SHUTTLE MISSION SIMULATOR N81-14148

Charles Olasky

Abstract

The Shuttle Mission Simulator, located in Building 5 at the Johnson Space Center, is the primary training device for both Shuttle flight crew and Shuttle flight control personnel. The simulator was designed to provide real time simulation capability for all phases of the Shuttle Transportation System orbital missions including prelaunch, ascent, on-orbit operations, deorbit, entry, approach/landing, and roll-out. Full mission continuity is provided in transition between these mission phases. Dual fixed and motion base crew stations, instructor/operator stations, and computer systems allow parallel, simultaneous crew training with either complex capable of being individually integrated with the Mission Control Center. This integrated training capability allows flight control personnel training in the air/ground interface areas of tracking, telemetry (vehicle systems monitoring), uplink command control, and communications. With the exception of the simulated Data Processing System, which utilizes actual flight computers and associated flight software, all orbiter onboard systems are functionally simulated with extensive simulated malfunction capabilities. Additionally, Shuttle propulsion systems, vehicle dynamics, atmospheric/orbital environment, crew out-the-window visual scenes, and aural cues are rigorously simulated. The Motion Base Crew Station has the added feature of being mounted to a six-degree-of-freedom motion system that provides on-set and acceleration cues for launch and deorbit through landing training. The total SMS facility represents a major growth in simulator fidelity, sophistication, and capability over previous NASA mission simulators in support of manned spaceflight programs.

Introduction

Since the beginning of the Mercury Program the need of a spacecraft systems and mission procedures crew training device has been recognized by the NASA. Past program requirements have been satisfied by the Mercury Procedures Trainer, Gemini Mission Simulator, Apollo Command and Lunar Module Simulators, Skylab Simulator, and Orbiter Aeroflight Simulator. Today, in Building 5 at the Johnson Space Center, the Shuttle Mission Simulator (SMS) is operational and heavily involved in crew and flight control training for the first Shuttle Transportation System (STS) orbital flight.

After an extensive study and requirements definition phase, the SMS development contract was awarded to the Singer Company, Link Division, in January 1976. The contractual schedule article called for a phased/incremental delivery plan reflecting the following build-up in capabilities:

Fixed Base Crew Station (FBCS) operational - May 1978
Network Simulation System (NSS) operational - June 1978
Motion Base Crew Station (MBCS) operational - August 1978
Fixed Base Crew Station Update complete[1] - March 1980

[1]This deliverable consisted of the Orbiter Closed Circuit Television (CCTV) simulation, the Remote Manipulator System (RMS), and Payload Accommodation System (PAS) simulation, and the crew station aft and overhead window visual simulation.

The composite capability of these deliverables resulted in two separate standalone systems, the fixed and motion base crew station simulations and the simulation of the Ground Spaceflight Tracking and Data Network (GSTDN) interface to the Mission Control Center (MCC). Both crew station simulations can be run independently and simultaneously with capability for either to be integrated with the control center through the switchable NSS. These real time simulations provide generic and flight specific:

- Familiarization with Orbiter flight deck controls, displays, and related onboard systems.
- Training in nominal, contingency, and emergency crew and ground interface procedures.
- Familiarization of Orbiter handling characteristics supplemented with dynamic out-the-window visual scenes and vehicle motion cues.
- Training in the use of actual flight software and hardware for guidance, navigation, and redundancy management functions.
- Training for "end-to-end" inflight mission procedures and timelines including support of mission control center operations.

The FBCS is the larger of the two crew stations in that all flight deck work stations are simulated. These include:

- Forward commander work station
- Forward pilot work station
- Aft mission specialist work station
- Aft payload specialist work station
- Z-axis rendezvous work station
- Payload handling/RMS operator work station

The MBCS contains commander and pilot work stations with a "jump seat" instructor capability. This crew station is mounted to a six-degree-of-freedom motion system for acceleration and onset motion cues. The training emphasis for this crew station is directed toward ascent, entry, approach and landing mission phases.

The present STS mission schedule calls for the first manned orbital flight in late 1980 with follow-on flights increasing in frequency from several months interval to several weeks interval after the orbital flight test phase. The remaining sections of this paper will describe in more detail the in-place architecture and capabilities of the SMS that is fulfilling a major and demanding role in the preparation and execution of Shuttle program objectives.

Simulator Computer Complex

The SMS digital computer complex consists of: a Univac 1100 multiprocessor, functioning as a host computer; two strings (three minicomputers per string) of Perkin Elmer 8/32 computers, functioning as input-output intelligent controllers (IC's), six 8/32's within the Digital Image Generation (DIG) systems, and three 8/32's associated with the Network Simulation System (NSS). Additionally, there are five flight type General Purpose Computers (GPC's) assigned to each crew station simulation. Figure 1 diagrams the top level functional interfaces between these computers.

