

DIGITAL SIMULATION OF AN AEROSPACE VEHICLE

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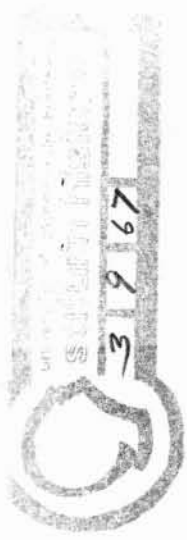
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ABSTRACT

The rapid development of computer technology and the creation of new engineering oriented languages has established that general purpose digital computers are now extremely suitable to perform simulation of large scale physical systems. With Aerospace Vehicle Simulation (AVS), an effort has been undertaken at MSFC to simulate continuous and discrete dynamics of an aerospace vehicle and its ground support equipment on a large digital computer. This simulation produces a copy of the physical vehicle configuration and its functions in the form of a large scale mathematical model in the computer. AVS will be an essential part of an integrated information system which can be used by several laboratories and offices at MSFC for the design, check-out, test, and management of aerospace vehicles.

Previous studies and simulation activity at MSFC have indicated that AVS must include such features as: modularity of computer program; user orientated language; incorporation of existing simulation programs; simulation to various levels of depth, i. e., systems, subsystems and/or component levels; incorporation of various mathematical algorithms and numerical methods to permit optimum performance of the simulation; use of a large variety of new computer features, i. e., time sharing, remote stations, graphical displays; and linkage of the AVS functional data base to the MSFC Configuration Management Data Base.

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This paper describes AVS in terms of the background simulation work and studies leading to its conceptual development and its objectives as related to the activities at MSFC. It also outlines a pilot implementation of AVS as applied to the navigation system of the Saturn V vehicle.

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A. INTRODUCTION

The rapid development of computer technology and the creation of new engineering oriented languages have established that general purpose digital computers are increasingly suitable for simulation of the dynamics of large physical systems. In the Aerospace Vehicle Simulation (AVS) Program, an effort has been undertaken at Marshall Space Flight Center (MSFC), Huntsville, Alabama, to simulate continuous and discrete dynamics of an aerospace vehicle and its ground support equipment (GSE) on a large digital computer. AVS is primarily being developed as a major tool for the checkout of space vehicles, but eventually it will become an essential part of an integrated engineering information system which can be used by various laboratories at MSFC for the design, checkout, and management of space vehicles.

B. OBJECTIVES

The digital simulation system will play a major role in the solution of several problems in the checkout and design evaluation of space vehicles. Thus far in the space program, the completely developed space vehicle has not been built; there are continuous modifications being made to each vehicle. Each time modifications occur, they cause two major problems:

- (1) The effects of these changes on the performance of the vehicle and its GSE must be assessed. Test techniques, procedures, and programs for the checkout and design evaluation of the hardware must be revised. This very often requires repeating a detailed analysis of the system which is time consuming and costly.

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(2) The documentation reflecting the changes is extremely slow in reaching those who need it. Therefore, the analysis and generation of new test procedures and programs is often based on false, outmoded documents.

To alleviate these problems, a centralized, constantly updated data source of the operational functions and configuration of the space vehicle and its GSE is needed to insure the validity and functional integrity of the space vehicle. This centralized data source could be utilized to update and verify operational and checkout functions prior to actual hardware modification. As the space vehicle becomes more intricate and as different missions are planned and flown, an updating or refining of the checkout techniques and methodology is in order. This means that checkout will become more sophisticated and, consequently, checkout personnel must obtain a more thorough knowledge of the operations and functional status of the vehicle systems by performing extensive analysis of the vehicle's functional behavior, more precise determination of test points, and more detailed failure analysis.

Hence, the simulation system would generate an up-to-date reference model of the continuous and discrete dynamics of the actual hardware system.

C. BACKGROUND

Several activities at MSFC which have had a significant input into the simulation program are: automatic generation of functional sequence diagrams,¹ the simulation of discrete networks,^{2,3} the simulation of continuous dynamics using a digital analog simulator program,^{4,5} and finally, a study to derive specifications for a versatile simulation system⁶.

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These previously conducted activities proved the feasibility and established the basic premise of performing a full digital simulation of an aerospace vehicle.

D. REQUIREMENTS OF THE SIMULATION

A few of the requirements of the simulation based upon user demands and interest are representative of the total simulation requirements.

