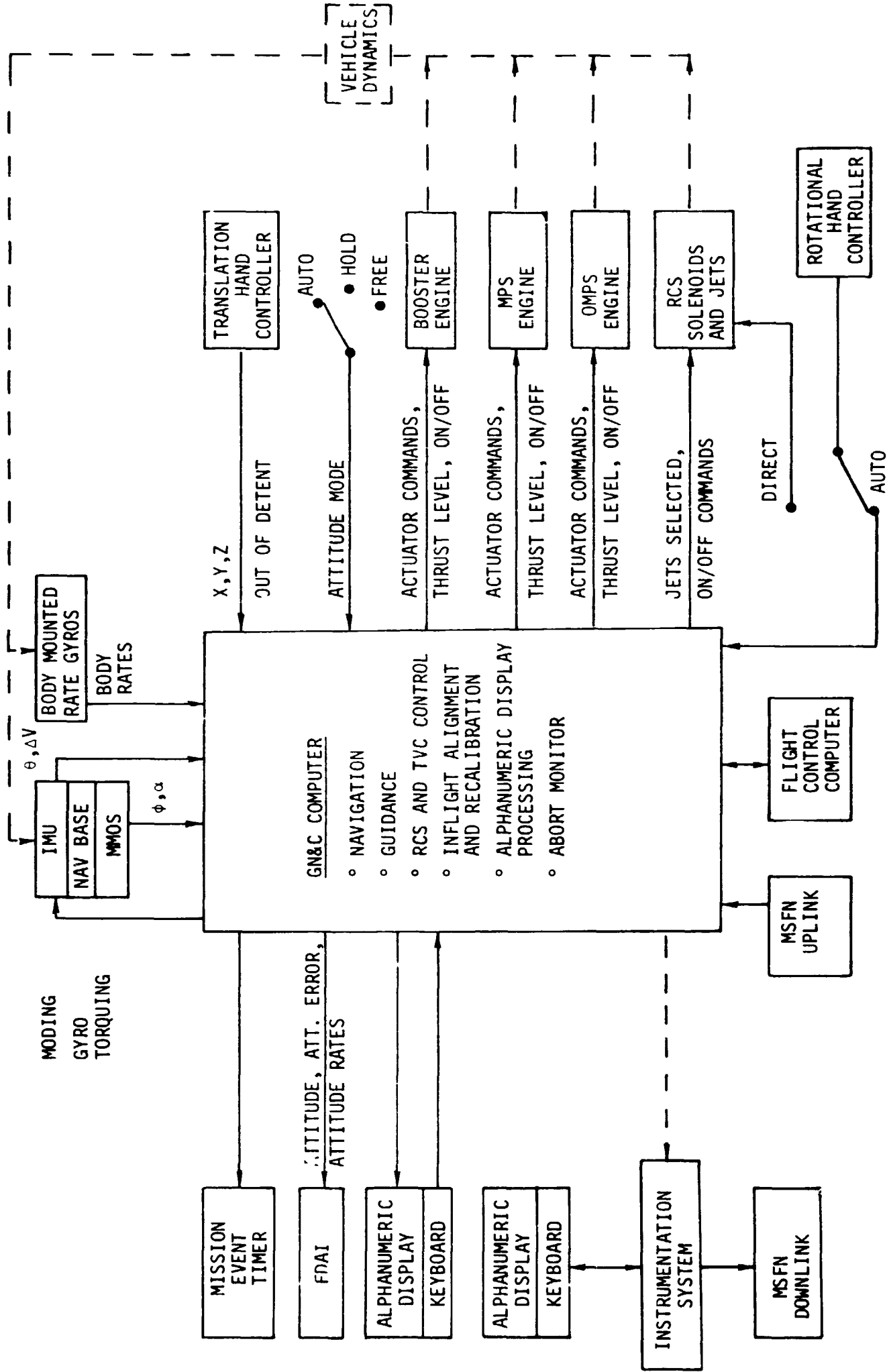


FIGURE 6-1
GN&C BASELINE SYSTEM
SPACECRAFT GN&C SYSTEM

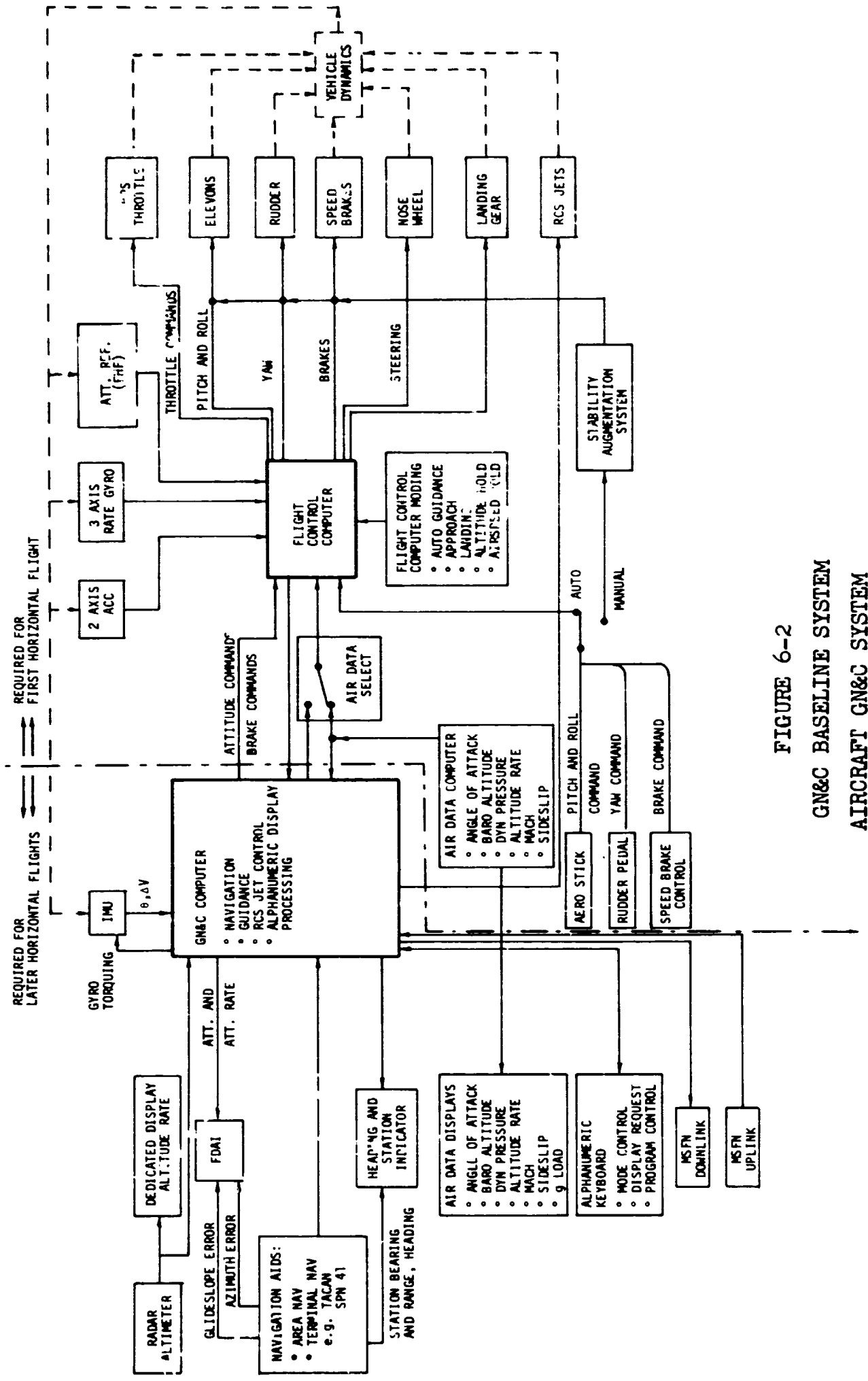


FIGURE 6-2
GN&C BASELINE SYSTEM
AIRCRAFT GN&C SYSTEM

7. GN&C SOFTWARE FUNCTIONAL REQUIREMENTS

A detailed definition of the GN&C software functional requirements for the orbiter is given in Reference a. These requirements are summarized in the matrices of Table 7-1, where requirements are correlated with mission phase and with software modules. A Design Equation status is presented in Table 7-2, where Equations submittals which satisfy requirements are listed against those requirements (under Modules) and where an asterisk (under Module) indicates insufficient definition. A requirement identified with neither module identifier nor asterisk may be assumed to be under active development.

TABLE 8-1
DISTRIBUTION OF ORBITER GN&C SOFTWARE FUNCTIONS AMONG SOFTWARE MODULES

MISSION/SYSTEM REQUIREMENT	GN&C SOFTWARE FUNCTION	SOFTWARE MODULES IN WHICH GN&C FUNCTION IS PERFORMED			
		GUIDANCE MODULE OG-	NAVIGATION MODULE ON-	CONTROL MODULE OC-	SENSOR MODULE OS-
1.0 Pre-launch	<ul style="list-style-type: none"> • Activate GN&C system. 	10-1			
1.1 Checkout and calibrate avionics system.	<ul style="list-style-type: none"> • Perform automatic onboard checkout of GN&C avionics systems through subsystem self-test utilizing operational stimuli; isolate failures to replacement module level. • Calibrate GN&C system and subsystems. • Perform control hardware checkout. • Perform integrated test with booster flight control system. 			9-1	1-1,2 2-1,2 3-1,2 5-1