The Univac host computer complex is split into two separate systems, one each for the fixed and motion base simulations. One system is configured with 6 Command Arithmetic Units (CAU's) and 3 Input Output Arithmetic Units (IOAU's) while the other is configured with 4 CAU's and 2 IOAU's. A T-bar switching network allows either system to operate with either fixed or motion base simulation. Since each of the real time simulations are capable of running within a 4x2 configuration, the additional resources of the 6x3 configuration are applied to background/batch processing. Each of the host systems communicate with their respective intelligent controllers via data channels and special logic that interfaces the Univac 36 bit work format to the IC 32 bit work format. Both host computer real time simulation loads reside in seven 65K work memory modules of primary memory and two 131K word modules of extended memory. There are additional single 65K word primary and two 131K word extended memory modules available within one complex that are applied to background batch processing. Both local and remote terminals are available to initiate background processing.

Each of the fixed and motion base simulations contain three Perkin Elmer 8/32 computers that function as intelligent controllers which interface, format, control, and route data to and from the host and the major, functional, hardware elements of the SMS. These are categorized as the Crew/Instructor/Operator Station (CIOS) interface, the Visual System interface, and the Simulation Interface Device (SID)/Flight Computer interface. The primary means of intracommunication within each set of associated IC's is through a common shared memory interface. All of the SMS 8/32 computers contain double precision floating point capability and have memory configurations that range in size from 25K bit to 512K bit (local memory) and 64K bit to 320K bit (shared memory). The capability to switch the NSS between fixed and motion base simulations is through shared memory.

Most of the SMS application software (Shuttle systems simulations) reside in the Univac host complex. Each real time simulation is structured into 13 frame jobs which are dispatched and executed in prescribed sequences. The basic frame time of each simulation is 40 milliseconds which allows the highest real time execution rate to be 25 iterations per second. Generally, this execution rate is applied to time critical (flight dynamics, flight software interfaces, (etc.) areas of the simulation. Other portions of the simulation are executed at lower execution rates. Dependencies between simulated vehicle systems are satisfied by ordering within frame jobs and by specifying the sequence of execution of specific frame jobs. Time critical simulation areas are synchronized and controlled through appropriate interfaces to the simulator Central Timing Equipment (CTE).

Crew Stations and Motion System

As previously mentioned, the FBCS contains all work positions of the Orbiter flight deck while the MBCS is limited to commander and pilot positions. Within this constraint both crew stations provide an accurate interior replication of the vehicle in all areas visible and accessible to flight crews. Both cockpits are presently in STS-1, Orbiter 102, mission configuration.

Ingress/egress for the FBCS is through flight deck floor hatch openings as in the actual Orbiter vehicle. Access to the MBCS is through a conventional door mounted at the aft bulkhead allowing a walk-in capability when the crew station is in a level attitude.

Both crew stations are supported by an aural cue system simulation. Sounds produced by the Shuttle vehicle that normally would be audible within the crew compartment, and characteristic of vehicle operational performance, are synthesized. Control of this simulation is from each respective instructor/operator station.

All FBCS and MBCS controls and displays, except for flight computer display and keyboard units, are interfaced through appropriate simulator signal conversion equipment (SCE), master controllers, and Crew/Instructor/Operator Station Intelligent Controllers, to the Univac host computing system--where the bulk of the onboard system simulations reside. Remaining simulated system sensor inputs/outputs are made available via the IC shared memory interface. The host to CIOS IC data channel interface also allows control for the MBCS motion system.

The MBCS motion system was specifically adapted for SMS use and features a unique tilt system in addition to the six-degree-of-freedom motion platform. These systems allow a composite 108 degree pitch-up hardware capability. For the normal liftoff, boost, and ascent mission phase an excursion to 90 degrees in pitch (80 degrees from the tilt mechanism and 10 degrees from the motion platform) has been programmed for the MBCS. This allows a sustained longitudinal acceleration cue by means of directable 1-g gravity vector through the backs of crew members. A maximum of 3-g real world axial acceleration is scaled and simulated for the launch/ascent phase. The motion system also provides acceleration cues for on-orbit, aeroflight and transition phases of orbital insertion, de-orbit, and abort. These onset cues are obtained through software filters for each of the six-degrees-of-freedom. Inputs to these filters are scaled vehicle translational accelerations and angular velocities which are output as proportional platform displacement commands in both position and attitude. Additional outputs by the motion software are vibration and buffet cues, for appropriate mission phases, as well as the necessary wash-out compensation to avoid reaching platform excursion limits (and to re-direct the earth's gravity vector to prevent its effect from resulting in false cues). Performance limits of the motion system are as shown in Table I.

Instructor Operator Stations

Two basic instructor operator stations (IOS's) are associated with the SMS. One station operates with the FBCS simulation and the other with the MBCS simulation with each functioning as the central controlling point for each respective simulation. In addition, there is an in-cockpit instructor/observer station within the aft section of the MBCS. Each of the two basic IOS's permit monitoring of all simulated vehicle systems, crew station panels and controls, and cockpit out-the-window visual scenes. Control and moding over all aspects of simulator operation is also provided for both training and checkout sessions. Procedurally, the operator stations are used to prepare the simulator for a training session and operate the simulation during the session. The instructor stations are manned to execute a specific training exercise including the, monitoring of simulated subsystem behavior, communication with the crew, and initiation of specific simulated malfunction cases or off nominal conditions. The primary interfacing medium at the IOS's are interactive alphanumeric CRT systems. Each station has CRT readout capability and keyboard/lightpen input capability. An extensive voice communications system allows coordination among all major elements of the SMS (crew stations, IOS's, NSS area, computer area, et cetera) as well as to the mission control center. The following console hardware exists at fixed and motion base IOS's:

