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REVISION 1

JSC DIVISON INTERNAL NOTE

SIMULATION MATH MODEL COORDINATION CATALOG

MAY 31, 1974

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Houston, Texas

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PROJECT SHUTTLE

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FLIGHT SIMULATION DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS

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Revisions to the

Simulation Math Model Coordination Catalog

Revision Number	Changes	Date
1	Replace cover, title page; insert iiA; replace v, 3, 11, 17, 19, 21, 23; insert 24; replace 25; insert 26, 30A; replace 37; insert 37B; replace 43; insert 44, 46A, 54A; replace 71; insert 72; replace 93; insert 94; replace 103; insert 103B, 118A; replace 129; insert 130; replace 131; insert 132, 136A, 138A, 140A; replace 145; insert 146, 150A, 150C; replace 163; insert 164; replace 205, 215, 217, 221, 223; insert 223B, 223D, 223F, 223H, 223J, 223L, 223N, 223P, 223R, 223T, 223V; replace 225 and 231.	31 May 1974

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TABLES

SIMULATION MATH MODEL COORDINATION CATALOG

1.0 SUMMARY

This document is a catalog of subsystem and environment math models used or planned for Space Shuttle Simulations. The purpose of the catalog is to facilitate sharing of similar math models between Shuttle simulations. It provides information on math model requirements, formulations, schedules and contact persons for further information.

2.0 INTRODUCTION

2.1 Purpose

The Simulation Math Model Coordination Catalog is designed to facilitate the sharing of similar subsystem and environment math models required for Shuttle simulations. This catalog identifies possible sharing of software model requirements, formulations, status, and development schedules in an effort to reduce redundant software development. During phases of simulation development, the catalog can be used to meet the requirements set forth in Book 2, "Program Allocation of Simulation Functions" of Level II, Volume XVIII, "Computer Systems and Software Requirements" (reference 1), whereby it states: "Prior to starting model development each project shall review and evaluate information from the Math Model Coordination Service to assure maximum utilization of existing models". With this in mind, the catalog can be used as a central source for operational simulation models, models under development, and models required at a later date. A developer can then acquire specific information for his model development, such as formulation documentation, to carry on his development effort in a timely and efficient manner. References are made to key individuals for each simulation model included in the model descriptions. These references can be used to identify lines of communication for additional detailed information. By sharing model information, it is anticipated that development testing and costly comparison studies between simulations can be minimized.

2.2 Method of Presentation

This catalog is presented in seven sections. A summary is provided in section 1. Section 2 describes the purpose and composition of the catalog. Major simulations are described in section 3. This section can be used by those unfamiliar with all the major Shuttle simulations.

Section 4 is divided into two parts. The math models contained within simulations have been grouped into twelve separate categories in this document. These categories are described in section 4.1. Each of the categories have been divided into subclassifications which are descriptive model names.

The basic tool for using this catalog is the model sharing matrix in section 4.2. This matrix groups similar models under the category headings described in section 4.1. By using the matrix, the user can readily identify those simulations which have developed or are planning to develop a particular type of model.

Where sufficient information about a model is available, a brief description of the model is included in section 5. The model descriptions are based on source documentation listed in references 2 through 27. The model descriptions include information on the purpose of the model, major inputs and outputs, development schedule, contact person, and source documentation.

Where model descriptions are not included in the catalog, the user may find section 6 helpful. For each simulation, this section lists all model names that have been identified for inclusion in this catalog. This information was supplied to the Math Model Coordination and Utilization Service which functions to facilitate sharing of similar math models between all Shuttle simulations. In addition, the development schedule dates, where available, contact persons, source documentation, and an indication as to whether additional information is available in section 5 are given for each model.

Section 7 presents schedule information for each simulation identified in the Model Sharing Matrix. This schedule identifies those simulations which are operational as well as those that are being developed or are planned to be developed. This data is provided to assist a developer to identify those developments which might meet his model development needs and schedule requirements.

2.3 Catalog Updates and Revisions

Currently only a small portion of the simulations have been documented. Therefore, this catalog is expected to be updated on a monthly basis to incorporate additional math model information. The monthly updates will be issued in the form of change pages, and at six month intervals a complete revision to the catalog will be published.

2.4 Source Documentation

A complete set of source documentation used in compiling this catalog is available on microfiche slides at the facilities listed in Table I. The microfiche slides can be found under this document's library number, e.g., JSC-08965. The microfiche documentation includes memos, unpublished working papers on model formulation, as well as formal published documents. The user can review the microfiche documentation about a particular model and arrange for hard copies to be made from the microfiche as needed. The microfiche of the source documentation will be updated concurrently with the catalog update.

2.5 Researcher's Model Information Sources

This catalog represents the best available data at the time of publication. As the Shuttle Program progresses in the areas of software development and testing, the data contained within can best be utilized through the following informational sources.

Microfiche Documentation - It is first recommended that the researcher, after consulting the catalog and finding a model which arouses his interest, can obtain additional information by reviewing the microfiche documentation on the particular model. The researcher, if he desires, can obtain a printed copy of the pages of interest in the documentation through his facilities reproduction department from the slides.

Contact Persons - The contact person, who deals with this particular model, can assist in any further research.

Shuttle Program Operational Data Book - The researcher can refer to the "Shuttle Program Operational Data Book" for a definition of performance capabilities and limitations of the spacecraft, payloads, and crew equipment as it pertains to the specific model. This information will be useful in verifying the completeness of the model and insuring the most up to date Shuttle design characteristics are simulated.

Catalog Manager - The catalog manager is John P. Mitchell, Johnson Space Center, (713) 483-3981. He can be contacted for assistance in completing the model research or act as a source contact for any additional aid during research not supplied by the above. The manager is the person to whom new data should be directed for inclusion into the catalog or for upgrading the model descriptions found within.

Figure 1 (Researchers Source of Model Information) is an illustration of the order and contents of the data information sources as they apply to the use of the catalog.

TABLE I. Facilities With Source Documentation On Microfiche Slides

FACILITY	MICROFICHE LOCATION	CONTACT INDIVIDUAL
Ames Research Center	Computer Science Information Center	John MacKay
Flight Research Center	NASA FRC Library, Room 2001	Librarian, x334
Goddard Space Flight Center	GSFC Library	A. Williams, x2218
Lyndon B. Johnson Space Center	Technical Library Room 2035, Building 30	Retha A. Shirkey John P. Mitchell, x3981
John F. Kennedy Space Center	Technical Library	Helen Kelley
Langley Research Center	Technical Library	P. E. Weatherwax
Lewis Research Center	Technical Library	Jack Harper, x7268
George C. Marshall Space Flight Center	Technical Library	Charlotte Dabbs
Space and Missile Systems Organization	Library Services, Building A4 Aerospace Corporation	

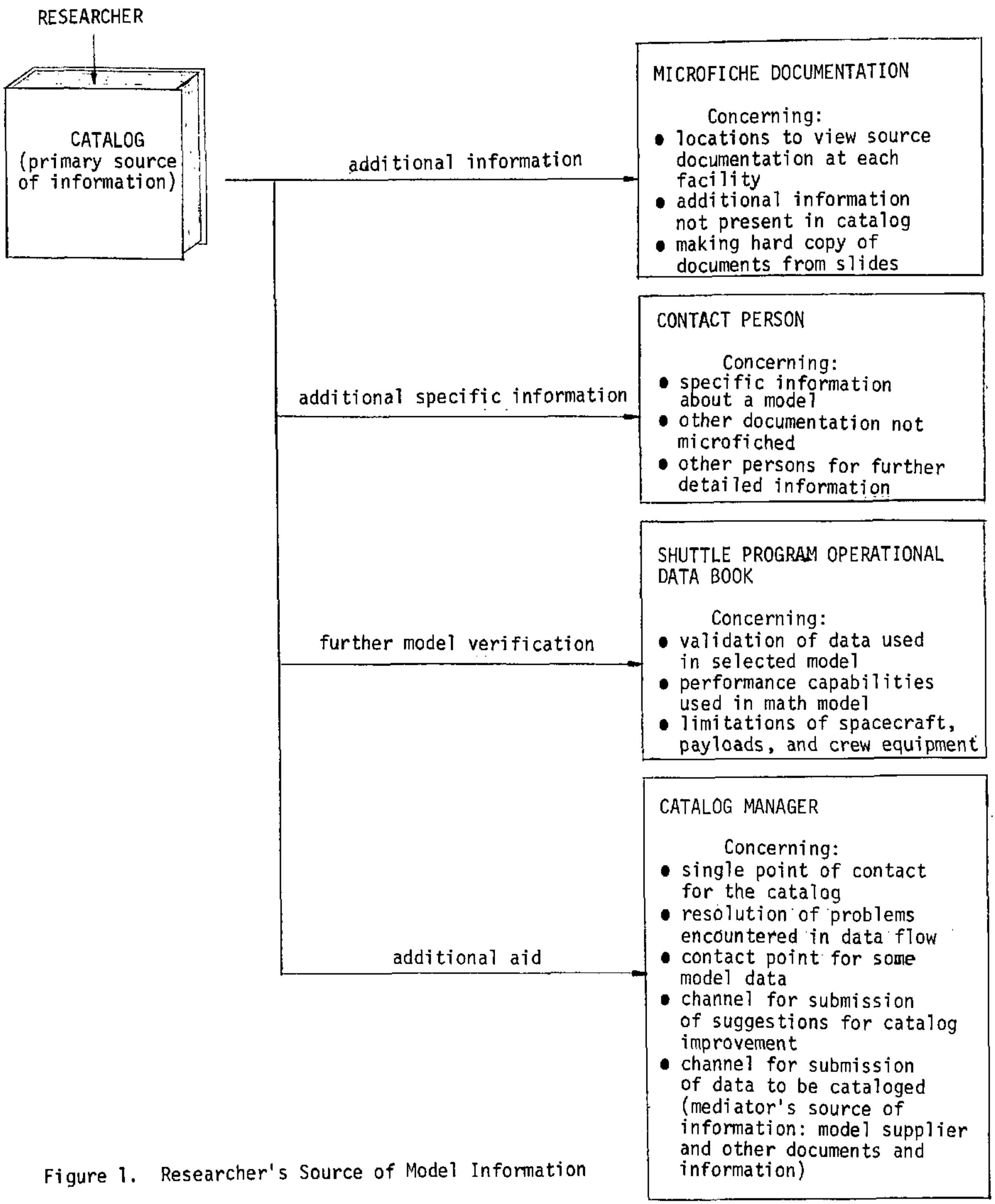


Figure 1. Researcher's Source of Model Information

3.0 SIMULATION DESCRIPTIONS

The following simulation descriptions identify the basic objectives of each Shuttle simulation having potential for model sharing. The descriptions are presented primarily as an informational aid to those unfamiliar with the overall Shuttle simulation effort or any individual simulation in which the user may have interest. The basic objectives of these simulations were extracted from Reference 1. Each description is introduced by its simulation name, acronym, and location.

SPACE DIVISION SHUTTLE SIMULATOR (SDSS) - RI/Downey

The objective of the SDSS is to provide the means for verifying the Orbiter avionics in the Avionics Development Laboratory (ADL) interfacing with the hydraulics in the Flight Control Hydraulic Laboratory (FCHL) in a closed-loop operation. The SDSS revises hydraulic actuator position information, simulates the vehicle flight characteristics, and provides sensor data inputs to the avionics. The SDSS consists of the crew station, an out-of-the-window scene generation system, and an analog/digital computer complex.

CONTROL SYSTEMS DEVELOPMENT DIVISION (CSDD) SIMULATION - JSC

The objective of the CSDD Simulation is to provide a high fidelity simulation of the Orbiter subsystems for evaluation of design approaches including real-time digital simulations of those guidance and flight control functions that are to be included in the onboard digital software. The simulation consists of a crew station, an out-of-the-window scene generation system, and an analog/digital computer complex.

SHUTTLE MISSION ENGINEERING SIMULATOR (SMES) - MDAC/St. Louis

The objective of the SMES is to study various high risk problems relating to vehicle flight control and dynamics and for assessing the implications of proposed configuration or programmatic changes. The SMES provides the capability to simulate the terminal area energy management (60K-10K feet, Mach 2.0-0.1) for studing variable entry point, spiral, cylindrical, and VORTAC reference design approaches. The SMES also provides the capability to simulate aerodynamics flight, landing, and rollout for evaluating flight control and autoland design concepts.

SHUTTLE PROCEDURES SIMULATOR (SPS) - JSC

The objective of the SPS is to provide the capability for development of crew procedures for nominal and backup flight modes and for specific mission oriented sequences. In addition, the SPS will provide the capability to support definition of display formats. The SPS will support the Program Design Review and Critical Design Review in defining crew-computer interface, cathode ray tube display formats, and provide a means for evaluating the crew interaction with the displays.

FLIGHT SIMULATOR FOR ADVANCED AIRCRAFT (FSAA) - ARC/Palo Alto

The objective of the FSAA is to be used for the design evaluation of control systems and crew interaction for the Orbiter. Failure mode effects will be simulated and evaluation of the pilot response to failure conditions will be the principal objective. The FSAA is oriented toward studing problems primarily in lateral-directional modes of flight. The computational capabilities of the FSAA allow sophisticated simulations of aircraft dynamics to be simulated. Visual displays and simulator vertical travel (±5 feet), longitudinal travel (±4 feet), and lateral travel (±50 feet) as well as roll (±45°), pitch (±22.5°), and yaw (±30°) may be exercised during a simulation.

ROCKETDYNE HYBRID SIMULATOR (RHS) - ROCKETDYNE/Canoga Park

The objective of the Rocketdyne Hybrid Simulation is to provide more cost effective and timely evaluation of the effects on engine performance due to design changes and to provide real-time simulations for comparison with results obtained using actual hardware interfaces. The simulation is a lower fidelity simulation than the Rocketdyne Digital Simulation but the integrity of the simulation is maintained over the normal operating range.

ROCKETDYNE DIGITAL SIMULATION (RDS) - RI/Downey

The objective of the digital simulation is to evaluate engine dynamic performance over an extended range of operating conditions. The simulation is to be used as a standard for evaluating control system design, start and shutdown procedures, major component design characteristics and engine response to failures.

SPACE SHUTTLE FUNCTIONAL SIMULATOR (SSFS) - JSC

The objective of the SSFS is to provide a rigorous environment for testing guidance, navigation, and control design software at both the subsystem (e.g., digital autopilot) and integrated system (e.g., mission phase) level. This system is currently operational and due to its level of fidelity and structure, does not perform its computations in real-time.

SHUTTLE VEHICLE DYNAMIC SIMULATION (SVDS) - JSC

The objective of the SVDS is to provide an environment for trajectory design and analysis, performance evaluation, and multi-vehicle separation for normal and abort missions. SVDS provides simplified (high-speed) and detailed simulation, depending on the complexity of the environment and subsystem models selected, the vehicle attitude control formulation, the integration algorithm chosen, the vehicle dynamics selected, the guidance and navigation selected, and the number of vehicles simulated. Simulations by SVDS support studies of performance analysis, trajectory shaping, guidance development and analysis, reference trajectories, staging and separation analysis, dispersion analysis, integration of navigation and guidance, flight software integration at a functional level, and generation of onboard displays and input schemes. This system is currently operational and due to its level of fidelity and structure, does not perform its computations in real-time.

STATEMENT LEVEL SIMULATION (SLS) - CSDL/Cambridge

The objective of the SLS is to provide a high fidelity simulator to support Guidance, Navigation, and Control (GN&C) program integration, including crew interface and operation, with realistic simulation of flight computer timing effects. The overall GN&C system performance can be evaluated by exercising module interfaces and system interactions. In order to provide as much commonality as possible with other simulators, the SLS makes extensive use of existing math model formulations of the external environment obtained from the SSFS (Space Shuttle Functional Simulator), SVDS (Shuttle Vehicle Dynamic Simulator), and the Apollo All-Digital Simulator. The SLS also makes maximum use of existing simulation software and verification system techniques developed at the Draper Laboratory for the Apollo, Skylab, and F-8 Fly-By-Wire projects.

DYNAMIC DOCKING TEST SYSTEM (DDTS) - JSC

The objective of the DDTS utilization is to accurately determine the Shuttle docking system component loads and kinematic stroking produced by realistic spacecraft relative motion dynamics. A simulator is required which produces the relative motion and the impact structural loading for docking systems in zero-G. The computer and the simulator operate as a closed-loop control system with simultaneous two-way data transfer between the two subsystems.

SPACE DIVISION EVALUATOR (SDE) - RI/Downey

The objective of the SDE is to provide the capability for avionics system design verification and will be used to perform avionics system verification testing until the Shuttle Avionics Integrated Laboratory facility is operational. The SDE consists of the Space Division Shuttle Simulator, the Avionics Development Laboratory, and the Flight Control Hydraulics Laboratory operating as a closed-loop avionics system verification facility.

AVIONICS DEVELOPMENT LABORATORY (ADL) - RI/Downey

The objective of the ADL is to conduct development tests for avionics hardware supplied by Rockwell and interface testing between components procured from subcontractors. These tests will be performed open-loop, generally single string, using breadboard or engineering model hardware. The ADL will also perform support vehicle checkout and flight test anomaly resolution.

FLIGHT CONTROL HYDRAULICS LABORATORY (FCHL) - RI/Downey

The objective of FCHL is divided into two testing phases. The Phase I tests are all open-loop tests of the horizontal flight test configuration. Phase I is essentially a tool for hydraulic/mechanical subsystems design and development. The Phase II testing is composed of closed-loop tests of the horizontal flight test configuration, using a hybrid computer to simulate short period, inner loop vehicle dynamics.

HARDWARE SIMULATION LABORATORY (HSL) - MSFC

The objective of HSL is to provide for the evaluation of Space Shuttle Main Engine (SSME) avionics hardware, software, control system, and mathematical models in a closed-loop simulation of the SSME performance. The laboratory will provide the capability to perform a wide spectrum of tests and run through operational procedures to ensure system component compatibility during the operational phases of the SSME. It will provide a test bed for integration of flight hardware, software, and hydraulics. The HSL will allow the evaluation and refinement of proposed changes during the development and operational phases of the Space Shuttle.

MAIN PROPULSION TEST FACILITY (MPTF) - Bay St. Louis

To be supplied at a later date

HONEYWELL VERIFICATION SIMULATION FACILITY (HVSF) - HONEYWELL/Minneapolis

The objective of the Honeywell facility is to establish control laws and verify their adequacy in controlling the engine, to verify the software logic, to verify the failure response and redundancy management capability, and to verify the integrated performance of the controller with the engine model and the Command and Data Simulator. It will also be used as a design tool to evaluate controller engine changes and their interacting effects upon the engine performance.

SOFTWARE DEVELOPMENT LABORATORY (SDL) - JSC

The objective of the SDL is to provide the facility for the generation and verification of onboard flight computer programs. Program generation includes the development of individual flight program modules, groups of related flight program modules, and complete integrated flight programs. Program verification includes facilities for static or dynamic program and module checkout utilizing digitally-simulated environment, vehicle, and subsystem modules.

SHUTTLE AVIONICS INTEGRATION LABORATORY (SAIL) - JSC

The objective of SAIL is to include the integration testing of the Shuttle element electronics; Orbiter avionics integrated hardware and software testing and verification; Orbiter avionics development support; and evaluation of mission, payload interface, and Shuttle system design change impact on the integrated Orbiter avionics. To the extent that interface testing between Shuttle elements requires operational flight equipment (including computer systems), the SAIL is to provide the facilities for implementing such test. Although the SAIL is not a simulation laboratory, direct support for final end-to-end system tests is planned through interface with the Flight Dynamics Simulation Complex and Flight Systems Simulations.

FLIGHT DYNAMICS SIMULATION COMPLEX (FDSC) - JSC

The objective of the FDSC is to provide a high fidelity simulated environment for modeling the effects of Shuttle vehicle systems and external vehicle forces upon the Inertial Measurement Unit (IMU) and the body mounted rate gyros and to provide the IMU and gyro sensor simulated data to the Avionics Test Article for closed-loop avionics testing and verification. The hybrid computer complex will provide simulations of both aerodynamic and non-aerodynamic flight including unique maneuvers such as rendezvous and docking, landing, etc.

FLIGHT SYSTEMS SIMULATORS (FSS) - JSC

The objective of FSS is to provide hardware simulations of those devices not directly available for Shuttle Avionics Integration Laboratory testing.

AUTOMATIC REENTRY FLIGHT DYNAMICS SIMULATOR (ARFDS) - LARC/Hampton

The objective of the ARFDS is to evaluate the candidate control and guidance schemes to tolerate off-nominal conditions at the start of the angle-of-attack transition maneuver. In addition, it will be used to provide an independent verification of the entry baseline guidance and control schemes.

SHUTTLE GROUND OPERATIONS SIMULATOR (SGOS) - KSC

The objective of the SGOS is to provide the capability for simulating the Shuttle vehicle, payload interfaces, ground support equipment, and launch station facilities required for operations. The SGOS is to provide for application programs verification, the initial Launch Processing System (LPS) activation verification, systems modification verification, and ground crew training during the Shuttle operational phase.

MISSION CONTROL CENTER SIMULATION SYSTEM (MCCS) - JSC

The objective of the MCCS System is to exercise operational functions in a mission environment for vertical flight test and operation flight phases of the Shuttle program. The exercises include the training of mission operations personnel (flight control and flight crew), the development and validation of operational concepts and procedures, the validation of mission plans, and the validation of ground systems processing/display and control capabilities. The training aspects of the simulation capability include the terminal phase of two separate training programs (i.e., flight control and flight crew), where the interrelationships between those two elements are exercised by interfacing the MCCS System with the flight crew simulators and trainers.

SHUTTLE TRAINING AIRCRAFT (STA) - JSC

The objective of the STA is to provide Shuttle flight crew training in Orbiter handling qualities, performance characteristics, and flight control procedures during the subsonic atmospheric flight phase from 35,000 feet altitude to touchdown. A basic Shuttle program requirement is that vehicle landing conditions and handling qualities shall not require skills greater than those needed for high performance aircraft. Shuttle Orbiter pilots normally will have little opportunity to fly the Orbiter as an aircraft other than in simulations. For this reason, simulator aircraft configured to duplicate the handling quantities and performance of the Orbiter vehicle will be required for crew training.

ORBITER AEROFLIGHT SIMULATOR (OAS) - JSC

The objective of the Orbiter Aeroflight Simulator (OAS) is to provide a moving base, high fidelity, man-in-the-loop simulation for Orbiter development test flight. The OAS is to provide a crew station with simulated displays and active controls necessary to train Shuttle crews for the test flights. This includes simulating the test flights with special emphasis on approach and landing.

SHUTTLE MISSION SIMULATOR (SMS) - JSC

The SMS will constitute the major simulation device to support the training of crew members and flight control personnel in the operation of the Space Shuttle system. This system includes the simulation of the orbiter vehicle, main engines, solid rocket engines, external tank, and the associated support equipment and interfaces required to achieve the Space Shuttle objectives. Capability will exist to train flight crews in all facets of the Shuttle vehicle assigned missions and in all system tasks associated with pre-launch, ascent, orbit, rendezvous, docking, payload operation from the orbiter, undocking, deorbit, entry, approach, landing, rollout, and abort. In addition, the simulation will operate in an integrated mode with the Mission Control Center to provide full mission training.

4.0 MATH MODEL SHARING

To assist the user in finding models of a particular type, math models are grouped under category headings. A particular model usually is included only in the category which is most descriptive of its function. Since some models could fall into several categories, the user is advised to look for models in related categories if a suitable model is not found in the most descriptive category. For example, models which deal primarily with an actuator function are contained in the category called Electrical-Mechanical Power Systems. However, an actuator function may also be included as part of a model of the system being actuated.

Twelve categories are defined. The following paragraphs describe the categories. Primarily, examples are used to illustrate the contents of each category. See Figure 2, Model Sharing Matrix, for the use of the categories.

4.1 Category Definitions

NATURAL ENVIRONMENT

The models combined under the Natural Environment category pertain to software models such as winds, atmosphere, gravity potential and gravity gradient, terrain, runway topography, earth oblateness, earth-sun-moon ephemerides, and star tables.

PROPULSION SYSTEMS

The Propulsion System category is composed of the Space Shuttle main engines, solid rocket booster engines, orbital maneuvering engines, and the reaction control jets. The calculation of fuel consumption, thrust, and throttling are also included where they apply to the above propulsion engines.

VEHICLE DYNAMICS

The Vehicle Dynamics category contains models for aerodynamics forces and moments (for both the Orbiter and other vehicles), landing gear forces and moments, drag chute forces and moments, other forms of the deceleration system such as the flap and speed brake effects, the tire contact forces and moments with the runway, and the nose wheel steering forces and moments. The overall deceleration system could also be referred to as the rollout forces and moments.

SPECIALIZED VEHICLE DYNAMICS

The software models under this category relate to specific areas of interest which are not included in the Vehicle Dynamics category. These models deal with the forces and moments normally internal to the vehicle of interest or to situations which occur on a one time basis. Examples of the models falling into this category are bending, separation-staging effects, docking effects, slosh, tail-wags-dog, plume effects, POGO, and Orbiter wing flutter.

EQUATIONS OF MOTION

The models contained within the Equations of Motion category sum the component input forces and moments from the Natural Environment, Propulsion Systems, Vehicle Dynamics, and Specialized Vehicle Dynamics categories. In addition, the calculations of the center of gravity, mass properties, integrator routines, derivative routines, state vector computations, vehicle attitude rate, and angular acceleration are included here. Basically, this category could be divided into rotational and translational equations of motion.

COMMUNICATIONS/TRACKING/NAVIGATION DEVICES

This category includes models of the hardware devices used to provide information to the flight computer or a ground station concerning navigation and tracking. The hardware models used for communications are also included. These devices include the inertial measurement unit (IMU), rate gyro, accelerometers, barometric and radar altimeters, air traffic control divices, microwave scan beam landing system, air data sensors, rendezvous radar, star tracker, Tactical Air Navigation (TACAN), Multiplexer/Demultiplexer, Very High Frequency and Ultra High Frequency tracking and communication systems, and the Space Ground Link System used by the Air Force for tracking satellites.

ONBOARD SOFTWARE

The Onboard Software category consists of software models related to the types of computational software utilized in the onboard flight computers. In some instances, several models comprise a simulation of the onboard software and its related computer activity within simulations. In other cases, the types of computations made by the onboard computer are grouped into this category. Examples of the models in this category are aerosurface control systems; approach and landing computational systems; engine interface controller models; event control; control for cruising at specific speed or rate of descent; latitude, longitude, altitude, and range computational routines; mass memory; thrust vector controls; engine controls; rendezvous computations; terminal area energy management and antenna switch logic. Essentially, the guidance, navigation, and control calculations models reside in this category.

PAYLOAD ACCOMMODATION AREA

This category contains models relating to the payload manipulator and its movement, payload attachment, payload television subsystem, payload door subsystem, and payload illumination system.

COCKPIT AND SIMULATOR ENVIRONMENT

The cockpit and simulator environment models consist of cockpit gages, switches, meters, indicators, levers, and control models; scene generation models; and keyboard input models.

THERMAL AND ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

The models within this category include thermal protection, thermal control, and environmental control and life support systems.

ELECTRICAL-MECHANICAL POWER SYSTEM

The models within this category include electrical power subsystem models, hydraulic power systems such as aerosurface actuators, payload door actuators, engine gimbal servos, and pyrotechnic devices such as the small rocket motors used to separate the solid rocket booster from the external tank or the mortor shell used to deploy the drag chute during landing.

OTHER

This cateogry contains primarily utility routines used in support of other software models. Also, if a routine does not appropriately fit into one of the above categories it is placed here. This category contains orbital elements models, coordinate transformation models, routines used to extract yaw, pitch, and roll from a coordinate transformation matrix, conic routines, error generating routines, etc.

4.2 Model Sharing Matrix

The Model Sharing Matrix in Figure 2 contains information relating descriptive model names by simulations. The descriptive model names are arranged by category along the left side of the matrix while the major Shuttle simulation names are listed along the top. In this way, one can identify the potential for sharing common models between simulations. Only models used by two or more simulations appear in the matrix. A complete listing of all the math models by simulation that have been identified is included in Section 6. The blank portions of the matrix indicate that no information has been supplied or that inadequate information was available for inclusion into the catalog at this time.

CATEGORY NAME / MODEL NAME	SIMULATION NAME																										
	SDSS	CSDD	SMES	SPS	FSAA	RHS	RDS	SSFS	SVDS	SLS	DDTS	SDE	ADL	FCHL	HSL	MPTF	HVSF	SDL	SAIL	FOSC	FSS	ARFDS	SGOS	MCCS	STA	OAS	SMS
NATURAL ENVIRONMENT																											
Atmosphere	*	*						(O)	(O)									(F)		*						0	*
Ephemeris (earth, moon, sun, planets)								(O)		(O)								*									(*)
Gravity Gradient	*							(O)										*									
Gravity Potential	*	*						(O)	(O)	(O)								(F)								0	
Runway Topography	*	(*)																									
Terrain																		F									*
Wind and Gusts	*	*						(O)	(O)									(F)		*						0	*
PROPULSION SYSTEMS																											
Main Engine System	*							(O)	(O)									*									(*)
Orbital Maneuvering System	*							(O)	(O)	(O)								*									(*)
Reaction Control System	*							(O)	(O)	(O)								*								(O)	(*)
Solid Rocket Booster	*							(O)	(O)									*									(*)
VEHICLE DYNAMICS																											
Deceleration Forces and Moments	*	*																(F)		*						0	(*)
Landing Forces and Moments	*	*		*														(F)		*						(O)	(*)
Orbiter Aerodynamic Forces and Moments	*	*						(O)	(O)									(F)		*						(O)	(*)
Target Vehicle Aero. Forces and Moments	*																	*									(*)
SPECIALIZED VEHICLE DYNAMICS																											
Bending	*							(O)	(O)									F		*							*
Docking/Undocking								0																			(*)
Slosh	*							(O)	(O)									*		*							*
Staging	*								(O)																		(*)
Tail-Wags-Dog	*							0												*							

* - PROPOSED CANDIDATE MODEL F - FORMULATION EXISTS 0 - OPERATIONAL MODEL

(*) OR (F) OR (0) - ADDITIONAL INFORMATION AVAILABLE IN SECTION 5

Figure 2. Model Sharing Matrix

SIMULATION NAME

CATEGORY NAME / MODEL NAME	SOSS	CSDD	SMES	SPS	FSAA	RHS	RDS	SSFS	SVDS	SLS	DDTS	SDE	ADL	FCHL	HSL	MPTF	HVSF	SDL	SAIL	FDSC	FSS	ARFDS	SGOS	MCCS	STA	OAS	SMS
EQUATIONS OF MOTION (EOM)																											
Integration Techniques	*							(O)	(O)					*				*									
Mass Properties	*	*						(O)	(O)	(O)								(F)								0	(*)
Rotational EOM	*	*						(O)	(O)					*				(F)		*						0	(*)
Translational EOM	*	*						(O)	(O)	(O)								(F)		*						0	(*)
COMMUNICATIONS/TRACKING/NAVIGATION DEVICES																											
Accelerometers	*	*							(O)				*					(F)		*						0	(*)
Air Data Sensors													*					F		*							(*)
Air Traffic Control																		*									*
Barometric Altimeter		*							(O)									F									
Inertial Measurement Unit (IMU)	*							(O)	(O)	(O)			*					(F)		*							(*)
Microwave Landing System	*	*						(O)					*					F		*						0	*
Multiplexer/Demultiplexer													*					F									
Radar Altimeter	*	*							(O)									F									(*)
Rate Gyros									(O)				*					(F)		*						0	(*)
Rendezvous Radar/Sensor								(O)		(O)								*									(*)
Star Sensor/Tracker	*									(O)								*									(*)
Tactical Air Navigation (TACAN)	*	*											*					F		*						0	(*)
VHF Communications																		*									(*)
ONBOARD SOFTWARE																											(*)
Aerosurface Control System	*	*						(O)	(O)				*					(F)								(O)	
Approach and Landing	*								0				*													(O)	
Data Processing													*					*									
Engine Interface/Engine Controller													*					*									
Events Control, Sequencing, Timing								0					*					*									

* - PROPOSED CANDIDATE MODEL F - FORMULATION EXISTS 0 - OPERATIONAL MODEL

(*) OR (F) OR (0) - ADDITIONAL INFORMATION AVAILABLE IN SECTION 5

Figure 2. Model Sharing Matrix (Continued)

CATEGORY NAME / MODEL NAME	SDSS	CSDD	SMES	SPS	FSAA	RHS	RDS	SSFS	SVDS	SLS	DDTS	SDE	ADL	FCHL	HSL	MPTF	HVSF	SDL	SAIL	FDSC	FSS	ARFDS	SGDS	MCCS	STA	OAS	SMS
ONBOARD SOFTWARE (Continued)																											
Guidance and Navigation Cruise								0	(0)				*													(*)	
Latitude, Longitude, Altitude, Range								(0)	(0)									*									
Mass Memory													*					*									
Main Engine Thrust Vector Control	*							(0)	0									*									(*)
Navigation Filter									0				*														(*)
Orbital Maneuvering Thrust Vector Control	*							(0)	0	(0)																	
Performance Monitoring System	*												*					*									
Reaction Jet Control	*							0	(0)									*								(0)	
Reentry Computations	*								0																		
Rendezvous Computations	*							0	0																		(*)
Terminal Area Energy Management	*								(0)				*													0	
PAYLOAD ACCOMMODATIONS AREA																											
Payload Manipulator	*																	*									(*)
Payload Monitoring System	*																										*
COCKPIT AND SIMULATOR ENVIRONMENT																											
Aural Characteristics		*																									*
Cockpit Gage, Indicator, Switch, Lever		*											*					*								0	(*)
Data Recording													*					*									*
Keyboard													*					*									
Scene Generation	*	*																		*							*
THERMAL AND ENVIRONMENTAL CONTROL AND LIFE SUPPORT																											
Environmental Control and Life Support																		*									*
Thermal Control									(0)																		(*)

SIMULATION NAME

* - PROPOSED CANDIDATE MODEL F - FORMULATION EXISTS 0 - OPERATIONAL MODEL

(*) OR (F) OR (0) - ADDITIONAL INFORMATION AVAILABLE IN SECTION 5

Figure 2. Model Sharing Matrix (Continued)

CATEGORY NAME / MODEL NAME	SDSS	CSDD	SMES	SPS	FSAA	RHS	RDS	SSFS	SVDS	SLS	DDTS	SDE	ADL	FCHL	HSL	MPTF	HVSF	SDL	SAIL	FDSC	FSS	ARFDS	SGOS	MCCS	STA	OAS	SMS
THERMAL & ENVIRONMENTAL CONTROL & LIFE SUPPORT (Continued)																											
Thermal Protection									0									*									*
ELECTRICAL-MECHANICAL POWER SYSTEMS																										0	*
Actuators and Servos	*								*				*							*							*
Electrical Power Subsystem																		*									
Pyrotechnics	*																	*									
OTHER																											
Orbital Elements								0	0									*								0	
Euler Angle Routines								0										*									
Transformation Generation Routines								0										*									

SIMULATION NAME

* - PROPOSED CANDIDATE MODEL F - FORMULATION EXISTS 0 - OPERATIONAL MODEL

* OR F OR 0 - ADDITIONAL INFORMATION AVAILABLE IN SECTION 5

Figure 2. Model Sharing Matrix (Continued)

5.0 DETAILED MODEL INFORMATION

The model descriptions contained in this section are grouped under the category names and descriptive model names used in the model sharing matrix of Section 4.2. For example, a gravity model would be titled "Category Name: Natural Environment (Gravity Potential)". In addition, the model name used by the simulation documentation is given (e.g., Model Name: GRAV2).

The ordering of the model descriptions within each category is by the model descriptive name used in the model sharing matrix, and then by alphabetized simulation. In some cases, model descriptions are available for several models of the same type from one simulation. For example, the SVDS has two atmosphere models - spline and layered. In these cases, the model's descriptions are in alphanumeric order.

Section 5 contains two entries which require further explanation. The heading "Source Documentation" refers to documents which were used to supply the information presented in the model description, inputs, and outputs. The second entry is "Development Schedule". This heading is used to present the current status of the model. The three classifications listed under this heading are "Requirements", "Formulation", and "Operational". The term "Requirements" indicates that a brief functional description of a model officially exists, and when available, the date at which the requirements were completed. The term "Formulation" refers to the completion of the basic equations and suggested logical flow to be used for the model. When a model is classified as "Operational", it is considered to have been coded, tested, and is currently being used for studies. If this heading is left blank, an unofficial requirement exists for the candidate model and indicates that the model may or may not be used in the simulation. For further information concerning schedule data, see Section 7.

5.1 Natural Environment

This section contains descriptive information about models of the natural environment.

Category Name: Natural Environment (Atmosphere)

Model Name: ATMSPL Simulation Name: SDL

Contact Person: J. C. Kirkpatrick Org: TRW Tel: (713)333-3133

Description of Model: Six standard reference atmosphere models for the years 1962, 1966 (for July and January at 30° and 60° north latitude), and 1963 (Patrick Air Force Base) are presented in tabular form. The tabulation is adequate for the accurate representation of the atmospheric parameters of pressure, density, speed of sound, and coefficients of viscosity as functions of altitude. The range of tabulated altitudes extends for 0 to 205 kilometers. Interpolation for the desired parameters is performed by using cubic spline functions. The recursive relations necessary to compute the cubic spline function coefficients are derived and implemented in SUBROUTINE form. This model is similar to the SVDS atmosphere model except for the interpolation scheme.

Major Inputs: Selected desired atmosphere model and altitude.

Major Outputs: Pressure, density, speed of sound, viscosity, pressure ratio, density ratio, velocity ratio, and viscosity ratio.

Source Documentation: J. C. Kirkpatrick, "Cubic Spline Function Interpolation in Atmosphere Models for the Software Development Laboratory (SDL): Formulation and Data", Software Development Branch, Mission Planning and Analysis Division, JSC Internal Note No. 74-FM-23, (JSC-08964), April 15, 1974.

Development Schedule: Requirements 10/12/73, Formulation 12/14/73 and 4/15/74.

Category Name: Natural Environment (Atmosphere)

Model Name: ATM4 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This model calculates the speed of sound, pressure, and air density from an altitude input. The Cape Kennedy Reference Atmosphere (TM-X-53872, Paragraph 14.7-MSFC" Computer Subroutine PRA-63") is used.

Major Inputs: Altitude above the mean earth surface.

Major Outputs: Speed of sound, pressure, atmospheric density.

Source Documentation: Engineering Systems Branch, JSC, "Space Shuttle Functional Simulator", Volume III - Environment, Revision B, JSC Internal Note No. 72-FD-010, (MSC-06726), November 1973.

Development Schedule: Operational

Category Name: Natural Environment (Atmosphere)

Model Name: ATM5 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This model provides a choice of either a simplified flat-earth atmosphere or a detailed model of the 1962 Standard Atmosphere.

Major Inputs: For the simplified flat-earth option inputs include vehicle position vector in airport coordinates, absolute velocity of vehicle in airport coordinates, velocity of wind in airport coordinates. For detailed model of 1962 Standard Atmosphere inputs are vehicle's position and velocity vectors in earth centered inertial coordinates.

