SHUTTLE MISSION SIMULATOR

REQUIREMENT REPORT

VOLUME II

REVISION A MARCH 23, 1973

SINGER
SIMULATION PRODUCTS

A DIVISION OF THE SINGER COMPANY • DEVELOPER AND MANUFACTURER OF THE LINK TRAINER SINCE 1929

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J. F. Burke
Principal Investigator
SMS Definition Study

This document is submitted in compliance with Line Item No. 3 of the Data Requirements List as Type I Data, Contract NAS9-12836

THE SINGER COMPANY
Simulation Products Division

SHUTTLE MISSION SIMULATOR
REQUIREMENTS REPORT
VOLUME II
REVISION A

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PREFACE

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1.0 Purpose

The training requirements for crew-training is self-evident due to crew safety considerations and the cost-effectiveness of the usage of a simulator rather than the STA or the vehicle itself. The training of ground personnel (MCC) has to be accomplished and using the SMS is cost-effective since the same training device will provide training for both crew and MCC personnel for a modest increase in the SMS cost. The booster components of the Shuttle System are required for simulation due to the fact that the Orbiter Vehicle provides the GN&C for the Boost Phase of the mission, the Main Engines are an integral part of the vehicle itself and the transition to aborts would be difficult if not impossible since the same on-board computer is used for both mission phases.

2.0 Scope

The four primary tasks defined form a logical division of the effort from both a chronological viewpoint and a functional viewpoint.

The WBS breakout was selected to provide sufficient visibility to NASA without creating costly reporting and monitoring requirements. Modifications will be made to this structure as cost and the criticalness of the program elements become clearer.

The program milestones were based on current NASA programming and NR schedules in the Crew Station definition area.

3.0 General Requirements

3.1 Performance

The selected configuration is based on six factors, namely:

1) Motion Cues are required for crew training in aerodynamic flight.

2) Contemporary motion systems are not capable of supporting a full visual system and the cockpit.

3) For boost and boost abort transitions to aerodynamic flights sustained logitudinal acceleration is a highly desirable training feature which could not be accommodated even if a limited visual system (i.e., no rear visual) were acceptable.

4) The vehicle design philosophy is to isolate crew activity between the front and rear stations. However current NR data indicates that the Mission Specialist may have duties associated with the Commander's wing panels. To cover this possibility and any growth of responsibility the Mission Specialist and Payload Specialist's seat positions have been included in the MBCS.

5) The quantity of training equipment requirement required is minimized by this division of crew stations and while not an absolute minimum, it provides less risk than the previous approach.

6) A high degree of fidelity is provided for orbital training in the FBCS.

The HFTS will support the horizontal flight tests which relieves the need for the SMS to support the HFT phase of the program. Conversely, the HFT phase overlaps significantly the VFT phase. Current NR schedules call for the rear crew stations to be incorporated in the orbiter to support the eight vertical flight.

The design of the SMS has as its goal a versatile training device capable of training crew members to the required level of proficiency in all phases of the Shuttle mission. The simulator consists of two crew stations (a Fixed Base Crew Station and a Motion Base Crew Station) which can be used for training simultaneously. Different training exercises can be practiced in each section simultaneously on a non-interference basis except for entry, ascent, launch aborts, and approach and landing. Since motion cues are deemed necessary for aerodynamic flight, the MBCS will be used primarily for this type of training after both crew stations are operational. The FBCS will be used primarily for orbital work for the same reason. A backup capability exists in case the MBCS is out of service or in case mission requirements while integrated with MCC call for four man participation for the FBCS to perform aerodynamic training. To reduce cost equipment unique to the aerodynamic flight regimes will be time shared between crew stations. With the SMS equipment specified crew members and ground personnel can be trained in basic system procedures and flight operation procedures for all mission phases.

4.0 Program Management

For the most part, this paragraph is standard Program Management requirements very close to the SLS requirements. Major differences are the post-acceptance modification effort which is required due to the concurrent design of the simulator and spacecraft.

The level of effort man-power requirements is to equalize the competition since the change activity cannot be predicted.

5.0 PROGRAM CONTROL REQUIREMENTS

The controls specified are in compliance with the intent of NHB 8040.2 and based on Skylab experience. Due to the short schedule the incremental PDR(s) and CDR(s) are required to all long lead items to be procured and manufactured within the program schedule.

6.0 Technical Requirements

6.1 System Engineering Requirements

The documentation requirements are consistent with the intent of NHB 8040.2 and the experience gained in the conduct of the Skylab Simulator program.

6.2 Design and Development Requirements

6.2.1 General Design Requirements

6.2.1.1 Operability

All of the requirements identified and specified under this heading are standard simulator type requirements normally defined in specifications such as the following:

MIL-T-9212B (USAF)	Trainer, Flight Simulator, Aircraft, General Requirements for
MIL-T-23991C	Military Specification, Training Devices, Military General Requirements for
MIL-T-82335A (TD)	Military Specification, Trainer, Fixed Wing, Flight, General Specification for

These requirements are all commensurate with the intended application of the training device. The specifications mentioned above were used as a guide in identifying and specifying SMS requirements.

6.2.1.2 Facility Interface

6.2.1.2.1 Product Configuration

The layout requirements for the simulator crew station, IOS and visual systems are based on NASA planning. The requirements in the equipment room, maintenance lab. and office area are based on the fact that the SCC will be in Houston during the program and on-site personnel will have to be quartered there to maintain it and install and checkout.

6.2.1.2.2 Power

The types of electrical power were chosen because they are available at the site and easily utilized.

The National Electrical Code shall be used extensively in addition to best commercial practices.

6.2.1.2.3 Air Conditioning

Describes air normally supplied to Bldg. 5 by NASA.

Supplier to stipulate Vol. & Cooling to permit NASA to verify adequacy of existing system or to plan for modifications.

6.2.1.2.4 Facility Layout

Reflects arrangements planned by NASA and defines the space for contractor layout. Permits NASA to estimate complexity and cost of Bldg. modifications required, and to coordinate building utilization plans.

FIG. 6.2-I shows dim. detailed info - Plan

FIG. 6.2-II shows detailed elev. view of SMS area

FIG. 6.2-III shows overall (N&S) Bldg. arrangement for space allocated to SMS equipment

6.2.1.3 Design and Construction Standards

Refer to Section 6.2.1.3.

6.2.1.4 Software Design

6.2.1.4.1 Simulator System Software

It is essential that the task structure be carefully evaluated to ensure the efficient use of the resources of the GFE Computer Complex is made. Otherwise, the situation could arise where the simulation task requirements cannot be met because of excessive core and/or execution time constraints.

The choice of Computer Languages can have a direct bearing upon the development schedule and man-hour requirements as well as in the operational phase. Another area of impact is the fidelity of the simulation software as changes are made and incorporated.

In order for configuration control of the simulation software to be reliable, full use of the GFE operating system facilities must be made. This is especially true in the case of source program up dates and load module creation. The support software must be as flexible and reliable as possible.

6.2.1.4.2 Simulated Shuttle Systems Software

6.2.1.4.2.1 Structure

The Shuttle Mission Simulator is expected to consist of:

1) A MBCS and,

2) a FBCS

3) Instructor/Operator Station separate for each plus an optional instructor jump-seat location in (1) above.

The training stations will be capable of independent part task training, as well as integrated training with the Mission Control Center

6.2.1.4.2.2 Training Configurations

The training instructor/monitor should have the option of selecting the load configuration from the options available.

6.2.1.4.3 Modifications

A well-known problem is the conflict in computer requirements between training and modification requirements with training usually taking priority due to schedule commitments. The specified system would allow modification development in parallel with training and, in some cases, simultaneously without conflict. The development modules would reside in mass storage and be loaded on-line on a non-interference basis with associated driver programs. After this stage of development (e.g., checked out with drivers for all modes of operation), the modification modules could be called into the training load and, on acceptance, become part of the operational training load under configuration control. The driver modules should also be available for diagnostic checkout for both hardware and software - especially for verification of the various integrated/non-integrated modes.

6.2.1.4.4 Simulator Modes

The simulator modes allow initial action of each training problem, operation under these initial conditions in real time, slow time or step-ahead as required for training and freeze or holding the problem at computed values to allow instructor participation in discussions with the trainee without distraction of the trainee from the simulation.

6.2.1.4.5 Training Modes

The Simulator will be required to participate in training exercises with the mission control center in conjunction with other computers and simulations. This mode is at the users option.

6.2.1.4.6 Telemetry, Digital Command System and Trajectory Interface

The interface is dictated by mission phase requirements. Formats and data rates are established by existing equipment. Any change to this existing equipment is expected to be for the purpose of modernization to improve reliability but will have only minimal impact on the simulator requirements.

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6.2.2 Work Breakdown Structure/CEI Organization

The WBS breakout was selected to provide sufficient visibility to NASA without creating costly reporting and monitoring requirements. Modification will be made to this structure as cost and the criticalness of the program elements become clearer.

The MBCS and FBCS specification trees are based on the currently identified equipment and software requirements of the SMS. Many of the elements of the FBCS end items will be minor modifications of the end items of the MBCS particularly in the software area.

6.2.3 Crew Station Requirements

6.2.3.1 Crew Station Hardware

6.2.3.1.1 General Description

This section describes the physical constraints of each Crew Station configuration imposed upon them by the motion system and visual system characteristics.

6.2.3.1.2 Cockpit Envelopes

This section describes the parameters for the crew station size.

6.2.3.1.3 Lighting

This paragraph emphasizes reproduction of vehicle lighting.

6.2.3.1.4 Interior Fidelity

This section itemizes the crew station content as being replicas of the actual vehicle.

6.2.3.1.5 Ingress/Egress

This section establishes the requirement for doors and escape hatches in a general fashion to preclude unnecessary constraints,on each section configuration.

6.2.3.1.6 Environment

This section reflects normal air conditioning requirements which can be readily achieved with a standard air conditioner equipped with heaters to achieve a comfortable environment. It further precludes inadequate ventilation by permitting additional outlets.

6.2.3.1.6.1 Pressure Suit

This section is typical of requirements for a hypothetical suit system. The feasibility of supplying sufficient volumes to satisfy the "3.5 psig at max. flow" is uncertain since the suit characteristics (i.e., the max. volume capability) are unknown.

The last paragraph is also typical wording to emphasize crew safety.

6.2.3.1.7 Stowage

This definition is general and primarily added to permit the trimming of the outer lines to less than actual spacecraft lines if the excess is devoted to stowage.

6.2.3.1.8 Layout Model

This section addresses the itemized content of a mockup to identify and evaluate the proposed configuration in an economical and timely manner. It further defines the intent of the mockup as a non-transportable model, i.e., intended for in-plant evaluation only.

6.2.3.2 Controls and Displays Hardware

The decision to use flight hardware as opposed to simulated hardware must be made on an item by item basis.

The use of flight hardware requiring complex hardware interfaces should be avoided.

Trainee and instructor station controls and instruments should duplicate the static and dynamic performance of the design basis orbiter vehicle in accordance with design data and tolerances specified by that data. Instrument oscillations, rates of change, and lags experienced in the operation of the design basis vehicle should be included in the SMS indication responses.

(Refer to Simulation Techniques Study, Section 2.0). Tolerances can only be approximated at this time since they are chosen as a function of actual spacecraft equipment tolerances.

6.2.4 Instructor-Operator Stations

The simulator complex for the SMS consists of two training devices. The training devices are: a motion base crew station (MBCS) and a fixed base crew station (FBCS). The MBCS would permit monitoring of training exercises for all phases of the mission except docking and payload handling. The MBCS would be used primarily to train the Commander and Pilot. It would also be used to train the Mission Specialist and Payload Specialist in those duties required to assist the Commander and Pilot during the Launch deorbit and landing phases of the mission. The MBCS would be mounted on a six degree-of-freedom motion system capable of tilting the simulator to a vertical launch position. A visual system capable of displaying the scene as seen from the forward cabin is also a part of the MBCS. The IOS for the MBCS is designed to be manned by two instructors. However, during training exercises involving one student, only one instructor is required.

The FBCS would provide instruction for all phases of flight associated with space and aerodynamic operation. The FBCS would be used to train all crew positions including the OMS station. The FBCS would be mounted on a fixed base and contain a visual system which would provide the views seen from the forward cabin windows and the cupola windows. Because of the number of crew positions to be trained on the FBCS, the IOS's would be designed in modular form. The FBCS IOS complex would consist of the following IOS modules: Commander and Pilot. Orbital

Maneuvering Station, Mission Specialist and Payload Specialist, and Telemetry Station. The Telemetry Station IOS would be shared by both the MBCS and FBCS.

The design of the simulator complex would be such that training exercises could be conducted simultaneously on the MBCS and FBCS. The FBCS would provide training for all crew positions. Training could be conducted individually at each crew station, but not at the same time, and collectively for integrated crew training, or mission rehearsals integrated with MCC.

The Commander-Pilot IOS would normally be manned by two instructors. When training was being conducted for one trainee, only one instructor would be required. The remaining IOS's would be manned by one instructor each.

Each IOS contains the necessary controls and displays to set up, control and monitor all simulated training exercises. Instructor functions are implemented through intelligence received from repeater indicators, CRT display units, TV monitors, and simulator peculiar controls.

Repeater indicators will be reserved for basic flight instruments (e.g., Flight Director Attitude Indicator, Horizontal Situation Indicator, Airspeed/Mach Number Indicator). The instructor will also be provided the capability to monitor CRT displays at the crew stations.

Provisions are also made for the instructor to monitor the visual scenes presented at the forward cabin windows and the cupola windows. CRT display/keyboard units at the IOS will permit the instructor to monitor and record the trainee's performance. Through the CRT display/keyboard unit the instructor will be able to monitor the following functions:

a. Event Time Monitor

b. Panel Displays (excluding those provided by dedicated displays)

c. Energy Management Predictor

d. Malfunction Insertion and Display

e. Circuit Breaker Status

f. Crew Station Setup Verification

g. Active Malfunctions and Tripped Circuit Breakers

h. Mission Parameters and Summary Display

i. Interface Data Stream and Telemetry Monitoring

j. Enroute and Approach Display

k. System Schematic Displays

l. Programmed Demonstration Displays

m. Training Exercise Displays

n. Performance Monitor Displays

o. External Environment Display

p. Simulator Reset Display

q. Simulator Status Display

The instructor is provided with all the switches and controls necessary for the safe operation of the simulator and its associated systems. The instructor has at his disposal the capability to "freeze" the simulator at any time during the training exercise, and to restart the mission from that point. In addition, the instructor can advance or "back-track" to any position in the training exercise. He can also reset the simulator to any one of the 20 reset points.

Each instructor has located at his position a voice communications terminal which allows selective voice communication within the simulator complex as well as associated support facilities.

In addition to the IOS's which are located external to the simulators, a one-position IOS is located within the MBCS. This station consists of a portable seat which is installed prior to those missions requiring Mission and Payload Specialist. The seat is located in the center of the cabin, just aft of the center console. The instructor is also provided a portable control box which permits limited control of the training exercise.

Locating an instructor at this position places him at a location where he can observe the trainee's performance more closely than is possible at the conventional instructor station. At the latter station, the instructor cannot observe the false starts associated with the trainee's performance. Being in the cockpit, the instructor is on the scene to provide immediate instruction when required. It is anticipated that this instructor position would be used during the early phases of the training program for procedural training, or at any time for remedial training.

6.2.5 Ancilliary Equipment

6.2.5.1 Aural Cue System

The best approach to vehicle sound simulation at this time is a computer controlled real time acoustic effects generator. Its initial cost is relatively low compared to other techniques. Modification and updates will involve primarily only software changes. In addition, repeatability is excellent.

6.2.5.2 Simulator Power - Hardware

The simulator power interface must first of all be compatible with the capabilities of the installation site.

Three phase power loads should be balanced.

The power distribution should be designed with on-off sequencing and interlocks to prevent damage to equipments and to insure the safety of operating personnel.

Shielding and grounding systems should be designed to minimize internal system noise and to insure safety.

Bonding should also be provided.

Filters and other noise suppression elements should be considered in the design to minimize EMI problems.

6.2.5.3 Central Timing Equipment

NASA supplied time signals are required in order to maintain systems coordination and synchronization. In non-integrated mode, these signals are provided by the SMS CTE to allow stand alone operation. All systems shall key on these signals to prevent time related events from becoming misaligned.

6.2.5.4 Hydraulic System Hardware

This paragraph is inserted to specifically define the area reserved for the hydraulic pump, etc., and emphasize the room sharing essential for future installations.

6.2.5.5 External Signal Interfaces

Specific SMS interface requirements which have been identified are the SMS/GSSC computer interface, the central timing equipment interface, and the voice communications interface.

Interface requirements with other control centers are not known at this time. Interface with another center could be accomplished either through the GSSC data link or by telephone data line to another computer installation.

Under the current concept of SMS crew training, the IOS shall provide all GCA and ATC functions. No external interface requirement exists for either of these functions.

The interface requirements and definition of tasks between the simulators in Building 5 and the Ground Support Simulation Computer (GSSC) is given by document "GSSC-604 Ground Support Simulation Computer Program Specifications - FCT Interfaces." This document should be used as reference only for a typical ICD. Any or all information in the referenced document is subject to change.

6.2.6 On-Board Computers

6.2.6.1 Data Processing & Software System

6.2.6.1.1 Fidelity

The simulation of the Data Processing & Software computer system of the Shuttle Vehicle is required to the level that all crew display data and telemetered data responses are extremely realistic for both displayed value and time response to interface signals, commands and switching logic, and simulator moding. Both the short period and long period accuracy of the simulation must be very high to maintain astronaut confidence in the simulated system and avoid negative training in the use of the system. This will be particularly true during M.C.C. integrated mission training where outputs of the ground computer system are compared with the calculations made in the simulator. Hence the requirement for use of actual OBC flight programs, and an accuracy no less than that of the actual on-board computers.

6.2.6.1.2 GFP Integration

As a minimum, the actual crew station display and control equipment should be used in the simulator to ensure high fidelity display and control. This should include the dual redundant tape readers. If actual real world computers are to be used in the simulator it must interface with the display, control, and tape reader equipment and also must interface with the main simulation computer complex.

6.2.6.1.3 Flight Software

Use of actual OBC flight software is a necessity for reasons of simulation fidelity and to avoid delays inherent in the functional simulation software development and test/verification processes.

6.2.6.1.4 Loading

If real world on-board computers are incorporated into the simulator, the loading can be accomplished using the same tape reader and tapes provided in the real world, with a minimum of tape editing. (This assumes that the OBC programs are to be reloaded in flight as a training procedure.)

If a translative or interpretive approach to the simulation is mechanized, the tapes will require editing and/or preprocessing to enable their use.

6.2.6.1.5 Moding

The simulated OBC must interact with the simulator mode functions without degradation. If a real world OBC is incorporated in the SMS special interface hardware, interrupt generators, will be required. Interrupt handling software will also be required to be added to the OBC software for these special functions.

6.2.6.1.6 Update

It is anticipated that software changes to the DP&S OBC programs will occur with very short notice. Therefore, the requirement for use of real world software is imposed. In conjunction with this, the simulator software should be capable of being rapidly updated and reverified, and any equipment or software required to expedite this operation should be provided.

6.2.6.1.7 Diagnostics

If real world computers are incorporated into the SMS, diagnostic software is required to verify its performance, isolate malfunctions and minimize the time required to repair. These programs should also enable test of interface, peripheral and control display equipment where applicable.

6.2.6.1.8 Interface

This equipment is required to the extent necessary to interface GFE OBC hardware to the GFE main simulation computer and to GFE control and display equipment.

6.2.6.1.9 Debugging Tools/Equipment

Debugging tools and equipment and any special test equipment should be provided in conjunction with diagnostic programs to minimize time to repair OBC hardware.

6.2.6.1.10 Synchronization

Time synchronization is essential for operation of all simulator clocks and MCC clocks to minimize errors between the trajectory calcuations in the vehicle and on the ground.

6.2.6.1.11 Reset

The reset function in the simulator is provided to enable rapid return and restart at mission time points where extensive training is required while skipping over time period of low activity, e.g., sleep periods - for the on-board computer, the reset function should also be synchronized with the main simulation computers to avoid errors in the trajectory calcuation.

6.2.6.1.12 Redundancy Requirements

The Astronaut should be able to select the active and stand-by GN&C computers, and switch to the Backup GN&C computer and realize the same effects as in an actual flight.

The requirement to simulate redundancy effects occurs in conjunction with the requirement for simulated malfunctions to train in all backup modes of operation.

6.2.6.1.13 Simulated Malfunctions

Simulated malfunctions should be chosen based on failure analysis of real world equipment coupled with the desire to train the astronauts in all backup modes and highly critical procedures to ensure their safety in the real flight.

6.2.6.2 Main Engine Controller and Interface System

6.2.6.2.1 Fidelity

Each of the three Main Engine Controllers consists of:

a) triple redundant input electronics

b) Double redundant computer interface electronics

c) Double redundant output electronics

d) Double redundant power supply electronics

e) Double redundant HDC-601 digital computers with a 12K word 16-bit plated wire memory. These computers are space rated versions of the Honeywell H-316, DDP-516 computers.

Each Main Engine controller interfaces with the orbiter avionics through a 1MHZ serial digital command and response data transmission system (3 buses per engine) plus an additional data path (2 buses per engine for recorded data and telemetry.

The simulation of the Main Engine computer programs should be of equivalent accuracy resolution and iteration rate as real world. Data rates and formats to recorders and to the Telemetry system must be simulated with high fidelity.

6.2.6.2.2 GFP Integration

Utilization of commercially available equivalents of the HDC-601 are envisioned for simulation of the Main Engine Controller.

6.2.6.2.3 Flight Software

Because the availability and anticipated amount of change of flight software are unknown, it is presently deemed essential to be able to utilize this software with a minimum amount of editing.

6.2.6.2.4 Loading

See Section 6.2.6.2.1

6.2.6.2.5 Moding

See Section 6.2.6.1.5

6.2.6.2.6 Update

See Section 6.2.6.2.3

6.2.6.2.7 Diagnostics

If real world computer hardware or equivalent is incorporated into the simulator, then diagnostics are required for this hardware.

6.2.6.2.8 Interface

See Section 6.2.6.1.8

6.2.6.2.9 Debugging Tools/Equipment

See Section 6.2.6.1.9

6.2.6.2.10 Synchronization

See Section 6.2.6.1.10

6.2.6.2.11 Reset Requirements

See Section 6.2.6.1.11

6.2.6.2.12 Redundancy Requirements

Simulation of the redundancy features is desired to enable training in backup modes and procedures by inserging malfunctions of one or more elements of the engine controllers.

6.2.6.2.13 Simulated Malfunctions

Each element of each engine controller will be malfunctioned to provide crew and MCC training in backup modes and procedures.

6.2.7 Computer Complex

The SMS computer complex shall consist of a commercially available general purpose digital computer system with associated software to activate, operate and support the simulator. All hardware with options, peripheral equipment, and software will be provided as GFE as specified in Exhibit 3.

The operating system requirements specified are mandatory to achieve optimum utilization of the GFE computer complex. The ability to support multi-programming, real-time batch processing, and local and remote terminal processing simultaneously will facilitate the development, maintenance, modification and utilization of the SMS task. Coordination of the elements in a system such as SMS to insure simulation and background processing integrity dictates the need for sophisticated communication facilities.

As the SMS continues to be used in training of flight crews new changes to the simulation will arise. To achieve this capability initial spare and expansion provisions are necessary. This expansion of the simulation will be in the areas of more input/output data, more memory, and more central processor time.

6.2.8 Digital Conversion Equipment

The current NASA planning envisions the DCE being provided GFP to the SMS contract. It shall be the SMS contractors responsibility to interface the SMS equipment to the GFP DCE and also to provide spares for the operational/modification phase.

