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SIMULATION TECHNIQUES STUDY

FINAL REPORT

17 NOVEMBER 1972

J. F. Burke
Principal Investigator
SMS Definition Study

This document is submitted in compliance with Line Item No. 4 of the Data Requirements List as Type I Data, Contract NAS9-12836.

SINGER COMPANY
Simulation Products Division

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SIMULATION TECHNIQUES STUDY

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SINGER COMPANY
Simulation Products Division

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SIMULATION TECHNIQUES STUDY
CONTENTS

Introduction

Objectives

This study is intended to explore the various techniques that have been used in the field of vehicle simulation and are likely to be applicable to the SMS.

Status-Interim/Final

The Interim report contains sections 1.0, 2.0, 6.4, 7.0, 8.0, 9.0 and 12.0. The final report will consist of the foregoing, updated to reflect late inputs from the survey, and include sections 3.0, 4.0, 5.0, 6.1, 6.2, 6.3, 10.0, 11.0 and 13.0.

Approach

Data for this study has come from a variety of sources. Literature search was aided by the information retrieval systems of MIT and the University of Pittsburgh. The Air Force Human Research Laboratory also contributed in this area. Simulator manufacturers and users were surveyed as were manufacturers of major equipment used in simulators (computers, displays, etc.).

The following is a summary of the responses to the survey to date:

Simulator Manufacturers

No. surveyed	21
Positive responses	1
Negative responses	8

Equipment Manufacturers

No. surveyed	74
Positive responses	26
Negative responses	9

Simulator Users
No. surveyed 19
Positive responses 4
Negative responses 1

In house expertise has also been a significant source.

This report, therefore, represents a distillation of a large body of information pertaining to flight simulation and may be considered to define the present state-of-the-art.

1.0 MOTION SIMULATION

1.1 Moving Base

1.1.1 Overview

Selection of a Motion System for the SMS should be governed by several parameters. Among them are:

a) Available suitable systems

b) Load carrying capability of state-of-the-art systems

c) Performance characteristics of systems

d) Adaptability of available systems for inclusion of additonal features.

e) Complexity/cost of various potentially suitable systems

Identification of potentially suitable systems involves recognition of the fact that the SMS configuration, as a minimum, must include the entire Commander/Pilot Crew Station of the Orbiter with all controls and panels functional. This minimum configuration must also provide for inclusion of a high fidelity visual display system thru the crew station windows. The inclusion of the lower flight deck was immediately ruled out due to the fact that the moments of inertia of the double deck configuration with visual exceed current state-of-the art capabilities.

Based on current Orbiter studies such minimum configuration results in a payload approximately the size of a large commercial air-line cockpit with dimensions of the order of 12 ft. wide x 10 ft. long x 10 ft. high and weighting in excess of 6,000# plus the visual system.

Increasing the motion requirements to include the near crew stations like the Mission Specialist, Payload Specialist and the Cargo Handling stations, results in an even larger payload and further restricts the list of potentially suitable systems.

A comprehensive study (Ref. 1), generated by the Boeing Company of Houston, Texas, established the requirements and characteristics desired in a Motion System for Simulation of Advanced Spacecraft to include 5 Degrees of Freedom.

1.1.2 Techniques

Virtually all Flight Simulator Motion Systems employ servo controlled hydraulic actuators to achieve the desirable response, rate and power characteristics essential to produce the required motion of the crew station. Basic differences are in the number and size of the actuators, and in the geometry of the systems to produce motion in varying numbers of degrees of freedom, with varying payload capacities, excursions and performance characteristics.

The evolution of motion systems for flight simulators started with fixed pivot, 2 degree of freedom motion systems providing only limited pitch and roll. A significant advance resulted in the development of a 3 D.O.F. system which added a heave capability.

Subsequent requirements for more degrees of freedom and greater simultaneous excursions resulted in systems which superimposed, or cascaded, driven platforms upon each other. This solution resulted in systems significantly more compliant in rigidity and penalizing response and payload capacity due to the increased tare weights created and the lowered system natural frequencies.

Whereas cascaded systems are still employed for small payloads and unique vehicle requirements, the requirement for more sophisticated training involving greater excursions, more degrees of freedom and extensively greater payload capacity associated with complex visual systems, resulted in the development of the 6 D.O.F. systems in use today.

Of the "state-of-the-art" motion systems, there are only two types considered as suitable candidates for this simulator due to the payload size and the performance required for this type of vehicle

The basic difference between the two types considered is that one type suspends the moving base from an overhead structure whereas the other type has a the base, or moving platform, supported from beneath.

The following is a brief description of some of the systems surveyed in the study with the reasons for rejecting them as potential candidates for the SMS:

A. Northrop - Flying Boom (F5E, A-9, P-530, P-600)

The system consists of a small fighter cockpit replica mounted on a gimbal at the end of a 24 ft. long boom. It provides pitch, roll and yaw at the end of the boom, independent of the boom motion which moves the payload along a spherical path with a useable 20 ft. chordal travel at a 24 ft. radius. Thus effectively 5 degrees of freedom are available, lacking only longitudinal motion.

Total weight at the end of the boom is limited to 3,000 lbs. including the tare associated with the mechanism which provides movement relative to the boom.

B. Singer (A.M.F.) - Space Flight Simulator - (T-27)

This system consists of a platform hinged at the rear for pitch, roll and yaw. The hinged pivot is fixed to a huge offset beam which can be rotated to produce a $\pm 90^{\circ}$ pitch attitude to the platform, tilting on a y-axis approximately thru the C.G. of the Simulated Vehicle.

It was designed to accommodate a 3 man Space Vehicle with a limited Visual Display such that the total payload as tested was approximately 10,000 lbs. The structure for the tilt pivots at the ends of the offset beam somewhat limits the configuration of the payload. The payload mounting surface is approximately 12 ft. long and 5 ft. wide and at level position sets approximately 10 ft. above the site floor.

A single device was built and initially operated in 1964.

C. Singer - 3 D.O.F. - (707, 727, C-130, J-35, J-37, etc.)

This motion system utilizes 3 actuators to produce heave, pitch and roll motion to a cockpit/visual system complex approaching the weight and size of the minimum payload considered for this device. It has operated with payloads of approximately 12,000#.

This system was developed in 1958 and has received wide acceptance despite a rather severe limitation of simultaneous excursion capabilities.

Both Redifon and C.A.E. produced this motion system under license from Singer.

Limited degrees of freedom and excursions exclude it as a potential candidate system.

D. C.A.E. - 4 D.O.F. - (DC-8, 747)

This system vaguely resembles the Singer 3 D.O.F. system with the yaw (lateral) degree of freedom added beneath the basic 3 D.O.F. mechanism thus cascading the system and limiting lateral acceleration to approximately .1 g due to moving 30,500 pounds of payload and tare in this mode.

As with the Singer 3 D.O.F. system interaction between the pitch and roll, and heave actuators limits the simultaneous capability of each. The natural frequency characteristics are not established.

E. Singer - 5 D.O.F. - (F-111A)

This system cascaded the yaw and lateral motion on the basic 3 D.O.F machine with a resulting reduction of payload capacity.

The payload including the framework to span the 3 point supports for the payload was designed and tested for approximately 9,000 lbs. at which weight the C.G. and moment of inertia must be relatively low.