Operator Station

- Two alphanumeric CRT displays
- Two keyboard/lightpen units
- Two graphic CRT displays
- Two visual monitors (CRTs)
- Two communication control panels

Shared Station Equipment

- Three 8-channel X-T recorders
- Two 2-channel X-Y recorders
- Two CRT hardcopy units

Instructor Station

- Nine alphanumeric CRT displays
- Four keyboard/lightpen units
- Five graphic CRT displays
- Two visual monitors (CRTs)
- Four flight computer display units
- One flight computer keyboard unit
- Six communication control panels

The motion base in-cockpit instructor/observer station is equipped with a single alphanumeric CRT and keyboard unit.

Visual System

The SMS visual system consists of two major functional areas, the image generation function and the image display function. Both SMS crew stations have identical forward window image generation and display configurations and capabilities. The FBCS has the additional Orbiter closed circuit television (CCTV) and aft/overhead window visual systems. Table II summarizes the visual scene content for each simulated mission phase of the SMS.

Each crew station simulation utilizes digital image generation (DIG) systems. The MBCS has a single system (forward windows) while the FBCS has three systems (forward windows, aft/overhead windows, and CCTV). All four DIG's are of the same basic configuration and differ only in data base (scene) content and in occlusion processing sophistication. Figure 2 illustrates a representative visual (single DIG) system interface for the SMS. The DIG controller 8/32 functions as the major data control center for a DIG. It receives simulated orbiter specific attitude, position, and dynamics data that is collected in the host computer then formatted and transmitted to visual shared memory by the visual intelligent controller. Relevant data base information is retrieved from disc storage by the DIG controller in response to these inputs from the intelligent controller. Formatted data and commands are then transmitted to the frame calculator.

The frame calculator performs coordinate transformations of received position and illumination vectors to an object coordinate system, accesses objects stored in the active data base via the DIG controller, and performs testing for visibility Data is then translated/rotated into a crew station window coordinate system reference where calculations of intensities as a function of illumination source and direction are performed. Data is limited (clipped) to only allow further processing of objects within the window field-of-view and converted into projected edges with associated display parameters in two dimensional coordinate form, for transmission to the scan line computer.

The scan line computer has double buffered memory that allows simultaneous writing of the present frame and reading of the next frame. An edge list function within the scan line computer, converts adjacent polygon boundaries to display edges, eliminates common edges, and sorts display edges by scan line. Occlusion calculations are performed to determine if the intersection of an edge with a scan line is visible or occluded. Intensity, color, shading, and edge smoothing calculations are done for each visible intersection. This data is output to the appropriate video generator where digital to analog signal conversion provides signals suitable to drive the SMS display system.

Do to the potentially large number of real world moving objects associated with the Shuttle RMS and payload bay operations, the SMS CCTV and aft DIGS both contain a sophisticated occlusion system. This system processes defined lists of objects, within view from a specific eyepoint, and continuously calculates and provides ordering of occlusion priorities for these objects.

There are three different image display systems used on the SMS. Both crew stations contain a direct view TV, wide angle collimated light, forward window display system. This system allows simultaneous color presentations on any four of the six Orbiter forward windows. Field-of-view for each window is 40 degrees vertical by 45 degrees horizontal with 9 arc minutes of resolution. The fixed base crew station contains the orbiter 525 line CCTV simulation. This system contains two split screen monitors with a capability of viewing three different scenes simultaneously. Presentation is in black and white as in the real world vehicle. Video from the CCTV is available for downlink transmission to the mission control center as in actual Shuttle flight. The aft/overhead window displays for the FBCS consist of four liquid crystal light valve projection systems coupled with four tilted pancake window optical assemblies. Resultant field-of-view for each window is 70 degrees vertical by 93 degrees horizontal with 9.6 arc minutes of resolution. These windows presently provide monochromatic presentations. SMS interface and special effects electronics generate alphanumeric data to be displayed on the CCTV displays, and provide horizon layer, terminator effects, and cloud simulation for forward window displays.

Flight Computer Interface

Each of the two SMS real time simulations is interfaced to five flight-type Shuttle General Purpose Computers (GPC's) which use actual flight software. Figure 3 illustrate the SMS to GPC hardware interfaces which exist for both the FBCS and MBCS. These interfaces, consisting of the GPC's, Simulation Interface Device (SID), and SID Intelligent Controller, allow a simulation of the Shuttle Data Processing System (DPS). Functionally, this simulation includes Guidance, Navigation, and Control, Air-to-Ground Telemetry and Command Interface, Displays and Controls, Shuttle Systems Monitoring and Management, Payload Handling and Management, and Systems Sequencing. The SID IC facilities communication between the GPC's/SID and vehicle system modeling in the remainder of the SMS.