6.2.9 Visual System

6.2.9.1 General Requirements

Visual simulation systems will be needed for the front windows, through which the spacecraft commander and pilot look, and the rear window at the cargo handling station. The front windows will be used during both atmospheric and space flight, and thus require a combination of the visual system capability found on simulators of commercial transports (e.g., L-1011) and on space vehicles (e.g., Apollo). Simulation of the view during atmospheric flight is not needed from the rear window, which is covered during launch and reentry. For some operations, synchrony of the views through front and rear windows is required, e.g., when an object passes from the field of view of the front windows to that of the rear window.

Throughout the treatment that follows, the emphasis will be on providing those aspects of the visual scene needed (1) to train the crew and (2) to verify the adequacy of their performance. Under this philosophy, there is no need to provide visual cues for those mission or phase segments during which such cues may not be present.

Assuming a full manual approach and landing capability will be required of the Shuttle Vehicle pilots, the question can be asked if it is necessary to provide the simulation for both a Category II instrument situation and the full VFR situation. If the skills required to perform the manual instrument approach and landing task are essentially the same as those used in the manual VFR approach, then it may not be necessary to provide the full VFR scene and simply confine the training to the instrument situation. Unfortunately, this does not seem to be the case for the following reasons:

a. Just as there is a possibility of failure of the automatic approach and landing system, there is the possibility of the failure effecting receivers and displays used in the manual instrument approach. Should this happen, one would expect the pilot to be able to make an "eyeball" approach if conditions are VFR. Economics will prevent this kind of practice in the actual vehicle, thus establishing a need for full VFR simulation.

b. Another consideration that suggests the need for VFR simulation has to do with normal pilot performance when all systems are operating normal and the approach and landing will be made under VFR conditions. Because a more precise approach can be made when the automatic system is operating than when manual skills are being utilized, and a manually flown instrument approach is more precise when used under VFR conditions than an "eyeball" approach, these become the preferred approach techniques under VFR conditions. However, when VFR cues are available, the pilot will intermittently use them to cross-check the validity of the situation as being depicted on his instruments. Since the scene as viewed out of the cockpit has the highest priority in determining the need for corrective responses, it is important that the pilot have the correct frame of reference for making these responses. Or, putting it another way, the visual scene he expects to see at any point in time if the situation is normal, becomes a sort of perceptual overlay on the actual scene from which he makes comparisons to detect discrepancies that require correction. Since these "expectancies" must be built from experience base and since the Shuttle Vehicle will fly a uniquely different approach path, the pilot's previous experience will not provide the necessary standards. It thus becomes essential to provide the kind of experience from which these "expectancies" can be properly structured. Again, and for all practical purposes, this can only be done through full VFR simulation.

c. In addition to the above arguments for full VFR simulation, one other rather subtle but never-the-less compelling argument can be made. This has to do with the fact that the approach and landing task is different and more difficult when some dependence is placed on cues arising outside the cockpit than when a pure instrument approach is made. Not only are attitudinal cues less discernable and precise when acquired outside the cockpit than when depicted on instruments, they are also subject to illusions and take longer to detect. This puts a lag in the control loop that increases the difficulty of the task and makes it more subject to error. Also, because the pilot is very poor in making judgements of rate and altitude, with extra cockpit cues, he must make frequent references to cockpit instrument even on a VFR approach. Each time he shifts his focus from distant references outside the cockpit to close references in the cockpit, more time is required for both his physiological and psychological adaptation to the new scene. This again puts a greater lag in the control/display loop; further increasing the difficulty of the task. Therefore, simply training a pilot on just the instrument skills will not assure an equal proficiency when VFR cues are available to him on an approach and landing. The economics of the Shuttle situation suggests that the total skill requirement for assuring safe approaches and landings must be acquired via VFR simulation.

Thus, the emphasis will not be on realism per se, but on the provisions of cues (or aspects of the visual scene) adequate to enable needed tasks to be accomplished. Under normal conditions, therefore, operational tasks will generally be easier than those practiced in the simulator, with the exception of zero-g effects.

Even with these delimitations, Shuttle visual simulation may require a combination of capabilities each one of which stretches the visual state-of-the-art: wide field of view, simultaneous viewing by two crewmen, disparate imagery (earth with cloud cover, viewed from near and far; celestial bodies; rendezvous vehicle), and, possibly, stereopsis (for manipulator arm control).

The problem of sun shafting merits special mention here. Assuming that the training objective (with respect to sun shafting) is to avoid sun shafting conditions, rather than attain competence in working under conditions of sun shafting, this phenomenon need not be simulated, but merely signaled, e.g., by a whiteout of the visual field or by a sun symbol.

The rear window is uncovered by the cargo doors during non-atmospheric flight, and, while its prime functions is to support the use of the manipulator arms during payload operations, and/or docking, and undocking, it can also be used by the spacecraft commander and pilot to view objects not in the forward windows' FOV. Since existing motion systems cannot support visual systems and cockpits for both front and rear stations, providing the rear window view to the spacecraft commander and pilot would require a separate FBCS, in addition to the MBCS, with visual systems, mounted on the motion system.

The resolution requirements for each of the mission phases depend upon the use to be made of the information provided by the visual system. When the visual system furnishes steering data that is closely coupled with control action, e.g., during the latter portion of approach and landing, high resolution is called for; when it furnishes general orientation data, a lower resolution can be accepted.

For example, verification that the SRM has separated does not require an accurate image of the SRM; a somewhat soft or fuzzy SRM image, provided it were easily recognizable, would be quite adequate. On the other hand, a rather sharp image of runway edges is required for proper lateral control during landing. Were the runway edge fuzzy, its exact position would be indeterminate, and large lateral deviations from nominal could occur before they could be perceived.

This is the same basic philosophy as that used by the Air Transport Association Training Committee in specifying resolution requirements for visual system (Visual Simulation for Airline Aircraft Simulators: Guidance Information, adapted 24 January 1968).

ATA established, for each of 6 points on the glide slope different distances from the end of the runway (6 mi, 4 mi, 2 mi, ½ mi, 1000" and end of runway), 1) What You Must See (at ½ mi, e.g., "complete runway detail"), 2) How Well (at ½ mi, e.g., "to recognize 6' vertical object on end of runway"); and 3) With Ability To Accomplish (at ½ mi, e.g., "Alignment, establish closing rate and maintain touchdown points").

Contrast requirements are less task dependent. Visual acuity and ease of perceiving a figure (object) against a ground (surround), depends on the contrast between them; low contrast ratios will cause visual tasks to take longer, be more fatiguing, and, in the extreme, fail to allow proper visual discriminations to take place. Fig. 6.2.9-1 shows the effect of contrast upon visual acuity at various brightness levels.

Brightness plays a similar role to contrast in determining visual acuity. The eye cannot sense the brightness of a visual field to better than an order of magnitude (if that); acuity becomes better with increasing brightness over a wide (10^7) range of brightness values. See Fig. 6.2.9-2 . The brightness(and contrast) of a visual

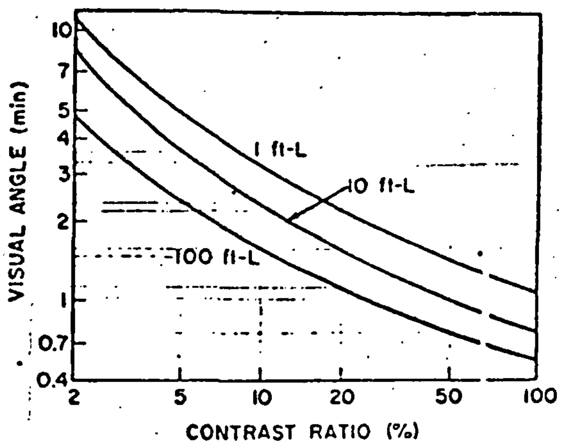

Fig. 6.2.9-1

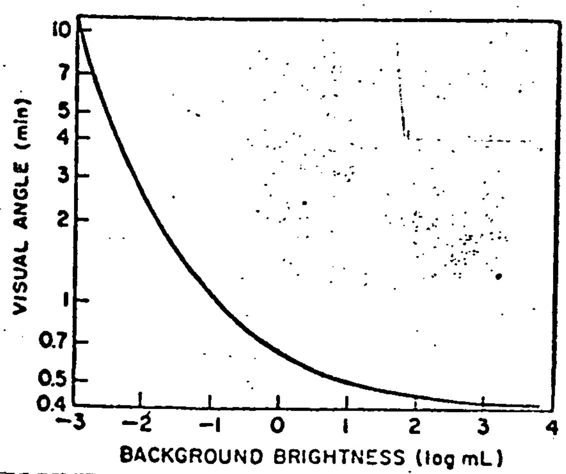

Fig. 6.2.9-2

simulation system should be such that acuity, in the darker portions of the field (e.g., those with .01 the highlight brightness) is still enough finer than the visual simulation system resolution so that the visual simulation system resolution, not human visual acuity, limits the man-machine system performance in resolving objects.

The problem of flicker will be noted here, but not treated in any depth. Other things being equal, flicker will become more perceptible (and hence more objectionable) as other important parameters of the visual simulation system--brightness, contrast, field of view--improve. Thus, inproving one of these parameters of a visual system may, by introducing flicker, make the resulting system less, rather than more acceptable.

For flight outside the earth's atmosphere, the orbiter can assume any attitude, and hence it is desirable to simulate the full field of view of the spacecraft windows, since objects of interest (stars, earth, rendezvous vehicle) can appear, depending on the orbiter's attitude, anywhere in the field of view. During atmospheric flight, attitude constraints, with respect to flight path, can limit the appearance of imagery of interest to selected portions of the window, and hence simulating the full field of view of the window may not be necessary. Because of the time sharing between crew members of tasks requiring extra-cockpit vision, the visual requirements for these crew stations could be non-concurrent. For example, during approach, the pilot may be viewing the external visual scene while the copilot's head is in the cockpit, viewing instruments.

In order to provide full freedom of head movement within the simulator a 12 inch radius sphere is desirable. However, a 12 inch diameter sphere would be adequate to provide sufficient training and permits a larger selection of possible hardware designs.

6.2.9.2 Ascent Phase (Vertical launch to orbit insertion)

While the external visual scene is visible during at least part of this phase, it is not used as a basis for any crew actions, with two possible exceptions:

a) Such visual information might aid in determing whether an abort is necessary.

b) Visual verification of SRM separation.

It appears that all control actions during this phase, such as the throttling of engine thrust below 100% to limit vehicle acceleration to 3g, are either accomplished automaticalay, or based upon cockpit instrumentation; no indication was found in NAR SD 72-SH-50-3, or other Shuttle data, that any external visual cues are used during ascent. However for transition to the abort modes, it is recommended that identical cues required for each abort mode be provided.

6.2.9.3 Aborts

During this phase, out-the-window visual data are needed to establish altitude and to perform a landing. This landing could take place at KSC, WTR, or at a generalized airport. Four separate aspects of approach and landing, each with different visual system requirements need to be distinguished:

1. IFR landings under Category I or Category II visibility conditions. As will be noted later, this requires only a narrow FOV.

2. VFR approaches after glide path has been attained. The 15° glide slope is intercepted, and thus the pilot does not need to look all over to orient himself. Hence, a narrow FOV is adequate.

3. VFR flight above approximately 10,000 feet. Before the 15° glide slope is intercepted, the pilot requires a wide FOV to orient himself properly.

4. VFR flight with air-breathing engines. The orbiter has air breathing engines only for ferry flight, therefore the capability exists for a missed approach and go-around, and hence a wide FOV is required.

For the first case, IFR landing under Category I or Category II visibility conditions, a horizon is needed at altitudes above possible cloud layers, and a presentation comparable to that of visual systems of commercial transport simulators for altitudes below Category II ceilings. Typical parameters for such a Category II visual landing simulation would be:

FOV: 30 x 50° This FOV, which has proven adequate for simulators of commercial transports, is far less than the FOV of the vehicle. A recent study* reported "The result of flight trials, at night and in low visibility, with restricted peripheral vision are described. They were undertaken to discover whether lack of peripheral vision was a major cause of poor landing performance on conventional flight simulators. The results show that landing performance in flight is almost unaffected by loss of peripheral vision, even in poor visibility."

* Armstrong, B. D., Flight Trials to Discover Whether Peripheral Vision is Needed for Landing. TRC Report No. BR-233291, Nov. 1970. Abstracted in Ergonomics Abstracts 1972, Vol. 4, No. 2; original not seen.

This confirms an older study** by Roscoe in which it was shown that pilots could execute satisfactory landings with only a $10^{\circ} \times 10^{\circ}$ periscope view.

** Roscoe, S. N., The Effects of Eliminating Binocular and Peripheral Monscular Visual Cues Upon Airplane Pilot Performance in Landing. Journal of Applied Psychology 1948, 32. 649-662.

The only conflicting data come from experience with the VAMP on an F-4 simulator; pilots reported that they could not land the simulator without a wider field of view than VAMP provided. However, the high angle of attack of the F-4 completely blocks out the view of the runway when landing, whereas the orbiter front window is specifically designed to provide "Sufficient up vision to see the entire length of a 10,000 ft. runway at preflare altitude with worst case transients in orbiter pitch attitude...(and) Sufficient down vision to see 2^{o} below the horizon at main gear touchdown at worst case nose up attitude (tail scrape angle of 18^{o}). This is to assure that the pilot never loses sight of the runway ahead of him" (J. D. Roebuck (NAR) Memo No. SSP-PE-72-034 of August 18, 1972).

As noted earlier, the task of landing the craft is qualitatively different if ceiling and visibility are substantially unrestricted, and hence a different set of visual requirements holds for these largely VFR landings. These requirements include a wider field of view, since the pilot has time to look around and utilize the data obtained, and terrain contents compatible with altitudes, during the terminal approach and along the glide slopes.

Color is desirable, but not absolutely necessary; if a pilot can shoot a landing with a monochromatic presentation, he certainly can do so with a color system.

A target acquisition study (Fowler, F. D., and Jones, D. B., "Target Acquisition! Achilles Heel or the Display's the Thing." Proceedings of Society for Information Display, June 1972.) indicated that "for the relatively high contrast target/background combinations (21-85%) there was no difference between color and black and white displays for either detection or recognition."

The repudiation of the need for color would be invalid if it were necessary to use as cues the different colors of airport runway and taxiway lighting. Lack of such color differentiation (in a monochromatic system) is thought to make the landing task slightly more difficult, but certainly not impossible. We may conclude that color, while desirable, is not absolutely necessary, and may be traded off, if needed for brightness, FOV, etc.

During Abort Modes 4 & 5, and to some extent during Abort Mode 3, the crew is engaged in space, rather than atmospheric flight, and the out-the-window visual requirements approximate those of orbital flight. These requirements are discussed in the following section.

Maneuver Range: Area simulated modestly larger that that visible under Category II conditions. Go-arounds will not be possible in the configuration without jet engines, which greatly increases the area that need be simulated.

6.2.9.4 Orbital Operations Phase

During this phase, both front and rear windows are available for use. The front windows only will be used during the actual performance of orbital changes, even though the rear, as well as the front. could be used for viewing the jettisoned external HO tank. Thus, the needed scene content is for the front windows only and includes external HO tank, the horizon, and perhaps celestial bodies, if these are used for orientation. The cloud cover over the earth may be homogeneous and extensive enough to eliminate position cues and hence simulation of ground points is not required; however, attitude cues are provided by the horizon.

During this phase, the alignment of the backup navigation system is accomplished by an optical sighting device similar to the CSM Crewman's Optical Alignment Sight (COAS); constellations should be provided for identification since the stars preferably are selected to be sighted. However, the sun, moon and any of the four brightest planets may also be used. The simulation of the starfield used with COAS need not be better than $\pm 0.75^{\circ}$ the accuracy of COAS. Apollo starfield simulation for COAS has proven satisfactory.

Field of View: Full window coverage desirable.

6.2.9.5 Rendezvous

During this phase, the visual requirements are similar to those of Orbital Operations, with the requirement of the rendezvous vehicle being substituted for the external hydrogen/oxygen tank.

At a slant range of 300 n.m. the target is acquired by means of TACAN. Assuming the rendezvous target to be another orbiter 110 ft. in length and perpendicular to the line of sight, the target will subtend an angle of 13 arc seconds, a subtense well below the resolution of any known system.

The distance at which visual acquisition of the rendezvous vehicle will occur depends on whether it is a bright object viewed against a dark background (rendezvous usually begins this way - in darkness) or vice-versa, and the contrast between it and the background

When the rendezvous vehicle is considerably brighter than the background, it will be detected when it subtends no more than a few seconds of arc, e.g., at the 300 n.m. TACAN acquisition range; when it is considerably darker than the background, it will be detected at about 130 n.m., when it subtends about half a minute of arc. The angular subtense of the rendezvous vehicle when it is visually acquired cannot be duplicated in a simulator within an order of magnitude with the resolution attainable with current visual system technology; however, visual acquisition at maximum range, while desirable for procedural purposes, does not appear to be a difficult task requiring training. To cope with this limitation, it is suggested that the simulator image of the rendezvous vehicle be maintained at no less than 2 or 3 resolution elements, or the actual subtense, whichever is greater, so that the rendezvous vehicle can be visually acquired and tracked properly. Critical visual tasks, from a training standpoint, during this phase include determining the direction and distance of the rendezvous vehicle, and maintaining own vehicle orientation. In addition to the rendezvous vehicle, the visual scene must include the horizon, celestial bodies that are used for orientation, and the earth.

Field of View: Full window coverage desirable

"Page missing from available version"

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for fidelity of simulation of the dynamics of the arm (e.g., iteration rate). It is believed that the difficulties reported by Martin-Marietta in accomplishing manipulator arm maneuvers (in a simulation setting) stem from the inherent difficulties of multi-dimensional tracking, rather than from simulation inadequacies, and that, compared with that tracking task, the perceptual tasks involved are comparatively easy. Hence, high fidelity simulation of the visual scene, in particular providing binocular (stereopsis) cues, should not be necessary, since monocular depth cues, such as relative size and interposition, provide sufficient visual information. The simulation of the dynamics of the relationship between movement of manipulator arm controls and the locus of the image of the arms must be simulated with high fidelity. With a one-dimensional tracking task, Warrick (WADC RN 55-348) reported that lags of as little as 50 milliseconds in display degraded tracking performance significantly. With a multi-dimensional tracking task, effects of such lags would be no less serious; a very tight coupling of the visual display to the manipulator arm controls in the simulator is therefore required.

The uncertainty of the position of the manipulator arm relative to a target, resulting from the limited resolution of the visual system, should be no worse than the inaccuracy of manipulator arm positioning itself. At a maximum arm reach of 50', the $\pm 2''$ tip positional accuracy corresponds to 11.5 arc minutes. Hence a visual system with a 6' resolution would increase manipulator arm positioning inaccuracy by $\frac{6^2}{11.5^2}$ or 27% (from 2" to 2½") at the maximum arm reach distance; at closer distances, which are both more likely and more task-critical, the incremental error due to visual system resolution (or rather the lack thereof) would be less.

Floodlights and especially, spotlights need to be accurately simulated, since they provide a number of cues: the position size, and shape of the shadows they cast, the brightness of the field they illuminate as a function of distance, etc. These cues enable the relative viewing distance of various elements in the field of view to be determined, i.e., what is closer, and what is further away.

FOV: Full window desirable.

Color: Monochrome adequate

6.2.9.8 Deorbit

The selection of a landing site, one of the objectives of this phase, is not performed visually; indeed, most of the earth below may be obscured by cloud cover and/or on the night side of the day/night terminator. The visual simulation requirements for this phase are identical with those of Orbit Operations.

6.2.9.9 Entry

The visual simulation requirements for entry are identical with those of the orbit phase that precedes it.

6.2.9.10 Approach and Landing

The visual simulation requirements for this phase are identical with those of the Abort Phase, since approach and landing is the same whether accomplished under abort conditions or under normal mission conditions.

6.2.9.11 Ferry Flight

This phase can be partitioned, for visual simulation purposes into five sub-phases:

Taxi

Takeoff & Climb

Cross-Country

In-Flight Refueling

Approach & Landing

The following paragraphs address, for each sub-phase, the desirability of visual simulation, and (if desirable) the visual simulation requirements.

6.2.9.11.1 Taxi

There is a paucity of information on visual simulation of aircraft taxi. No training simulators have stressed taxi, though the capability for taxi exists, as a fallout of landing simulation, in camera-model and computer-generated-image visual systems. It is generally accepted that, 1) commercial transport pilots are exposed to enough actual aircraft taxiing during normal training, even in training programs emphasizing simulation and minimizing flying, to eliminate the need for simulator training in taxiing, and 2) taxiing is a skill that is easily learned, and 3) the cost and risks of training taxiing (as contrasted with other flight phases) in the aircraft itself are quite acceptable.

There thus appears to be no requirement for simulating the visual aspects of taxiing,* although if such capability "falls out" of other requirements, it could be utilized.

* This is in spite of the fact, noted by J. Roebuck in NAR Internal Letter SSP-PE-72-034 of 18 August 1972, that "Because of his height above the ground (approximately 22 feet) during rollout and taxiing the pilot (based on 747 experience) will think he is moving about 1/2 as fast as he actually is........".

6.2.9.11.2 Takeoff and Climb

As with taxi, there is a paucity of information on visual simulation of takeoff and climb. The out-the-cockpit visual scene provides, during this phase

. steering information, to aid the pilot in keeping the aircraft on the runway.

. run distance to aid in determining whether to abort takeoff

. horizon or equivalent data that aids in keeping wings level, or as a bank angle reference

. height information that tells, for example, when the wheels have left the ground and the landing gear can be retracted

The visual simulation system requirements for this phase are identical with those for landing, discussed earlier.

6.2.9.11.3 Cross Country

Since weather and visibility conditions may require this sub-phase to be conducted entirely on instruments, without visual reference, there is no requirement for visual simulation here. However if a horizon and cloud cover can be provided with no increase in complexity, it is desirable.

6.2.9.11.4 In-Flight Refueling

The flight by visual reference required during this phase is similar to formation flight. The Air Force has conducted in-flight refueling on a routine operational basis for some two decades, but has not moved seriously toward developing visual simulation for training in in-flight refueling. A development program in this direction was initiated in the early sixties, but dropped before prototype construction.

In light of the Air Force's experience, it would appear that visual simulation for Orbiter in-flight refueling is not really necessary, and, in view of the small number of in-flight refueling that can be anticipated with the small number of ferry flights projected, no substantial effort should be directed toward development of visual simulation specifically for in-flight refueling. As with taxi & cross country, if the capability for visually simulating in-flight refueling "falls out" of other visual simulation efforts, it might very well be exploited. The image generation requirements for in-flight refueling appear to be similar to those of rendezvous (when the tanker aircraft is distant) and to payload operations (when the tanker aircraft is near by).

6.2.9.11.5 Approach and Landing

The visual scene during this sub-phase of Ferry Flight differs from that during the Approach and Landing phase of an orbital mission in several respects:

1. The flight profile is different; during Ferry approach and landing it resembles that of a commercial transport.

2. Power from jet engines is (barring catastrophic malfunctioning) always available; during return from orbital missions such power is not available.

3. As a consequence of 1 and 2 above, such maneuvers as circling approaches and rejected landings (go-arounds) can be performed during ferry.

4. Many additional airfields are candidates for Orbiter use during Ferry, both programmed and emergency.

Hence a visual scene meeting the requirements noted for the Approach and Landing phase of orbital missions should also meet the requirements for the approach and landing sub-phase of Ferry.

6.2.9.12 Summary

Tables 6.2.9-1 through 6.2.9-6 summarize the visual system requirements phase by phase; the total requirement derives from the need of the simulator to meet these individual phase requirements.