1.2 Perform targeting for launch utilizing all azimuth launch capability.	<ul style="list-style-type: none"> • Perform targeting computations based on ground supplied target data. • Navigate orbiter and target to launch time. • Generate a reference mission profile. 	10-1		7-1, 7-3 7-1	
1.3 Align, calibrate and verify inertial reference automatically	<ul style="list-style-type: none"> • Align inertial reference utilizing surface alignment techniques and instruments through automatic sequencing. • Calibrate inertial reference through automatic sequencing. 				4-2, 5-2 4-1
2.0 Vertical launch into orbit	<ul style="list-style-type: none"> • Initialize powered flight navigation. • Initialize the launch control system monitor. • Initialize timing functions. • Perform a checklist search to determine that all systems are configured properly for launch. 	12-1 10-2	1-1,2		6-1
2.1 Booster powered flight with maximum 3g load factor	<ul style="list-style-type: none"> • Perform powered flight navigation. • Provide data for abort decision. • Perform guidance computations. • Control vehicle attitude. • Control booster MPS thrust vector. • Provide for manual control of boost. 	OBG1-1 to 6	1-1,2	OBG1-2,5 OBG1-1,3,4 OBG1-7	6-1
2.2 Stage orbiter from booster	<ul style="list-style-type: none"> • Continue powered flight navigation. • Command staging sequence. • Perform separation maneuver. • Command orbiter engine on. • Perform attitude control during coast. • Provide for manual control of separation. 	OBG1-7 1-5	1-1,2	OBG1-6 2-2 6-1,2	6-1

