MSC-06747

N73-11682

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MARCH 24, 1972

PROJECT/SPACE SHUTTLE

SPACE SHUTTLE ORBITER GUIDANCE, NAVIGATION AND CONTROL SOFTWARE FUNCTIONAL REQUIREMENTS - HORIZONTAL FLIGHT OPERATIONS

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NASA SPACE SHUTTLE PROGRAM WORKING PAPER

SPACE SHUTTLE ORBITER GUIDANCE, NAVIGATION AND CONTROL SOFTWARE FUNCTIONAL REQUIREMENTS - HORIZONTAL FLIGHT OPERATIONS

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FOREWORD

This document has been generated to provide a working document by which the shuttle GN&C software functions for horizontal flight operations may be defined. At this stage of development of the shuttle program, it was desirable to be as inclusive as possible in the identification of software functional requirements. Therefore, the software functional requirements are grouped into two categories: first horizontal flight requirements and full mission horizontal flight requirements. At this time, several requirements still remain open (see Section 6.2) and the description of the software functions must remain general. As the higher level requirements become established and requirements analyses and tradeoff studies completed, more definitive descriptions can be published. As these data become available, they will be referenced in the detailed functional definitions such that the requirement can be traced to its source. Subsequent issues of this document will reflect this process.

The document will provide the initial step in the shuttle GN&C software design process. It will also serve as a management tool to identify analyses which are required to define requirements. It is recommended that parties having an interest in this area submit comments on this document to the Guidance and Control Division.

This document is a result of a combined effort of the Systems Analysis Branch personnel and contractor personnel supporting the Systems Analysis Branch.

1.0 PURPOSE

The purpose of this document is twofold. The first and primary purpose is to identify the SS (Space Shuttle) Orbiter GN&C (Guidance, Navigation, and Control) software functional requirements for the horizontal flight operations preceding the vertical flight test. The second is to provide an instrument which can be used (1) to identify the analysis tasks necessary to satisfactorily accomplish the functional requirements, (2) to make changes to the requirements based on analysis, and (3) to make available a standard of communications for information concerning the software functional requirements.

2.0 SCOPE

This document defines the SS orbiter GN&C software functional requirements for horizontal flight operation of the SS. The requirements are based on higher level requirements including mission requirements, avionics requirements, and GN&C system requirements. For this issue, it is assumed that the horizontal flight operations will include a first horizontal flight test and horizontal flight demonstration tests. Therefore, the orbiter may have varying degrees of autonomy and automatic GN&C capability for horizontal flight operations. Since the baseline orbiter configuration has not presently been finalized for horizontal operations, the approach taken in this issue will provide the most comprehensive identification of the GN&C functional requirements. The requirements are divided into two categories. One set contains the first horizontal flight functional requirements which represent the minimum set of functions necessary to implement the first flight test of ABES engine performance, structural integrity, and vehicle flying characteristics. The second set contains the first set plus additional functions required for the demonstration tests.

3.0 APPLICABILITY

This document is applicable to the MSC NASA space shuttle GN&C software development. The GN&C software functional requirements for the orbiter during horizontal flight operations are defined. The document will provide background on requirements to support the GN&C software design process, and provides information to the phase C contractor.

4.0 REFERENCE DOCUMENTS

The following documents were used as references for this document.

1. MSC-00141, Rev M. "Guidelines and Constraints Document - Space Station Program Definition (Phase B)," dated 20 March 1970.

2. "Statement of Work - Space Shuttle System Program Definition (Phase B) - Appendix C - Desired System Characteristics," dated 20 February 1970.

3. NASA/MSC Document, "Technical Requirements for Space Shuttle Vehicle Avionics System" dated 22 December 1969.

4. NASA/MSC Transmittal EG7-70-38, "Preliminary Space Shuttle Vehicle Orbiter Guidance, Navigation and Control Functional and Performance Requirements," dated 1 May 1970.

5. MSC Memorandum EG2-70-43, "Control Routines for SSV," dated 17 March 1970.

6. MSC Memorandum EG2-70-44, "Preliminary Identification of G&C Computer Program for SSV," dated 18 March 1970.

7. MSC Internal Note MSC-EG-70-25, "Space Shuttle Vehicle Guidance, Navigation and Control Software Functional Requirements," dated 16 June 1970.