An individual GPC consists of a central processing unit, a memory, and an input/output processor (IOP). The IOP provides 24 buses (out of a total of 25) for interfacing to 10 types of Bus Terminal Units (BTU's). These BTU's are functionally categorized as:

- Multiplexer/Demultiplexer
- Mission Event Sequencing and Control
- Main Engine Interface Unit
- Mass Memory Unit
- Multifunction Crew Display System (consists of Display Electronics Unit, CRT display, and keyboard)

- Solid Rocket Boosters
- Launch Processing Unit
- Dedicated Display Unit

The remaining bus is for inter-computer communications and is connected directly to the IOP's of each GPC.

The SMS SID was designed and developed specifically to interface the GPC's to Perkin Elmer 8/32 computers. It contains IOP interfacing hardware that emulates the front half (IOP side) of the BTU's. The remainder of the BTU's are functionally simulated on the SMS side of the SID interface. The SID also contains a modified IBM System 7 computer that functions as the Air/Ground Equipment (AGE) controller. It is programmed to interface with the GPC AGE connector interface and with the SID IC. It allows the SID IC to command GPC moding control functions, the processing of GPC in/out discretes, and the support of equipment real time synchronization. The AGE controller performs SID IC commanded functions and transmits appropriate feedback responses to the SID IC. Many of the AGE discrete interfaces are to the SMS crew station (via SCE) for panel switches and controls which have a direct GPC function.

Non-AGE, GPC input data flow consists of data collected from SMS subsystem programs (mainly residing in the host computer), processed to proper units and format by the SID IC, and placed on an GPC/IOP bus by the SID via the appropriate BTU model. GPC output data is commanded through an IOP data bus to the appropriate BTU simulation (SID), then to the SID IC for processing to proper units, and finally stored for access by the using SMS system programs.

There are a category of SMS crew station displays that are driven directly by GPC commands through the Dedicated Display Unit BTU. These are the Attitude Direction Indicator, Horizontal Situation Indicator, Alpha/Mach Indicator, Altitude/Vertical Velocity Indicator, and Surface Position Indicator. Additionally, the Multifunction Crew Display System has a direct crew station to GPC interface. This system of Display Electronic Units, CRT displays, and keyboards are the primary means of crew interaction and communication with the GPC's.

The SMS flight computer interface supports flight Mass Memory Units (MMU's) (tied to the SID via BTU simulated interface) as well as the capability of interfacing with simulated MMU's through the SID IC.

Shuttle Systems Simulation

The SMS contains mathematical modeling that simulates all Shuttle onboard systems that have crew and flight control (MCC) interfaces. Both of the FBCS and MBCS software loads execute in real time. Individual onboard systems are simulated to sufficient fidelity that crew station display and control responses and inputs are indistinguishable from those of the actual vehicle. Actual flight software is used and interfaced to simulated vehicle systems. Both hardware and software redundancy management features of the GPC/flight software are exercised. Reset/initialization points are provided throughout the various Shuttle mission phases that allow the simulation to be brought up with all systems fully synchronized relative to time. Over 3,800 individual simulated malfunctions have been preprogrammed within the application software and are menu selectable for activation from the instructor operator stations. Table III tabulates the major vehicle subsystems, as well as the environmental, visual, and MCC interface capabilities simulated within the SMS.

Network Simulation System

The Network Simulation System (NSS) simulates the real world Ground Spaceflight Tracking and Data Network (GSTDN) and its associated interface with the Mission Control Center (MCC). The GSTDN is a world-wide network of stations, tied to the MCC through Goddard Space Flight Center (GSFC), which provides telemetry, tracking, and communication capability for manned spacecraft--including the Shuttle. These stations provide the RF links necessary for the reception of downlink telemetry data (incuding the stripping, conversion, and shipping of digitized voice data) the transmission of uplink command data, and the acquisition/computation of tracking data.

Figure 4 illustrates the NSS interfaces within the SMS. The NSS consists of three Perkin Elmer 8/32 computers, an instructor operator station, wideband and flight type recording equipment, special purpose synchronization and channelization equipment, and modem input/output interface devices. The NSS can be switched to either FBCS or MBCS simulation and communicates through the IC shared memory interface that is accessable by the CIOS IC, the Visual IC, and the SID IC.

Shuttle downlink data consists of Operational Instrumentation (OI) data merged with GPC downlist and digitized voice data. The SMS simulates this process and the resultant simulated downlink stream is the same as the actual vehicle output. The NSS downlink system accounts for the transmission of telemetry (real time and recorded) from the vehicle to the tracking sites, to GSFC, and then to the MCC. NSS downlink simulation functions include reception of formatted air-to-ground data; voice data stripping; remote site formatting, addition of header information, recording, site status message generation/routing, GSFC multiplexing, and routing to MCC. SMS CCTV video is also made available to the MCC in analog form.

The Shuttle uplink stream is used to send command and telemetry data to the Shuttle as well as acquisition data to the remote tracking sites. The NSS uplink function accounts for the GSFC reception of data from MCC and the conversion and routing of same to the sites. Simulated uplink site functions include data reception, validation, reformatting, recording, and transmission to the SMS via SMS IC shared memory.