Excursions in the lateral mode are ±6", and the same limitations on simultaneous motions prevail as exist on the basic 3 D.O.F. system.

The following motion systems are considered to be candidates for the SMS:

A. Singer - 6 D.O.F. Floor Mounted Synergistic System

(60" stroke) - (747, L-1011, F-4D, ASUPT, S3A, DC-10)

This system represents the ultimate in conceptual simplicity, consisting of a platform 6 identical actuators, 3 identical sets of upper joints and 3 identical sets of lower joint assemblies and base pads.

The 6 actuators are arranged as 3 pairs of bipods, connected such that the apex of the actuator by pods support the platform on the joint assemblies spaced to describe a 12 ft. equilateral triangle. The lower ends of the actuators are attached to castings arranged in a similar pattern such that they describe a fail-safe geometry which cannot attain a gimbal-lock, or fall-thru attitude.

Since the actuators push directly beneath the platform the system rigidity characteristics are a maximum with the major compliant medium being the oil column itself.

Performance characteristics are shown in Figure I.

The system has been tested with a payload in excess of 18,000# and payload moments of inertia about the centroid of the upper joints of

I_{x-x} = 30,136 slug-ft.^{2}

I_{y-y} = 34,102 slug-ft.^{2}

I_{z-z} + 12,871 slug-ft.^{2}

B. C.A.E. - 6 D.O.F. Synergistic System (L-1011)

This system is essentially the same as the Singer system except that they employ six additional actuators. The geometry is slightly different and their advertised payload of 18,000 pounds includes the weight of the platform.

C. Redifon - 6 D.O.F. Suspended System - (DC-10)

The Redifon system consists of a platform supported by 3 servo actuators (plus 3 safety jacks) suspended from a huge overhead frame, and positioned laterally by 3 additional actuators lying in a horizontal plane. The surge actuators are approximately 18' long at mid-stroke.

The vertical actuators produce pitch, roll and heave motion, and the horizontal actuators produce lateral, longitudinal and yaw motions.

The advertised maximum payload capacity is 16,000 lbs. Four systems have been installed at this time.

D. Singer - 6 D.O.F. Floor Mounted Synergistic System (48" stroke) - (F-4F, DLH-727)

This system is essentially identical to the 60" stroke Singer system except that it employs 48" stroke actuators. Performance and Payload characteristics are essentially unchanged except that the excursion capabilities are reduced and the pump size has been halved. The actuator lower joint locations have been changed to achieve a fail-safe geometry with the reduced actuator stoke, maintaining the identical platform and upper joint geometry.

Fig. 1.1.2

6 D.O.F. MOTION SYSTEM CHARACTERISTICS

Type		Floor Mounted				O'Head
Name		Singer (48")	Singer (60")	CAE	** Reflectone	Redifon
Usage		F4F (4) 727 2F101(28)	747 (7) L-1011(3) DC-10(3) ASUPT(2) S3A(2) F4D Res.Tool.(3)	747 (3) L-1011(2) DC-10 (4)	HH-53C	DC-10(2) 707 L-1011
Total		33	21	6		4
Payload (Lbs.)		18,240	18,240	*18,000	--	16,000
Heave	Excurs.	±26"	+39,-30	±34	+34,-37	±48
	Vel.	24"/sec	24"/sec	36"/sec	--	24"/sec^2
	Accel.	.8g	.8g	.66g	2g	.75g
Lat	Excurs.	±42	±48	±48	±43	±72
	Vel.	24"/sec	24"/sec	31"/sec	--	24"/sec
	Accel.	.6g	.6g	.5g	2g	.25g
Long	Excurs.	±48	±49	±50	+52,-42	±33
	Vel.	24"/sec	24"/sec	24"/sec	--	24"/sec
	Accel.	.5g	.6g	.5g	2g	.5g
Pitch	Excurs.°	+26,-24	±30,-20	+32,-28	+30,-25	±28
	Vel.°/sec	15	15	20	--	15
	Accel.	50°/sec^2	50°/sec^2	60°/sec^2	200°/sec^2	80°sec^2
Roll	Excurs.°	±22	±22	±25	±27	±19
	Vel.°/sec	15	15	20	--	12½
	Accel.	50°/sec^2	50°/sec^2	60°/sec^2	200°/sec^2	80°/sec^2
Yaw	Excurs.°	±29	±32	±32	±33	±10
	Vel.°/sec	15	15	22	--	10
	Accel.	50°/sec^2	50°/sec^2	60°/sec^2	200°/sec^2	80°/sec^2

* Including platform wt.

** Payload capacity undefined thus accelerations cited are not directly comparable to those of other systems

(Reflectone also produces a small machine with a much lower payload capacity).

Summary:

We thus conclude that the most logical candidate systems for the SMS be confined to the 6 D.O.F. systems with the greater payload capacities. Of these there are 2 generic types, the suspended system and the Floor Mounted systems which are supported by 3pairs of bipods from beneath. In the latter category Singer presents 2 sizes, one with 60 inch stroke actuators and a small system with 48 inch stroke actuators.

A comparison of these candidate systems is presented in FIG.1.1.2.

Unfortunately none of the candidate systems provide the tilt capability to position the payload with the x-axis vertical to simulate the launch attitude. Neither do any of the systems provide sufficient excursions or velocity capability to produce significantly different sustained acceleration cues keeping in mind the greater excursion required for "washout" from the slightly higher velocities attained during the onset cue.

1.1.2.1 Redifon Suspended 6 D.O.F. System

1.1.2.1.1 Description (Ref. 2), (Ref. 3)

The system consists of a platform, or base frame, suspended by 3 hydraulic actuators from an overhead structure, the actuators forming the corners of a triangle in plan view.

Three "safety jacks" are fitted with one adjacent to each of the three vertical actuators to form part of an unconditional fail safe system.

Attached to the base frame are three actuators lying in a horizontal plane to provide surge, sway and yaw.

1.1.2.1.2 Current Usage

The system is used for (1) 707 simulator, (2) DC-10 simulators and (1) L-1011.

1.1.2.1.3 Characteristics

See Fig. 1.1.2.

1.1.2.1.4 Advantages

The suspended system:

1) provides the largest simultaneous excursions.

2) provides the largest independent excursions in the heave and lateral modes

3) provides the greatest safety of any system

4) results in a lower settled payload elevation than other systems

1.1.2.1.5 Disadvantages

The suspended system:

1) has lower natural frequency and response characteristics due to the overhead structure and extremely long actuators (fluid column) required. The shortest actuator is more than 16 ft. long at neutral extension.

2) occupies a much larger installation space than the other systems. The basic supporting structure requires a space of 44 ft. long x 44 ft. wide x 34 ft. high with a 2 ft. aisle around the outside, versus an installation space approximately 32 ft. x 32 ft. x 29 ft. high for a comparable floor-mounted system.

3) presents a much more complex system with actuators and plumbing restricting access around the simulator payload.

4) imposes restrictions on the configuration of the payload due to the vertical actuators. The resulting payload confined by the locus of actuator travel is limited to a shape resembling a triangular pyramid with a triangular cross section only 4 ft. wide at an elevation of 8 ft. above the forward edge of the moving base. This is especially restrictive on a visual system capable of producing a wide angle display.