	ASCENT (*)/ABORT PHASE MODES #1,2,3,4,5 h < 10,000 FT.	10,000 ≤ h ≤ 50,000 FT.	50,000 FT < h	ORBITAL OPERATIONS PHASE	RENDEZVOUS PHASE	DOCKING & UNDOCKING PHASE	PAYLOAD OPERATIONS PHASE	DE-ORBIT PHASE	ENTRY PHASE	APPROACH & LANDING PHASE H < 10,000 FT.	APPROACH & LANDING PHASE 10,000 FT. ≤ h ≤ 50,000 FT.	FERRY FLIGHT PHASE (**) TAKEOFF	FERRY FLIGHT PHASE (**) APPROACH AND LANDING
FIELD OF VIEW 1) PILOT W.R.T. DESIGN EYE	30°V 50°H	FULL WINDOW	FULL WINDOW	FULL WINDOW	FULL WINDOW	FULL WINDOW	NOT REQUIRED	FULL WINDOW	FULL WINDOW	30°V 50°H	FULL WINDOW	30°V 50°H	30°V 50°H
2) CO-PILOT W.R.T. DESIGN EYE	30°V 50°H NON-CONCURRENT	FULL WINDOW (NON-CONCURRENT)	FULL WINDOW (NON-CONCURRENT)	FULL WINDOW (NON-CONCURRENT)	FULL WINDOW (NON-CONCURRENT WITH PILOTS'S)	FULL WINDOW (NON-CONCURRENT)	NOT REQUIRED	FULL WINDOW (NON-CONCURRENT)	FULL WINDOW (NON-CONCURRENT)	30°V 50°H (NON-CONCURRENT)	FULL WINDOW (NON-CONCURRENT)	30°V 50°H (NON-CONCURRENT)	30°V 50°H (NON-CONCURRENT)
3) REAR WINDOW VIEWER	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	FULL WINDOW (CONCURRENT WITH PILOT OR CO-PILOT)	FULL WINDOW	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED
HEAD MOTION ENVELOPE 1) PILOT	12" DIA. SPHERE	12" DIA. SPHERE	12" DIA. SPHERE	12" DIA. SPHERE	12" DIA. SPHERE	12" DIA. SPHERE	NOT REQUIRED	12" DIA. SPHERE	12" DIA. SPHERE	12" DIA. SPHERE	12" DIA. SPHERE	12" DIA. SPHERE	12" DIA. SPHERE
2) CO-PILOT	12" D SPHERE	12" D SPHERE	12" D SPHERE	12" D SPHERE	12" D SPHERE	12" D SPHERE	NOT REQUIRED	12" D SPHERE	12" D SPHERE	12" D SPHERE	12" D SPHERE	12" D SPHERE	12" D SPHERE
3) REAR WINDOW VIEWER	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	DEFINED BY HEAD CLEARANCE ENVELOPE ABOVE BOTTOM WINDOW SILL OF AFT WINDOW	DEFINED BY HEAD CLEARANCE ENVELOPE ABOVE BOTTOM WINDOW SILL OF AFT WINDOW	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED
FOCAL DISTANCE	CATEGORY 1 (SEE LEGEND)	CATEGORY 1 (SEE LEGEND)	CATEGORY 1 SEE LEGEND)	CATEGORY 1 (SEE LEGEND)	CATEGORY 1 (SEE LEGEND)	CATEGORY 3 (SEE LEGEND)	CATEGORY 3 (SEE LEGEND)	CATEGORY 1 (SEE LEGEND)	CATEGORY 1 (SEE LEGEND)	CATEGORY 1 (SEE LEGEND)	CATEGORY 1 (SEE LEGEND)	CATEGORY 1 (SEE LEGEND)	CATEGORY 1 (SEE LEGEND)
COLOR	REQUIRED	REQUIRED	NOT CRITICAL	NOT CRITICAL	NOT CRITICAL	NOT CRITICAL	NOT CRITICAL	NOT CRITICAL	NOT CRITICAL	REQUIRED	REQUIRED	REQUIRED	REQUIRED
IDENTIFY OF SIMULTANEOUS VIEWING OBJECTS	OWN VEHICLE EARTH SCENE HORIZON	OWN VEHICLE EARTH SCENE HORIZON	OWN VEHICLE EARTH SCENE HORIZON CELESTIAL BODIES	OWN VEHICLE EARTH SCENE HORIZON CELESTIAL BODIES	OWN VEHICLE EARTH SCENE HORIZON CELESTIAL BODIES TARGET VEHICLE	OWN VEHICLE EARTH SCENE CELESTIAL BODIES TARGET VEHICLE	OWN VEHICLE CELESTIAL BODIES TARGET VEHICLE R.M.S. ARMS	OWN VEHICLE EARTH SCENE HORIZON CELESTIAL BODIES	OWN VEHICLE EARTH SCENE HORIZON CELESTIAL BODIES	OWN VEHICLE EARTH SCENE HORIZON	OWN VEHICLE EARTH SCENE HORIZON	OWN VEHICLE EARTH SCENE HORIZON	OWN VEHICLE EARTH SCENE HORIZON
						SEE NOTE 1			See Note 2				

LEGEND FOR FOCAL DISTANCE:
CATEGORY 1 - INFINITY (i.e., IMAGE DISTANCE 10') REQUIRED
CATEGORY 2 - INFINITY DESIRABLE BUT NOT CRITICAL
CATEGORY 3 - MONOCULAR AND BINOCULAR DISTANCE CUES DESIRABLE, HOWEVER, BINOCULAR NOT CRITICAL. ACTUAL OBJECTS DISTANCE LESS THAN INFINITY, HOWEVER, INFINITY ACCEPTABLE.
CATEGORY 4 - MONOCULAR DISTANCE CUES REQUIRED AND BINOCULAR CUES DESIRABLE. ACTUAL OBJECTS DISTANCE LESS THAN INFINITY AND INFINITY NOT ACCEPTABLE.
CATEGORY 5 - MONOCULAR AND BINOCULAR DISTANCE CUES REQUIRED AND INFINITY NOT ACCEPTABLE.

* NO VISUAL REQUIRED FOR NOMINAL ASCENTS
** NO VISUAL REQUIRED FOR TAXIING, CROSS COUNTRY & IN-FLIGHT REFUELING
NOTE 1: REAR WINDOW VIEWER FULL WINDOW DISPLAY IMPLIES AFT, UPPER AND ONE SIDE WINDOW SIMULTANEOUSLY.
NOTE 2: EITHER OWN VEHICLE, EARTH SCENE, AND HORIZON OR OWN VEHICLE AND STAR FIELD.

COMMON SYSTEM REQUIREMENTS

Table 6.2.9-1

	ABORT PHASE MODE #1,2	ABORT PHASE MODE #3	ABORT PHASE MODE #4,5	ORBITAL OPERATIONS PHASE	RENDEZVOUS PHASE	DOCKING & UNDOCKING PHASE	PAYLOAD OPERATIONS PHASE	DE-ORBIT PHASE	ENTRY PHASE	APPROACH & LANDING PHASE	FERRY PHASE TAKEOFF	FERRY PHASE APPROACH & LANDING
[illegible]												
EXTERNAL HYDROGEN OXYGEN TANK	REQUIRED: 1) IN ATTACHED POSITION 2) DURING SEPARATION	REQUIRED: 1) IN ATTACHED POSITION 2) DURING SEPARATION	REQUIRED: 1) IN ATTACHED POSITION 2) DURING SEPARATION	REQUIRED 1) IN ATTACHED POSITION 2) DURING SEPARATION 3) VERIFICATION OF SAFE SEPARATION	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
PLUME FROM SRM TERMINATION	REQUIRED: 1) EFFECT OF PLUME ONLY	REQUIRED t <109 SEC 1) EFFECT OF PLUME ONLY - N/Rt >109 SEC	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
SIDE OF VEHICLE BECAUSE OF HEAD MOTION (MANIPULATOR STATION ONLY)	N/R	N/R	N/R	N/R	N/R	REQUIRED	REQUIRED	N/R	N/R	N/R	N/R	
CARGO BAY	N/R	N/R	N/R	N/R	N/R	REQUIRED: 1) DOCKING TUNNEL IN EXTENDED POSITION ONLY	REQUIRED: 1) DOCKING TUNNEL AND CARGO BAY DOORS DYNAMIC 2) PAYLOAD FROM STOWED POSITION TO DYNAMIC POSITION 3) TRUNION LOCATIONS VISIBLE EMPTY BAY 4) CARGO BAY FLOODLIGHTS ILLUMINATING CARGO BAY	N/R	N/R	N/R	N/R	N/R

IMAGE CONTENT - "OWN VEHICLES" — TABLE 1 of 5

Table 6.2.9-2

	ABORT PHASE MODE #1	ABORT PHASE MODE #2	ABORT PHASE MODE #3,4,5	ORBITAL OPERATIONS PHASE	RENDEZVOUS PHASE	DOCKING & UNDOCKING PHASE	DE-ORBIT PHASE	ENTRY PHASE	APPROACH & LANDING PHASE	FERRY PHASE TAKEOFF	FERRY PHASE APPROACH & LANDING
HORIZON-INTERFACE BETWEEN TOP OF CLOUD LAYER AND SKY	NOT REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	NOT APPLICABLE	NOT APPLICABLE
HORIZON-INTERFACE BETWEEN EARTH AND SKY	REQUIRED	REQUIRED	REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	NOT REQUIRED	REQUIRED	REQUIRED	REQUIRED
CEILING HEIGHT	100-50,000 FT.	100-50,000 FT.	100-50,000 FT.	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	100-50,000 FT.	100-50,000 FT.	100-50,000 FT.
VISIBILITY	1,300 FT. TO UNLIMITED	1,300 FT. TO UNLIMITED	1,300 FT. TO UNLIMITED	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	1,300 FT. TO UNLIMITED	1,300 FT. TO UNLIMITED	1,300 FT. TO UNLIMITED
ILLUMINATION BY OWN VEHICLE LANDING LIGHTS	DESIRABLE	DESIRABLE	DESIRABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	DESIRABLE	DESIRABLE	DESIRABLE
TIME OF DAY	DAYLIGHT TO DARKNESS	DAYLIGHT TO DARKNESS	DAYLIGHT TO DARKNESS	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	DAYLIGHT TO DARKNESS	DAYLIGHT TO DARKNESS	DAYLIGHT TO DARKNESS
CLOUD COVER	NOT APPLICABLE	HOMOGENEOUS	HOMOGENEOUS	HOMOGENEOUS	HOMOGENEOUS	HOMOGENEOUS	HOMOGENEOUS	HOMOGENEOUS	HOMOGENEOUS	NOT APPLICABLE	NOT APPLICABLE
DAY/NIGHT TERMINATOR	NOT APPLICABLE	NOT APPLICABLE	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE
ONE LANDING STRIP: KSC, WITH FAA CATEGORY II RUNWAY MARKINGS AND LIGHTS	REQUIRED	REQUIRED	REQUIRED	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE	REQUIRED	REQUIRED	REQUIRED
NOSE OF VEHICLE OCCULTATION	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED

IMAGE CONTENT - "EARTH SCENE AND HORIZON" TABLE 2 of 5

Table 6.2.9-3

	ABORT PHASE			ORBITAL OPERATIONS PHASE	RENDEZVOUS PHASE	DOCKING & UNDOCKING PHASE	PAYLOAD OPERATIONS	DE-ORBIT PHASE	ENTRY PHASE
	MODE #1	MODE #2	MODE #3,4,5						
CONSTELLATIONS	NOT REQUIRED	NOT REQUIRED	REQUIRED - QUANTITY ~88	REQUIRED QUANTITY ~88	REQUIRED QUANTITY ~88	NOT REQUIRED	NOT REQUIRED	REQUIRED QUANTITY ~88	NOT REQUIRED
NUMBER OF STARS	NOT REQUIRED	NOT REQUIRED	$\geq$ 1000	$\geq$ 1000	$\geq$ 1000	SUFFICIENT NUMBER FOR ATTITUDE MOTION REFERENCE ONLY	NOT REQUIRED	$\geq$ 1000	SUFFICIENT NUMBER FOR ATTITUDE MOTION REFERENCE ONLY
CONSTELLATION IDENTIFICATION	NOT REQUIRED	NOT REQUIRED	REQUIRED BY CONFIGURATION AND MAGNITUDE	REQUIRED BY CONFIGURATION AND MAGNITUDE	REQUIRED BY CONFIGURATION AND MAGNITUDE	NOT REQUIRED	NOT REQUIRED	REQUIRED BY CONFIGURATION AND MAGNITUDE	NOT REQUIRED
MOON (SYMBOLIC)	NOT REQUIRED	NOT REQUIRED	REQUIRED INCLUDING PHASES	REQUIRED INCLUDING PHASES	REQUIRED INCLUDING PHASES	REQUIRED INCLUDING PHASES	REQUIRED	REQUIRED INCLUDING PHASES	REQUIRED INCLUDING PHASES
SUN (SYMBOLIC)	NOT REQUIRED	NOT REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED	REQUIRED
PLANETS (FOUR BRIGHTEST)	NOT REQUIRED	NOT REQUIRED	REQUIRED	REQUIRED	REQUIRED	NOT REQUIRED	NOT REQUIRED	REQUIRED	NOT REQUIRED

IMAGE CONTENT - "CELESTIAL BODIES" TABLE 3 of 5

Table 6.2.9-4

	RENDEZVOUS PHASE	DOCKING AND UNDOCKING PHASE	PAYLOAD OPERATIONS PHASE
VISUALLY DETECT TARGET	300 n.m.	0 TO 10 n.m. (COLLISION POSSIBLE)	0 TO 1 n.m. (COLLISION POSSIBLE)
SUBTENDED ANGLE AT WHICH [illegible] TARGET ATTITUDE IS IDENTIFIABLE	NOT REQUIRED	≥1.50 °	≥1.50 °
QUANTITY OF SIMULTANEOUS TARGET VEHICLE	ONE TARGET	ONE TARGET	FIVE TARGETS.
MAXIMUM/MINIMUM SIZE	ANOTHER ORBITER: LENGTH = 111 FT., SPAN = 80 FT/SATELLITE: 100 INCH DIAMETER SPHERE	ANOTHER ORBITER: LENGTH = 111 FT., SPAN = 80 FT./SPACE STATION: CYLINDRICAL, LENGTH = 15 FT., DIAMETER = 15 FT.	ANOTHER ORBITER: LENGTH = 111 FT., SPAN = 80 FT./SATELLITE: 100 INCH DIAMETER SPHERE
TARGET VEHICLE MOVING PARTS	NOT APPLICABLE	N/R: [illegible]	N/R: [illegible]
TARGET LIGHTS, i.e., ACQUISITION, TRACKING AND ANTI-COLLISION LIGHTS ONLY	REQUIRED: SOME TARGET VEHICLE WILL HAVE NO LIGHTS. FOR TARGET VEHICLES THAT DO HAVE LIGHTS THEY WILL BE CONTROLLABLE AND THE LIGHTS WILL BE FIXED TO TARGET, HOWEVER, TARGET ATTITUDE IS A VARIABLE.	REQUIRED: SOME TARGET VEHICLES WILL HAVE NO LIGHTS. FOR TARGET VEHICLES THAT DO HAVE LIGHTS THEY WILL BE CONTROLLABLE AND THE LIGHTS WILL BE FIXED TO TARGET, HOWEVER, TARGET ATTITUDE IS A VARIABLE.	REQUIRED: SOME TARGET VEHICLES WILL HAVE NO LIGHTS. FOR TARGET VEHICLES THAT DO HAVE LIGHTS THEY WILL BE CONTROLLABLE AND THE LIGHTS WILL BE FIXED TO TARGET, HOWEVER, TARGET ATTITUDE IS A VARIABLE.
OWN VEHICLE LIGHTS ILLUMINATING TARGET VEHICLE	NOT REQUIRED	REQUIRED: (1) ILLUMINATION BY SPOTLIGHT FOR RELATIVE VEHICLE ATTITUDE REFERENCE, (2) ILLUMINATION BY FLOODLIGHT. SHADOWS ALSO REQUIRED.	NOT APPLICABLE - SEE IMAGE CONTENT - "REMOTE MANIPULATOR ARMS" TABLE 5 of 5
SUN SHADOWS ON TARGET VEHICLE	NOT REQUIRED	REQUIRED	REQUIRED
VISUALLY DETECT PAYLOAD RETENTION FITTINGS	NOT REQUIRED	NOT REQUIRED	REQUIRED: RANGE = 0 TO 60 FT.

IMAGE CONTENT - "TARGET VEHICLE" TABLE 4 of 5

Table 6.2.9-5

	PAYLOAD OPERATIONS
PHYSICAL DIMENSION	LENTH = 50 FT. (TO END OF TERMINAL DEVICE) DIAMETER = 8 INCH MAXIMUM
TERMINAL DEVICE MAXIMUM/ MINIMUM RANGE	50 FT./10 FT.
VISUALLY DETECT DEGREES OF FREEDOM	REQUIRED: VISUALLY DETECT EACH DEGREE OF FREEDOM BY EFFECT OF CHANGE IN POSITION AND/OR ATTITUDE. ALSO, MOTION OF TERMINAL DEVICE FOR OPEN/ CLOSE TRANSITION
LIGHTS	REQUIRED: SIMULATION TO SIGNIFY BLINDING BY THE SPOTLIGHTS ON EACH ARM NEAR TERMINAL DEVICE BY SOME MEANS IS REQUIRED. SPOTLIGHT SHADOWS BY EITHER ARM OR OWN VEHICLE OR TARGET VEHICLE.
ARMS FIXED TO DOOR	REQUIRED: ALSO MOTION FROM FIXED POSITION TO OPERATIONAL POSITION AND VICE-VERSA.
VISUALLY DETECT ARM JETTISONING AND EXPLOSION	REQUIRED: AN EXPLOSIVE BOLT DEVICE IN CASE OF FROZEN JOINT MALFUNCTION

IMAGE CONTENT - "REMOTE MANIPULATOR SYSTEM ARMS" TABLE 5 of 5

Table 6.2.9-6

6.2.9.13 Visual and Motion Cue Coordination

Motion and visual cues are important in a number of critical mission phases and flight maneuvers. The visual scene provides essential control information, while cockpit motion cues permit the crew to anticipate some control requirements, and to assess the effects of others, before they are reflected either in the visual scene or in the cockpit instruments. The development of the piloting skills required in a specific aircraft consists largely in learning specific relationships between motion, visual and instrument cues and aircraft responses in various configurations and flight environments. The coordination of motion and visual cues in the flight simulator is thus critical, in providing a learning environment which is as representative of the actual aircraft operating environment as is possible.

It is impractical to design a simulator which duplicates all aspects of the vehicle being simulated. Some aspects of the vehicle must be neglected for economic reasons and some due to limitations in the technology of simulation. Some vehicle characteristics must be modified to permit optimum control of the training situation. Decisions concerning the representation, deletion and modification of vehicle characteristics will be based on a complete training analysis. However, when visual and motion cues are identified as relevant to training, it will be necessary to coordinate their simulation within limits established by the perceptual capabilities of the crews to be trained.

In learning the skills required to operate a specific aircraft, the pilot must, largely through trial and error, learn to predict the timing and magnitude of control inputs in a variety of flight maneuvers, aircraft configurations and operating environments. When the aircraft responds to a control input, or to turbulence or to some other external disturbance, the pilot must sense the direction and magnitude of the aircraft response, estimate the input required to cancel it, make the input, observe the effect of the input and repeat the cycle until the desired aircraft response or state is attained. Depending on the circumstances, the pilot may concentrate his primary attention on either the visual scene or the cockpit instruments. Regardless of which source of data is primary under a given set of conditions, cockpit motion usually provides additional information which is useful in establishing control. Motion cues have the primary effect of alerting the pilot to the general nature, direction and extent of aircraft response. Because they are frequently sensed prior to the visual and instrument cues accompanying a response, they tend to "quicken" the pilot's control capability, and in some aircraft and flight conditions, make the difference between acceptable and unacceptable pilot control. The alerting function of motion cues makes it essential that they be provided in the simulator in the same temporal relationship to the visual and instrument cues which they accompany in the aircraft. The perceptual limitations of the pilot permits some discrepancies to exist between the simulator and the aircraft, but these are relatively small, and are proportional to the normal time periods existing in the aircraft, between the occurrence of motion and visual cues. In research by Woodrow (1) and by Blakely (2) on the estimation and reproduction time intervals, from 0.2 to 2.0 seconds, it was found that subjects could perceive differences of about 8% of the standard interval. Assuming a reasonable correspondence between these laboratory functions and the timing functions in multi-dimensional aircraft control, accuracy of visual and motion cue coordination should be within 10% of the relationships measured in the aircraft itself.

1. Woodrow, H., Time Perception, Chapter 32, Handbook of Experimental Psychology, S. S. Stevens, Ed., Wiley, 1951.
2. Blakely, W. in Woodrow, H., Time Perception, Chapter 32, Handbook of Experimental Psychology, S. S. Stevens, Ed., Wiley, 1951.

6.2.9.14 Visual System Monitoring Requirements

Traditionally, the simulator instructor monitors student performance in order to provide guidance in the learning of well-defined tasks and to evaluate progress in the development of specific, essential skills. In the Shuttle, the procedures and skills being trained will be somewhat less well-defined until operational experience becomes available. As a result, the simulator will be used initially, as much for the development of effective and efficient operating procedures as for pure crew training. The instructor will provide guidance and he will evaluate crew performance, but he will not operate in the classic instructor-student relationship. He will operate as a skilled and experienced colleague in a team responsible for bringing both operating procedures and crews to optimum levels of efficiency prior to Shuttle operation.

Although the instructor will be a member of a well-integrated team, his functions require information and control capabilities unique to these functions, to enable him to control the operating situation for optimum learning and to monitor performance parameters which are not normally accessible to the crew in flight operation, but which have significance for optimizing training.

Requirements for instructor monitoring of crew visual tasks were derived through a gross analysis of crew and instructor functions in relation to training for atmospheric and orbital operations. This analysis is summarized in Table 6.2.9-7, IOS Visual Monitoring

1.0 ABORT 1 (0-30 sec)	1.1 MONITOR ABORT PROGRAM. 1.2 CONTROL VEHICLE ATTITUDE AND FLIGHT PATH TO APPROACH ABORT RUNWAY AT NOMINAL AIRSPEED, SINK RATE AND ANGLE OF ATTACK. 1.3 ALIGN VEHICLE WITH RUNWAY AT NOMINAL RANGE AND ALTITUDE. 1.4 CONTROL VEHICLE TO ATTAIN NOMINAL AIRSPEED AND SINK RATE AT TOUCHDOWN (FLARE); MAINTAIN RUNWAY ALIGNMENT.	1.1 RECOGNIZE CORRECT OR INCORRECT ABORT SEQUENCE; JUDGE REQUIREMENT FOR MANUAL CONTROL OF ABORT. 1.2 PERCEIVE AND CONTROL ATTITUDE, HEADING, SINK RATE AND AIRSPEED TO ATTAIN REQUIRED APPROACH FLIGHT PATH. 1.3 PERCEIVE GROUND TRACK ALIGNMENT WITH RUNWAY CENTERLINE EXTENSION. 1.4 SENSE FLARE-OUT ALTITUDE; CONTROL ATTITUDE TO ACHIEVE NOMINAL AIRSPEED AND SINK RATE AT FLARE-OUT ALTITUDE.	1.0 - 5.0 MONITOR: a. VEHICLE ATTITUDE FLIGHT PATH AND GROUND TRACK DATA, AS AVAILABLE TO THE CREW. b. VEHICLE LAUNCH SEQUENCE EVENTS AS RELATED TO PRESENT AND FUTURE FLIGHT PATHS. c. FLIGHT CONTROL MODE. d. EXTRAPOLATIONS OF VELOCITY, ANGLE OF ATTACK, ATTITUDE, FLIGHT PATH AND GROUND TRACK RESULTING FROM PROGRAMMED AND/OR MANUAL CONTROL INPUTS. e. DATA REFLECTING SYSTEM PERFORMANCE, PERFORMANCE CRITERIA AND PERFORMANCE/CRITERIA DISCREPANCIES. SELECT: a. DATA DISPLAY MODES. b. CREW PRACTICE CONDITIONS. c. MALFUNCTIONS AND DEGRADED CONDITIONS d. ORIENTATION OF FLIGHT PATH AND GROUND TRACK DISPLAYS FOR PERFORMANCE DIAGNOSIS AND GUIDANCE. EVALUATE AND DIAGNOSE: a. ABILITY OF CREW TO SENSE AND INTEGRATE DEVIATIONS FROM PROGRAMMED LAUNCH SEQUENCE.	1.0 - 5.0 a. GRAPHIC DISPLAY OF SPATIAL RELATIONS AMONG VEHICLE POSITION AND ATTITUDE, LAUNCH AND RETURN SITES AND DESIRED AND ACTUAL FLIGHT PATHS, GROUND TRACKS AND MISSION EVENTS. SUPERIMPOSED ALPHANUMERIC DISPLAY OF ESSENTIAL FLIGHT AND PROCEDURAL PARAMETERS. READOUTS OF PERFORMANCE COMPARISON DATA FOR CREW PERFORMANCE EVALUATION AND DIAGNOSIS. EXTRAPOLATIONS OF EFFECTS OF CREW ACTIONS ON VEHICLE FLIGHT PATH AND GROUND TRACK.
2.0 ABORT 2 (GLIDE RETURN; 30-86 sec)	2.1 CONTROL ANGLE OF ATTACK, "g" LOAD AND ATTITUDE TO REDUCE AIRSPEED AND ALTITUDE TO NOMINAL VALUES FOR RETURN TO LANDING SITE; MAINTAIN TOTAL TEMPERATURE WITHIN NOMINAL LIMITS. 2.2 ALIGN VEHICLE WITH RUNWAY AT NOMINAL RANGE AND ALTITUDE. 2.3 CONTROL VEHICLE TO ATTAIN NOMINAL AIRSPEED AND SINK RATE AT TOUCHDOWN; MAINTAIN RUNWAY ALIGNMENT.	2.1 PERCEIVE ATTITUDE AND GROUND TRACK TO PERMIT CONTROL OF FLIGHT PATH TO RUNWAY. 2.2 PERCEIVE GROUND TRACK ALIGNMENT WITH RUNWAY CENTERLINE EXTENSION. 2.3 SENSE FLARE-OUT ALTITUDE; CONTROL ATTITUDE TO ACHIEVE NOMINAL AIRSPEED AND SINK RATE AT FLARE-OUT ALTITUDE.		
3.0 ABORT 3 (86-300 sec)	3.1 MONITOR ABORT PROGRAM. 3.2 ORIENT VEHICLE THRUST AXIS 180° TO ORIGINAL FLIGHT PATH; CONTROL MAIN ENGINE THRUST TO DECELERATE TO ENTRY VELOCITY.	3.1 MONITOR VEHICLE ATTITUDE DURING RETRO-THRUST; MONITOR ABORT PROGRAM. 3.2 CONTROL VEHICLE ATTITUDE AND GROUND TRACK ALIGNMENT PRIOR TO AND DURING RETRO-THRUST.		