The user needs to be able to select any portion of the vehicle and its GSE and to simulate it at any defined level of depth. The data he is using should correspond to the up-to-date hardware configuration which he is simulating. Therefore, permanent and temporary changes of the hardware have to be immediately reflected by the data base of the simulation system. Modifications of the model should be handled easily by the user. He also wishes freedom in selecting and formatting the outputs after imposing a variety of predetermined conditions on them. In order to obtain control of the simulation, the language for man-machine communications has to be readily understood by the practical engineer. The simulation system should also be capable of accounting for the possibility that several users may want to simulate simultaneously the same system or part of the same system from different locations. In essence, the simulation system has to be of a flexible and evolutionary structure.

These requirements and others led to the selection of the computer hardware system. Basically, a large time-shared digital computer with rapid access bulk storage capacity and remote input/output stations is required. A hybrid computer system is not readily adaptable for this simu-

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lation because the analog portion cannot be time-shared and the wiring of its patchboard cannot be changed as rapidly as a list in a digital computer.

We will discuss the following areas to define more specific requirements:

- (1) Modeling of the vehicle
- (2) Structure of the data base
- (3) Processing of the simulation
- (4) Language
- (5) Control of data base
- (6) Organization of simulation system

1. Modeling of the Vehicle. In checkout, we are concerned with the simulation of the internal functions of a space vehicle. We do not deal with the dynamics of the mechanical structure of the vehicle and the flight trajectories except in basic form to close the guidance and control loop of the vehicle.

In order to checkout a complete vehicle, it is broken into a set of rather independent functional systems, e. g., the Instrument Unit, S-IVB Stage, etc. These systems can be further divided into subsystems, e. g., guidance and control, propulsion, networks, etc. This process of successively breaking down a subsystem into several components of the next lower level can be carried on until we reach the piece-part level.

Each subsystem may be thought of as a functional block which is defined by its name, the names of its input/output variables, and the functional relationships between its input and output variables. If two functional blocks are connected in series, the characteristic of each block

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must not change. The functional relationship is mathematically expressed by a set of characteristic equations. For one hardware subsystem there may be several functional blocks defined, depending on the depth of the simulation. For instance, the stabilized platform may be represented as a first approximation by linear transfer functions of low order. A more sophisticated model will include nonlinearities and high order transfer functions.

There are many ways to mathematically describe the functional relationships between the input variables and output variables of a system, e. g. , differential equations, transfer functions, impulse responses, etc. We distinguish between several large categories of systems: continuous, discrete, and combined continuous/discrete systems. The continuous systems can further be subdivided into linear and nonlinear systems. A discrete system is understood as a system which contains binary variables only, i. e. , on-off states of relays, valves, etc. The functions are represented by Boolean equations associated with pick-up and drop-out time. If a continuous system is combined with a discrete system, threshold conditions have to be considered. A change of state of a discrete variable occurs when a threshold of a continuous signal is exceeded.

2. Structure of Data Base. The central data base shall contain all data that are necessary to describe a vehicle, i. e. , the location, interconnections, and functions of its subsystems and components. These data are stored in a number of lists. We distinguish between three basic data bases, namely the "physical data base", the "parameter data base", and the "functional data base."

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The "physical data base (PHDB)" is part of the Configuration Management Accounting System, which is partly in operation at MSFC, and contains the data that are necessary to manufacture the hardware of a vehicle. It contains in generic order the Contract End Item (CEI) number, part numbers, the location of parts within the equipment, wiring connections, etc. It also includes "technological data", e. g., the inductance of a coil, the elasticity of a spring, etc.

The "functional data base (FDB)" contains a list of functional blocks which describe the functions of components and subsystems. It constitutes the mathematical model of the hardware to be simulated. Each functional block is described by a list of several items; name of block, input and output variables, type of mathematical model, characteristic equations and/or names, and interconnections of functional blocks within this block. Hence, a functional block might be expressed by a series of other functional blocks, which are inside this single block and of successively lower level.

The "parameter data base (PDB)" contains the algebraic equations which generate from the technological data of the PHDB, the functional parameters of the characteristic equations of the FDB.

The three permanent basic data bases are of extensive size and will be stored as master file on magnetic discs.

3. Processing of Simulation. During the processing of the simulation, several basic tasks have to be performed which may be classified as:

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- (1) Preparation of the simulation (pre-simulation)
- (2) Numerical solution of the mathematical equations
(simulation run)
- (3) Utilization of the output signals (post-simulation).