1.1.2.1.6 Prospects for Improvement

The above disadvantages appear to be characteristic of this type of system. (The Conductron System was somewhat similar in configuration and characteristics)

1.1.2.1.7 Applicability to SMS

As cited before, the system is capable of carrying the proposed payload and remains a candidate providing the disadvantages do not become unacceptable.

1.1.2.1.8 Cost/Complexity and Risk

The system cost is reputedly in the same general range as the other motion systems of like capability.

1.1.2.1.9 Implications

The implications of this system are that the configuration of the payload must be confined to that permitted by the vertical struts; also that the other disadvantages must be circumvented.

1.1.2.2 Floor Mounted 6 D.O.F. System (large stroke)

The following discussion applies to all of the larger-stroke, floor mounted systems as all have very comparable excursion, payload and dynamic characteristics. Singer, C.A.E., Reflectone and Franklin Institute produce these similar systems, all of which evolved in response to similar specifications.

1.1.2.2.1 Description

The systems basically consist of a platform supported by 3 pairs of actuators arranged in the form of bipods acting in intersecting planes to establish stability in all axes. The lower end of the actuators is attached thru univeral joints to structures which are lagged to the site floor.

Both upper and lower joints describe a triangular pattern with the geometry arranged to preclude a gimbal-lock or fall-thru attitude.

All actuators extend simultaneously to provide heave and differentially to provide other degrees of freedom.

Basic differences are in the joint design, platform design, and actuator orientation relative to the platform.

The C.A.E. system includes, in all systems, a set of 6 safety legs located within the prime actuator pattern. The Singer system incorporates this capability although it uses larger bore actuators and joints designed to carry the loads with adequate safety factors to preclude their inclusion.

All employ hydraulically driven servo actuators with follow-up positioning devices attached to each leg.

1.1.2.2.2 Current Usage

Singer:	747 Simulators (7)
	L-1011 Simulators (3)
	DC-10 Simulators (3)
	ASUPT Simulators (2)
	S-3A Simulators (2)
	F-4D Test Bed (1)
	NASA Research Tool (2)
	NAR Research Tool (1)
C.A.E.:	L-1011 (2)
	CH-47
	USAF/Canadian A.F. Evaluation Tool (1)
	DC-10 (4)
	747 (3)

Reflectone: HH-53C Helicopter

Franklin Institute: Sikorsky Helicopter

1.1.2.2.3 Characteristics

See Fig. 1.1.2.

1.1.2.2.4 Advantages:

The large stroke floor-mounted systems possess the following advantages.

1) Inherently high-natural frequency and response characteristics with the major compliant medium being the fluid column since actuators act directly beneath the payload and the system employs shorter stroke actuators than the suspended system.

2) Clean design with all moving components located beneath the platform.

3) simplified maintenance capable of being performed at/near floor level.

4) Permits shortest cable routing with a center of motion located beneath the platform sufficiently high to preclude chafing of cables.

5) Utilizes a minimum of space, being defined by payload configuration plus excursions.

6) Provides a mounting surface for the payload unencumbered by surrounding structure.

7) provides more space around the outside for payload maintenance.

1.1.2.2.5 Disadvantages

These systems have the following disadvantages:

1) limited simultaneous excursions.

2) Somewhat obstructed payload access from beneath.

3) Can assume toggled attitudes, under failed modes, in excess of programmed attitudes thus dictating greater clearances than would be required for a cascaded system.

1.1.2.2.6 Prospects for Improvement

The simultaneous excursion limitations have been accepted as a compromise whose shortcomings are minimized by "washout" techniques and programmed anticipation of desired excursions.

The limitations on access from beneath varies with the individual system selected. It can be alleviated to some degree by repositioning of the payload to utilize the available access paths.

The extreme toggled attitudes attainable are inherent in all of these synergistic systems and the ills of such feature must be minimized by designing the payload to accommodate the loads and clearance requirements imposed.

1.1.2.2.7 Applicability to SMS

As evidenced by the characteristics and usage of these sytems they are all most suitable candidates for the SMS possessing the load carrying capacity, adaptability to modification for visual system support, and presenting the best combination of performance and excursions of the state-of-the-art devices available.

1.1.2.2.8 Cost/Complexity and Risk

The systems are off-the-shelf items with little or no risk.

1.1.2.3 Floor Mounted 6 D.O.F. System (short stroke)

1.1.2.3.1 Description

This section describes the Singer System which employs actuators with a 48" stroke in lieu of the 60" stroke actuators used on the Basic System described in section 1.1.2.2. The moving platform is identical to that of the larger machine. The basic differences are the relocation of the lower joint assemblies to accomplish the fail-safe geometry with the shorter struts, the changes in plumbing and the elimination of one of the pumps, all to achieve acceptable performance characteristics at a reduced cost. The payload capacity and performance capability remain essentially unchanged with reduced excursions and reduced duty cycles being the significant difference.

1.1.2.3.2 Current Usage

F4F Simulator (4)

727 Simulator (1)

2F101 Simulator (28)

1.1.2.3.3 Characteristics

See Figure 1.1.2.

1.1.2.3.4 Advantages

The advantages of the smaller system are the same as for the larger, floor-mounted system plus the following:

1) Reduced initial cost.

2) Reduced operating cost due to elimination of one pump.

3) Slightly smaller space requirement due to reduced excursions.

1.1.2.3.5 Disadvantages

The disadvantages are the same as for the larger floor-mounted system plus the following:

1) Further reduction of excursion capability.

2) Slightly higher potential strut loading.

3) Reduced duty cycle capability.

1.1.2.3.6 Prospects for Improvement

This system, as a modification to the larger system, consolidated the best features of the large system and incorporated the refinements essential to creating a cost-effective design. As such no further modifications for improvement were entertained.

1.1.2.3.7 Applicability to SMS

The reduced cost of this smaller system renders it a very strong candidate for the SMS Flight Simulator.

1.1.2.3.8 Cost/Complexity and Risk

This small-system cost is less than larger stroke and off-the-shelf.

1.1.2.3.9 Implications

Development of this smaller machine was prompted by the apparent decay of emphasis on "greater excursions". During the period from 1965 thru 1969 the using agencies were clamoring for greater excursions in all translational modes, thus prompting the development of all of the 6 D.O.F. machines. However, as the machines were programmed we discovered that even the limited excursion capabilities available were not fully utilized, as the slight difference in duration of cues was not significant. Thus, this smaller machine was the result of a compromise which would provide effective training at reduced cost. The trend toward acceptance of this smaller machine reflects this philosophy.

1.1.3 Tradeoffs and Recommendations

Current motion base technology imposes a limitation of approximately 18,000 pounds on the payload, This limitation along with the constraints on moment of inertia and space available on the motion base mandate tradeoffs with far reaching implications.

If the launch attitude is to be simulated a pitch augmentation cascade must be added to the motion base. Only the two forward crew stations can be accommodated in this configuration. Visual simulation for the forward stations is included in this evaluation.

If the launch attitude is not simulated all four crew stations can be accommodated on the motion base but the aft visual system cannot be included.

Meeting all assumed desired criteria will require development of a new motion system.