8. MSC Working Paper MSC-03690 Rev A, "Space Shuttle Guidance, Navigation and Control Software Functional Requirements," dated 15 June 1971.

9. MSC Working Paper MSC-04075 Rev C, "Functional and Performance Requirements Specification, Space Shuttle Avionics System-Core," dated 29 July 1971.

10. MSC Memorandum EG7-71-149, "Baseline GN&C System for 040A Shuttle," dated 3 December 1971.

11. MSC-04225 Rev B, "Core Avionics Statement of Work," dated 27 July 1971.

12. MSC-04715, "Functional and Performance Requirements for Space Shuttle Avionics Systems - Orbiter Non-Core," dated 29 July 1971.

13. General Information from Phase B and B' Space Shuttle contractors.

5.0 DEFINITION OF TERMS

The abbreviations used in this document are defined below.

ABES	Air Breathing Engine System
ATC	Air Traffic Control
CAS	Collision Avoidance System
cg	Center of gravity
DME	Distance Measuring Equipment
FHF	First Horizontal Flight
GN&C	Guidance, Navigation and Control
ILS	Instrument Landing System
IRU	Inertial Reference Unit
OHF	Operational Horizontal Flight
VOR	VHF Omni-directional Radar

6.0 SUMMARY OF GN&C SOFTWARE REQUIREMENTS

6.1 GENERAL DESCRIPTION OF MISSION PHASES AND GN&C SYSTEM AND FUNCTIONS

The following sections present definitions of the GN&C functions and their associated mission phases. Tabulations of the functional requirements are presented on a mission phase basis in categories of guidance, navigation and control.

6.1.1 Description of Mission Phases

The eight sections below describe the general mission phases identified for the Space Shuttle horizontal flight missions.

6.1.1.1 Preflight - This phase involves the checkout and initialization of the GN&C software and hardware systems and the alignment of certain hardware subsystems preparatory to takeoff.

6.1.1.2 Takeoff - This phase begins with the orbiter aligned to the takeoff runway and ends with liftoff of the orbiter from the runway. The primary functions during this phase are the accumulation of a takeoff speed and maintenance of a center-of-the-runway heading and a wings-level roll attitude.

6.1.1.3 Climb - This phase starts with the completion of the takeoff phase and ends with the attainment of the desired cruise altitude. The primary functions during this phase are the establishment of a climb rate, maneuver to the desired course heading, and attainment of the desired cruise altitude.

6.1.1.4 Cruise - This phase constitutes the major portion of a ferry flight during which the desired course heading and airspeed are held.

6.1.1.5 Descent - This is the phase during which the orbiter descends from the cruise altitude to the approach altitude. Vertical speed, heading, and altitude control are the primary functions during this phase.

6.1.1.6 Approach - This phase contains the period of time during which the orbiter maneuvers to intercept, capture, and track the ILS localizer and glideslope beams. Also, during this phase, the orbiter maneuvers to align itself with the desired runway.

6.1.1.7 Final Approach and Landing - During this phase, the orbiter is aligned to the runway, descending for touchdown, and tracking the ILS glideslope beam. A flare maneuver is performed to effect a smooth touchdown and braking and steering is performed after touchdown to attain a taxi speed and to maintain alignment with the center of the runway during rollout.

6.1.1.8 Go-Around - This phase is applicable for an aborted climb from takeoff or an aborted landing. In either case, the orbiter is maneuvered to a desired airspeed, vertical speed or altitude, and heading preparatory to attempting a landing or second landing. A safe flight path is established such that the approach and final approach and landing phases can be entered.

6.1.2 System Description

A GN&C system description is included here to define the baseline hardware configuration assumed in the definition of the GN&C software functional requirements and is not intended to define the GN&C system baseline. The assumed baseline aircraft GN&C system is shown in Figure 6-1. At this time, the baseline remains general and the software functional requirements are intended to be as inclusive as possible. Therefore, the functional requirements defined in this document are broader in scope than the requirements implied by the system presented.

6.1.3 Definitions of General GN&C Functions

The categorization of functions into guidance, navigation and control functions is made with the same guidelines as the categorization presented in MSC-03690 Rev B, "Space Shuttle Orbiter GN&C Software Functional Requirements - Vertical Flight Operations," dated 15 December 1971. This fact is noted because the categorization differs somewhat from the classical aircraft categorizations. The grouping of functions into the various categories is not intended to be precise but serves as a convenience in the identification on development and analysis areas. The more significant goal is the identification of the functional requirements regardless of their categorizations.