TABLE 7-1
DISTRIBUTION OF ORBITER GN&C SOFTWARE FUNCTIONS AMONG SOFTWARE MODULES (con't)

MISSION/SYSTEM REQUIREMENT	GN&C SOFTWARE FUNCTION	SOFTWARE MODULES IN WHICH GN&C FUNCTION IS PERFORMED			
		GUIDANCE MODULE OG-	NAVIGATION MODULE ON-	CONTROL MODULE OC-	SENSOR MODULE OS-
2.3 Orbiter powered flight with maximum 3g load factor.	<ul style="list-style-type: none"> Continue powered flight navigation. Provide insertion phase guidance. Control vehicle attitude. Control orbiter engine thrust vector. Perform abort monitor. Trim residual ΔV. 	1-1 TO 6 2-1 TO 9	1-1,2	1-1, 1-2, 1-3 1-1, 1-6 3-3	6-1
3.0 Launch aborts with intact return of both booster and orbiter.	<ul style="list-style-type: none"> Determine mode of abort. Accept and process abort commands from crew. Continue powered flight navigation. Perform targeting for orbiter. Command staging sequence at appropriate time. Perform separation maneuver. Command orbiter engine on. Sequence orbiter into proper mission phase at the completion of the abort maneuver. Provide lateral and axial load relief. <p style="text-align: center;">If abort during boost</p>	8-1 TO 4	1-1,2	5-10 1-5, 1-7 1-2	6-1
4.0 Orbital Flight					
4.1 Perform orbital navigation	<ul style="list-style-type: none"> Perform autonomous orbital navigation by incorporating fix data from navigation sensors. Provide capability for automatic pointing and acquisition for each navigational instrument. 		2-1 TO 3		
4.2 Realign and calibrate inertial reference	<ul style="list-style-type: none"> Perform automatic realignment of the inertial reference using sequential star sightings. Automatically acquire sequential stars to provide fixes for the alignment process. Provide automatic attitude maneuvers to present suitable star pairs. Calibrate inertial reference using measured trend data. 			2-1	4-4 4-4 4-4 4-3
4.3 Provide crew flight controls	<ul style="list-style-type: none"> Provide manual 3-axis translation control inputs. Provide manual 3-axis rotational control. Provide manual thrust vector control. Provide direct RCS control including rate, direct acceleration, and minimum impulse control modes. Normal operations will be automatic but crew will have capability to control orbiter for any flight phase. 			6-1 6-2 6-5 2-5, 6-2 2-4	6-1

TABLE 7-1
 DISTRIBUTION OF ORBITER GN&C SOFTWARE FUNCTIONS AMONG SOFTWARE MODULES (con't)

MISSION/SYSTEM REQUIREMENT	GN&C SOFTWARE FUNCTION	SOFTWARE MODULES IN WHICH GN&C FUNCTION IS PERFORMED			
		GUIDANCE MODULE DG-	NAVIGATION MODULE ON-	CONTROL MODULE OC-	SENSOR MODULE OS-
4.4 Provide automatic vehicle control.	<ul style="list-style-type: none"> • Provide attitude hold vehicle control during free flight with a selectable deadband. • Provide jet selection and jet failure logic to automatic and manual RCS control modes. • Provide automatic thrust vector control. 			2-2, 2-3 2-1, 2-7, 3-3, 6-2 3-1, 3-5, 3-8	6-1
4.5 Provide switching of communication antennas, transmitter, and receiver	<ul style="list-style-type: none"> • Provide automatic switching of omni-antennas. • Provide continuous antenna pointing information. 			8-1, 8-3 8-2	

TABLE 7-1
DISTRIBUTION OF ORBITER GN&C SOFTWARE FUNCTIONS AMONG SOFTWARE MODULES (cont)