Table 6.2.9-7

	3.3 ... ATTITUDE, AND THRUST TO MAINTAIN ANGLE OF ATTACK, TOTAL TEMPERATURE, "g" LOADS AND GROUND TRACK TO RETURN TO LANDING SITE.	... TRACK WITH RESPECT TO NAVIGATIONAL LANDMARKS.	... QUIRED ACCURACIES.	
	3.4 CONTROL ATTITUDE, HEADING AND ANGLE OF ATTACK TO MAINTAIN AIRSPEED, GROUND TRACK AND SINK RATE REQUIRED TO RETURN TO LANDING SITE.	3.4 SENSE AND CONTROL ATTITUDE, ALTITUDE AND GROUND TRACK IN RESPECT TO LANDING SITE.	e. VALIDITY OF PROGRAMMED AND MANUAL ABORT SEQUENCES.	
	3.5 ALIGN VEHICLE WITH RUNWAY AT NOMINAL RANGE AND ALTITUDE; MAINTAIN ANGLE OF ATTACK, AIRSPEED AND SINK RATE WITHIN NOMINAL LIMITS.	3.5 PERCEIVE GROUND TRACK ALIGNMENT WITH RUNWAY CENTERLINE EXTENSION.		
	3.6 CONTROL VEHICLE TO ATTAIN NOMINAL AIRSPEED AND SINK RATE AT TOUCHDOWN; MAINTAIN RUNWAY ALIGNMENT.	3.6 SENSE FLARE-OUT ALTITUDE; CONTROL ATTITUDE TO ACHIEVE NOMINAL AIRSPEED AND SINK RATE AT FLARE-OUT ALTITUDE.		
4.0 ABORT 4 (ONCE-AROUND; 300-440 sec)	4.1 MONITOR ABORT PROGRAM.	4.1 MONITOR VEHICLE ATTITUDE AND GROUND TRACK DURING EXECUTION OF PROGRAMMED ABORT SEQUENCE.		
	4.2 EMPLOY COAS TO CHECK COMPUTATIONS FOR THRUST CONTROL, INJECTION RETARGETING AND TANK DISPOSAL.	4.2 STAR IDENTIFICATION AND SIGHTING.		
	4.3 EMPLOY COAS TO MONITOR THRUST CONTROL, INJECTION AND TANK DISPOSAL.	4.3 STAR IDENTIFICATION, SIGHTING AND CORRELATION WITH ENTRY CONTROL PROGRAM.		
	4.4 SEE 3.1	4.4 SEE 3.1		
	4.5 SEE 3.2	4.5 SEE 3.2		
	4.6 SEE 3.3	4.6 SEE 3.3		
	4.7 SEE 3.4	4.7 SEE 3.4		
	4.8 SEE 3.5	4.8 SEE 3.5		

Table 6.2.9-7
continued

(ABORT TO ORBIT 440-551 sec)	[illegible] AND DEORBIT. 5.2 EMPLOY COAS TO MONITOR THRUST CONTROL, DE-ORBIT AND RE-ENTRY. 5.3 ORIENT VEHICLE 180° TO FLIGHT PATH; APPLY THRUST TO REDUCE VELOCITY FOR ENTRY. 5.4 SEE 3.2 5.5 SEE 3.3 5.6 SEE 3.4 5.7 SEE 3.5	5.2 SEE 4.4 5.3 SENSE AND CONTROL VEHICLE ATTITUDE AND FLIGHT PATH. 5.4 SEE 3.2 5.5 SEE 3.3 5.6 SEE 3.4 5.7 SEE 3.5		
6.0 RENDEZVOUS	6.1 DETERMINE DIRECTION, ORIENTATION AND DISTANCE OF RENDEZVOUS TARGET. 6.2 CONTROL VEHICLE ATTITUDE AND THRUST TO ATTAIN CO-PLANAR ORBIT WITH RENDEZVOUS TARGET. 6.3 CONTROL VEHICLE ATTITUDE AND THRUST TO ATTAIN NOMINAL CLOSURE RATE WITH RENDEZVOUS TARGET.	6.1 DETERMINE ATTITUDE, RELATIVE BEARING AND ORBITAL PATH OF RENDEZVOUS TARGET. 6.2 SENSE RELATIVE ORBITAL ALIGNMENT OF TARGET AND OWN VEHICLE. 6.3 SENSE AND CONTROL TARGET/VEHICLE CLOSURE RATES AND ORBITAL PATHS.	6.0 MONITOR: a. CREW VIEW OF RENDEZVOUS TARGET. b. TARGET/VEHICLE CLOSURE RATES. c. RELATIVE ORBITAL PATH OF TARGET AND SHUTTLE. d. EXTRAPOLATION OF TARGET VELOCITY AND POSITION RESULTING FROM CURRENT CONTROL INPUTS. e. CREW PERFORMANCE DATA, PERFORMANCE CRITERIA AND PERFORMANCE/CRITERIA COMPARISONS, RELEVANT TO THE CONTROL OF VEHICLE ATTITUDE AND THRUST IN ROLLING TARGET-VEHICLE MOTION IN RENDEZVOUS. SELECT: a. DATA DISPLAY MODES. b. CREW PRACTICE CONDITIONS, INCLUDING TARGET SIZE, ORBIT, PASSIVE/ACTIVE CHARACTERISTICS, RANGE AND RELATIVE VELOCITY. c. MALFUNCTIONS AND DEGRADED CONDITIONS. d. ORIENTATION OF DISPLAYS FOR EFFECTIVE PERFORMANCE DIAGNOSIS AND CREW GUIDANCE.	6.0 a. GRAPHIC DISPLAY OF TARGET AND SHUTTLE ORBITAL RELATIONS. SUPERIMPOSED ALPHANUMERIC DISPLAY OF CLOSURE RATES. GRAPHIC EXTRAPOLATION OF TARGET/VEHICLE SPATIAL RELATIONS RESULTING FROM CREW ACTIONS. [illegible] OF COMPARISONS OF CREW PERFORMANCE WITH NOMINAL PERFORMANCE CRITERIA. b. REPEAT OF CREW VISUAL SCENE. c. [illegible] SCENE WINDOW, PERFORMANCE COMPARISON DATA, GRAPHIC DISPLAY DATA AND DISPLAY ORIENTATION, SYSTEM MALFUNCTIONS AND CREW PRACTICE CONDITIONS.

Table 6.2.9-7
continued

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			a. [illegible] RELATIVE MOTION WITHIN NOMINAL LIMITES. b. CREW FUEL UTILI[illegible]TION. c. VALIDITY OF RENDEZVOUS TECHNIQUES.	
7.0 DOCKING/ UNDOCKING	7.1 CONTROL VEHICLE THRUST AND ATTITUDE TO ATTAIN NOMINAL TARGET CLOSURE; REDUCE TARGET/VEHICLE RELATIVE MOTION TO ZERO. 7.2 CONTROL ATTITUDE AND THRUST TO TRANSLATE TARGET TO PAYLOAD HANDLING WINDOW FIELD OF VIEW. 7.3 STABLIZE TARGET AND VEHICLE WITH DOCKING ADAPTERS IN PROXIMITY TO EACH OTHER. 7.4 ORIENT DOCKING ADAPTERS FOR LATCHING, USING VEHICLE ATTITUDE AND THRUST CONTROLS AND REMOTE MANIPULATOR SYSTEM, AS REQUIRED.	7.1 RECOGNITION OF SMALL TARGET ATTITUDE AND VELOCITY CHANGES. 7.2 RECOGNITION OF SMALL TARGET ATTITUDE, VELOCITY AND FLIGHT PATH CHANGES; CRITICALITY OF TARGET/VEHICLE PROXIMITY. 7.3 RECOGNITION OF DOCKING LATCHES AND LATCH ORIENTATION. 7.4, 7.5 SEE 7.3	7.0 MONITOR: a. RELATIVE POSITIONS AND VELOCITIES OF TARGET AND SHUTTLE, AS OBSERVED BY CREW. b. EXTRAPOLATIONS OF TARGET/VEHICLE MOTIONS INDUCED BY CURRENT ATTITUDE AND THRUST INPUTS. c. COMPARISONS OF DOCKING AND UNDOCKING PERFORMANCE WITH NOMINAL PERFORMANCE CRITERIA. d. CREW FUEL UTILIZATION. e. INERTIAL MOMENTS APPLIED TO TARGET AND SHUTTLE BY CREW INPUTS. SELECT: a. DATA DISPLAY MODES b. TARGET CHARACTERISTICS. c. MALFUNCTIONS AND DEGRADED CONDITIONS. d. ORIENTATION OF MONITORING DISPLAY(S). EVALUATE AND DIAGNOSE: a. CONTROL OF TARGET/VEHICLE RELATIVE MOTION WITHIN NOMINAL LIMITS.	7.0 a. GRAPHIC DISPLAY OF TARGET, VEHICLE AND DOCKING ADAPTER RELATIONS. EXTRAPOLATIONS OF CREW INPUT EFFECTS ON TARGET, VEHICLE RELATIONS. ALPHANUMERIC DISPLAY OF CLOSURE RATES BETWEEN TARGET AND VEHICLE, AND OF CREW FUEL USAGE. DATA REFLECTING COMPARISON OF DOCKING PERFORMANCE AND NOMINAL PERFORMANCE. b. REPEAT OF CREW VISUAL SCENE. REPEAT OF CREW TV MONITOR SCENES AND OF OUTPUTS OF OTHER TV CAMERAS IN DOCKING AREA. c. CONTROLS FOR THE SELECTION OF DISPLAYS AND DISPLAY MODES, DETERMINATION OF TARGET CHARACTERISTICS AND SYSTEM MALFUNCTIONS. CONTROLS FOR THE RE-ORI[illegible] DISPLAYS OF PAYLOAD/VEHICLE RELATIONSHIPS.

Table 6.2.9-7
continued

	LATCHING. 7.6 RELEASE DOCKING LATCHES; APPLY THRUST TO SEPARATE VEHICLE FROM TARGET. 7.7 APPLY THRUST, CONTROL ATTITUDE TO STATION-KEEP ON TARGET. 7.8 MONITOR TARGET POSITION RELATIVE TO NEXT ORBITAL TASK.	7.6 THRU 7.8 SEE 7.2	b. MINIMIZATION OF INADVERTENT CONTACTS BETWEEN TARGET AND VEHICLE, AND OF TARGET INERTIAS OVER AND ABOVE THOSE REQUIRED BY THE TASK. c. CREW FUEL UTILIZATION. d. VALIDITY OF DOCKING AND UNDOCKING TECHNIQUES.	
8.0 PAYLOAD OPERATIONS (CAPTURE)	8.1 TRANSFER PAYLOAD FROM FRONT WINDOW VIEW TO FIELD OF VIEW OF PAYLOAD HANDLING WINDOW. 8.2 CONTROL ATTITUDE AND THRUST TO STATIONKEEP ON PAYLOAD, AT NOMINAL DISTANCE. 8.3 UNSTOW MANIPULATOR ARM(S); ACTIVATE TV MONITOR SYSTEMS; TRANSLATE EFFECTOR(S) TO VICINITY OF PAYLOAD RETENTION FITTING(S). 8.4 MONITOR PROXIMITY OF EFFECTORS AND ARM(S) TO PAYLOAD; APPLY ATTITUDE AND/OR THRUST INPUTS TO CANCEL MOTIONS OF PAYLOAD DUE TO ARM CONTACTS WITH PAYLOAD. 8.5 TRANSLATE OPEN EFFECTOR(S) TO CONTACT PAYLOAD RETENTION FITTING(S); ENGAGE EFFECTOR(S). 8.6 CONTROL MANIPULATOR ARM(S) TO MOVE PAYLOAD INTO CARGO BAY. 8.7 ENGAGE PAYLOAD RETENTION FITTINGS WITH PAYLOAD TRUNNION GUIDES.	8.1 RECOGNITION OF SMALL TARGET VELOCITY RATES AND ATTITUDE CHANGES. 8.2 RECOGNITION OF SMALL TARGET VELOCITY RATES AND ATTITUDE CHANGES. 8.3 RECOGNITION AND CONTROL OF ARM AND EFFECTOR POSITION WITH RESPECT TO PAYLOAD; CRITICALITY OF INADVERTENT EXCESSIVE CONTACT WITH PAYLOAD. 8.4 RECOGNITION OF SMALL PAYLOAD VELOCITIES AND ATTITUDE CHANGES. 8.5 PERCEPTION OF RETENTION FITTING/EFFECTOR SPATIAL RELATIONS. 8.6 RECOGNITION OF PAYLOAD TRANSLATIONAL PATH AND ATTITUDE WITH RESPECT TO CARGO BAY. 8.7 PERCEPTION OF RETENTION FITTING/TRUNNION SPATIAL RELATIONS.	8.0 MONITOR: a. DISPLAY OF RELATIVE MOTION BETWEEN PAYLOAD AND VEHICLE. b. CREW DISPLAYS OF RELATIVE PAYLOAD/VEHICLE MOTION. c. MANIPULATOR/PAYLOAD SPATIAL RELATIONS; EXTRAPOLATIONS OF MANIPULATOR/PAYLOAD RELATIONS RESULTING FROM CREW INPUTS. d. COMPARISONS OF CREW PERFORMANCE WITH NOMINAL MANIPULATOR/PAYLOAD ACCELERATIONS AND MOTIONS. SELECT: a. DATA DISPLAY MODES. b. TV MONITOR REPEATS. c. ORIENTATION OF DATA DISPLAYS. d. MALFUNCTIONS AND DEGRADED OPERATING CONDITIONS. EVALUATE AND DIAGNOSE: a. CREW CONTROL OF MANIPULATOR MOTION AND VEHICLE ATTITUDE AND THRUST. b. CREW MINIMIZATION OF UNDUE PAYLOAD ACCELERATIONS. c. UNDUE PAYLOAD/SHUTTLE/MANIPULATOR CONTACTS. d. VALIDITY OF PAYLOAD CAPTURE PROCEDURES.	8.0 a. GRAPHIC DISPLAY OF VEHICLE/PAYLOAD RELATIVE MOTION AND POSITION. REPRESENTATION OF MANIPULATOR/PAYLOAD CONTACTS AND OF ACCELERATIONS IMPARTED BY THE MANIPULATORS. INTEGRATED ALPHANUMERIC DISPLAYS OF CREW ENERGY UTILIZATION IN PAYLOAD CAPTURE. PERFORMANCE COMPARISON DISPLAY. b. REPEAT OF CREW DIRECT AND TV VIEWS OF MANIPULATOR AND PAYLOAD. DISPLAY OF OUTPUTS OF TV CAMERAS NOT BEING USED BY THE CREW. c. CONTROLS FOR THE SELECTION OF DISPLAY MODES, AND FOR THE SELECTION OF TV MONITOR VIEWS. CONTROLS FOR THE INTRODUCTION OF PAYLOAD CHARACTERISTIC DATA AND FOR THE INTRODUCTION OF SYSTEM MALFUNCTIONS. CONTROLS FOR REORIENTING THE GRAPHIC DISPLAY POINT OF VIEW.

Table 6.2.9-7
continued

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9.0 PAYLOAD OPERATIONS (DEPLOY)	9.1 UNSTOW MANIPULATOR ARMS.	9.1 MONITORING OF STOWED POSITION OF ARMS AND OF GROSS ARM MOTION.	9.0 SEE 8.0	9.0 SEE 8.0
	9.2 TRANSLATE EFFECTORS TO PAYLOAD RETENTION FITTINGS.	9.2 SEE 8.7		
	9.3 ENGAGE PAYLOAD RETENTION FITTINGS WITH EFFECTORS.	9.3 SEE 8.7		
	9.4 RELEASE PAYLOAD FROM CARGO BAY RETENTION SYSTEM.	9.4 NOT APPLICABLE.		
	9.5 TRANSLATE MANIPULATOR ARMS TO MOVE PAYLOAD FROM CARGO BAY; MONITOR PAYLOAD MOTION TO AVOID CONTACT WITH CARGO BAY WALLS AND FITTINGS.	9.5 PERCEPTION OF SMALL PAYLOAD ATTITUDE AND VELOCITY CHANGES; PERCEPTION OF FINE SPATIAL RELATIONS AMONG PAYLOAD AND CARGO BAY COMPONENTS.		
	9.6 MOVE PAYLOAD TO STATION KEEPING POSITION OUTSIDE CARGO BAY, AT A NOMINAL POSITION FROM VEHICLE; STABILIZE PAYLOAD/VEHICLE POSITIONS.	9.6 PERCEIVING SMALL PAYLOAD VELOCITIES IN RELATION TO OWN VEHICLE.		
	9.7 DISENGAGE EFFECTORS FROM PAYLOAD RETENTION FITTINGS.	9.7 SENSING SMALL TRANSLATIONS OF PAYLOAD IMPARTED BY MANIPULATOR CONTACT.		
	9.8 STOW MANIPULATOR ARMS.	9.8 SEE 8.8		
10.0 PAYLOAD OPERATIONS (PERFORM PAYLOAD EXPERIMENTS)	10.1 UNSTOW MANIPULATOR ARMS.	10.1 SEE 9.1	10.1 MONITOR: a. MANIPULATOR/PAYLOAD VIEW AS SEEN BY CREW. b. EXPERIMENT DISPLAYS AS VIEWED BY CREW. c. PAYLOAD ORIENTATION AND ORIENTATION REQUIRED BY EXPERIMENTS.	10.0. a. REPEAT OF CREW VISUAL SCENE. TV MONITORS. REPEAT OF CREW EXPERIMENT DISPLAYS. DISPLAY OF PAYLOAD REQUIRED AND ACTUAL ORIENTATION. b. CONTROLS FOR SELECTION OF TV/VISUAL DISPLAYS. CONTROLS FOR INTRODUCTION OF TASK CONDITIONS AND SYSTEM MALFUNCTIONS.
	10.2 ENGAGE PAYLOAD RETENTION FITTINGS WITH MANIPULATOR EFFECTOR(S).	10.2 SEE 9.2, 9.3		
	10.3 RELEASE PAYLOAD RETENTION FITTING(S) FROM CARGO BAY RETENTION SYSTEM.	10.3 NOT APPLICABLE		

Table 6.2.9-7
continued

	[illegible] FOR EXECUTION OF EXPERIMENT. 10.5 EMPLOY MANIPULATOR ARMS TO STABILIZE SHUTTLE/PAYLOAD ORIENTATION. 10.6 EMPLOY ATTITUDE, THRUST INPUTS TO ORIENT PAYLOAD WITH RESPECT TO GROUND TRACK, ORBITAL PLANE, CELESTIAL SPHERE, ETC., AS REQUIRED FOR EXPERIMENTS. 10.7 EMPLOY MANIPULATOR ARM AND EFFECTOR TO EXECUTE PAYLOAD EXPERIMENT PROCEDURES. 10.8 EMPLOY MANIPULATOR ARMS TO RESTOW PAYLOAD RETENTION FITTINGS IN CARGO BAY RETENTION TRUNNIONS; ENGAGE CARGO RETENTION SYSTEM. 10.9 DISENGAGE EFFECTORS; RESTOW MANIPULATOR ARMS.	[illegible] 10.5 PERCEPTION OF PAYLOAD MOTION IN CARGO BAY. 10.6 PERCEPTION OF PAYLOAD ATTITUDE WITH RESPECT TO FLIGHT PATH AND ATTITUDE OF SHUTTLE VEHICLE. 10.7 PERCEPTION OF FINE SPATIAL RELATIONS BETWEEN EFFECTORS AND PAYLOAD COMPONENTS; PERCEPTION OF SMALL RATES OF EFFECTOR MOTION. 10.8 PERCEPTION OF FINE SPATIAL RELATIONS AMONG EFFECTORS, ARMS, CARGO BAY TRUNNIONS AND PAYLOAD RETENTION FITTINGS; PERCEPTION OF SMALL CHANGES IN PAYLOAD ATTITUDE. 10.9 SEE 8.8	SELECT: a. MONITORING DISPLAY MODES. b. ORIENTATION OF PAYLOAD/VEHICLE VIEW. c. DEGRADED OPERATING CONDITIONS. EVALUATE AND DIAGNOSE: a. ACHIEVEMENT OF EXPERIMENT CRITERIA. b. VALIDITY OF EXPERIMENT PROCEDURES.	
11.0 PAYLOAD OPERATIONS (SPACE STATION MODULE DEPLOYMENT)	11.1 ESTABLISH STATION KEEPING POSITION WITH SPACE STATION, USING ATTITUDE AND THRUST INPUTS. 11.2 UNSTOW MANIPULATOR ARMS. 11.3 ENGAGE PAYLOAD RETENTION FITTINGS WITH MANIPULATOR EFFECTORS. 11.4 DISENGAGE PAYLOAD FROM PAYLOAD RETENTION SYSTEM. 11.5 TRANSLATE PAYLOAD OUTSIDE CARGO BAY; MONITOR PAYLOAD/BAY POSITIONS TO AVOID CONTACT WITH CARGO BAY WALLS, FITTINGS.	11.1 SENSING SMALL PAYLOAD VELOCITIES AND ATTITUDE CHANGES. 11.2 SEE 8.3 11.3 SEE 8.5 11.4 NOT APPLICABLE 11.5 SEE 9.5	11.0 MONITOR: a. SPATIAL RELATIONS AND RELATIVE MOTIONS AMONG SPACE STATION, SHUTTLE AND PAYLOAD. b. CREW VIEW OF MANIPULATOR EFFECTOR POSITIONS. c. MANIPULATOR EFFECTOR TV CAMERA VIEW. d. CREW VIEWING MODE SELECTED. e. EXTRAPOLATIONS OF MANIPULATOR, PAYLOAD AND SHUTTLE POSITIONS AND ATTITUDES RESULTING FROM CURRENT CREW INPUTS.	11.0 a. GRAPHIC DISPLAY OF SPATIAL RELATIONS AMONG PAYLOAD, SHUTTLE, SPACE STATION AND DOCKING PORT. DISPLAY OF PROJECTED (EXTRAPOLATED) EFFECTS OF CREW INPUTS ON POSITION AND VELOCITY OF PAYLOAD. DISPLAY OF CONTACTS AMONG EFFECTORS, PAYLOAD, CARGO BAY AND SPACE STATION.