6.1.3.1 Guidance and Targeting - These functions provide steering commands (either directly to the autopilot for automatic guidance or to displays in support of manual control) to maintain the orbiter on a desired trajectory. The degree of complexity in the guidance function can vary depending upon the accuracy desired in the vehicle trajectory. Guidance can consist of preprogrammed trajectories, single-shot onboard target determination, or continuous targeting/guidance. The outputs of this function are thrust magnitude or airspeed, and steering commands.

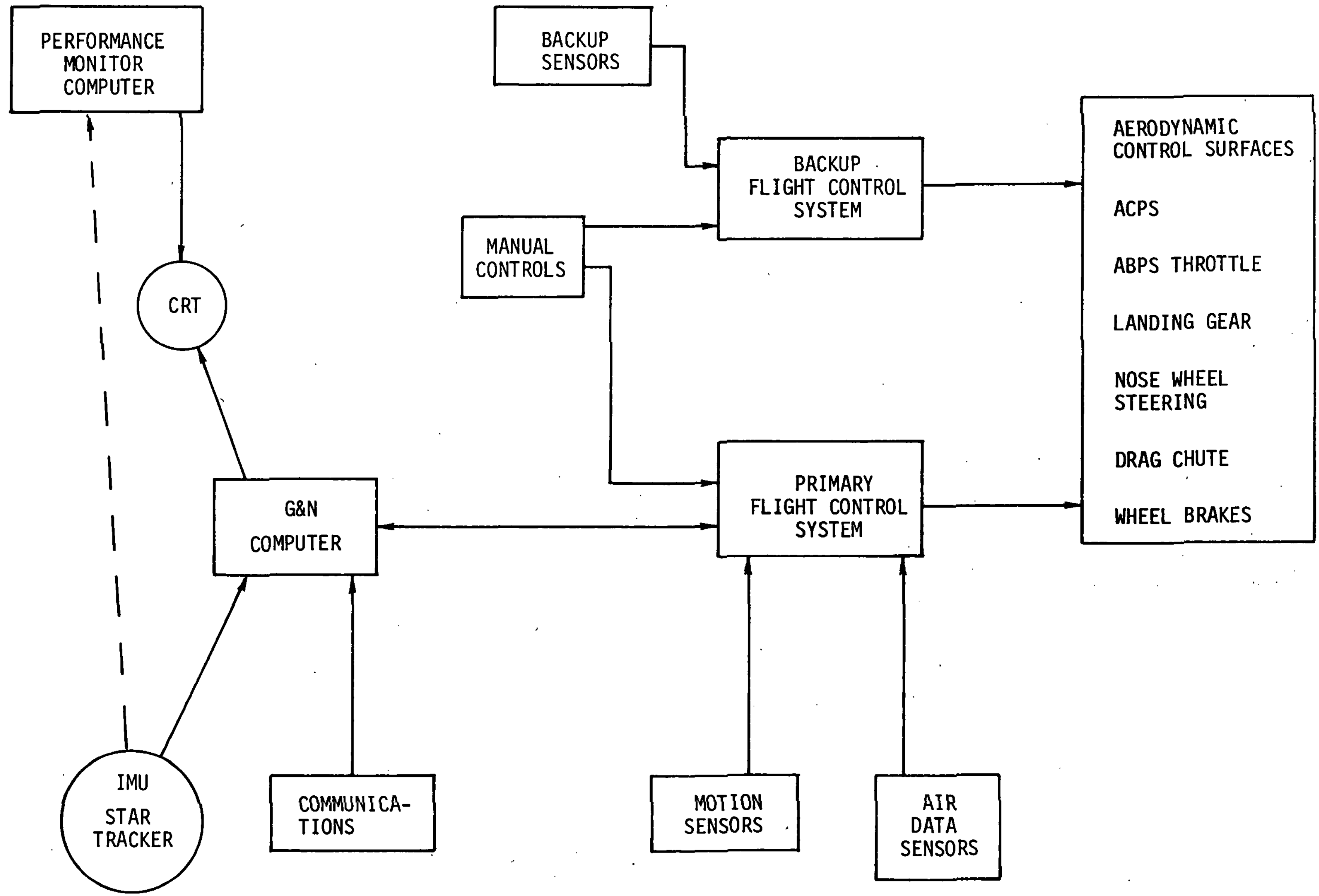

FIGURE 6-1
HORIZONTAL FLIGHT BASELINE GN&C SYSTEM

6.1.3.4 Hardware Interface/Processor Functions - The GN&C software interfaces with hardware and the processor software dependent upon hardware are discussed in this section.

a. Auto diagnostics is the onboard evaluation of the useability of subsystem components such as computers, sensors, manual controllers, actuators, and power supplies.