MISSION/SYSTEM REQUIREMENT	GN&C SOFTWARE FUNCTION	SOFTWARE MODULES IN WHICH GN&C FUNCTION IS PERFORMED			
		GUIDANCE MODULE DG-	NAVIGATION MODULE ON-	CONTROL MODULE DC-	SENSOR MODULE OS-
5.0 Rendezvous with both cooperative, uncooperative, and passive targets.		2-1 TO 9 3-1 TO 7	3-1 TO 6		
5.1 Maintain relative state with respect to target	<ul style="list-style-type: none"> Provide automatic search and acquisition capability for rendezvous tracking system. Perform rendezvous navigation utilizing outputs of tracking systems. 	2-1 TO 9 3-1 TO 7	1-1,2 3-1 TO 6		
5.2 Perform required maneuvers to place orbiter in coelliptic orbit with target	<ul style="list-style-type: none"> Perform targeting - provide maneuver to adjust the phase angle and orbital characteristics so that the orbiter is coelliptic with respect to the target with the required differential height and phase angle at TPI. Typical sequences of maneuvers are (1) phasing adjustment, (2) height adjustment, and (3) a concentric maneuver. For each of these maneuvers, perform the following functions: <ul style="list-style-type: none"> Terminate rendezvous navigation; Realign, if necessary, the inertial reference using star sighting data; Determine if RCS or orbiter engine is required for the maneuver. Perform pre-thrust computations utilizing targeting data; Maneuver the orbiter to the thrust attitude and maintain that attitude; Perform checklist search to determine that all systems are configured properly for the maneuver; Initiate powered flight navigation and continue through maneuver; Perform automatic guidance and control of maneuvers; Perform thrust vector control. Provide for manual control of maneuver by crew including capability and engine thrust and on-off commands. Terminate powered flight navigation. Reacquire target, reinitialize navigation system, and resume rendezvous navigation. 			6-1 4-4	2-1, 2-2, 6-1 7-3 3-1, 3-2, 3-3 3-1, 3-5, 3-7 6-1, 6-2, 6-5

Table 7-1
DISTRIBUTION OF ORBITER GNBC SOFTWARE FUNCTIONS AMONG SOFTWARE MODULES (con't)

MISSION/SYSTEM REQUIREMENT	GNBC SOFTWARE FUNCTION	SOFTWARE MODULES IN WHICH GNBC FUNCTION IS PERFORMED			
		GUIDANCE MODULE DG-	NAVIGATION MODULE ON-	CONTROL MODULE OC-	SENSOR MODULE OS-
5.3 Perform required maneuvers to initiate intercept transfer.	<ul style="list-style-type: none"> Perform terminal phase initiation targeting to place the orbiter on an intercept course with the intended target. Perform targeting of the midcourse maneuvers required to keep the orbiter on an intercept course. All functions described in 5.2 are required for each of the terminal phase maneuvers. 	2-2 TO 9	1-1,2 3-1 TO 6		6-1
5.4 Perform automatic braking to place the orbiter in a station-keeping attitude with respect to the target.	<ul style="list-style-type: none"> Perform targeting computations required to brake orbiter into station-keeping attitude with respect to target. Terminate rendezvous navigation. Initiate powered flight navigation with tracking systems operating to provide relative data for braking computations. Perform automatic guidance and control of RCS braking maneuvers. Terminate powered flight navigation at the completion of the braking maneuver. Provide for manual control of the braking maneuver. 	2-2 TO 9	1-1,2 3-1 TO 6	3-3 6-1	6-1
6.0 Stationkeeping and docking					
6.1 Perform automatic station-keeping	<ul style="list-style-type: none"> Maintain orbiter placement with respect to target such that it will not interfere with target LOS requirements. Perform stationkeeping navigation utilizing rendezvous tracking system outputs. Maintain orbiter in preferred tracking attitude. Provide for manual control of station-keeping. 	4-1 TO 5	1-1,2 2-1,2 3-1 TO 6	2-2, 2-3, 2-6 2-4, 2-5, 6-1, 6-2	6-1
6.2 Perform docking	<ul style="list-style-type: none"> Perform computations to control orbiter attitude with respect to the target. Perform stationkeeping navigation utilizing tracking systems and/or docking sensors Compute maneuvers required to place orbiter on the required approach corridor to the docking port. Perform automatic guidance and control of the RCS docking maneuvers. Provide for crew control of docking 	4-1 TO 5	1-1,2 3-7	2-2 2-6, 3-4, 3-6 6-1, 6-2	6-1
7.0 Docked operations	<ul style="list-style-type: none"> Perform ΔV maneuvers while docked to the space station/base to provide space base orbit maintenance. 		2-3	3-5, 3-7, 3-8	6-1

TABLE 7-1
DISTRIBUTION OF ORBITER GN&C SOFTWARE FUNCTIONS AMONG SOFTWARE MODULES (cont.)

MISSION/SYSTEM REQUIREMENT	GN&C SOFTWARE FUNCTION	SOFTWARE MODULES IN WHICH GN&C FUNCTION IS PERFORMED			
		GUIDANCE MODULE OG-	NAVIGATION MODULE ON-	CONTROL MODULE OC-	SENSOR MODULE OS-
7.1 Perform docked maneuver.	<ul style="list-style-type: none"> Provide for attitude hold and rate damping of Space Station/Base. Activate GN&C system. 			2-7	6-1
7.2 Initialize avionics for undocking.	<ul style="list-style-type: none"> Perform automatic checkout of avionics. Align inertial reference while docked. 			7-2	4-5
8.0 Undocking					
8.1 Perform automatic undocking	<ul style="list-style-type: none"> Perform checklist search to determine if all systems are configured for undocking. Update onboard state vector from either space base (if existent) or ground. Initiate powered flight navigation and maintain until the end of the undocking maneuver. Perform automatic guidance and control of RCS undocking maneuver. Maintain orbiter placement with respect to target such that it will not interfere with target LOS requirements. Initiate coasting flight navigation upon completion of the undocking maneuver. Provide capability for manual control. 		1-1,2 3-7	7-2 3-4 2-6 6-1, 6-2	6-1
9.0 Deorbit and Entry	<ul style="list-style-type: none"> Checkout the TVC and aerosurface control hardware by manual and automatic inputs prior to deorbit. 		2-1,2	7-1, 7-3	
9.1 Perform deorbit (may consist of one or more maneuvers)	<ul style="list-style-type: none"> Perform targeting to provide desired trajectory conditions at entry interface based upon ground supplied landing point. Terminate orbital navigation. Realign inertial reference using star sighting data. Perform pre-thrust computations utilizing targeted data. Maneuver orbiter to the thrust attitude and maintain that attitude. Perform checklist search to determine that all systems are configured for the deorbit maneuver. Initiate powered flight navigation and continue through maneuver. Perform automatic guidance and control of maneuver and insure that ΔV residuals are small. Perform thrust vector control of orbiter engines. Terminate powered flight navigation. Provide for manual control of the deorbit maneuver. 		1-1,2	2-1, 2-2 7-1, 7-3 3-3, 3-4, 3-7 3-1, 3-2, 3-5 6-1, 6-2, 6-5	6-1 4-4