Before the user can start his simulation, he has to select the system(s) he wants to simulate. He then initiates an extraction of the lists of all functional blocks which are required for the simulation from the "master file" to an intermediate file, the "temporary file." If he wants to make some temporary changes for his simulation run, he can modify this file. He also specifies initial conditions. The functional data are then compiled and transferred to a "data working file," which serves as data base for the subroutines to solve the mathematical equations.

To guarantee minimum running time, certain criteria will be established upon which a selection can be made as to what type of mathematical model will be solved by what optimum numerical method. These criteria include stability of solution, computation speed, algebraic loops, storage requirements, etc. Each functional block will have a designator attached that tells which numerical method is recommended. Unless the user overrides this designator through a control statement and chooses another mathematical method from the library, the designated method will be used automatically.

During the actual simulation run, or immediately after the simulation run, the output signals can further be processed to generate outputs. For example, the output signal may be printed only if certain conditions are being met (e. g. , certain voltage limits are exceeded). Additional calculations on the output variables may be performed or comparisons may be made with pre-established values. The output values may be ordered together with other

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items as listings. For the output of data, various types of peripheral equipment may be selected. If the simulation is fast enough, the output signals may be sent directly to hardware as stimuli, or hardware responses may be compared in real time.

4. Language. Since the system to be simulated is specified in terms of functional blocks, a block-diagram-oriented language which uses engineering type expressions is to be strived for. Thereby, a close correspondence between the model and the computer input is guaranteed. Similar to analog simulation languages such as DSL/90⁷, MIMIC⁸, etc., the input format is divided into independent segments, i. e., connection statements, data statements, procedural statements, and control statements.

The "connection" statements describe how the functional blocks are to be connected with one another to form the block diagram which represents the model. The "data statements" specify the values of the parameters and initial conditions. The "procedural statements" describe the functional relationships between the input and output variables. The "control statements" contain all the information to control the large variety of inputs and outputs of the simulation and allow some influence on the internal processing.

All variables and parameters may be designated by any symbolic names which may coincide with those in engineering documentation. No programming knowledge is necessary for the user since all data are written in free form and only a few simple rules must be observed.

The language can easily be expanded by creation of new functional blocks and new statements. If the user violates any of the simple formal rules and/or if inconsistencies occur, the computer will tell the user where and what mistake has been made.

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5. Control of Data Base. Before the simulation system can be put to work, the permanent "functional data base" for those physical systems which are to be simulated must be established. As the first step in the development of this data base, the documentation in form of schematics, reports, etc., must be studied to derive valid mathematical models of the desired different levels of depth for the physical system considered. Through this process the various functional blocks will be determined.

After the validity of the models has been approved, the statements which describe the various functional blocks will be transferred to the permanent master file of the functional data base. To assure that only approved data are stored in the master file, special control schemes have to be applied.

If a permanent design change occurs, it is located by its Contract End Item (CEI) number and part number and initiated in the physical data base. Along with the data statements of the different data bases, special control designators are used which allow a routing of changes from the physical data base to the functional and parameter data bases. If the configuration of the mathematical model is to be modified, the user is notified by a flag which tells him what has been changed in the physical data base, and he can then manually rearrange his model.

A distinction is made between permanent and temporary changes. Permanent changes affect the permanent data base in the master file and occur only when a CEI engineering change has been approved. The master file must be protected against erroneous changes by a system of controls. These controls may be obtained by allowing only one NASA office at MSFC to write into the computer's master file via an individual transmission line.

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All other users of the simulation system would be able to read only from the master file.

The functional data in the bulk storage of the magnetic disc will be grouped with respect to the functional blocks. Each functional block will be stored dynamically at random in order to save storage space and time, because the data base will be continuously changing.

6. Organization of Simulation System. In order to be able to expand the software system at any given phase of its development and to modify it easily, the simulation system is constructed of a number of program modules. The interplay of these program modules is controlled by several monitors and an overall executive monitor (Figure 1).

The program modules perform specific processing functions. Before the actual simulation run starts, the statements of the functional blocks and program modules for the computations are taken from the master file and temporary file, respectively, and compiled into the "working file" in core memory. During the simulation run, the working file only is being used.

Each monitor is responsible for the control of one major processing task: the input, the output, the preparation of the simulation, the simulation run, and the maintenance of the data base (Figure 2). The executive monitor provides the proper sequence of operations of these monitors.