   1) Failure detection consists of the detection of failures, isolation of the failed component, and identification of the redundant components in service.

   2) Calibration requires the estimation of and compensation for null bias and scalefactor errors in the sensor measurements.

   3) Systems checkout consists of a series of tests using simulated sensor inputs or artificial commands to generate system outputs such as control surface motion or display activity. These tests are performed prior to the more critical system activities.

b. The alignment function can be generally defined as proper orientation of the hardware or sensor elements or the determination of the orientation of these elements.

   1) One alignment function is to determine the attitude relation between a basic reference frame and the orbiter sensors such as the IRU, optical sensors, body-bending sensors, and air data sensor. The rendezvous sensors and stationkeeping sensors also require alignment.

   2) Another alignment function consists of positioning such elements as engine gimbals and aerodynamic surfaces to a specified orientation.

c. The GN&C software also issues actuator commands or processes manual controller commands.

   1) The actuators commanded by the GN&C software include ABES on/off and throttle actuators, aerosurface actuators, speed brake and spoiler actuators, landing gear deployment actuators, wheel brakes, nose-wheel steering actuators, and drag-chute deployment actuator.

6.1.3.2 Navigation - Navigation consists of advancing a known state in inertial space forward in time.

a. Specific force integration is used to propagate the vehicle state during atmospheric flight by using accelerometers to sense external forces with an on-board gravity model.

b. Incorporating data from external navigation aids to the specific force integration will improve the accuracy of the state vector determination. In some mission phases, the navigation aids may be the primary form of navigation depending upon accuracy requirements and capabilities. The external navigation aids include a radio altimeter, a barometric altimeter, VOR/DME, ILS, compass, and marker beacons.

c. Initialization consists of loading erasable constants based on data from an external source such as a tracking station.

d. The attitude determination function consists of determining the vehicle body attitude with respect to local vertical, etc.

e. A possible navigation function consists of locating weather fronts and other aircraft in the flight path of the orbiter.

6.1.3.3 Controls - For horizontal flight operations, the control functions are the conversion of steering commands (from automatic guidance or from crew inputs) into deflections of the aerodynamic control surfaces. The control system must correlate the attitude control dictated by flight path commands with airspeed and control surface positions to provide a stable dynamic flight configuration. The control system functions in three basic modes: manual, semi-automatic, and automatic. In the manual mode, the control system translates hand controller inputs into coordinated deflections of the aerodynamic surfaces. In the semi-automatic mode, it provides automatic control in the absence of manual inputs and responds to manual inputs in all or selected control axes. An example of this mode is a wings-level, heading hold configuration with pitch attitude hold about a pitch attitude commanded by the pilot via the hand controller. In the automatic mode, the autopilot is reacting to the steering commands from the automatic guidance system. The control system also has the capability to modify the control gains and the hand controller resistance force gradients and deadzones to change the control sensitivity during turbulence and other mission phases.

2) The control software will process manual inputs commanded through the side arm controller, rudder pedals, manual throttle, and aerosurface trim wheels.

d. The GN&C system will process data from the GN&C sensors into forms amenable to the GN&C software or to display drivers. These sensors include the IRU, rate gyros, accelerometers, altimeters, air data sensors, and navigation aids.

6.1.4 Mission/System Functional Requirements for Orbiter

A detailed definition of the GN&C software functional requirements for the orbiter horizontal flight operations is presented in Table 6.1. The functional requirements are identified on a mission phase basis and an attempt is made to categorize those functions which are absolutely required to support the first horizontal test flights and those demonstration functions which can be added to support the operational horizontal flights. This study cannot be precise at this time since the objectives of the first horizontal flight tests and of the operational flights have not been defined in detail at present.