TABLE 7-1
DISTRIBUTION OF ORBITER GN&C SOFTWARE FUNCTIONS AMONG SOFTWARE MODULES (cont.)

MISSION/SYSTEM REQUIREMENT	GN&C SOFTWARE FUNCTION	SOFTWARE MODULES IN WHICH GN&C FUNCTION IS PERFORMED			
		GUIDANCE MODULE OG-	SOFTWARE NAVIGATION MODULE ON-	CONTROL MODULE OC-	
9.2 Perform entry with a maximum load factor of 3g.	<ul style="list-style-type: none"> • Orient orbiter to the correct attitude for atmospheric entry. • Perform checklist search to determine if all systems are configured for entry. • Initiate powered flight navigation just prior to entry interface. • Provide guidance and control of orbiter through atmospheric entry including g-limiting capability. • Provide for manual control of the entry maneuvers. • Provide RCS control. • Realign the inertial reference unit as required. • Accept ground updates after blackout. 	5-1 TO 9	1-1,2	2-1 4-1, 4-2, 4-3, 4-5 6-1, 6-2, 6-3 4-2, 4-4	6-1 4-4
10.0 Approach with maximum bank angle of 60° (Nominal 45°)	<ul style="list-style-type: none"> • Issue ABPS engine-on command. • Provide ABPS engine throttle control. • Initiate approach navigation. • Continue powered flight navigation. • Provide orbiter guidance in conjunction with ground commands to perform those maneuvers required to attain the required approach corridor. • Provide aerodynamic surface control. • Provide for manual control during approach. • Provide data for ground controllers. 	6-1 TO 7	1-1,2 4-1,2	5-1, 5-7, 5-9 6-3, 6-4	6-1
11.0 Final Approach and landing					
11.1 Final Approach	<ul style="list-style-type: none"> • Continue powered flight navigation. • Continue autonomous approach navigation utilizing airways, navigational aids and radar altimeter. • Provide orbiter final approach corridor guidance utilizing approach and landing sensors. • Provide aerodynamic surface control. • Initiate landing gear deployment. • Provide ABPS-engine throttle control. • Monitor for possible go-around. • Provide for manual control of final approach phase. • Provide control of speed brakes. 	7-1 TO 3	1-1,2 5-1,2,3	5-4, 5-7 5-8 6-3, 6-4, 6-7 5-8	6-1
11.2 Landing	<ul style="list-style-type: none"> • Continue powered flight navigation. • Continue final approach guidance until landing. • Provide aerodynamic surface control. • Deploy drag chute. 	7-1 TO 3	1-1,2 5-1,2,3	5-7 5-8	6-1

TABLE 7-1
 DISTRIBUTION OF ORBITER GNAC SOFTWARE FUNCTIONS AMONG SOFTWARE MODULES (cont)

MISSION/SYSTEM REQUIREMENT	GNAC SOFTWARE FUNCTION	SOFTWARE MODULES IN WHICH GNAC FUNCTION IS PERFORMED			
		GUIDANCE MODULE 06-	NAVIGATION MODULE 07-	CONTROL MODULE 08-	SENSOR MODULE 05-
11.2 (cont'd)	<ul style="list-style-type: none"> • Provide nose wheel steering commands. • Provide ABPS-engine throttle control. • Provide reverse thrust and landing gear braking. • Provide for manual control of landing phase. • Provide control of speed brakes. 			5-8 5-8 6-3, 6-4, 6-6, 6-7 5-8	
12.0 Ferry Operations	<ul style="list-style-type: none"> • Activate GNAC System • Provide manual capability during ferry. • Perform automatic onboard checkout of GNAC avionics systems through subsystem self-test using operational stimuli; isolate failures to replacement module level. • Calibrate GNAC system and subsystems. • Verify all calibrations. • Perform control hardware checkout. 			6-3, 6-4, 6-6, 6-7	6-1
12.1 Checkout and calibrate avionics system	<ul style="list-style-type: none"> • Align inertial reference using surface alignment techniques and instruments through automatic sequencing. • Calibrate inertial reference through automatic sequencing. • Verify alignment of inertial reference. 			9-1, 9-2, 9-3	4-3, 5-1
12.2 Align, calibrate and verify inertial reference automatically	<ul style="list-style-type: none"> • Initialize powered flight navigation. • Initialize launch control navigation system. • Initialize timing functions. • Perform a checklist search to determine that all systems are configured properly for horizontal launch. • Provide rollout steering. • Provide attitude control. 			7-1	6-1
12.3 Rollout and horizontal takeoff	<ul style="list-style-type: none"> • Perform powered flight navigation. • Perform guidance computations. • Provide ABPS throttle commands. • Provide aerodynamic surface control. 	9-1 TO 4	1-1,2 4-1,2	5-8 5-6, 5-7	6-1
12.4 Horizontal flight	<ul style="list-style-type: none"> • Functions essentially the same as those defined above in Sections 10 and 11. 		1-1,2 4-1,2; 5-1,2,3	5-2, 5-3, 5-5, 5-7	6-1
12.5 Approach, final approach, landing and rollout	<ul style="list-style-type: none"> • Provide downlink GNAC information. • Accept uplink information. 			8-4 8-5	
13.0 Provide uplink and downlink					