Major Outputs: Velocity of vehicle with respect to atmosphere, dynamic pressure, Mach number, atmospheric density, speed of sound. In addition, the simplified flat-earth option outputs vehicle altitude above landing strip and airspeed. The detailed model of 1962 Standard Atmosphere outputs vehicle altitude above Fischer ellipsoid, time model was called, time for 10% change in dynamic pressure.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Natural Environment (Atmosphere)

Model Name: ATMOS Simulation Name: SVDS

Contact Person: Ernest M. Fridge Org: JSC Tel: (713)483-3532

Description of Model: This model simulates atmospheric conditions with layered functions. The atmospheric quantities are based on the 1962 U.S. Standard Atmosphere and 1966 Supplemental Atmosphere Algorithmic Model. The user may choose the atmosphere model from as follows:

> 1962 US Standard Atmosphere; July Atmosphere at 30 degrees north latitude, January atmosphere at 30 degrees north latitude, July atmosphere at 60 degrees north latitude, or January atmosphere at 60 degrees north latitude when using the 1966 Supplemental Atmosphere.

Major Inputs: Geodetic altitude, atmosphere option.

Major Outputs: Pressure, kinetic temperature, density, speed of sound, coefficient of viscosity.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Schedule: Operational

Category Name: Natural Environment (Atmosphere)

Model Name: ATMSPL

Simulation Name: SVDS

Contact Person: Ernest M. Fridge Org: JSC Tel: (713)483-3532

Description of Model: This model simulates atmospheric conditions by interpolation for required atmospheric data at an altitude using spline coefficients.

Major Inputs: Geodetic Altitude.

Major Outputs: Atmospheric pressure, atmospheric density, speed of sound, coefficient of viscosity.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Schedule: Operational

Category Name: Natural Environment (Ephemeris)

Model Name: REFTOFIX Simulation Name: SLS

Contact Person: Lance Drane Org: C. S. Draper Lab. Tel:(617)258-1178

Description of Model: The Earth Orientation Model REFTOFIX models the angular position of the earth's polar axis and Greenwich meridian with respect to Basic Reference Inertial coordinates for any desired time by providing the transformation matrix from Basic Reference Inertial Coordinates to Earth-Fixed Cartesian Coordinates at the desired time. The model has three levels of fidelity. The most accurate model includes the full precession, principal nutation, and non-uniform Greenwich rotation motions of the earth.

Major Inputs: Julian Ephemeris Data of the date of interest and the number of days elapsed since noon ephemeris time on the day before January 1, 1900.

Major Inputs: Transformation from Basic Reference Inertial coordinates to Earth-Fixed Coordinates and the Greenwich rotation matrix.

Source Documentation: Lawrence Berman, et al, "ESIM Model Book for the C.S. Draper Laboratory Statement Level Simulator", the Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Category Name: Natural Environment (Ephemeris)

Model Name: Celestial Body Direction   Simulation Name: SMS

Contact Person: Charles Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The inertial directions from the vehicle of the following celestial bodies will be maintained: sun; moon; plantes: Mercury, Venus, Mars Jupiter, and Saturn; and stars detectible by star tracker. Planetary, lunar, and solar directions will take into account both the changing true directions of other celestial bodies with respect to the earth, and the position of the vehicle with respect to the earth. Relative motion of sun, stars, ecliptic plane, and equatorial plane will be ignored. Since stellar parallax is neglibible, the true directions of the stars will be provided in a table of reset constants. Aberration effects will be included only for solar, planetary, and stellar observations. The apparent positions of sun and planets will be calculated. Since apparent position of only a few particular stars must be known at any given time, it is more efficient to perform aberation corrections in the using models (e.g., star tracker) for just those stars required. True earth referenced positions and velocities of sun, moon, and planets will be obtained in real-time by interpolation on pre-stored tables. The JPL Ephemeris tapes will be the source for the pre-stored tables and an Everett interpolation scheme will be used.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Natural Environment (Ephemeris)

Model Name: Earth Orientation

Simulation Name: SMS

Contact Person: C. C. Olasky

Org: JSC

Tel: (713)333-2481

Description of Model: Based on the current time, this model will compute the Greenwich hour angle. Since reorientation of the equator due to precession and nutation are not significant over a period of seven days, it will be assumed that the equinox and spin axis remain inertially fixed over that period. To achieve the required accuracy of ±2 arc-seconds without perceptible jitter, the Hour angle will be updated ten times per second.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Natural Environment (Ephemeris)

Model Name: POSSUM Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This model calculates the position vectors from the earth to the sun and from the earth to the moon in earth centered inertial coordinates.

Major Inputs: Time in seconds measured from July 1, 1971.

Major Outputs: Position vectors of the sun and moon.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Natural Environment (Gravity Gradient)

Model Name: GGT1 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: GGT1 models the generalized gravity gradient torque, which is produced about the vehicle's center of mass by the earth's gravitational acceleration acting on heterogeneous and asymmetrical vehicles. A spherical earth is used since the torque produced due to earth oblateness is negligible.

Major Inputs: Inertial state vector in vehicle body coordinates, vehicle inertia tensor, gravity gradient torque axial multipliers (one for each axis) used to scale or turn off the torque about a particular axis.

Major Outputs: Gravity gradient torque about the vehicle center of gravity.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Natural Environment (Gravity Potential)

Model Name: Gravity and Oblateness   Simulation Name: SDL

Contact Person: B. F. Cockrell   Org: JSC   Tel: (713)483-6181

Description of Model: This earth gravity model computes the gravitational acceleration as a function of the inertial position vector. It includes the effects of earth oblateness with terms for J_2, J_3, J_4, C_{22}, and S_{22}. The model does not exibit the singularity at the poles. Because the model does not have the capability to model other terms, it is intended only for Horizontal Flight Test and accelerated flight for the Vertical Flight Test.

Major Inputs: Position vector of vehicle in Earth-fixed coordinates.

Major Outputs: Acceleration vector in body-fixed coordinates, central body gravity constant, earth radius.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Software Development Laboratory Math Model Development Plan", JSC Internal Note 73-FM-158, (JSC-08626), 31 October 1973.

B. F. Cockrell, "Earth Gravity Model for SDL", JSC Working Paper Memorandum, 21 December 1973.

Development Schedule: Formulation 12/21/73

Category Name: Natural Environment (Gravity Potential)

Model Name: OBLTGRAV Simulation Name: SLS

Contact Person: Lance Drane Org: C. S. Draper Lab. Tel: (617)258-1178

Description of Model: OBLTGRAV computes the gravitational acceleration due solely to the earths oblateness (non-sphericity). OBLTGRAV actually consists of a set of several models ranging from the single zonal harmonic J_2 term through a completely general spherical harmonic expression of arbitrary order (currently 10).

The models use the traditional formulation of the gradient of a spherical harmonic expansion of the gravitational potential truncated at a desired order (or including only the desired terms). For the often used low order models, explicit analytic expressions have been utilized in order to economize the computation. A completely general recursive high order model is also included (which involves all coefficients at or below this order).

The acceleration due to oblateness depends upon the spacecraft position with respect to earth-fixed coordinates since the non-sphericity of the earth's mass rotation with the earth. In the purely "zonal" cases (J_2, or J_2, J_3, J_4), the models are symmetric around the earth's axis of rotation, and hence the oblateness acceleration is independent of longitude but dependent on latitude. In the general case, it is dependent on both latitude and longitude. This dependency on earth-fixed coordinates has been expressed in the formulation by the use of three mutually perpendicular unit vectors which rotate with the earth and which express the directions of 0° latitude and 0° longitude, 0° latitude and 90° east longitude and the north pole, in Basic Reference Inertial Coordinates. This permits the oblateness acceleration to be written directly in Basic Reference Inertial Coordinates.

Major Inputs: Spacecraft position vector in Basic Reference Inertial Coordinates.

Major Outputs: Oblateness acceleration and the earth's north polar axis unit vector in Basic Reference Inertial Coordinates as well as the unit vectors in the direction of intersection of earth's prime meridian and equator and in the direction of intersection of earth's 90° east longitude meridan and equator both expressed in Basic Reference Inertial coordinates.

Source Documentation: Lawrence Berman, et al., "ESIM Model Book for the C. S. Draper Laboratory Statement Level Simulator", the Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Category Name: Natural Environment (Gravity Potential)

Model Name: GRAV2 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This model provides a gravity model for earth orbital operations. Various degrees of fidelity in gravity calculation can be selected. For the lowest degree of fidelity, the model returns the spherical earth gravity; whereas for the highest, the models adds perturbations caused by the sun, the moon, and the nonspherical nature of the earth. The user may select any combination of the perturbations caused by the sun, the moon, and the nonspherical earth gravity. The earth centered inertial coordinate system is used.

Major Inputs: Current time, position vector at which gravitational acceleration is to be calculated, flag specifying which perturbutions if any are to be used.

Major Outputs: Gravitational acceleration vector.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Natural Environment (Gravity Potential)

Model Name: GRAV3

Simulation Name: SSFS

Contact Person: J. E. Vinson

Org: Lockheed

Tel: (713)333-4875

Description of Model: This model provides a gravity model for earth orbital operations. It calculates the spherical earth gravity and the perturbations caused by the nonspherical nature of the earth.

Major Inputs: Current time, inertial position vector at which the gravitational acceleration is to be calculated.

Major Outputs: Gravitational acceleration vector

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010. (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Natural Environment (Gravity Potential)

Model Name: GRAVTY Simulation Name: SVDS

Contact Person: Ernest M. Fridge Org: JSC Tel: (713)483-3532

Description of Model: GRAVTY computes the gravitational acceleration as a function of the inertial position vector, latitude and longitude for each vehicle, spherical earth radius, and gravitational potential constants. The flow of computation is as follows: the dependent parameters (latitude and longitude) and the necessary trigonometic functions are computed. These computed parameters along with built-in constants are used to calculate the partials of gravity potentials using the Fischer Ellipsoid Model. The inertial components of the gravitational acceleration vector are then computed in the last set of operations.

Major Inputs: Vehicle position in earth centered inertial coordinates, earth gravitational constants.

Major Outputs: Acceleration due to gravity.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I) 20 July 1973.

Development Schedule: Operational

Category Name: Natural Environment (Runway Topography)

Model Name: Runway Surface

Simulation Name: CSDD

Contact Person: D. Gilbert

Org: JSC

Tel: (713)483-4235

Description of Model: A rubber tire interface with a concrete runway is assumed as the basis for braking force, side force, and rolling friction force coefficients. The rolling friction force is modeled as an algebraic function and the coefficients for braking force and side force are modeled as table lookups. All coefficients are dependent on the inertial velocity of the gear parallel to the X-Y inertial plane. Side and braking coefficients are also dependent on the angle between the rotational plane of the tire and the inertial velocity of the gear. A second set of table lookup variables for side and braking force coefficients are provided for wet runway conditions. The wet runway conditions assume less than 1/4 inch of water on the runway surface. A crowned runway is assumed.

Major Inputs: Inertial velocity of the gear parallel to the X-Y inertial plane, angle between rotational plane of tire and inertial velocity of the gear.

Major Outputs: Braking force, side force, and rolling friction force coefficients.

Source Documentation: Avionics System Evaluation Branch, "Horizontal Flight Test and Ferry Flight Presimulation Report", Johnson Space Center, January 1974.

Development Schedule:

Category Name: Natural Environment (Wind and Gusts)

Model Name: Wind and Gust Simulation Name: SDL

Contact Person: Willis M. Bolt Org: JSC Tel: (713)483-6347

Description of Model: This model consists of a steady-state winds plus shears model and wind gust model for simulation of the Horizontal Flight Test and entry through landing portion of the Vertical Flight Test. The model basically consists of a velocity vector as a function of altitude with wind gusts superimposed. The steady-state winds plus shears model will be in tabular form and controlled through input. The independent variable will be altitude and the dependent variables will be the East and North wind components. Gust will be computed from the Dryden spectral gust environment. The gust model will define wind gust velocity as a function of altitude and vehicle velocity magnitude. The gust components, which vary with time and position, have been assumed not to vary with time. The justification for this assumption is that for reasonable flight speeds, the changes in the gust components are smaller with respect to time than with respect to position.

Major Inputs: Orbiter altitude, orbiter ground speed, flight-path angle, orbiter heading from North (positive toward East).

Major Outputs: Wind velocity vector in Up-East-North coordinates where up is along the unit position vector.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Software Development Laboratory Math Model Development Plan", JSC Internal Note 73-FM-158, (JSC-08626), 31 October 1973.

Willis M. Bolt, "Wind Model to be Used in the Software Development Laboratory for Space Shuttle Onboard Software Verification for the Horizontal Flight Test Program", JSC Memo FM42 (73-125), 21 December 1973.

Development Schedule: Formulation 12/21/73

Category Name: Natural Environment (Wind and Gusts)

Model Name: WIND3 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This is a model of horizontal wind shear plus gusts. The mean horizontal wind is calculated by linear interpolation of tabulated values for various altitude bands. The downrange and crossrange components of mean wind are calculated using a heading angle supplied by the user. There is no vertical component of mean wind. The X and Y components of mean wind are expressed in airport coordinates. The simulation of gusts employs the Dryden model. This model is designed for wind updates at a constant time interval and should be called at a fixed unvarying frequency.

Major Inputs: Altitude, vehicle velocity vector in airport coordinates, airport to body coordinates transformation matrix, mean wind heading angle.

Major Output: Total wind velocity vector in body coordinates.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Natural Environment (Wind and Gusts)

Model Name: WIND4 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This model provides horizontal wind shear as a function of altitude, computing the data for a number of aerodynamic stations of a flexible body vehicle. The model uses tables of altitude and corresponding wind speed and azimuth. Given the altitude of the center of gravity and the position of the aerodynamic stations relative to the center of gravity, the model calculates wind speed and azimuth for each station via a linear interpolation.

Major Inputs: Current altitude of the vehicle's center of gravity, desired number of aerodynamic stations, and position of each station relative to the center of gravity.

Major Outputs: Wind speed and azimuth for each station.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Natural Environment (Wind and Gusts)

Model Name: WIND5 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: WIND5 models horizontal winds. The user can choose a constant wind or one of several shearing winds as a function of vehicle altitude. The shearing modes can be either a linear function of altitude, a logarithmic function of altitude, or a table look-up of magnitude and direction versus altitude with linear interpolation between the table points.

Major Inputs: Altitude, vehicle position vector in earth centered inertial coordinates, vehicle to earth centered inertial coordinates transformation matrix, airport to vehicle coordinates, transformation matrix, runway heading from North.

Major Outputs: Wind velocity vector in vehicle, North-East-Down coordinates and either earth centered inertial or airport coordinates.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Natural Environment (Wind and Gusts)

Model Name: WIND6 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel:(713)333-4875

Description of Model: WIND6 provides a model for horizontal steady-state winds. WIND6 provides three models for three altitude ranges up to 150,000 meters. WIND azimuth is fixed down to 1000 meters where a ground wind twist is simulated. Between 1000 meters and 20,000 meters altitude, one of five sector profiles is selected based on the wind azimuth. Gusts are not simulated in WIND6.

Major Inputs: Inertial position vector, runway azimuth, vehicle flight azimuth, altitude, high altitude wind azimuth, ground wind azimuth, wind twist flag, and fraction of twist desired.

Major Outputs: Wind vector in ECI coordinates.

Source Documentation: L. C. Baumel, "SSFS Model Documentation Series - WIND6", Lockheed Electronics Company Technical Report No. LEC1917, February 1974.

Development Schedule: Operational

Category Name: Natural Environment (Wind and Gusts)

Model Name: WIND7 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: WIND7 provides a model of horizontal wind shear with azimuth specified by component and tabulated strength above 1000 meters altitude, and with a twist to ground wind azimuth and bounded tailwinds below 1000 meters. WIND7 calculates wind azimuth and wind strength for altitudes between 150,000 meters and ground level. Above 24,000 meters, a pure headwind, tailwind, or crosswind is simulated, as selected by user input. A linear interpolation scheme is used to compute wind speed from tabulated data for altitudes above 24,000 meters.

Major Inputs: Altitude, runway azimuth, and flight azimuth.

Major Outputs: Wind vector in the ECI frame.

Source Documentation: K. M. Parris, "SSFS Model Documentation Series - WIND7", Lockheed Electronics Company Technical Report No. LEC1833, January 1974.

Development Schedule: Operational

Category Name: Natural Environment (Wind and Gusts)

Model Name: AROCAL   Simulation Name: SVDS

Contact Person: Ernest M. Fridge   Org: JSC   Tel: (713)483-3532

Description of Model: This model computes aerodynamic altitude angles and atmospheric winds required by the aerodynamic forces and moments and for the interaction forces and moments. The atmospheric wind components in the geodetic-system are obtained by a table lookup. The X, Y, Z components correspond to the North, East, Down direction, respectively. The components are then transformed to earth centered inertial coordinates. Computations for free-stream velocity are then performed in earth centered inertial coordinates and transformed to the body system. Then dynamic pressure, Mach number, Reynolds number, and current temperature are computed. If desired, aerodynamic angles may be computed.

Major Inputs: Geodetic altitude, atmospheric density, speed of sound, target vector at landing point, earth relative velocity in body centered coordinates, vehicle inertial position in earth centered inertial coordinates, coordinate transformation matrices.

Major Outputs: Pitch, yaw, and total angle of attack; atmospheric wind components; Mach number; aerodynamic roll angle, vehicle pressure ratio, instantaneous atmospheric pressure, freestream dynamic pressure, current Reynolds number, current temperature.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Schedule: Operational

5.2 Propulsion Systems

This section contains descriptive information about models of the propulsion systems.

Category Name: Propulsion Systems (Main Engine System)

Model Name: Main Engine Subsystem

Simulation Name: SMS

Contact Person: C. C. Olasky

Org: JSC

Tel: (713)483-2481

Description of Model: The simulation of the main engine by a functional model may be used to represent the real world system with high degree of accuracy. The intent of the design is to use the engine model developed by Marshall Space Flight Center with minor modifications so as to allow the simulation to run in real-time. The simulation will use multiple digital computers. The interfacing computer between the flight computer and the main computer will execute at a rate of 25 iterations per second. Within the simulation the following systems will be simulated: (1) main engine functional simulation, (2) helium storage tank, (3) helium pressurization manifold, (4) propellant tank equations, and (5) engine performance equations.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, December 21, 1973.

Development Schedule:

Category Name: Propulsion System (SRB/ME/OMS)

Model Name: THR6 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: THR6 calculates forces and moments in body coordinates due to thrust forces from all engines, given gimbal angles, throttle settings, and atmospheric pressure. This is the standard thrust model for the Launch-to-Orbit Integrated Vehicle, VLS-000061. Table lookups are used for the solid rocket motor vaccum thrust and mass flow rate along with power-on base drag and the three main propulsion engines.

Major Inputs: Engine exit area, engine locations in body coordinates, throttle setting, vacuum thrust, atmospheric pressure, and engine pitch and yaw gimbal angles, and vehicle center of mass.

Major Outputs: Total forces in the X, Y, and Z body coordinates and the total moments in the X, Y, and Z body coordinate system.

Source Documentation: Engine System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Propulsion Systems (SRB/ME/OMS)

Model Name: MAENG   Simulation Name: SVDS

Contact Person: Ernest M. Fridge   Org: JSC   Tel: (713)483-3532

Description of Model: The purposes of Subroutine MAENG are to

1) Compute thrust as a function of atmospheric pressure if the user selects this capability. (This option can be exercised for only one vehicle during a particular phase.)
2) Compute throttle level and modify thrust from input tables if user selects this capability. (This option can be exercised for only one vehicle during a particular phase.)
3) Evaluate main engine gimbal drive actuator if the servo model is selected by the user.
4) Compute main engine thrust and specific impulse if tables are input.
5) Compute main engine fuel and oxidizer flow rates for each subsystem if variable mass is simulated.
6) Compute current subsystem weights if variable mass is simulated.

Subroutine MAENG allows a maximum of 15 engines per vehicle. Gimbaled or fixed engines, in any combination, are allowed. Thrust magnitude is determined via a table look-up using burn time as the independent variable. Components of thrust in each individual engine coordinate system are determined by rotating through the actual engine gimbal angles. A second transformation is used to convert from the engine coordinate system to the vehicle reference coordinate system. Subroutine MAENG outputs the total thrust and moment vector in the body system.

Major Inputs: Initial main engine gimbal angle deflection values about the y and z engine axes of each main engine (Rad), change in thrust required to maintain desired constant acceleration (lbs), location of each engine gimbal point with respect to the vehicle CG (ft), array of thrust tables for all engines, total force on vehicle, total maximum steady state vacuum thrust of each engine (lbs), oxidizer to fuel mixture ratio for each main engine, number of the vehicle and engine generating a plume that impinges on each vehicle, total number of engines being simulated, specific impulse for each engine, thrust magnitude (lbs), and total moment on vehicle (ft-lb).

Major Outputs: Thrust of each engine for each of three vehicles, e.g., Orbiter and two solid rocket boosters, total force on vehicle (lbs), specific impulse for each engine on each vehicle, current weight of subsystem (lbs), engine systems to body systems transformation for each engine, thrust magnitude, magnitude of current plume thrust per vehicle (lbs), total moment on vehicle (ft-lbs), total weight flow rate (lbs,sec), and vehicle mass (slugs).

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume IV, Subroutines M through P, JSC Internal Note 73-FM-110, (JSC-08065), July 20, 1973

Development Schedule: Operational

Category Name: Propulsion Systems (SRB/ME/OMS)

Model Name: THROTL

Simulation Name: SVDS

Contact Person: Ernest M. Fridge Org: JSC Tel: (713)483-3532

Description of Model: The purpose of subroutine THROTL is to compute a thrust level which will maintain constant acceleration specified by the user. The basic computations are as follows: (1) computed from the magnitude of the sensed velocity increment over the last full integration step and the integration step size, (2) the required acceleration change to achieve that desired constant acceleration is computed as the difference of the total thrust acceleration and the desired constant acceleration, and is used to calculate the estimated mass of the vehicle at the mid-point between two throttle computations. Other parameters used in this computation are (1) present mass of the vehicle, (2) mass flow rate computed in the last pass through subroutine MAENG, (3) throttle computation step size, and (4) time lag to account for throttle reaction time and delta-time from command time to the time the throttle change actually begins. The mass change from the present to the mid-point is estimated. To improve accuracy an adjustment to the acceleration is computed. Then the change in thrust required to maintain the desired constant acceleration is computed and used to determine the thrust commanded for the next cycle. TSLOPE is computed as a function of the sign of the change in thrust and the absolute value of the limit in thrust, input by the user.

Major Inputs: Magnitude of constant sensed acceleration to the maintained (G's), rotational integration step size (sec), time lag to account for throttle reaction time (sec), time interval between two consecutive throttle computation cycles (sec), sensed velocity increment per delta time (ft/sec), gain factor for acceleration adjustment equations, total force on vehicle (lbs), number of integration step sizes since the last throttle update, total weight flow rate (lbs/sec) and vehicle mass (slugs).

Major Outputs: Change in thrust required to maintain desired constant acceleration (lbs), thrust required to maintain desired constant acceleration (lbs), thrust required to maintain desired constant acceleration (lbs), and slope limit with sign of delta frequency (lbs/sec).

Source Documentation: Software Development Branch, Dynamics Analysis Section, "Space Vehicle Dynamics Simulation (SVDS) - Program Subroutine Library", Volume VI - Subroutines T Through Z, JSC Internal Note 73-FM-110, (JSC-08065), July 20, 1973.

Development Schedule: Operational

Category Name: Propulsion Systems (Orbital Maneuvering System)

Model Name: OMS THRUST Simulation Name: SLS

Contact Person: Lance Drane Org: C. S. Draper Lab. Tel: (617)258-1178

Description of Model: Calculation of the OMS engine thrust vectors is divided into two major sections: thrust magnitude and thrust direction.

1. Thrust Magnitude

The two OMS engines are modeled as constant thrust, constant specific impulse motors, with the same characteristics for each engine. The buildup of thrust that occurs when an engine is turned on and the tailoff that occurs during shutdown are modeled by instantaneous (step) changes in the thrust magnitude, shifted in time from the electrical command. The shift is different for the application and removal of thrust, the amount of the shift being calculated to give the same total impulse during a transient firing as would be obtained from an actual engine. The model also includes a minimum impulse time associated with the transient characteristics of the OMS engine.

2. Thrust Direction

The location and orientation of each OMS engine is determined by OMS THRUST with the aid of four different coordinate frames.

   a. The Fabrication frame initially defines the engine locations.
   b. The Vehicle body frame is the frame in which vehicle forces and torques are ultimately expressed.
   c. An Actuator coordinate system is defined for each OMS engine actuator to account for the mounting orientation of the engine on the vehicle.
   d. An Engine coordinate system is defined for each OMS engine to account for the engine deflection in pitch and yaw due to TVC.

The OMS engine locations are initially specified in the Fabrication frame; the VEHICLE file generating program transforms the position vectors into Vehicle coordinates for use by OMS THRUST. The thrust vector orientations relative to the Vehicle frame are calculated in two steps: first, the orientation of the Actuator frame relative to the Fabrication frame is defined using the engine mounting angles in pitch and yaw. To go from the F frame to the A frame, the rotation in yaw is first applied about the Z Frabrication axis, then the rotation in pitch is applied about the new Y Fabrication axis. This matrix is pre-multiplied by the transformation matrix from the Fabrication frame to the Vehicle frame to obtain the transformation from the Actuator frame to the Vehicle frame for each OMS engine.

Major Inputs: Pitch and yaw gimbal angles for each OMS engine and the position of the vehicle's center of gravity.

Major Outputs: Thrust and torque vector for each OMS engine.

Source Documentation: Lawrence Berman, et al, "ESIM Model Book for the C. S. Draper Laboratory Statement Level Simulator", the Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Revision 1
31 May 1974

Category Name: Propulsion Systems (Orbital Maneuvering System)

Model Name: Orbital Maneuvering Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-248

Description of Model: The simulation of the Orbital Maneuvering Subsystem is divided into five different sets of equations. These five sets of equations are (1) fuel supply equations, (2) oxidizer supply equations, (3) helium pressurization equations, (4) thrust calculations, and (5) instrumentation and signal conditioning equations. The fuel supply and oxidizer supply equations provide the calculations for the fuel and oxidizer quantity remaining in the tank. Fuel and oxidizer usage will be calculated by the thrust equations. A fuel available and oxidizer available and pressurized boolean will be generated for the thrust equations. Primary helium storage tank pressure and mass is calculated from helium usage. Helium usage is based on the amount of propellants left in the oxidizer and fuel tanks. Helium pressure and the fuel and oxidizer is calculated as dependent on the helium regulation supply. The thrust calculations are to compute the impulse of the engines during the time period from the last iteration to the present iteration. This particular method will allow simulation of the correct impulse during both start-up and engine shut-down transients. The impulse from the engine will reflect the fuel and oxidizer pressure and the mixture ratio corrected by atmospheric pressure. The instrumentation and signal conditioning equations will accept parameters simulating the actual system state and condition these parameters using sensor and display logic booleans from the Electrical Power Subsystem from crew station display, for input to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, December 21, 1973.

Development Schedule:

Category Name: Propulsion Systems (Orbital Maneuvering System)

Model Name: THR2 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: THR2 can model up to three Orbital Maneuvering System engines which have the same thrust magnitude. The force direction depends upon location and deflection of the engine. All engine locations are initially defined in the Fabrication frame. During initialization, THR2 calculates the locations of the Orbital Maneuvering System engines in the vehicle's body frame. An engine coordinate system is identified for each engine. An actuator coordinate system is defined for each engine actuator. The fuel mass flow rate is calculated along with the fuel used by each engine and the total fuel used by all the engines. Some fuel is lost each time an engine is fixed and is included in this model. The characteristics of each engine are the same. Therefore, the mass flow rate and fuel loss per firing are the same for each engine. A sum of the time each engine has been on is calculated. Only when an engine is on is it incorporated in the summation. The mass properties are updated and the position of the vehicle's center of mass is obtained from the mass properties model. In addition, the force vector produced by each engine, the produced torques of each engine and the summed forces and torque are computed.

Major Inputs: Position of each engine actuator, engine mounting angle, thrust vector, thrust vector divided by the gravitational acceleration, fuel lost per engine firing, specific impulse, number of gimbal engines, thrust command on and off delays, and minimum impulse time.

Major Outputs: Forces and torques of each engine and the total forces and torques.

Source Documentation Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Note 72-FD-010, (MSC-06726, Volume III) November 1973.

Development Schedule: Operational

Category Name: Propulsion Systems (Reaction Control System)

Model Name: Reaction Control System

Simulation Name: OAS

Contact Person: G. F. Prude

Org: JSC

Tel: (713)483-5104

Description of Model: The Reaction Control System math model provides a functional simulation of the Orbiter reaction control system jets, sufficient for evaluation of entry Flight Control Systems. Commands from the Flight Control System are in the form of "On-Time" commands for rotation about the Body X, Y, and Z axes corresponding to roll, pitch, and yaw, respectively. The resultant forces and moments are calculated at 1000 pounds thrust per jet. The present model assumes that only the aft reaction control system pod is used and that the moment due to center of gravity shifts away from the nominal are negligible. The coupled roll-yaw effects from the yaw reaction control jets is simulated because of the present vehicle configuration (089B) where the reaction control system pod is well above the center of gravity. Fuel consumption is based on a fixed specific impulse of 230 seconds.

Major Inputs: Pitch, roll, and yaw jet commands; roll, yaw, and roll-yaw moments; and pitch and yaw forces.

Major Outputs: X, Y, and Z forces and moments along with remaining reaction control system fuel.

Source Documentation: Singer-General Precision, Inc., Link Division, "Space Shuttle Procedures Evaluator", working papers.

Development Schedule: Operational

Category Name: Propulsion Systems (Reaction Control System)

Model Name: ACPS Simulation Name: SLS

Contact Person: Lance Drane Org: C. S. Draper Lab Tel: (617)258-1178

Description of Model: ACPS provides a model for the orbiter vehicle's Attitude Control Propulsion System jets. The model can accommodate a variable number of jets, with 40 being included presently. All jets have the same thrust magnitude and specific impulse. ACPS calculates the forces and torques on the vehicle due to individual jet firings and sums them to produce the total force and torque due to ACPS jets. These values are included in the equations that calculate the linear and rotational motion of the orbiter vehicle. When the mass properties due to fuel consumption change, the center of gravity and hence the torque vector of each jet is updated.

An orbiter ACPS jet is modeled as a constant thrust, constant specific impulse motor, and all jets have the same characteristics (thrust, propellant flow rate, etc.). Each jet may be individually commanded on and off; the buildup of thrust that occurs when a jet is turned on and the tailoff that occurs during shutdown are modeled by instantaneous (step) changes in the thrust magnitude, shifted in time from the electrical command. ACPS also has the capability to permit the user to command forces and torques directly. ACPS can be commanded to fire translation jets along positive or negative vehicle X, Y, and Z axes, with the number of jets along each axis specified. Each jet in this case is assumed to fire with nominal ACPS thrust along the axis specified for that jet and to produce no torque on the vehicle even if the vehicle's center of gravity is locatec on that axis. ACPS can also be commanded to apply a torque to the vehicle, with the magnitude about each vehicle axis specified, to simulate the effect of pure jet couples. This results in vehicle rotation only, with no translation.

Major Inputs: Center of gravity location, jet on and off commands.

Major Outputs: Force and torque due to the jet firings, number of times each jet has been fired.

Source Documentation: Lawrence Berman, et al, "ESIM Model Book for the C. S. Draper Laboratory Statement Level Simulator", The Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Revision 1
31 May 1974

Category Name: Propulsion Systems (Reaction Control System)

Model Name: Reaction Control Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-24

Description of Model: The Reaction Control Subsystem can be simulated by dividing the system into four basic areas of equations. The areas are (1) thrust force equations, (2) fuel equations, (3) helium pressurization equations, and (4) instrumentation and signal conditioning equations. Because of the fast response rate of the real world system, the simulation is approached for thrust from the equivalent engineering parameter of total impulse. The thrust and force equations will calculate the total impulse of the RCS jets as they fire. An interface program with the flight computer will provide the thrust equations with booleans for firing the jets and a length of time fired parameter. The computed impulse will take into account the loss of efficiency as the result of atmospheric pressure. The hydrazine fuel equations provide the calculations for the fuel remaining in the tank. Fuel usage will be calculated by the thrust equations. A fuel available and pressurized boolean will be generated for the thrust equations. The primary helium storage tank pressure and mass is calculated from helium usage in the helium pressurization equations. Helium usage is based on RCS fuel remaining in the tank. Helium pressure on the bladder hydrazine tank is calculated as dependent on the helium regulation supply. The instrumentation and signal conditioning equations will accept parameters simulating the actual system state and condition these parameters using sensor and display logic booleans.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, December 21, 1973.

Development Schedule:

Category Name: *Propulsion Systems (Reaction Control System)*

Model Name: RCS1 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: RCS1 provides an elementary model of the Reaction Control System where rotational on-off commands are simulated instead of jet on-off commands. RCS1 calculates the torque acting upon the vehicle, in vehicle coordinates, as well as the mass of the fuel consumed by the RCS since the beginning of the simulation. RCS1 assumes the vehicle is the MSC 040A.

Major Inputs: RCS1 requires no input parameters. All variables vital to RCS1 computations are maintained within the RCS1 program. RCS1 defines initial values of the torque to be applied to the vehicle (in vehicle coordinates) as a result of each rotational on command. Initial values for the rate of fuel flow during "on" condition and mass of non-propulsional fuel ejected each time a rotation jet is turned on are also defined. These initial values may be changed by input if desired.

Major Outputs: The RCS1 output parameters are the total RCS torque acting upon the vehicle (in vehicle coordinates) and mass of fuel consumed by RCS since beginning of simulation and current active vehicle time.

Source Documentation: Engineering Systems Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Note 72-FD-010, (MSC-06726, Volume III), November, 1973.

Development Schedule: Operational

Category Name: Propulsion System (Reaction Control System)

Model Name: RCS3 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This program calculates the moments and linear accelerations applied to the vehicle due to RCS thrust commands from the flight software. The following limitations are placed on thrust commands:

1) A jet cannot be commanded to ignite unless the duration of ignitions is some minimum value,
2) No jet can be ignited continuously longer than a given number of seconds,
3) A jet cannot be commanded to ignite unless a minimum amount of time has elapsed since the previous ignition has ceased.

Major Inputs: Engine position vector for each jet, the center of gravity position, current time, the flight software command, and moment vector due to thrust from each jet.

Major Outputs: Total effective moment from all RCS jets, reduction in mass of vehicle due to RCS fuel usage, and the total effective linear force.

Source Documentation: Engineering Systems Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Propulsion Systems (Reaction Control System)

Model Name: RCS4 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The RCS4 subroutine provides a scalable force and torque model for any configuration of RCS engines on a vehicle. The resultant force and torque about the vehicle's center of mass is calculated and filed for incorporation into the vehicle's dynamics. The forces and torques that can be commanded are input into an array and remain unchanged. When commands are issued, the command state is used to turn the force and torque on or off. The throttling effect can be obtained by increasing or decreasing either positively or negatively the command state. The force and torque inputs can be used to represent any configuration of engines or groups of engines about the vehicle's center of mass. The total fuel consumed is calculated and filed for updating the vehicle's mass properties. RCS4 assumes constant mass properties and therefore a fixed center of gravity.

Major Inputs: Number of commands to be used (limit of 12), force vector of the commands in the vehicle body frame, torque vectors of the commands in the vehicle body frame, and mass flow rates associated with the commands.

Major Outputs: The equivalent number of positive and negative firings, the total on-time for all commands, the fuel used as a result of this command, the total fuel used as a result of all commands, the resultant force and torque.

Source Documentation: Engineering Systems Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Note 72-FD-010, (MSC-06726, Volume III), November, 1973.

Development Schedule: Operational

Category Name; Propulsion Systems (Reaction Control System)

Model Name: RCS10 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The RCS10 subroutine provides a dynamic model for the NR Direct Docking Orbiter vehicle containing 40 attitude control propulsion system engines, which are individually controlled and commanded. Associated with the engines on/off commands are on/off delays, a minimum impulse time, and fuel loss per firing. The forces, torques, and fuel used by each engine are calculated. The resultant force and torque about the vehicle's center of mass is calculated and filed for incorporation into the vehicle's dynamics. The total consumed fuel is calculated and filed for updating the vehicle's mass properties. RCS10 can model up to three different size jets.

Major Inputs: Position vector of the vehicle's center of mass in the vehicle body frame, position vector of the vehicle body frame in the fabrication frame, fabrication to vehicle body force attitude matrix, position of each jet in the fabrication frame, force vector of each jet in the vehicle body frame, on and off delays, mass flow and mass lost for each size jet firing, and the number of engines to be used.

Major Outputs: The force along which the force for each jet is directed, the number of time each engine has been fired, the total on-time for each engine, the fuel used by each engine, the total fuel used by all the jets, the force vector for each jet and the torque vector for each jet engine.

Source Documentation: Engineering Systems Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Propulsion Systems (Reaction Control System)

Model Name: RCS11 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: RCS11 can model up to three different size attitude control propulsion system engines and is the same as RCS10 except for the following data changes, which are: (1) change thrust of each jet from 1100 pounds to 950 pounds, (2) change mass flow rate from 4.5 to 4.13045 pounds/second and (3) change on and off delays to zero.

Major Inputs: Position vector of the vehicle's center of mass in the vehicle body frame, position vector of the vehicle body frame in the fabrication frame, fabrication to vehicle body force attitude matrix, position of each jet in the fabrication frame, force vector of each jet in the vehicle body frame, on and off delays, mass flow and mass lost for each size jet firing, and the number of engines to be used.

Major Outputs: The force along which the force for each jet is directed, the number of times each engine has been fired, the total on-time for each engine, the fuel used by each engine, the total fuel used by all the jets, the force vector for each jet and the torque vector for each jet engine.

Source Documentation: Engineering Systems Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Propulsion Systems (Reaction Control System)

Model Name: RCS12 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: RCS12 can model up to three different size attitude control propulsion system engines and is the same as RCS11 except for data changes to make the nose jets (first 16) vernier jets of 25 pounds of thrust.

Major Inputs: Position vector of the vehicle's center of mass in the vehicle body frame, position vector of the vehicle body frame in the fabrication frame, fabrication to vehicle body force attitude matrix, position of each jet in the fabrication frame, force vector of each jet in the vehicle body frame, on and off delays, mass flow and mass lost for each size jet firing, and the number of engines to be used.

Major Outputs: The direction in which each jet's force is alined, the number of times each engine has been fired, the total on-time for each engine, the fuel used by each engine, the total fuel used by all the jets, the force vector for each jet and the torque vector for each jet engine.

Source Documentation: Engineering Systems Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Propulsion Systems (Reaction Control System)

Model Name: RCS13 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The RCS13 subroutine is identical to RCS11 with the exception of data. Data for the attitude control propulsion system engine location and thrust direction are stored in the subroutine and were taken from the Space Shuttle Guidance and Control Book, SD73-SH-0097A, July 13, 1973, produced by Space Division, Rockwell International, which represents the July 73 configuration for the RI0147B orbiter vehicle. Fuel consumption data were obtained from JSC personnel. The data for on delay and fuel loss for the 900 pound thrust engines are used to approximate the thrust buildup and include a 0.013 pound dribble penalty. Fuel flow rates are based on specific impulse times of 260 seconds for the 900 pound thrusters and 240 for the vernier jets.

Major Inputs: Position vector of the vehicle's center of mass in the vehicle body frame, position vector of the vehicle body frame in the fabrication frame, fabrication to vehicle body force attitude matrix, position of each jet in the fabrication frame, force vector of each jet in the vehicle body frame, on and off delays, mass flow and mass lost for each size jet firing, and the number of engines to be used.

Major Outputs: The force along which the force for each jet is directed, the number of times each engine has been fired, the total on-time for each engine, the fuel used by each engine, the total fuel used by all the jets, the force vector for each jet and the torque vector for each jet engine.