To effect the categorization, it was assumed that the first horizontal flight tests will be designed to evaluate the structural loading, flying characteristics, and ABES performance. There will be no transport cruise phase associated with the FHF in that the orbiter will remain in the proximity of the takeoff and landing site. Some software may be required to process sensor data to provide navigational displays. The primary mode of guidance and control will be manual or semi-automatic. The semi-automatic capabilities are included to alleviate some of the crew work load. These semi-automatic capabilities include automatic heading hold, semi-automatic attitude hold such as wings-level hold and pitch hold about a stick commanded attitude, and aerosurface trim.

For the operational horizontal flights, it was assumed that a ferry capability is required and that the approach and landing techniques designed for the vertical flight operation will be demonstrated. Again, with the uncertainties in the detailed objectives of the operational horizontal flights, the software functional requirements were identified with a goal of being as comprehensive as possible. As the details of flight objectives become established, these functional requirements will be modified.

Certain requirements are not included in the table because they are not uniquely guidance, navigation or control functions, and, in general, are applicable to all mission phases. These requirements are defined below.

a. Failure Detection (Applicable to OHF)

1) Provide GN&C operational output, special test measurements, built-in-test information, and sensor health status information for failure detection analysis.

2) Provide GN&C trend data limits, marginal test requirements, failure criteria, and required test stimuli to aid in failure detection analysis.

3) Provide logic for failure detection, isolation, and switching of GN&C hardware as required.

b. Communication Control

1) Process GN&C downlink and uplink data.

c. Air Data Sensor

1) Process air data sensor information into proper format for GN&C displays.

2) Process air data sensor information into proper format for GN&C software equations. (OHF).

3) Provide reference alignment for and perform calibration of air data sensors. (OHF only).

d. Navigation Aids

1) Process the navigation aids data into format for displays.

2) Process the navigation aids data into format compatible with GN&C software equations. (OHF only).

3) Perform calibration of and provide reference alignment for navigation aids sensors. (OHF only).

e. Interlock Logic

1) Disarm GN&C components during mission phases where they are not required and where they would create crew hazards if inadvertantly activated.

TABLE 6.1

MISSION/SYSTEM GN&C SOFTWARE REQUIREMENTS

MISSION/SYSTEM REQUIREMENTS	GN&C SOFTWARE FUNCTIONS REQUIRED FOR FIRST HORIZONTAL FLIGHT	ADDITIONAL GN&C SOFTWARE FUNCTIONS REQUIRED FOR OPERATIONAL HORIZONTAL FLIGHT	SUPPORT FUNCTION
1.0 PREFLIGHT	°Activate GN&C system.		
1.1 Checkout and calibrate avionics system.	°Perform checkout of GN&C avionics system using ground support. °Calibrate GN&C system and subsystems. °Perform control hardware checkout.	°Perform automatic checkout of GN&C avionics system.	°Provide avionics checkout for FHF and monitor automatic checkout on OHF.
1.2 Establish flight plan.	°Initialize GN&C system.	°Incorporate desired flight plan for heading computations.	°Generate a reference mission profile. °Provide erasable load.
1.3 Align and calibrate inertial reference.		°Align inertial reference using surface alignment techniques and instruments through automatic sequencing.	
2.0 TAKEOFF	°Perform a checklist search to determine that all systems are configured properly for takeoff. °Initialize timing functions.		°Monitor takeoff.
2.1 Provide takeoff steering.	°Drive displays to give visual cues for manual control to a wings level roll attitude, an optimum rotation and climb-out maneuver, and to a desired takeoff speed.	°Provide automatic steering commands for heading hold based on crew input of desired course and provide pitch steering commands. °Provide auto throttle control coordinated with pitch-axis control to preclude stall. °Modify steering commands to be consistent with structural and passenger comfort limits.	
2.2 Provide takeoff *navigation.*	°Process compass and altimeter data to provide heading, *altitude and altitude rate information.* °Process marker beacon data to determine orbiter location relative to takeoff runway.	°Advance vehicle state with specific force integration *using sensed accelerometer data on onboard model for* gravity forces. °Maintain navigated state using onboard and ground navigation aids. (Radio altimeter, marker beacon system, etc.)	°Provide marker beacon system.
2.3 Provide takeoff control.	°Provide stall warning based on angle-of-attack, airspeed, and aerosurface positions. °Provide manual control of aerodynamic control surfaces. °Provide manual ABES throttle control. °Provide semi-automatic attitude hold. (Hold about the attitude at time of release of manual controllers). °Provide stability augmentation.	°Provide automatic attitude hold and automatic attitude maneuvers in response to steering commands.	
3.0 CLIMB			
3.1 Provide climb steering.	°Drive displays to give visual cues for manual control of attitude, airspeed and vertical speed. °Provide automatic steering commands for automatic heading hold.	°Provide automatic steering commands for heading select and hold, vertical speed hold, and altitude select and hold. °Provide auto throttle control coordinated with pitch-axis control to preclude stall in indicated airspeed hold mode. °Provide for acceptance of Air Traffic Control (ATC) commands. °Modify steering commands to be consistent with structural *and passenger comfort limits.*	