Table 6.2.9-7
continued

	TO PROXIMITY WITH SPACE STATION; ROTATE PAYLOAD TO ALIGN PAYLOAD WITH SPACE STATION PORT.	SPACE STATION RELATIVE POSITION AND MOTION; PERCEPTION OF SPACE STATION DOCKING PORT ORIENTATION.	[illegible] g. PAYLOAD/MANIPULATOR/ CARGO BAY/SPACE STATION CONTROLS. SELECT: a. DISPLAY MODES. b. PAYLOAD CHARACTERISTICS; SPACE STATION CHARACTERISTICS. c. TV CAMERA VIEW. d. DISPLAY ORIENTATION. e. NOMINAL PERFORMANCE CRITERIA DISPLAY. f. DEGRADED OPERATING CONDITIONS. EVALUATE AND DIAGNOSE: a. CREW CONTROL OF PAYLOAD ATTITUDE AND VELOCITY. b. CREW UTILIZATION OF MONITOR SYSTEMS. c. CREW ABILITY TO PERFORM TASKS WITH MINIMUM INERTIAL MOMENTS APPLIED TO COMPONENTS. d. VALIDITY OF PAYLOAD HANDLING PROCEDURES AND TECHNIQUES.	REPEAT OF OTHER TV CAMERA INPUTS. • CONTROLS FOR SELECTION OF DISPLAY MODES, DISPLAY OF TV CAMERA INPUTS AND CONTROLS FOR THE IDENTIFICATION OF NORMAL AND DEGRADED OPERATING CONDITIONS.
	11.7 STABILIZE PAYLOAD RELATIVE TO SPACE STATION; STABILIZE SHUTTLE POSITION IN RELATION TO SPACE STATION AND PAYLOAD.	11.7 SEE 11.6		
	11.8 TRANSLATE PAYLOAD INTO SPACE STATION PORT; RELEASE PAYLOAD; RE-STOW MANIPULATOR ARMS.	11.8 SEE 11.6		
12.0 PAYLOAD HANDLING (PAYLOAD ASSEMBLY)	12.1 STATIONKEEP ON ORBITAL COMPONENT TO BE ASSEMBLED.	12.1 PERCEPTION OF SMALLEST INCREMENT ATTITUDE AND VELOCITY CHANGES.	12.0 SEE 11.0	12.0 SEE 11.0
	12.2 TRANSLATE PAYLOAD FROM CARGO BAY TO STATIONKEEP WITH ORBITAL PAYLOAD.	12.2 PERCEPTION OF FINE SPATIAL RELATIONS BETWEEN ORBITING AND MANIPULATED COMPONENTS.		
	12.3 USE MANIPULATOR ARMS, TV MONITORS, TO ALIGN PAYLOAD MATING SURFACES; RELEASE ONE MANIPULATOR ARM FROM PAYLOAD TO EXPLORE MATING SURFACE ORIENTATIONS.	12.3 SELECTION AND USE OF TV CAMERAS AND MONITORS FOR EXPLORING MATING SURFACE ORIENTATIONS; PERCEPTION OF SPATIAL RELATIONS BETWEEN MATING SURFACES.		
	12.4 STABILIZE ONE COMPONENT BY ENGAGING COMPONENT WITH ONE EFFECTOR.	12.4 NOT APPLICABLE.		
	12.5 TRANSLATE SECOND COMPONENT USING SECOND MANIPULATOR ARM, WITHOUT IMPARTING EXCESSIVE VELOCITY TO EITHER COMPONENT; MAINTAIN MATING SURFACE ORIENTATION UNTIL SURFACES ARE ENGAGED.	12.5 PERCEPTION OF FINE VELOCITIES, SPATIAL RELATIONS AND ATTITUDES OF COMPONENTS BEING ASSEMBLED.		
	12.6 DISENGAGE AND STOW MANIPULATOR ARMS.	12.6 SEE 8.8		

Table 6.2.9-7
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13.0 DE-ORBIT	13.1 [illegible] EVALUATE VALIDITY OF FLIGHT CONTROL COMMANDS.	[illegible] FOR DE-ORBIT.	[illegible] b. VISUAL SCENE AS VIEWED BY CREW. c. EXTRAPOLATIONS OF EFFECTS OF CREW INPUTS. d. SYSTEM PERFORMANCE COMPARISONS WITH NOMINAL PERFORMANCE CRITERIA. SELECT: a. ORBITAL CHARACTERISTICS b. DE-ORBIT PROGRAM MALFUNCTIONS. c. DATA DISPLAY MODES. d. DISPLAY ORIENTATION. e. DISPLAYS OF COMPARISONS OF CREW AND NOMINAL PERFORMANCE. EVALUATE AND DIAGNOSE: a. CREW SELECTION OF SYSTEM TEST MODES AND BACKUP PROCEDURES. b. CREW CONTROL OF VEHICLE ATTITUDE AND THRUST.	[illegible] DISPLAY OF CREW INPUTS, DISPLAY OF PERFORMANCE/ [illegible] COMPARISONS. b. REPEAT OF CREW VISUAL SCENE. c. CONTROLS FOR DEFINING ORBITAL CHARACTERISTICS, PROGRAM MALFUNCTIONS AND SYSTEM DEGRADED MODES. CONTROLS FOR RE-ORIENTATION OF GRAPHIC DISPLAY AND FOR SELECTION OF PERFORMANCE DATA DISPLAYS AND PERFORMANCE COMPARISON DISPLAYS.
	13.2 RECOGNIZE FLIGHT CONTROL DEVIATIONS FROM ANTICIPATED PARAMETERS.	13.2 SEE 13.1		
	13.3 EXERCISE MANUAL CONTROL OVER THRUST, ATTITUDE, ANGLE OF ATTACK AND TOTAL TEMPERATURE AS REQUIRED TO REDUCE VELOCITY TO SUB-ORBITAL CONDITION.	13.3 PERCEPTION OF VEHICLE ATTITUDE WITH RESPECT TO ORBITAL PATH AND HORIZON.		

Table 6.2.9-7
continued

	"γ", ANGLE OF ATTACK, GEOGRAPHIC POSITION AND CONTROL SYSTEM OPERATION FOR CORRECT EXECUTION OF ATMOSPHERIC ENTRY. 14.2 EXERCISE MANUAL CONTROL OF CONTROL SYSTEM MODE, ANGLE OF ATTACK, "q", "γ", ATTITUDE AND GROUND TRACK FOR OPTIMIZING TOTAL TEMPERATURE AND FLIGHT PATH FOR ACHIEVING ENTRY PROGRAM CRITERIA.	ATTITUDE WITH RESPECT TO ORBITAL PATH AND HORIZON. 14.2 PERCEPTION OF VEHICLE ATTITUDE; CORRELATION OF VISUAL AND INSTRUMENT DATA FOR EFFECTIVE RE-ENTRY.	a. CREW VIEW OF RE-ENTRY VISUAL SCENE. b. CREW PERFORMANCE OF TEST AND BACKUP MODE PROCEDURES. c. EXTRAPOLATIONS OF VEHICLE ORBITAL PARAMETERS RESULTING FROM CURRENT CREW INPUTS, INCLUDING ORBITAL DATA, TOTAL TEMPERATURE, "q", "γ", ATTITUDE AND VELOCITY. d. VEHICLE GROUND TRACK. SELECT: a. ORBIT AND VEHICLE CHARACTERISTICS b. ORIENTATION OF ORBITAL DISPLAY. c. DISPLAY MODE. d. ENTRY PROGRAM MALFUNCTIONS. e. COMPARISONS OF SYSTEM PERFORMANCE WITH SYSTEM PERFORMANCE CRITERIA. EVALUATE AND DIAGNOSE: a. CREW DIAGNOSIS OF SYSTEM MALFUNCTIONS. b. CREW CONTROL OF RE-ENTRY c. VALIDITY OF RE-ENTRY PROCEDURES.	VEHICLE ... GROUND TRACK, WITH SUPERIMPOSED ALPHANUMERIC AND ... DISPLAY OF ATTITUDE, HEADING, ANGLE OF ATTACK, "γ" LOAD "q" AND TOTAL TEMPERATURE. SPATIAL RELATIONS AMONG ORBITAL PATH, GROUND TRACK, ATTITUDE AND LANDING SITE. EXTRAPOLATIONS OF THE EFFECTS OF CREW INPUTS. b. REPEAT OF CREW VISUAL SCENE. c. CONTROLS TO SELECT ORBITAL PARAMETERS, SYSTEM MALFUNCTIONS AND DISPLAY MODES. CONTROLS TO SELECT PERFORMANCE, PERFORMANCE CRITERIA AND COMPARISON DISPLAYS. CONTROLS TO RE-ORIENT GRAPHIC DISPLAY POINT OF VIEW.
15.0 APPROACH AND LANDING	15.1 MONITOR AIRSPEED, ATTITUDE, ALTITUDE, ANGLE OF ATTACK, GROUND POSITION AND SINK RATE DURING AUTOMATIC APPROACH AND LANDING. 15.2 MANUALLY CONTROL AIRSPEED, ATTITUDE, SINK RATE, ANGLE OF ATTACK AND GROUND POSITION TO: 15.2.1 ACHIEVE NOMINAL AIRSPEED AND SINK RATE AT INTERSECTION WITH 12° GLIDE SLOPE AT 10,000 FEET, OVER OUTER MARKER, ON RUNWAY HEADING AND CENTERLINE EXTENSION.	15.1, 15.2, 15.3 INTEGRATED CONTROL OF FLIGHT AND FLIGHT PATH PARAMETERS FROM INSTRUMENT, RADIO AND/OR VISUAL INFORMATION IN IFR/VFR APPROACH AND LANDING, UNDER NORMAL AND EMERGENCY CONDITIONS.	15.0 MONITOR: a. CREW VIEW OF TERRAIN. b. SPATIAL RELATIONS AMONG RADIO AIDS, LANDMARKS, RUNWAY AND APPROACH AND LANDING AIDS; VEHICLE FLIGHT PERFORMANCE PARAMETERS RELATIVE TO ATTITUDE, SINK RATE, GROUND TRACK AND ENERGY MANAGEMENT.	15.0 a. GRAPHIC DISPLAY OF SPATIAL RELATIONS AMONG VEHICLE, FLIGHT PATH, TERRAIN, RUNWAY, RADIO AIDS AND SIGNIFICANT LANDMARKS. DISPLAY OF RELEVANT FLIGHT PARAMETER SUPERIMPOSED ON GRAPHIC DISPLAY; DISPLAY OF EXTRAPOLATIONS OF FLIGHT PATH AND GROUND TRACK RESULTING FROM CREW INPUTS. DISPLAY OF PERFORMANCE/PERFORMANCE CRITERIA COMPARISONS. b. REPEAT OF CREW VISUAL SCENE c. CONTROLS TO SELECT PERFORMANCE DATA AND

Table 6.2.9-7
continued

	...ECTION WITH 3° GLIDE SLOPE OVER INNER MARKER, ON RUNWAY HEADING AND CENTERLINE EXTENSION. 15.2.3 MAINTAIN NOMINAL AIRSPEED AND SINK RATE TO 100' ALTITUDE, ON RUNWAY CENTERLINE; CORRECT FOR EFFECTS OF CROSS WIND. 15.2.4 EXECUTE FLARE AT 20' ALTITUDE TO ACHIEVE NOMINAL TOUCHDOWN AIRSPEED AND SINK RATE; CANCEL DRIFT CORRECTION PRIOR TO GROUND CONTACT. 15.2.5 MAINTAIN RUNWAY ALIGNMENT DURING ROLLOUT; REDUCE GROUND SPEED BY USING DRAG DEVICES AND BRAKES. 15.3 EXECUTE EMERGENCY PROCEDURES ASSOCIATED WITH POWERED/UNPOWERED/IFR/VFR APPROACH AND LANDING.		CONTROL OF APPROACH AND LANDING. d. EXTRAPOLATIONS OF VEHICLE ATTITUDE, VELOCITY, GROUND TRACK, FLIGHT PATH, SINK RATE, ETC., RESULTING FROM CURRENT CREW INPUTS. e. COMPARISONS OF NOMINAL PERFORMANCE PARAMETERS WITH ACTUAL SYSTEM PERFORMANCE. SELECT: a. SYSTEM PERFORMANCE DATA DISPLAYS. b. ORIENTATION OF GRAPHIC DISPLAYS OF CREW AND SYSTEM PERFORMANCE. c. COMPARISONS OF SYSTEM PERFORMANCE WITH NOMINAL PERFORMANCE CRITERIA. EVALUATE AND DIAGNOSE: a. ABILITY OF CREW TO DIAGNOSE FLIGHT SYSTEM MALFUNCTIONS. b. CREW PERFORMANCE OF FLIGHT CONTROL FUNCTIONS IN APPROACH AND LANDING. c. VALIDITY OF APPROACH AND LANDING PROGRAM.	... VIEW, AND TO INTRODUCE DEGRADED CONDITIONS AND SYSTEM MALFUNCTIONS.
16.0 FERRY FLIGHT AND AIRCRAFT TRANSITION TRAINING	16.1 TAXI AIRCRAFT FROM PARKING RAMP TO RUNWAY; ALIGN AIRCRAFT WITH RUNWAY, EXECUTE TAKEOFF. 16.2 PERFORM EMERGENCY PROCEDURES ASSOCIATED WITH ENGINE AND AIRCRAFT SYSTEM MALFUNCTIONS; EXECUTE TAKEOFF ABORTS, AS REQUIRED. 16.3 EXECUTE CLIMBOUT; PERFORM SYSTEM MALFUNCTION PROCEDURES AS REQUIRED.	16.1 CONTROL OF AIRCRAFT/RUNWAY ALIGNMENT AND AIRCRAFT VELOCITY. 16.2 PERCEPTION OF GROUND TRACK, ATTITUDE AND VELOCITY. 16.3, 16.4 CONTROL OF VEHICLE ATTITUDE AND FLIGHT PATH DURING UNUSUAL FLIGHT CONDITIONS	16.0 MONITOR: a. CREW PERFORMANCE OF NORMAL AND EMERGENCY ATMOSPHERIC FLIGHT PROCEDURES. b. PERFORMANCE/PERFORMANCE CRITERIA COMPARISON DATA.	16.0 a. GRAPHIC DISPLAY OF REQUIRED AND ACTUAL FLIGHT PATH AND ATTITUDE, ALPHANUMERIC DISPLAY OF FLIGHT PARAMETERS AND PERFORMANCE COMPARISON DATA. GRAPHIC EXTRAPOLATION OF SYSTEM PERFORMANCE RESULTING FROM CREW INPUTS. b. REPEAT OF CREW VISUAL SCENE. c. CONTROLS TO SELECT AND ORIENT GRAPHIC DISPLAY, CONTROLS FOR INTRODUCING ENVIRONMENTAL CONDITIONS, MALFUNCTIONS AND DEGRADED MODES.

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continued

16.4 PERFORM IFR/VFR ENROUTE MALFUNCTIONS; EXECUTE SYSTEM MALFUNCTION AND DEGRADED MODE PROCEDURES AS REQUIRED.		c. EXTRAPOLATIONS OF FLIGHT PARAMETERS RESULTING FROM CREW INPUTS.	
16.5 PERFORM IN-FLIGHT REFUELING	16.5 NOT APPLICABLE	SELECT: a. PERFORMANCE DATA DISPLAYS.	
16.6 EXECUTE APPROACH AND LANDING UNDER IFR/VFR DAY/NIGHT CONDITIONS. PERFORM SYSTEM MALFUNCTION AND DEGRADED MODE PROCEDURES, AS REQUIRED.	16.6 CONTROL OF FLIGHT PATH, GROUND TRACK AND ATTITUDE IN LOW ALTITUDE SITUATION.	b. GRAPHIC DISPLAY ORIENTATION. c. PERFORMANCE COMPARISON DISPLAYS.	
16.7 PERFORM TRANSITION MANEUVERS.	16.7 CONTROL OF ALTITUDE AND FLIGHT PATH IN MARGINAL FLIGHT CONDITIONS IN EXPLORING ENVELOPE OF POWERED/UNPOWERED VEHICLE IN ATMOSPHERIC FLIGHT.	EVALUATE AND DIAGNOSE: a. CREW PERFORMANCE OF FERRY FLIGHT AND TRANSITION PROCEDURES. b. VALIDITY OF FLIGHT PROCEDURES.	

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Requirements. Two types of visual monitoring requirements were identified, one a repeat of the crew's visual scene, the other, a graphic and alphanumeric representation of significant system performance parameters.

<u>Visual Scene Repeater</u>. The repeat of the crew's visual scene is important in providing the instructor with a basis for establishing rapport with the crew's problems in abort, orbital operations, payload handling and ferry operations. It is also necessary to permit him to communicate with the crew on points of emphasis in visual procedures, which may escape the crew in their preoccupation with the tasks themselves. The instructor should have enough information in his display to be able to see the same spatial relationships and vehicle attitudes as observed by the crew in their visual scene.

<u>Graphic Display</u>. The instructor's job is to facilitate learning through interpretation and guidance of crew performance. The graphic display will facilitate these functions by providing both raw and processed crew and system performance data having special significance for training. This display will have five basic capabilities:

<u>Performance Criteria</u>. This display will provide a graphic representation of the performance required of the system in each relevant mission task and maneuver, and of the criteria established for acceptable performance ground track, flight path, orbiter, altitude, attitude and other similar parameters will be displayed in graphic form, to minimize requirements for instructor interpretation of discrete data.

Some parameters, such as orbital velocity, closure rates and the proximity among effectors, cargo bay payload, space station, etc., will be displayed in alpha-numeric (i.e., as discrete data) form. Depending on the crew task, it will be necessary to display some parameters both graphically and numerically, to support monitoring of performance trends as well as diagnosis of specific sources of some trends. Current display systems will permit alpha-numeric and graphic data to be displayed at the same time on the same display.

Crew Performance. The instructor can monitor some crew performance by observing the visual system repeater, but precise information will require the graphic and alphanumeric capability. Simultaneous display of ideal performance, the acceptable performance envelope and current performance will permit the instructor to identify trends and provide guidance on a timely basis.

Performance Comparison. In addition to displaying desired and actual performance at the same time, summary data repeating the magnitude and direction of discrepancies will be displayed, to minimize the degree of interpretation required of the instructor in identifying performance trends and in providing guidance.

Display Orientation. The graphic display will be able to be viewed from any angle, regardless of the orientation of the crew to the task situation under consideration. This will permit the instructor to view the effects of crew performance from a point of view not available to the crew. The view of a docking exercise, for example, can be rotated so that it is seen at right angles to the crew's normal orientation. This will make closure rates and vehicle/target alignment more obvious to the instructor than would a simple repeat of the crew's visual scene. In addition, re-orientation of the graphic display will provide the instructor with greater perspective concerning the quality of crew performance and of mission procedures as well. It will also be possible for crew members to observe the repeated display to form a better understanding of the dynamics of many mission tasks.

Performance Extrapolation. Almost all crew performance is characterized by an attempt on the part of the crew to predict the effects of inputs on the performance of the system. One aspect of the instructor's job is also to predict system performance so that he can help the crew to make appropriate responses. Ordinarily, both crew and instructor predictions are based on experience with the system and the operating environment; in fact, crew learning is largely a matter of gaining experience with the system by generating, employing and evaluating responses to specific combinations of mission and task requirements and operating circumstances.

It is important in the Shuttle system to minimize trial and error learning where possible. In unpowered returns, and during ferry flights when engines are available for go-around, crew inputs have extreme, and under many circumstances, irreversible effects. The graphic display will display required system performance, current performance and extrapolations of current performance to show the instructor the eventual effects of specific crew actions. This will be particularly important in approach and landing, where decisions made at 50,000 ft. will determine the capabilities available and the kinds of decisions which must be made at 10,000 ft. and on final approach. If speed brakes are deployed too soon, for example, an extrapolation of the resulting flight path to the touchdown point will help the instructor to guide the crew in selecting the correct point for speed brake deployment on the next approach.

Both displays of visual task data will be used primarily by the flight crew and payload handling crew instructors. Both should also be available to the crew members themselves, for reference during debriefing. They should also be available during pre-training briefings to facilitate crew preparation for training practice, through playback of prior training sessions or of prepared idealized or representative performance.

6.2.9.15 Visual Graphics

Visual Graphic masters are required due to the normal breakage occurred during the operational phase of the simulator.

6.2.10 Shuttle Systems Simulation Software

6.2.10.1 Electrical Power System

The simulation of the electrical power system of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, as specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for study of normal operating life support systems and of malfunctioning system components.

Sensor accuracy is normally only ± 1% maximum over the range of the sensor. An accuracy of ± 1% of the most sensitive sensor simulated was therefore chosen as the determining factor for system display accuracy for items such as voltage and current.

Accuracy of simulation is not only based on the equations and method used in solving the equations, but also on supplied data. Data on electrical power loads normally has an accuracy of ± 5% for large loads and ± 10% for small loads (Experience factor from Skylab, CMS, and LMS). Battery performance data has in the past not been available until post-flight, therefore all simulation equations are based on theoretical batteries. Fuel cell data has not been available because of the proprietary nature of the data. Supplied fuel cell thermodynamic data normally has an accuracy of ± 20%. Again, theoretical data must be used. A past simulation technique used in EPS has been to simulate minor loads (1 to 2 watts) as one accumulative load under control of the instructor. These loads remain as gross estimates with accuracies of ± 10%. All of the above factors contribute to errors which become apparent normally only after a simulation run of eight hours continuous. Over shorter periods, these errors are not monitorable or detectable by crew or telemetry. Items simulated which are in this category of errors are battery watt-hour indicators and fuel cell temperature. An arbitrary accuracy of ± 10% of the real world range measurement over an eight-hour period was selected.

The simulation meter and display response is based on having non-detectable meter motion after two seconds of computations. At five iterations per second, this will allow ten cycles of computations for the simulated system to "settle" to the ± 1% error. Since meter movements normally have 2% hysterisis, the meter needle should remain motionless until an input parameter or load transient occurs.

The display and control converters normally are 5 watt to 10 watt units. To account for all the loads and provide realistic transient loads would require approximately 20,000 additional instructions at five per second or 100,000 instructions per second. In addition the loads here are normally in the range of 5-50 milliwatts. The EPS simulation neglects individual simulation of electrical loads below 3.0 watts and lumps these loads into one constant load.

To account for transient loads by software where the load pulls down the lighting level would require extensive digitally controlled electronic devices. If it is felt that this is significant, the electrical loads of the lighting or converter circuits could be actually placed on a current limited device to simulate real world conditions. This would be expensive but can be done without software loading simulation.

6.2.10.2 Mechanical Power System

The simulation of the mechanical power system of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, as specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for study of normal operating life support systems and of malfunctioning system components.

Sensor accuracy is normally only ±1% maximum over the range of the sensor. An accuracy of ±1% of the most sensitive sensor simulated was therefore chosen as the determining factor for system display accuracy for items such as speed, temperature, and pressure.

The simulation meter and display response is based on having non-detectable meter motion after two seconds of computations. At five iterations per second, this will allow ten cycles of computations for the simulated system to "settle" to the ±1% error. Since meter movements normally have 2% hysterisis, the meter needle should remain motionless until an input parameter or load transient occurs.