Source Documentation: Engineering Systems Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Propulsion System (Reaction Control System)

Model Name: RCS15 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel:(713)333-4875

Description of Model: The RCS15 subroutine provides a dynamic model of up to 30 attitude control propulsion system bipropellant engines of a single constant thrust magnitude, comprising attitude-control jets arranged in six positions-and direction-dependent clusters, and translational jets. All jets have the same on-delay, off-delay, minimum impulse time, and fuel loss per firing. Mass flow is a function of specific impulse which in turn is a function of jet on-time. Individual forces are computed for each engine, then summed. The total RCS torque is computed using aerodynamic interaction and coupling factors. RCS15 is intended for use in the Entry phase with the RI 140C Orbiter vehicle. RCS15 is adapted from RCS13.

Major Inputs: Angle of attack, dynamic pressure, Mach number, position vector of vehicle's center of mass in vehicle body frame, position vector of the vehicle body frame origin in the fabrication frame, and fabrication to vehicle body frame attitude matrix.

Major Outputs: Mass loss per jet firing, maximim number of jets in any of the six attitude control groups, number of jets, jet thrust magnitude, array of force vectors for the attitude control propulsion system engines in vehicle body frame, RCS engine on and off delay times, standard torque moment per jet, in roll, pitch, and yaw components, and RCS engine minimum impulse time.

Source Documentation: K. M. Parris, "SSFS Model Documentation Series - RCS15", Lockheed Electronics Company Technical Report No. LEC3322, April 1974.

Development Schedule: Operational

Category Name: Propulsion System (Reaction Control System)

Model Name: RCS16 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel:(713)333-4875

Description of Model: The RCS16 subroutine provides a dynamic model of up to 30 attitude control propulsion system bipropellant engines of a single constant thrust magnitude, comprising attitude-control jets arranged in six position-and direction-dependent clusters, and translational jets. All jets have the same on-delay, off-delay, minimum impulse time, and fuel loss per firing. Mass flow is a function of specific impulse which in turn is a function of jet on-time. Individual forces are computed for each engine using translational amplification factors for -Z translation only, then summed over all engines. The total RCS torque is computed using aerodynamic interaction and coupling factors. RCS16 is intended for use in the abort phase with the RI 140C Orbiter vehicle. RCS16 is adapted from RCS15.

Major Inputs: Angle of attack, position vector of vehicle's center of mass in vehicle body frame, position vector of the vehicle body frame origin in the fabrication frame, and fabrication to vehicle body frame attitude matrix.

Major Outputs: Time of jet action, a listing and total number of the jets currently on, the number of times the commanded jet has been fired, total on-time for the commanded jet, fuel used by this jet, total fuel used by this jet, total fuel used by all jets, force vector for this jet, and the total torque vector for all jets.

Source Documentation: K. M. Parris, "SSFS Model Documentation Series - RCS16", Lockheed Electronics Company Technical Report No. LEC3500, May 1974.

Development Schedule: Operational

Category Name: Propulsion Systems (Reaction Control System)

Model Name: RCSENG Simulation Name: SVDS

Contact Person: Ernest M. Fridge Org: JSC Tel: (713)483-3532

Description of Model: Subroutine RCSENG is the RCS thrust model routine. It computes the thrust of up to 35 user specified RCS jets for each vehicle by using an "equivalent square wave" for simulating the on and off delays due to the hardware and electrical system. For any integration interval in which thrust is acting, this square wave is averaged to produce a constant thrust over the entire interval with the total impulse remaining unchanged. Capability is also provided, through a jet status table, for manual on-off control of the jets or for simulating jet failures when a control system is also being simulated. Subroutine RCSENG is executed only under the following conditions.

1) Program initialization, or
2) The first Runge-Kutta equation set for rotation is to be evaluated and
1) Open loop control is being simulated, or
2) A control system model is being simulated, or
3) A control system model and jet failures are being simulated.

Major Inputs: RCS jet minimum electrical on time once the electrical on signal has been activated (sec), time delay in turning off each RCS jet after the electrical off signal has been issued, time delay for each jet on-time, total thrust force from all jets, jet status such as failed or operational, number of RCS jets being simulated, direction cosines of thrust vector of the RCS jet, location of each jet, thrust magnitude of each RCS jet, and total moment about vehicle center of gravity in body coordinates (ft-lb).

Major Outputs: Total thrust force from all jets, total moments about vehicle center of gravity in vehicle coordinates.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume V, Subroutines Q through S, JSC Internal Note 73-FM-110, (JSC 08065), July 20, 1973.

Development Schedule: Operational

Category Name: Propulsion Systems (Solid Rocket Booster)

Model Name: Solid Rocket Motor Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The Solid Rocket Motor Subsystem will be simulated by use of performance data tables. The data that must be matched most closely is from the reference trajectory data. The method requiring the least amount of computer time with a high accuracy is a table look-up and interpolation between points of the table for immediate time values. The suggested table will be composed of thrust, mass, mass position, and moment of inertia data stored at fixed time intervals. The time related parameters will be based on time from Solid Rocket Motor ignition.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, December 21, 1973.

Development Schedule:

Category Name: Propulsion Systems (SRB/ME)

Model Name: THR3 Simulation Name: SSFS

Contact Person: Jim E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This flexible body program defines the thrust model for the flexible launch configuration during first stage boost. The thrust forces and moments account for bending effects as well as the tail-wags-dog contribution. The engine forces which are calculated consist of the thrust with respect to rigid body, forces with respect to engine mounting plus reaction forces, and the bending deflections. The individual moments in the X, Y, Z body coordinates for each engine is computed and totaled.

Major Inputs: Ambient atmospheric pressure, throttle setting, and engine gimbal angles.

Major Outputs: Forces and moments due to thrust from all engines in body coordinates.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, JSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

5.3 Vehicle Dynamics

This section contains descriptive information about models of the vehicle dynamics.

Category Name: Vehicle Dynamics (Deceleration Forces and Moments/Landing Forces and Moments)

Model Name: Landing and Deceleration System Simulation Name: SDL

Contact Person: C. A. Chao Org: TRW Tel: (713)333-3133

Description of Model: The Landing and Deceleration System Model characterizes the dynamic effects of the system upon the orbiter during a landing and rollout phase. The primary function of this model is to determine the forces and moments induced on the vehicle due to any of the gears in contact with the runway surface and to evaluate the aerodynamic effects due to landing gear deployment as well as drag chute deployment. Upon contacting the runway surface, the gear strut/tire deflection and deflection rate are determined in order to compute the forces induced in the strut/tire system. For this purpose, table lookups for a crown model of a straight runway, the nonlinear spring force, and the nonlinear portion of damping are used. The gear velocity is then determined for each gear in contact with the runway, which in turn is used to determine the wheel rolling friction coefficient and the velocity direction with respect to the corresponding wheel plan. The nosewheel steering is evaluated and its actuator is modeled as a first order lag with a rate limit. The main gear brake forces are computed along with the side-skid friction coefficients, the rolling friction, side-skid friction, brake force, and the normal reaction from the runway are properly combined and transformed, for each gear in contact with the runway, to the body frame as the landing forces induced on the vehicle through that particular gear. The aerodynamic effects are evaluated to include landing gear deployment and drag chute deployment. A set of linearly increasing aerodynamic coefficients is computed when the gears or the chutes are being deployed. These coefficients reach and stay at their nominal value when full deployment is attained. For the gears, only the longitudinal aerodynamic coefficients are computed.

Major Inputs: Vehicle wing span, curves for incremental aerodynamic coefficients due to drag chute deployment, landing gear-down, nonlinear damping coefficients for each gear strut/tire, simulation time, and vehicle center of gravity velocity vector.

Major Outputs: Brake force applied on each gear, total force acting on the vehicle due to landing gear contact with runway, total moment acting on each gear and all the gears, landing gear heading angle and landing gear skid angle.

Source Documentation: C. A. Chao, "Landing and Deceleration System Model", Systems Dynamics Department, TRW Systems Group, Working Paper for the SDL.

Development Schedule: Formulation 3/1/74.

Category Name: Vehicle Dynamics (Deceleration Forces and Moments)

Model Name: Drag Chute Subsystem Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The drag chute will require a minimum logical simulation approach. Chute deployment logic will be computed from electrical power available, circuit breaker, and switch state. Following deployment, the chute drag force will be generated based on vehicle airspeed and the distance of the chute centerline above the ground. The logic of chute release will be nearly identical to the chute deployment equation. Parameters used for display or as inputs to the Caution and Warning or Telemetry programs will be signal conditioned with sensor power booleans from the Electrical Power Subsystem. The malfunctions for the drag chute simulation are to be designed into the simulation for minimum computer impact.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Vehicle Dynamics (Landing Forces and Moments)

Model Name: Landing Gear Simulation Name: OAS

Contact Person: G. F. Prude Org: JSC Tel: (713)483-5104

Description of Model: The Landing Gear Math Model contains equations to simulate landing gear forces and moments while the aircraft is on the ground. Forces are modeled as second-order spring dampers, and longitudinal and lateral friction forces. Moments are based on overall vehicle ground dynamics, including strut reactions and nose gear deflections. No attempt is made to simulate street geometry - the total aircraft frequency and damping ratio is calculated as a second-order system, except when this interfaces with vehicle geometry (for example, when the tail strikes the ground after a pitch rotation).

Major Inputs: Nominal weight; nominal mass; X, Y, and Z axis moments of inertia; wheelspan; nose gear deflection; center of gravity at 0 degree pitch; pitch angle for tail drag; pitch angle with brakes on; pitch angle for steady state; and pitch angle for nose gear contact.

Major Outputs: Pitch, roll, and yaw moments; turning forces and moments; landing gear friction forces.

Source Documentation: Singer-General Precision, Inc., Link Division, "Space Shuttle Procedures Evaluator", Working Papers.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Landing Forces and Moments)

Model Name: Landing Gear Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The simulation of the Landing Gear Subsystem can be divided into the four related groups of equations: gear deployment and retraction equations, landing force equations, steering force equations, and braking and anti-skid equations.

The equations for gear deployment and retraction will consider electrical power through switches and circuit breakers to the hydraulic servo valves used to unlock/lock, open/close wheel well doors, and raise/lower the landing gear. Time sequential delays will be incorporated into the equations to simulate the hydraulic power factor. A load parameter will be generated for the Hydraulic Power Subsystem. Gear-up and gear-down parameters will be generated for use by other landing gear equations, and for display in the crew station. Drag force cues for gear and doors will be calculated for use by the Aerodynamic Forces Subsystem.

The landing force equations will take into account the equations of motion data for groundspeed rate of descent, position above the runway surface, and vehicle attitude to calculate the forces at each gear. Audio cues will be generated for touchdown of each gear. The oleo pressure and shock absorber deflection of each gear will be taken into account during landing and rollout so that the resultant position of the vehicle above the runway is realistic.

Steering forces for deflection of the vehicle from nose wheel attitude will be calculated. The position of the nose wheel will be calculated based on inputs from the crew station and the hydraulic power factor time response. Cues will be generated for audio indication of nose wheel steering movement including nose wheel shimmy. Hydraulic fluid usage load will be generated for the Hydraulic Power System.

The Braking and Anti-Skid equations will generate the horizontal braking force applied to each gear wheel set. Anti-skid system braking forces will be generated using simulated wheel revolutions per minute and the ground speed of the vehicle. Cues will be generated for the audio devices indicating braking of the carbon-on-carbon surfaces.

Off-nominal landing effects from water, ice, defective systems, etc., will all be instructor controlled inputs as malfunctions.

The equations will be repeated for each landing gear unit either by programmed loops or by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the landing gear are to be designed into the simulation for minimum computer impact.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: Aerodynamics   Simulation Name: OAS

Contact Person: G. F. Prude   Org: JSC   Tel: (713)483-5104

Description of Model: The Aerodynamics (AERO) Math Model calculates the aerodynamics forces (lift, drag, and side force) and moments (roll, pitch, and yaw) that act upon the Shuttle during flight. It also includes the forces and moments generated by the landing gear when the Shuttle is on the ground. These aerodynamic forces and moments are referenced to the Stability or Velocity-Oriented axes of the Shuttle. The resulting forces and moments are transformed to the Fixed Body axis for use by the equations of motion. The aerodynamic forces are calculated by use of aerodynamic coefficients. Whenever feasible, these coefficients are based on linear variations caused by vehicle attitude, Mach number, control deflections, and rotational velocities. In other cases these coefficients are based on interpolated values from the source data. This system enables the math model to be used to simulate a wide variety of vehicles by changing the aerodynamic constants and coefficients. The design assumptions are (1) only one vehicle may be simulated during one run, (2) the altitude is limited to 150,000 feet, (3) the flaps, speedbrake, and landing gear are not extended at supersonic speeds, (4) a rigid vehicle is assumed, except for control surface deflections, (5) tricycle landing gear with differential braking and nose wheel steering interconnected with the rudder are used and (5) the elevators, rudder, ailerons, flaps, and speedbrake control surfaces are used.

Major Inputs: Wind direction, wind shear profile table, wind speed, inertial to geographic transformation matrix, reference attitude.

Major Outputs: Angle of attack, sideslip angle, roll helix angle, pitch helix angle, yaw helix angle, lift coefficient, drag coefficient, side force coefficient, roll moment coefficient, pitch moment coefficient, yaw moment coefficient, aerodynamic lift, drag, side, and aerodynamic body forces; roll, pitch, yaw, and aerodynamic body moments.

Source Documentation: Singer-General Precision, Inc., Link Division, "Space Shuttle Procedures Evaluator", working papers.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: Aerodynamics Simulation Name: SDL

Contact Person: Oliver Hill Org: JSC Tel: (713)483-4418

Description of Model: The six-degree-of-freedom aerodynamic model is based on the 147B orbiter configuration and will be updated to accommodate all configuration changes. The model will accommodate changes in the center of gravity in the X- and Z-body direction, body flap modulation, and speed brake modulation. Perturbation in the aerodynamic data resulting from ground effects, landing gear, aeroelastic effects, air breathing propulsion system, on orbit maneuvering system pods, and the base pod have been included. A viscous interaction model is also available. A linear interpolation scheme is used to extract the aerodynamic data from tables.

Major Inputs: Old and new center of gravity, mean aerodynamic chord, Mach number, angle of attack, speed brake deflection per schedule, speed brake deflection, body flap deflection, height of wing trailing edge above ground.

Major Outputs: Rudder derivatives, aerodynamic moment coefficients, aileron roll derivatives, roll and yaw rate derivatives, side slip derivatives, longitudinal dynamic derivatives, rate derivative transfer equations, aerodynamic forces, side force coefficient, and coefficients of lift, drag and pitch moment.

Source Documentation: Oliver Hill, "A Shuttle Orbiter Aerodynamic Model in Six Degrees of Freedom", Flight Performance Branch, Mission Planning and Analysis Division, JSC Internal Note 73-FM-172, (JSC-08672), 11 December 1973.

Development Schedule: Requirements 11/02/73, Formulation 12/11/73

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: Aerodynamics - Shuttle Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-248

Description of Model: The simulated shuttle vehicle aerodynamics provides forces and moments due to vehicle motion through the atmosphere to the shuttle vehicle equations of motion. Vehicle position and velocity will be used to calculate velocity with respect to rotating atmosphere. Wind and rough air effects are then included to obtain velocity with respect to the moving atmosphere. A pre-stored wind profile will be utilized, with instructor override capability. During spaceflight missions, provision will be made for differing wind profiles for boost and entry. During boost, orbit, and high-altitude phases of entry, nominal profiles of atmospheric density, temperature, and pressure versus altitude will be used. During low-altitude phases of entry, and during ferry flights, instructor control over atmospheric conditions will be provided through variable settings of sea level temperature and barometric pressure. In this regime, simulation of atmospheric properties will be based on pressure-altitude. During reentry, delta-effects due to instructor settings will be gradually included below a specific altitude, until they are fully effective at a lower altitude, in order to provide smooth transition. Separate calculations of aerodynamic forces and moments are provided for each of the three principal configurations present during space missions. Orbiter alone calculations will be capable of simulating both the space mission and ferry mission configuration aerodynamic properties. Aerodynamic forces and moments will be computed in the body-coordinate system for both boost configurations and in stability axes during orbiter-alone configuration. Stability axis forces and moments will be transformed to the body-coordinate system before exiting the program. Aerodynamic coefficients will be simulated using combinations of functions of one, two, and/or three variables, constants, and mathematical expressions. The effects of vehicle elasticity on vehicle aerodynamics will be simulated in the conventional manner by introducing aeroelastic corrections into the aerodynamic equations. The general approach will be to generate aerodynamic characteristics of a "clean" aircraft in cruise status. Incremental effects of aerosurfaces, ground or target vehicle proximity, etc. will then be combined with the above to obtain all-condition performance simulation. Prime aerodynamic parameters will be simulated to extended values of angle-of-attack and sideslip to afford reasonable stalling characteristics. During orbital phases, effects upon aerodynamic forces of aerosurface deflections will not be simulated.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: AERO11 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This is the aerodynamic model for the launch configuration during first stage boost. It uses a generalized module approach to bending which represents the elastic response by standard normal modal equations with viscous damping. The model sums all the forces acting on each of the equivalent mass points. The number of mass points at which aero forces are calculated will be less than 50. The number of modes at these points will be less than 10 each.

Major Inputs:

Major Outputs: Latitude and longitude of vehicle position, contribution to velocity due to wind speed and direction, flight-path angle, Mach number, dynamic pressure, angle of attack, angle of attack, sum of flexible body vehicle forces and moments due to the air and control surface deflections.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-08065, Volume III), November 1973.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: AERO16 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This model computes the aerodynamic force and torque acting upon the vehicle, in vehicle coordinates. It is assumed that the vehicle is the NR000089B Orbiter. The aerodynamic force in the wind coordinate system is computed and then transformed to the vehicle coordinate system. The torque is computed directly in the vehicle coordinate system. This model allows the torque acting upon the vehicle to be adjusted for an alternate vehicle center of gravity. Thirty-two aerodynamic coefficients are used to compute the aerodynamic force and torque acting upon the vehicle.

The values of coefficients are determined within the model by linear interpolation using large data tables.

Major Inputs: Elevator, aileron, rudder, rudder flare, and body flap deflections; landing gear mode; Mach number; dynamic pressure; speed of vehicle with respect to atmosphere; angle of attack; sideslip angle; angular velocity of vehicle; transformation matrix from wind to vehicle coordinates; vehicle mass; position vector of vehicle center of gravity; altitude above ellipsoidal earth; vehicle's position and velocity vectors.

Major Outputs: Aerodynamic force and torque, hinge moment coefficients, rudder hinge moment derivatives, hinge moments, lift and drag accelerations, lift and drag coefficients, lift over drag, pitching moment derivatives.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-08065, Volume III), November 1973.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: AERO17 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This is the standard aerodynamic model for the Launch-to-Orbit Integrated Vehicle Configuration VSL-000061. The model calculates latitude and longitude of vehicle position, the contribution to velocity due to wind speed and direction, flight-path angle, Mach number dynamic pressure, angle of attack, and angle of sideslip. The vehicle forces and moments due to the air control surface deflections are calculated and summed.

Major Inputs: Vehicle position and velocity in plumbline coordinates; wind velocity and wind azimuth from table look-ups; air density and pressure; speed of sound; location of center of gravity; elapsed time; aerodynamic control surface deflections; vehicle roll, pitch, and yaw rates; table of aerodynamic coefficients.

Major Outputs: Current air pressure, components of aerodynamic forces, moments due to aerodynamic forces.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: AERO18 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This is a model of the aerodynamic forces and torques exerted on the orbiter vehicle for the on-orbit mission phase. The orbiter vehicle configuration is the NR-89B. On-orbit aerodynamics are approximated using the Newtonian Impact Theory for a flat plate. For the orbit altitude range being considered, the drag coefficient is assumed constant. Further, at this altitude the lift coefficient is zero. Therefore, torque on a vehicle can be approximated by modeling the vehicle as a combination of flat plates and determined from the drag forces acting on each plate.

Major Inputs: Locations of the center of pressure in the Fabrication frame, atmospheric density, drag coefficient, magnitudes of the true planform areas, inertial velocity vector, vehicle to inertial attitude transformation matrix, fabrication to vehicle position vector, fabrication to vehicle altitude transformation matrix.

Major Outputs: Sum of the aero forces and torques.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: AERO19 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This model computes the aerodynamic force and torque acting upon the NR000147B orbiter, in vehicle coordinates. It is assumed that the mission phase is Entry-to-Landing. The aerodynamic force in the wind coordinate system is computed and then transformed to the vehicle coordinate system. The torque is computed directly in the vehicle coordinate system. This model allows the torque acting upon the vehicle to be adjusted for an alternate vehicle center of gravity. Thirty-two aerodynamic coefficients are used to compute the aerodynamic force and torque acting upon the vehicle. The values of coefficients are determined within the model by linear interpolation using large data tables. The user may request computation of viscous interaction corrections to be added to the lift and drag coefficients.

Major Inputs: Elevator, aileron, rudder, speed brake, and body flap deflections; landing gear mode; Mach number; dynamic pressure, speed of vehicle with respect to atmosphere; angle of attack; sideslip angle; angular velocity of vehicle; transformation matrix from wind to vehicle coordinates; vehicle mass; position vector of vehicle center of gravity; altitude above ellipsoidal earth; vehicle's position and velocity vectors.

Major Outputs: Aerodynamic force and torque, hinge moment coefficients, rudder hinge moment derivatives, hinge moments, lift and drag accelerations, lift and drag coefficients, lift over drag, pitching moment derivatives.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamics Forces and Moments)

Model Name: AERO21 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: AERO21 computes the aerodynamic force and torque acting upon the RI000140C Orbiter in vehicle coordinates. AERO21 computes the aerodynamic force in the wind coordinate system and then transforms to the vehicle coordinate system. Thirty-two aerodynamic "coefficients" appear in the equations which AERO21 uses to compute the aerodynamic force and torque acting upon the vehicle. These coefficients are computed as a function of Mach number, angle-of-attack, elevator deflection, speed brake deflection, and the ratio of vehicle altitude above the Fischer ellipsoid to the vehicle wingspan. AERO21 determines the values of coefficients by linear interpolation using large data tables.

Major Inputs: Elevator, aileron, rudder, speed brake, and body flap deflections; Mach number; dynamic pressure; magnitude of velocity of vehicle with respect to the atmosphere; angle-of-attack; sideslip angle; and landing gear mode.

Major Outputs: Aerodynamic force and torque acting upon the vehicle, expressed in vehicle coordinates, and twenty variables for printout purposes only.

Source Documentation: J. C. Erck, "SSFS Model Documentation Series - AERO21", Lockheed Electronics Company Technical Report No. LEC2005, February 1974.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: AERORD Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: The purpose of this model is to obtain forces and moments caused by interaction aerodynamics on any one of the three vehicles. The model is written in a general form and the user actually formulates the aerodynamic forces and moments consistent with the general format of interaction force models. The first set of operations performed is to call AROCAL to compute certain aerodynamic quantities such as angle of attack, angle of sideslip, and Mach number. After storing independent and dynamic variables, IAFORC is called to compute the interaction aerodynamic forces and moments.

Major Inputs: Interaction forces computed by the interaction force model, maximum length of vehicle common, number of vehicles simulated, interaction moments computed by the interaction force model.

Major Outputs: Interaction aerodynamic force in the body system, moments about the center of mass of the body due to the interaction aerodynamic forces in the body system.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: ARODYN Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: This model simulates the independent aerodynamics forces and moments on the vehicle. The model does not include close proximity interference effects, but is used when the vehicle is out of the staging flight regime. After calling AROCAL for aerodynamic quantities, ARODYN determines the aerodynamic coefficients by interpolation of coefficient tables. Then the aerodynamic forces and moments are computed.

Major Inputs: Aerodynamic reference areas and lengths, body rates, earth relative velocity vector, location of aerodynamic reference area relative to center of gravity.

Major Outputs: Aerodynamic forces and moments.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Schedule: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: ARO3S1 Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: This model obtains aerodynamic coefficients of lift and drag and computes the normal and axial coefficients. Aerodynamic quantities are computed for three-degree-of-freedom entry and approach-to-landing. Computations may optionally include provisions for viscous interaction effects.

Major Inputs: Aerodynamic table data, pitch angle of attack, zero lift angle of attack, aerodynamic reference area, hypersonic drag coefficient and zero lift, center of gravity, aerodynamic reference center of gravity, lift increment from body flap deflection, split rudder deflection, normal and axial body shape factors, Mach number, flight-path angle, geodetic altitude, landing gear switch, freestream dynamic pressure, aerodynamic reference temperature, Reynolds number, temperature, body wall temperature.

Major Outputs: Elevator deflection, aerodynamic reference lengths, aerodynamic forces, lift to drag ratio.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Status: Operational

Category Name: Vehicle Dynamics (Orbiter Aerodynamic Forces and Moments)

Model Name: AR03S6 Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: This model obtains aerodynamic coefficients of lift and drag using table look-ups and computes the normal and axial coefficients.

Freestream aerodynamic quantities for three-degrees-of-freedom simulations are computed. The computations may optionally include viscous interaction effects.

Major Inputs: Pitch angle of attack, zero lift angle of attack, aerodynamic reference area and reference temperature, axial and normal body shape factors, Mach number, freestream dynamic pressure, Reynolds number, current temperature, body wall temperature.

Major Outputs: Aerodynamic reference lengths and forces, lift to drag ratio.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Status: Operational

ɛgory Name: Vehicle Dynamics (Target Vehicle Aerodynamic Forces and Moments)

ɛl Name: Aeroflight Aerodynamics-Target Vehicle Simulation Name: SMS

:act Person: C. C. Olasky Org: JSC Tel: (713)483-2481

:ription of Model: The simulated target vehicle aeroflight aerodynamics :ulates aerodynamic forces and moments on detached target vehicles operating ıin the atmosphere, (namely boost SRM's and external tank) and proximity ›spheric effects upon both shuttle vehicle and target vehicle. Velocity :he target vehicle with respect to the moving atmosphere is calculated in target vehicle body-fixed coordinate system using the same wind and rough effects which are included in Shuttle aerodynamics. Speed of sound and ›spheric density are obtained from the same median profiles used by shuttle ›dynamics as functions of altitude only. Proximity effects will be :ulated as functions of Mach number and target vehicle displacement for both :cles. Aerodynamic forces and moments are computed in the target vehicle ' fixed coordinate system. Proximity effects will be included with isolated ' characteristics by multiplicative and additive factors to obtain total :es and moments.

›r Inputs:

›r Outputs:

·ce Documentation: Singer Company, Simulation Products Division, "Shuttle ;ion Simulator Baseline Definition Report", Volume II, 21 December 1973.

ɛlopment Schedule:

Category Name: Vehicle Dynamics (Target Vehicle Aerodynamic Forces and Moments)

Model Name: Spaceflight Aerodynamics-Target Vehicle Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The simulated target vehicle spaceflight aerodynamics calculates aerodynamic forces and moments on detached spaceflight target vehicles (all target vehicles except boost SRM's and external tank). Inputs to simulated spaceflight aerodynamics include target vehicle position, velocity, and altitude (target vehicle translational EOM), and target vehicle attitude direction cosines (target vehicle rotational EOM). Velocity of the target vehicle with respect to the atmosphere is calculated in the target vehicle body-fixed coordinate system, assuming an atmosphere rotating uniformly with the earth. Atmospheric density is obtained from the same median profile used by shuttle aerodynamics as a function of altitude alone.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

5.4 Specialized Vehicle Dynamics

This section contains descriptive information about models of the specialized vehicle dynamics.

Category Name: Specialized Vehicle Dynamics (Bending)

Model Name: BEND1 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This flexible body program contains the bending model for the launch configuration during first stage boost. It uses a generalized modal approach to bending which represents the elastic response by standard normal modal equations with viscous damping. Included are models for aerodynamic forces and moments and thrust forces and moments to account for bending effects as well as the tail-wags-dog contribution to bending. The model sums all the forces acting on each of the equivalent mass points and for a given mode numerically integrates the sum with a second order linear differential equation in modal displacement. The number of mass points at which aero forces and modal displacements are calculated will be less than 50. The number of modes at these points will be less than 10 each.

Major Inputs: Number of aero stations, number of engines, number of slosh stations, damping coefficients for each mode, frequency of each mode, normalized mass for each mode, aero forces and moments at each station, thrust forces at moments at each station, slosh forces and moments at each station, and mode shapes and slopes for each mode at each station.

Major Outputs: Modal displacements due to each bending mode.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Specialized Vehicle Dynamics (Bending)

Model Name: BEND   Simulation Name: SVDS

Contact Person: E. M. Fridge, III   Org: JSC   Tel: (713)483-3532

Description of Model: The purpose of this routine is to compute elastic body and linear slosh derivatives. Subroutine BENDAT is called to generate mass stiffness and damping matrices. The bending accelerations and slosh accelerations are computed. The pseudo rigid body displacement, velocity, and acceleration is computed for both slosh and bending. Finally, the bending and slosh derivatives are computed and stored for later use.

Major Inputs: Input array containing the modal slopes necessary to compute the small angle elastic rotation transformation matrix, an array containing the "pseudo rigid body" model slopes, mass stiffness, and damping matrices.

Major Outputs: Elastic body transformation matrix and bending and slosh derivatives.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Schedule: Operational

Category Name: Specialized Vehicle Dynamics (Docking/Undocking)

Model Name: Docking Subsystem Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The simulated docking subsystem will simulate the operation of the docking mechanism. The docking mechanism is assumed to be deployable and to be operated only when deployed. State information for the two vehicles will be used to calculate the relative positions and attitudes of the two docking devices. Depending on present relative state, forces and moments upon both vehicles due to the operation of the guide cone, actuators/alternators, or alignment rings are calculated. When relative position and attitude is proper, capture latches will be simulated to be closed and resulting forces and moments will be calculated. Unlatching of a docked vehicle will be simulated as occurring upon remote command, providing relevant switches and breakers are properly configured, power is available, and the system has not been malfunctioned in such a way as to prevent release. The fail-safe docking device jettison will be simulated for emergency use. An update interval of 100 milliseconds is used for the docking subsystem simulation, which matches the update rate for target vehicle Equations of Motion.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report," Volume II, 21 December 1973.

Development Schedule:

Category Name: Specialized Vehicle Dynamics (Slosh)

Model Name: SLSH1 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This flexible body program contains the slosh model for the launch configuration during first stage boost. The number of slosh masses will be less than five and the number of modes per slosh mass will be less than five.

Major Inputs: Damping factor for each slosh mode, characteristic frequency of each slosh mode, position of each slosh mass, mass of sloshing fluid at each mode, vehicle body accelerations, modal acceleration due to bending each mode, vehicle contact accelerations, and mode shapes translation for each mode at each location.

Major Outputs: Displacements of each slosh mass, velocity of each slosh mass, and acceleration of each slosh mass.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III) November 1973.

Development Schedule: Operational

Category Name: Specialized Vehicle Dynamics (Slosh)

Model Name: SLOSH Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: Subroutine SLOSH is based on a general large amplitude slosh model developed by the TRW Dynamics Analysis Section for use in studying the motion of the service module following its jettison from the command module prior to command module reentry. The model programmed in this subroutine is a modified version of the model developed for Apollo.

Subroutine SLOSH computes the time derivatives of the slosh position vector, the position vector of the rigid body c. g., the angular velocity vector of the rigid body, and the quaternions. These are the time derivatives required to integrate the equations of motion for this slosh model. This model is based on the assumption that the forces and moments of a contained liquid reacting on a rigid body can be approximated by a point mass constrained to move interior to and on a closed surface (slosh surface). The slosh surface is taken to be an ellipsoid for this subroutine.

This model uses a constraint equation that constrains the velocity of the slosh mass relative to the origin of the slosh surface to be perpendicular to the normal vector of the slosh surface when the slosh mass is on the surface. This constraint couples the rigid body rotational and translational equations of motion with the slosh equations of motion and requires a simultaneous evaluation of the derivatives for these variables.

The variables required to define this model in addition to the standard trajectory variables are the location of the origin of the slosh coordinate system relative to the c.g. of the rigid body, the transformation matrix from the slosh coordinate system to the body coordinate system, the slosh mass, the slosh position vector, and the slosh velocity vector.

Major Inputs: Thrust acceleration, total force and moment in the body system, constant defining slosh surfaces, acceleration due to gravity, number of slosh masses for vehicle, body rates, position vector from vehicle center of gravity to origin of slosh surface for slosh mass, weight of slosh mass, vehicle mass, vehicle inertial velocity and acceleration, and slosh damping constants.

Major Outputs: Thrust acceleration, body acceleration, matrix containing slosh forces, position vector from vehicle center of gravity to origin of slosh surface for slosh mass, position vector from origin of slosh surface to slosh mass, vehicle inertial acceleration, and acceleration relative to primary vehicle.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume V, Q through S, JSC Internal Note 73-FM-110, (JSC-08065, Volume V), 20 July 1973.

Development Schedule: Operational

Category Name: *Specialized Vehicle Dynamics (Staging)*

Model Name: External Tank Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The simulation of the sequential logic and mechanical functions for External Tank System separation will be accomplished by logic equations. These equations will take into account explosive device armament by the crew and separation cues either by switch command or Onboard Computer inputs.

The explosive device equations will provide an audio cue, a cue to the equations of motion indicating physical separation, and a cue to the retro solid rocket motor (SRM) engines to ignite. The retro rocket ignition cue will be based on the simulated external tank avionics state and separation attitude and distance data calculated from the equations of motion attitude and position data. The separation SRM equations will provide the thrust force of the small rocket to the equations of motions for the new "target" vehicle. Once the separation SRM has burned out, this model is no longer used.

The instrumentation and signal conditioning equations accept parameters simulating the actual system state and condition these parameters using sensor and display logic booleans from the Electrical Power Subsystem for crew station display, for input to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program. Required malfunctions for the simulation are to be designed into the simulation for minimum computer impact.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Specialized Vehicle Dynamics (Staging)

Model Name: CONTAC   Simulation Name: SVDS

Contact Person: E. M. Fridge   Org: JSC   Tel: (713)483-3532

Description of Model: Subroutine CONTAC computes interaction forces and moments between vehicles due to physical attachment, impingement, and separation forces. Three separate force model options are provided.

(1) Option 1 - Structural Spring Model
The structural spring model computes pre-separation structural attachment forces and post separation recontact or impingement forces.
(2) Option 2 - Ejection Spring Model
The ejection spring model computes ejection forces including lateral and friction forces.
(3) Option 3 - Cone Model
The cone model computes recontact forces due to bobbing or bouncing immediately post separation within and external to the structural attachment fittings.

Major Inputs: Separation distance at which ejection spring force is terminated, separation distance at which the structural springs disconnect, force vector of link damping model, coefficients of ejection spring force polynomial, total vehicle moment due to the spring model, total vehicle forces due to the spring model, body rates, number of modes between primary vehicle and a particular secondary vehicle, position components of modes in primary and secondary vehicle reference coordinate system, components of rotation spring constant and lateral/normal forces, activation time of ejection springs measured from current time, coefficient of friction and others.

Major Outputs: Forces and moments for the primary vehicle, activation time of ejection springs measured from current time, total vehicle forces due to the spring model, link forces on primary vehicle, cone interaction force along structural spring axes and others.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Schedule: Operational

5.5 *Equations of Motion*

This section contains descriptive information about models of the equations of motion (EOM).

Category Name: Equations of Motion (Integration Techniques)

Model Name: DIFEQ2 | Simulation Name: SSFS

Contact Person: J. E. Vinson | Org: Lockheed | Tel: (713)333-4875

Description of Model: This model provides a very simple method for integrating an acceleration over a time interval to derive velocity and position. This model may be used to integrate any acceleration vector regardless of coordinate system.

Major Inputs: Acceleration, integration time interval, accumulated velocity from beginning of simulation, velocity and position vectors.

Major Outputs: Updated accumulated velocity from beginning of simulation, updated velocity and position vectors.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Integration Techniques)

Model Name: TRAJMT Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: TRAJMT is a trajectory maintenance routine which integrates the gravity forces acting on a vehicle to update the state vector. It also adds on to this the change in the state vector due to contact forces integrated by the vehicle program.

TRAJMT was revised to include a flat earth model which may be selected by the user. A four-pass Runge-Kutta integration scheme is used. In performing the integration, TRAJMT uses a rectification scheme to keep the magnitude of the numbers being integrated small.

Major Inputs: Time to which TRAJMT must update, current TRAJMT time, input position and velocity vectors, position and velocity vector changes due to contact forces.

Major Outputs: Updated position and velocity vectors.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Integration Techniques)

Model Name: TRJMTD Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: TRJMTD is a trajectory maintenance routine that updates the vehicle state vector. The vehicle program integrates the change in the state due to non-gravitational forces and passes these changes to TRJMTD. TRJMTD integrates the change in the state due to gravitational forces. The state is then updated by adding these changes to the previous state.

TRJMTD includes a flat earth gravitational model which may be selected by the user. TRJMTD does the same type calculation as TRAJMT except that TRJMTD has some additional precision features that make it desirable when comparing environment and software navigation schemes.

Major Inputs: Time to which TRJMTD must update, current TRJMTD time, input position and velocity vectors, change in position and velocity vectors due to non-gravitational accelerations, vectors of lower order position and velocity terms.

Major Outputs: Updated position and velocity vectors.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Integration Techniques)

Model Name: INTEGR   Simulation Name: SVDS

Contact Person: E. M. Fridge, III   Org: JSC   Tel: (713)483-3532

Description of Model: INTEGR is a collection of utility routines used by the integration drivers. The four routines RKG1, RKG2, RKG3, and RKG4 contain respectively the four sets of equations that make the total Runga-Kutta-Gill integration scheme. Routine ROTRES places the body angular velocities and aerodynamic velocities from the integration array into their proper locations in named common. ROTRES also normalizes the quaternions and places them into their proper named common location. Routine TRNRES stores translational quantities from the integration array into their proper named common location for a 6-D simulation. The quantities stored are the displacements and velocities and sensed velocities. The current gravitational accelerations are placed in a save location for use during the next integration step. Routine TRNRS1 stores translational quantities from the integration array into their proper named common location for a 3-D translational only simulation. The quantities stored are the displacements and velocities. Also the 3-D quaternions are normalized and stored into their proper named common location. Velocities are also stored for aerodynamic computations. Routine SLOSRS stores translational and slosh quantities from the integration array into their proper named common location for a slosh simulation. The quantities stored are the rigid body displacements and velocities and the slosh mass displacements and velocities. Routine ADAMS computes the normalized integration coefficients. An upper fourth-order backwards-difference operation is performed to complete the Adams-like integration. Routine PREADR serves as a pre-Adams rotational integration interface with the Adams routine. Variables for the rotational dynamics integration are set up and the proper coefficients are stored. Routine PSTADR serves as a post-Adams rotational integration interface with the Adams routine. It performs the necessary logic to locate the past derivatives in the derivative array for rotational integration. Routine PREADT serves as a pre-Adams translational interface with the Adams routine. Variables for the translational dynamics integration are set up and the proper coefficients are stored. Routine PSTADT serves as a post-Adams translational integration interface with the Adams routine. It performs the necessary logic to locate the past derivatives in the derivative array for translational integration.

Major Inputs: Adams integration constants, derivative and integration arrays, integration step sizes, acceleration due to gravity, option flags, normalized quaternions, vehicle inertial position and velocity vectors, position and velocity vectors relative to primary vehicle.