The remaining NSS major function, Groundtrack, receives SMS generated Orbiter position, velocity, and communications systems status data to simulate the site function of vehicle tracking relative to site location. This includes calculations of Acquisition-of-Signal (AOS) and Loss-of-Signal (LOS) and signal strength as appropriate for the C-band and S-band site simulations. Formatters, upon proper simulated site moding control, place tracking data into an MCC compatable format for transmission.

The NSS complex contains its own independent instructor operator station with both analog displays and controls as well as an interactive alphanumeric CRT system. CRT displays are constructed using both SMS available data and NSS internally generated data. Capability for simulation set-up, moding, systems monitoring, malfunction insertion, and voice communications are provided.

Conclusion

The SMS exemplifies numerous real time simulation advancements within one complex for flight crew training. Advancements have been realized in, utilization of computer image generation, interfacing of flight computers and associated software, completeness and sophistication of simulated systems, and computer system interfaces and software structuring. This facility will play a major role in execution of Space Shuttle program objectives for the remainder of the decade.

References

1. The Singer Company, SMS Digital Image Generator Operation and Maintenance Manual, JSC 11002-01, 1978.

2. IBM, SMS Interfaces and Capabilities, CDRL 007A2, 1978.

Table I

MBCS Motion System Dynamic Performance Units

ROTATION	EXCURSION (DEG)	VELOCITY (DEG/SEC)
PLATFORM PITCH	+28.0 -26.5	15.0
ADDITIVE EXTENDED PITCH	+0 to 80	42.1 UP 43.0 DOWN
ROLL	±18.5	15.0
YAW	±23.0	15.0

DISPLACEMENT	EXCURSION (M)	VELOCITY (M/SEC)	ONSET ACCEL (G/SEC)
LONGITUDINAL	1.1	.61	±3
LATERAL	1.1	.61	±3
VERTICAL	0.9	.61	±3

Table II

SMS Visual Scene Content

FBCS and MBCS Forward Windows

- o Launch and Ascent Mission Phase
  - o Launch site area detail
  - o Low altitude earth Terminal Area Energy Management (TAEM) and landing area scene
  - o Solid rocket booster separation effects
  - o High altitude earth scene with horizon
  - o Star field
- o On-Orbit Mission Phase
  - o Day and night high altitude earth scene
  - o Star field, sun, and moon
  - o Rendezvous vehicle (mission dependent)
- o Entry and Landing Mission Phase
  - o Low altitude detailed earth scene
  - o Primary and contingency landing sites
  - o Runways, terrain features, landing site detail

FBCS Aft/Overhead Windows and CCTV Displays

- o On-Orbit Mission Phase
  - o Simplified earth
  - o Starfield, sun, and moon
  - o Orbiter ownship features
  - o Payload bay including doors, radiator panels, lights, and CCTV cameras with pan/tilt units
  - o Remote Manipulator System (RMS) arm including attached cameras and lights
  - o Payloads (mission dependent)

Table III

Shuttle Systems Simulation Content

- COMMUNICATION, TRACKING AND INSTRUMENTATION
  - OPERATIONAL INSTRUMENTATION SYSTEM
  - NETWORK SIGNAL PROCESSOR
  - MICROWAVE LANDING SYSTEM
  - RADAR ALTIMETER
  - MASTER TIMING UNIT
  - PULSE CODE MODULATION UNIT
  - PAYLOAD INSTRUMENTATION SYSTEM
  - INTERCOM AND UHF COMMUNICATIONS
  - S-BAND SYSTEM
  - TACAN
  - FLIGHT RECORDERS
  - CAUTION AND WARNING SYSTEM

- DATA PROCESSING SYSTEM
  - OPERATIONAL INSTRUMENTATION INTERFACE
  - FLIGHT COMPUTER INPUT/OUTPUT PROCESSING
  - MASTER EVENTS CONTROLLER
  - LAUNCH PROCESSING INTERFACE
  - PRIMARY AND BACKUP FLIGHT SOFTWARE
  - MAIN ENGINE INTERFACE
  - RMS MASTER CONTROL INTERFACE UNIT
  - FLIGHT COMPUTERS AND FLIGHT SOFTWARE

- ELECTRICAL POWER
  - POWER DISTRIBUTION AND CONTROL
  - FUEL CELLS
  - POWER REACTANTS STORAGE AND CONTROL

- ENVIRONMENTAL CONTROL AND LIFE SUPPORT
  - ATMOSPHERE CIRCULATION AND PURIFICATION
  - SPACE RADIATORS
  - FREON AND WATER COOLANT
  - GASEOUS SUPPLY

- GUIDANCE, NAVIGATION, AND CONTROL
  - THRUST VECTOR CONTROL
  - GN&C CONTROLS AND DISPLAYS
  - AERO SURFACE CONTROL
  - INERTIAL MEASUREMENT UNIT
  - STAR TRACKER
  - RATE GYROS AND ACCELEROMETERS
  - AIR DATA SYSTEM