E. IMPLEMENTATION

The Computation Laboratory, in cooperation with the Quality and Reliability Assurance Laboratory of MSFC, NASA, has started as a pilot implementation, the simulation of a restricted, but significant portion

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of a space vehicle, i. e., the guidance and control system of the Saturn V vehicle Instrument Unit, S-IVB Stage and its associated GSE. This system contains electrical, mechanical, electromechanical, and digital components. This pilot implementation will produce the techniques, modular programs, and data base organization of the Aerospace Vehicle Simulation based on the principles outlined previously. The results of the pilot implementation will be used as the premise for the simulation of additional systems of a space vehicle.

The development of the simulation system is not a small effort, and it is a challenging endeavor. It requires a team of experts in different fields such as systems engineering, electrical and mechanical engineering, numerical mathematics and computations, and systems programming.

Although the pilot implementation is directed toward the Saturn Apollo Vehicle, the techniques and programs will be capable of processing other configurations, provided that these configurations are described by a properly structured data base. The simulation system could become the standard evaluation means through which any system design or modification must be demonstrated prior to hardware development.

Thus, the simulation system can be of great benefit to any future aerospace program or, for that matter, any large program which requires review, analysis, evaluation, and decision in rapid-fire order.

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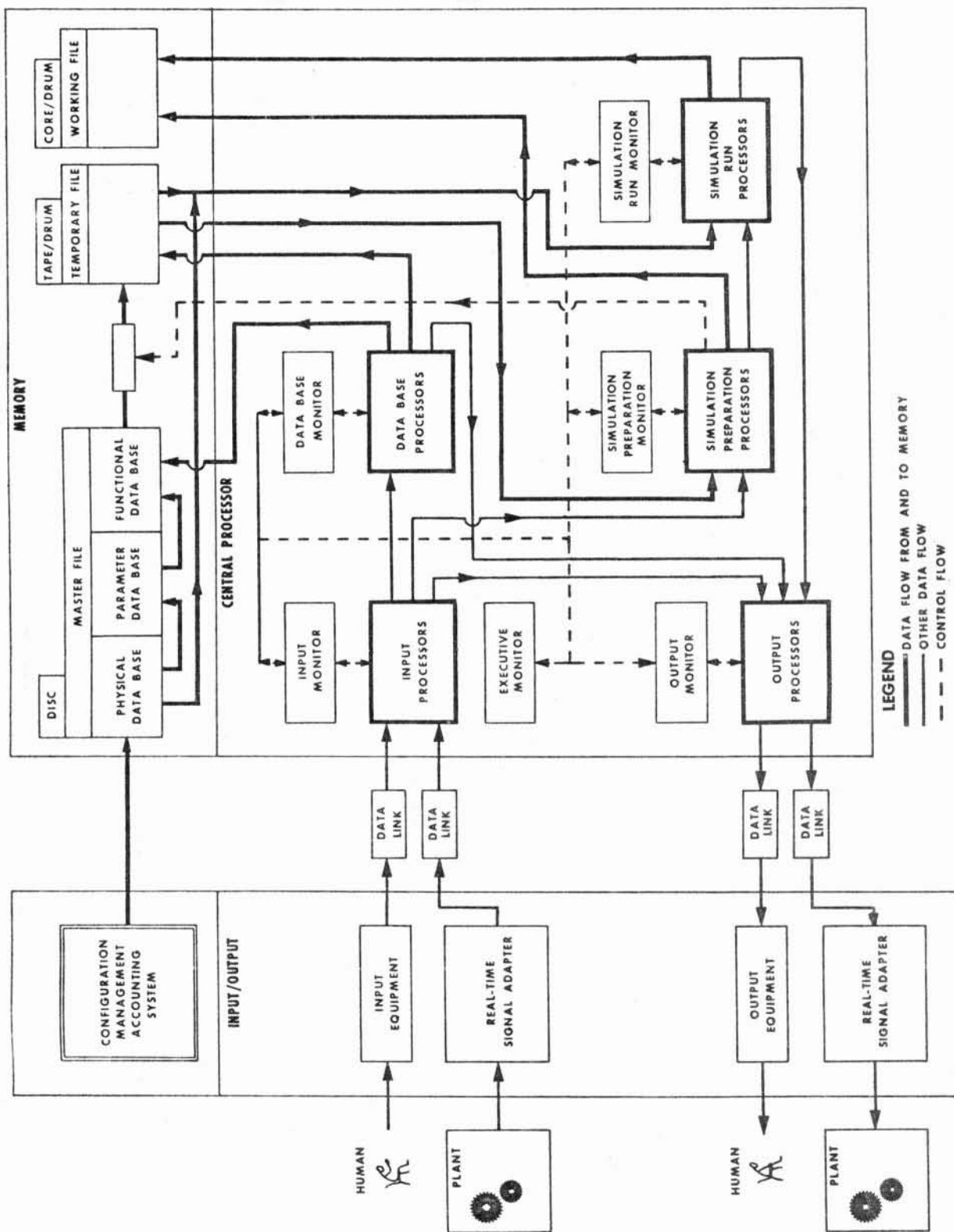