Major Outputs: Past value of gravitational acceleration, normalized quaternions, body rates, position vector from origin of slosh surface to slosh mass, velocity vector of slosh mass relative to the slosh coordinate system, current trajectory time, phase elapsed time, vehicle intertial position and velocity vectors, vehicle rotational velocity vector, sensed velocity vector, position and velocity vectors relative to primary vehicle, integration array.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

INTEGR (Continued)

Source Documentation: (Continued)

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume III, I through L, JSC Internal Note 73-FM-110, (JSC-08065, Volume III), 20 July 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: Mass Properties   Simulation Name: SDL

Contact Person: T. J. Smith   Org: TRW   Tel: (713)333-3133

Description of Model: The mass properties model maintains record of the total vehicle's mass, center of gravity, moments, and products of inertia. The model describes all status subsystems, the dynamic subsystems (OMS, RCS, SRB, etc.) and vehicle configuration changes. Interpolation tables for nominal depletion mass properties are included for the following configurations: vertical flight (VF) orbiter/payload/solid rocket boosters, VF orbiter/payload/external tank, VF orbiter/payload, VF orbiter, and horizontal flight orbiter. Three depletion options are available: nominal depletion, off-nominal depletion, and fixed mass properties.

Major Inputs: Inertia elements, mass, components of centroid vector.

Major Outputs: Inertia elements, mass, components of centroid vector.

Source Documentation: T. J. Smith, "SDL Mass Properties Math Model", TRW IOC 73:7153.7-35, 27 December 1973.

Development Schedule: Formulation 12/73.

Category Name: Equations of Motion (Mass Properties)

Model Name: MASSPROP Simulation Name: SLS

Contact Person: Lance Drane Org: C. S. Draper Lab Tel: (617)258-1178

Description of Model: The MASSPROP model maintains the mass, center of gravity, and inertia matrix of the orbiter vehicle. Mass is decremented to account for propellant consumption by the attitude control propulsion system jets and the OMS engines; it also changes when the payload is deployed or retrieved. The vehicle center of gravity and inertia matrix remain constant and do not reflect OMS or attitude control propulsion system jets and the OMS engines; it also changes when the payload is deployed or retrieved. The vehicle center of gravity and inertia matrix remain constant and do not reflect OMS or attitude control propulsion system propellant usage.

In addition to the total orbiter mass, MASSPROP maintains the propellant mass used by each attitude control jet and the total mass of attitude control jet propellant remaining. The propellant mass used by each OMS engine and the total mass of OMS propellant remaining are also computed.

The orbiter center of gravity is defined relative to the vehicle axis system. The moments and products of inertia are taken about the vehicle center of gravity and are with respect to the vehicle axes. The product of inertia elements of the inertia tensor are defined as positive integrals. Two sets of center of gravity and inertia data are used by MASSPROP, corresponding to the orbiter vehicle after orbital insertion with and without payload. These values of center of gravity and inertia remain constant during a simulation and do not reflect propellant usage. MASSPROP switches from one set of data to the other whenever a payload deployment or retrieval command is received by the driving program.

Major Inputs: Number of firings for each attitude control propulsion system jet.

Major Outputs: Values of vehicle mass; center of gravity; inertia matrix; total masses of propellant remaining for the OMS and attitude control propulsion system; total number of firings, total on-time, and propellant usage for each attitude control jet.

Source Documentation: Lawrence Berman, et al, "ESIM Model Book for the C. S. Draper Laboratory Statement Level Simulator", The Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: Mass Properties - Shuttle   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The shuttle vehicle mass properties simulation must calculate the current vehicle mass, center of mass, and inertial tensor for the vehicle equations of motion. Mass properties will be calculated in the body coordinate system. In order to accomplish this, the mass properties simulation obtains information on mass and mass distribution of on-board consumables from the simulated vehicle systems, and on vehicle configuration from the environmental control system, payload accommodation system, simulated docking system, simulated SRM's, and simulated external tank. The consumable masses will be added to the vehicle dry mass to obtain shuttle vehicle mass. Then the location of the shuttle center of mass will be calculated using the consumable masses and mass centers, masses and mass centers of configuration changeable portions, and the mass and mass center of the remainder of the vehicle.

Once shuttle vehicle (less payload) mass properties are found, they are then combined with mass properties of attached payloads to obtain cluster mass properties.

Major Inputs:

Major OUtputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Equations of Motion (Mass Properties)

Model Name: Mass Properties - Target Vehicle   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: Many target vehicles will not require a dynamic real-time mass properties simulation. Over the interval of interest, changes in mass properties will be negligible. Other target vehicles, e.g., those with propulsive stages, will demonstrate significant changes in mass properties. Thus, reset booleans will be provided which will allow dynamic mass property simulation to be bypassed for certain target vehicles. Certain other target vehicles (e.g., SRM's, external tank) will have their mass properties calculated elsewhere (in the cases of SRM's or external tank, in the appropriate on-board system simulation programs). Thus, in those cases also, the target vehicle mass properties simulation is bypassed. In those cases in which the simulation is not bypassed, inputs to the simulation are engine mass flow and reaction control system mass flow. Total mass is decremented accordingly. Provision will be made to permit interpolation on mass to obtain target vehicle center of mass and tensor of inertia. An iteration rate of twice per second is estimated, under fairly conservative rocket assumptions, to require a 1/2 second overburn to erase resulting error on a 7000 ft/sec change in velocity burn, which should be quite acceptable in terms of ability of the crew or ground to notice. Mass distribution parameters could probably be iterated even more slowly, if time is critical.

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS4 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The MASS4 model defines the mass properties of the Orbiter (active) vehicle and the Space Base (passive) vehicle for the A/DOCK portion of the SSFS. The model assumes a constant mass and rigid body for both vehicles. It performs its calculations only during the initialization pass. With no mass change, MASS4 does not update the vehicle inertia matrices and the center of mass vectors.

Major Inputs: Active vehicle mass, position of the active vehicle's center of mass in the fabrication frame, position of active vehicle in the fabrication frame, attitude of the active vehicle's body frame in the fabrication frame, active vehicle inertia tensor, passive vehicle mass, position of the passive vehicle's center of mass in passive vehicle body frame, passive vehicle inertia tensor.

Major Outputs: Active vehicle mass, center of mass location in active vehicle's body frame, active vehicle inertia tensor, inverse of active vehicle inertia tensor, position of active vehicle's body frame in the fabrication frame, fabrication to active vehicle's body frame attitude matrix and attitude, position of center of mass in fabrication frame, passive vehicle mass, center of mass location in passive vehicle body frame, passive vehicle inertia tensor, inverse of passive vehicle inertia tensor.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS5 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This model provides the mass properties, which consist of center of gravity, moments of inertia as a function of weight, and total mass calculation.

Major Inputs: Mass to weight conversion constant, altitude, total vehicle mass.

Major Outputs: Total vehicle mass, center of gravity, mass moments of inertia.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS16 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The MASS16 subroutine defines the mass properties for the North American Rockwell Pilot Evaluation Simulation Orbiter Vehicle. The center of mass and vehicle inertia are held constant while the mass can be decremented to model fuel consumption by the RCS jets and main propulsion engines.

Major Inputs: Active vehicle mass, position of the center of mass in the fabrication frame, position of the vehicle body frame in the fabrication frame, attitude of the vehicle body frame in the fabrication frame, active vehicle inertia tensor.

Major Outputs: Active vehicle mass, center of mass location in vehicle body frame, active vehicle inertia tensor, inverse of active vehicle inertia tensor, position of the vehicle body frame in the fabrication frame, fabrication to vehicle body frame attitude matrix and attitude, position of the center of mass in the fabrication frame, initial active vehicle mass.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS17 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: MASS17 supplies values for the NR-89B Orbiter (April version) mass, center-of-gravity, inertia matrix, and inverse inertia matrix. The center-of-gravity and inertia matrices are held constant while the mass is decremented to model fuel consumption by the RCS jets and main propulsion engines.

Major Inputs: Total mass of RCS fuel consumed, total mass of main propulsion engine fuel consumed.

Major Outputs: Vehicle mass, vehicle center of gravity in body coordinates, vehicle inertia matrix, and inverse inertia matrix.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS18 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The MASS18 subroutine defines the mass properties for the NR-89B Orbiter, April version. The center of mass and vehicle inertia are held constant while the mass can be decremented to model fuel consumption by the RCS jets and main propulsion engines. The mass properties represent the Orbiter at Entry with a 25,000 pound payload, after a 40,000 pound polar payload mission.

Major Inputs: Active vehicle mass, position of the center of mass in the fabrication frame, position of the vehicle body frame in the fabrication frame, attitude of the vehicle body frame in the fabrication frame, active vehicle inertia tensor.

Major Outputs: Active vehicle mass, center of mass location in the vehicle body frame, active vehicle inertia tensor, inverse of active vehicle inertia tensor, fabrication to vehicle body frame attitude matrix and attitude, position of center of mass in fabrication frame, initial active vehicle mass.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS19 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: MASS19 is the standard mass properties model for the Launch-to-Orbit Integrated Vehicle, MLS-000061. Model MASS19 provides the mass properties which consist of center of gravity, moments of inertia as a function of weight and total mass calculation. Mass depletion is determined in this model and a flag signaling the end of the first stage is set based on mass depletion.

Major Inputs: Mass, center of gravity, moment of inertia tables, mass depletion due to RCS and main engine thrusting.

Major Outputs: Current vehicle mass, center of gravity, moments of inertia.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS20 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: MASS20 supplies values of the mass, center of gravity location, inertia matrix, and inverse inertia matrix for the NR-147B orbiter. Center of gravity location and inertia matrices are held constant. Mass is decremented to model fuel consumption by the RCS jets and main propulsion engines. The model contains initial mass properties for two configurations: landing (forward center of gravity) and landing (aft center of gravity).

Major Inputs: Total mass of RCS fuel consumed, total mass of main propulsion engine fuel consumed.

Major Outputs: Vehicle mass, vehicle center of gravity in body coordinates, vehicle inertia matrix, inverse inertia matrix.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS21 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-

Description of Model: The MASS21 subroutine defines the mass properties for the RI-147B Orbiter. The center of mass and vehicle inertia are held constant while the mass can be decremented to model fuel consumption by the RCS jets and main propulsion engines. The mass properties represent the Orbiter at Entry with a 25,000 pound payload, after a 65,000 pound payload due east mission.

Major Inputs: Active vehicle mass, position of center of mass in fabrication frame, position of the vehicle body frame in the fabrication frame, attitude of the vehicle body frame in the fabrication frame, active vehicle inertia tensor.

Major Outputs: Active vehicle mass, center of mass location in vehicle body frame, active vehicle inertia tensor, inverse of active vehicle inertia tensor, position of vehicle body frame in fabrication frame, fabrication frame to vehicle body frame attitude matrix and attitude, position of center of mass in fabrication frame, initial active vehicle mass.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS23 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: MASS23 supplies values of the mass, center of gravity location, inertia matrix, inverse inertia matrix for the RI000140C Orbiter. Center of gravity location and inertia matrices are held constant. Mass is decremented to model fuel consumption by the RCS jets and main propulsion system engines. MASS23 contains inertial mass properties, stored via data statements, for two landing configurations, 32000-pound-payload (near forward c.g.) and no-payload (near aft c.g.).

Major Inputs: Total mass of RCS fuel consumed; the total mass of main propulsion engine fuel consumed; mass of the vehicle; center of gravity; and inertia matrix.

Major Outputs: Vehicle mass; vehicle center of gravity in body coordinates; vehicle inertia matrix; and inverse inertia matrix.

Source Documentation: K. M. Parris, "SSFS Model Documentation Series - MASS23", Lockheed Electronics Company Technical Report No. LEC1889, February 1974.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: MASS24 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The MASS24 subroutine defines the mass properties for the RI-140C Orbiter as specified in the Aerodynamic Design Data Book. The center of mass and vehicle inertia are held constant while the mass can be decremented to model fuel consumption by the RCS jet and main propulsion engines. The nominal mass properties represent the Orbiter at Entry with a 32,000 pound payload, after a 65,000 pound payload due east mission. An optional mass properties data set may be selected to represent the Orbiter with no payload.

Major Inputs: Vehicle mass, position of the center of mass in the fabrication frame, position of the vehicle body frame in the fabrication frame, the attitude of the vehicle body frame in the fabrication frame, and the active vehicle inertia tensor.

Major Outputs: Active vehicle mass, center of mass location in vehicle body frame, active vehicle inertia tensor, inverse of active vehicle inertia tensor, fabrication to vehicle frame attitude matrix, fabrication to vehicle frame attitude, position of the center of mass in the fabrication frame, and the initial active vehicle mass.

Source Documentation: K. M. Parris, "SSFS Model Documentation Series - MASS24", Lockheed Electronics Company Technical Report No. LEC2032, February 1974.

Development Schedule: Operational

Category Name: Equations of Motion (Mass Properties)

Model Name: VARMAS Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: A space vehicle may be considered to be made of a number of subsystems. The mass properties of the total vehicle is then the sum of the mass properties of each subsystem. If the mass properties of each subsystem remains constant, as is the case with a coasting vehicle, the mass properties of the total vehicle remain constant. However, if the mass properties of the subsystems are changing, as is the case with a thrusting vehicle, the problem of determining the mass properties of the total vehicle becomes somewhat involved. The function of VARMAS is to compute the current mass properties of a changing mass vehicle.

The algorithm used by VARMAS in determining the mass properties of total vehicle can be divided into two separate operations. Step one is to determine the current mass properties of each subsystem as a function of the current mass properties of each subsystem as a function of the current weight of each subsystem. The second step uses the parallel axis theorem to sum the current mass properties of each subsystem in order to obtain the mass properties of the total system.

Major Inputs: Center of gravity, location of main engine gimbal point with respect to the vehicle center of gravity in the body system, inertia and inertia inverse matrices, number of RCS jets being simulated, total number of main engines being simulated, location of the RCS jets, current weight of the subsystems.

Major Outputs: Vehicle mass; location of the RCS jets; inertia matrix; estimated X, Y, Z body axes moments of inertia, location of main engine gimbal point, center of gravity, polynomial coefficients for up to nine subsystems.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume V, Q through S, JSC Internal Note 73-FM-110, (JSC-08065), Volume V), 20 July 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM)

Model Name: Equations of Motion - Rotational Simulation Name: SDL

Contact Person: P. Misra Org: TRW Tel: (713)333-3133

Description of Model: The rotational equations of motion maintain the vehicle attitude and attitude rate with respect to the inertial coordinate system given the initial attitude, vehicle inertia tensor, and the moments about the vehicle dynamic axes. The model consists of the summation of moments about the vehicle dynamics axes, the computation of angular acceleration and rates, and the derivation of the transformation between the vehicle dynamic and inertial coordinate systems. The formulation at this time is limited to Horizontal Flight Test to the extent of the moments accounted for and the options provided.

Major Inputs: Vehicle inertia matrix about the body dynamic axes; moments due to air breathing engine thrust, aerodynamics and landing dynamics in the body dynamic coordinate system; vehicle angular velocity vector in body dynamic coordinate system; quaternion.

Major Outputs: Vehicle angular acceleration vector and updated vehicle angular velocity vector in body dynamic coordinate system; updated quaternion; updated transformation from body dynamic to inertial coordinates.

Source Documentation: P. Misra, "Formulation of the Equations of Motion for the Software Development Laboratory", TRW Working Paper.

Development Schedule: Formulation 11/73.

Category Name: Equations of Motion (Rotational EOM)

Model Name: Rotational EOM and Attitude Control-Target Vehicle   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The simulated target vehicle rotational equations of motion maintain target vehicle or payload attitudes and attitude rates when not attached to the shuttle vehicle or manipulator. Inputs to the equations of motion are attitude control moments, thrust moments, aerodynamic moments, moments exerted by the docking mechanism, and vehicle mass center and inertia properties. Mass center and inertia properties are obtained from simulated target vehicle mass properties, and aerodynamic moments from simulated target vehicle aerodynamics. Attitude control moments may be obtained either from a specific target vehicle control system simulation program, or from a generalized approximate control logic and thruster simulation located within the rotational EOM program. Attitude commands will be obtained from simulated target vehicle guidance, the shuttle vehicle, or the instructor. Reset terms will be used to approximate the control phase plane logic. The generalized phase plane logic will be capable of simulating the nominal shuttle orbiter phase plane; the only approximations required being of the formula for the commanded rate changes in two of the seven firing regions.

Reaction control moments will be added to aerodynamic moments and thrust moments. Gravity gradient moments will be calculated and included. Euler's equations will be solved to obtain angular accelerations, which will be integrated to obtain angular rates. Rates will be integrated to obtain direction cosines in a fashion similar to that described for shuttle vehicle rotational EOM. The direction cosine matrix will transform from the body coordinate system to the target coordinate system.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Equations of Motion (Rotational EOM)

Model Name: Rotational EOM - Shuttle   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The simulated shuttle vehicle rotational equations of motion will maintain vehicle attitude and attitude rates given current vehicle position, center of mass, inertia tensor, and vehicle body forces and moments. Body forces and moments included in the calculation of vehicle rotational dynamics are: SRM thrust, MPS thrust (including venting), OMS thrust, RCS thrust, ABPS forces, gear/braking forces, drag chute forces, aerodynamic moments (including proximity and ground effects), payload manipulation moments, and docking moments.

Body moments resulting from body forces are calculated using the fixed position of the application point and the current position of the vehicle center of mass. The rotational effects of moving payload doors/space radiators will be calculated, and included within the rotational dynamics. Gravity gradient torques will be calculated and included in the aggregate body moments. Euler's equations will be solved to obtain angular accelerations, and will be integrated to obtain angular rates. Rates and attitude changes due to prelaunch constraints will be simulated prior to liftoff. The structural body fixed coordinate system will be used for the inertia tensor and angular velocity. The direction cosine matrix will be obtained from the angular velocity vector using self-normalizing difference equations. Euler angles with respect to local horizontal are then calculated for purposes of display using the direction cosines.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Equations of Motion (Rotational EOM)

Model Name: ROTDER   Simulation Name: SVDS

Contact Person: E. M. Fridge, III   Org: JSC   Tel: (713)483-3532

Description of Model: ROTDER computes body angular accelerations and quaternion rates for all vehicles being simulated. This model also computes translational accelerations in the earth centered inertial system if multi-loop and aerodynamics are being simulated. The first set of equations computes the angular accelerations which are then placed in the derivative array. Next, the quaternions rates are computed and placed in the derivative array. The next set of operations checks flags to determine if multi-loop and aerodynamics are being simulated. If multi-loop and aerodynamics are being simulated, translational accelerations are computed in the earth centered inertial system and placed in the derivative array. Otherwise program control is transferred from ROTDER.

Major Inputs: Body system to earth centered inertial transformation matrix, total force and total moment in the body system, normalized quaternions, quaternion rates, inertia and inertia inverse matrices, acceleration due to gravity, past value of gravitational acceleration, body rates, body acceleration, vehicle earth centered inertial rotational acceleration, vehicle mass.

Major Outputs: Derivative array, quaternion rates, vehicle earth centered inertial rotational acceleration.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume V, Q through S, JSC Internal Note 73-FM-110, (JSC-08065, Volume V), 20 July 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM/Translational EOM)

Model Name: AVEH1 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The active vehicle model, AVEH1, provides a six-degree-of-freedom simulation of a rigid body vehicle in three-dimensional inertial space. The vehicle dynamics use the forces and torques caused by firing jets of an attitude control propulsion system and by firing the orbit maneuver system (OMS) engines. The gravitational acceleration of the earth and the torque due to the gravity gradient are used in the AVEH1 vehicle dynamics. Computation of the vehicle's state vectors is performed relative to an earth centered inertial coordinate system. The rotational sequence used is roll, pitch, yaw.

Major Inputs: Position, linear velocity, and linear acceleration vectors of the active vehicle in the inertial frame; attitude of the active vehicle in the inertial frame; angular velocity and angular acceleration vectors of the vehicle in the vehicle body frame.

Major Outputs: Current active vehicle time; position, linear velocity, and linear acceleration vectors of the active vehicle in the inertial frame; angular velocity and angular acceleration vectors of the vehicle in the vehicle body frame; attitude, attitude rate, and attitude acceleration of the active vehicle in the inertial frame.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM/Translational EOM)

Model Name: AVEH2 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: AVEH2 defines the motions of the center of gravity of the vehicle. For convenience it is separated into three parts: translation equations, rotation equations, and Euler angles. These equations should be solved at least once each second during powered flight. In the vicinity of environmental discontinuities more frequent solution is required; for instance, the vehicle can fly completely through a wind gust at maximum dynamic pressure within 0.1 second. Other discontinuities include: staging, start of closed loop guidance, and engine or actuator failures. As a rule of thumb, the integration rate during transients can be 1/2 times rotational acceleration.

Major Inputs: Forces due to aerodynamics, thrust, RCS, engine deflection, and slosh; transformation matrices from body to inertial plumbline and from inertial polar-equatorial to inertial plumbline; vehicle mass; initial conditions; moments due to aerodynamics, main propulsion, reaction control system, engine accelerations, and slosh.

Major Outputs: Sums of forces in the X, Y, Z body axes directions; inertial plumbline position, velocity, and acceleration components; body rates; integral of body rates; aero and Euler angles.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM/Translational EOM)

Model Name: AVEH5 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: AVEH5 provides a six-degree-of-freedom simulation of the shuttle orbiter dynamics. The equations of motion are defined using aerodynamic, reaction control system, and air-breathing propulsion system inputs. AVEH5 integrates the contact forces equations of motion and stores the results in delta state vector arrays. A utility routine is called to integrate the gravitational (non-contact) forces and to add the delta state vectors calculated by AVEH5 to maintain the total state vector.

The current vehicle attitude information is contained in a vehicle-to-inertial transformation matrix, expressed in terms of the direction cosines and integrated forward by AVEH5.

AVEH5 may also operate in a wind tunnel mode, which by-passes calls to the atmosphere routine and simulates only rotational dynamics.

Major Inputs: Initial vehicle orientation with respect to local horizontal coordinate system, initial state vector, time between mass properties updates, vector from center of gravity to vehicle motion sensor location.

Major Outputs: Delta state vector arrays.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM/Translational EOM)

Model Name: AVEH6 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The active vehicle model, AVEH6, provides a 6-degree-of-freedom simulation of a rigid body in 3-dimensional inertial (orbital motion) and free (relative motion) space. AVEH6 can simulate the active vehicle for all SSFS orbital mission phases: coast, powered flight, docking and undocking, rendezvous, and stationkeeping. It is written primarily to be used in simulating a three-body problem (active and passive vehicles in inertial space) in which a state vector rectification scheme is used to insure accuracy for calculating the relative relationships between vehicles for very small state changes. The vehicle dynamics for orbital and relative motion use the forces and torques caused by firing jets of an attitude control propulsion system and by firing the orbit maneuver system (OMS) engines. When simulating orbital motion, the gravitational acceleration of the earth and the torque due to the gravity gradient are used in the vehicle dynamics. Computation of the vehicle's state vectors is performed relative to a nonrotating orthogonal coordinate system. The rotational sequence used in AVEH6 is roll, pitch, yaw. The user may request orbital motion and/or relative motion.

Major Inputs: Position, linear velocity, and linear acceleration vectors of the active vehicle; attitude; angular velocity and angular acceleration of the vehicle; position and attitude of the sensor.

Major Outputs: Updated position, linear velocity, and linear acceleration vectors, updated attitude; vehicle angular velocity and angular acceleration vectors; vehicle to sensor position vector and attitude; vehicle to docking probe position vector and attitude; probe to sensor position vector and attitude.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM/Translational EOM)

Model Name: AVEH12 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: AVEH12 is a three-degree-of-freedom model of the dynamics of the shuttle orbiter. It was written especially for use in the entry-to-touchdown simulation. The vehicle state can be computed in either the earth centered inertial or airport coordinate frame.

Major Inputs: Position and velocity vectors of the active vehicle, aerodynamic force, altitude, velocity with respect to atmosphere, mass, gravitational acceleration, commanded angle of attack, commanded roll about velocity vector, commanded pitch and roll angles, commanded pitch rate.

Major Outputs: Position and velocity vectors.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM/Translational EOM)

Model Name: AVEH13 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The active vehicle program, AVEH13, provides a three or six-degree-of-freedom simulation of a rigid body vehicle in free space. The vehicle dynamics use the forces and torques caused by firing jets of an attitude control propulsion system. Computation of the vehicle's state vectors is performed relative to an inertial coordinate system. The rotational sequence used is roll, pitch, yaw.

Major Inputs: Delta position vector of active vehicle, linear velocity and linear acceleration vectors of the active vehicle, attitude, angular velocity and angular acceleration vectors of the vehicle.

Major Outputs: Current active vehicle time; delta position, linear velocity, linear acceleration, angular velocity, and angular acceleration vectors of the vehicle; attitude; attitude rate and attitude acceleration.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM/Translational EOM)

Model Name: AVEH14 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The active vehicle program, AVEH14, provides a six-degree-of-freedom simulation of a rigid body vehicle in three-dimensional inertial space. The vehicle dynamics use the forces and torques caused by firing jets of an attitude control propulsion system. The gravitational acceleration of the earth and the torque due to the gravity gradient are used in the AVEH14 vehicle dynamics. Computation of the vehicle's state vectors is performed relative to a non-rotating orthogonal coordinate system with the origin at the center of the earth. The rotational sequence used is roll, pitch, yaw.

Major Inputs: Initial translational and rotational state vectors.

Major Outputs: Current active vehicle time; position, linear velocity, linear acceleration, angular velocity, and angular acceleration vectors; attitude; attitude rate; and attitude acceleration.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM/Translational EOM)

Model Name: AVEH15 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: AVEH15 is the vehicle program for the Launch-to-Orbit phase of the Integrated Shuttle vehicle VLS - 000061 configuration, known as the 2A configuration. It contains the six-degree-of-freedom equations of motion which define the motions of the center of gravity of the vehicle - translation, rotation, and Euler angles. It also calls the 3-degrees-of-freedom model for a second stage simulation while omitting 6-degrees-of-freedom calculations entirely.

Major Inputs: Geodetic latitude of launch site; rotational rate of the earth; earth flattening constant; equatorial radius of the earth; launch azimuth; thrust forces; RCS forces; engine deflection forces; slosh forces; gravitational acceleration components; moments due to aerodynamics, engine thrust, engine deflections, reaction control, and slosh.

Major Outputs: Initial state vector; sum of forces in X, Y, Z body axis directions; current inertial plumbline state vector; transformation matrices from body to inertial plumbline and inertial polar-equatorial to inertial plumbline coordinates; angular accelerations of the rigid body; angular accelerations and their integrals; Euler angles.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Rotational EOM/Translational EOM)

Model Name: PVEH1 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The passive vehicle model, PVEH1, provides a 6-degree-of-freedom simulation of a rigid body in a 3-dimensional inertial (orbital motion) or free (relative motion) space. PVEH1 can simulate the passive vehicle for the docking and undocking, rendezvous, and stationkeeping mission phases. When used in simulating a three-body problem (active and passive vehicles in inertial space), a state vector rectification scheme is used to insure accuracy for calculating the relative relationships between vehicles for very small state changes. The vehicle dynamics for orbital and relative motion use the forces and torques obtained by commanding the passive vehicle force sequencing logic. When simulating orbital motion, the gravitational acceleration of the earth and the torque due to the gravity gradient are used in the vehicle dynamics. Computation of the vehicle's state vectors is performed relative to a nonrotating orthogonal coordinate system. The rotational sequence used in PVEH1 is roll, pitch, and yaw.

Major Inputs: Relative to body frame position vector and attitude, target to body frame position section and attitude, angular velocity vector of the passive vehicle, angular velocity vector of the target.

Major Outputs: Position, linear velocity, linear acceleration vectors and attitude of the passive vehicle; angular velocity and angular acceleration vectors.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Translational EOM)

Model Name: Equations of Motion - Translational   Simulation Name: SDL

Contact Person: P. Misra   Org: TRW   Tel: (713)333-3133

Description of Model: The translational equations of motion maintain one vehicle translational state vector (position, velocity, time) with respect to inertial coordinates given body forces, vehicle mass gravitational acceleration, and vehicle orientation. The model consists of the computation of induced accelerations along the vehicle dynamic axes, the computation of vehicle acceleration in inertial space, and a suitable integration scheme to derive the vehicle state vectors. The formulation at this time is limited to Horizontal Flight Test to the extent of the forces accounted for and the options provided.

Major Inputs: Thrust vector, aerodynamic force vector, and landing dynamics forces in the body dynamic axes; vehicle mass; gravitational acceleration vector, vehicle position vector, and vehicle velocity vector in the inertial coordinate system; transformation matrix from body dynamic to inertial coordinates.

Major Outputs: Induced acceleration and induced velocity change along the body dynamic axes, updated vehicle position and velocity vectors in the inertial coordinate system.

Source Documentation: P. Misra, "Formulation of the Equations of Motion for the Software Development Laboratory", TRW Working Paper.

Development Schedule: Formulation 11/73.

Category Name: Equations of Motion (Translational EOM)

Model Name: TARGET   Simulation Name: SLS

Contact Person: Lance Drane   Org: C. S. Draper Lab.   Tel: (617)258-1178

Description of Model: The TARGET model maintains the state vector of a passive vehicle serving as a rendezvous target or navigation aid. The assumption is made that the vehicle is to be on a free-fall trajectory in the Earth's gravitational field with a capability of performing impulsive thrust maneuvers. It provides a point-mass model only; the attitude and rotational dynamics of the vehicle are not considered.

TARGET serves as a subroutine to other models which call it with requests to update the passive vehicle state vector to a specified time. The actual state vector integration is not performed within the TARGET model; rather it uses the precision state extrapolation mode of another subroutine to carry out the integration.

In addition to maintaining a free-fall trajectory, the TARGET model can incorporate instantaneous changes in vehicle position and velocity that represent the results of impulsive thrust maneuvers. Desired value of the radius vector change and the velocity vector change can be in either Reference Inertial or Local Vertical coordinates. If the latter coordinate system is chosen, TARGET transforms the local vertical radius and velocity vectors into Reference Inertial coordinates before incorporating them into the passive vehicle state vector.

Major Inputs: Time to which the passive vehicle state vector is to be updated.

Major Outputs: Passive vehicle position and velocity vectors and the time associated with them.

Source Documentation: Lawrence Berman, et al, "ESIM Model Book for the C. S. Draper Laboratory Statement Level Simulator", the Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Category Name: Equations of Motion (Translational EOM)

Model Name: Translational EOM and Propulsion - Target Vehicle   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The simulated target vehicle translational equations of motion maintain target vehicle or payload center of mass positions and velocities when not attached to the shuttle vehicle or manipulator. Inputs to the equations of motion are thrust force, aerodynamic forces, docking mechanism forces, and vehicle mass. Vehicle mass is obtained from simulated target vehicle mass properties and aerodynamic forces from simulated target vehicle aerodynamics. Thrust force may be obtained either from a specific target vehicle propulsion system simulation program or from a generalized approximate thrust simulation located within the translational EOM program. Thrust and associated mass flow rate will be obtained by reset constants when the engine(s) fire, and will be zero at other times. Engine firing times and durations will be obtained from the simulated generalized target vehicle guidance, with instructor override provided. Thrust force from the generalized engine will always act along the body longitudinal axis and directly through the vehicle mass center. Body forces will be summed, transformed to the target system, and divided by mass to obtain accelerations. Two integration loops will be provided which calculate gravity and integrate total acceleration to obtain velocity and position. The loop in use at a given time is determined on the basis of the current magnitude of body acceleration. For atmospheric target vehicles (SRM's, external tank), a check will be made for recontact. For this purpose, the shuttle fuselage will be approximated as a rectangular solid, and wings and vertical stabilizer by infinitely thin planar surfaces. The target vehicle will be approximated as a cylindrical solid.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Equations of Motion (Translational EOM)

Model Name: Translational EOM - Shuttle   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The simulated shuttle vehicle translational equations of motion will maintain vehicle translational state given body forces, vehicle mass, and vehicle orientation in terms of the direction cosine matrix relating body fixed coordinates to EOM reference coordinates. Body forces which will be summed to obtain total body force are: SRM thrust, MPS thrust (including venting), OMS thrust, RCS thrust, ABPS forces, gear/braking forces, drag chute forces, aerodynamic forces (including proximity and ground effects), payload manipulation forces, and docking forces.

The body forces are then transformed to the appropriate EOM reference coordinate system and divided by total vehicle mass to obtain vehicle body acceleration. During orbital flight, an Encke orbit determination scheme together with Runge-Kutta integration will update the vehicle state each 8 seconds. Vehicle state will be estimated in the intervening time by extrapolating gravity from past values calculated at 8 second intervals, and integrating directly to find velocity and position. Position and velocity deltas resulting from body accelerations will be included in the appropriate fashion into the Encke accumulated central body deviation state vector. During other than orbital flight, vehicle state will be maintained using a low-order predictor scheme (e.g., rectangular or Adams) and a Cowell orbit determination scheme. During prelaunch the state vector will be recalculated directly using the earth rotation rate, rather than integrated. State will be maintained in the target system during space flights, until final approach, at which time translation to the appropriate flat-earth fabrication coordinate system will be accomplished. A flat-earth fabrication coordinate system will be used for ferry flights. Gravitational accelerations will be calculated using the J_2, J_3, J_4, and J_{22} harmonics during regimes in which the target coordinate system is used. During regimes in which the fabrication coordinate system is used, a central body gravitational field with magnitude that of 30° latitude will be used.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Equations of Motion (Translational EOM)

Model Name: TDER1 Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: TDER1 computes translational derivatives for vehicles being simulated in three translational degrees-of-freedom only. These derivatives are also placed into the derivative array. The first set of operations in the subroutine places the velocities of the primary and secondary vehicles into the proper locations of the derivative array. Next the sensed accelerations for all vehicles and the inertial acceleration for the primary vehicle are computed and placed into the derivative array. The relative accelerations for the secondary vehicles are computed and placed into the derivative array. The final operations of TDER1 are to compute and store the quaternion rates and store accelerations for aerodynamic computations.

Major Inputs: Body system to ECI transformation matrix, total force in body system, normalized quaternions, quaternion rates, acceleration due to gravity, body rates, vehicle mass, sensed accelerations, vehicle inertial velocity, vehicle inertial acceleration, velocity and acceleration relative to primary vehicle.

Major Outputs: Derivative array, quaternion rates, vehicle inertial rotational acceleration, sensed accelerations, vehicle inertial acceleration, acceleration relative to primary vehicle.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume VI, T through Z, JSC Internal Note 73-FM-110, (JSC-08065, Volume VI), 20 April 1973.

Development Schedule: Operational

Category Name: Equations of Motion (Translational EOM)

Model Name: TRNDER Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: TRNDER is used when a vehicle is being simulated in six-degrees-of-freedom. It computes translational derivatives and places them into the derivative array. The following derivatives are evaluated in subroutine TRNDER: inertial velocity, vehicle relative velocity, sensed acceleration, total inertial acceleration, vehicle relative acceleration. In addition to the derivative evaluations, the inertial velocity is updated to the value obtained from updating translational equations.

Major Inputs: Body system to ECI transformation matrix, total force in body system, acceleration due to gravity, vehicle mass, sensed accelerations, vehicle inertial velocity and acceleration vectors, velocity and acceleration relative to the primary vehicle.

Major Outputs: Derivative array, vehicle rotational velocity and acceleration in earth centered inertial frame, sensed accelerations, acceleration relative to primary vehicle.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume VI, T through Z, JSC Internal Note 73-FM-110, (JSC-08065, Volume VI), 20 July 1973.

Development Schedule: Operational

5.6 Communications/Navigation/Tracking Devices

This section contains descriptive information about models of the communications, navigation, and tracking devices.

Category Name: Comm./Nav./Tracking Devices (Accelerometers)

Model Name: Normal/Lateral Accelerometers Simulation Name: SDL

Contact Person: T. J. Smith Org: TRW Tel: (713)333-3133

Description of Model: The normal/lateral accelerometer assemblies will be torqued pendulous accelerometers and for each axis the response to a specific force input is represented. The model formulation includes the logic to introduce fault and built-in test equipment stimulus outputs, but the computation of these outputs will have to be defined later when the hardware components are selected. Specific force is determined for each operating normal/lateral accelerometer assembly. If the built-in test equipment stimulus is present, then the stimulus output is computed on the basis of whether a fault is present or whether the accelerometer is operating normally. This stimulus output is later added to the nominal accelerometer response. If no built in test equipment is present, then the stimulus response is set to zero. The model checks for fault conditions and if present, then the fault output is computed and no further computations are required. The measured acceleration vector is then resolved into normal and lateral components scaled appropriately and the model then cycles to the next accelerometer assembly. If no fault is present, then the model checks to see if a unity response output is desired. If so, the measurement error and frequency response computations are bypassed and the output is set equal to the specific built-in test equipment force plus the specific force. If unity response is not desired, then the measurement error is computed and added to the specific force. This sum is then processed through the frequency response discrete transfer function. The resulting quantity is then added to the built-in test equipment response and resolved into normal and lateral components and scaled. The final output consists of an analog signal scaled in volts/ft/sec^2.

Major Inputs: Inertial acceleration at center of mass, vehicle angular velocity, vehicle angular acceleration, forward bay accelerometer location, aft bay accelerometer location, center of mass location, local gravity, displacement vector at forward and aft bay location for each bending mode, and generalized coordinate second time derivative for each bending mode.

Major Outputs: Normal/lateral acceleration.

Source Documentation: T. J. Smith, "SDL N/L Accelerometer Math Model", TRW Systems Group, IOC 73:7153.7-30, 5 December 1973.

Development Schedule: Functional Requirements 10/5/73, Formulation 12/7/73.

Category Name: Comm./Nav./Tracking Devices (Accelerometers)

Model Name: Body Accelerometers Subsystem Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The body-mounted accelerometers simulation will simulate the operation of each of the body-mounted accelerometers (excepting those accelerometers which comprise a part of primary Strapdown Inertial Measurement Units) which form a part of the Shuttle orbiter. The operation of each body-mounted accelerometer will be simulated independently and simultaneously in simulated real-time. It is assumed that, in the latest shuttle real-world GN&C configuration, these accelerometers serve only to provide load relief inputs in the vehicle control loop. Thus, even 3-sigma biases, scale factor errors, etc., will probably be sufficiently small as to have no noticeable effect on vehicle control and will not affect vehicle navigation. The component of body acceleration (from translational equations of motion) along the accelerometer axis will be calculated. If the device is located sufficiently far from the vehicle mass center for significant accelerations to result from vehicle angular rates or accelerations, these accelerations will also be included. Since the equations of motion will be updated each 50 milliseconds, a similar update rate is specified for the simulated accelerometers.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Comm./Nav./Tracking Devices (Accelerometers)

Model Name: VSINSD Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: This routine generates the simulated accelerometer output data for either a gimballed or a strapdown inertial sensor system. For the gimballed platform system, the routine simulates three orthogonally mounted single-axis integrating accelerometers. For the strapdown system, the routine simulates up to six body-mounted single-axis integrating accelerometers. The simulated accelerometer data includes instrument errors (bias, input axis misalinement, etc.), quantization, and the effect of attitude reference misalinement.

The equations used to simulate the accelerometer data are coded in two separate blocks within subroutine VSINSD -- one for the gimballed platform system and one for the strapdown system. The error model equations for the accelerometer output are essentially identical for both types of inertial systems. The primary difference in the simulation mechanization is that the platform accelerometers provide sensed acceleration in an inertially fixed coordinate frame whereas the body-mounted accelerometers provide an acceleration measurement in the rotating vehicle coordinate system.

Major Inputs: Accelerometer bias, accelerometer noise, least-squares weighting matrix, measured delta-velocity sent to the navigation filter, measured delta-velocity in vehicle coordinates, input axis unit vectors for the individual sensors, and misalinement matrix.

Major Outputs: Quantized accelerometer output delta-velocity vector and the measured delta-velocity sent to the navigation filter.

Source Documentation: L. S. Diamant, "Engineering and Programing Guide for the Navigation Analysis Program (NAP)", TRW Note 74-FMT-930, Revision 1, 4 January 1974.