- MECHANICAL POWER
  - AUXILIARY POWER UNIT
  - HYDRAULIC POWER SYSTEM

- MECHANICAL SYSTEMS
  - SEPERATION LOGIC
  - LANDING, BRAKING, GROUND CONTACT
  - EJECTION SEAT
  - UMBILICAL DOORS

- PAYLOAD ACCOMMODATION SYSTEMS
  - REMOTE MANIPULATOR SYSTEM KINEMATI MODEL
  - END EFFECTOR AND SERVO SIMULATION
  - RMS ATTACHMENT INTERFACE AND PYRO
  - PAYLOAD RETENTION SYSTEM
  - PAYLOAD BAY DOORS
  - PAYLOAD BAY LIGHTING AND CCTV SELECTION AND CONTROL

- PROPULSION
  - MAIN ENGINE SYSTEM
  - MAIN ENGINE CONTROLLER
  - SOLID ROCKET BOOSTER SYSTEM
  - REACTION CONTROL SYSTEM
  - ORBITER MANEUVERING SYSTEM

- VEHICLE DYNAMICS
  - ORBITER AND TARGET EQUATIONS OF MOTION
  - AERODYNAMICS AND RCS/AERO INTERACTION
  - BODY BENDING AND FUEL SLOSH
  - MASS PROPERTIES

- SHUTTLE ENVIRONMENT
  - EPHEMERIS
  - ATMOSPHERE/GRAVITY/WINDS
  - AURAL CUES
  - MOTION

- VISUAL SYSTEMS
  - FORWARD WINDOW DIGITAL IMAGE GENERATION
  - CLOSED CIRCUIT TV DIGITAL IMAGE GENERATION
  - AFT/OVERHEAD WINDOW DIGITAL IMAGE GENERATION
  - VISUAL MODING, CONTROL AND FORMATTING
  - VISUAL SPECIAL EFFECTS
  - FORWARD WINDOWS DISPLAY SYSTEM
  - CLOSED CIRCUIT TV DISPLAY SYSTEM
  - AFT/OVERHEAD WINDOW PROJECTION AND DISPLAY SYSTEM

- NETWORK SIMULATION SYSTEM
  - UPLINK AND DOWNLINK TELEMETRY
  - TRACKING
  - DATA PROCESSING, FORMATTING, MODING, AND RECORDING
  - COMMUNICATIONS
  - MISSION CONTROL CENTER INTERFACE

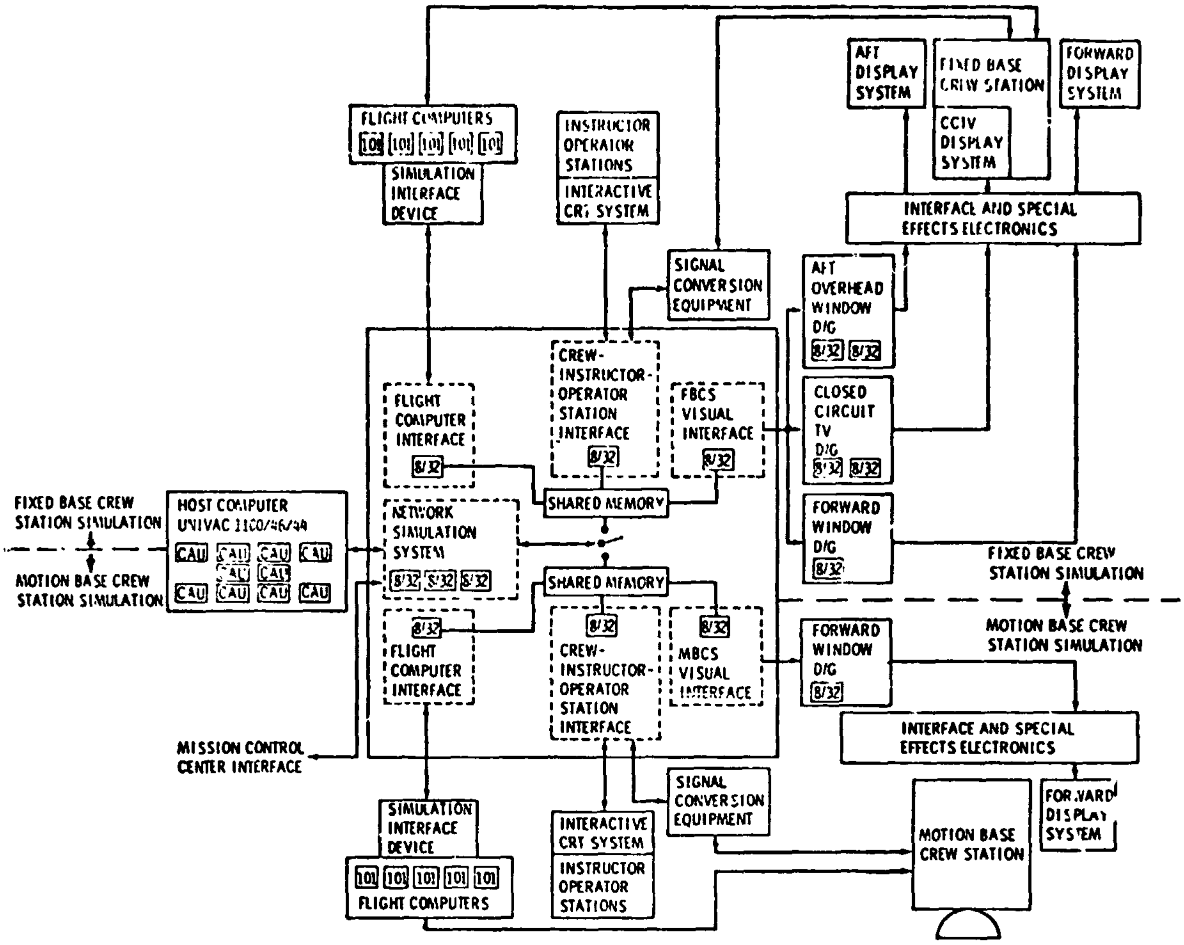

Fig. 1 SMS top level block diagram.