6.2.10.2.1 Auxiliary Power Unit

The accuracy of simulation of the auxiliary power unit over long simulation runs is based on having good experimental performance data made available. With test data made available the simulation of such items as fuel quantity remaining should be able to be held to ±2% over an eight hour simulation run. Without good data, the simulation fidelity will probably be $\pm$10% - based on theoretical performance. The selection of the $\pm$2% value was an arbitrary selection based on experience from CMS and LMS simulators.

6.2.10.2.2 Hydraulic Power Unit

The accuracy of the simulation of the hydraulic system is based on the fact that the system does not have consumables. For that reason, the hydraulic system accuracy was arbitrarily selected as $\pm$2%. A higher accuracy than this is not warranted. Neither the crew displays or telemetry data is monitored with performance tolerances in this range.

The largest error in this system will probably be in calculation of heat transfer. The theoretical coefficients for the transfer equations are normally $\pm$5% in accuracy. Temperatures of the hydraulic fluid are most seriously affected by these errors. If test data is available, the temperature should be able to be controlled within $\pm$2%. This rationale is based on previous CMS, SLS and LMS simulations.

6.2.10.3 Main Propulsion System

The simulation of the main propulsion system of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for crew safety procedures for both normal flight and malfunction abort situations.

Sensor accuracy is normally only $\pm$ 1% maximum over the range of the sensor. An accuracy of $\pm$ 1% of the most sensitive sensor simulated was therefore chosen as the determining factor for system display accuracy for items such as pump speed, temperatures, or pressures.

The simulation meter and display response rate requirement is based on having non-detectable meter motion within one second after a system change. At ten iterations per second, ten cycles of computation will allow the simulated system to "settle" to the $\pm$ 1% error.

Thrust computations and mass calculations are essentially based on the allowable error in thrust cutoff time. Previous simulations have had a maximum allowable difference of $\pm$ 0.5 seconds as compared to the reference trajectory data. At cutoff, the body acceleration is approximately 97 ft/sec^2. With the maximum cutoff time error of 0.5 seconds, a velocity error of 48 fps can be accumulated. Of the 48 fps, approximately 50% could result from aerodynamic model simulation errors. This allows a maximum propulsion error simulation of 24 fps. Up to staging the average vehicle mass is approximately 100,000 slugs. A 1000 lb. thrust error up to this point of trajectory would only amount to 1 fps error. However, following the second phase of boost, the average vehicle mass is approximately 30,000 slugs. With a 1000 lb. thrust error, the trajectory velocity would be in error approximately $\pm$ 15 fps at the end of a 440 second burn. This velocity error would be within the allowable tolerance.

Refer to rationale for Weights and Balance and Equations of Motion.

6.2.10.4 Reaction Control System

The simulation of the reaction control system of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for crew safety procedures for both normal flight and malfunction abort situations.

Sensor accuracy is normally only ± 1% maximum over the range of the sensor. An accuracy of ± 1% of the most sensitive sensor simulated was therefore chosen as the determining factor for system display accuracy for items such as engine thrust,temperatures, or pressures.

The simulation meter and display response rate requirement is based on having non-detectable meter motion within one second after computation. At ten iterations per second, ten cycles of computation will allow the simulated system to "settle" to the ± 1% error.

Thrust computations and mass calculations are essentially based on the allowable error in thrust at cutoff time. In manual attitude or translational control mode, the human in the loop cannot distinguish between burn periods to an accuracy greater than 0.1 second. Since the thrust of an RCS jet is approximately 1000 lbs.,the total specific impulse allowing a ± 0.1 second deviation as the result of manual control error would be less than 100 lb seconds. In an automatic or computer controlled mode, the cutoff time is accurate to ± 0.001 seconds. The maximum allowable simulation error then becomes 1 lb-sec under the auto controlled conditions.

6.2.10.5 Orbital Maneuvering System

The simulation of the orbital maneuvering system of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for crew safety procedures for both normal flight and malfunction abort situations.

Sensor accuracy is normally only ± 1% maximum over the range of the sensor. An accuracy of ± 1% of the most sensitive sensor simulated was therefore chosen as the determining factor for system display accuracy for items such as pump speed, temperatures, or pressures.

The simulation meter and display response rate requirement is based on having non-detectable meter motion within one second after computation. At ten iterations per second, ten cycles of computation will allow the simulated system to "settle" to the ± 1% error.

Thrust computations and mass calculations are essentially based on the allowable error in thrust cutoff time. Equation of motion requirements have a maximum allowable difference of ± 2.0 second as compared to reference trajectory data. During deorbit burns, a maximum burn time of 20 minutes is possible for one engine out in high orbit. This burn time requirement dictates a maximum allowable error of ± 0.2% or ± 20 lb. thrust (or 40 lb-seconds total specific impulse) and a mass accuracy of ± 0.2%.

6.2.10.6 Air Breathing Engine System

The simulation of the Air Breathing Engine System of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for crew safety procedures for both normal flight and malfunction abort situations.

Sensor accuracy is normally only ± 1% maximum over the range of the sensor. An accuracy of ± 1% of the most sensitive sensor simulated was therefore chosen as the determining factor for system display accuracy for items such as pump speed, temperatures, or pressures.

The simulation meter and display response rate requirement is based on having non-detectable meter motion within one second after computation. At ten iterations per second, ten cycles of computation should allow the simulated system time to "settle" to the ± 1% stability error.

The system calculation accuracy requirements are essentially based on the assumption that the data made available on the F401-PW-400 Pratt & Whitney engine and on the fuel supply system will not be known to an accuracy greater than ± 4%. It is desirable that the engine thrust and fuel weight have greater than this accuracy, therefore for these two items an accuracy requirement of ± 2% was called out. All simulation accuracy for this system will be based on data to be made available.

6.2.10.7 Solid Rocket Motor

The simulation of the Solid Rocket Motors of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for crew safety procedures for both normal flight and malfunction abort situations.

Sensor accuracy is normally only ± 1% maximum over the range of the sensor. An accuracy of ± 1% of the most sensitive sensor simulated was therefore chosen as the determining factor for system display accuracy for items such as pump speed, temperatures, or pressures.

The simulation meter and display response rate requirement is based on having non-detectable meter motion within one second after computation. At ten iterations per second, ten cycles of computation should allow the simulated system time to "settle" to the ± 1% stability error.

The system calculation accuracy requirements are essentially based on the assumption that the data to be made available on the solid rocket engines will not be known to an accuracy greater than ± 2%. It is required that the engine thrust and fuel weight data for the engines have greater than this accuracy; therefore, for these two items an accuracy requirement of ± 0.05% was called out. All simulation accuracy for this system will be based on data to be made available.

6.2.10.8 External Tank

The simulation of the External Tank Separation system of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for crew safety procedures for both normal flight and malfunction abort situations.

Effects of the sloshing of the fuel mass is an unknown factor with respect to vehicle guidance and control dynamics which is detectable by the crew, Until additional data is made available, it is assumed that the G&N nulls all sloshing so that the effects are not noticeable.

The range safety ordinance equipment is not required for simulation since it does not provide crew training.

All other equipment located in the external tank is simulated within either the Main Propulsion System or the Solid Rocket Motor System.

6.2.10.9 Guidance, Navigation and Control

6.2.10.9.1 Aerodynamic Flight Control

It appears from most recent design data that a digital ASAS will be used, and be incorporated into the on-board computers. Thus, only the aero-surface actuators and the air data system remain to be simulated apart from on-board computers. If additional portions of the aerodynamic control system are removed from the on-board computers, this will require a specification change. Aerosurface positions are required for aerodynamic control and dynamics simulation, and hydraulic flows for hydraulic simulation. Insufficient data is available at this time to establish the exact degree of simulation required of the actuator servos in either nominal or hydraulic failure cases. General standards for determing these are known, however, and are specified. It may be that time constants are sufficiently small and actuator torque capability (nominal and malfunctioned) vs. anticipated hinge moments are such that dynamic simulation of the actuation system is not required for accurate surface or control system response. Real world hydraulic pressure monitors may be used to disengage failed channels, and should in that case be simulated. Effects of malfunctions upon response characteristics must be simulated if significant. Simulation of load-limiting bungees, etc., may be necessary for proper response, but this is not now known. Air data readouts must be consistent with data used in simulated vehicle aero, except for any nominal sensor dispersions. Unless proper precautions are taken, severe transients may occur in the simulated system upon passing from reset to operate. Insofar as these transients have no real-world analog, they should not be present. Of course, if a gust hits an aircraft immediately upon transferring to Operate, that transient should be simulated. Only transients arising from numerical problems in the simulation should be forbidden.

6.2.10.9.2 Spacecraft Flight Control

The MPS and OMS Thrust Vector Control systems must be simulated for proper rotational dynamics during periods of thrusting. For proper simulated response and control authority, position and rate limits must be properly simulated. Response accuracy requirements are driven by both open and closed loop requirements. Not only must the simulated gimbals respond to commands in the proper fashion, but the full closed-loop dynamics-control loop must also respond reasonably. The two requirements are not synonymous, so both must be specified. Design of MPS TVC system should not preclude simulation of bending/sloshing modes, providing that iteration rate penalties are not excessive. The highest frequency dynamic mode currently advertised is 3.25 HZ. Frequencies up to about 1/4 the sampling frequency can ordinarily be handled reasonably well using sampled data methods. Thus, simulation fidelity up to 4 HZ should be achievable at 20/sec iteration rate, and will probably be adequate to represent dynamic modes. A 4 HZ limit should also cover most readily perceptible oscillations. More precise tolerances may be placed on TVC response when design data becomes available. Simulation of all sensors (star tracker, horizon sensor, rate gyros, body accelerometers) is required for realistic control loop simulation. It appears that pickoffs from the star tracker will be azimuth and elevation angles with respect to body-fixed boresight. If this is changed, the specification should be altered accordingly. Field-of-view for wide scan, fine scan, tracking, and other star tracker modes must be correct for proper simulation. The same is true for horizon sensor field-of-view. Star tracker and horizon sensor errors should be comparable to real-world errors for proper operation of the on-board computer navigational filters. Provision should also be made for instructor control of dispersions. This has been a useful tool in prior simulators. Quantization errors, being essentially determined by the input data, should always be simulated unless their magnitude is insignificant. At present, inadequate information is available to judge their significance. Accurate simulation of star tracker search speed (if slow enough to be noticeable) and detectable visual magnitude threshold is needed for accurate response characteristics. The simulated horizon sensor's sun detection capability and response must compare to that of the real world device to prevent seriously erroneous response on that occasion. Rate sensors and accelerometers must be simulated for control loop feedback. Accuracy limits are looser here, since these devices should not affect on-board navigation. Error large enough to be noticeable will probably require malfunction rather than dispersion, so instructor control of dispersions is not specified. Quantization error will probably be insignificant for these devices, but might not be. The avionics bay may be 50 feet from vehicle c.m., so transverse and certrifugal forces on accelerometers displaced from the vehicle c.m. could be significant. Exact accelerometer positions are not known, but the avionics bay appears to be a likely location. Precise estimates of transverse/certrifugal force significance also await firm definition of the appropriate control loops. Significance of those effects was marginal on the Saturn 1B, but the shuttle is a much less symmetrical vehicle, and may well have more serious aerodynamic effects as well as a less responsive control system, resulting in higher angular rates and accelerations. This would increase the magnitude of these disturbing forces. NAR data on the proposal configuration indicates rates of 10 $\frac{deg}{sec}$ and, angular accelerations of 5 $\frac{deg}{sec^2}$ are possible under certain wind conditions, which greatly exceed Saturn values previously simulated. If body bending simulation is required, the requirement that rate sensors reflect rates at their physical position rather than rates at the c.m. should be added.

6.2.10.9.3 Inertial Measurement Unit

The on-board IMU's must be simulated in order to provide the on-board computers (and on-board displays) with vehicle attitude and current accumulated velocity from body accelerations (i.e., non-gravitational accelerations - thrusting, aero effects, etc.). As IMU realignment is one of the more important on-board navigational tasks, it should be simulated, requiring the simulated IMU's to possess the same realignment capability as the actual devices. The same operating modes and self-test are required for realistic crew interface. Correct Electrical Power System simulation and training requires the IMU interface be simulated properly. IMU's ordinarily require a warm-up period following restoration of power before becoming operational. Temperature variations ordinarily influence IMU accuracy significantly, and should be simulated. As a result, special temperature control systems are usually present. If this is the case for shuttle, both temperature effects and temperature control (which should interface significantly with Electrical Power and Environmental Control systems) should be simulated. The shuttle IMU will be all-attitude, so no gimbal lock condition exists. Since real-world IMU's reflect vehicle dynamics (plus dispersions), the simulated devices should reflect simulated dynamics (namely, the equations of motion), plus dispersions. To avoid unrealistic navigational errors, the simulated IMU's, in nominal operation should follow the equations of motion with no more than real-world magnitudes of dispersion. For proper simulation of on-board navigational activities, however, the IMU's should not be perfect; i.e., they should reflect dispersions in attitude (and sensed linear acceleration) similar to those of the actual devices and require periodic realighment. Instructor capability to vary dispersions (drift, bias, etc.) has proven useful in the past for training in off-nominal conditions. Quantization error will quite possibly be significant, especially in accelerometer readouts.

In the malfunction list, a 4-gimballed IMU is sometimes assumed. No final decision has currently been made between gimballed and strapdown IMU's for the shuttle, but gimballed devices are baselined. The malfunction list should be revised and possibly the specification made more specific if a strapdown device is selected. If "local horizontal hold" type attitude extrapolation is used or selected for "step ahead" mode, the IMU's must reflect resulting changes in inertial attitude upon returning to normal operation following the step ahead. Otherwise, the simulation is not returned to normal operation in a fully operable condition.

6.2.10.10 Communication and Tracking

6.2.10.10.1 Navigation and Landing Aids

The simulated NAVAIDS correspond to the equivalent on-board and ground based equipment to be used for the shuttle with the exception of GCA Radar and the Microwave Landing System. No requirement has been stated for GCA radar, however, ground landing stations are generally so equipped and simulation should be included for the instruction displays. An auto land system has been proposed for the orbiter, however, the methods have not been detailed. It is assumed that a system similar to the Microwave Landing System will be required and is therefore included in the simulation requirements.

6.2.10.10.1.1 S-Band System

Simulation of the S-Band voice and data communication link is required to provide IOS crew communication and crew displays and telemetered data responses that are realistic for both value and time response to commands and switching logic. The requirements describe a simulation system that will provide adequate in depth crew training for crew safety procedures during both normal and malfunction flight situations.

Simulation of the carrier and sub-carrier frequencies is not required because the crew does not change frequencies on the S-Band transmitters and receivers during flight.

The telemetry data is transmitted continuous during integrated modes of training to provide total data to the GSSC system. The loss-of-signal boolean completes the simulation where required for other simulators.

A dedicated S-Band voice loop is required for total vehicle simulation. A direct line provide a means of communication for checkout of simulator operations during training when the simulation is not in contact with a ground station.

6.2.10.10.1.2 VHF System

Simulation of the VHF voice communications link is required to provide IOS crew communication and crew display responses that are realistic for both value and time response to commands and switching logic. The requirements describe a simulation system that will provide adequate in depth crew training for crew safety procedures during both normal and malfunction flight situations.

Simulation of the carrier frequencies is required because the crew does change frequencies on the VHF transmitters and receivers during flight.

During non-integrated and possibly some integrated modes of training the IOS must provide the voice responses the crew would expect from a ground station.

6.2.10.10.1.3 Audio Communication Center

The Audio Communication Center must be simulated to provide the input/output logic to the communication systems of interim UHF, VHF, S-Band, and to the navigation system audio devices. All logic of the system must be provided for crew training with overall communication responses that are realistic for both value and response rate.

6.2.10.11 Instrumentation System

The simulation of the Instrumentation System of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for crew procedures for both normal flight and malfunction situations.

The simulation display response rate requirement is based on having non-detectable response delays following switching or command inputs. Two iterations per second is as slow as an electrical system can be run without having this noticeable delay.

All recorder functions are assumed to be furnished by GSSC. Switch position and/or relay status are to be transferred to GSSC for control of recorders.

Each simulated system is to include signal conditioning booleans prior to display or transfer to telemetry where applicable.

Under the present simulation concept all GSE PCM data used for preflight checkout are to be handled as an IOS function. If the GSE provides computation of parameters for compliance to tolerance limits during preflight checkout, it may be required to establish a special software routine for the instructor display parameters. Malfunctions in the GSE PCM Link are required only where crew training shall result.

All sensor power provided by the Caution and Warning System has the same characteristics as instrumentation signal conditioning. Interface definition of whether parameters are to be tested by the Caution and Warning program or by the generating software programs is a conceptual design task.

6.2.10.12 Environmental Control/Life Support System

The simulation of the ECS system of the shuttle vehicle is required to the level that all crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for crew safety procedures for both normal flight and malfunction situations.

Sensor accuracy is normally only ± 1% maximum over the range of the sensor. An accuracy of ± 1% of the most sensitive sensor simulated was therefore, chosen as the determining factor for system display accuracy for items such as flow rate, temperatures, or pressures.

The simulation meter and display response rate requirement is based on having non-detectable meter motion within one second after computation. At five iterations per second, ten cycles of computation will allow the simulated system to "settle" to the ± 1% error.

The minimum response rate of this system is based on having accurate simulation of gas/liquid flows immediately following a transient or valve opening. Five iterations per second will also provide this response rate required.

Simulation of parameters is required only to the extent that crew display or ground T/M can display the system. During re-entry it is felt the interfaces between ECS and TCS and TPS will require response to rapidly changing heat rates. It is not felt that an active cabin wall temperature cue is required for training.

Because of the nature of the training conducted, that isfor shirt-sleeve environment, it is not necessary to condition the crew station atmosphere or provide EVA/IVA to the simulated environment. Instruments are satisfactory for this training requirement. The interior of the crew station shall be maintained at a comfortable level by air conditioning.

The long term simulation error is given as $\pm$ 10% because of the many assumptions and simplifications of heat transfer and balance equations. The data provided of the shuttle heat transfer coefficients will probably have 5% error. Lack of data will require assumptions to be made where data is necessary. Efficiencies of heat exchangers, pumps, and heaters will be at best within 5% of the final design. Test results will also be available either after design of the simulation or not be made available until the maintenance phase of simulator operation. These many unknowns are typical of previous space vehicles, and, it is felt, will be typical for the shuttle.

6.2.10.13 Payload Accommodation System

No requirement is specified for payload recorder simulation. Specialized payload recorders may not be present on all missions. If present, there is no apparent provision for on-board reduction of payload recorder data. Recorder data can be decoded later on the ground, or perhaps recordings may be mounted and transmitted to ground via the orbiter communication system. Thus, there is no crew training value in recorder simulation. During integrated runs, in the apparently unlikely event that payload recordings are played back to the ground, the GSSC complex should be able to handle this task, as specified in paragraph 6.2.5.8.

6.2.10.13.1 Interfaces

The simulation of the interface between the payload and the shuttle vehicle is required to the level that all orbiter crew display and telemetered data responses are realistic for both value and time response to commands and switching logic. The simulation requirements, specified in Volume I, are based on the requirement that adequate in-depth crew training must be provided for crew safety procedures for both normal flight and malfunction situations.

6.2.10.13.2 Payload Structural Attachment

Payload attachment/release is a significant event in the retrieval/deployment process, and should be simulated. Attachment fittings should have similar contact rate constraints to the real world system to avoid negative training. Upon release, EOM for the payload must be initialized dynamically, as initial value is determined by orbiter translational/rotational state and attach position. Since payload mass may be up to 2/5 orbiter mass, reactions of all forces exerted upon the payload should be simulated. The trunnion guides may have significant effect on relative state, which should be simulated by maintaining both vehicle states correctly.

6.2.10.13.3 Payload Deployment and Retrieval Mechanism

As the primary device used by the crew for payload deployment and retrieval, the manipulator arm must be simulated. Angular position and velocity of joints should be maintained to incorporate joint position/velocity limits, for display purposes, and for checkout and discrepancy tracing purposes. In order to simulate properly control characteristics and decal bands, dynamics accuracy must be well within control accuracy. A tolerance of 1/3 control accuracy should assure minimum distortion of deadbands and responses. The tachometers and potentiometers will apparently be used in the real world system in the control loop, for crew displays, and as sensors. Accurate control response requires motor and servo loop simulation. To train positively in manipulator operation, control response must be accurate to within operator perception, with any payload within design tolerance. EPS failures or overloads should effect the simulated manipulator in the expected way, and the manipulator drive EPS realistically in order to properly simulate EPS. It is not clear what physical or electrical limits will be incorporated into the real-world manipulator system at this time, but all sources appear to agree that one or more of these joint limits will be present: position limits, torque limits, velocity limits, and/or runaway actuator limits. Details of manipulator design do not appear fixed at this time, and the remaining specifications may require alteration at a later date for this reason. The current specifications are based on several designs, and are not inconsistent with any specific data on known designs. However, certain designs are not well documented, and if adopted may not require all the specifications for their simulation. Redundant torque motors must be simulated, if present, for proper malfunction recovery. Braking and checkout systems will presumably be present on any design. Some designs use the checkout system as a backup direct arm control mode, which must be simulated if present. The terminal device must be simulated to provide training in arm operation. One kind of terminal device, one which "grasps" payloads, is generally agreed upon by all sources as present or available on the manipulator. In payload deployment/retrieval missions, it (or something quite similar) is going to be necessary. Some system descriptions provide alternate terminal devices, which are rarely well defined as to configuration or utilization. Thus, it is hard to determine training requirements for them. At this point, it appears that the best procedure is to require the simulation of a grasping type device, and require modularity for ease of modification. Revision may be advisable as manipulator design becomes better defined. The contact and berthing indicators are specified in some designs, and must be simulated if present. Wrist TV orientation must be provided to the visual system.

6.2.10.13.4 Payload Doors

The position of the payload doors effects the feasibility and execution of payload deployment/retrieval and the operation of the space radiators. The proposed door design is segmentally operable, requiring the simulated doors to be so operable. Door latching must be simulated analogously to real world operation to prevent negative training. Hinge operation must be simulated faithfully to achieve reasonable door dynamics. Mass properties, motion rates, etc., of the payload doors/space radiators are not now known. It is difficult to tell what noticeable effects reaction torques, etc., will have upon vehicle dynamics during door motion. Some crude simulation is probably required, and a general specification for same is included. To require that angular momentum be conserved (assuming no RCS firings, etc.) in the dynamic system may be unnecessarily stringent for training purposes, for it is not clear that such accuracy is required to provide training cues. The doors will be used, in the proposed design, to deploy the space radiators, requiring the structural interface be simulated. The manipulator will be latched to the doors, during boost and entry requiring that structural interface be simulated to train in manipulator deployment/stowage.

6.2.10.13.5 Rendezvous and Docking Sensor

The phase C/D RFP specifies this piece of equipment.

6.2.10.13.6 Aft Crew Stations

Since the interface between the payload accommodation system and the crew controls/displays has an obviously significant effect on crew activity and payload accommodation system operation, it must be simulated. For realistic training simulation, each crew control and display should be operable and should exhibit reasonable response characteristics. Crew training also requires malfunction capability.

6.2.10.13.7 Payload Bay Lighting

Lighting of the payload bay will have significant effect upon crew capability to perform payload manipulation, visual monitoring, and other significant payload bay related activity. For realistic training, the lighting should reflect off-nominal conditions in the electrical power system. For realistic simulation of the electrical power system, power loads due to the floodlights need to be simulated. Floodlights attached to the manipulator arm wrist-to-hand beam are movable and may have orientation changed along with said beam. This will significantly affect illumination around the manipulator terminal device, and must be simulated. Other floodlights may not be fixed in orientation. If so, for proper training, the simulated lights must be moveable. It may be possible to re-orient other floodlights, and perhaps even optionally automatically track the terminal device with certain floodlights. If this capability is provided, it should be simulated for realistic training.