1.1.4 <u>References and Assumptions</u>

The foregoing discussion and evaluation is predicated on the following assumed requirements:

1) A 5 or 6 D.O.F. motion system is essential to effective flight training.

2) The motion system must simulate launch attitude (x axis of trainee compartment vertical).

3) The trainee compartment must accommodate all four crew members.

4) A forward visual system is required and will weigh approximately 7,000 lbs.

5) An aft visual system is required and will weigh approximately 7,000 lbs.

It it further assumed that the trainee compartment for a crew of four will weight approximately 8,000 lbs.

<u>References:</u>

1) Boeing Document #D2-118374-1
General Motion System Requirements for Simulation
of Advanced Spacecraft
The Boeing Company, Houston Texas

2) Redifon Spec. C8011/2 Issue 3
Redifon 6 Axis Motion System
Redifon Limited

3) Patent Specification 1224505
Improvements In or Relating to Ground - Based
Flight Simulating Apparatus
The Patent Office, London

4) Misc. Singer "Motion System Capabilities Charts"

4A) Misc. Singer T-27 File

5) "Orders" listing by McKnight

6) CAE Brochure - #D.8 Motion System
"DWG. #62576:01:7:879

7) Aviation Week, May 8, 1972 (Northrop System)

8) CAE DWG. 56 1201 B899
1879-01-899

4 D.O.F.

1.2 Drive Equations

1.2.1 Overview

Since a simulator motion system cannot attain the excursions of the aircraft, its motions have to be tailored to minimize these limitations. The term "drive equations" refers to the set of equations that relates simulator motion at a particular instant to simulated aircraft motion and the state of the motion system itself.

1.2.2 Techniques

1.2.2.1 Proportional Drive Techniques

1.2.2.1.1 Description

This drive technique utilizes a command signal to the appropriate axis of the simulator that consists of a percentage of the maneuvering aircraft acceleration for the corresponding axis. For example, the following equation is used with the proportional technique to drive the vertical axis of the simulator.

$$a_{Z_{BASE}} = K_P \; a_{Z_{AIRPLANE}}$$

where,

$K_P < 1.0$

$a_{Z_{BASE}}$ = vertical acceleration of base—ft/sec^2

$a_{Z_{AIRPLANE}}$ = vertical acceleration of aircraft—ft/sec^2

1.2.2.1.2 Current Usage

GAT-1 (pitch and roll).

1.2.2.1.3 Characteristics

This drive technique requires advance knowledge of the maximum anticipated aircraft acceleration and the minimum frequency of the aircraft maneuver. In other words, the maximum displacement of the aircraft in the real world establishes the required attenuation factor, K_p, so that the travel of the simulator is restrained to its physical displacement limit.

1.2.2.1.4 Advantages

Simplicity

Minimal computation required

1.2.2.1.5 Disadvantages

1. The high frequency or small amplitude accelerations of maneuvering aircraft must be attenuated needlessly so that the design limitations of the simulator are not exceeded during a maneuver where low frequency and corresponding large displacements are required.

2. Maneuvers requiring large linear or angular changes in aircraft position or attitude may cause displacement stand-offs in the simulator from its neutral position if the maneuver is performed in one direction. Maneuvers requiring 360 degree roll angles or heading changes are typical of those that create the problem of displacement stand-offs.

3. The initial acceleration or the rate of change of acceleration (jerk) induced on the simulator pilot at the start of a maneuver does not match the initial acceleration induced on the aircraft pilot.

1.2.2.1.6 Prospects for Improvement

None.

1.2.2.1.7 Applicability to SMS

Not applicable, in reasons cited in 1.2.2.1.5.

1.2.2.1.8 Cost/Complexity and Risk

Not applicable.

1.2.2.1.9 Implications

Not applicable.

1.2.2.2 Clipped Drive Technique

1.2.2.2.1 Description

This drive technique consists of driving each axis of the moving base with a limited or "clipped" aircraft acceleration command signal. The drive signal for the vertical axis, for example, is as follows:

$$a_{Z_{BASE}} = (a_{Z_{AIRPLANE}})_{Lim.} = \pm LZ$$

$$\text{where, } L_Z < (a_{Z_{AIRPLANE}})_{Maximum}$$

1.2.2.2.2 Current Usage

Not known.

1.2.2.2.3 Characteristics

Here, as with the proportional drive technique, advance information pertaining to the anticipated magnitude of the aircraft accelerations is required.

1.2.2.2.4 Advantages

The clipped technique does have some advantages over the proportional drive. For example, not all aircraft accelerations are needlessly attenuated. Furthermore, the initial jerk induced on the simulator pilot matches that induced on the aircraft pilot.

The advantages of simplicity and minimal computational requirements are retained.

1.2.2.2.5 Disadvantages

The clipped drive technique has the same inherent drawback as the proportional drive technique in that the moving base does not have the ability to neutralize itself or return to zero displacement once the maneuver is completed.

1.2.2.2.6 Prospects for Improvement

None.

1.2.2.2.7 Applicability to SMS

Not applicable, for reasons cited in 1.2.2.2.5.

1.2.2.2.8 Cost/Complexity and Risk

Not applicable.

1.2.2.2.9 Implications

None.

1.2.2.3 Onset or Washout Drive Technique

1.2.2.3.1 Description

The following equation represents the washout drive equation for the vertical axis of the moving base.

$$a_{Z_{BASE}} = a_{Z_{AIRPLANE}} - K_{\dot{Z}} \, \dot{Z}_{BASE} - K_Z \, Z_{BASE}$$

or written in Laplacian operator form

$$\frac{a_{Z_{BASE}}}{a_{Z_{AIRPLANE}}} = \frac{S^2/\omega^2_{BR}}{\left(\frac{S^2}{\omega^2_{BR}}\right) + \left(\frac{2\zeta}{\omega_{BR}}\right) S + 1}$$

where, $K_Z = \omega^2{}_{BR}$ and Z_{BASE} = vertical displacement of base - Ft.

$K_{\dot{Z}} = 2\zeta\omega_{BR}$ and $\dot{Z}_{BASE}$ = vertical velocity of base - Ft/Sec.

$S = \frac{d}{dt}(\quad)$; Laplace operator

1.2.2.3.2 Current Usage

Almost all motion systems (except the GAT-1) employ some varients of washouts.

1.2.2.3.3 Characteristics

The term ω_{BR} represents the break frequency of the simulator drive. If the frequency content of the acceleration is less than the value of ω_{BR}, the aircraft acceleration, which is used to command the base acceleration, is attenuated by the correct amount; thereby, the base travel does not exceed the design limits of the moving-base flight simulator. The damping factor, ζ, is selected as 0.707 so that the base acceleration does not exceed the aircraft acceleration. Therefore, the proper attenuation or "washout" of the moving base commanded acceleration is obtained by adjusting the feedback gains on the velocity and displacement terms of the moving base. To set the feedback gains correctly requires prior knowledge of the type of maneuvers (what frequency) to be simulated so that maximum capability of the simulator is utilized.

1.2.2.3.4 Advantages

For maneuvers with frequencies above ω_{BR}, the acceleration induced on the simulator pilot tends to match the acceleration he would feel in the aircraft.