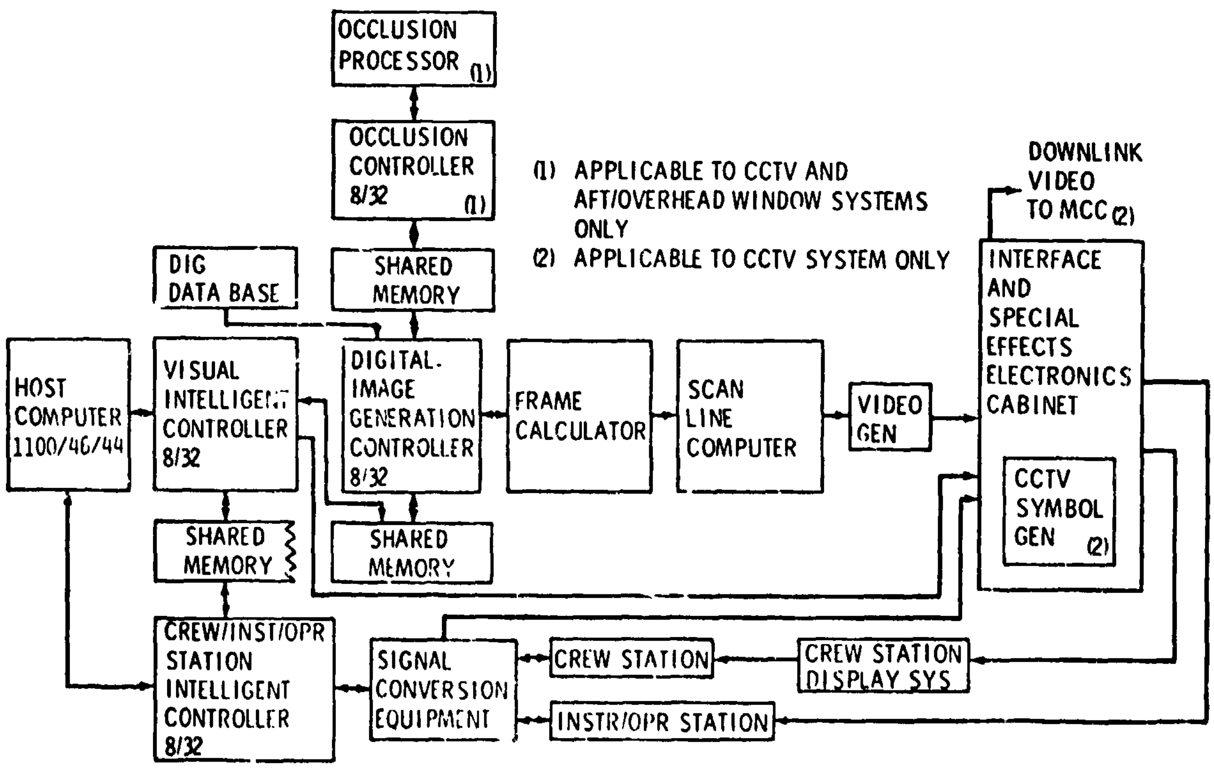

Fig. 2 SMS visual system interface.