6.2.10.13.8 Payloads

Because of the substantial changes in the nature and characteristics of payloads between shuttle missions, payload simulation is one of the most difficult and dangerous areas to specify. Creation of a full fledged highly accurate simulation for each payload would probably be astronomically expensive. It would also probably be unnecessary. Training requirements are not crystal clear at this point, but it would appear that for most payloads, there would be limited training value in a full-up simulation of, for example, the payload electrical power system. For a few payloads, like perhaps the space tug, there might be training value to justify at least a moderately detailed electrical power simulation. Much the same thing can be said about many other payload on-board systems. Writing a new on-board system simulation for each payload, and maintaining same for recurrent payloads, would probably absorb exorbitant engineering, programming, and checkout time. However, since certain payload on-board systems interface with orbiter systems when attached, and with payload dynamics when not attached, and since certain permanent display panels, (e.g., caution and warning) may be devoted to payloads, training value of payload simulation will probably not be insignificant. If a generalized simulation of all or certain on-board systems could be written which could drive certain displays, dynamics, and/or orbiter systems realistically, and such that payload reconfiguration would involve only altering values of reset terms, it would be desirable. Cost would not then be inordinate, and additional training capability would be gained. It is difficult to evaluate the extent to which would be worthwhile at this point. Characteristics of many of the individual payloads are unknown, orbiter systems are often not altogether well defined, and payload-related displays are ill-defined. Apparently, however, certain payload-related displays will be on permanent panels, which increases the likely applicability of generalized simulation. Generalized simulation would have to concentrate on driving these panels. If particular-payload-unique display panels were to be driven, that would almost certainly require a special modification. As a result, we have specified that computer core and time must be available to add generalized or specific payload system simulations with modifications at a later date. We have made certain exceptions, however. For certain systems involving payload dynamics, the feasibility of generalized simulation is more easily evaluated. The requirements here are more evident, as the physical laws of the universe are not payload configuration dependent, and requirements of crew interaction with target vehicle dynamics is fairly predictable. For a payload possessing attitude control jets, a tolerable simulation can be obtained simply by simulating approximately the deadband phase plane, and expected rate resulting from jet firings. All this should require for update is a few reset parameters describing the phase plane and rates. Similarly, translational propulsion can be simulated reasonably accurately, if steady state thrust/mass flow, and total impulse/total mass loss are reasonably accurate. Again, it should be possible to accomplish this with a few reset parameters. The only known vehicle to require a burn targetting guidance system is the tug. However, it is probably a reasonable assumption that any other vehicle would use an analogous rendezvous guidance strategy, as the coelliptic strategy has become well established for spaceflight rendezvous. Again, certain parameters (e.g., coelliptic delta-h's) can be altered by reset. Thus, it appears safe to require these systems to be simulated in a generalized fashion. Such simulation is important for training in rendezvous procedure, and such simplified simulation should be adequate for such purposes. Moreover, it is highly desirable to require such simulation as a portion of the initially delivered simulator, since its presence will enable much more detailed and complete checkout of EØM, orbiter G&N; etc. Other systems, however, are of less obvious training value, less clear feasibility as to mode (generalized vs. specific), and are of much less importance in verifying the complete simulator. It should be possible to add them later, if desired, without substantial impact on existing systems.

6.2.10.14 Miscellaneous Systems

6.2.10.14.1 Purge and Vent System

Simulation of the Purge and Vent System is required to provide crew training for handling of hazardous fluids and gases, heat dissipation, and pressure control of the air frame cavities. No crew training would be provided by simulation of the GSE activities, prior to the crew boarding the shuttle vehicle. The degree of simulation required is based on the measurements provided for crew display and Thermal Control state and boolean logic.

6.2.10.14.2 Landing/Braking System

Simulation of the Landing Gear and Braking System is required to provide crew training for both normal and malfunctioned systems. Simulation fidelity is required only to the depth that the crew or T/M displays react or the crew can sense either through motion or audio cues. An iteration rate of five per second is based on a realistic response for the real world response of braking for both manual and drogue chute operation.

6.2.10.14.3 Speed Brake System

Simulation of the Speed Brake System is required to provide crew training for both normal and malfunctioned systems. An iteration rate of twice per second is based on providing a realistic response rate for hydraulic servo response.

6.2.10.14.4 Ejection Seat Mechanism

Simulation of the logic and preliminary motion of the ejection seat provides the crew with training on escape techniques. It is felt that actual ejection training is not required by this simulation and will be provided by a part task trainer.

A program iteration rate of twice per second is based on providing realistic response for crew display and telemetry.

6.2.10.14.5 Thermal Protection System

Simulation of the Thermal Protection System is required for realistic crew display during liftoff and re-entry and for telemetry for those periods of flight that are not blacked out for RF transmission. An iteration rate of twice per second is felt to be adequate to provide realistic display response rates.

Malfunctions to this system are not given. It is felt that there is no training value for re-entry aerodynamic changes resulting in vehicle destruction. A related malfunction could be established for the visual system showing loss of a ceramic insulation panel on visual inspection via the TV monitor system.

6.2.10.14.6 Thermal Control System

Simulation of the Thermal Control System is required for realistic crew instrumentation display and for telemetry data for those periods of flight not blacked out for RF transmission.

An iteration rate of twice per second is considered to be adequate to provide realistic display response rates.

6.2.10.14.7 Docking Mechanism

The docking process is a significant constituent of spacecraft crew training. It must be simulated. For proper familiarization with docking procedures, dynamics should be simulated properly. The guide cone, hydraulic attentuators, alignment rings, and capture latches are all significant constituents of docking dynamics. Since at least two configurations are being considered for the docking mechanism (manipulator docking and standard docking), it is required that each device be simulated only when present. Proper docking latch simulation is also necessary to verify successful simulated docking. As the mechanism will apparently be extendible, the simulated mechanism should not operate unless successfully deployed. As with payloads, it is assumed that most target vehicle on-board systems will, if simulated, be added later as modifications. It is, however, desirable to require initially that provision be made to ensure that orbiter simulated on-board systems will be able to interface with target vehicle systems.

6.2.10.14.8 Air Breathing Engine Lubrication System

The lube oil system of each engine shall not be simulated. Neither meters nor telemetry are provided for lube oil temperature or pressure measurement or display.

6.2.10.14.9 In-Flight Refueling

In-flight refueling will not be required for simulation at this time. The in-flight refueling system simulation for the SMS has not justified its cost of installation. Refer to Paragraph 3.5.3.

6.2.11 Simulator Applications Software (Hdr)

6.2.11.1 Equations of Motion

6.2.11.1.1 Translation and Rotation Dynamics

6.2.11.1.1.1 Vehicles

Display parameters are selected from similar parameters on the CMS and SLS. Prelaunch accuracy requirements are equivalent to about 1 arc-second error in central angle, considered to be reasonable based on the 2 arc-second tolerance on hour angle, and the fact that it is well within required insertion accuracy. Error change is constrained similarly to hour-angle error to avoid positional "jumping" on the pad. Boost insertion position and velocity requirements are precisely those stated for the real world vehicle. Insertion accuracy also includes GN&C dispersions (e.g., platform drift), so the requirement on EØM is somewhat stiffer than it looks. The cutoff time tolerance is set sufficiently low to ensure against crew concern about overburn or underburn. This tolerance should be well within 3σ tolerances, both for the above reason and to provide reasonable malfunction response. Since more than a 1% flight propellant reserve is deemed necessary for non-aborted flights, it appears that 1/2 sec. should be well within 3σ tolerances. It is the same as the current CMS-S1B tolerance, so should be realizable. Since the iterative guidance scheme largely flies out position and velocity dispersions, cutoff time is most likely to be affected by errors. Thus, the tolerance on cutoff largely limits errors in the boost envelope. To further ensure a reasonable envelope, it is required that the trajectory be within 3σ dispersions throughout boost. A similar requirement on the CMS-S1B has apparently proven satisfactory. Orbital accuracy requirements are set with respect to burn targetting. They should assure no more than 0.5 ft/sec dispersions (direction or magnitude) in targetted ΔV's over the span at one orbit. Past experience has indicated that up to .5 ft/sec dispersions are acceptable. However, with Shuttle's increased autonomy, crewmen could acquire their concept of what burns are "reasonable" from simulation which would tend to tighten acceptable dispersions. Other accuracy drivers (acceptable earth or star scene, tracking acquisition/loss of signal, etc.) are less severe, considering 25,000 ft/sec orbital velocities. Since gravitational uncertainties are of the order of $.3^{-4}$ X 10 ft/sec^2 in central body constant and .2 X 10^{-4} ft/sec^2 in perturbation, the desired accuracy should be realizable. The most severe real-world orbital powered-flight accuracy requirements seem to be on the de-orbit burn, so requirements are set thereon. Real world entry trajectory accuracy requirements are looser than boost requirements (be within $\pm$20 n.mi. and 130 ft/sec at 1000,000 feet altitude), so it should be adequate to require no degradation of integration scheme accuracy between boost and entry, and that the entry trajectory be within 3σ dispersions. The primary requirements upon rotational EØM are agreement with IMU (within nominal dispersions) and reasonable control response. Since guidance will maintain IMU attitude at the correct value (or value range), these two requirements should ensure good visual and display cues and good trajectories. Since provisions are made aboard the shuttle vehicle for up to five payloads, and the external tank and another shuttle vehicle could act as target vehicles, the figure seven was decided upon as an upper limit for the number of target vehicles. During a manual control phase following boost-abort, it is necessary to ensure that the vehicle does not recontact jettisoned portions of the vehicle. (Since backup flight control can operate during boost, this is apparently possible.) However, so long as aerodynamic forces remain significant, the possibility of recontact after successful clearance (or visual sighting) should be fairly remote, as maneuver is somewhat limited in this regime and relative acceleration should remain substantial. A dynamic pressure of 2 lb/ft^2 was chosen as the cutoff point since it is the lower limit on dynamic pressure for tank separation; and since orbiter aero acceleration at this pressure, at mean orbital velocity, is about .1 ft/sec^2 at α=0° and about 1 ft/sec^2 at α=45°. External tank relative acceleration here (making crude assumptions as to its aero characteristics due to lack of data) would appear to be at least .1 ft/sec^2. This appears to be about at low as one would wish to go and still consider atmospheric relative force to be significant. In orbit, a different problem presents itself. Since any attitude might be assumed, external tank position should be maintained until visual contact is minimal. Further, in the case of tank deorbit SRM failure, tank position should be maintained until recontact is out of the question. A range of 40 n.mi. was chosen to satisfy both requirements. At that range, the tank will distend about 2 1/2 arc-minutes side·on (similar to a 6 foot man at 1 1/2 statute miles) and about 25 arc-seconds end on (a 6 foot man at 10 statute miles). Since payload manipulation could involve 2000 slug payloads, with respect to a 5500 slug orbiter, momentum considerations establish that noticeable perturbations upon the orbiter could be generated. Orbiter ranging distance is currently 300 n.mi. It could also be necessary to consider ground tracking requirements on other vehicles, which could extend the position maintenance requirements. Definition awaits further procedure definition on rendezvous methodology, etc. It is assumed that target vehicle attitude control will appear realistic if the target vehicle RCS impulse is simulated properly, and control phase plane logic is simulated. Rendezvous display parameters are largely adapted from those provided on CMS. Angular rates as well as attitudes are specified as reset parameters to permit realistic initialization. In what follows, "step-ahead" is as defined in Volume I, and is not synonymous with "fast-time" or "non-real time". Since, in "step-ahead", only gravitational and aerodynamic forces are simulated, it would be quite unrealistic to step-ahead during boost or powered flight. Within sensible atmosphere, reasonable simulation requires RCS and/or control surface effects. These, in turn, require operation of the full G&N system, which, in turn, requires attitude simulation. So, it is also unrealistic under the "step-ahead" constraints. However, during orbital coast, fixing attitude and using only gravitational aerodynamic effects provides an excellent trajectory at very high speed, since rotational EØM, G&N, etc. can be ignored. So, this high speed state advancement capacity is valuable in that situation, while unrealistic in others. At this point, it is difficult to determine whether body bending or fuel sloshing effects must be simulated. Insufficient data is available to determine whether their simulation is or is not required. Simulation of Saturn boosters without bending or sloshing effects has proven adequate for crew training on the CMS, though not necessarily desirable. It is reasonable to assume that the shuttle boost configuration, which is more complex structurally, will have more severe bending effects. Also, in aircraft flight, structural flexibility may well be a significant effect. But, as information is currently too sketchy, no requirements have been specified as they cannot be firmly justified. As structural and sloshing information becomes available, this decision should be reviewed.

No requirement is specified for maintaining the states of element of the tracking and Data Relay Satellite (TDRS) system. Although it is anticipated that shuttle will utilize this system it is not expected to be operational until 1983. These satellites will be in in synchronous orbits. In all probability, then, to use their "median" sub-vehicle ground point plus the Greenwich hour angle to determine their position at any point in time will probably be sufficiently accurate for training simulation purposes. Thus, very little impact on EOM is anticipated. In any case, such provisions need not be made until the early 80's, and are therefore not specified as a part of the initial simulator. It should not be difficult to add this capability later when needed.

6.2.11.1.1.2 Orbiter Vehicle Configurations

The configurations listed are those currently foreseen for the orbiter vehicle.

6.2.11.1.1.3 Forces and Moments

Maximum perturbing accelerations from the J2, J3, J4, and J22 harmonics are on the order of, respectively, .09 ft/sec2, .2 X 10^{-3} ft/sec^2, .2 X 10^{-3} ft/sec^2, .5 X 10^{-3} ft/sec^2. Each zonal harmonic is so directed as to largely cancel itself over the duration of an orbit; the tesseral so as to largely cancel itself over a portion of an orbit. Furthermore, for most of an orbit, or all of a low inclination orbit, the zonal harmonics will be of less than maximum power. Assuming that, over a revolution, perturbing acceleration error mounts linearly from maximum magnitude in one direction to maximum magnitude in the other direction, then back again, the largest error permitted by the tolerances on orbital EØM in Sect 3.5.33.1.1. is about 2 X 10^{-4} ft/sec^2. Error arising from neglecting higher order zonal harmonics should be well within this tolerance. It does not, however, permit ignoring J2, J3, or J4. With a shorter "period", J22 presents a different problem. Its maximum value, however, is reached at low latitudes unlike the zonals, (making it occur in all orbits) and is considerable. CMS targetting experience also indicates that it is desirable for improved results. During ferry flights, latitude does not vary widely as it does in orbit (e.g., over 55° in 45 minutes), so a central force field should suffice. Also, perturbations at 30°N aggregate about .1% of the gravitational force field. Changes in gravitational perturbations within ± 5° latitude of 30°N are considerably smaller. Considering uncertainties in aerodynamic coefficients, atmospheric conditions, etc., discrepancies of this magnitude do not appear significant. 30°N latitude was chosen since the proposed Vandenburg/KSC ferry route is within ± 5° latitude of 30°N. Numerical error was constrained to 10^{-5}ft/sec^2 to permit growth in accuracy without unnecessary reprogramming. It should be achievable with floating-point arithmetic with over 24-magnitude bit mantissas; or as little as 23-magnitude bit mantissas using care. Gravity gradient torques could reach 15 ft-lb at certain attitudes in low altitude orbits, and result in angular accelerations of 2 X 10^{-6} rad/$sec^2 \cong 10^{-4}$ deg/sec^2. In a 500 n.mi. orbit, gradient torques of 10 ft-lb are possible, and are, at that altitude, much larger than aero disturbing torques. At 10^{-4} deg/sec^2, a 1° displacement in 2 1/2 minutes is possible. Since docking misalignments of 6 inches and 5°-7°, and relative rates of .5 ft/sec^2 and 1 deg/sec are possible, docking with a massive target vehicle (e.g., space station, another shuttle) could exert sizable forces and torques upon the orbiter. Tank venting and dumping ΔV can reach 30 ft/sec, which is certinaly significant. Separation SRM's for the boost SRM's can attain 80,000 lb thrust, which is significant. Since these SRM's are located so as to cancel or override residual thrust, it too should be simulated. Body cavity venting during boost and entry is non-propulsive, so simulation is not required. ØMS design sketches indicate that dumping of residual ØMS propellant during entry is not propulsive, so simulation is not required.

6.2.11.1.1.4 Aerodynamics

Orbital aerodynamic data is sparse. However, assuming that α=90° is worst case, with C_A=0., C_N=2.5, C_M=.3, which values appear reasonable in terms of existing lower α or outdated data, one obtains, with a "worst case" atmospheric density at 275 n.mi., aero force of .2 lb (acceleration about .4 X 10^{-4} ft/sec^2) and pitching moment of 1ft-lb at α=90°. With median atmospheric density, forces of .05 lb and pitching moments of .3 ft-lb are likely at α=90°. Since gravity gradient torques can reach 10 ft-lb, it seems safe to ignore such aerodynamic torques. Such forces are similar to gravitational uncertainty, so they should be ignorable. Also, flight at low-α is much more likely, and forces and torques are considerably smaller there. Transients detected upon passing between aero simulation and no aero simulation should be negligible at these forces and torques. Furthermore, orbital differences between a 274 n.mi. circular and a 276 n.mi. circular should not be alarming, as force deltas are similar to gravitational uncertainty in magnitude. It is not felt that the cost would justify simulation of non-nominal atmospheric flight configurations. It would also probably be very difficult to obtain reliable data for such configurations. Winds, because aero force is proportional to the square of velocity, can be significant perturbations during boost and entry. They are, of course, quite significant during ferry flight. Gusts and turbulence exist in the real-world, and affect vehicle dynamics significantly in the atmosphere, so they should be simulated. It is considered necessary to permit certain instructor control over winds, gusts, and turbulence, to satisfy varying training requirements. At altitudes about 300,000 feet, atmospheric density varies substantially as a function of solar activity, geomagnetic heating, and gravity waves. There are also diurnal, semiannual, and seasonal-latitudinal variations. All these effects are somewhat predictable except gravity waves. Up to about 400,000 feet, semiannual and seasonal-latitudinal effects are, relatively speaking, quite significant. Well above that altitude, temperature dependent parameters predominate (e.g., solar activity, diurnal). At altitudes above 400,000 feet, total force deltas due to these effects as percentages are sizable, but not as forces. For example, at 425,000 feet, the maximum force is about 60 lb (α=90^{0}) the median force about 40 lb.(α=90^{0}). At 500,000 feet, maximum force is about 15 lb.; the median about 10 lb. (α=90^{0}). Below 400,000 feet, the dominant seasonal-latitudinal effects are most pronounced above 45^{0} latitude, and are opposite in sign between northern and southern hemispheres, thus largely cancelling over an orbit, and affecting lower inclination orbits less seriously. At the approximate altitude of maximum density effect, about 360,000 feet, maximum to median range is

800 to 500 pounds ($\alpha=90^0$). The maximum is 650 lb. for latitudes of 45^0 or less (much less for lower angle-of-attack). Since effects are most pronounced at altitudes between 50 and 100 n.mi., and the trajectory envelope for most missions will not involve extended flight in this area, and 90^0 angles of attack are unlikely, it is not believed the improvement gained in training by simulating these density variables would justify the cost. This conclusion should probably be reviewed as definition and development of training requirements continues. With load-relief steering, providing minimal angles of attack, it is estimated that a 2% density error could produce a 10 ft/sec velocity discrepancy at boost cutoff. This should be within the ability of the simulation to erase by an overburn/underburn well within the stated cutoff tolerance. Proximity axial force coefficient changes of 5%, normal force coefficient changes of over .01 and pitching moment coefficient changes of about .01 upon the orbiter + tank ($\alpha=0^0$) and axial force coefficient changes of 60%, normal force coefficient changes of nearly .01 and pitching moment coefficient changes of over .01 for the SRM's during nominal separation ($\alpha=0^0$) indicates the significance of proximity aerodynamics for good separation simulation. Landing gear deployment results in an increase in drag coefficient of about 0.011 at $\alpha=13^0$, which is significant. Simulation of the effects of individual gear deployment is required for proper simulation of the failure of an individual gear to deploy. Lift due to ground forces ranges from about 7000 lb. at 50 ft. to 85,000 lb. at 10 ft. Ground force pitching moment coefficient deltas range from .003 at 50 ft. to .038 at 10 ft. Thus, simulation of ground effects is required. Introducing the force at 75 ft. or above should guard against noticeable transients as the terms are added. Display terms required are mostly chosen from those currently found useful for training and checkout on the CMS and CMS-SIB booster.

6.2.11.1.1.5 Coordinate Systems

During orbital flight, vehicle state should be maintained in an earth-centered, space-fixed coordinate system, to avoid inclusion of coriolis and centrifugal effects, to provide for load verification, etc. During the landing phase, a runway based coordinate system should be maintained, for calculation of touchdown effects, ILS data, high-resolution landing visual requirements, etc. Certain ILS-related data might be displayed with respect to this system as well. Some body-fixed system is required for calculation of body forces and moments. If this is parallel to the orbiter longitudinal and pitch axes, orbiter rates, and accelerations can be displayed in the system which should be most meaningful to the instructor. Attitude as pitch, yaw, roll about local horizontal has proven useful to CMS instructors, and to engineers during checkout.

6.2.11.2 MASS PROPERTIES

6.2.11.2.1 Vehicles

Total vehicle mass must be available at any time body forces can occur, in order to obtain body acceleration. During boost, when total vehicle mass is rapidly changing, and body is acceleration is substantial, errors in mass cause porportional errors in body acceleration, which can build to serious errors in vehicle state. A particularly insidious numerical error can arise in the integration of acceleration to obtain velocity. For example, suppose rectangular integration was used to obtain delta-velocity from acceleration. To obtain correct results when this scheme, the accelerations used should be the "average" acceleration over to integration interval. Thus, forces should be "average" forces (except perhaps for gravity, they should be sufficiently close approximations), and mass should be "average" mass. If, however, trapezoidal or Adams schemes are used, forces and mass should represent values at the beginnings and ends of integration intervals. Thus, the precise valves of mass (whether at endpoints or "averages") provided EØM which would cause zero numerical error is a function of the integration scheme selected. Thus, during boost (or other powered flight), tolerances on mass should be set against that value of mass available during each integration interval which will introduce zero error into the ΔV calculations - unless the integration scheme is specified, which does not seem proper. As for the tolerances themselves, during boost, the driver is the requirement to meet cutoff time within 1/2 second. To assure meeting this requirement, accumulated ΔV error due to erroneous mass should not greatly exceed 20 $\frac{ft}{sec}$. This is crudely equivalent (ignoring adaptive guidance, gravity dispersions due to different positions, etc.) to a steady body acceleration error of .03 $\frac{ft}{sec^2}$. Using current mass properties, the worst cases for mass change caused acceleration error are at booster max acceleration and at cutoff. In each case, mass flow, in $\frac{slugs}{sec}$, is about 1% of total mass in slugs, and body acceleration about 100 $\frac{ft}{sec^2}$. Thus, a .06% mass error will result in acceleration errors of .06 $\frac{ft}{sec^2}$. Assuming average mass caused acceleration error will be 1/2 this (it is likely to be considerably less), we are within our tolerance. Such a tolerance will then require a mass re-calculation frequency of 1/10 second, or smoothing. This result is consistent with S-1B experience, which indicates that 1/5 second iteration interval during boost is too slow. During other mission phases, the most severe mass requirement is on the deorbit burn. The deorbit burn may be 20 minutes long, under extreme orbital and malfunction conditions. In that case, it should not have cutoff delayed by more than 4 seconds (will translate to 1-2 second delays in nominal cases). This can be accomplished by a .3% tolerance on mass. Vehicle center of mass must be available wherever significant torques arising from body forces can occur, in order to find moment arms. The inertia tensor is required at any time the calculation of body angular accelerations from torques may occur. Center of mass errors can require different "steady-state" gimbal angle and control surface settings (in order to cancel torques and thereby null angular accelerations), and can alter the response of the TVC, RCS and aero-surfaces (depending on scheme used to compute moments) to command changes or pertubations by changing their moment arms. Inertia tensor errors can also alter response of TVC, RCS, and aero-surfaces by changing the angular acceleration resulting from given torques. Proper tolerances upon these parameters to satisfy these requirements are somewhat configuration dependent. As the configuration is currently undergoing substantial design changes, it is considered unwise to set such tolerances at this time. However, using a number of simplifying assumptions, some rough approximations were made pertaining to tolerances. A 1 foot error in center of mass location in the x direction during first-stage boost would appear to require a gimbal angle change of about .2° or less to track it (aero ignored, but aero center appears to remain consistently safely behind cg), a 1 inch Z-direction error a gimbal angle change of as much as .25^0 during mated boost, but little more than .1^0 during second stage burn. In terms of a simplified pitch TVC loop, adapted from that in the NAR proposal, a 1 ft. x-direction c.g. change (or a 1% change in y moment of intertia) would appear to change transient rise time, overshoot, and undamped natural frequency by about 1% or less. It would appear, then, that with the current configuration, tolerance of 1 foot on x-c.g. position, 1 inch on y and z c.g. position during mated ascent and 2 inches thereafter would be reasonable tolerances. Judging from proposal mass properties estimates, these tolerances would apparently require updates at least once per second. However, although tolerances would be met, resulting step changes could create perceptible pertubations which would not exist in the real world, especially if at some time coupled to guidance minor loop updates. Thus, the requirement that perceptible step changes not be introduced would probably force a faster minimum update rate - perhaps 5 times per second. Since mass changes are much smaller during OMS burns and entry, update rates could probably be decreased then. It appears that the tolerances cited for the inertia tensor in orbit are also reasonable for boost, since, as indicated above, 1% error seems tolerable for one-axis control dynamics, and the arguments concerning errors arising from rate-dependent terms in the Euler equations in orbital coast are similarly applicable during boost. In orbit, assuming no torques and rates of 1 $\frac{deg}{sec}$ (which are not likely to be exceeded for long in nominal or most malfunctioned operation), errors in angular accelerations due to a discrepancy of 5% of the smallest moment of inertia in any product of inertia would be about 5 $\frac{\text{arc-sec}}{\text{sec}^2}$ or less, and errors in angular accelerations due to 1.0% errors in any moment of inertia would be about 6 $\frac{\text{arc-sec}}{\text{sec}^2}$ or less (maximum values in roll pitch-yaw values substantially less). Effects of torques upon angular acceleration should be included within 0.5% tolerance. These approximate values should hold so long as the orbiter retains the shape of a delta-wing airplane. Of course, if exact principal axes Euler equations are used, products of inertia do not exist. When separation rotational dynamics of SRM's are simulated, SRM mass properties must be maintained. Target vehicle or payload mass properties must be available while their states are maintained. It would not be necessary to maintain mass properties to extreme precision if only an attitude control propulsion system is aboard another vehicle. Mass changes of 5% should not force mass property changes of a great deal more than 5%, which should be adequate to simulate general behavior. In any case, it should not be necessary to simulate target vehicle behavior to any greater extent than to make its behavior seem reasonable to an outside observer, which permits fairly gross estimates of mass properties (except possibly for total mass of vehicles with translational propulsion - other mass properties are involved in rotational dynamics, which can be fairly gross for a target vehicle without being alarming, so long as basic behavior characteristics are preserved).