1.2.2.3.5 Disadvantages

Aircraft maneuvers which are performed at frequencies below the break frequency selected for the simulator drive, are not duplicated on the simulator. The acceleration felt by the simulator pilot is reduced in magnitude and is out of phase with that felt by the aircraft pilot if the frequency of the flight maneuver is lower than the break frequency.

1.2.2.3.6 Prospects for Improvement

The preceding discussions treated each degree of freedom independently. In actual practice, there are interactions among various degrees of freedom; pitch and longitude, yaw and lateral, etc. There may be improvements in putting together drive equations for the six degrees of freedom. Other possible improvements: shift of neutral position, variable washback acceleration, and using pitch and roll to simulator longitudinal acceleration are discussed in Cohen, 1971.

1.2.2.3.7 Applicability to SMS

Some type of washout drive is applicable for SMS; it would appear appropriate to start with one that has proven acceptable on a commercial transport simulator, and "tweak" it to SMS requirements.

1.2.2.3.8 Cost/Complexity and Risk

Modest cost/complexity, low risk.

1.2.2.3.9 Implications

None.

1.2.3 Tradeoffs and Recommendations

Some type of washout drive is recommended for SMS; one should start with one that has proven acceptable on a commercial transport simulator such as that described in Taylor,et al, and "tweak" it to SMS requirements.

1.2.4 References and Assumptions

1.2.4.1 References

Cohen, E. How Much Motion is Really Needed in Flight Simulators? SAE Paper 710488, May 1971

Hayden, W. D. Analytic Technique for Establishing the Motion Requirements for a Ground-Based Aircraft Flight Simulator AIAA Paper No. 70-348, March 1968.

Taylor, R. L., Gerber, A., et al. Study to determine Requirements for Undergraduate Pilot Training Research Simulation System AFHRL-TR-68-11, July 1969.

1.2.4.2 Assumptions

None.

1.3 G-seats

1.3.1 Overview

The purpose of a G-seat is to augment the motion provided by a motion base, especially in the area of sustained linear accelerations.

1.3.2 Techniques

1.3.2.1 Inflated Bladders

1.3.2.1.1 Description

The only technique known to be available for G-seat is thatof inflating bladders in the seat pan and seat back. Symetrical inflation of bladders on each side of the centerline simulates accelerations in the vertical plane; differential inflation of left and right bladders simulates lateral acceleration.

1.3.2.1.2 Current Usage

G-seats are being developed for ASUPT and SAAC.

1.3.2.1.3 Characteristics

These G-seats have 16 square air cells in the seat pan, arranged in a 4 x 4 matrix, nine rectangular air cells in the back rest, arranged in a 3 x 3 matrix, and two 3-cell thigh panels, also on the surface of the seat pan.

Air, under pressure, is delivered to a series of five pressure regulators, each of which maintains the pressure of its associated manifold at a preset level. Each of the 31 (16 + 9 + 6) air cells is connected to each of the five manifolds by solenoid actuated valves, and so any cell can be pressurized to any of five pressures, or exhausted to atmospheric pressure by means of an exhaust solenoid valve, under computer control.

1.3.2.1.4 Advantages

Such a G-seat could augment the motion platform in simulating sustained acceleration.

1.3.2.1.5 Disadvantages

The effectiveness of this system has not been proven; its role in ASUPT and SAAC is experimental/developmental.

1.3.2.1.6 Prospects for Improvement

Not known; depends on results of use in ASUPT and SAAC.

1.3.2.1.7 Applicability to SMS

It is possible that G-seats will be useful in SMS, but their present status is unproven.

1.3.2.1.8 Cost/Complexity and Risk

The cost of G-seats, as a developmental item, runs well into the five figure range, even though they are not especially complex. The risk associated with their use stems not from any substantial doubt that they will function as specified, but rather a doubt that they will create the effect desired.

1.3.2.1.9 Implications

If SMS can incorporate developmental items, G-seats are appropriate for inclusion.

1.3.3 Tradeoffs and Recommendations

It is recommended that G-seats be incorporated in SMS. Although the concept is not proven, failure of G-seats to fulfill their intended function will not compromise the simulation program, and the duration of the Shuttle program will allow time to explore the concept and evalute its utility.

1.3.4 References and Assumptions

1.3.4.1 References

Kron, G. J. G-Seat Developments. Singer Co. March 1972

Taylor, R., Gerber, A., etal. Study to Determine Requirements for Undergraduate Pilot Training Research Simulation System. AFHRL-TR-68-11, July 1969.

1.3.4.2 Assumptions

None.

1.4 Restraining Belts

Restraining belts can be of the fixed type, against which the inflated cushions of a G-seat work, or of the movable type, pulled under computer control; movable belts can work against either inflatable or fixed cushions. The working of restraining belts is thus very similar both in concept and practice to the working of G-seats, discussed in the previous section. To avoid duplication, that material is not repeated here.

1.5 G-Suits

G-suits, commonly used in fighter type aircraft, play a role in the perception of acceleration, since the pressure with which they are inflated varies linearly with the "g's" the aircraft is pulling. However, the shirtsleeve environment planned for the Shuttle would appear to preclude the use of G-suits, even though accelerations up to 3 g can be anticipated. Unless G-suits are worn in the vehicle, there is no training value in using them in the simulator.

2.0 Flight Hardware Integration

2.1 Overview

Flight hardware integration, rather obviously, hinges on the decision, in each instance, to use flight hardware. This decision in turn is strongly influenced by techniques available to integrate the flight hardware with the simulator. The decision to use or not use flight hardware in one case may mandate or preclude the use of some associated item. An example of this might be an on-board computer control and display unit. If the actual computer is to be used, use of the actual control and display unit would probably be indicated and vice versa.

Flight hardware has the following advantages: guaranteed realism, ease of integration (in some instances), cost advantage (in some instances), easy update (in some instances), spares availability (in some instances). Simulated hardware, strangely enough, has (in some instances) the same advantages with the exception of guaranteed realism. From this it is apparent that decisions with respect to the use of flight hardware rate careful study.

The flight hardware which is applicable to a simulator can be placed in four categories: instrument, panels, controls and miscellaneous. The first three are largely self explanatory. The miscellaneous category includes such items as interior trim, landing gear warning horns, placards, etc. Integration of items in this category is rather trivial and will not be discussed further.

The techniques used to integrate flight hardware into a simulator are a significant part of the art of simulation.

2.2 Techniques

2.2.1 Unmodified Direct Use

2.2.1.1 Description

Flight hardware is interfaced to the simulation computer by means of"standard" DCE. "Standard" DCE consists of digital input, digital output, analog input and analog output devices. This technique is generally feasible with panels, some instruments, and some controls.

2.2.1.2 Current Usage

This technique has been used on essentially all digital flight simulators.

2.2.1.3 Characteristics

Self-evident.

2.2.1.4 Advantages

This is the most straight-forward approach. Other techniques are used only if this one is not feasible.

2.2.1.5 Disadvantages

None.

2.2.1.6 Prospects for Improvement

None.

2.2.1.7 Applicability to SMS

Fully applicable.

2.2.1.8 Cost/Complexity and Risk

This is the least costly way of using flight hardware. "Standard" DCE is relatively inexpensive due to its general purpose nature. Hardware design is reduced to a clerical, form filling effort.

2.2.2 Modified Direct Use

2.2.2.1 Description

Flight hardware is modified to permit the use of the previous technique.