Development Schedule: Operational

Category Name: Comm./Nav./Tracking Devices (Air Data Sensor)

Model Name: Air Data Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The shuttle orbiter air data computer sensors will be simulated throughout its useful altitude range. It is assumed that sensors as inputs to the on-board computer are required to allow the computer to compute parameters similar to that computed in a DC-10 type system. It is assumed that all control functions are performed by the on-board guidance computers. The results will be used for crew displays. If there are no other uses, a detailed dispersion model is probably unnecessary, especially for temperatures. Requirements for simulation of digital filters are also questionable in this case. It will be assumed herein that filtering effects are not significant. If required, filters will be adjusted, if necessary, to compensate for a change in iteration rate. Pressure inputs (static and total) will be found from the inputs from shuttle aerodynamics. Noise can be added but is probably unnecessary. Outputs which are a function of the pressure terms will then be calculated with the same equations as those used in the real-world device (pressure-altitude, baro-corrected altitude, altitude rate, Mach, computed air-speed). Temperature dependent parameters will be calculated directly from the temperature datum from shuttle aerodynamics, as well as previously calculated air data parameters, by methods analogous to the equations used by the real-world device for an input of sensed total air temperature. A 20 per second update rate is used herein for the simulated air data sensors. However, if the data is used only for the purposes cited herein, and with the assumed accuracy, it would appear that a 10 per second update rate may well be sufficient.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Comm./Nav./Tracking Devices (Barometric Altimeter)

Model Name: ALTIMB Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: This subroutine simulates the output of a barometric altimeter. The true altitude (calculated externally from the reference trajectory) is perturbed to approximate the effect of three major barometric altimeter error sources: (1) non-standard atmosphere, (2) pilot-static errors, and (3) instrument noise. An error due to uncertainty in the true density to altitude relationship due to incomplete knowledqe of sea level density, pressure/altitude algorithm (functional form), and spatial variations. The error model used in this routine corresponds to linearly increasing percentage error in altitude from zero to two per cent as altitude goes from zero to 100,000 feet. This error is taken as a one-sigma number and is randomized at the beginning of each cycle (simulated mission) and held constant (bias error) throughout. The pitot-static errors are due to the dynamics of the free-stream air flow interacting with surface anomalies near the sensing port. The equation used in this model is empirical and assumes software calibration. As with the non-standard atmospheric errors, it is treated as a bias value for each cycle. The error is a function of true airspeed which must be calculated. For the instrument noise error, a zero-mean, white noise empirical equation is used. The barometric altitude reading is, therefore, the sum of error sources plus the true altitude.

Major Inputs: True altitude, state vector, and the earth rotation rate.

Major Outputs: Total errored altitude.

Source Documentation: L. S. Diamant, "Engineering and Programming Guide for the Navigation Analysis Program (NAP)", TRW Note 74-FMT-930, Revision 1, 4 January 1974.

Development Schedule: Operational

Category Name: Comm./Nav./Tracking Devices (Inertial Measurement Unit)

Model Name: Inertial Measurement Unit (IMU) Simulation Name: SDL

Contact Person: J. R. Thibodeau Org: JSC Tel: (713)483-618

Description of Model: The proposed SKI-2076 IMU consists of an all attitude, four-gimbal, inertially stablized platform and associated equipment which supplies outputs proportional to vehicle attitude and incremental velocity changes. The inertial sensing frames of the accelerometers and gyroscopes are collinear and are defined by conventional orthogonal triads.

The IMU model mathematically simulates the operation of an IMU via a set of differential equations which relate platform attitude and output velocities to externally applied torquing rates, vehicle turning rates, and accelerations. The model provides outputs equivalent to an actual platform operating under the imposed acceleration and torquing environment consistent with the error sources simulated. The direction cosine method update is used for platform misalinement updates and Euler updates for synchro angles.

Degraded or "failed" performance is simulated by altering the error model coefficients consistent with the "failure mode" that is desired. For purposes of IMU error modeling, failures are those which corrupt the IMU performance and are indicated by degraded measurements in the IMU output. Other failures; e.g., loss of power or short or open circuits, are external to the IMU error modeling and are controlled by simulation of the built-in test equipment results.

Major Inputs: Attitude, attitude rates, sensed acceleration, slew rates, constants, misalinement matrix and gyro drift.

Major Outputs: X, Y, and Z gimbal angles for roll, pitch, and azimuth, X, Y, and Z velocity components and redundant gyro axis sensed rates.

Source Documentation: J. R. Thibodeau, "Inertial Measurement Unit Simulation Description for the Space Shuttle Software Development Laboratory", Mathematical Physics Branch, Mission Planning and Analysis Division, JSC Memo FM83 (73-365), 5 December 1973.

Development Schedule: Formulation 11/30/73

Category Name: Comm./Nav./Tracking Devices (Inertial Measurement Unit)

Model Name: IMU4GIM Simulation Name: SLS

Contact Person: Lance Drane Org: C. S. Draper Lab. Tel: (617)258-1178

Description of Model: This is a static model of a four-gimballed IMU, that is, it does not integration but works only in terms of transformation matrices and gimbal angles obtained at a given time. The user may select one IMU or a set of three IMU's, each of which may be treated independently. The platform alignment is set by commands of Euler angles or commands of the Reference-to-Stable-Member transformation. The platform alignment is modified by drifts during a simulation. The outputs of the program are the gimbal angles and their digitized equivalent and the sensed velocity change, and its digitized equivalent. In the extraction of gimbal angles, the outer-middle gimbal angle is assumed to be between + 90° and - 90°. This is equivalent to saying that gimbal angle never passes through ± 90°, but instead when it reaches 90°, the inner and outer gimbal angles rotate 180°. This occurrence is known as gimbal flip. The model provides two choices of orientation for the IMU in the spacecraft. The standard, or aircraft orientation has, with zero gimbal angles,

Inner Gimbal Axis along Vehicle Z (yaw) axis,
Outer Middle Gimbal Axis along Vehicle Y (pitch) axis, and
Outer Gimbal Axis along Vehicle X (roll) axis.

This orientation is suitable for transport aircraft, which do not make large pitch maneuvers. For the Shuttle, however, a local vertical attitude causes a 360° pitch every orbit. A different orientation has been proposed:

Inner Gimbal Axis along Vehicle Z (yaw) axis,
Outer Middle Gimbal Axis along Vehicle X (roll) axis, and
Outer Gimbal Axis along Vehicle -Y (pitch) axis.

Major Inputs: Time to which vèhicle has been updated, vehicle angular velocity, vehicle to Reference Inertial coordinates, acceleration of IMU and integral of the acceleration of IMU.

Major Outputs: Time to which IMU's have been updated, maximum time simulation will be allowed to go to without an IMU update, gimbal angles, digitized representation of gimbal angles, Euler rotation angles required to rotate platform from Reference Inertial to Stable Member coordinates, Reference-to-Stable Member transformation, and the sum of error-free change in velocity since the start of the simulation.

Source Documentation: Lawrence Berman, et al, "ESIM Model Book for the C. S. Draper Laboratory Statement Level Simulator", The Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Revision 1
31 May 1974

Category Name: Comm./Nav./Tracking Devices (Inertial Measurement Unit)

Model Name: Inertial Measurement Unit (IMU) Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The IMU simulation will simulate the operation of each of the on-board IMU's. The operation of each of the redundant devices will be simulated independently and simultaneously. It is not currently clear whether the shuttle will use gimballed or strapdown IMU's. A gimballed IMU used on the Shuttle vehicle would be a four-gimballed, "all-attitude" device, posessing one redundant gimbal to protect against loss of inertial reference during "gimbal lock". It is assumed that an IMU thermal control subsystem exists, in order to minimize temperature related biases to achieve acceptable accuracy. If it exists, it must be functionally simulated. Heat added to the IMU by significant sources will be estimated as a function of electrical power drawn by those sources. Effect of surrounding gas temperature will be included. Heaters, if they exist, will also be simulated in this fashion. All IMU operational modes will be simulated, including modes in which the platform stabilization loops are opened. When in cage mode, the platform angles will be returned to null and maintained there. Gimball torqueing commands (if the capability exists) and power failure effects will be simulated, and the resulting platform orientation with respect to inertial space maintained. When the stabilization loops are closed (normal operation), gyro drifts will be calculated and propagated through the simulation. Drift sources will include free bias and random drift, acceleration sensitive (mass unbalance) drift, and acceleration squared sensitive (anisoelastic) drift. Acceleration components in gyro input, spin, and output axes will be obtained from the accelerometer simulation in platform axes, and be conditioned by a matrix representing gyro misalignments. Drift properties will be supplied using random numbers, and will exhibit proper standard deviation and autocorrelation when appropriate.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 April 1973.

Development Schedule:

Category Name: Comm./Nav./Tracking Devices (Inertial Measurement Unit)

Model Name: IMU3 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: IMU3 models a three-gimbal Inertial Measurement Unit. It is a simplified version of IMU2 for three dimensional simulations and uses rectangular integration of both the gimbal drift rates and sensed acceleration for the change in velocity. IMU3 measures the true platform acceleration vector as well as the change in acceleration due to accelerometer errors and misalignments. The change in velocities are filed in the counters for the flight software. In IMU3, the time derivatives of the misalignment angles are set equivalent to the total gyro drift vector.

Major Inputs: Contact acceleration vector in earth-centered inertial coordinates, vectors of spin and input axis - sensitive gyro drift coefficients, vector of coupled input and cross axis g^2-sensitive gyro drift, vector of constant gyro bias drifts, vector of constant accelerometer bias drifts, vector of gyro alignments, vector of accelerometer alignment, and vector of initial platform misalignment angles.

Major Outputs: Sensed acceleration vector along input axis of accelerometers in true inertial platform system, acceleration error vector due to accelerometer errors, vector of platform misalignment angles, IMU sensed acceleration vector, delta velocity over an update, and the time derivative of the misalignment angles due to the gyro drift.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Comm/Nav/Tracking Devices (Inertial Measurement Unit)

Model Name: IMU6 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: IMU6 performs the duties of filing the translational and rotational counter increments for the flight software which make use of the communicator. The counter increments are defined simply by differencing current and previous values of the translational velocities and rotational angles as supplied by the active vehicle model. There is no capability for aligning the stable member or navigation base in an orientation different from the inertial frame. The center of mass is assumed to remain constant throughout the simulations.

Major Inputs: Inertial acceleration of the vehicle; the Vehicle to Inertial transformation matrix; Fabrication to Vehicle transformation matrix; position of the vehicle center of mass in the Fabrication frame position of the stable member in the Fabrication frame; translational expire delta time; rotational expire delta time.

Major Outputs: Counter increments and their associated rates, accelerations, expire and original, and dynamic flags.

Source Documentation: N. B. Bald, "SSFS Model Documentation Series - IMU6", Lockheed Electronics Company Technical Report No. LEC1363, November 1973.

Development Schedule: Operational

Category Name: Comm./Nav./Tracking Devices (Inertial Measurement Unit)

Model Name: PLTFRM   Simulation Name: SVDS

Contact Person: E. M. Fridge, III   Org: JSC   Tel: (713)483-3532

Description of Model: This routine simulates the inertial attitude reference for either a gimballed or a strapdown inertial sensor system. For the gimballed platform system, the routine simulates three orthogonally mounted single-axis rate integrating gyros. The true platform orientation, misalined from the reference orientation due to gyro drift, is maintained within this routine and used in subroutine VSINSD to generate the accelerometer measurements.

For the strapdown system, the routine simulates up to six body mounted rate gyros. An estimated vehicle attitude matrix is computed from the simulated rate gyro data. This attitude matrix is then used in subroutine VSINSD to preprocess the strapdown accelerometer measurements.

Subroutine PLTFRM is divided into three main blocks of code:

1. Realinement logic and equations
2. Gimballed platform simulation
3. Strapdown attitude reference simulation

The realinement section is used to reinitialize the attitude reference errors when simulating an inflight alinement. The alinement times are specified by the user through the input. At each simulated alinement, the platform misalinement (gimballed system) or vehicle attitude error (strapdown system) is reset with random errors generated that defines the one sigma uncertainty (per axis) for the alinement process.

Major Inputs: Bias drift, modeled as an exponentially correlated random process, least-squares weighting matrix; vector of g-sensitive drift coefficients for accelerations along the gyro input, spin, and output axes; g^2-sensitive drift coefficient input/spin axis acceleration product; vector of scale factor and input axis misalinements; alinement one sigma uncertainties; input axis unit vector; random noise; initial alinement error; and the three Euler Angles that define the orientation of the vehicle relative to an imaginary platform system.

Major Outputs: Transformation from true to estimated vehicle coordinates, and the estimate of vehicle attitude that would be obtained by software processing of rate gyro data.

Source Documentation: L. S. Diamant, "Engineering and Programming Guide for the Navigation Analysis Program (NAP)", TRW Note 74-FMT-930, Revision 1, 4 January 1974.

Development Schedule: Operational

Category Name: Comm./Nav./Tracking Devices (Inertial Measurement Unit)

Model Name: TVPLT   Simulation Name: SVDS

Contact Person: E. M. Fridge, III   Org: JSC   Tel: (713)483-3532

Description of Model: This routine computes an exponentially-correlated, stationary, first-order, Gauss-Markov process for each of two error sources associated with inertial reference units. The error sources are gyro bias and accelerometer bias.

Major Inputs: Bias for each parameter at each point for both the gyro and accelerometer, standard deviation of the process for each parameter for the gyro and accelerometer, and time constant for each parameter for the gyro and accelerometer.

Major Outputs: Bias output for the gyro and accelerometer.

Source Documentation: L. S. Diamant, "Engineering and Programming Guide for the Navigation Analysis Program (NAP)", TRW Note 74-FMT-930, Revision 1, 4 January 1974.

Development Schedule: Operational

Category Name: Comm./Nav./Tracking Devices (Microwave Landing System)

Model Name: LNDA2 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: The instrument-landing system (ILS - but more properly, instrument low-approach system) is designed to provide approach path guidance for exact alignment and descent of an aircraft on final approach to a runway and consists of two directional transmitting systems. The directional transmitters provide a glide-slope beam and a localizer beam. The glide-slope provides vertical steering signals for landing in one direction only (the front-course) on the runway. The localizer provides lateral steering signals for front-course and back-course approaches to the runway. There are steep (high) and shallow (low) glide-slope beams. The glide-slope and localizer antennas establish radiation patterns in space from which a signal is derived proportional to the displacement from the glide path or runway center line, respectively. These signals drive the cross-pointer needle or flight director in the aircraft. Associated with these radiation patterns are linear and saturated regions in which the cross-pointer needle is proportional to the signal or hard against the stops, respectively. Also, associated with the glide-slopes are false nulls or harmonics of the reference null. In LNDA2, only the harmonics of the low glide-slope are considered. Random noise and bias can be included in the glide-slope and localizer signals for various range gates as the vehicle makes its approach to the runway. LNDA2 assumes the vehicle's ILS equipment includes reverse sensing capability when making a back-course approach.

Major Inputs: Vehicle position vector in airport coordinates, positions of localized, high and low glide slope antennas, range and altitude limits on the high and low glide slope, localizer coverage volume, high and low glide slope volumes, and the harmonics associated with the low glide slope.

Major Outputs: Sensed and perfect localizer signal, indicator for acquisition of localizer signal, high and low glide slope signal, and sensed and perfect high and low glide slope signals.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Category Name: Comm./Nav./Tracking Devices (Radar Altimeter)

Model Name: Navaids Radar Altimeter Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: A typical Federal Aviation Administration radar altimeter is assumed. This subsystem will provide warning cues as well as an accurate measurement of vehicle altitude above local terrain for display and input purposes for other systems. The antennas are located sufficiently close to the vehicles center of gravity that no apparent change in indicated altitude occurs with vehicle attitude change. Gross attitude change can, however, cause a loss of return.

A local terrain software model will be constructed and data specified at the intersection of azimuth radials and range circles centered at the runway. Linear interpolation between data points will provide a smooth change in terrain altitude with the values in the tables representing exact terrain altitude at the specific points. Simulation requirements indicate a requirement for maximum accuracy at touchdown and near the normal approach azimuth. Lower accuracy can be tolerated at long range from the landing sits and at large relative bearings to the runway leadings.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Comm./Nav./Tracking Devices (Radar Altimeter)

Model Name: ALTIMR Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: This routine simulates the output of a radar (radio) altimeter. The true altitude and altitude rate (calculated externally from the reference trajectory) are perturbed to approximate the effects of a fixed bias and random noise. The routine presently computes a fixed bias for the altitude and altitude rate at the beginning of each cycle using input standard deviations. At each additional time, a noise is added in a similar manner. The total error at a specific time is then computed and added to the true height.

Major Inputs: True height, bias and noise deviations, and true altitude rate.

Major Outputs: Altimeter height and altitude rate readings.

Source Documentation: L. S. Diamant, "Engineering and Programming Guide for the Navigation Analysis Program (NAP)", TRW Note 74-FMT-930, Revision 1, 4 January 1974.

Development Schedule: Operational

Category Name: Comm./Nav./Tracking Devices (Rate Gyros)

Model Name: Rate Gyro

Simulation Name: SDL

Contact Person: T. J. Smith

Org: TRW

Tel: (713)333-3133

Description of Model: A total of nine rate gyro assemblies are used to simulate the Flight Control System. The rate gyro assemblies are spring restrained constant damped gyros. The math model formulation includes the logic to introduce fault and built-in test equipment stimulus outputs, but the computations of these outputs will have to be defined later after hardware failure modes and built-in test equipment stimulus have been defined.

The model logic is currently designed to check to see if the unit is operating. If it is not operating, the output is set to zero. The rate input is determined for each operating gyro assembly by summing rigid body and bending body rates. If a built-in test equipment stimulus is present, then the stimulus output is computed on the basis of whether a fault is present or whether the accelerometer is operating normally. This stimulus output is later added to the nominal accelerometer response. If no built-in test equipment stimulus is present, then the built-in test equipment response is set to zero.

The model checks for fault conditions. If a fault exists, the fault output is computed and no further computations are performed. The measured rate vector is scaled appropriately and the model cycles to the next gyro assembly. If no fault is present, the model checks to see if a unity response output is desired. If so, the measurement error and frequency response computations are bypassed and the output is set equal to the input rate plus the built-in test equipment response.

Major Inputs: Gyro on status flag; model rotation vector at each of the three gyro assemblies; the generalized coordinate time derivative for the bending made under consideration; a vector of scale factor error and input axis alignment; the rate gyro scale factor nonlinearity for each gyro assembly; and Gaussian distributions with variences.

Major Outputs: Bending body rate, measurement error, and frequency response of each rate gyro within a gyro assembly.

Source Documentation: T. J. Smith, "SDL Rate Gyro Math Model", TRW Systems Group, Interoffice Correspondence Memo, 10 December 1973.

Development Schedule: Requirements 10/12/73, Formulation 12/14/73

Revision 1
31 May 1974

Category Name: Comm./Nav./Tracking Devices (Rate Gyros)

Model Name: Rate Sensors Subsystem

Simulation Name: SMS

Contact Person: C. C. Olasky

Org: JSC

Tel: (713)483-2481

Description of Model: The rate sensor simulation will simulate the operation of each of the vehicle rate gyros (excepting gyros which comprise a part of the primary Inertial Measurement Units) which form a part of the shuttle orbiter. Each rate sensor's operation will be simulated independently and simultaneously in simulated real-time. It is assumed that these rate sensors serve only to provide rate feedback in the vehicle control loop. Thus, even 3-sigma drifts, scale factor errors, etc., are unlikely to have any significant effect on vehicle dynamics, since resulting false rates will be small compared with vehicle rates, and will not propagate in navigation. Since the equations of motion are updated once each 50 milliseconds, a similar update rate is specified for the body-mounted rate gyros.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Comm./Nav./Tracking Devices (Rate Gyros)

Model Name: RNDPLT

Simulation Name: SVDS

Contact Person: E. M. Fridge, III   Org: JSC   Tel: (713)483-3532

Description of Model: This routine generates the random samples for the uncorrelated noise in the gyro and accelerometer error models. The one sigma values for the uncorrelated noise modeled in the gyro and accelerometer outputs are defined by input parameters. The one sigma values are multiplied by samples from the random number generator to generate the simulated noise in the gyro and accelerometer error model.

Major Inputs: One sigma values for the uncorrelated noise modeled in the gyro and accelerometer.

Major Outputs: Simulated noise in the outputs for each gyro and accelerometer.

Source Documentation: L. S. Diamant, "Engineering and Programming Guide for the Navigation Analysis Program (NAP)", TRW Note 74-FMT-930, Revision 1, 4 January 1974.

Development Schedule: Operational

Category Name: Comm/Nav/Tracking Devices (Rendezvous Radar/Sensor)

Model Name: RRADAR Simulation Name: SLS

Contact Person: Lance Drane Org: C. S. Draper Lab. Tel: (617)258-1178

Description of Model: The Rendezvous Radar sights on a target and computes the range to the target, the range rate, and the azimuth and elevation angles from the sensor bore sight to the target line-of-sight. It is assumed to be mounted at the vehicle center of gravity, with its axes aligned with the Vehicle axes. No error sources are included within this model.

Major Inputs: Vehicle position, target position, transformation matrix from Vehicle to Reference Inertial coordinate systems, time associated with the targets position and vehicle and targets velocity.

Major Outputs: Range, range rate, azimuth and elevation.

Source Documentation: Lawrence Berman, et al, "ESIM Model Book for the C. S. Draper Laboratory Statement Level Simulator", The Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Category Name: Comm./Nav./Tracking Devices (Rendezvous Radar/Sensor)

Model Name: Rendezvous Radar Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The rendezvous radar subsystem will simulate the operation of each of the shuttle vehicle on-board rendezvous radar subsystems in multi-modes. Passive free-flight payloads are detected by "skin" tracking. The target may be enhanced by transponder. The two major orbiter assemblies are the on-board avionics and the deployable assembly. The deployable assembly is stowed inside the payload bay area with jettison capability. The radar is pulse modulation with a maximum range of 32 nautical miles. Two modes will be simulated - search and auto tracking after lock-on. Angular position will be obtained from computation of the antenna angles and angular rate by simulation of rate gyros.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Comm./Nav./Tracking Devices (Rendezvous Radar/Sensor)

Model Name: RSEN2 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: RSEN2 calculates the relative translation and rotational relationships between the active vehicle (Orbiter) and the passive vehicle (Target) for both orbital and/or relative motion simulations. Additionally, RSEN2 calculates range and range rate of the passive vehicle and the shaft and trunnion angles based on the relative line-of-sight vector. For orbital motion, RSEN2 uses the rectified values of the vehicle's state vectors to insure accuracy in calculating the relative motion relationships between the active and passive vehicles. The rotational sequence used in RSEN2 is roll, pitch, yaw.

Major Inputs: Translational and rotational state vectors from the active and passive vehicles for relative and orbital motion.

Major Outputs: Updated translational and rotational state vector from the active and passive vehicles, range of the passive vehicle, range rate of the passive vehicle, and shaft and trunnion angle.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Comm./Nav./Tracking Devices (Star Sensor/Tracker)

Model Name: STARTRAK   Simulation Name: SLS

Contact Person: Lance Drane   Org: C. S. Draper Lab. Tel:(617)258-1178

Description of Model: The Star Tracker sights on a rendezvous target and computes the azimuth and elevation angles from the sensor boresight to the target line of sight. The Star Tracker first calculates the position of the sensor in Reference Inertial coordinates. It then calculates the line-of-sight vector from the sensor to the target, converting to sensor coordinates.

The Star Tracker has a square field of view centered on the sensor X-axis that defines the maximum and minimum values of the azimuth and elevation angles. There are no models of sensor errors for this simulation.

Major Inputs: Vehicle center of gravity position, vehicle position, target position, transformation matrix from Vehicle to Inertial coordinates, and time associated with the target position.

Major Outputs: Time of the last read of any sensor, the time of the last read of each sensor and azimuth and elevation for each sensor.

Source Documentation: Lawrence Berman, et al, "ESIM Model Book for the C. S. Draper Laboratory Statement Level Simulator", The Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Category Name: Comm./Nav./Tracking Devices (Star Sensor/Tracker)

Model Name: Star Tracker Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The Star Tracker simulation will simulate the operation of each of the shuttle vehicle star trackers. The operation of each of the redundant devices will be simulated independently and simultaneously. It is assumed that the star tracker possesses two basic operational modes, search and track. In search mode, the brightest light source within a small portion of the device field of view centered about a point commanded by the on-board computer will be acquired. If no light source of sufficient magnitude exists in that region, the entire field of view will be scanned and the brightest object acquired. Upon acquisition, the star tracker switches to tracking mode, and tracks the acquired light source, within a very small portion of the field of view. It is also assumed that the computer can place the device in an inactive mode. When a tracker is active, the transformation between tracker boresight coordinates and the inertial reference coordinate system is calculated. Positions of earth, sun, and moon are found in the sensor coordinate system. It is assumed that the presence of the sun, illuminated moon, or illuminated earth in or near the tracker search or track field of view will cause interference. It is further assumed the tracker can detect this interference and will send an error discrete when it occurs. When the entire field of view is occulted by a darkened earth, it is assumed that the tracker will revert to and remain in search mode. It should be noted that the proposed on-board computer software has logic which will prevent any of these error conditions from occurring except in extreme inertial measurement unit or computer malfunction cases. Thus, precise simulation thereof should not be necessary. In search mode, a table of star positions and magnitudes will be used to determine which stars are within the field of view. Planets in the field of view will be determined using ephemeris data.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Comm./Nav./Tracking Devices (Tactical Air Navigation)

Model Name: Navaids TACAN Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-248

Description of Model: Station identification for the TACAN system is provided by receipt of the transmitted 1350 hertz station identification call letters. The TACAN operates by flight interrogation pulsing of the ground based beacon system. There is a search mode in which the system is pulsed at a relative high frequency. Once lock-on is achieved, the system provides bearing and distance information for use by the GN&C computer and for various displays including the Attitude Direction Indicator, Horizontal Situation Indicator, and/or cathode ray tube displays.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Comm./Nav./Tracking Devices (VFH Communications)

Model Name: VHF Communication Subsystem Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-

Description of Model: The simulation of the VHF duplex and simplex voice and da communication link will be modeled by calculating the signal strength of the received signal from the ground stations and the transmitted power level out of the vehicle antennas to the ground station. To determine the signal strength, i is necessary to also determine if a station is occulted by the earth and if it i operating on the correct frequency.

The number of possible stations that have line-of-sight coverage is excessive wh it is considered that the area of coverage may be as large as the United States. With such coverage, it is necessary to limit the number of ground stations loade in working core of the computer. The process of identifying those stations havi line-of-sight, on correct frequency, receiver-transmitter operation, receiver-transmitter signal strength, and signal-to-noise ratio is computed for those twe five stations which will reside in core. The elevation angle is computed for ea station and those stations having a positive elevation are considered to be in l of-sight. The attenuation of the signal paths between the two positions will th be calculated based on antenna pattern orientation and vehicle separation distan The relative bearing angles will be calculated and applied to the equations representing the antenna pattern.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

5.7 Onboard Software Models

This section contains descriptive information about models of the onboard software.

Category Name: Onboard Software (Aerosurface Control System)

Model Name: Aerodynamics Control Surface   Simulation Name: SDL

Contact Person: T. J. Walsh   Org: TRW   Tel: (713)333-3133

Description of Model: The Aerodynamics Control Surface Model characterizes the operation of both the aerosurface driver (actuators) and the aerodynamic control surfaces. The model described is suitable for simulating the response and effects of the aerodynamic control surfaces during the ascent, entry, terminal area energy management, and landing phases of a Vertical Flight Test as well as during all phases of the Horizontal Flight Test.

There are seven actuators controlling the position and motion of the aerodynamic control surfaces. Each is identified by the surface it controls. The surfaces controlled are left and right outboard and inboard elevons, left and right rudder, and body flap. The first six above are driven hydraulically. The elevons are moved by a valve controlled piston. For the speed brake and rudder, a valve controlled hydraulic motor is used. The body flap actuator is electromechanical. The input to the actuator is a command voltage. It is assumed that the scheme used to integrate the differential equations is an explicit one. It is also assumed that the aerodynamic parameters model and the algebraic equations are coupled.

Major Inputs: Left and right elevon servo command; rudder servo command; speed brake servo command; aerodynamic hinge moments for each surface; discretes from the flight computer; and discretes input from the manual controls model.

Major Outputs: Aerosurface pressures, positions, rates, and deflections.

Source Documentation: T. J. Walsh, "Preliminary Aerodynamic Control Surface Model", TRW Systems Group, Memo No. 2533.5-74-21, 20 February 1974.

Development Schedule: Requirements 9/28/74, Formulation 2/20/74.

Category Name: Onboard Software Models (Aerosurface Control System)

Model Name: Aerosurface Control Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The aerosurface control subsystem for each elevon, the vertical stabilizer (rudder/speed brake) and body flap will be simulated. Each of the aerosurface control subsystems will be simulated simultaneously and independently when in operation. Inputs to the aerosurface control system include aerosurface setting commands through each of the input channels for elevon, rudder, and speed brake, electrical power available, hydraulic power factors for each hydraulic system, crew station switch and breaker configuration, and instructor inputs. Outputs from the aerosurface control system will include elevon and differential elevon settings, rudder setting, speed brake setting, electrical power load, hydraulic flows, and status outputs. Aerosurface control will exhibit considerable redundancy, with multiple command signal input channels for the primary control servos, multiple hydraulic pressure sources for each surface hydraulic actuator, and multiple actuators for each surface. Failed channels are disconnected in the case of single channel failure. Operation of the failure detection and redundancy management provisions will be simulated and will respond properly to failures. Failure discretes, hydraulic pressure monitor outputs, etc., generated by the aerosurface control subsystem, will be simulated and output from the simulation. The summing of rudder and speed brake commands to obtain commands for the split vertical stabilizer surface will be simulated to obtain the appropriate surface hydraulic actuator inputs. Actuator dynamics for each surface will be simulated as a function of input commands, failure detection status, hydraulic power factors in each hydraulic system, and malfunctions. Other effects, such as hinge-moments, will be simulated if significant. Rate and position limits of the aerosurface, as well as other limits internal to the subsystem, will be simulated.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Onboard Software Models (Aerosurface Control System)

Model Name: ACS8 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: ACS8 provides a model of the aerodynamic control system of the NR89B orbiter. It simulates the response of the orbiter's aerodynamic control surfaces to flight software commands. It contains models of the elevons, rudder, rudder flare, body flap, and landing gear. The user may select the level of fidelity desired for the servo models by choosing either instantaneous response or first order response models.

Major Inputs: Commanded deflections of the aileron, rudder, elevator, right elevon, and left elevon; commanded landing gear position; commanded rudder flare angle; servo gain for elevon, rudder, and rudder flare; elevon maximum and minimum position limits; elevon rate limit; rudder rate limit; rudder maximum and minimum position limits; rudder flare rate limit; rudder flare maximum and minimum angles; body flap rate limit.

Major Outputs: Position of the elevator, ailerons, rudder, rudder flare, body flap, and landing gear.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Aerosurface Control System)

Model Name: ACS9 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: ACS9 provides a simplified model of the NR-89B orbiter aerodynamic control system. It is intended for use in three-degree-of-freedom simulations. Models are included for trim elevator, body flap, rudder flare (speed brake), and landing gear. ACS9 provides an elevator deflection corresponding to vehicle trim. The body flap model agrees with the schedule in the NAR Aerodynamic Design Data book with the addition of a rate limit of one degree per second. The rudder flare moves at a constant rate of 7.2 degrees per second to the commanded setting within the range 0 - 100.8 degrees. The landing gear is instantaneously set to the commanded position.

Major Inputs: Commanded landing gear position, commanded rudder flare, rudder flare rate limit, maximum and minimum rudder flare angles, body flap rate limit.

Major Outputs: Trim elevator setting, body flap deflection, rudder flare angle, landing gear position.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Aerosurface Control System)

Model Name: ACS10 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: ACS10 provides a model of the aerodynamic control system for the NR000147B orbiter, simulating the response of the vehicle's aerodynamic control surfaces to flight software commands. It contains models of the elevors, rudder, speed brake, body flap, and landing gear. The user may select the level of fidelity desired for the servo models by choosing either instantaneous response or first order response models.

Major Inputs: Mach number; X-component of position vector of vehicle center of gravity; left and right elevon hinge moments; hinge moment due to speed brake deflection; hinge moment due to rudder deflection and sideslip angle; elevon, rudder, and speed brake servo gains; elevon, rudder, body flap, and speed brake rate limits; maximum and minimum position limits for elevon and rudder; maximum and minimum angles for speed brake; commanded aileron, rudder, elevator, right elevon, and left elevon deflections; commanded landing gear position; commanded speed brake angle.

Major Outputs: Elevator, aileron, rudder, speed brake, and body flap deflections.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Aerosurface Control System)

Model Name: ACS11 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: ACS11 provides a simplified model of the aerodynamic control system for the RI000147B orbiter. It is designed for use in three-degree-of-freedom simulations of the entry-to-landing mission phase. Models are included for trim elevator, speed brake, landing gear, and body flap. ACS11 provides an elevator deflection corresponding to vehicle trim. Speed brake deflection is modeled with an instantaneous response to commands. The speed brake rate is limited to ±7.2 degrees per second and the deflection is limited to the range of 0 - 87.2 degrees. Landing gear deployment/retraction is linear with time. The time required for full up or full down is 10 seconds. Body flap deflection is a function of Mach number, with separate curves for forward and aft center of gravity locations.

Major Inputs: Mach number; X-component of position vector of vehicle center of gravity; speed brake deflection; elevator minimum and maximum position limits; speed brake minimum and maximum position limits; rate limits for body flap and speed brake; commanded landing gear position; commanded speed brake deflection.

Major Outputs: Elevator, speed brake, and body flap deflections; landing gear position.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Aerosurface Control System)

Model Name: ACS12 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel:(713) 333-4875

Description of Model: ACS12 provides a model of the aerodynamic control system for the RI000140C Orbiter, simulating the response of the vehicle's aerodynamic control surfaces to flight software commands. It contains models of the elevons, rudder, speed brake, body flap, and landing gear. ACS12 permits the user to select the level of fidelity he desires for the servo models. The logic for elevons, rudder, and speed brake is exactly analogous. An instantaneous position change is assumed for a low fidelity model of a control surface whereas the high fidelity model computes the driving rate. The fourth order Runga-Kutta integration method is used by this model.

Major Inputs: Mach number; left and right elevon hinge moments; X-component of position vector of vehicle's center of gravity; hinge moment due to the speed brake deflection, rudder deflection, and sideslip angle.

Major Outputs: Elevator deflection, aileron deflection, rudder deflection, speed brake deflection, landing gear mode, and body flap deflection.

Source Documentation: K. M. Parris, "SSFS Model Documentation Series - ACS12", Lockheed Electronics Company Technical Report No. LEC1890, February 1974.

Development Schedule: Operational

Category Name: Onboard Software Models (Aerosurface Control System)

Model Name: ACS13 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713) 333-4875

Description of Model: ACS13 provides a simplified model of the aerodynamic control system for the RI000140C Orbiter. It is designed for use in three-degree-of-freedom simulations of the Entry-to-Landing Mission Phase. Models are included for trim elevator, speed brake, landing gear, and body flaps.

Although rotational dynamics are ignored in three-degree-of-freedom simulations, it is desirable to have realistic lift/drag characteristics. For this reason ACS13 provides an elevator deflection corresponding to vehicle trim (i.e., zero pitch moment). Speed brake deflection is modeled with an instantaneous response to commands from the flight computer modules. Landing gear deployment/retraction is considered linear with time or a 10 second interval.

Major Inputs: Mach number and X-component of position vector of vehicle's center of gravity.

Major Outputs: Elevator, speed brake, and body flap deflection along with landing gear mode.

Source Documentation: K. M. Parris, "SSFS Model Documentation Series - ACS13", Lockheed Electronics Company Technical Report No. LEC 1891, February 1974.

Development Schedule: Operational

Revision 1
31 May 1974

Category Name: Onboard Software Models (Aerosurface Control System)

Model Name: ACS14 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel:(713) 333-4875

Description of Model: ACS14 provides a model of the aerodynamic control system for the RI000140C Orbiter, simulating the response of the vehicle's aerodynamic control surfaces to flight software commands. It contains models of the elevons, rudder, speed brake, body flap, and landing gear. ACS14 differs from ACS12 on the body flap command logic and the separate speed brake rate limits for opening and closing.

Major Inputs: Mach number, left and right elevon hinge moments, X-component of position vector of vehicle center of gravity, and hinge moments due to speed brake deflections, rudder deflection, and sideslip angle.

Major Outputs: Elevator, aileron, rudder, speed brake, and body flap deflections and landing gear mode.

Source Documentation: L. S. Baumel, "SSFS Model Documentation Series - ACS14", Lockheed Electronics Company Technical Report No. LEC3281, April 1974.

Development Schedule: Operational

Category Name: Onboard Software Models (Aerosurface Control System)

Model Name: DELVT2 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: DELVT2 calculates by interpolation trim elevator as a function of angle of attack and Mach number. This mode is used in three-degree-of-freedom entry-to-touchdown simulations to make the three-degree-of-freedom vehicle fly a lift over drag ratio that is closer to that of a trimmed six-degree-of-freedom vehicle. The tables of trim elevator values as a function of mach number and angle of attack are for the 040A vehicle used in model AERO15.

Major Inputs: Mach number, angle of attack.

Major Outputs: Trim elevator value.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Onboard Software System (Aerosurface Control System)

Model Name: STEER   Simulation Name: SVDS

Contact Person: E. M. Fridge, III   Org: JSC   Tel: (713)483-3532

Description of Model: Subroutine STEER reflects the six-degrees-of-freedom logic of the open loop steering model. Its function is to maintain a predefined attitude by performing a table look-up on Euler angles relating the initial matrix to the desired body to earth centered inertial matrix, a table look-up on gimbal angles or a table lock-up on aerodynamic attitude angles and then computing the desired gimbal angles that are issued to the digital autopilot (DAP) control system and about which attitude hold is to be maintained. STEER is called at the beginning of each trajectory phase and at some user specified time interval (integer multiple of the integration step size). Included in subroutine STEER is the three-degrees-of-freedom open loop steering table look-up logic on aerodynamic attitude angles and body rates. The computations involved in the three-degrees-of-freedom and six-degrees-of-freedom open loop steering options of subroutine STEER are presented below.

(1) Tabulated Euler Angles (ISTEER=2) - After performing a table look-up on Euler angles referencing the initial body-to-earth centered inertial matrix to the desired body-to-earth centered inertial matrix and storing these angles into the angle array, a call is made to subroutine ROTMAT to generate the initial body coordinate system to desired body coordinate system transformation matrix, by performing a sequenced number of rotations about specified axes through specified angles. Next, the desired body coordinate to earth centered inertial transformation matrix and the desired body coordinate system to platform coordinate system transformation matrix are computed. Finally, the desired outer, inner, and middle gimbal angles are computed.

(2) Tabulated Gimbal Angles (ISTEER=3) - For this option, STEER performs a table look-up on gimbal angles and stores these angles.

(3) Tabulated Aerodynamic Attitude Angles (ISTEER=4) - This option can be executed for three-degree-of-freedom as well as six-degree-of-freedom simulations. If the DAP3D-PHSPLN logic is being executed, a table look-up on attitude angles is performed and the desired alpha and roll commands will be issued to the digital autopilot (DAP3D) control system. Control is then returned to the appropriate driver routine. For six-degrees-of-freedom simulations, attitude hold can be maintained on aerodynamic attitude angles or on gimbal angles. If hold is to be maintained on attitude angles, STEER performs a table look-up on attitude angles and stores these angles. Control is then returned to the appropriate driver. If attitude hold is to be maintained on gimbal angles, then STEER computes the following: Geocentric coordinate system to earth centered inertial transformation matrix, trajectory triad to geocentric coordinate system transformation matrix, and trajectory triad to earth centered inertial to trajectory triad transformation matrix. The final computations are desired body coordinate system to earth centered inertial transformation matrix, desired body coordinate system to platform coordinate system transformation matrix, and the desired outer, inner, and middle CDUD gimbal angles.