6.2.11.2.2 Vehicle Configurations

The configurations specified are all possible shuttle vehicle configurations, each with significantly different mass properties. Instructor alteration of crew location dependent mass properties has been used on SLS.

6.2.11.2.3 Consumables

The consumable containers mentioned all contain consumable quantities which may change in time during a shuttle mission.

6.2.11.3 Ephemeris

6.2.11.3.1 Celestial Bodies

Solar direction relative to the vehicle affects vehicle temperature distribution, star tracker resolution (when pointed near the sun due to G&N malfunctions), and out-the-window views. The moon can also cause interference with the star tracker. The visible planets (Mercury, Venus, Mars, Jupiter, Saturn) could cause star tracker interference, since all can be of apparent magnitude of 1.0 or greater (only 15 stars are of such magnitude), and there is no logic in the proposed on-board computer program driving the star tracker to account for planetary position. Astronomical sortie missions may create requirements for solar, lunar, and planetary position information. Some such payloads will presumably be pointed at these celestial objects. There is no indication in the orbiter GN&C requirements or preliminary software that the orbiter GN&C computers will be able to, unassisted, point the vehicle with respect to a celestial body in perceptible relative motion. If this is the case, a computer or sensor on-board the payload may provide the GN&C computers with pointing attitude updates. This computer or sensor would then have to be functionally simulated, which would in turn require knowledge of current target position. Apparent motion of Uranus should not exceed 10 $\frac{\text{arc-sec}}{\text{hr}}$, so can probably be ignored over the period of a training session. That of Neptune and Pluto will be much less. Thus, astronomical sortie missions should not require ephemerides of any other planets. Star trackers 1σ accuracy is 30 arc-seconds. Since solar, lunar, and planetary effects upon the star-tracker involve only interference, it should be sufficient to maintain their positions within the star tracker accuracy. Star directions, however, should be maintained well within star tracker accuracy, to permit star tracker dispersions to be simulated within the star tracker simulation itself. Simulated orbital sunrise should not take place at a perceptibly different time than real world orbital sunrise. At orbital sunrise, apparent solar motion with respect to the horizon may be of the order of 250 $\frac{\text{arc-seconds}}{\text{second}}$. Thus, if solar direction accuracy is within 25 arc-seconds, maximum sunrise error will be of the order of 1/10 second. Astronomical sortie mission accuracy requirements have not been defined, and are therefore not considered. However, best baseline pointing accuracy (3σ) is 36 arc-seconds. Solar aberration can exceed 20 arc-seconds. Therefore, it should be simulated. Lunar aberration, which is at most of the order of 5 arc-seconds, is much smaller than the required lunar direction accuracy, and need not be simulated. It is anticipated that lunar position accuracy requirements can be easily satisfied at an iteration rate of about 10 times per minute. Solar (and stellar) requirements are much less. There is no evidence that automatic star trackers will be used for navigation during atmospheric flight. Evidently, radio aids only will be used. The brevity of shuttle atmospheric cruise (one hour or less), the fact that all hops on the proposed ferry routes are over or very near land, the limited range (400 n. mi.), the distinct possibility of daytime flight, etc., would tend to render star tracker navigation unlikely in the atmosphere. If star trackers were so used, one should consider atmospheric refraction of starlight. Index of refraction of the atmosphere is about 1.0003 at sea level. Thus starlight refraction at 30^0 incidence is 40 arc-sec, at 60^0 incidence is 1½ arc-min, at 90^0 incidence is 25 arc-min, at sea level. Even accounting for shuttle cruise altitudes (near 20,000 feet), the effect is significant at high angles of incidence. The proposed on-board computer program takes no account of the effect, further reinforcing the assumption that star tracker use in the atmosphere is not anticipated. If it is utilized, however, atmospheric refraction effects will be required in the calculation of apparent star position.

6.2.11.3.2 Coordinate Transformations

Star positions should be available within any of the systems to well within the star tracker's accuracy to ensure good star tracker simulation. The figure of $\pm$ 5 arc-seconds was established in the preceding section as an adequate accuracy limit to satisfy this constraint. Thus, the simulated transformations must be within this accuracy to ensure the meeting of this constraint. If each axis is within 2 arc-seconds, any vector will be within 2 $\sqrt{3}$ arc-seconds, or about 3½ arc-seconds, safely within the constraint. 3½ arc-seconds is equivalent to about 350 feet of ground track position, so updates of the systems in orbit should not cause perceptible jump in earth scene (at orbital speed, the vehicle passes about 2500 feet of ground track in 1/10 second). These transformations are usually calculated using a star-fixed coordinates to true-of-date coordinates transformation and the true Greenwich Hour Angle. On the True-of-Date System, precession effects over 10 days will aggregate about 1 1/3 arc-seconds in the x-axis, and less in other axes. Nutation effects over the same time will not exceed about ½ arc-second in any axis. Precession and nutation effects upon the hour angle are analogous. Hence, over a seven day period, real-time recalculation of precession and nutation is unnecessary to meet a 2 arc-second tolerance. It appears that most shuttle missions will last no more than seven days. In any case, simulation runs covering more than seven days without resetting seem unlikely. On the other hand, requiring such tight accuracy for a 30 day period (for example) on either side of a reset point would result in a considerable time/core impact to recalculate precession and nutation. It does not appear to be worth it. Since the requirements exists to maintain the parameters over any mission interval, it would appear that the worst that could happen in the case of super-long simulation runs is degradation to existing

CMS-Skylab accuracy levels, which, while not good for Shuttle, will not have any disastrous results. The Greenwich hour angle changes by about 15 arc -seconds per second. Thus, an error limit of 2 arc-seconds should be within the limits of perception. It also corresponds to a ground track error of about 200 feet (at the equator) which should be acceptable so long as it is not oscillatory. It would, for example, at orbital velocity, change deorbit time by, at most, 1/100 seconds.

6.2.11.3.3 Displays

Occultation of the sun and Greenwich Hour Angle are expected to be of interest to instructors and for checkout.

6.2.12 Simulator Control Software

6.2.12.1 Data Recording

A method of recording data is necessary to obtain hard copy of simulator parameters for debug and training aid purposes. The approaches are as follows:

6.2.12.1.1 Plotters and Recorders

A method of obtaining data to ascertain the dynamic relationships of parameters to one another and to time is necessary for evaluating simulator performance. The selection of parameters to be recorded must be dynamic to assure maximum flexibility.

6.2.12.1.2 Real-Time Print

A method of obtaining immediate hard copy of parameters for quick analysis is necessary in debugging and training evaluation. Only a limited number of parameters is needed, but a dynamic selectability is necessary to assure maximum flexibility.

6.2.12.1.3 Logging

A method of analyzing simulator performance for debugging and training purposes is important. For this evaluation, as much data pertaining to inputs and outputs and dynamic simulator calculations as can be obtained is necessary. A logging facility is the best solution for this need. Data of all types will not always be needed, so the types of data to be logged must be selectable. The selection must be done in real-time to prevent interrupted training sessions.

6.2.12.2 Real-Time Input/Output

The SMS will require real-time inputs and outputs in order to perform a realistic simulation. This I/O will utilize both standard and non-standard computer complex devices. Access to these devices will necessitate a complete set of software support that can be readily utilized by the simulation control software. Logging will be a necessary feature during the checkout of simulation systems and subsystems. Provision for the dummying or substitution of real-time devices will allow checkout during periods when devices may not be available for operational use.

6.2.12.3 Synchronous Simulation Program Processor

Historically, simulation of aircraft and spacecraft systems requires that a predefined order and rate of execution be maintained for critical simulation functions. This is anticipated to be the case in SMS as well.

6.2.12.4 Master Timing

All crew station and IOS clocks must be updated in real-time, and they must remain in synchronization with one another. For best simulation performance, all clocks and times should originate from one single system.

6.2.12.5 Master Control

Certain basic control functions are inherent in the operation of any realistic training facility. The master control program provides these functions in the SMS.

6.2.12.6 Advanced Training

6.2.12.6.1 Automated Training

This feature will relieve the instructor of certain tedious simulation control functions, allowing him to concentrate upon instruction and evaluation of trainee performance.

It also has the advantage that all trainees can be provided with exactly the same training problems.

6.2.12.6.2 Performance Comparison

This feature will allow a display and/or hardcopy of the trainees' performance. This information will allow for a full evaluation of his performance under certain prescribed conditions. Potential weak spots in the training regeme can be spotted, or areas of further training pointed out. A "profile" of the strengths and weaknesses of a trainee can be rapidly arrived at.

It must be emphasized that this feature by no means would attempt to "score" the trainees performance. Performance comparison would only report the conditions found during the mission.

6.2.12.6.3 Record Playback

This feature will provide the instructor with the capability to record the actions of the trainee during a mission phase, then critique the trainee by playing back exactly what he did.

It will also be possible to build a library of mission phases to show how a maneuver is to be performed. Thus, a "textbook" docking sequence can be shown to the trainee prior to training in that area. Likewise, a docking sequence can be recorded that is full of "errors" and the trainee can be shown the consequence of several actions at one time.

It should be noted that emphasis is placed upon "flyout" from a playback. This was done to emphasize the potential danger that can exist should the crew controls be in an unsafe condition prior to release from playback control. Thus, if the simulator was performing a sequence of "touch and go" landings and the playback was stopped while the simulator was "on the ground", but the controls were in an "in the air" condition, personnel are in danger of severe motion base transients if the landing gear is not in a "down" state.

6.2.12.7 CRT Pages

The assumption is made that the CRT's on SMS will be used in the same fashion as those on Skylab, and since the SLS CRT system proved to be of great value in debugging and simulation monitoring, it is recommended that these requirements be applied in SMS.

6.2.12.7.1 Malfunction Control

Since it is desirable to provide for a software method for inserting and deleting malfunctions, using a CRT page for this appears to be the most logical approach.

6.2.12.7.2 Setup Verification

This is a logical equivalent of a proven SLS page program application.

6.2.12.7.3 Parameter Display

Since there will be few hardware displays, and many computer parameters, this requirement is necessary.

6.2.12.8 CRT System

Since the assumption is made that CRTs will be used for the display of simulation data, the requirement for a package to control the processing of that data is necessary.

6.2.12.8.1 CRT Hard Copy

This will provide for hard copy of all parameters displayed on a CRT independent of any other data recording technique.

6.2.12.8.2 Look and Enter

The capability to monitor and change data pool parameters in real-time is necessary.

6.2.12.8.3 Graphics

Since the assumption is made that the SMS CRTs will be graphic in nature, this requirement is necessary.

6.2.12.9 Operating System Interface

Systems involving multi-tasking capability as required in SMS, are normally under control of a sophisticated operating system. It is imperative that adequate interface between the application and the operating system be maintained for proper simulation in this environment.

6.2.13 Support Software

6.2.13.1 Operating System

The multi-tasking environment required for SMS with multiple part task simulations, batch, and terminal processing makes an operating system a necessity. This is dictated by the need to properly allocate and control computer system resources between the multiple simultaneous tasks that are executing in the system.

6.2.13.2 Software Processors

The requirement that the SMS have assemblers, compilers and loaders is self evident and these are assumed to be supplied GFP with the SCC. What is delineated are requirements for 'non-standard' features.

The requirement for a CRT page program processor is necessary.

The syntax and mnemonics of the CRT processor is parallel the assembler of the operating system is to minimize the number of programming languages to be learned.

6.2.13.3 Data Base Generator

The formation from simple inputs of a data pool of the complexity necessary for SMS is best done by a computer program(s). The associated listings are a natural by-product of the data pool formation. A mechanism for referencing from the simulation programs to the data pool is easier and faster through a computer program. A statistical analysis is necessary to have a complete understanding of the what, where, when, and why of the data pool construction.

6.2.13.4 Reset Generator

For proper training, the SMS must receive initialization at various points. A computer program is required to construct these points very rapidly with some assurance as to the validity of the data. This program is the reset generator. Also, some points may be taken during real-time training sessions. These points must be upgradable as changes are made to the simulation package. Since most of the criteria for these points apply to normal reset points, the reset generator is a prime candidate for doing the upgrading.

6.2.13.5 On-Board Computer Support Software

The on-board computer flight program must be processed from its delivery medium to hard copy listings and loadable object code. More than one copy of the loadable code will be needed for simulated change over from one computer to another. Patches to the flight program may have to be generated. The on-board computer support software will be responsible from these tasks.

6.2.13.6 Utility Programs

The functions performed by various utility programs are essential to support a complex operation such as the SMS successfully.

6.2.13.6.1 Diagnostics

The requirement for diagnostic routines will greatly reduce down time due to hardware failures which cannot be quickly diagnosed by other means. These routines will also aid in preventive maintenance activities by providing data on random device failures.

6.2.13.6.2 Support Utilities (Plotting, Trace, Snapshots)

Debug routines will reduce the time required to gather data during off-line and integrated test phase. They will also be helpful in documenting system performance during test and operational phases of activity.

6.2.13.6.3 Subroutine Library

The requirement for a subroutine library is dictated by the need for support of standard facilities such as the use of trigonometric functions. Routines such as this should not be left to individual users to provide because of the chance for deviation from standard results.

6.2.13.7 Delog

A mechanism for reducing real-time log data to a useable form is necessary for the data logging function to be useful. A computer program is the best method of implementation.

6.2.13.8 Statistics Gathering System

A method of computing computer loading is needed to allow the evaluation of the effects which changes to the simulation will cause. This loading also allows the evaluation of the computer resources available for non-real-time simulation activities. A record of computer usage and downtime is required for performance and cost evaluation. A Statistics Gathering System is the ideal approach to this effort.

6.2.13.9 Automated Documentation

Obviously, the SMS will consist of a large number of software packages. Although the exact number of such packages is not known, it is possible to ball-park the number at several hundred.

With this volume of software, the only reasonable way to document it is by using software that will release the programmers from these tedious and time consuming tasks. Two further benefits are realized by this method: the documentation can assume a standard format isolated from the idiosyncrasies of the individual; and with an automated system, as changes are incorporated, the chances that program documentation can be kept up-to-date are better, since the programmer can leave the updating of flowcharts, cross references and so on to the computer.

6.2.13.10 Data Management System

The need to know the simulation configuration at any point in time, together with its prospective configuration, necessitates a comprehensive and flexible configuration management system. Due to the complexity of the configuration management required to support the SMS, an automated system with various minimum manual controls is required. This type of system will afford several users a common data base of related elements of the same information. At the same time it will reduce the amount of paper work that usually exists. Cross relationships of one element of data to another can also be generated in an easy manner. This type of system will afford the capability for more people to be made aware of more information that is current all the time.

6.2.14 Systems Integration

The test drivers will be useful for the follow-on modification phase particularly in light of the time-sharing capability of the SCC.

6.2.15 Demonstration Installation Test

6.2.15.1 Factory Test and Demonstration

6.2.15.1.1 Layout Model

This layout model is deemed necessary to enable planning of installation to improve traffic flow, minimize cable runs, and eliminate noise problems.

6.2.15.1.2 Factory Test

These tests will verify simulator hardware fidelity. They will also minimize on-site test time and cost, and optimize overall test schedule.

6.2.15.2 On-Site Installation and Test

6.2.15.2.1 General

6.2.15.2.1.1 On-Site Hardware Installation, Integration and Test

These tests reverify hardware, check for damage in shipment, and will eliminate all hardware problems prior to system software tests.

6.2.15.2.1.2 System Test

These are nearly a dry-run of the acceptance tests to verify system performance prior to ATP, and are preceded by other software tests at the subsystem level.

6.2.15.3 <u>Acceptance Tests</u>

Acceptance tests are provided on the system level, to isolate major problem areas. Tests are sequentially ordered to minimize total test time and eliminate problems which will affect subsequent tests.

6.2.15.3.1 <u>Simulator Operation and Procedure Tests</u>

These are a prerequisite to Systems Tests and Mission Tests.

6.2.15.3.2 <u>System Acceptance Tests</u>

These tests are a prerequisite to Mission Tests.

6.2.15.3.3 <u>Mission Oriented Tests</u>

This is the final series of tests.

6.2.15.3.4 <u>Visual Graphics Tests</u>

These are a prerequisite to Visual System Tests.

6.2.15.3.5 <u>Visual System Tests</u>

Some of these tests can be conducted independent of and in parallel with other tests above. Hence, total calendar test time will be minimized.

6.2.16 Omitted

6.2.17 Omitted

6.2.18 Omitted

6.2.19 Motion System

The six degree-of-freedom motion system will provide the astronauts with the necessary cues to simulate the movement of the Shuttle vehicle during atmospheric flight. Motion simulation, during these phases, is most important since it furnishes feedback of the pilot's control action or is the direct stimulus for pilot action. The proposed motion system will be representative of the sensations experienced in the Shuttle vehicle. (Reference Bibliography Item 18)

As evidenced in the Simulation Techniques Study Interim Report current six degree-of-freedom motion systems are the only systems possessing the load carrying capability, adaptation to modification for visual system support, and present the best combination of performance and excursions of the state-of-the-art devices available. In fact, the load carrying capability of current motion systems limits its capability to the upper forward crew compartment and its associated visual system.

6.2.19.3.1 <u>Hydraulic & Electromechanical Design</u>

This paragraph establishes the requirement for a separate control loading pump.

It cites the specific characteristics for

a) filters

b) relief valves

c) plumbing

d) maintenance features

e) accumulators

f) heat exchangers

g) access ramp

h) hydraulic fluid

i) overtemperature sensors

j) constraints on component design

6.2.19.3.2 <u>Motion & Control Loading System Controls</u>

This section defines the requirements for safety and operational characteristics.

6.2.19.3.3 <u>Maintenance Controls</u>

This section defines the maintenance features for ease of maintenance and safety considerations.

6.2.19.3.4 <u>Floor Loading</u>

This is a typical motion system requirement and the site must be verified to see if the "1500 pounds per square foot" value is compatible.

6.2.19.4 Performance Requirements

6.2.19.4.1 Simulated Motions

This section defines the quality of the motion and the types of motion cues to be simulated.

6.2.19.4.2 Payload Weight

This paragraph is intentionally non-quantitative since it is subject to the individual bidders design (crew station/visual/tilt concept). It is inserted to define the payload imposed on the motion system.

6.2.19.4.3 Worst Case Maneuvers

Further definition of motion system performance requirements.

6.2.19.4.4 Rough Air

Same rationale as above, to specify performance.

6.2.19.4.5 Response

To quantify response time.

6.2.19.4.6 Excursions, Velocities and Accelerations

Quantitative values given are those characteristic of the Singer 60" stroke 6 D.O.F. machine. They are deemed to be adequate for the simulation of a vehicle of orbiter size which is expected to have rather docile flight characteristics.

6.2.19.4.7 Acceleration Onset

To define motion system capability.

6.2.19.4.8 Frequency Response

To define max. phase shift limits (performance).

Specifically limits the natural frequency of the system to greater than 5 Hertz.

6.2.19.5 Safety Requirements

This section itemizes the safety requirements deemed essential to the motion system.

6.2.19.6 Synchronization

This paragraph inserted to insure inclusion of synchronization features and alignment of software cues.

6.2.19.7 Maintenance Features

This section defines specific maintenance features required.

6.2.19.9 Tilt Provisions

During the pre-launch period, the flight crew will be seated in an upward-facing orientation, and this orientation will continue through the first part of the launch phase, with the magnitude of the gravity vector increasing from the normal 1g. To provide, during training in the simulator, the same gravity-combating effort in reaching controls on the instrument panel as would obtain during the pre-launch and launch portions of actual flight, it is necessary that the simulator cockpit be tilted so that the flight crew are properly oriented with respect to the gravity vector. Part of the pitch capability of the regular 6 DOF motion system can be used here, but a tilt mechanism will be needed for the greater part of the angular excursion.

6.3 Test Requirements

See Section 6.2.15.

6.4 Logistics

The specified items are essential to enable NASA to maintain and operate the SMS after acceptance, and are in line with past NASA simulator procurements.

6.5 Reliability and Quality Assurance Requirements

Stringent Quality Assurance requirements are dictated by the large scope and cost and the intended usage of the SMS. The Quality Assurance program should be planned and used in a manner to effectively support the contractors reliability and maintainability programs.

Inspections should include in-process and quality conformance operations.

Tests of the following types should be included as a minimum:

a) Structural

b) Electrical

c) Environmental

d) EMI

e) Human Factors

f) Reliability

g) Grounding

h) Functional

i) Trainer operation

The program should emphasize the prevention of deficiencies and provide for the early detection, correction and control of deficiencies. Special emphasis should be placed on quality control with respect to new and unproven program areas and equipment.

6.6 System Support

The complexity of the SMS warrants engineering support to train personnel in the operations and maintenance of the simulator. In addition, the support should include coordination of data and spares support. The support personnel should comprise a group who are experienced in the various technical areas associated with the simulator and form a part of the installation, checkout and testing crew. Beside providing training in the operation and maintenance of the simulator, training should cover the use of operations and maintenance manuals. It is anticipated that a six-month program would be required to provide adequate engineering support.

7.0 Documentation Requirements

This paragraph defines the effort associated with the cost of the Documentation work package and will provide visibility into the division of effort between work packages.

The Data Manager at Houston should alleviate the need for a NR representative based at the SMS contractors facility and minimize the communication problems between NR, NASA and the SMS contractor.