TABLE 7-2

MISSION PHASE PROGRAMS VERSUS
GN&C FUNCTIONS AND MODULES

MISSION PHASE PROGRAM	MISSION PHASE SUBPROGRAM	FUNCTIONS ¹	MODULES ¹	
1.0 Prelaunch	1.1 Initialization	<ul style="list-style-type: none"> o Activate GN&C system. o Navigate orbiter and target to launch time. 	ONL-1	
	1.2 Targeting	<ul style="list-style-type: none"> o Perform targeting computations based on ground supplied target data. 		
	1.3 Sensor Calibration and Alignment	<ul style="list-style-type: none"> o Align inertial reference utilizing surface alignment techniques and instruments through automatic sequencing. o Calibrate inertial reference through automatic sequencing. o Verify alignment of inertial reference. 		
2.0 Boost	2.1 Rapid Real-Time State Advancement During Specific Force Sense	<ul style="list-style-type: none"> o Perform powered flight navigation. 	ONL-1	
	2.2 Booster Control	<ul style="list-style-type: none"> o TVC and Attitude Control during Boost through separation. 		OBCI-1,2,3,4,7
	2.3 Booster Guidance	<ul style="list-style-type: none"> o Compute and command time for MPS ignition and lift-off. o Compute and command attitude during first-stage boost, throttle setting, and booster MPS cut-off. 		
3.0 Separation	3.1 Separation Control	<ul style="list-style-type: none"> o Command staging sequence (booster positive separation). o Perform RCS separation maneuver. o Command orbiter engine on. o Perform attitude control during coast. 	ONL-1	
	3.2 Separation	<ul style="list-style-type: none"> o Continue powered flight navigation. 		
4.0 Orbit Insertion	4.1 Navigation	<ul style="list-style-type: none"> o Provide insertion phase guidance. o Trim residual ΔV. 	OGI-1,2,3	
	4.2 Powered Ascent Guidance	<ul style="list-style-type: none"> o Provide insertion phase guidance. o Trim residual ΔV. 		

¹As identified in "Space Shuttle GN&C Software Functional Requirements," Ref. a.

TABLE 7-2

MISSION PHASE PROGRAMS VERSUS
GN&C FUNCTIONS AND MODULES (Continued)

MISSION PHASE PROGRAM	MISSION PHASE SUBPROGRAM	FUNCTIONS ¹	MODULES ¹
4.0 (cont'd)	4.3 Attitude Control	<ul style="list-style-type: none"> o Control vehicle roll attitude. o Control orbiter engine thrust vector. 	OU1-1
	4.4 Abort Monitor	<ul style="list-style-type: none"> o Perform abort monitor. 	*
5.0 Ascent Abort	5.1 Abort Decision and Mode Determination	<ul style="list-style-type: none"> o Determine mode of abort. o Accept and process abort commands from crew. 	*
	5.2 Abort Targeting	<ul style="list-style-type: none"> o Perform targeting for orbiter. 	
	5.3 Guidance	<ul style="list-style-type: none"> o Command staging sequence at appropriate time. } If abort during boost o Perform separation maneuver. } o Command orbiter engine on. o Sequence orbiter into proper mission phase at the completion of the abort maneuver. 	
	5.4 Navigation	<ul style="list-style-type: none"> o Continue powered flight navigation. 	
	5.5 Attitude Control	<ul style="list-style-type: none"> o Control vehicle attitude. o Provide lateral and axial load relief. 	
6.0 Orbital Coast	6.1 Orbital Navigation	<ul style="list-style-type: none"> o Advance state vector with conic solutions o Augment conic solutions with numerical solutions o Perform autonomous orbital navigation by incorporating fix data from ground transponders. o Provide capability of automatic pointing and acquisition for each navigational instrument. o Perform automatic realignment of the inertial reference using sequential star sightings. 	ON2-1 ON2-1 ON2-2 OS2-2
	6.1.1 Conic State Extrapolation		
	6.1.2 Precision State and Filter Matrix Extrapolation		
	6.1.3 Using sensors		
	6.2 Sensor Calibration and Alignment		

¹As identified in "Space Shuttle GN&C Software Functional Requirements," Ref. a.

* Requirements inadequately defined.