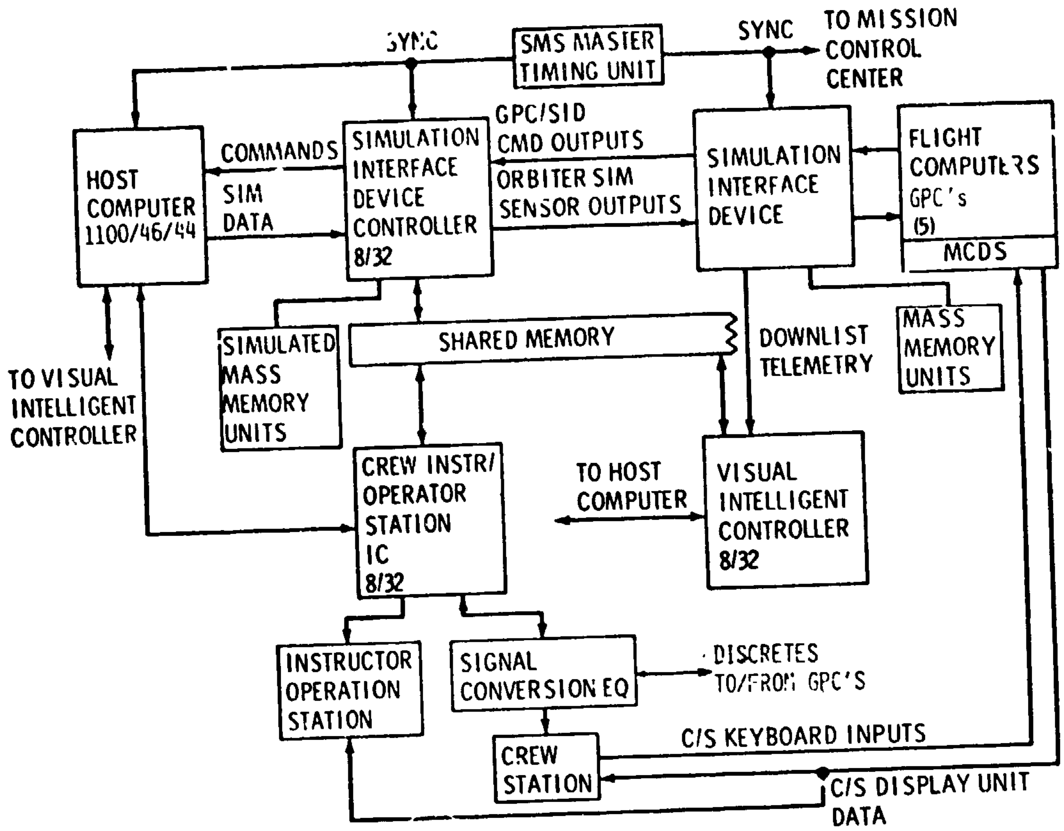

Fig. 3 SMS/Flight computer interface.

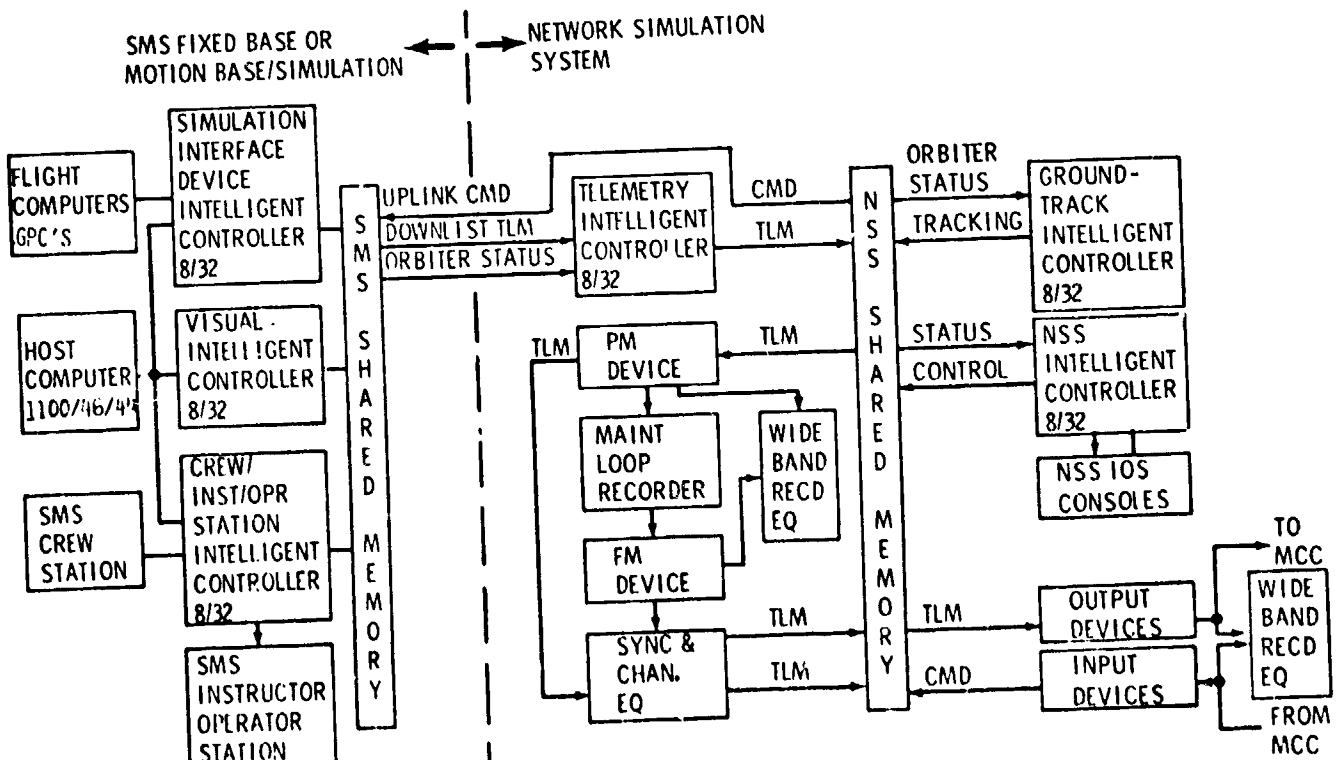

Fig. 4 SMS, network simulation system interface.