TABLE 6.1 (Con't)

MISSION/SYSTEM GN&C SOFTWARE REQUIREMENTS

MISSION/SYSTEM REQUIREMENT	GN&C SOFTWARE FUNCTIONS REQUIRED FOR FIRST HORIZONTAL FLIGHT	ADDITIONAL GN&C SOFTWARE FUNCTIONS REQUIRED FOR OPERATIONAL HORIZONTAL FLIGHT	SUPPORT FUNCTION
3.2 Provide climb navigation.	°Process compass and altimeter data to provide heading, altitude and altitude rate information.	°Advance vehicle state with specific force integration using sensed accelerometer data and onboard model for gravity forces. °Maintain navigated state using onboard and ground navigation aids. (Radio altimeter, barometric altimeter, VOR/DME, ATC sensors, etc.).	°Provide VOR/DME stations.
3.3 Provide climb control.	°Provide stall warning based on angle-of-attack, airspeed, and aerosurface position. °Provide manual control of aerodynamic control surfaces. °Provide manual ABES throttle control. °Provide semi-automatic attitude hold. °Provide stability augmentation. °Provide automatic aerosurface trim. °Provide for reduced control gains and increased manual controller force levels and deadzones during operation in turbulence.	°Provide automatic attitude hold and attitude maneuvers in response to steering commands.	
4.0 CRUISE			
4.1 Provide cruise guidance.	°Drive displays to give visual cues for manual control of attitude, airspeed, and vertical position. °Provide automatic steering commands for constant heading hold.	°Provide automatic steering commands for heading select and hold, vertical speed hold, and altitude select and hold. °Provide auto throttle control in indicated airspeed on Mach hold. °Provide for acceptance of ATC or Collision Avoidance System (CAS) commands. °Provide for acceptance of weather avoidance commands. °Provide automatic path prediction and altitude targeting consistent with orbiter fuel and state. °Modify steering commands to be consistent with structural and passenger comfort limits.	
4.2 Provide cruise navigation.	°Cruise phase of FHF limited to visual proximity of launch and landing site. Process altimeter and compass data to provide altitude, altitude rate, and heading information.	°Advance state with specific force integration using sensed accelerometer data and onboard model for gravity forces. °Maintain navigated state using onboard and ground navigation aids (Barometric altimeter, VOR/DME, compass, etc.) °Determine location of weather fronts in flight path with weather radar. °Determine location of aircraft in possible collision situation with orbiter.	°Provide VOR/DME stations.
4.3 Provide cruise control.	°Provide stall warning based on angle-of-attack, airspeed, and aerosurface positions. °Provide manual control of aerosurfaces. °Provide manual ABES throttle control. °Provide semi-automatic attitude hold. °Provide stability augmentation. °Provide automatic aerosurface trim. °Provide for reduced control gains and increased manual controller force levels and deadzones during operation in turbulence.	°Provide automatic attitude hold and attitude maneuvers in response to steering commands.	