Figure 1. Information Flow in Simulation System

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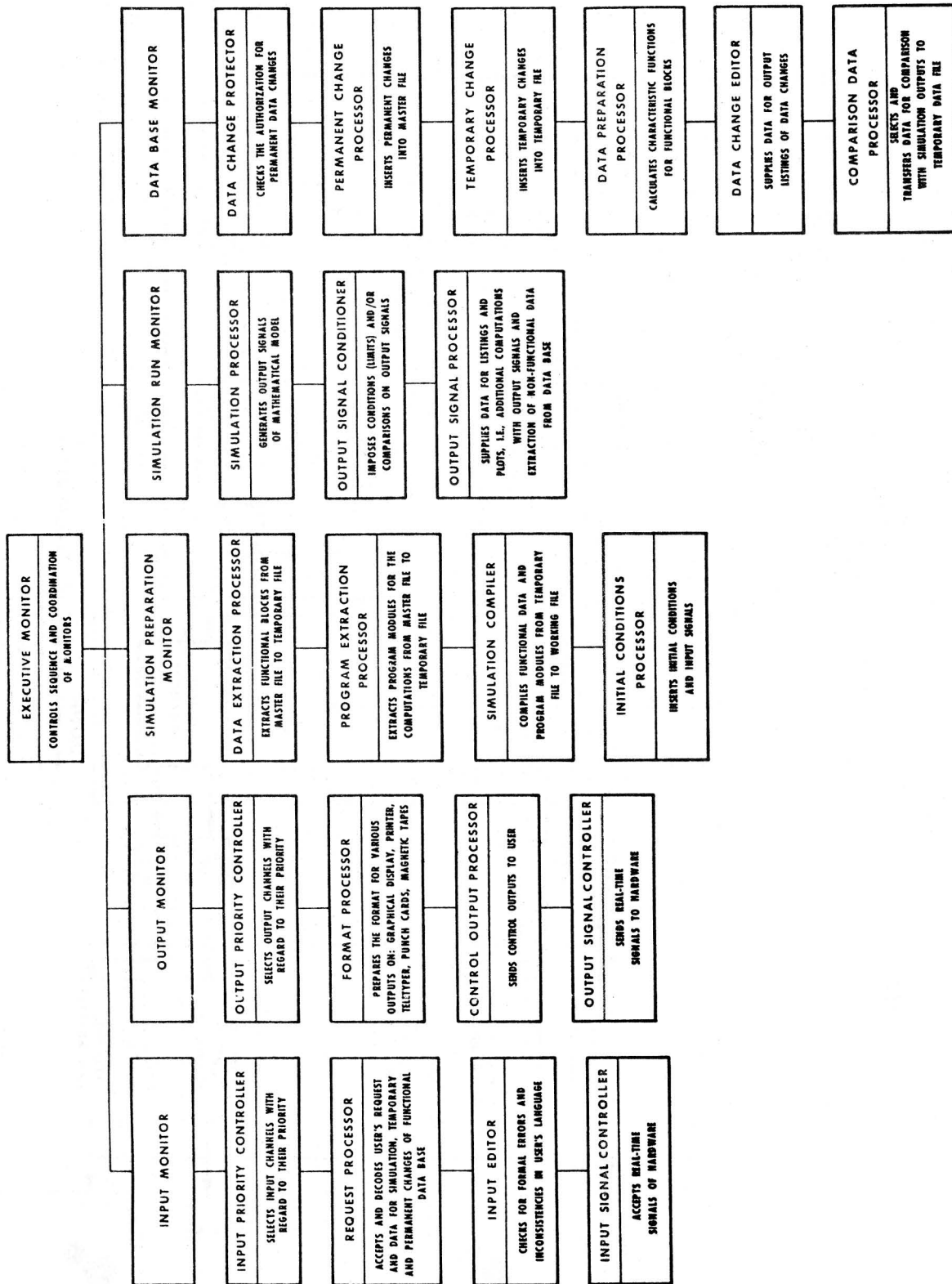


Figure 2. Organizational Structure of the Aerospace Vehicle Simulation System

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