(4) Tabulated Body Rates (ISTEER=5) - For this option (3-dimension simulations only), STEER performs a table look-up on body rates and stores these rates.

STEER (Continued)

Major Inputs: Necessary transformations, earth rotation angle, longitude relative flight-path angle, geocentric latitude, relative azimuth, aerodynamic pitch and yaw angles of attack, and roll angle desired.

Major Outputs: Updated transformations, commanded pitch angle of attack, aerodynamic pitch and yaw angles of attack and roll angle desired, autopilot reference angles about which attitude hold is to be maintained, body rates and command roll angle.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume V, Q through S, JSC Internal Note 73-FM-110, (JSC-08065, Volume V), 20 July 1973.

Development Schedule: Operational

Category Name: Onboard Software System (Aerosurface Control System)

Model Name: SURCON Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-353?

Description of Model: Subroutine SURCON simulates the aircraft autopilot using conventional aerodynamic control surfaces. The basic purpose of SURCON is to provide aileron, elevator, and rudder deflection information that will give the desired control.

The aircraft autopilot consists of two control modes: longitudinal autopilot control and lateral autopilot control. Capability is provided to simulate both autopilot control modes simultaneously or each separately. The longitudinal autopilot simulated is the pitch orientational control system. Essentially a rate damper, the pitch orientational control system has as its input a desired pitch rate and generates the desired elevator deflection as its output.

Included in the lateral autopilot simulation are the yaw orientation control system and the roll angle control system. Both lateral autopilots include logic for damping the dutch roll and for achieving coordination during a turn (minimizing sideslip). In the case of the yaw orientational control system, a turn is obtained by commanding a desired yaw rate. However, in the roll angle control system a turn is achieved by commanding a desired bank angle (roll angle). Output from both lateral autopilots are the aileron deflection and the coordinating rudder deflection. The aircraft autopilot logic of SURCON assumes that the conventional aircraft body axes notation and control surface (aileron, elevator, rudder) deflections are in effect. The body axis system is located at the center of gravity of the aircraft, with the X-axis taken forward, the Y-axis out the right wind, and the Z-axis downward as seen by the pilot to form a right-handed axis system. The control surface deflections are defined such that

1. A positive aileron deflection produces a positive rolling moment,
2. A positive elevator deflection produces a negative pitching moment,
3. A positive rudder deflection produces a negative yawing moment.

There are three transfer functions whose response must be evaluated by some numerical technique. These are the rate integrator, servo, and washout circuit. A technique of assuming that the transfer function inputs are linearly time varying over the integration step interval is used for the required numerical integrations.

Subroutine SURCON is structured using internal subroutines so that subroutine SURCON acts as a driver for 6 other subroutines. The other subroutines (POC, YOC, RAC, COORD, SERVO, and WSHOUT) are internal subroutines in the sense that they use variables directly from SURCON and do not have their own common block inputs. The function or functions of SURCON and the internal subroutines are discussed below.

SURCON - This subroutine is the driver routine for the aircraft autopilot using conventional aerodynamic control surfaces.

PCC - This subroutine reflects the pitch orientational control system logic.

YOC - This subroutine reflects the yaw orientational control system logic. Subroutine YOC generates the aileron servo input signal.

RAC - This subroutine reflects the roll angle control system logic. Subroutine RAC generates the aileron input signal and coordinating rudder deflection signal.

SURCON (Continued)

COORD - This subroutine, called by subroutines YOC and RAC, simulates the aileron servo and coordinated aircraft autopilot combination of dutch roll damper and sideslip feedback.

SERVO - This subroutine simulates the servo transfer function.

WSHOUT - This subroutine simulates the WSHOUT circuit used to damp the dutch roll.

Major Inputs: Elevator servo transfer function coefficients, yaw angle of attack, aileron deflection, elevator deflection, rudder deflection, desired bank angle, body rates, desired pitch and yaw rate command, pitch and yaw rate integrating gyro sensitivity, pitch and yaw rate gyro sensitivity, sideslip sensor sensitivity and time constant of washout circuit.

Major Outputs: Expected coast times between stages, elevator, rudder, and aileron deflection.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume V, Q through S, JSC Internal Note 73-FM-110, (JSC-08065, Volume V), 20 July 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Approach and Landing/G&N Cruise/ Aerosurface Control System)

Model Name: Auto Flight Modes   Simulation Name: OAS

Contact Person: G. F. Prude   Org: JSC   Tel: (713)483-5104

Description of Model: The Auto Flight Modes math model includes functional simulation of autoland and autopilot modes. These modes are designed primarily to provide for closed loop checkout of flight control systems, and to assist in simulation evaluation. Several modes are available in this program. In the pseudo guidance mode, a bank and angle of attack profile is calculated which resembles an actual guidance profile, but is not guiding the vehicle to a target. The mode flies the vehicle from the beginning of transition (about Mach 8) to landing, using a Singer-developed guidance scheme. The guidance scheme used is based on homing in on a TACAN station at the airport while using a blended alpha-gamma pitch control law. An overhead landing pattern is flown for energy management, followed by an Instrument Landing System final approach. Landing flare is accomplished as a function of altitude rate vs. altitude (based on the radar altimeter).

The energy management cylinder mode contains equations for flying an energy management cylinder instead of the overhead pattern from the end of entry until final approach initiation.

The heading command mode contains equations to force the aircraft to fly to and hold a commanded heading.

The autopilot mode contains equations to fly the aircraft automatically straight and level for powered cruise simulations.

The speedhold mode calculates reference airspeed for use by auto throttle or speedbrake speedhold modes.

Major Inputs:

Major Outputs:

Source Documentation: Singer-General Precision, Inc., Link Division, "Space Shuttle Procedures Evaluator", Working Papers.

Development Schedule: Operational

Category Name: Onboard Software Models (G&N Cruise/Aerosurface Control System)

Model Name: GTURN Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: Subroutine GTURN simulates the gravity turn steering options which orient the vehicle to thrust along one of the following vectors: the inertial velocity vector, the earth relative velocity vector, or the earth relative velocity vector projected into the X-Z earth centered plumbline plane. The subroutine computes a set of parameters that determine how the reorientation is to be accomplished and transmits them out to the program through an argument list.

Major Inputs: Constant angle of attack to be maintained during gravity turn, earth rotation rate, and vehicle inertial position and velocity vectors.

Major Outputs: Earth centered inertial components of the unit vector defining the axis of rotation about which the vehicle is to maneuver in order to attain the desired attitude in a single rotation, and the computed maneuver angle through which the vehicle must transverse in a single rotation about the unit vector axis of rotation in order to achieve the desired attitude.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume II, D through H, JSC Internal Note 73-FM-110, (JSC-08065, Volume II), 20 July 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (G&N Cruise/Aerosurface Control System)

Model Name: PHZPLN Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: Subroutine PHZPLN provides an analytic estimate to actual vehicle attitude for 3-degrees-of-freedom simulations. This control model is able to automatically compute maneuver times and compare them with the integration step size selected by the user. Depending on the results of the comparison, appropriate attitude and attitude rate estimates are made automatically. This method of control insures attitude stability independent of integration step size.

The method of simulating actual vehicle attitude is to null the attitude errors in minimum time through use of an optimal control technique. The attitude error and attitude rate error trajectories are segments of parabolas. A switching curve is also present. Since the user can select the integration step size, system acceleration, and system rate limit, the model must predict ahead to determine if an overshoot will occur, otherwise an instability may be generated. In order to eliminate this problem logic has been added to the model which determines the time required to reach the origin from the initial state. If the time to reach the origin is less than the step size, the state is placed at the origin for the next step. The phase plane is divided into seven zones. Each time the model is evaluated the zone in which the current state lies is determined. Then equations are evaluated to determine if the state, when subjected to a control trajectory, will reach the origin within the next integration step size or for fourth order Runge-Kutta-Gill integration within one-half the integration step size, since the model is evaluated on the mid and end Runge-Kutta passes.

Major Inputs: Attitude deadband, angular acceleration, actual vehicle attitude, commanded vehicle attitude, attitude rate error, and rate limit.

Major Outputs: Test value of vehicle attitude and post value of attitude rate error.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume IV, M through P, JSC Internal Note 73-FM-110 (JSC-08065, Volume IV), 20 July 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Latitude, Longitude, Altitude, Range)

Model Name: ORBITR

Simulation Name: SSFS

Contact Person: J. E. Vinson

Org: Lockheed

Tel: (713)333-4875

Description of Model: The model calculates vehicle acceleration from active guidance commands and integrates to get velocity and position in platform coordinates. Polar-equatorial and local vertical coordinate systems are erected to calculate latitude, longitude, and flight-path angle. Logic is included for acceleration limiting, integration time rectification, and velocity cutoff.

Major Inputs: Target velocity in guidance coordinates, acceleration command in platform coordinates, acceleration due to gravity in platform coordinates.

Major Outputs: Present vehicle latitude and longitude, flight-path angle, position and velocity of vehicle on last pass, total vehicle acceleration, mass of vehicle on last pass, velocity in local vertical coordinates.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Latitude, Longitude, Altitude, Range)

Model Name: AZTTAR Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: Subroutine AZTTAR computes the flyback azimuth and flyback range given the vehicle position and a target latitude and longitude. Also computed is the absolute difference between the current azimuth and flyback azimuth.

Major Inputs: Earth equatorial radius, vehicle position, and target latitude and longitude.

Major Outputs: Difference between the flyback azimuth and the current azimuth, flyback range angle between target and vehicle and the flyback range, and flyback and current azimuth.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume I, Subroutines A through C, JSC Internal Note 73-FM-110, (JSC-08065, Volume I), 20 July 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Main Engine TVC)

Model Name: MPS Thrust Vector Control   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The Thrust Vector Control (TVC) system for each of the three shuttle Main Propulsion System (MPS) engines will be simulated. Each of the three MPS engines TVC systems will be simulated simultaneously and independently during the times at which the MPS TVC system is in operation. Inputs to the TVC simulation include TVC drive signals through each of the input channels, main engine thrust, electrical power available, hydraulic power factors for each hydraulic system, crew station switch and breaker configuration, and instructor inputs. Outputs from the TVC simulation will include gimbal positions, engine force vectors, electrical power load, hydraulic flows, and status outputs. The MPS TVC will exhibit considerable redundancy, with multiple command signal input channels for each actuator, multiple hydraulic pressure sources for each actuator, and multiple actuators for each gimbal motion direction. Failed channels are disconnected in the case of single channel failure. Actuators are mechanized to drive to null upon certain multiple failures. The operation of the actuator redundancy management systems will be simulated and will respond properly to failures. Failure discretes, hydraulic pressure monitor outputs, etc., generated by the TVC drivers and monitors will be simulated and output from the TVC simulation. Actuator dynamics in each gimbal degree-of-freedom will be simulated as a function of input commands, failure detection status, hydraulic power factors in each hydraulic system, and malfunctions. Other effects, such as engine bell damping, will be simulated if significant. Gimbal rate and position limits, and other limits internal to the TVC, will be simulated. After gimbal positions are calculated, each engine's thrust magnitude will be resolved through the calculated gimbal angles to obtain the engine force vector.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Onboard Software Models (Main Engine TVC)

Model Name: TVC3 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: This flexible body model defines thrust vector control for the flexible launch configuration during first stage boost. The reaction forces and moments of the engines due to tail-wags-dog is computed considering the bending effects of the vehicle. This model describes the motion of the engine with limits on deflection, deflection rate, and acceleration.

Major Inputs: Pitch and Yaw deflection commands.

Major Outputs: Engine deflection, engine deflection rate, engine deflection acceleration.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Main Engine TVC)

Model Name: TVC6 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: TVC6 describes the motions of massless engines with limits on deflection, deflection rates, and acceleration. Data values used in the model are for the 150k orbiter (also known as the 2A boost configuration).

Major Inputs: Engine gimbal deflection commands

Major Outputs: New engine gimbal positions

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III) November 1973.

Development Schedule:

Category Name: Onboard Software Models (Orbital Maneuvering TVC)

Model Name: OMS TVC Simulation Name: SLS

Contact Person: Lance Drane Org: C. S. Draper Lab. Tel: (617)258-1178

Description of Model: The two OMS engines on the orbiter vehicle are mounted on gimbals that permit nozzle rotations in pitch and yaw for thrust vector control during on-orbit powered flight. OMS TVC models the dynamics of the actuators that gimbal the OMS engines. There are separate actuators in the pitch and yaw planes for each engine; each one is represented dynamically as a second-order system with limits on deflection, deflection rate, and deflection acceleration. The OMS engines are assumed to be massless and hence produce no forces and torques on the orbiter vehicle due to their rotation.

OMS TVC uses a fourth-order Runge-Kutta integration scheme. The deflection acceleration for each active gimbal actuator is calculated and limited in the program's dynamic loop. At the end of each integration step, deflection and deflection rate are compared against their maxima and limited as necessary. The deflection limit reflects the limitation imposed on gimbal actuator motion by engine stops; these stops are modeled as "brick walls" (i.e., no snubber springs are included) that cause the actuators to stop instantaneously and remain fixed at the deflection limit until their dynamics drive them away from the stops.

Major Inputs: Pitch and yaw gimbal angle commands.

Major Outputs: Thrust vector control pitch and yaw angles.

Source Documentation: Lawrence Berman, et al, "ESIM Model Book for the C. S. Draper Laboratory Statement Level Simulator", The Charles Stark Draper Laboratory, Inc., R-776, Amendment Number 2, April 1, 1974.

Development Schedule: Operational

Revision 1
31 May 1974

Category Name: Onboard Software Models (Orbital Maneuvering TVC)

Model Name: OMS Thrust Vector Control | Simulation Name: SMS

Contact Person: C. C. Olasky | Org: JSC | Tel: (713)483-2481

Description of Model: The Thrust Vector Control (TVC) system for each of the two Orbital Maneuving System (OMS) engines will be simulated. Each of the two OMS engines' TVC systems will be simulated simultaneously and independently, during the times at which the OMS TVC system is in operation. Inputs to the TVC simulation include TVC drive signals, OMS engine thrust, electrical power available, crew station switch and breaker configuration, and instructor inputs. TVC simulation outputs will include gimbal positions, engine force vectors, electrical power loads, and status outputs. It appears that the OMS TVC is an electrical-mechanical system, with no hydraulic components, somewhat similar to the Apollo Spacecraft Propulsion System TVC. The actuator dynamics of the Apollo system are significant, especially in malfunction cases. Thus, lags, overshoots, finite rise times, etc., of the actuators will be simulated. There appears to be considerable redundancy in the system, with multiple command signal input channels. Operation of system redundancy management will be simulated, and any resulting failure discretes will be generated. Actuator outputs in each gimbal degree of freedom will be simulated as a function of input commands, failure detection status and malfunctions. Gimbal rate and position limits, and other limits internal to the TVC, will be simulated. Effects such as engine bell damping will be simulated if significant. After gimbal positions are calculated, each engine's thrust magnitude will be resolved through the calculated gimbal angles to obtain the engine force vector.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Onboard Software Models (Orbital Maneuvering TVC)

Model Name: TVC2 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: TVC2 provides a dynamic actuator model for the orbit maneuvering system (OMS) engines of the orbiter. All three engines can be gimballed in both the pitch and yaw planes. Each OMS engine gimbal actuator deflection, deflection rate, and deflection acceleration are maintained and limited individually. The engines, as modeled, are considered as massless, and produce no forces and torques. After calculating the deflection acceleration, the deflection and deflection rate are obtained by integrating the deflection acceleration using a four-pass Runge-Kutta integrator only. Limiting of the deflection, deflection rate, and deflection acceleration is done during each integration step.

Major Inputs: Commanded engine gimbal deflections; forward gain, rate feedback gain, and position feedback gain; initial gimbal misalignments; maximum engine gimbal deflection, deflection rate, and deflection acceleration allowed.

Major Outputs: Time and engine gimbal deflections.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Onboard Software Models (Reaction Jet Control/Aerosurface Control System)

Model Name: Flight Control System   Simulation Name: OAS

Contact Person: G. F. Prude   Org: JSC   Tel: (713)483-5104

Description of Model: The Flight Control System (FCS) math model contains equations for simulation of shuttle flight controls including RCS jets and aerodynamic surfaces. There are three sets of control logic available in the FCS math model. The North American Rockwell FCS 10 uses RCS to initiate turns at hypersonic speed and conventional ailerons to damp roll. It switches to rudder turn coordination below alpha = 18 degrees. The North American Rockwell FCS 11 uses reversed ailerons and minimum impulse RCS for hypersonic turns and is the same as FCS 10 below alpha = 18 degrees. The Singer FCS is a gain-scheduled control concept used for interim testing and evaluation of inner loop control schemes.

Major Inputs: Manual or automatic commands; feedback from accelerometers, rate gyros, and the air data computer.

Major Outputs: Control surface deflection commands and RCS jet on-time commands.

Source Documentation: Singer-General Precision, Inc., Link Division, "Space Shuttle Procedures Evaluator", Working Papers.

Development Schedule: Operational

Category Name: Onboard Software Models (Reaction Jet Control)

Model Name: DAP Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: Subroutine DAP simulates the RCS (reaction Control System), TVC (Thrust Vector Control) and the DAP (Digital Autopilot) logics that are used to stablize and control the vehicles during coasting and powered flight.

The RCS autopilot has two control functions -- (1) attitude hold and rate limiting, and (2) automatic maneuvering. The input of the first control logic is a set of reference angles corresponding to the desired outer, inner, and middle gimbal angles. (If attitude hold is maintained about the aerodynamic attitude angles, the reference angles are the desired aerodynamic roll angle, aerodynamic pitch angle of attack, and aerodynamic yaw angle of attack, respectively.) These angles are then differenced with the current CDU angles and the result is resolved into the three control axes, using the small angle difference approximation in order to yield a set of body attitude errors. The attitude errors and body rates are fed to the RCS control law phase plane logic, where, as a function of attitude error and rate, nonlinear switching functions are used to generate RCS jet on time for each control axis. The rate limiting function is incorporated in the phase plane. A jet selection and timing logic is then used to select the individual jets to be fired and establish the firing time durations.

Attitude maneuvers are implemented with exactly the same logic as that used in attitude hold, except for the additional inputs. One important difference is that the reference angles will, in general, be functions of time. Since the steering program of the attitude maneuver routine generates these desired gimbal angles with an interval that is much greater than the autopilot sample rate, a set of incremental angles are computed. The steering program also computes a set of desired spacecraft rates, which are subtracted from the measured body rates by the autopilot, and the results are used in the RCS control law phase plane computations. This procedure allows the autopilot to maneuver the spacecraft smoothly at the required rate. In addition, the steering program may generate a set of attitude error biases, which are added to the attitude errors in order to provide additional lead and prevent overshoot when starting and stopping an automatic maneuver. The biases remain fixed until the maneuver is completed, then they are reset to zero. Note that when steering is completed, desired spacecraft rates, reference CDU angle increments, and bias (or lag) angles are reset to zero, and, in effect, the autopilot reverts to attitude hold about the final desired gimbal angles. During thrusting postions of flight, spacecraft attitude control in pitch and yaw is achieved by driving the engine actuator servos of the gimballed main engines. The resulting offset of the thrust vectors with respect to the vehicle center of gravity results in the generation of control torques about the spacecraft pitch and yaw axes. The computations of the engine actuator commands in response to attitude errors and rates (in the pitch and yaw channels) is the function of the TVC autopilot. A separate autopilot, the RCS roll autopilot logic, provides attitude and rate control in the roll axis by means of the RCS jets.

DAP (Continued)

Because of the general manner in which the RCS/TVC DAP logic must be implemented, the following assumptions are made:

1) The control axes are the body axes.
2) The state estimator logic is not simulated to compute the estimate of angular velocity of the vehicle (the estimates are assumed to be the actual body rates computed from rotational dynamics).
3) The DAP logic is cycled at some integer multiple number of rotational integration step sizes.
4) The RCS autopilot logic exercises control over a maximum number of 35 RCS jets.
5) The TVC autopilot logic exercises control over a maximum number of 15 gimballed engines.
6) For a selected rotational maneuver (plus or minus roll, plus or minus pitch, plus or minus yaw), the RCS autopilot fires all jets capable of performing the maneuver.
7) A maximum number of 10 jets are allowed to perform a particular rotational maneuver.
8) The jet status table of the RCS engine model (subroutine RCSENG) must be used to perform translational control along the three control axes (since no controlled translational logic exists, opposing jets will fire to maintain attitude) and to simulate undetected jet failures.
9) The RCS roll autopilot logic (provides roll control when the TVC autopilot mode is exercised) is executed at integer multiples of the TVC sample period interval.

Subroutine DAP is structured using internal subroutines so that subroutine DAP acts as a driver for 11 other subroutines. The other subroutines (JETYP, ACCEL, JETIMI, IMUCDU, MGB, ATTERR, TVC, JETIME, JSELCT, KALMAN, and COROL) are internal subroutines in the sense that they use variables directly from DAP and do not have their own common block inputs. The function or functions of DAP and the internal subroutines are discussed below.

DAP - This subroutine is the driver and timing logic for the RCS and TVC.

JETYP - Subroutine JETYP groups all the RCS jet numbers according to the type of rotational maneuver the RCS jet is expected to perform (+roll, +pitch, +yaw, -roll, -pitch, -yaw) into a jet storage array.

ACCEL - Subroutine ACCEL computes the magnitudes of the angular acceleration expected for + roll, + pitch, + yaw, - roll, - pitch, and - yaw control that are generated by firing all the RCS jets capable of providing the desired control (+ roll, + pitch, etc.).

JETIMI - Subroutine JETIMI computes the RCS control law phase plane boundary decision lines and the magnitude of the slope of the target rate.

DAP (Continued)

IMUCDU - Subroutine IMUCDU simulates the analog to digital conversion of the gimbal angle data. The gimbal angles from rotational dynamics are input to the routine and the corresponding quantized gimbal angles are output.

MGB - Subroutine MGB computes the elements of the gimbal axes to body axes transformation matrix as a function of the observed CDU angles (IATT=0), or the wind axes to body axes transformation matrix as a function of the observed aerodynamic attitude angles (IATT=1).

ATTERR - Subroutine ATTERR computes the autopilot attitude errors and rate errors that are used by the RCS and TVC control law logics.

TVC - Subroutine TVC reflects the control law logic that maintains attitude control in pitch and yaw by driving the gimballed engines.

JFTIME - Subroutine JFTIME reflects the RCS control law phase plane switching logic and computes the required jet burn times for RCS control.

JSELCT - Subroutine JSELCT computes the on-off times for the RCS jets. The logic is cycled for each of the rotational control modes (+roll, +pitch, +yaw, -roll, -pitch, -yaw).

KALMAN - Subroutine KALMAN is designed to generate commands for the RCS DAP to automatically reorient the vehicle during coasting flight from an initial attitude to some desired attitude specified by THETAD.

COROL - Subroutine COROL is the coordinated roll maneuver driver logic for the RCS and TVC flight modes that exercise attitude hold on the aerodynamic attitude angles (IATT=1).

Major Inputs: Time rate of change in pitch angle of attack; pitch angle of attack; yaw angle of attack; time rate of change in yaw angle of attack; pitch and yaw TVC attitude and rate error gains; center of gravity location; attitude error deadband; RCS jet minimum electrical on-time once the electrical on signal has been activated; location of main engine gimbal point with respect to the vehicle center of gravity; the estimated X, Y, Z body axis moments of inertia; number of RCS jets being simulated; number of movable main engines; magnitude of the automatic maneuvering rate; pitch rate limit; aerodynamic roll angle; time rate of change in aerodynamic roll angle; body rates; direction cosines of thrust vector of the RCS jet; location of the RCS jets; desired terminal outer, inner, and middle gimbal angles, respectively, about which attitude hold is to be maintained; thrust magnitude of each RCS jet; and vehicle mass.

Major Outputs: Set of main engine TVC gimbal commands about the Y and Z engine axes of each gimballed main engine, RCS on and off times, control axes attitude and rate errors, roll acceleration level, and flags to be used by the other subroutines which are called by DAP.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume II, D through H, JSC Internal Note 73-FM-110, (JSC-08065, Volume II), 20 July 1974.

DAP (Continued)

Development Schedule: Operational

Category Name: Onboard Software Models (Rendezvous Computations)

Model Name: Target Vehicle Guidance and Control Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: A functional target vehicle guidance system will be simulated for target vehicles. The guidance system will consist of a major loop which performs burn targeting and runs in interruptible time, and a minor loop which feeds attitude commands to the generalized target vehicle control system, and firing commands to the generalized target vehicle propulsion system. A reset boolean will be provided to bypass generalized target vehicle guidance entirely, and another provided to bypass the major loop only, for use in the case that more detailed guidance schemes for particular vehicles are added following simulator delivery. The minor loop guidance system will accept thrusting and attitude commands from either instructor input, command from shuttle vehicle, or guidance major loop/prestored commands in that order of priority. Instructor input may take the form of direct command, or initiation of prestored commands. Shuttle vehicle commands will be honored only when a reset boolean is set indicating that this target vehicle possesses the capability to accept commands from the shuttle vehicle. Prestored commands may be used either in place of the major loop burn targetting, or merely to specify attitude following the final burn. Prestored commands will be stored as functions of time. Attitude commands may be given in terms of either inertial Euler angles or local horizontal angles, or inertial hold of a local horizontal orientation at the initial point in time. Burn targeting will be provided to the minor loop by specifying ignition time, burn duration, and inertial burn attitude. The minor loop will process this information and provide inertial attitude commands for the generalized target vehicle control, and engine ignition and cutoff times to generalized target vehicle propulsion. The major loop will calculate burn targeting assuming a coelliptic rendezvous sequence of three burns. The coelliptic sequence could be expanded to later include preliminary phasing burns, if necessary. Targeting presettings will be instructor-changeable, and targeting for a given burn can be recycled by instructor command. Targeting data will be available for instructor display. Provision will be made to inhibit terminal phase initiation targeting if the shuttle vehicle will perform this burn. Burn targetings will be performed immediately following the preceding burns's conclusion, and re-performed about 10 minutes before estimated burn time.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Onboard Software Models (TAEM)

Model Name: LAGS

Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: The Launch Abort Guidance Simulation (LAGS) is designed to guide the shuttle orbiter to explicit velocity, flight-path angle, and altitude conditions at fuel depletion. The algorithm provides pitch and yaw steering commands in a guidance coordinate system and an estimate of the time-to-go to burnout each major integration cycle. The scheme utilizes instantaneous state variables from the SVDS trajectory processor as well as the specified end conditions. The guidance steering commands are transformed into pitch and yaw information which is consistent with the IMU (platform) alignment. Inertial turning rates are then computed in the SVDS computational coordinate system for the derivative/integrator package. These rates are maintained constant over the entire integration interval.

The abort guidance algorithm consists of three distinct guidance stages relative to specific vehicle events. These are defined as follows:

Stage 1 - Guidance initiation to pitchover
Stage 2 - Pitchover to 3G limit is reached
Stage 3 - Maintain 3G accelerations to burnout.

Stages 1 and 2 are constant thrust phases, however, during stage 3 the engine is throttled to maintain the desired constant acceleration level. Throughout stage 1 the flight path is directed upward and away from the launch site. The pitch maneuver initiating the second guidance stage orients the vehicle in a retrograde attitude so that is is essentially pointing uprange in the direction of the site or target. The stage 2 and 3 guidance algorithm then nulls the downrange velocity component and adds the necessary velocity uprange, as designated by the end condition, to effectively permit an unpowered atmospheric abort landing.

Major Inputs: Velocity bias used in computing the excess velocity to be expended before initiating the reorientation maneuver, thrusting magnitude for initializing the guidance sensed acceleration, sensed acceleration gravitational limit, desired relative flight-path angle at burnout, desired altitude at burnout, effective specific impulse of the propulsion system, desired relative velocity magnitude at burnout, normal burnout weight, commanded turning rate during the reorientation maneuver, geocentric latitude of the landing site, and the longitude of the landing site.

Major Outputs: Instantaneous position and velocity vectors, expressed in the platform coordinate system, sensed velocity vector expressed in the platform coordinate system, magnitude of the velocity-to-be gained, instantaneous sensed acceleration magnitude, thrust vector offset relative to the positive X-body, measured about the Y-body axis, instantaneous velocity components in the guidance coordinate system axes, desired components at burnout in the guidance coordinate system axis, estimated time-to-go-to-burnout, instantaneous mass-to-mass flow rate ratio, estimated time required to perform the retrograde reorientation maneuver, estimated burn time of the respective guidance stages, desired thrust attitude measured in the guidance coordinate pitch and yaw planes, thrust attitude required to achieve the desired velocity end conditions only, inertial pitch and yaw attitude commands, excess velocity to be expended before initiating the reorientation maneuver and predicted velocity vector-to-be gained at the completion of the reorientation maneuver.

LAGS (Continued)

Source Documentation: R. F. Sievers, "SVDS Launch Abort Guidance Simulation", TRW IOC 6534.7-72-19, Task MSC/TRW A-517, 29 November 1972.

Development Schedule: Operational

5.8 Payload Accommodation Area

This section contains descriptive information about models of the payload accommodation area.

Category Name: Payload Accommodation Area (Payload Manipulator)

Model Name: Payload Manipulator Subsystem Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The simulated payload manipulator subsystem simulates the dynamics and interfaces of the shuttle payload manipulators. Inputs to the simulated subsystem include manipulator arm joint and terminal device position commands, power available booleans, shuttle vehicle translational state and body forces, shuttle vehicle attitude, angular velocity and total moments, payload position, payload attitude, payload mass inertia tensor and center of mass location and crew station switch and circuit breaker settings. Provided these inputs, the manipulator simulation will calculate each manipulator joint angle position and rate, terminal device and deployment device positions, joint potentiometer and tachometer outputs, forces and torques exerted upon the vehicle by the manipulator system, payload translational and rotational state upon release, electrical power loads, checkout system outputs, and relative state of a jettisoned arm.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

5.9 Cockpit and Simulator Environment Models

This section contains descriptive information about models of the cockpit and simulator environment.

Category Name: Cockpit and Simulator Environment (Cockpit Gauge, Indicator, Switch, Lever)
Model Name: Caution and Warning Subsystem Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The Caution and Warning Subsystem is composed of four types of crew cues: alert, caution, warning, and emergency. All four have one common identity - the audio cues.

The alert power and display logic equations determine if alert power is available, whether the sensors are active, and generates booleans for display in the crew station when input parameters are out of tolerance. A boolean will be generated for cue to the audio device each time a new parameter is sensed out of tolerance.

The caution and warning power equations simulate the separate internal power supplies of caution power and warning power. Since these units are controlled by the same switch, circuit breaker, relay functions, they are included together. The equations generate caution sensor power available and warning sensor power available booleans to the using subsystem.

The emergency power equations simulate the emergency power unit and its control switches and circuit breakers. An emergency sensor power available boolean will be generated by the equations for inclusion in equations of the using subsystems. Inputs for emergency alarms from the using systems will then be tested against upper and lower limits in the emergency parameter test equations. The test equation will take into account the crew station inhibit switch position.

Booleans generated by the alert, caution, warning, and emergency equations will be included in equations in the audio alarm section to provide cues to the audio devices as to which alarms are on. Volume control of the intercom speakers for the alarms will be a hardware control.

The instrumentation signal conditioning of Caution and Warning Subsystem parameters will be accomplished using sensor and display logic booleans from the Electrical Power Subsystem for crew station display, for reinput to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program. The equations of the Caution and Warning Subsystem will be repeated for each unit, either by programmed loops or by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the Caution and Warning simulation are to be designed into the simulation for minimum computer impact.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Cockpit and Simulator Environment (Cockpit Gauge, Indicator, Switch, Lever)

Model Name: Operational Instrumentation Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The power conditioning units, transducer power supplies, and the associated power for signal conditioning of measured and display parameters will be simulated using only dynamic bilevel parameter measurements. These measurements read the nominal value or the minimum value if disabled by malfunctions entered or by loss of power to the unit.

The program will simulate conversion of DC power from the main buses to DC power at voltages required by instrumentation DC power system loads. This simulation will include power supplies such as ±5, ±24, ±28 volt supplies and loads such as display transducers and signal conditioning equipment. All major components such as DC-DC converters, transducers, and signal conditioning equipment will be simulated using Boolean terms representing the state of circuit breakers and switches of the major components.

The program will perform the dynamic bilevel calculations of the required supply voltages and equipment operational status. The system will also provide the computed load parameters to the power bus loading subsystem for bus conductance computations and to the ECS subsystem for heat loading. Signal conditioning of parameters for telemetry processing will be simulated by each system checking a Boolean term representing "signal conditioning equipment operational".

Individual components of the DC-DC converters, transducers, and signal conditioning equipment will not be simulated. Dynamic multilevel parameter calculations will not be necessary since unit input power is not monitored. A converter ON/OFF Boolean will be used to calculate converter temperature since the heat generated by the converter is assumed to be constant when the converter is operational. The overall effect of simulation will be that the unit is either totally operational or completely inoperable.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

5.10 Thermal and Environmental Control and Life Support Systems Models

This section contains descriptive information about models of the thermal and environmental control and life support systems (ECLSS).

Category Name: Thermal and ECLSS (Thermal Control)

Model Name: Thermal Control Subsystem Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: This subsystem consists mainly of passive elements such as heat sinks, surface coatings and insulators. The subsystem simulation will consist mainly of conduction heat transfer equations. The conduction equations will be applied to each layer of insulation material until the cabin walls are reached. At this point, the Environmental Control and Life Support Subsystem will accept the heat flux and determine the influence of the internal walls and cabin atmospheric temperatures. The equations will be executed at a once per second rate.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Thermal and ECLSS (Thermal Protection)

Model Name: Thermal Protection Subsystem   Simulation Name: SMS

Contact Person: C. C. Olasky   Org: JSC   Tel: (713)483-2481

Description of Model: The Thermal Protection Subsystem (TPS) is intended to thermally shield the vehicle from high temperatures during atmospheric flight. Two basic arrangements are planned, one for high temperatures (up to 2500°F) on the leading and lower surfaces of the exterior and one for moderate temperatures (below 650°F) for the upper surfaces.

The simulation will cover both atmospheric and orbital flight cases. A critical altitude will be used to determine which case is dominant, i.e., aerodynamic heating from atmospheric flight or radiative effects encountered in orbital flight.

For the simulation, the exterior vehicle surface will be divided into a number of sections so that heat fluxes and temperatures at various points can be calculated. The radiation sources to be considered are solar, earth emission, deep space, and solar reflection from the earth. The heat transfer due to aeordynamic heating will be considered when below a critical altitude. For aerodynamic heating, actual test data will be used to generate curve fit equations. All heat transferred into and out of a given section will be summed and its influence on the temperature of the sections will be calculated.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Thermal and ECLSS (TPS/TCS)

Model Name: TPS Simulation Name: SVDS

Contact Person: E. M. Fridge, III Org: JSC Tel: (713)483-3532

Description of Model: The TPS model computes the thermal protection system weights for the shuttle vehicle given trajectory and control profile. A weight summary based on a 20-panel configuration of the MSC-040A baseline orbiter is computed at case termination for each of the following: (1) the reusable surface insultative system, (2) the metallic skin reradiative system, and (3) the ablative insulation weights. In addition, the TPS model computes the individual panel heating rates, temperatures, and integrated heat loads at some user-specified integer multiple of the integration step size.

Major Inputs: TPS computation frequency interval, connective heat rate coefficient for the shuttle vehicle, Apollo heat shield radius, number of panel areas, and array of panel areas.

Major Outputs: Panel number, panel area, heating rate, temperature, total heat load, insulation and support weights.

Source Documentation: Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Development Schedule: Operational

5.11 Electrical-Mechanical Power Systems

This section contains descriptive information about models of the electrical and mechanical power systems.

Category Name: Electrical-Mechanical Power Systems (Actuators and Servos)

Model Name: Hydraulic Power Subsystem Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The Hydraulic Power Subsystem will be divided into four blocks of generally related equations for simulation purposes. The mathematical equations used as representative of the real world system could be derived engineering functions, however, the crew station controls and displays are minimal. At present, the crew displays are limited to hydraulic fluid temperature and quantity. Caution and Warning displays relate to high and low fluid temperature, low fluid quantity, and low pressure. Realistic functional equations will be written to generate the required display parameters without an excessive computer time requirement.

The loading equations will calculate the summation of the fluid flow from the four main supply lines. The program will also calculate flow from the main supply lines to the two accumulators. These fluid flow summations form load request parameters for the pump-reservoir equations and the accumulator equations. The load request parameters are to be generated by the using systems for elevons, rudder-speed brake, main engine TVC, engine controls, OMS TVC, SRM TVC, gear uplock, gear deployment/retraction, wheel braking, steering, RCS door operation, and payload bay doors.

The accumulator equations will simulate the stored power by calculating a load response factor for all units that use accumulator hydraulic pressure. This load response factor is a function of the mass, temperature, and volume occupied by the entrapped gas. The volume occupied by the gas will be calculated by a summation of hydraulic fluid usage and resupply for the accumulator. Load requests will be generated by the equations for use in the loading equations as hydraulic fluid is used from the accumulator.

The pump-reservoir equations are to simulate the four sources of power to each manifold supply pipe. The pumps are the two Auxiliary Power Unit gear pumps, the Air Breathing Propulsion System gear pump, and the AC driven circulation gear pump. Simulation logic will be incorporated to prevent back flow into these pumps where check valves exist. Relief and by-pass valves will be logically represented for equation usage. A summation of total pump capability will be made to furnish a load response factor for using subsystems based on load request. Reservoir quantity will be calculated from a summation of pump usage-return fluids to the reservoir.

A heat load is to be calculated for heat balance equation usage to determine the temperature of the hydraulic fluid. The calculation of temperature of the hydraulic fluid will take into account coolant valve positions as the result of crew switch, circuit breaker, and electrical power conditions. Interface parameters of heat load on the water boiler heat exchanger will be calculated for use by the Environmental Control System simulation. The Environmental Control System will calculate a return fluid temperature for use by the heat balance equations.

From these groups of equations, parameters simulating the actual system state will be conditioned using sensor and display logic booleans from the Electrical Power System for crew station display, for input to the Caution and Warning

Hydraulic Power Subsystem (Continued)

Subsystem, or for input to the Telemetry Subsystem Multiplexer Program. The equations will be repeated for each hydraulic pump and manifold supply pipe, either by programmed loops or by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the Hydraulic System are to be designed into the simulation for minimum computer impact.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

Category Name: Electrical-Mechanical Power Systems (Actuators and Servos)

Model Name: GMDACT　　　　Simulation Name: SVDS

Contact Person: E. M. Fridge, III　　Org: JSC　　Tel: (713)483-3532

Description of Model: The function of GMDACT is to simulate the main engine servo actuators of the movable main engines on each of the three vehicles utilized in the MAENG model. Capability is provided for simulating a maximum of five engine servo actuators. On the initialization pass, the initial main engine gimbal deflections are those specified by the user. On subsequent passes, the deflections are updated according to a computational algorithm. The user specifies the appropriate main engine servo actuator to be used for the engine under consideration.

Major Inputs: Gimbal drive rate limits, initial main engine gimbal deflection values, gimbal deflection limits, feedback loop gains, and forward loop gains about engine axes for main engine servo actuator; variable or constant gimbal drive rate option; current trajectory time; designation of main engine and main engine servo; time of last main engine model evaluation.