TABLE 6.1 (Con't)
MISSION/SYSTEM GN&C SOFTWARE REQUIREMENTS

MISSION/SYSTEM REQUIREMENTS	GN&C SOFTWARE FUNCTIONS REQUIRED FOR FIRST HORIZONTAL FLIGHT	ADDITIONAL GN&C SOFTWARE FUNCTIONS REQUIRED FOR OPERATIONAL HORIZONTAL FLIGHT	SUPPORT FUNCTION
5.0 DESCENT			
5.1 Provide descent guidance.	°Drive displays to give visual cues for manual control of attitude, airspeed, and vertical speed. °Provide automatic steering commands for heading hold.	°Provide automatic steering commands for heading select and hold, vertical speed hold, and altitude select and hold. °Provide auto throttle control coordinated with pitch axis control to preclude stall in indicated airspeed hold or Mach hold. °Provide for acceptance of ATC and CAS commands. °Provide for acceptance of weather avoidance commands. °Provide automatic descent path prediction consistent with orbiter fuel and state, and landing site location. °Modify steering commands to be consistent with structural and passenger comfort limits.	
5.2 Provide descent navigation.	°Process compass and altimeter data to provide heading altitude, and altitude rate information.	°Advance vehicle state with specific force integration using sensed acceleration data and onboard model for gravity forces. °Maintain navigated state using onboard and ground navigation aids. (Barometric altimeter, VOR/DME, compass, etc.). °Determine location of weather fronts in flight path with weather radar. °Determine location of aircraft in possible collision situation with orbiter.	°Provide VOR/DME stations.
5.3 Provide descent control.	°Provide stall warning based on angle-of-attack, airspeed, and aerosurface positions. °Provide manual control of aerosurfaces. °Provide manual ABES throttle control. °Provide semi-automatic attitude hold. °Provide stability augmentation. °Provide automatic aerosurface trim. °Provide for reduced control gains and increased manual controller force levels and deadzones during operation in turbulence.	°Provide automatic attitude hold and attitude maneuvers in response to steering commands.	
6.0 APPROACH			
6.1 Provide approach guidance.	°Drive displays to give visual cues for manual intercept, capture, and track of ILS localizer and glideslope beams. °Provide automatic steering commands for heading hold.	°Provide automatic steering commands to intercept, capture and track the ILS localizer and glideslope beams. °Before capture of the ILS beams, provide steering commands for heading select and hold, vertical speed hold, and altitude select and hold. °Provide automatic approach path prediction; establish alert if approach or final approach conditions cannot be met; compute alternate solutions taking into account possible change of approach azimuth or landing facility. °Modify steering commands to be consistent with structural and passenger comfort limits. °Provide auto throttle control coordinated with pitch-axis control to preclude stall in indicated airspeed hold.	

TABLE 6.1 (Con't)
MISSION/SYSTEM GN&C SOFTWARE REQUIREMENTS

MISSION/SYSTEM REQUIREMENT	GN&C SOFTWARE FUNCTIONS REQUIRED FOR FIRST HORIZONTAL FLIGHT	ADDITIONAL GN&C SOFTWARE FUNCTIONS REQUIRED FOR OPERATIONAL HORIZONTAL FLIGHT	SUPPORT FUNCTION
6.2 Provide approach navigation.	°Process ILS localizer and glideslope beam information to provide heading and glideslope error information for displays.	°Advance vehicle state with specific force integration using sensed accelerometer data and onboard sensed accelerometer data and onboard model for gravity forces. °Maintain navigated state using onboard and ground navigation aids (Barometric altimeter, radio altimeter, VOR/ILS, etc.)	°Provide VOR/DME stations and ILS.
6.3 Provide approach control.	°Provide stall warning based on angle-of-attack, airspeed, and aerosurface positions. °Provide manual control of aerosurfaces. °Provide manual ABES throttle control. °Provide semi-automatic attitude hold. °Provide stability augmentation. °Provide automatic aerosurface trim. °Provide for reduced control gains and increased manual controller forces levels and deadzones during operation in turbulence.	°Provide automatic attitude hold and attitude maneuvers in response to automatic steering commands.	
7.0 FINAL APPROACH AND LANDING			
7.1 Provide final approach and landing guidance.	°Drive displays to give visual cues for manual track of the ILS localizer and glideslope beams. °Provide automatic steering commands for heading hold.	(The following functions provide an autohold capability which is not a near term requirement but will be added at a future development stage of the orbiter). °Provide automatic steering commands to track the ILS localizer and glideslope beams. °Before capture, provide automatic steering commands for heading select and hold, altitude select and hold, and vertical speed hold. °Provide automatic final approach path prediction, establish alert if final approach or landing conditions cannot be met; compute go-around commands. °Provide automatic runway alignment steering commands. °Perform flare maneuver computation to provide automatic flight path commands for smooth touchdown. °Provide commands for direct lift control. °Provide auto throttle control coordinated with pitch axis control for angle-of-attack hold. °After touchdown, provide automatic steering commands to track the center of the runway during rollout.	
7.2 Provide final approach and landing navigation.	°Process ILS data to provide heading and glideslope error information for manual landing.	°Advance vehicle state with specific force integration using sensed accelerometer data and onboard model for gravity forces. °Maintain navigated state using onboard and ground navigation aids (Radio altimeter, VOR/ILS, marker beacon system, etc.)	°Provide VOR/ILS and marker beacon system.