2.2.2.2 Current Usage

This technique has been extensively used.

2.2.2.3 Characteristics

Self-evident.

2.2.2.4 Advantages

This is the "second choice" approach yielding the same advantages as the previous technique.

2.2.2.5 Disadvantages

Modification of flight hardware requires special handling to preclude any possibility of its use in an actual vehicle. Documentation of the modification is often cumbersome.

2.2.2.6 Prospects for Improvement

Slight.

2.2.2.7 Applicability to SMS

This technique is applicable to SMS.

2.2.2.8 Cost/Complexity and Risk

Costs are greater for this approach due to the modification cost.

2.2.3 Special Interface Hardware

2.2.3.1 Description

With this approach, simulation hardware is used to bridge the gap between the characteristics and requirements of the flight hardware and those of the DCE/Computer Complex. This hardware can be as simple as a series resistor between an analog output and a current sensitive meter movement or as complex as a dedicated special purpose computer.

This technique is used when flight hardware cannot be integrated by means of standard DCE and modification of the flight hardware is not desirable. The latter situation can be due either to excessive cost of modification or to specification requirements prohibiting modification of flight hardware.

A number of these interfacing problems have relatively standard solutions. Typical of these is the problem of a flight instrument requiring synchro input. This is usually solved by use of standard interfacing device called an electronic synchro/resolver driver.

2.2.3.2 Current Usage

To some extent this technique has been used on all flight simulators.

2.2.3.3 Characteristics

As noted in the description,the characteristics of a special interface hardware are extremely varied and are meaningless out of specific context.

2.2.3.4 Advantages

Avoidance of flight hardware modification is the only advantage.

2.2.3.5 Disadvantages

The prime disadvantage is cost. Over extension of this technique can lead to very complex hardware systems whose performance and reliability are marginal.

2.2.3.6 Prospects for Improvement

Improvement in this technique will be largely dependent on improvements in electronics in general, new components, etc.

2.2.3.7 Applicability to SMS

This approach is applicable to SMS.

2.2.3.8 Cost/Complexity and Risk

Risk with this approach lies principally in over extending it. This risk can be minimized by the use of simulated hardware in those applications where the use of flight hardware will lead to a large interfacing problem. The cost and complexity inherent in this technique is higher than in the previous techniques.

2.3 Tradeoffs and Recommendations

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

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

See Figure 2.3 for preliminary recommendations for SMS.

2.4 References and Assumptions

It is assumed that it will be feasible to use flight hardware in some instances for SMS.

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FIGURE 2.3

Item	Simulated Hardware	Flight Hdw: Direct Use	Flight Hdw: Modified	Flight Hdw: Spec. Interface Hardware	Recommendations
A. Instruments					
1. FDAI	X		X	X	Modified flight hardware with special interface. Usage not sufficient to justify design of simulated instrument.
2. HSI	X			X	Flight hardware. Design of simulated instrument not cost effective.
3. Meter Movement Instruments	X			X	Simulated. This has proven to be cost effective.
4. Altimeter	X			X	Simulated. This has proven to be cost effective.
5. Rate of Climb	X			X	Simulated. This has proven to be cost effective.
6. Mach/Airspeed	X			X	Simulated. This has proven to be cost effective.
7. G-Meter	X				Simulated.
8. Radar Altimeter	X			X	Flight hardware. Usage not sufficient to justify design of simulated instrument.
9. Digital Readouts	X	X	X	X	Flight hardware if availability will support simulator schedule. This is usually advisable to guarantee realism. Specific application must dictate implementation.
10. Tape Instruments	X	X		X	Usage may be sufficient to justify design of simulated instrument, but use of flight hardware probably indicated.

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FIGURE 2.3 (Continued)

Item	FEASIBLE TECHNIQUES: Simulated Hardware	Flight Hdw: Direct Use	Flight Hdw: Modified	Flight Hdw: Spec. Interface Hardware	Recommendations
11. Engine Gimbal Angle Ind.	X			X	Simulated. Should be most cost effective.
12. CRT Displays	X		X	X	Decision must be compatible with on-board computer simulation technique.
B. Panels	X	X			Simulated. This is based on schedule constraints and expected change traffic. Use of flight hardware versus simulated would be a cost tradeoff involving engineering design cost versus component costs.
C. Panel Components					
1. Switches	X	X			Similar to flight hardware. (Not flight qualified)
2. Circuit Breakers	X				Simulated. Must be "popable."
3. Annunciator Lites	X	X			Similar to flight hardware. (Not flight qualified)
4. Flags	X	X			Similar to flight hardware. (Not flight qualified)
D. Controls					
1. Rotation Hand Controller	X	X		X	Flight hardware. Design of simulated item not cost effective.
2. Translation Hand Controller	X	X		X	Flight hardware. Design of simulated item not cost effective.
3. Parking Brake	X		X	X	Flight hardware if possible. Schedule may preclude.

FIGURE 2.3 (Continued)

	Feasible Techniques				
		Flight Hdw			
Item	Simulated Hardware	Direct Use	Modified	Spec. Interface Hardware	Recommendations
4. Power Levers	X		X	X	Flight hardware if possible. Schedule may preclude.
5. Landing Gear Handle	X	X			Flight hardware.
6. Speed Brake Handle	X		X	X	Flight hardware.
7. Rudder Pedals	X		X	X	Flight hardware.
8. Manipulator Controls	X		X	X	Insufficient data. Flight hardware probably indicated.

X Use of flight hardware not possible for certain specific instruments.

3.0 On-Board Computer

3.1 Overview

In this section are reviewed the several methods of real time simulation of airborne and aerospace vehicle on-board computers. Techniques which have been discussed include the use of real (or equivalent non-flight qualified) computer hardware, translators, interpreters, functional simulation, and lastly, the application of micro-programmable computers to the solution of the problem by emulation translation, and interpretive methods.

It is worthy to note that as shown in Table 3.1-1 there are a total of eighteen digital computers of several types and manufacture which are planned for use on the Space Shuttle vehicle.

Table 3.1-1

Space Shuttle On-Board Computers

Application	Quantity	Manufacture	Type	Memory Size (Bytes)
GN&C	3	IBM	AP-101	256K
GN&C MDE	2	IBM	SP-1	32K
PM MDE	2	IBM	SP-1	32K
PLH MDE	2	IBM	AP-101	32K
Main Engine Control	6	Honeywell	HDC601	24K
Air Data	3	Honeywell	HG280	1472*

*Consisting of 12, 16 and 18 Bit words.

Selection of the optimum method of simulation for each function should be governed by many factors including:

- Availability for simulator test and for crew training
- Performance characteristics
- Logistic requirements
- Maintainability
- Reliability
- Ease of modification
- Total system cost and complexity
- Risk

3.2 Techniques

3.2.1 Real Hardware

3.2.1.1 Description

Use of real (or functionally identical non-space rated) on-board computers in a training device is possible but also must include interface hardware to allow communication to and from the main simulation computer(s) and also include peripheral equipment for computer loading and I/O to associated displays and controls. Figure 3.2-1 is a block diagram of a typical complex.