Major Outputs: Gimbal drive rate limits, gimbal deflection limits, feedback loop gains, forward loop gains about engine axes for from 1 to 5 main engine servo actuators; variable or constant drive rate option for from 1 to 5 main engine servo actuators.

Source Documentation: JSC/TRW, "Space Vehicle Dynamics Simulation", Program Description, Milestone 2, 27 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "User's Guide for the Space Vehicle Dynamics Simulation (SVDS) Program", JSC Internal Note 73-FM-67, (JSC-07950), 20 April 1973.

Software Development Branch, Mission Planning and Analysis Division, "Space Vehicle Dynamics Simulation (SVDS) Program Subroutine Library", Volume II, D through H, JSC Internal Note 73-FM-110, (JSC-08065, Volume II), 20 July 1973.

Development Schedule: Operational

Category Name: Electrical-Mechanical Power Systems (Electrical Power Subsystem)

Model Name: Electrical Power Subsystem Simulation Name: SMS

Contact Person: C. C. Olasky Org: JSC Tel: (713)483-2481

Description of Model: The Electrical Power Subsystem may be generally divided into six problem areas requiring math models. These are power interface, switching logic, bus loading, power generation and storage, power distribution, and control and display. For the shuttle vehicle there are three types of electrical power having distinct requirements for simulation. These are the direct current (DC) subsystem, the single phase alternating current (AC) subsystem, and the three phase alternating current subsystem. Each of these subsystems interface with the others through electrical loads or by providing power sources. The concept presented here describes the subsystems separately with interfacing parameters between subsystems.

The direct current has fuel cells, batteries, and transformer-rectifiers supplying power to three main direct current buses, two battery buses, two essential control buses, and two sequencer buses. Because of malfunction consideration, the tie bus must also be considered as a load bus.

The power sources for the single phase alternating current subsystem network are the Air Breathing Engine generators, the Auxiliary Power Unit, and the Ground Support Equipment power. For the purposes of simulation, the loads are assumed to have an overall power factor of 1.0. It is also assumed that the generators cannot be brought into sync for load sharing between units.

The Air Breathing Engine generator equations give the output frequency as a function of the generator revolutions per minuts. The voltage output of the generator will be a function of both revolutions per minute and the power load. Since the frequency is not displayed but is probably supplied to Caution and Warning as an out of tolerance condition will be generated.

The three phase AC subsystem simulation is very similar to the single phase subsystem with one significant difference. Loss of a single phase will not cause shutdown of the equipment in the three phase subsystem as it would do in the single phase subsystem. Where one phase is out in the three phase subsystem, the two supporting buses will reflect increased loading.

The simulation purposes the loads on each log are assumed to have an overall power factor of 1.0. For the three phased subsystem, it is assumed that the units sync immediately from the master sync line of the selected unit.

Major Inputs:

Major Outputs:

Source Documentation: Singer Company, Simulation Products Division, "Shuttle Mission Simulator Baseline Definition Report", Volume II, 21 December 1973.

Development Schedule:

5.12 Other Models

This section contains descriptive information about other models.

Category Name: Other (Euler Angle Routines)

Model Name: EULERD

Simulation Name: SSFS

Contact Person: J. E. Vinson

Org: Lockheed

Tel: (713)333-4875

Description of Model: This model calculates the Euler angle rates and accelerations. Three sets of equations are contained in the model to avoid indeterminancies.

Major Inputs: Euler angles roll, pitch, and yaw; vehicle body angular rates; vehicle body angular accelerations.

Major Outputs: Euler angle rates and accelerations.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Other (Orbital Elements)

Model Name: Parameter EOM

Simulation Name: OAS

Contact Person: G. F. Prude

Org: JSC

Tel: (713)483-5104

Description of Model: The parameter equations of motion model calculates additional variables not available from the translational or rotational equation of motion.

Major Inputs: Outputs of rotational and translational equations of motion.

Major Outputs: Loss of signal distance to airport, magnitude of shuttle velocity, altitude above the airport and above sea level, altitude rate, latitude, and longitude.

Source Documentation: Singer-General Precision, Inc., Link Division, "Space Shuttle Procedures Evaluator", Working Papers.

Development Schedule: Operational

Category Name: Other (Orbital Elements)

Model Name: ORBP1 Simulation Name: SSFS

Contact Person: J. E. Vinson Org: JSC Tel: (713)333-4875

Description of Model: ORBP1 calculates the orbital parameters associated with the orbital mission phase. The equations contained in ORBP1 define the characteristics of a vehicle's motion in inertial space using the basic central motion trajectory equations for elliptical orbits. No perturbations are considered. A spherical earth is assumed.

Major Inputs: Time, inertial position and velocity vectors, earth's gravitational constant, rotational rate of earth, gravitational acceleration vector.

Major Outputs: Semimajor axis, semilatus rectum, eccentricity, simiminor axis, apogee radius, eccentric anomaly, angular momentum vector, perigee radius, orbital velocity at apogee and perigee, flight-path angle, orbital central angle, radial velocity, radial acceleration, mean anomaly, orbital period, mean motion, right ascension of vehicle (geocentric longitude), geocentric latitude, geographic longitude, time of perigee passage, longitude of the ascending node, orbital inclination, true anomaly, argument of perigee, angle between ascending node and projection of vehicle on the equatorial plane, azimuth angle, angle of elevation.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 72-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

Category Name: Other (Transformation Generation Routines)

Model Name: APIC Simulation Name: SSFS

Contact Person: J. E. Vinson Org: Lockheed Tel: (713)333-4875

Description of Model: APIC converts a vehicle state from airport coordinates to earth centered inertial coordinates. The algorithms used by APIC for coordinate transformation produce an approximation of the earth centered inertial state.

Major Inputs: Vehicle position vector in airport coordinates, airport geocentric latitude, airport longitude, and vehicle velocity vector in airport coordinates (or velocity magnitude, flight-path angle, airport runway heading, and vehicle heading angle).

Major Outputs: Vehicle position and velocity vectors in earth centered inertial coordinates.

Source Documentation: Engineering System Branch, Computation and Analysis Division, "Space Shuttle Functional Simulator", Volume III, Revision B, Johnson Space Center, MSC Internal Note 73-FD-010, (MSC-06726, Volume III), November 1973.

Development Schedule: Operational

6.0 MODELS BY SIMULATION

This section contains listings of all math models that have been identified for development for the various simulations. The model names used in Tables II through X correspond to the names used in the source documentation of the individual simulations. The tables include contact persons, formulation completion date, and a reference number for the source documentation. For each simulation, the math models are grouped under the category names used throughout this document.

Table II. ADL Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
EQUATIONS OF MOTION	Guidance & Navigation Attitude and Pointing OFP	3/74	D. W. Gilbert, JSC, 483-2381	9
	Guidance and Navigation Propagation OFP	3/75	D. W. Gilbert, JSC, 483-2381	9
COMMUNICATIONS/ NAVIGATION/ TRACKING DEVICES	Accelerometer Assembly TSP	7/74	D. W. Gilbert, JSC, 483-2381	9
	Air Data Transducer Assembly TSP	7/74	D. W. Gilbert, JSC, 483-2381	9
	Guidance and Navigation Beacon Search and Navigation Sensor Pointing OFP	3/75	D. W. Gilbert, JSC, 483-2381	9
	Inertial Measurement Unit Alignment OFP	11/74	D. W. Gilbert, JSC, 483-2381	9
	Inertial Measurement Unit Calibration OFP	11/74	D. W. Gilbert, JSC, 483-2381	9
	Inertial Measurement Unit Processing OFP	11/74	D. W. Gilbert, JSC, 483-2381	9
	Interial Measurement Unit TSP	11/74	D. W. Gilbert, JSC, 483-2381	9
	Microwave Scan Beam Landing System TSP	--	D. W. Gilbert, JSC, 483-2381	9
	Multiplexer/Demultiplexer Breadboard TSP	11/73	D. W. Gilbert, JSC, 483-2381	9
	Multiplexer/Demultiplexer Prototype TSP	2/74	D. W. Gilbert, JSC, 483-2381	9
	Pulse Code Modulation Master TSP	--	D. W. Gilbert, JSC, 483-2381	9
	Rate Gyro Assembly TSP	7/74	D. W. Gilbert, JSC, 483-2381	9
	TACAN Processing OFP	3/75	D. W. Gilbert, JSC, 483-2381	9
	TACAN TSP		D. W. Gilbert, JSC, 483-2381	9

Table II. ADL Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
ONBOARD SOFTWARE MODELS	Engine Interface Unit TSP	--	D. W. Gilbert, JSC, 483-2381	9
	Flight Computer Operating System OFP	10/74	D. W. Gilbert, JSC, 483-2381	9
	Flight Control Cruise OFP	3/75	D. W. Gilbert, JSC, 483-2381	9
	Flight Control Fault Tolerance OFP	6/75	D. W. Gilbert, JSC, 483-2381	9
	Flight Control Landing OFP	4/75	D. W. Gilbert, JSC, 483-2381	9
	Flight Control TAEM OFP	4/75	D. W. Gilbert, JSC, 483-2381	9
	Flight Control Takeoff OFP	2/75	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Approach/ Landing (Autoland) OFP	5/75	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Area Navigation OFP	--	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Control Processing	3/75	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Cruise (Horizontal & Ferry) Flight OFP	3/75	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Fault Tolerance OFP	6/75	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Filter OFP	3/75	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Multi-Phase Operations OFP	7/75	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Preflight Software OFP	2/75	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Postflight Software OFP	2/75	D. W. Gilbert, JSC, 483-2381	9
	Input/Output Box (IOB) Breadboard TSP	11/73	D. W. Gilbert, JSC, 483-2381	9
	Mass Memory TSP	4/74	D. W. Gilbert, JSC, 483-2381	9
	Navigation Timing, Sequencing and Control OFP	3/75	D. W. Gilbert, JSC, 483-2381	9
	TAEM OFP	5/75	D. W. Gilbert, JSC, 483-2381	9

Table II. ADL Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
COCKPIT AND SIMULATOR ENVIRONMENT	Angle/Surface Gimbal Indicator	--	D. W. Gilbert, JSC, 483-2381	9
	Annunciator Driver Unit PM	--	D. W. Gilbert, JSC, 483-2381	9
	AP-101 TSP	2/74	D. W. Gilbert, JSC, 483-2381	9
	Display Decoder Driver TSP	10/74	D. W. Gilbert, JSC, 483-2381	9
	Display Electronics Unit TSP	4/74	D. W. Gilbert, JSC, 483-2381	9
	Display Unit TSP	4/74	D. W. Gilbert, JSC, 483-2381	9
	Flight Log Recorder	--	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Crew Station Display Processing	2/74	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Dedicated Display Processing OFP	--	D. W. Gilbert, JSC, 483-2381	9
	Keyboard TSP	4/74	D. W. Gilbert, JSC, 483-2381	9
	Rotation Hand Controller TSP	7/74	D. W. Gilbert, JSC, 483-2381	9
	Rudder Pedal Transducer Assembly TSP	7/74	D. W. Gilbert, JSC, 483-2381	9
	Speed Brake Hand Controller TSP	7/74	D. W. Gilbert, JSC, 483-2381	9
ELECTRICAL-MECHANICAL POWER SYSTEMS	Aerosurface Servo Amplifier TSP	7/74	D. W. Gilbert, JSC, 483-2381	9
	Dual Aerosurface Servo Amplifier TSP	7/74	D. W. Gilbert, JSC, 483-2381	9
OTHER	Guidance & Navigation Environment Models	3/75	D. W. Gilbert, JSC, 483-2381	9
	Guidance & Navigation Landing Site and/or Way Point OFP	3/75	D. W. Gilbert, JSC, 483-2381	9
	Input Output Processor #1 TSP	5/74	D. W. Gilbert, JSC, 483-2381	9
	State Vector OFP	7/75	D. W. Gilbert, JSC, 483-2381	9

Table III. CSDD Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
NATURAL ENVIRONMENT	Atmospheric Density and Acoustic Velocity		D. W. Gilbert, JSC, 483-2381	10
	Gravity		D. W. Gilbert, JSC, 483-2381	10
	Runway Surface*		D. W. Gilbert, JSC, 483-2381	10
	Wind and Gusts		D. W. Gilbert, JSC, 483-2381	10
VEHICLE DYNAMICS	Aerodynamic Coefficients		D. W. Gilbert, JSC, 483-2381	10
	Landing Gear		D. W. Gilbert, JSC, 483-2381	10
EQUATIONS OF MOTION	Physical Characteristics		D. W. Gilbert, JSC, 483-2381	10
	Rotational Equations of Motion		D. W. Gilbert, JSC, 483-2381	10
	Translational Equations of Motion		D. W. Gilbert, JSC, 483-2381	10
COMMUNICATIONS/ NAVIGATION/ TRACKING DEVICES	Accelerometer		D. W. Gilbert, JSC, 483-2381	10
	ILS		D. W. Gilbert, JSC, 483-2381	10
	Pressure Altimeter		D. W. Gilbert, JSC, 483-2381	10
	Radar Altimeter		D. W. Gilbert, JSC, 483-2381	10
	TACAN		D. W. Gilbert, JSC, 483-2381	10
ONBOARD SOFTWARE MODELS	Control System		D. W. Gilbert, JSC, 483-2381	10
COCKPIT AND SIMULATOR ENVIRONMENT	Aural Characteristics		D. W. Gilbert, JSC, 483-2381	10
	Cockpit Gages, Meters, Indicators, Switches, and Levers		D. W. Gilbert, JSC, 483-2381	10
	Scene Characteristics		D. W. Gilbert, JSC, 483-2381	10

Table IV. OAS Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
NATURAL ENVIRONMENT	Atmosphere(see Aerodynamics)	Operational	G. F. Prude, JSC, 483-5104	7
	Gravity	Operational	G. F. Prude, JSC, 483-5104	7
	Wind and Gust(see Aerodynamics)	Operational	G. F. Prude, JSC, 483-5104	7
PROPULSION SYSTEMS	Reaction Control System*	Operational	G. F. Prude, JSC, 483-5104	7
VEHICLE DYNAMICS	Aerodynamics*	Operational	G. F. Prude, JSC, 483-5104	7
	Deceleration System	Operational	G. F. Prude, JSC, 483-5104	7
	Landing Gear*	Operational	G. F. Prude, JSC, 483-5104	7
EQUATIONS OF MOTION	Attitude	Operational	G. F. Prude, JSC, 483-5104	7
	Rotational Equations of Motion	Operational	G. F. Prude, JSC, 483-5104	7
	Translational Equations of Motion	Operational	G. F. Prude, JSC, 483-5104	7
	Weights and Balances	Operational	G. F. Prude, JSC, 483-5104	7
COMMUNICATIONS/ NAVIGATION/ TRACKING DEVICES	Accelerometers	Operational	G. F. Prude, JSC, 483-5104	7
	Microwave Landing System	Operational	G. F. Prude, JSC, 483-5104	7
	Rate Gyros	Operational	G. F. Prude, JSC, 483-5104	7
	TACAN	Operational	G. F. Prude, JSC, 483-5104	7
ONBOARD SOFTWARE MODELS	Aerosurface Control Surfaces (see Aerodynamics)	Operational	G. F. Prude, JSC, 483-5104	7
	Auto Flight Modes*	Operational	G. F. Prude, JSC, 483-5104	7
	Flight Control System*	Operational	G. F. Prude, JSC, 483-5104	7
	TAEM	Operational	G. F. Prude, JSC, 483-5104	7
COCKPIT AND SIMULATOR ENVIRONMENT	System Displays	Operational	G. F. Prude, JSC, 483-5104	7

* Additional Information Available in Section 5

Table IV. OAS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
ELECTRICAL-MECHANICAL POWER SYSTEMS	Aerosurface Actuators	Operational	G. F. Prude, JSC, 483-5104	7
OTHER	Parameter EOM*	Operational	G. F. Prude, JSC, 483-5104	7

* Additional Information Available in Section 5

Table V. FDSC Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
NATURAL ENVIRONMENT	Air Data, Wind and Wind Gusts		M. Moul, LRC, (804)827-3777	3
	Atmosphere		M. Moul, LRC, (804)827-3777	3
	Gravity		M. Moul, LRC, (804)827-3777	3
VEHICLE DYNAMICS	Main Landing Gear & Nosewheel		M. Moul, LRC, (804)827-3777	3
	Vehicle Aerodynamics		M. Moul, LRC, (804)827-3777	3
SPECIALIZED VEHICLE DYNAMICS	Bending		M. Moul, LRC, (804)827-3777	3
	Slosh		M. Moul, LRC, (804)827-3777	3
	Tail-Wags-Dog		M. Moul, LRC, (804)827-3777	3
EQUATIONS OF MOTION	Equations of Motion		M. Moul, LRC, (804)827-3777	3
	Mass Properties (Orbiter)		M. Moul, LRC, (804)827-3777	3
COMMUNICATIONS/ NAVIGATION/ TRACKING DEVICES	Air Data Sensor		M. Moul, LRC, (804)827-3777	3
	Body Mounted Rate Gyro		M. Moul, LRC, (804)827-3777	3
	IMU		M. Moul, LRC, (804)827-3777	3
	Microwave Scan Beam Landing System		M. Moul, LRC, (804)827-3777	3
	Navaids		M. Moul, LRC, (804)827-3777	3
	Normal/Lateral Accelerometer		M. Moul, LRC, (804)827-3777	3
	TACAN		M. Moul, LRC, (804)827-3777	3
COCKPIT AND SIMULATOR ENVIRONMENT	Scene Generation		M. Moul, LRC, (804)827-3777	3

Table VI. SDL Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
NATURAL ENVIRONMENT	Analytical Ephemeris Generator	--	--	2
	Atmosphere*	12/73	J. C. Kirkpatrick, JSC, 483-3532	2
	Ephemeris	--	--	2
	Gravity & Oblateness*	12/73	B. F. Cockrell, JSC, 483-6181	2
	Gravity Gradient	--	--	2
	Star Tables	--	--	2
	Sun-Moon-Earth Ephemerides	--	E. W. Henry, JSC, 483-6182	2
	Terrain	12/73	R. T. Savely, JSC 483-4366	2
	Wind and Gust*	12/73	W. M. Bolt, JSC, 483-6347	2
PROPULSION SYSTEMS	MPS Engines	--	--	2
	OMS Engines	--	--	2
	RCS Engines	--	--	2
	SRB Engines	--	--	2
VEHICLE DYNAMICS	Aerodynamics*	12/73	O. Hill, JSC, 483-4418	2
	Landing & Deceleration System*	3/74	J. V. West, JSC, 483-5944	2
	Target Dynamics	--	--	2
SPECIALIZED VEHICLE DYNAMICS	Elastic Body Bending	1/74	--	2
	Slosh	--	--	2
EQUATIONS OF MOTION	Equations of Motion-Rotational*	11/73	P. Misra, TRW, 333-3133	2
	Equations of Motion-Translational*	11/73	P. Misra, TRW, 333-3133	2
	Mass Properties*	12/73	T. J. Smith, TRW, 333-3133	2
	Numerical Integrators	--	--	2

* Additional Information Available in Section 5

Table VI. SDL Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
COMMUNICATIONS/ NAVIGATION/ TRACKING DEVICES	Air Data Sensors	11/73	J. V. West, JSC, 483-5944	2
	Air Traffic Control Navigation Aid	--	--	2
	Barometric Altimeter	11/73	J. V. West, JSC, 483-5944	2
	Inertial Measurement Unit*	12/73	J. R. Thibodeau, JSC, 483-6182	2
	Microwave Landing System	3/74	P. T. Pixley, JSC, 483-4366	2
	Multiplexer/Demultiplexer	1/74	--	2
	Normal/Lateral Accelerometers*	12/73	A. J. Bordano, JSC, 483-4491	2
	One-Way Doppler	--	--	2
	Optical Sensor	--	--	2
	Radar Altimeter	--	--	2
	Rate Gyros *	12/73	A. J. Bordano, JSC, 483-4491	2
	Rendezvous Radar	--	--	2
	Sensor Sites/Reference Ellipsoid	--	--	2
	Space Ground Link System	--	--	2
	Star Tracker	--	--	2
	Tactical Air Navigation	12/73	P. T. Pixley, JSC, 483-4366	2
	Target Sensor	--	--	2
	VHF	--	--	2
	VHF Omni-Range	--	--	2
ONBOARD SOFTWARE MODELS	Aerodynamic Control Surfaces *	12/73	J. V. West, JSC, 483-5944	2
	Communications Antenna Switch Logic	--	--	2
	Data Acquisition and Control Buffer	1/74	--	2
	Engine Interface/MPS Engine Controller	--	--	2
	Events Controller	12/73	--	2
	Input/Output Bus	1/74	--	2

* Additional Information Available in Section 5

Table VI. SDL Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
ONBOARD SOFTWARE MODELS (CONT.)	Intercomputer Interface Channels	12/73	--	2
	Mass Memory	1/74	--	2
	Master Timing	12/73	B. F. Cockrell, JSC, 483-6181	2
	Performance Monitoring System		--	2
	Reaction Jet Driver	--	--	2
	Thrust Vector Control Driver	--	--	2
PAYLOAD ACCOMMODATION AREA	Manipulator	--	--	2
COCKPIT AND SIMULATOR ENVIRONMENT	Cockpit Displays	1/74	--	2
	Crew Simulation	1/74	--	2
	Display Electronics Unit/ Cathode Ray Tube	1/74	--	2
	Keyboard	1/74	--	2
	Manual Controls	1/74	--	2
	Recorder Controls	--	--	2
THERMAL AND ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS	Environmental Control and Life Support System	--	--	2
	Thermal Protection System	--	--	2
ELECTRICAL-MECHANICAL POWER SYSTEMS	Electrical Power System	--	--	2
	Pyrotechnics	--	--	2

Table VI. SDL Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
OTHER	Conic Routines	--	--	2
	Coordinate Systems and Transformations: Non-Vehicle Dependent	12/73	J. B. Williamson, JSC, 483-3278	2
	Coordinate Systems and Transformations: Vehicle Dependent	12/73	J. B. Williamson, JSC, 483-3278	2
	Earth Relative Vector	--	--	2
	Orbital Parameters	--	--	2
	Refraction Correction of Electromagnetic Waves	--	--	2

Table VII. SDSS Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
NATURAL ENVIRONMENT	Air Density		D. Gilbert, JSC, 483-2381	8
	Air Pressure		D. Gilbert, JSC, 483-2381	8
	Earth Characteristics		D. Gilbert, JSC, 483-2381	8
	Gravitational Gradient		D. Gilbert, JSC, 483-2381	8
	Gravity Potential		D. Gilbert, JSC, 483-2381	8
	Runway Topography		D. Gilbert, JSC, 483-2381	8
	Speed of Sound		D. Gilbert, JSC, 483-2381	8
	Sun Angle		D. Gilbert, JSC, 483-2381	8
	Turbulence		D. Gilbert, JSC, 483-2381	8
	Winds		D. Gilbert, JSC, 483-2381	8
PROPULSION SYSTEMS	Orbital Maneuver System		D. Gilbert, JSC, 483-2381	8
	Reaction Control System		D. Gilbert, JSC, 483-2381	8
	Solid Rocket Boosters		D. Gilbert, JSC, 483-2381	8
	Space Shuttle Main Engine		D. Gilbert, JSC, 483-2381	8
VEHICLE DYNAMICS	Body Dynamics Rotational		D. Gilbert, JSC, 483-2381	8
	Body Dynamics Translational		D. Gilbert, JSC, 483-2381	8
	Rigid Body Aerodynamics		D. Gilbert, JSC, 483-2381	8
	Rollout Forces & Moments		D. Gilbert, JSC, 483-2381	8
	Third Body Dynamics		D. Gilbert, JSC, 483-2381	8
SPECIALIZED VEHICLE DYNAMICS	Bending		D. Gilbert, JSC, 483-2381	8
	Flexible Body Aerodynamics		D. Gilbert, JSC, 483-2381	8
	Separation Influence Coefficient		D. Gilbert, JSC, 483-2381	8
	Slosh		D. Gilbert, JSC, 483-2381	8
	Tail-Wags-Dog		D. Gilbert, JSC, 483-2381	8
EQUATIONS OF MOTION	Direction Cosines		D. Gilbert, JSC, 483-2381	8
	Euler Angle Generation		D. Gilbert, JSC, 483-2381	8
	Integration & Predictors		D. Gilbert, JSC, 483-2381	8
	Mass Properties		D. Gilbert, JSC, 483-2381	8
	Mass Variation		D. Gilbert, JSC, 483-2381	8
	Moments		D. Gilbert, JSC, 483-2381	8

Table VII. SDSS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
COMMUNICATION/ NAVIGATION/ TRACKING DEVICES	Accelerometer-Body Mounted		D. Gilbert, JSC, 483-2381	8
	Instrument Landing System		D. Gilbert, JSC, 483-2381	8
	Inertial Measurement Unit		D. Gilbert, JSC, 483-2381	8
	Precision Ranging		D. Gilbert, JSC, 483-2381	8
	Radio Altimeter		D. Gilbert, JSC, 483-2381	8
	Star Sensor/Tracker		D. Gilbert, JSC, 483-2381	8
	TACAN		D. Gilbert, JSC, 483-2381	8
ONBOARD SOFT-WARE MODELS	Approach and Landing (Autoland)		D. Gilbert, JSC, 483-2381	8
	Atmospheric Flight Control System		D. Gilbert, JSC, 483-2381	8
	Boost		D. Gilbert, JSC, 483-2381	8
	Boost Abort		D. Gilbert, JSC, 483-2381	8
	DAP Executive		D. Gilbert, JSC, 483-2381	8
	DAP Library		D. Gilbert, JSC, 483-2381	8
	Deorbit Guidance and Navigation		D. Gilbert, JSC, 483-2381	8
	Entry Control System		D. Gilbert, JSC, 483-2381	8
	Guidance Executive		D. Gilbert, JSC, 483-2381	8
	Guidance Library		D. Gilbert, JSC, 483-2381	8
	Main Engine Thrust Vector Control		D. Gilbert, JSC, 483-2381	8
	OMS-Thrust Vector Control		D. Gilbert, JSC, 483-2381	8
	On-Orbit RCS Control		D. Gilbert, JSC, 483-2381	8
	Orbital Powered Flight		D. Gilbert, JSC, 483-2381	8
	Performance Monitoring System		D. Gilbert, JSC, 483-2381	8
	Rendevous Guidance and Navigation		D. Gilbert, JSC, 483-2381	8
	Rollout (Autoland)		D. Gilbert, JSC, 483-2381	8
	Terminal Area Energy Management		D. Gilbert, JSC, 483-2381	8

Table VII. SDSS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON ORGANIZATION, PHONE	REFERENCE NUMBER
PAYLOAD ACCOMMODATION AREA	Manipulator Arm Dynamics		D. Gilbert, JSC, 483-2381	8
	Manipulator Motors		D. Gilbert, JSC, 483-2381	8
	Payload Handler		D. Gilbert, JSC, 483-2381	8
	Payload Handling (Manipulator)		D. Gilbert, JSC, 483-2381	8
	Payload Monitor		D. Gilbert, JSC, 483-2381	8
COCKPIT AND SIMULATOR ENVIRONMENT	Celestial Sphere Drive Display		D. Gilbert, JSC, 483-2381	8
	Earth Drive Display		D. Gilbert, JSC, 483-2381	8
	Gimbal Drive Display		D. Gilbert, JSC, 483-2381	8
	Horizon Display		D. Gilbert, JSC, 483-2381	8
	Manipulator Arms Display		D. Gilbert, JSC, 483-2381	8
	Probe Drive Display		D. Gilbert, JSC, 483-2381	8
	Star Tracker Display		D. Gilbert, JSC, 483-2381	8
	Sun Display		D. Gilbert, JSC, 483-2381	8
	Visual Scene Generator Drive		D. Gilbert, JSC, 483-2381	8
ELECTRICAL-MECHANICAL POWER SYSTEMS	Electronic Explosive Devices		D. Gilbert, JSC, 483-2381	8
	Elevons Actuator		D. Gilbert, JSC, 483-2381	8
	Landing Gear Actuator		D. Gilbert, JSC, 483-2381	8
	Nosewheel Steering Actuator		D. Gilbert, JSC, 483-2381	8
	OMS Actuator		D. Gilbert, JSC, 483-2381	8
	Payload Door Actuator		D. Gilbert, JSC, 483-2381	8
	RCS Jet Door Actuator		D. Gilbert, JSC, 483-2381	8
	Rudder Actuator		D. Gilbert, JSC, 483-2381	8
	Speed Brake Actuator		D. Gilbert, JSC, 483-2381	8
	SRB Actuator		D. Gilbert, JSC, 483-2381	8
	SSME Actuator		D. Gilbert, JSC, 483-2381	8

Table VIII. SMS Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
NATURAL ENVIRONMENT	Atmosphere (see Aerodynamics)	--	C. C. Olasky, JSC, 483-2481	6
	Wind and Gust (see Aerodynamics)	--	C. C. Olasky, JSC, 483-2481	6
	Celestial Body Direction*	--	C. C. Olasky, JSC, 483-2481	6
	Earth Orientation*	--	C. C. Olasky, JSC, 483-2481	6
	Terrain (see Navaids Radar Altimeter Subsystem)	--	C. C. Olasky, JSC, 483-2481	6
PROPULSION SYSTEMS	Main Engine Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Orbital Maneuvering Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Reaction Control Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Solid Rocket Motors Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
VEHICLE DYNAMICS	Aerodynamics-Shuttle*	--	C. C. Olasky, JSC, 483-2481	6
	Aeroflight Aerodynamics - Target Vehicle*	--	C. C. Olasky, JSC, 483-2481	6
	Drag Chute Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Landing Gear Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Spaceflight Aerodynamics-Target Vehicle*	--	C. C. Olasky, JSC, 483-2481	6
SPECIALIZED VEHICLE DYNAMICS	Bending	--	C. C. Olasky, JSC, 483-2481	6
	Docking Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Slosh	--	C. C. Olasky, JSC, 483-2481	6

* Additional Information Available in Section 5

Table VIII. SMS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
EQUATIONS OF MOTION	Mass Properties-Shuttle*	--	C. C. Olasky, JSC, 483-2481	6
	Mass Properties-Target Vehicle*	--	C. C. Olasky, JSC, 483-2481	6
	Rotational EOM and Attitude Control-Target Vehicle*	--	C. C. Olasky, JSC, 483-2481	6
	Rotational EOM-Shuttle*	--	C. C. Olasky, JSC, 483-2481	6
	Translational EOM & Propulsion-Target Vehicle*	--	C. C. Olasky, JSC, 483-2481	6
	Translational EOM-Shuttle*	--	C. C. Olasky, JSC, 483-2481	6
COMMUNICATION/ NAVIGATION/ TRACKING DEVICES	Air Data Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Body Accelerometers Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	DCS Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	IMU Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Navaids ATC Transponder Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Navaids ILS Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Navaids MLS Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Navaids Radar Altimeter Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Rate Sensors Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Rendezvous Radar Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	S-Band Communications Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Star Tracker Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	TLM Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	UHF Communications Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	VHF Communications Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Wide Band Data Link Subsystem	--	C. C. Olasky, JSC, 483-2481	6

* Additional Information Available in Section 5

Table VIII. SMS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
ONBOARD SOFTWARE MODELS	Aerosurface Control Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	External Tank Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	MPS TVS Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	OMS TVC Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	SRM TVC Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Target Vehicle Guidance and Control Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
PAYLOAD ACCOMMODATION AREA	Payload Attachment Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Payload Bay Doors Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Payload Illumination Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Payload Manipulator Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Payload TV Subsystem	--	C. C. Olasky, JSC, 483-2481	6
COCKPIT AND SIMULATOR ENVIRONMENT	Advanced Training	--	C. C. Olasky, JSC, 483-2481	6
	Aural Cue	--	C. C. Olasky, JSC, 483-2481	6
	Caution & Warning Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	CRT Interactive Processor	--	C. C. Olasky, JSC, 483-2481	6
	CRT Pages	--	C. C. Olasky, JSC, 483-2481	6
	Data Recording	--	C. C. Olasky, JSC, 483-2481	6
	Instructor Aids	--	C. C. Olasky, JSC, 483-2481	6
	Intercom Switching Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Master Control	--	C. C. Olasky, JSC, 483-2481	6
	Master Timing	--	C. C. Olasky, JSC, 483-2481	6
	MCC Interface TLM, DCS, Trajectory Interface	--	C. C. Olasky, JSC, 483-2481	6
	Motion	--	C. C. Olasky, JSC, 483-2481	6
	Operational Instrumentation*	--	C. C. Olasky, JSC, 483-2481	6
	Real-Time Input/Output	--	C. C. Olasky, JSC, 483-2481	6
	Recorder Control Logic Subsystem	--	C. C. Olasky, JSC, 483-2481	6

* Additional Information Available in Section 5

Table VIII. SMS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
COCKPUT AND SIMULATOR ENVIRONMENT (CONTINUED)	Supplementary Control for IOS	--	C. C. Olasky, JSC, 483-2481	6
	Supplementary Display for IOS	--	C. C. Olasky, JSC, 483-2481	6
	Synchronous Simulation Program Processor	--	C. C. Olasky, JSC, 483-2481	6
	Visual Aft	--	C. C. Olasky, JSC, 483-2481	6
	Visual Forward	--	C. C. Olasky, JSC, 483-2481	6
	Voice Recorder	--	C. C. Olasky, JSC, 483-2481	6
THERMAL AND ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM	Environmental Control	--	C. C. Olasky, JSC, 483-2481	6
	Thermal Control Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Thermal Protection Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
ELECTRICAL-MECHANICAL POWER SYSTEMS	Auxiliary Power Subsystem	--	C. C. Olasky, JSC, 483-2481	6
	Electrical Power Subsystem*	--	C. C. Olasky, JSC, 483-2481	6
	Hydraulic Power Subsystem*	--	C. C. Olasky, JSC, 483-2481	6

* Additional Information Available in Section 5

Table IX. SSFS Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
NATURAL ENVIRONMENT	ATM4*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	ATM5*	Operational	J. E. Vinson, Lockheed, 33304875	11
	GGT1*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	GRAV2*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	GRAV3*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	POSSUM*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	WIND3*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	WIND4*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	WIND5*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	WIND6*	Operational	J. E. Vinson, Lockheed, 333-4875	39
	WIND7*	Operational	J. E. Vinson, Lockheed, 333-4875	40
PROPULSION SYSTEMS	RCS1*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	RCS3*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	RCS4*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	RCS10*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	RCS11*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	RCS12*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	RCS13*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	RCS15*	Operational	J. E. Vinson, Lockheed, 333-4875	37
	RCS16*	Operational	J. E. Vinson, Lockheed, 333-4875	38
	THR2*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	THR3	Operational	J. E. Vinson, Lockheed, 333-4875	11
	THR6*	Operational	J. E. Vinson, Lockheed, 333-4875	11
VEHICLE DYNAMICS	AERO11*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AERO16*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AERO17*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AERO18*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AERO19*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AERO21*	Operational	J. E. Vinson, Lockheed, 333-4875	33

* Additional Information Available in Section 5

Table IX. SSFS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTRACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
SPECIALIZED VEHICLE DYNAMICS	BEND1*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	SLSH1*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	Tail-Wags-Dog (see TVC3)	Operational	J. E. Vinson, Lockheed, 333-4875	11
EQUATIONS OF MOTION	ATERP	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AVEH1*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AVEH2*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AVEH5*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AVEH6*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AVEH12*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AVEH13*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AVEH14*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	AVEH15*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	DIFEQ2*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	MASS4*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	MASS5*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	MASS16*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	MASS17*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	MASS18*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	MASS19*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	MASS20*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	MASS21*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	MASS23*	Operational	J. E. Vinson, Lockheed, 333-4875	35
	MASS24*	Operational	J. E. Vinson, Lockheed, 333-4875	36
	PVEH1*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	TRAJMT*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	TRJMTD*	Operational	J. E. Vinson, Lockheed, 333-4875	11

* Additional Information Available in Section 5

Table IX. SSFS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
COMMUNICATIONS/ NAVIGATION/ TRACKING DEVICES	IMU3*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	IMU6*	Operational	J. E. Vinson, Lockheed, 333-4875	34
	LNDA2*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	RSEN1	Operational	J. E. Vinson, Lockheed, 333-4875	11
	RSEN2*	Operational	J. E. Vinson, Lockheed, 333-4875	11
ONBOARD SOFTWARE MODELS	ACS8*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	ACS9*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	ACS10*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	ACS11*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	ACS12*	Operational	J. E. Vinson, Lockheed, 333-4875	30
	ACS13*	Operational	J. E. Vinson, Lockheed, 333-4875	31
	ACS14*	Operational	J. E. Vinson, Lockheed, 333-4875	32
	DELVT2*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	ORBITR*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	TVC2*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	TVC3*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	TVC6*	Operational	J. E. Vinson, Lockheed, 333-4875	11
OTHER	APIC*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	CECIAP	Operational	J. E. Vinson, Lockheed, 333-4875	11
	EULER	Operational	J. E. Vinson, Lockheed, 333-4875	11
	EULERD*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	EXTRCT	Operational	J. E. Vinson, Lockheed, 333-4875	11
	LLCONV	Operational	J. E. Vinson, Lockheed, 333-4875	11
	ORBP1*	Operational	J. E. Vinson, Lockheed, 333-4875	11
	ORBIT1	Operational	J. E. Vinson, Lockheed, 333-4875	11

* Additional Information Available in Section 5

Table X. SVDS Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
NATURAL	AROCAL*	Operational	Ernest M. Fridge,III, JSC, 483-3532	12
ENVIRONMENT	ATMOS*	Operational	Ernest M. Fridge,III, JSC, 483-3532	12
	ATMSPL*	Operational	Ernest M. Fridge,III, JSC, 483-3532	12
	GRAVTY*	Operational	Ernest M. Fridge,III, JSC, 483-3532	13
PROPULSION	MAENG*	Operational	Ernest M. Fridge,III, JSC, 483-3532	15
SYSTEMS	RCSENG*	Operational	Ernest M. Fridge,III, JSC, 483-3532	16
	THROTL*	Operational	Ernest M. Fridge,III, JSC, 483-3532	17
VEHICLE	AERORD*	Operational	Ernest M. Fridge,III, JSC, 483-3532	12
DYNAMICS	ARODYN*	Operational	Ernest M. Fridge,III, JSC, 483-3532	12
	ARO3S1*	Operational	Ernest M. Fridge,III, JSC, 483-3532	12
	ARO3S6*	Operational	Ernest M. Fridge,III, JSC, 483-3532	12
	EQCOM*	Operational	Ernest M. Fridge,III, JSC, 483-3532	13
SPECIALIZED	BEND*	Operational	Ernest M. Fridge,III, JSC, 483-3532	12
VEHICLE	CONTAC*	Operational	Ernest M. Fridge,III, JSC, 483-3532	12
DYNAMICS	GRSHOP*	Operational	Ernest M. Fridge,III, JSC, 483-3532	13
	LINKS*	Operational	Ernest M. Fridge,III, JSC, 483-3532	14
	PLUME*	Operational	Ernest M. Fridge,III, JSC, 483-3532	15
	SLOSH*	Operational	Ernest M. Fridge,III, JSC, 483-3532	16
EQUATIONS OF	INTEGR*	Operational	Ernest M. Fridge,III, JSC, 483-3532	14
MOTION	ROTDER*	Operational	Ernest M. Fridge,III, JSC, 483-3532	16
	TDER1*	Operational	Ernest M. Fridge,III, JSC, 483-3532	17
	TRNDER*	Operational	Ernest M. Fridge,III, JSC, 483-3532	17
	VARMAS*	Operational	Ernest M. Fridge,III, JSC, 483-3532	17
COMMUNICATIONS/	ALTIMB*	Operational	Ernest M. Fridge,III, JSC, 483-3532	24
NAVIGATION/	ALTIMR*	Operational	Ernest M. Fridge,III, JSC, 483-3532	24
TRACKING	GLOAD*	Operational	Ernest M. Fridge,III, JSC, 483-3532	13
DEVICES	PLATFM*	Operational	Ernest M. Fridge,III, JSC, 483-3532	24
	RNDPLT*	Operational	Ernest M. Fridge,III, JSC, 483-3532	24
	TVPLT*	Operational	Ernest M. Fridge,III, JSC, 483-3532	24
	VSINSD*	Operational	Ernest M. Fridge,III, JSC, 483-3532	24