TABLE 6.1 (Con't)

MISSION/SYSTEM GN&C SOFTWARE REQUIREMENTS

MISSION/SYSTEM REQUIREMENT	GN&C SOFTWARE FUNCTIONS REQUIRED FOR FIRST HORIZONTAL FLIGHT	ADDITIONAL GN&C SOFTWARE FUNCTIONS REQUIRED FOR OPERATIONAL HORIZONTAL FLIGHT	SUPPORT FUNCTION
7.3 Provide final approach and landing control.	°Provide stall warning based on angle-of-attack, air-speed, and aerosurface positions. °Provide manual control of aerosurfaces. °Provide manual ABES throttle control. °Provide manual control of speed brakes, ~~spoilers~~, nose wheel steering, wheel brakes, and chute actuation. °Provide semi-automatic attitude hold. °Provide stability augmentation. °Provide automatic aerosurface trim.	°Provide automatic attitude hold and attitude maneuver in response to automatic steering commands. °For autoland, provide automatic ~~spoiler~~ control for direct lift and speed control. °For autoland, provide automatic nose wheel steering, braking, and chute actuation.	
8.0 GO-AROUND	°Control vertical speed to allow a safe turn maneuver to establish a new approach and landing flight path.		°Monitor takeoff and landing to support a go-around decision.
8.1 Provide go-around guidance.	°Drive displays to give visual cues for manual control of attitude, airspeed, and vertical speed. °Provide automatic steering commands for heading hold following achievement of safe go-around vertical speed. °Drive displays to give visual cues for manual intercept, capture, and track of ILS glideslope and localizer beams to establish new approach and landing sequence.	°Provide automatic steering commands for heading select and hold, vertical speed hold, and altitude select and hold to intercept, capture, and track the ILS localizer and glideslope beams to establish a new approach and landing sequence. °Provide auto throttle control coordinated with pitch axis control to arrest descent rate with a minimum al altitude loss and establish a climb rate. °Modify steering commands to be consistent with structural and passenger comfort limits.	
8.2 Provide go-around navigation.		°Advance vehicle state with specific force integration using sensed accelerometer data and onboard model of gravity forces. °Maintain navigated state using onboard and ground naviga-tion aids. (Radio altimeter, VOR/DME, ILS, etc.)	°Provide VOR/DME stations and ILS.
8.3 Provide go-around control.	°Provide stall warning based on angle-of-attack, air-speed, and aerosurface positions. °Provide manual control of aerosurfaces. °Provide manual ABES throttle control. °Provide semi-automatic attitude hold. °Provide stability augmentation.	°Provide automatic attitude hold and attitude maneuver in response to automatic steering commands.	

6.2 CRITICAL AREAS

The following critical areas are identified in order to focus attention in the areas where the GN&C functional requirements are not clear or firm. Tradeoff analyses and/or more system development must be performed in order to define the requirements related to these critical areas.

1. Ground/Shuttle Interface - The functions of ground support to shuttle horizontal flight operations (both preflight and inflight) are not clearly defined. Tradeoff studies are required to determine the best utilization of ground support.

2. Shuttle Autonomy - The requirement for shuttle autonomy during horizontal flight operations is not clearly defined. That is, will operational horizontal flights be similar to commerical airline flights with ground support limited to monitoring the orbiter flight path for air traffic control or will the horizontal flights be heavily controlled with air corridors cleared for orbiter flight and flights limited by weather conditions?

3. Automatic Fault Detection, Isolation and Switchover - Fault detection and isolation will be implemented for the operational horizontal flights. The requirements for automatic fault detection, isolation and switchover must be determined on a GN&C component or hardware string basis.

4. Operational Mode Switchover - The interfaces between operational modes such as automatic and manual override modes have not been defined. These interfaces must be defined in order to identify the specific functions of the software.