This interface hardware may be complex and include signal level conversion equipment, parallel and serial data channels, buffer memories, and synchronization depending on the complexity of the OBC I/O and the compatibility with the main simulation computer I/O interfaces. Additional software may also have to be added to the OBC to permit its function in a simulation environment.

3.2.1.2 Current Usage

Computer hardware functionally identical to the actual flight hardware is presently being used on the Skylab Apollo Telescope Mount Digital Computer (ATMDC). The computer used is a non-space rated IBM System 4π Model TC-1 computer with interfacing to an IBM Model 360.

3.2.1.3 Characteristics

Refer to description and Figure 3.2.1-1.

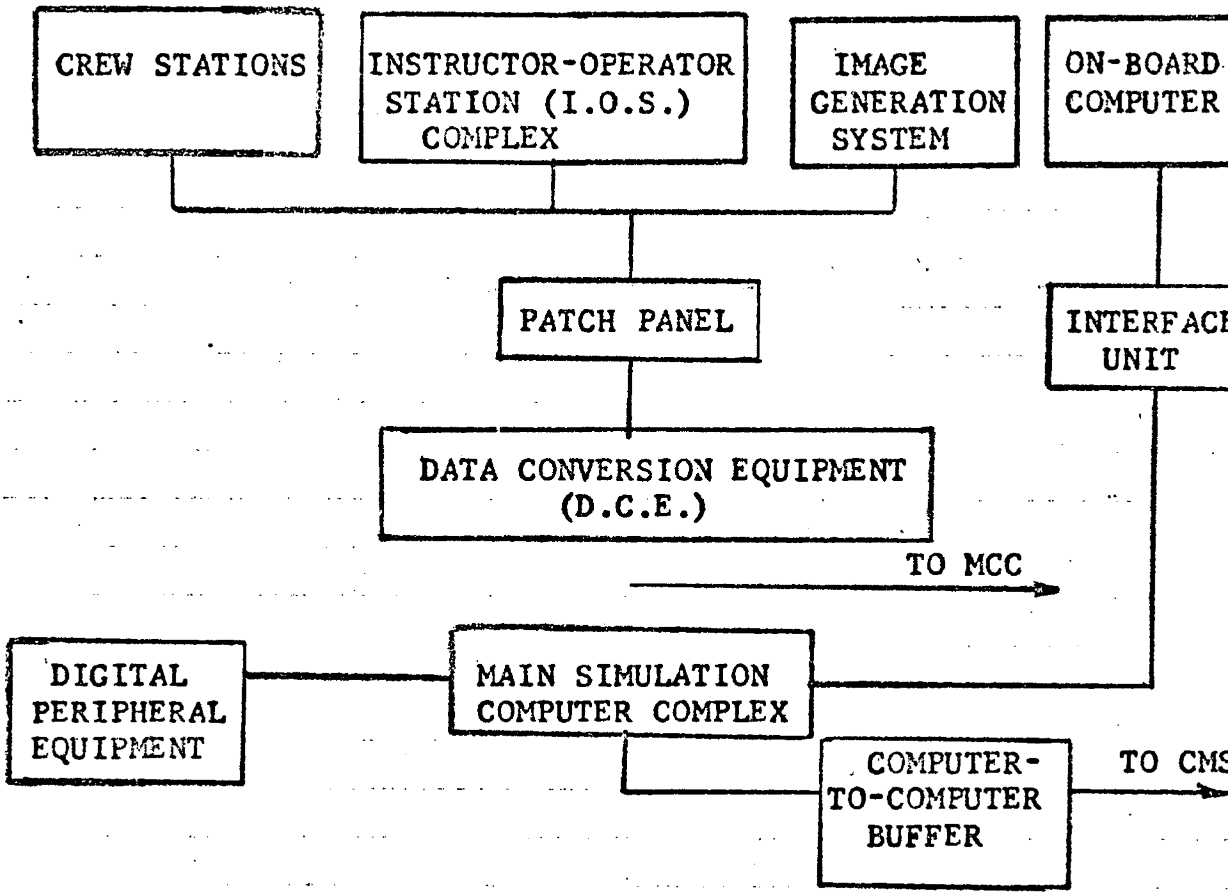

FIGURE 3.2.1-1 SIMPLIFIED BLOCK DIAGRAM OF SIMULATOR INCORPORATING REAL ON-BOARD AND INTERFACE COMPUTER

3.2.1.4 Advantages

Advantages in the use of an actual (or functionally identical) OBC are as follows:

1) The CPU time and core memory loading requirements in the main simulation computer will be reduced.

2) Flight programs may be used without modification.

3) New modified flight programs can be loaded at any time without modifications to the main simulation computer load.

4) Effort necessary to maintain correct documentation and configuration control for changes in the flight programs would not be duplicated.

3.2.1.5 Disadvantages

Use of the real OBC hardware requires the design and development of special interface hardware. Cost, availability, and delivery schedules of the OBC and interface hardware may be prohibitive. Additional communication and synchronization software are also required in the main simulation computer to implement the computer to OBC computer interface.

In addition, the actual OBC, or equivalent, is designed for an entirely different environment than a large commercial computer. The OBC may require modification to be made compliant to the simulator computer specification. Special software may also have to be developed to provide this compliance.

Logistic support requirements are also increased.

3.2.1.6 Prospects for Improvement

The Real hardware approach to OBC simulation has a certain very definite advantage over other approaches. This approach can be still further improved perhaps by the implementation of an overall system plan aimed at reducing the cost of the OBC hardware in the simulator.

Such a plan might include the use of non-flight qualified hardware, or,as will be discussed in section 3.2.5, by the development of a special microprogrammed processor which emulates the OBC function at reduced cost.

3.2.1.7 Applicability to SMS

Real hardware is certainly an acceptable method for the OBC simulation in the SMS if the constraints mentioned below are not prohibitive.

3.2.1.8 Cost/Complexity and Risk

Historically, use of real world hardware in simulators has been characterized as providing a very high fidelity simulation capability. Associated with this fidelity has been a high initial cost. Primarily the sum of the computer plus interface hardware design, interface hardware material,and a small effort for interface software development. If more than one simulator is built, a large percentage of this cost is recurring. The non-recurring costs relate primarily to design and development of interface equipment. Since the interface requirements are usually well defined, it can be stated that the technical risk involved in this approach is low.

The major risk lies in scheduling to have flight programs available in time for Simulator Test and Crew Training.

3.2.1.9 Implications

The primary constraints to incorporating hardware in a simulator are as previously mentioned:

a) The definition, design and development of special interface hardware, and the procurement of the on-board computer.

It is also apparent that flight software must be available in a timely manner if this approach is to be viable. This software must be available in time to test the simulator prior to crew training.

3.2.2 Translator

3.2.2.1 Description

In a translative simulation of a computer, the actual flight program must be preprocessed to convert the flight program to an equivalent simulation computer program. This technique differs from the interpretive simulation in that the instruction decoding is done off-line and each OBC instruction is replaced by one or more simulation computer instructions to perform the same operation. A translative simulation is feasible when the two computers' instruction sets are similar enough to permit translation without an enormous increase in required core memory or CPU simulation execution speed.

3.2.2.2 Current Usage

Although translators have been used for software development related to functional simulations, there has been no known direct application of a translator to convert actual OBC programs to a form executable in a real time simulation.