* Additional Information Available in Section 5

Table X. SVDS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PLAN	REFERENCE NUMBER
ONBOARD SOFTWARE MODELS	ACMEAS	Operational	Ernest M. Fridge, III, JSC, 483-3532	12
	AZTTAR*	Operational	Ernest M. Fridge, III, JSC, 483-3532	12
	BURN	Operational	Ernest M. Fridge, III, JSC, 483-3532	12
	CIRC	Operational	Ernest M. Fridge, III, JSC, 483-3532	12
	CONGID	Operational	Ernest M. Fridge, III, JSC, 483-3532	12
	CONSTG	Operational	Ernest M. Fridge, III, JSC, 483-3532	12
	DAP*	Operational	Ernest M. Fridge, III, JSC, 483-3532	24
	DAP3D	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	DAP509	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	DEORB	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	FILTER	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	GDALGN	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	GDORI	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	GIMBAL	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	GTURN*	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	GUID	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	LAGS	Operational	Ernest M. Fridge, III, JSC, 483-3532	14
	LANDAP	Operational	Ernest M. Fridge, III, JSC, 483-3532	14
	NAV	Operational	Ernest M. Fridge, III, JSC, 483-3532	15
	OBERR	Operational	Ernest M. Fridge, III, JSC, 483-3532	15
	PHSPLN	Operational	Ernest M. Fridge, III, JSC, 483-3532	15
	PHZPLN*	Operational	Ernest M. Fridge, III, JSC, 483-3532	15
	RANGF	Operational	Ernest M. Fridge, III, JSC, 483-3532	16
	SDBP	Operational	Ernest M. Fridge, III, JSC, 483-3532	16
	SEPD	Operational	Ernest M. Fridge, III, JSC, 483-3532	16
	STEER*	Operational	Ernest M. Fridge, III, JSC, 483-3532	16
	SURCON*	Operational	Ernest M. Fridge, III, JSC, 483-3532	16
	VARGID	Operational	Ernest M. Fridge, III, JSC, 483-3532	17

* Additional Information Available in Section 5

Table X. SVDS Math Models (Continued)

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
THERMAL AND ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS	ABLTPS	Operational	Ernest M. Fridge, III, JSC, 483-3532	12
	HTRATE	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	RE	Operational	Ernest M. Fridge, III, JSC, 483-3532	16
	SUPORT	Operational	Ernest M. Fridge, III, JSC, 483-3532	16
	TI	Operational	Ernest M. Fridge, III, JSC, 483-3532	17
	TPS*	Operational	Ernest M. Fridge, III, JSC, 483-3532	17
	WINSL	Operational	Ernest M. Fridge, III, JSC, 483-3532	17
	WSKIN	Operational	Ernest M. Fridge, III, JSC, 483-3532	17
ELECTRICAL-MECHANICAL POWER SYSTEMS	GMDACT*	Operational	Ernest M. Fridge, III, JSC, 483-3532	13
	SURCON	Operational	Ernest M. Fridge, III, JSC, 483-3532	16

* Additional Information Available in Section 5

Table XI. SLS Math Models

CATEGORY NAME	MODEL NAME	FORMULATION COMPLETION DATE	CONTACT PERSON, ORGANIZATION, PHONE	REFERENCE NUMBER
NATURAL ENVIRONMENT	ELLPSOID	Operational	Lance Drane, Draper Lab, (617)258-1178	28
	OBLTGRAV*	Operational	Lance Drane, Draper Lab, (617)258-1178	28
	OTHRBDYS	Operational	Lance Drane, Draper Lab, (617)258-1178	28
	REFTOFIX*	Operational	Lance Drane, Draper Lab, (617)258-1178	28
PROPULSION SYSTEMS	ACPS*	Operational	Lance Drane, Draper Lab, (617)258-1178	28
	OMS THRUST*	Operational	Lance Drane, Draper Lab, (617)258-1178	28
EQUATIONS OF MOTION	MASSPROP*	Operational	Lance Drane, Draper Lab, (617)258-1178	28
	TARGET*	Operational	Lance Drane, Draper Lab, (617)258-1178	28
COMMUNICATIONS/ NAVIGATION TRACKING DEVICES	DOPPLER	Operational	Lance Drane, Draper Lab, (617)258-1178	28
	IMU4GIM*	Operational	Lance Drane, Draper Lab, (617)258-1178	28
	RRADAR*	Operational	Lance Drane, Draper Lab, (617)258-1178	28
	STARTRAK*	Operational	Lance Drane, Draper Lab, (617)258-1178	28
ONBOARD SOFTWARE MODELS	OMS TVC*	Operational	Lance Drane, Draper Lab, (617)258-1178	28

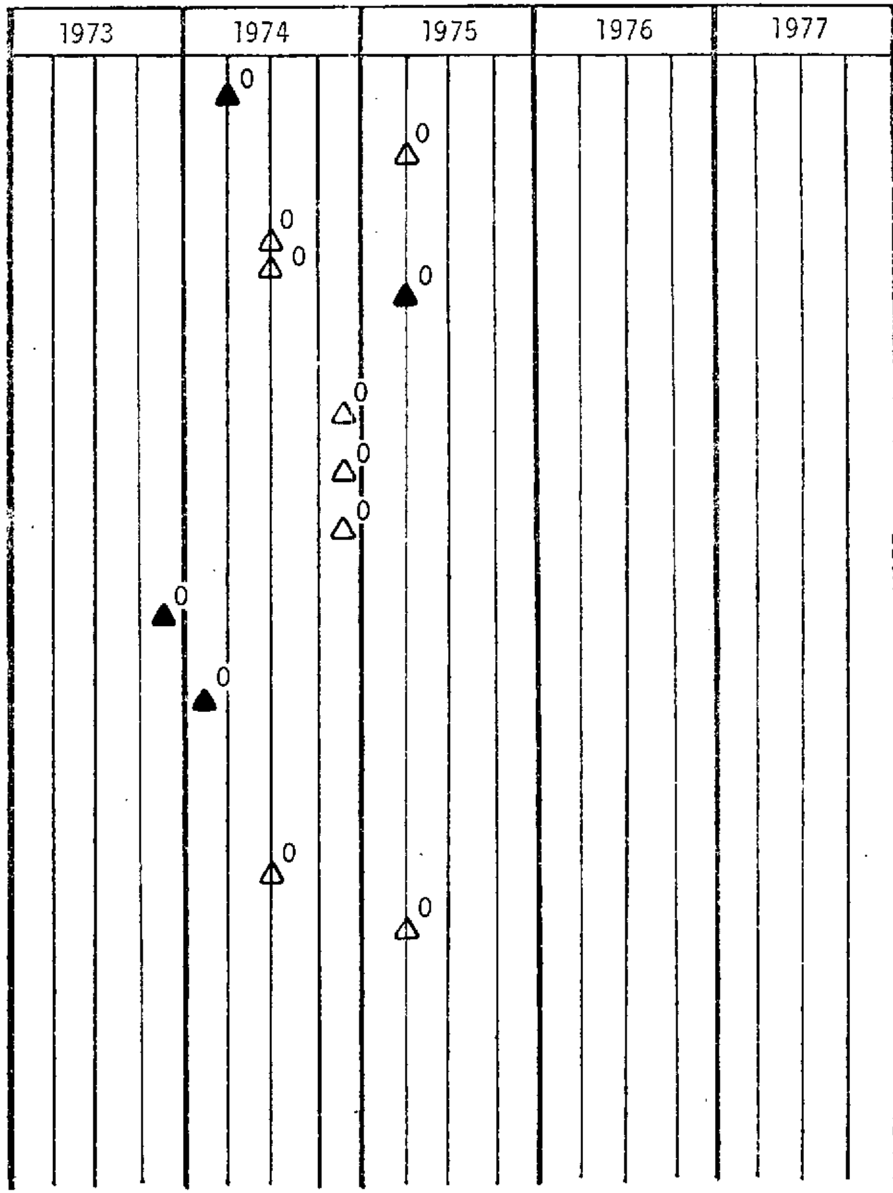
* Additional Information Available in Section 5

7.0 SIMULATION SCHEDULE DATA

The information presented in this section consists of model schedule data. The section is arranged by simulation, in alphabetical order, then by category, and finally by model name. The time intervals are divided into calendar year quarters. Scheduled and completed model information is presented for software requirements, development, and models which are operational.

ADL MATH MODELS

CATEGORY NAME	MODEL NAME
EQUATIONS OF MOTION	Guidance & Navigation Attitude and Pointing OFP
	Guidance and Navigation Propagation OFP
COMMUNICATIONS/ NAVIGATION/TRACKING DEVICES	Accelerometer Assembly TSP
	Air Data Transducer Asembly TSP
	Guidance & Navigation Beacon Search and Navigation Sensor Pointing OFP
	Inertial Measurement Unit Alignment OFP
	Inertial Measurement Unit Calibration OFP
	Inertial Measurement Unit Processing OFP
	Inertial Measurement Unit TSP
	Microwave Scan Bean Landing System TSP
	Multiplexer/Demultiplexer Breadboard TSP
	Multiplexer/Demultiplexer Prototype TSP
	Pulse Code Modulation Master TSP
	Rate Gyro Assembly TSP
	TACAN Processing OFP
	TACAN TSP



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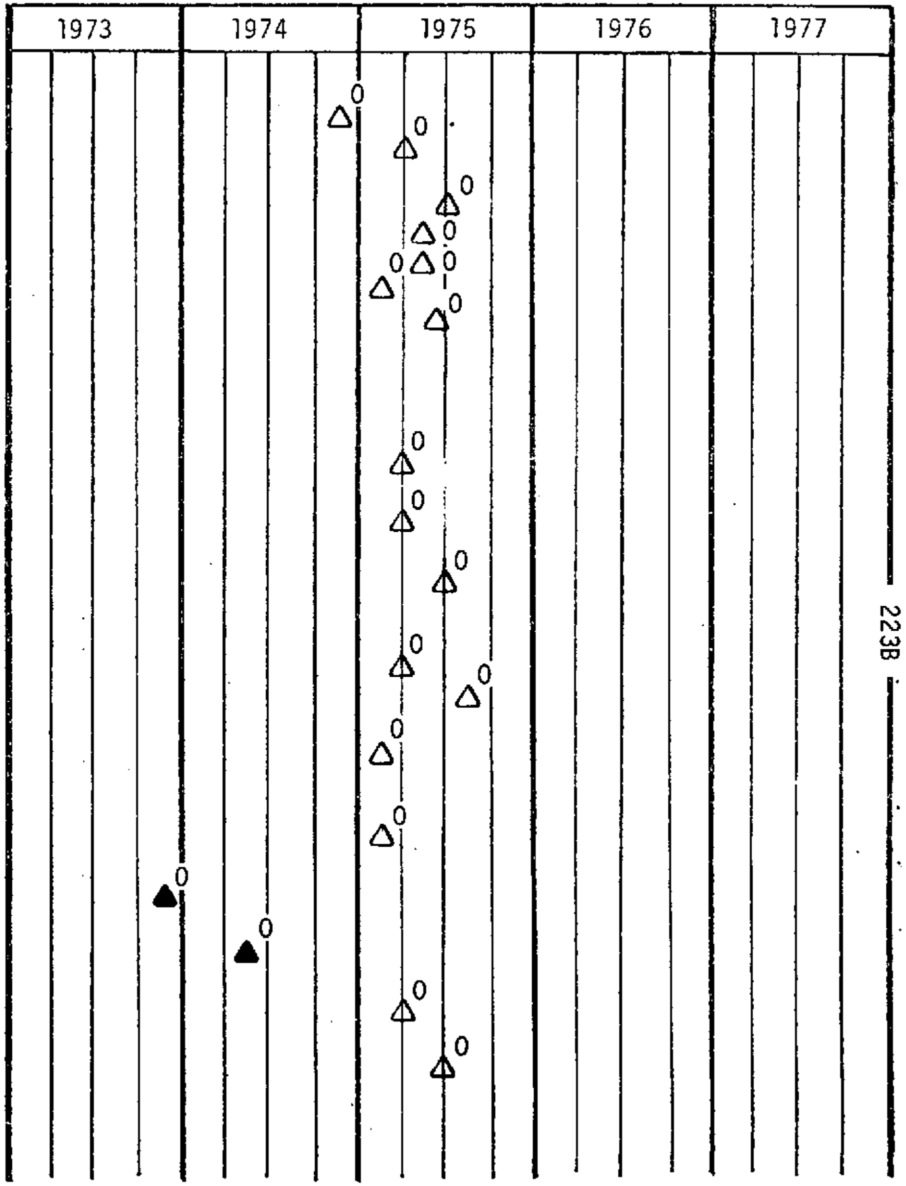
R-Requirements, D-Development, O-Operational, ∆-Scheduled, ▲-Completed

ADL MATH MODELS (Continued)

CATEGORY NAME	MODEL NAME
ONBOARD SOFTWARE MODELS	Engine Interface Unit TSP
	Flight Computer Operating System OFP
	Flight Control Cruise OFP
	Flight Control Fault Tolerance OFP
	Flight Control Landing OFP
	Flight Control TAEM OFP
	Flight Control Takeoff OFP
	Guidance & Navigation Approach/ Landing (Autoland) OFP
	Guidance & Navigation Area Navigation OFP
	Guidance & Navigation Control Processing
	Guidance & Navigation Cruise (Horizontal & Ferry) Flight OFP
	Guidance & Navigation Fault Tolerance OFP
	Guidance & Navigation Filter OFP
	Guidance & Navigation Multi-Phase Operations OFP
	Guidance & Navigation Preflight Software OFP
	Guidance & Navigation Postflight Software OFP
	Input/Output Box (IOB) Breadboard TSP
	Mass Memory TSP
	Navigation Timing, Sequencing and Control OFP
	TAEM OFP

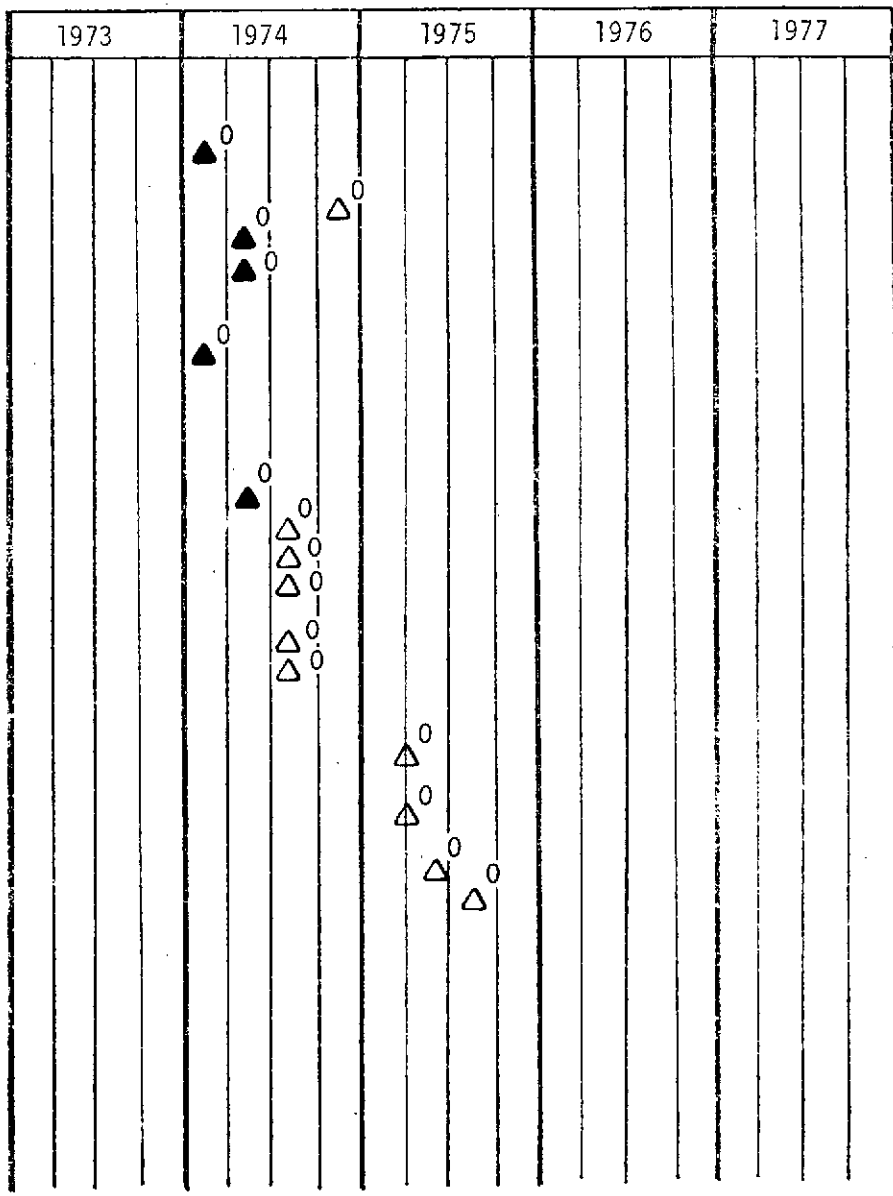


Revision 1
31 May 1974

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

ADL MATH MODELS (Continued)

CATEGORY NAME	MODEL NAME
COCKPIT AND SIMULATOR ENVIRONMENT	Angle/Surface Gimbal Indicator
	Annunciator Driver Unit PM
	AP-101 TSP
	Display Decoder Driver TSP
	Display Electronics Unit TSP
	Display Unit TSP
	Flight Log Recorder
	Guidance & Navigation Crew Station Display Processing
	Guidance & Navigation Dedicated Display Processing OFP
	Keyboard TSP
	Rotation Hand Controller TSP
	Rudder Pedal Transducer Assembly TSP
	Speed Brake Hand Controller TSP
ELECTRICAL-MECHANICAL POWER SYSTEMS	Aerosurface Servo Amplifier TSP
	Dual Aerosurface Servo Amplifier TSP
OTHER	Guidance & Navigation Environment Models
	Guidance & Navigation Landing Site and/or Way Point OFP
	Input Output Processor #1 TSP
	State Vector OFP



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Revision 1
31 May 1974

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

CSDD MATH MODELS

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
NATURAL ENVIRONMENT	Atmospheric Density and Acoustic Velocity					
	Gravity					
	Runway Surface					
	Wind and Gusts					
VEHICLE DYNAMICS	Aerodynamic Coefficients					
	Landing Gear					
EQUATIONS OF MOTION	Physical Characteristics					
	Rotational Equations of Motion					
	Translational Equations of Motion					
COMMUNICATIONS/ NAVIGATION/TRACKING DEVICES	Accelerometer					
	ILS					
	Pressure Altimeter					
	Radar Altimeter					
	TACAN					
ONBOARD SOFTWARE MODELS	Control System					
COCKPIT AND SIMULATOR ENVIRONMENT	Aural Characteristics					
	Cockpit Gages, Meters, Indicators, Switches, and Levers					
	Scene Characteristics					

R-Requirements, D-Development, O-Operational, △-Scheduled, ▲-Completed

FDSC MATH MODELS

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
NATURAL ENVIRONMENT	Air Data, Wind and Wind Gusts					
	Atmosphere					
	Gravity					
VEHICLE DYNAMICS	Main Landing Gear & Nosewheel					
	Vehicle Aerodynamics					
SPECIALIZED VEHICLE DYNAMICS	Bending					
	Slosh					
	Tail-Wags-Dog					
EQUATIONS OF MOTION	Equations of Motion					
	Mass Properties (Orbiter)					
COMMUNICATIONS/ NAVIGATION/TRACKING DEVICES	Air Data Sensor					
	Body Mounted Rate Gyro					
	IMU					
	Microwave Scan Beam Landing System					
	Navaids					
	Normal/Lateral Accelerometer					
	TACAN					
COCKPIT AND SIMULATOR ENVIRONMENT	Scene Generation					

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R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

OAS MATH MODELS

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
NATURAL ENVIRONMENT	Atmosphere (see Aerodynamics)	▲ O				
	Gravity	▲ O				
	Wind and Gust (see Aerodynamics)	▲ O				
PROPULSION SYSTEMS	Reaction Control System	▲ O				
VEHICLE DYNAMICS	Aerodynamics	▲ O				
	Deceleration System					
	Landing Gear	▲ O				
EQUATIONS OF MOTION	Attitude	▲ O				
	Rotational Equations of Motion	▲ O				
	Translational Equations of Motion	▲ O				
	Weights and Balances	▲ O				
COMMUNICATIONS/ NAVIGATION/TRACKING DEVICES	Accelerometers	▲ O				
	Microwave Landing System	▲ O				
	Rate Gyros	▲ O				
	TACAN	▲ O				
ONBOARD SOFTWARE MODELS	Aerosurface Control Surfaces (see Aerodynamics)	▲ O				
	Auto Flight Modes	▲ O				
	Flight Control System	▲ O				
	TAEM	▲ O				
COCKPIT AND SIMULATOR ENVIRONMENT	System Displays	▲ O				
ELECTRICAL-MECHANICAL POWER SYSTEMS	Aerosurface Actuators	▲ O				
OTHER	Parameter EOM	▲ O				

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R-Requirements, D-Development, O-Operational, △-Scheduled, ▲-Completed

SDL MATH MODELS

1973 | 1974 | 1975 | 1976 | 1977

CATEGORY NAME	MODEL NAME	Milestone
NATURAL ENVIRONMENT	Analytical Ephemeris Generator	
	Atmosphere	▲ D
	Ephemeris	
	Gravity and Oblateness	▲ D
	Gravity Gradient	
	Star Tables	
	Sun-Moon-Earth Ephemerides	
	Terrain	▲ D
	Wind and Gust	▲ D
PROPULSION SYSTEMS	MPS Engines	
	OMS Engines	
	RCS Engines	
	SRB Engines	
VEHICLE DYNAMICS	Aerodynamics	▲ D
	Landing & Deceleration System	▲ D
	Target Dynamics	
SPECIALIZED VEHICLE DYNAMICS	Elastic Body Bending	▲ D
	Slosh	
EQUATIONS OF MOTION	Equations of Motion - Rotational	▲ D
	Equations of Motion - Translational	▲ D
	Mass Properties	▲ D
	Numerical Integrators	

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R-Requirements, D-Development, O-Operational, △-Scheduled, ▲-Completed

SDL MATH MODELS (Continued)

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
COMMUNICATIONS/ NAVIGATION/TRACKING DEVICES	Air Data Sensors	▲D				
	Air Traffic Control Navigation Aid					
	Barometric Altimeter	▲D				
	Inertial Measurement Unit		▲D			
	Microwave Landing System		▲D			
	Multiplexer/Demultiplexer		▲D			
	Normal/Lateral Accelerometers		▲D			
	One-Way Doppler					
	Optical Sensor					
	Radar Altimeter					
	Rate Gyros		▲D			
	Rendezvous Radar					
	Sensor Sites/Reference Ellipsoid					
	Space Ground Link System					
	Star Tracker					
	Tactical Air Navigation		▲D			
	Target Sensor					
	VHF					
	VHF Omni-Range					
ONBOARD SOFTWARE MODELS	Aerodynamic Control Surfaces		▲D			
	Communications Antenna Switch Logic					
	Data Acquisition and Control Buffer		▲D			
	Engine Interface/MPS Engine Controller					
	Events Controller		▲D			
	Input/Output Bus		▲D			

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R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
ONBOARD SOFTWARE MODELS (Continued)	Intercomputer Interface Channels		▲D			
	Mass Memory		▲D			
	Master Timing		▲D			
	Performance Monitoring System					
	Reaction Jet Driver					
	Thrust Vector Control Driver					
PAYLOAD ACCOMMODATION AREA	Manipulator					
COCKPIT AND SIMULATOR ENVIRONMENT	Cockpit Displays		▲D			
	Crew Simulation		▲D			
	Display Electronics Unit/Cathode Ray Tube		▲D			
	Keyboard		▲D			
	Manual Controls		▲D			
	Recorder Controls					
THERMAL AND ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS	Environmental Control and Life Support System					
	Thermal Protection System					
ELECTRICAL-MECHANICAL POWER SYSTEMS	Electrical Power System					
	Pyrotechnics					

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

SDL MATH MODELS (Continued)

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
OTHER	Conic Routines					
	Coordinate Systems and Transformations: Non-Vehicle Dependent		▲ D			
	Coordinate Systems and Transformations: Vehicle Dependent		▲ D			
	Earth Relative Vector					
	Orbital Parameters					
	Refraction Correction of Electromagnetic Waves					

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
NATURAL ENVIRONMENT	Air Density					
	Air Pressure					
	Earth Characteristics					
	Gravitational Gradient					
	Gravity Potential					
	Runway Topography					
	Speed of Sound					
	Sun Angle					
	Turbulence					
	Winds					
PROPULSION SYSTEMS	Orbital Maneuver System					
	Reaction Control System					
	Solid Rocket Boosters					
	Space Shuttle Main Engine					
VEHICLE DYNAMICS	Body Dynamics Rotational					
	Body Dynamics Translational					
	Rigid Body Aerodynamics					
	Rollout Forces and Moments					
	Third Body Dynamics					
SPECIALIZED VEHICLE DYNAMICS	Bending					
	Flexible Body Aerodynamics					
	Separation Influence Coefficient					
	Slosh					
	Tail-Wags-Dog					
EQUATIONS OF MOTION	Direction Cosines					
	Euler Angle Generation					
	Integration and Predictors					
	Mass Properties					
	Mass Variation					
	Moments					

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

SDSS MATH MODELS (Continued)

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
COMMUNICATION/ NAVIGATION/TRACKING DEVICES	Accelerometer-Body Mounted					
	Instrument Landing System					
	Inertial Measurement Unit					
	Precision Ranging					
	Radio Altimeter					
	Star Sensor/Tracker					
	TACAN					
ONBOARD SOFTWARE MODELS	Approach and Landing (Autoland)					
	Atmospheric Flight Control system					
	Boost					
	Boost Abort					
	DAP Executive					
	DAP Library					
	Deorbit Guidance and Navigation					
	Engry Control System					
	Guidance Executive					
	Guidance Library					
	Main Engine Thrust Vector Control					
	OMS-Thrust Vector Control					
	On-Orbit RCS Control					
	Orbital Powered Flight					
	Performance Monitoring System					
	Rendevous Guidance and Navigation					
	Rollout (Autoland)					
	Terminal Area Energy Management					

R-Requirements, D-Development, O-Operational, △-Scheduled, ▲-Completed

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
PAYLOAD ACCOMMODATION AREA	Manipulator Arm Dynamics					
	Manipulator Motors					
	Payload Handler					
	Payload Handling (Manipulator)					
	Payload Monitor					
COCKPIT AND SIMULATOR ENVIRONMENT	Celestial Sphere Drive Display					
	Earth Drive Display					
	Gimbal Drive Display					
	Horizon Display					
	Manipulator Arms Display					
	Probe Drive Display					
	Star Tracker Display					
	Sun Display					
	Visual Scene Generator Drive					
ELECTRICAL-MECHANICAL POWER SYSTEMS	Electronic Explosive Devices					
	Elevons Actuator					
	Landing Gear Actuator					
	Nosewheel Steering Actuator					
	OMS Actuator					
	Payload Door Actuator					
	RCS Jet Door Actuator					
	Rudder Actuator					
	Speed Brake Actuator					
	SRB Actuator					
	SSME Actuator					

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

SMS MATH MODELS

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
NATURAL ENVIRONMENT	Atmosphere (see Aerodynamics)					
	Wind and Gust (see Aerodynamics)					
	Celestial Body Direction					
	Earth Orientation					
	Terrain (see Navaids Radar Altimeter Subsystem)					
PROPULSION SYSTEMS	Main Engine Subsystem					
	Orbital Maneuvering Subsystem					
	Reaction Control Subsystem					
	Solid Rocket Motors Subsystem					
VEHICLE DYNAMICS	Aerodynamics - Shuttle					
	Aeroflight Aerodynamics - Target Vehicle					
	Drag Chute Subsystem					
	Landing Gear Subsystem					
	Spaceflight Aerodynamics - Target Vehicle					
SPECIALIZED VEHICLE DYNAMICS	Bending					
	Docking Subsystem					
	Slosh					
EQUATIONS OF MOTION	Mass Properties - Shuttle					
	Mass Properties - Target Vehicle					
	Rotational EOM and Attitude Control-Target Vehicle					
	Rotational EOM - Shuttle					
	Translational EOM & Propulsion - Target Vehicle					
	Translational EOM - Shuttle					

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
COMMUNICATION/ NAVIGATION/TRACKING DEVICES	Air Data Subsystem					
	Body Accelerometers Subsystem					
	DCS Subsystem					
	IMU Subsystem					
	Navaids ATC Transponder Subsystem					
	Navaids ILS Subsystem					
	Navaids MLS Subsystem					
	Navaids Radar Altimeter Subsystem					
	Rate Sensors Subsystem					
	Rendezvous Radar Subsystem					
	S-Band Communications Subsystem					
	Star Tracker Subsystem					
	TLM Subsystem					
	UHF Communications Subsystem					
	VHF Communications Subsystem					
	Wide Band Data Link Subsystem					
ONBOARD SOFTWARE MODELS	Aerosurface Control Subsystem					
	External Tank Subsystem					
	MPS TVS Subsystem					
	OMS TVC Subsystem					
	SRM TVC Subsystem					
	Target Vehicle Guidance and Control Subsystem					

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R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

SMS MATH MODELS (Continued)

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
PAYLOAD ACCOMMODATION AREA	Payload Attachment Subsystem					
	Payload Bay Doors Subsystem					
	Payload Illumination Subsystem					
	Payload Manipulator Subsystem					
	Payload TV Subsystem					
COCKPIT AND SIMULATOR ENVIRONMENT	Advanced Training					
	Aural Cue					
	Caution & Warning Subsystem					
	CRT Interactive Processor					
	CRT Pages					
	Data Recording					
	Instructor Aids					
	Intercom Switching Subsystem					
	Master Control					
	Master Timing					
	MCC Interface TLM, DCS, Trajectory Interface					
	Motion					
	Operational Instrumentation					
	Real-Time Input/Output					
	Recorder Control Logic Subsystem					
	Supplementary Control for IOS					
	Supplementary Display for IOS					
	Synchronous Simulation Program Processor					
	Visual Aft					
	Visual Forward					
	Voice Recorder					

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
THERMAL AND ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM	Environmental Control					
	Thermal Control Subsystem					
	Thermal Protection Subsystem					
ELECTRICAL-MECHANICAL POWER SYSTEMS	Auxiliary Power Subsystem					
	Electrical Power Subsystem					
	Hydraulic Power Subsystem					

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

SSFS Math Models

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
NATURAL ENVIRONMENT	ATM4	▲O				
	ATM5	▲O				
	GGT1	▲O				
	GRAV2	▲O				
	GRAV3	▲O				
	POSSUM	▲O				
	WIND3	▲O				
	WIND4	▲O				
	WIND5	▲O				
	WIND6	▲O				
	WIND7	▲O				
	WIND8	▲O				
PROPULSION SYSTEMS	RCS1	▲O				
	RCS3	▲O				
	RCS4	▲O				
	RCS10	▲O				
	RCS11	▲O				
	RCS12	▲O				
	RCS13	▲O				
	RCS15	▲O				
	RCS16	▲O				
	THR2	▲O				
	THR3	▲O				
	THR6	▲O				
VEHICLE DYNAMICS	AERO11					
	AERO16	▲O				
	AERO17	▲O				
	AERO18	▲O				
	AERO19	▲O				
	AERO21	▲O				

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
SPECIALIZED VEHICLE DYNAMICS	BEND1	▲O				
	SLSH1	▲O				
	Tail-Wags-Dog (see TVC3)	▲O				
EQUATIONS OF MOTION	ATERP	▲O				
	AVEH1	▲O				
	AVEH2	▲O				
	AVEH5	▲O				
	AVEH6	▲O				
	AVEH12	▲O				
	AVEH13	▲O				
	AVEH14	▲O				
	AVEH15	▲O				
	DIFEQ2	▲O				
	MASS4	▲O				
	MASS5	▲O				
	MASS16	▲O				
	MASS17	▲O				
	MASS18	▲O				
	MASS19	▲O				
	MASS20	▲O				
	MASS21	▲O				
	MASS23	▲O				
	MASS24	▲O				
	PVEH1	▲O				
	TRAJMT	▲O				
	TRJMTD	▲O				

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

SSFS MATH MODELS (Continued)

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
COMMUNICATIONS/ NAVIGATION/TRACKING DEVICES	IMU3	▲O				
	IMU6	▲O				
	LNDA2	▲O				
	RSEN1	▲O				
	RSEN2	▲O				
ONBOARD SOFTWARE MODELS	ACS8	▲O				
	ACS9	▲O				
	ACS10	▲O				
	ACS11	▲O				
	ACS12	▲O				
	ACS13	▲O				
	ACS14	▲O				
	DELVT2	▲O				
	ORBITR	▲O				
	TVC2	▲O				
	TVC3	▲O				
	TVC6	▲O				
OTHER	APIC	▲O				
	CECIAP	▲O				
	EULER	▲O				
	EULERD	▲O				
	EXTRCT	▲O				
	LLCONV	▲O				
	ORBP1	▲O				
	ORBIT1	▲O				

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

SVDS MATH MODELS

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
NATURAL ENVIRONMENT	AROCAL					
	ATMOS	▲ O				
	ATMSPL	▲ O				
	GRAVTY	▲ O				
PROPULSION SYSTEMS	MAENG	▲ O				
	RCSENG	▲ O				
	THROTL	▲ O				
VEHICLE DYNAMICS	AERORD	▲ O				
	ARODYN	▲ O				
	ARO3SI	▲ O				
	ARO3SG	▲ O				
	EQCOM	▲ O				
SPECIALIZED VEHICLE DYNAMICS	BEND	▲ O				
	CONTACT	▲ O				
	GRSHOP	▲ O				
	LINKS	▲ O				
	PLUME	▲ O				
	SLOSH	▲ O				
EQUATIONS OF MOTION	INTEGR	▲ O				
	ROTDER	▲ O				
	TDERI	▲ O				
	TRNDER	▲ O				
	VARMAS	▲ O				
COMMUNICATIONS/ NAVIGATION/TRACKING DEVICES	ALTIMB	▲ O				
	ALTIMR	▲ O				
	GLOAD	▲ O				
	PLATFM	▲ O				
	RNDPLT	▲ O				
	TVPLT	▲ O				
	VSINSD	▲ O				

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SVDS MATH MODELS (Continued)

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
ONBOARD SOFTWARE MODELS	ACMEAS	▲O				
	AXTTAP	▲O				
	BURN	▲O				
	CIRC	▲O				
	CONGID	▲O				
	CONSTG	▲O				
	DAP	▲O				
	DAP3D	▲O				
	DAP509	▲O				
	DEORB	▲O				
	FILTER	▲O				
	GDALGN	▲O				
	GDORI	▲O				
	GIMBAL	▲O				
	GTURN	▲O				
	GUID	▲O				
	LAGS	▲O				
	LANDAP	▲O				
	NAV	▲O				
	OBERR	▲O				
	PHSPLN	▲O				
	PHZPLN	▲O				
	RANGF	▲O				
	SDBP	▲O				
	SEPD	▲O				
	STEER	▲O				
	SURCON	▲O				
	VARGID	▲O				

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

SVDS MATH MODELS (Continued)

CATEGORY NAME	MODEL NAME	1973	1974	1975	1976	1977
THERMAL AND ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS	ABLTPS	▲O				
	HTRATE	▲O				
	RE	▲O				
	SUPORT	▲O				
	TI	▲O				
	TPS	▲O				
	WINSL	▲O				
	WSKIN	▲O				
ELECTRICAL-MECHANICAL POWER SYSTEMS	GNDACT	▲O				
	SURCON	▲O				

R-Requirements, D-Development, O-Operational, Δ-Scheduled, ▲-Completed

ACRONYMS AND ABBREVIATIONS

ABPS	Air Breathing Propulsion System
AC	Alternating Current
ADL	Avionics Development Laboratory
ARC	Ames Research Center
ARFDS	Automatic Reentry Flight Dynamics Simulator
ATC	Air Traffic Control
CDU	Coupling Data Unit
CG	Center of Gravity
CRT	Cathod Ray Tube
CSDD	Control Systems Development Division
CSDL	Charles Stark Draper Laboratory
DAP	Digital Autopilot
DC	Direct Current
DCS	Digital Command Subsystem
DDTS	Dynamic Docking Test System
ECI	Earth-Centered Inertial
ECLSS	Environmental Control and Life Support System
ECS	Environmental Control System
EOM	Equations of Motion
FCHL	Flight Control Hydraulics Laboratory
FCS	Flight Control System
FDSC	Flight Dynamics Simulation Complex
FRC	Flight Research Center
FSAA	Flight Simulator for Advanced Aircraft
FSS	Flight Systems Simutors
ft	Feet
G,g	Gravity
GN&C	Guidance, Navigation, and Control
GSFC	Goddard Space Flight Center
HSL	Hardware Simulation Laboratory
HVSF	Honeywell Verification Simulation Facility
ILS	Instrument Landing System
IMU	Inertial Measurement Unit
IOB	Input/Output Box
IOS	Instructor Operator Station

JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
$J_2, J_3, J_4, C_{22}, S_{22}$	Zonal, Tesseral, and Sectorial Harmonics accounting for deviation in the shapes of the earth's equipotential surfaces from perfect spheres.
K	Thousand
KSC	Kennedy Space Center
LAGS	Launch Abort Guidance Simulation
lbs	Pounds
LPS	Launch Processing System
MCC	Mission Control Center
MCCS	Mission Control Center Simulation
MDAC	McDonnell Douglas Astronautics Company
ME	Main Engine
MLS	Microwave Landing System
MPS	Main Propulsion System
MPTF	Main Propulsion Test Facility
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
NAP	Navigation Analysis Program
OAS	Orbital Aeroflight Simulator
OFP	Operational Flight Programs
OMS	Orbital Maneuvering System
RCS	Reaction Control System
RDS	Rocketdyne Digital Simulator
RHS	Rocketdyne Hybrid Simulator
RI	Rockwell International
SAIL	Shuttle Avionics Integration Laboratory
SDE	Space Division Evaluator
SDL	Software Development Laboratory
SDSS	Space Division Shuttle Simulator
sec	Second
SGOS	Shuttle Ground Operations Simulator
SLS	Statement Level Simulator
SMES	Shuttle Ground Operations Simulator
SMS	Shuttle Mission Simulation

SPS	Shuttle Procedures Simulator
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SSFS	Space Shuttle Functional Simulator
SSME	Space Shuttle Main Engine
STA	Shuttle Training Aircraft
SVDS	Space Vehicle Dynamic Simulation
TACAN	Tactical Air Navigation
TAEM	Terminal Area Energy Management
TCS	Thermal Control System
TLM	Telemetry
TPS	Thermal Protection System
TSP	Test Software Program
TV	Television
TVC	Thrust Vector Control
UHF	Ultra High Frequency
US	United States
VF	Vertical Flight
VHF	Very High Frequency
VORTAC	Site with variable omni-ranging and tactical air navigation equipment.
X,Y,Z	Vector components in an orthogonal coordinate syste
3-D	Three Dimensional
6-D	Six Dimensional

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