TABLE 7-2

MISSION PHASE PROGRAMS VERSUS
GN&C FUNCTIONS AND MODULES (Continued)

MISSION PHASE PROGRAM	MISSION PHASE SUBPROGRAM	FUNCTIONS ¹	MODULES ¹
6.0 (cont'd)	6.3 Orbital Coast Attitude Control	<ul style="list-style-type: none"> o Automatically acquire sequential stars to provide fixes for the alignment process. o Calibrate inertial reference using measured trend data. o Provide automatic attitude maneuvers to present suitable star pairs. o Provide direct RCS control including proportional rate, direct acceleration, minimum impulse control modes. o Provide attitude hold vehicle control during free flight with a selectable deadband. o Provide jet selection and jet failure logic to automatic and manual RCS control modes. o Provide manual 3-axis translation control inputs. o Provide manual 3-axis rotational control. o Provide manual thrust vector control. 	
7.0 Orbital Powered Flight	7.1 Targeting	<ul style="list-style-type: none"> o Perform targeting for orbit modifications. 	ON1-1
	7.2 Navigation (Same as 2.1)	<ul style="list-style-type: none"> o Perform powered flight navigation 	OG2-2,4,5,6
	7.3 Guidance	<ul style="list-style-type: none"> o Compute initial thrust attitude o Command axial engines on. o Compute velocity to be gained. o Provide attitude (steering) commands. o Compute time-to-cutoff, and issue engine-off commands. o Null residual velocities (if required). 	
	7.4 Attitude Control	<ul style="list-style-type: none"> o Provide RCS and TVC commands to achieve the commanded attitude. 	OC3-1,2,5

¹As identified in "Space Shuttle GN&C Software Functional Requirements," Ref. a.

TABLE 7-2
MISSION PHASE PROGRAMS VERSUS
GN&C FUNCTIONS AND MODULES (Continued)

MISSION PHASE PROGRAM	MISSION PHASE SUBPROGRAM	FUNCTIONS ¹	MODULES ¹
8.0 Rendezvous	8.1 Rendezvous Targeting	<ul style="list-style-type: none"> o Perform targeting to provide maneuver to adjust the phase angle and orbital characteristics so that the orbiter is coelliptic with respect to the target with the required differential height and phase angle at TPI. o Perform Terminal Phase initiation targeting to place the orbiter on an intercept course with the intended target. Perform targeting of the midcourse maneuvers required to keep the orbiter on an intercept course. o Perform targeting computations required to brake orbiter into station-keeping attitude with respect to target. 	OG3-1,2,3,6
	8.2 Relative State Updating	<ul style="list-style-type: none"> o Perform relative navigation utilizing outputs of tracking systems. o Provide automatic search and acquisition capability for tracking system. 	ON1-1 ON2-1 OG3-1,2,3,4,7
	8.3 Guidance	<ul style="list-style-type: none"> o Compute initial thrust attitude. o Command axial engines on. o Compute velocity to be gained. o Provide attitude (steering) commands. o Compute time-to-cutoff, and issue engine-off commands. o Null residual velocities (if required). 	OG2-2,4,5,6
	8.4 Attitude Control	<ul style="list-style-type: none"> o Provide RCS and TVC commands to achieve the commanded attitude. 	

¹As identified in "Space Shuttle GN&C Software Functional Requirements," Ref. a.

TABLE 7-2
MISSION PHASE PROGRAMS VERSUS
GN&C FUNCTIONS AND MODULES (Continued)

MISSION PHASE PROGRAM	MISSION PHASE SUBPROGRAM	FUNCTIONS ¹	MODULES ¹
9.0 Station keeping	9.1 Navigation	o Perform station-keeping navigation utilizing radar, optics, and/or laser tracking system outputs.	*
	9.2 Guidance	o Maintain orbiter placement with respect to target such that it will not interfere with target LOS requirements.	
	9.3 Attitude Control	o Maintain orbiter in preferred tracking attitude.	
10.0 Docking & Undocking	10.1 Docking and Undocking Navigation	o Perform automatic guidance and control of the RCS docking maneuvers.	OC2-6
	10.2 Automatic Docking Control Law (Guidance and Control)	o Perform computations to control orbiter attitude with respect to the target. o Compute maneuvers required to place orbiter on the required approach corridor to the docking port. o Sense soft dock. o Allow for crew maneuver to hard dock.	
11.0 Docked Operations	11.1 Targeting	TBD	*
	11.2 System Initialization	TBD	
	11.3 Navigation	TBD	
	11.4 Guidance	TBD	
	11.5 Attitude Control	TBD	

¹As identified in "Space Shuttle GN&C Software Functional Requirements," Ref. a.

* Requirements inadequately defined.

TABLE 7-2

MISSION PHASE PROGRAMS VERSUS
GN&C FUNCTIONS AND MODULES (Continued)

MISSION PHASE PROGRAM	MISSION PHASE SUBPROGRAM	FUNCTIONS ¹	MODULES ¹
11.0 (cont'd)	11.6 Sensor Calibration and Alignment	TBD	
	11.7 System Monitor, Test, and Checkout	TBD	
12.0 Deorbit and Entry	12.1 Deorbit Targeting	o Perform targeting to provide desired trajectory conditions at entry interface based upon specified landing point.	OG5-1,2,4,5
	12.2 Entry Navigation	o Perform coasting and powered flight navigation. o Initiate powered flight navigation and continue through maneuver.	ON1-1 ON2-1
	12.3 Entry Guidance	o Perform automatic guidance and control of maneuver and insure that ΔV residuals are small. o Perform thrust vector control of orbiter engines. o Provide guidance and control of orbiter through atmospheric reentry including g-limiting capability.	OG5-7,8,9
	12.4 Reentry Autopilot	o Achieve commanded attitude during powered flight and entry. o Maneuver orbiter to the thrust attitude. o Orient orbiter to the correct attitude for atmospheric reentry.	OC4-1,2,3,4
13.0 Transition	13.1 Transition Attitude Control	o Control transition maneuver from high angle of attack profile to low angle of attack cruise profile. o Provide aerodynamic control of orbiter.	OC5-1,7

¹As identified in "Space Shuttle GN&C Software Functional Requirements," Ref. a.

TABLE 7-2

MISSION PHASE PROGRAMS VERSUS
GN&C FUNCTIONS AND MODULES (Continued)

MISSION PHASE PROGRAM	MISSION PHASE SUBPROGRAM	FUNCTIONS ¹	MODULES ¹
14.0 Cruise and Ferry	14.1 Navigation	<ul style="list-style-type: none"> o Continue powered flight navigation. o Continue autonomous cruise navigation utilizing airways navigational aids and radar altimeter. 	ON4-1
	14.2 Guidance	<ul style="list-style-type: none"> o Provide orbiter guidance in conjunction with ground to perform those maneuvers required to attain the required approach corridor. o Provide cruise-engine throttle control. 	OG6-1, 2, 4, 7
	14.3 Attitude Control	<ul style="list-style-type: none"> o Provide aerodynamic surface control. 	OC5-1, 7
15.0 Approach and Landing	15.1 Navigation	<ul style="list-style-type: none"> o Continue powered flight navigation. o Continue autonomous cruise navigation utilizing airways navigational aids and radar altimeter. 	ON5-1
	15.2 Guidance	<ul style="list-style-type: none"> o Provide orbiter approach corridor guidance utilizing approach and landing sensors. c Provide cruise-engine throttle control. o Provide braking and steering commands after touchdown. o Provide aerodynamic surface control. 	OG7-1, 3
	15.3 Attitude Control	<ul style="list-style-type: none"> o Provide aerodynamic surface control. 	OC5-1, 7
16.0 Horizontal Takeoff	16.1 Navigation	<ul style="list-style-type: none"> o Provide powered flight navigation. 	
	16.2 Guidance	<ul style="list-style-type: none"> o Provide attitude and thrust throttle commands. 	
	16.3 Attitude Control	<ul style="list-style-type: none"> o Achieve commanded attitude. 	
17.0 Communications and Pointing	17.1 Antenna/Sensor Switching	<ul style="list-style-type: none"> o Provide auto switching of omni-antennas 	*

¹As identified in "Space Shuttle GN&C Software Functional Requirements," Ref. a.

* Requirements inadequately defined.

TABLE 7-2
MISSION PHASE PROGRAMS VERSUS
GN&C FUNCTIONS AND MODULES (Continued)

MISSION PHASE PROGRAM	MISSION PHASE SUBPROGRAM	FUNCTIONS ¹	MODULES ¹
17.0 (cont'd)	17.2 Antenna/Sensor Pointing	o Provide continuous antenna pointing information.	
	17.3 Transmission Frequency Selection	o Provide auto selection of transmission frequency.	
	17.4 Provide Communications Link Data	o Process downlink data. o Process uplink data.	
18.0 Failure Detection	18.1 Preflight Failure Detection	o Provide data for automatic preflight and inflight GN&C system checkout and failure detection.	*
	18.2 Inflight Failure Detection		

¹As identified in "Space Shuttle GN&C Software Functional Requirements," Ref. a.

* Requirements inadequately defined.

3. COORDINATE SYSTEMS AND TRANSFORMATIONS

The coordinate systems which will be employed for GN&C functions of the Space Shuttle missions are probably included in the following listing:

1. Earth Centered Inertial (ECI)
2. Earth Centered - Earth Fixed Systems (several orientations may be desirable)
3. Launch Site Centered, Earth Fixed
4. Landing Site Centered, Earth Fixed
5. IMU stable member (a function of the IMU alignment)
6. Navigation Base Coordinate System(s) (vehicle fixed systems for convenient reference to sensors)
7. Sensor Centered Coordinate Systems (fixed to onboard and ground sensors and transponders)
8. Vehicle or Body Coordinate System (along the axes of geometric symmetry)
9. Vehicle Centered Control System Coordinate System(s) (specific orientations to be based on mass properties, propulsion properties, and aerodynamic conditions)
10. Vehicle Centered Local Vertical Coordinate System (along the local vertical, downrange, cross range)
11. Docking Port Centered, Target Vehicle Fixed Coordinate System
12. Docking Port Centered, Shuttle Vehicle Fixed

These coordinate systems and others are documented in MSC-04400, Recommended Space Shuttle Coordinate System Standards, May 1971. It is recommended that future Equations submittals employ these standards.

It is proposed that the next revision of this document will identify the various coordinate systems employed in the different software sections. Also transformations between the coordinate systems will be documented.