3.2.2.3 Characteristics

As mentioned above, the effectiveness of a translative approach to OBC simulation is a function of the similarity of the instruction sets and computer architectures of the OBC and the simulation computers.

The assembly language capabilities and formats should also be similar enough to allow straight forward translation, and the simulation computer complex memory size and speed must be capable of the task.

3.2.2.4 Advantages

Translative Simulation - Translative simulation offers many of the same advantages as use of real OBC hardware in that the simulation is based on the actual flight program coding. Translation is faster in real-time execution than interpretation because the burden of decoding an OBC instruction and substituting simulation computer coding is handled by off-line preprocessing.

New modified flight programs may be translated and loaded at any time with negligible effect on the main computer load.

Effort necessary to maintain documentation and configuration control for changes in the flight program would not be duplicated.

The translative approach also offers the opportunity for validation of the translated program by comparing its performance with the flight program. Input data used during test runs on the flight program could be made available for similar runs on the translated program. A comparison of outputs from the two programs could be used for detecting errors.

3.2.2.5 Disadvantages

A translative simulation is only feasible if the OBC instruction and the simulation computer instruction sets are similar enough to permit translation without an enormous increase in required core memory or impact on execution performance. In addition, the host computer must be several times faster than the OBC which is being simulated to compensate for the increase in code volume brought about by the translation.

3.2.2.6 Prospects for Improvement

Past generations of on-board computers have been programmed using highly specialized techniques (e.g., the Apollo Command Module and Lunar Module computers) or by means of special assembly languages created especially for the computer in use, e.g., Military aircraft such as the F-4 or F-111.

As an example, the Apollo computers contained up to 36 banks of 1024 word 16 bit MO-PERM core rope memory which are random access parallel read but with no write operations. That is to say, the program is loaded as the memory is manufactured. It is conceivable that in the near future OBC programs will be programmed in a higher level language such as FORTRAN, PC1, or JOVIAL.

If such is the case, with an appropriate compiler, the OBC source language program can be compiled for execution on the simulation computer at much less cost and more efficiently then is possible now. Again, it may be possible to use microprogramming techniques to advantage to obtain a more efficient and cost effective simulation system.

3.2.2.7 Applicability

The translative approach to OBC simulation is certainly applicable to the SMS and its appeal may become greater as higher level languages come into use for OBC programming.

3.2.2.8 Cost/Complexity and Risk

Costs of the translative approach to OBC simulation include the required simulation computer hardware (CPU time and memory) plus the non-recurring costs of translator software development. The risk must be considered to be higher than when using real hardware but less than that for the interpretive approach.

3.2.2.9 Implications

As in the real OBC hardware approach, a major constraint to the translative simulation approach is the availability of flight programs. This software must be available in time to test the simulator prior to crew training. Extra care must be taken in the choice of simulation computer to ensure that special anomalies in the OBC are not the source of impossible to solve problems. The simulation computer must be several times as fast as the OBC to allow real time simulation.

3.2.3 Interpreter

3.2.3.1 Description

In an interpretive simulation of an on-board computer, the simulation computer must accept an actual OBC flight program as a data set. The host computer must then execute that flight program "interpretively". The interpretive simulator must decode each OBC instruction sequentially in real time and then execute a set of host computer instructions to duplicate the requested action. In its purest form an interpretive simulation requires the dedicated use of the host computer. Ideally, this host computer must also be compatible with other computers in the simulation computer complex.

3.2.3.2 Current Usage

The interpretive simulation technique has been used with considerable success to simulate the Block II AGC and LM guidance computer in CMS and LMS simulators.

3.2.3.3 Characteristics

To give an example of the detailed requirements of an interpretive simulation, some of the details of the ISCMC Interpretive Simulated Command Module Computer (ISCMC) are given below:

CMC Characteristics:

The CMC consists of one Block II Apollo Guidance Computer (AGC), two identical display and keyboard (DSKY) units, and certain other display and control devices. The CMC is a general purpose digital computer with the following characteristics:

A. Eight (8) banks of 256 words of sixteen (16) bits each of magnetic core memory (random access with parallel read and write operations). This is referred to as the E-Memory.

B. Thirty-six (36) banks of 1024 words of sixteen (16) bits each of MO-PERM core rope memory (random access with parallel read and no write operations). This is referred to as the F-Memory.

C. A central processing unit (CPU) with the capability of executing fifty-six (56) separate operations indicated by programs stored in the F-Memory or by hardware signals received from elsewhere in the computer or the PGNCS. The memory cycle time is maintained at 11.7 microseconds by a central clock and most instructions take two cycles for completion.

D. Arithmetic is performed in special CPU registers in fixed reference one's complement or cyclic two's complement modes using fifteen (15) bit numbers with an overflow indicator bit. (Note that a parity bit appears in memory but not in the CPU registers).

E. The CMC has no indirect or indexed addressing inherent in its basic hardware design. However, both are implemented in a limited way in the Interpretive Instruction language.

F. Input and output to the CMC is handled through sixteen (16) bit data channels and special E-Memory locations denoted as counters.

The AGC differs from standard general purpose computers in that its programs are loaded into F-Memory at the time memory is constructed. Thus, the phrase, "A CMC Program", refers to the entire contents of the F-Memory of the CMC.

A CMC program may consist of Regular Instruction language codes, Interpretive Instruction language codes, or both. The Regular Instruction language consists of thirty-eight (38) of the fifty-six (56) basic instruction order codes mentioned above. These include operations usually found in general purpose computers as well as some special functions. The Interpretive Instruction language consists of no more than 128 different interpretive instructions and includes double and triple precision arithmetic, vector operations, and matrix operations. The Interpretive Instructions are decoded and executed by a sub-program entitled "List-Processing Interpretor". This sub-program is a standard part of all AGC programs.

The CPU of this computer is operated in a time-sharing mode during the execution of flight programs. An executive program common to all Block II AGC flight programs uses five (5) time-based interrupts to control this time-shared processing. In addition, certain spacecraft systems can cause interrupts to occur during the processing of mission programs by the CMC These interrupts cause further time-shared processing by the CPU in that each activates one or more high priority jobs for the computer to perform. The processing of programs by the CMC in response to a DSKY key being depressed is an example of this type of interrupt based processing.

DDP-224 Characteristics:

The DDP-224 computer is a commercially available, general purpose digital computer. It has the following characteristics:

A. Up to sixteen (16) banks of 4096 words of twenty-four (24) bits each of magnetic core memory (random access with parallel read and write operations).

B. A central processing unit (CPU) with the capability of executing approximately seventy-five (75) separate operations indicated by programs stored in its memory or by hardware signals received from elsewhere in the DDP-224 system. The memory cycle time is maintained at 1.90 microseconds by a central clock and most instructions take two cycles for completion.

C. Arithmetic is performed in special CPU registers in fixed and floating reference sign-magnitude arithmetic. (Note that no parity bits are maintained in the DDP-224 memory or CPU registers).

D. The DDP-224 has indirect addressing and indexed addressing capabilities. It has up to three (3) fifteen (15) bit index registers.

E. Input and output in a DDP-224 is handled through character buffers, word buffers, and/or other special input and output devices. These units may be attached directly to core memory or may function through the special CPU registers.

The DDP-224 computer executes programs in a fashion similar to all other general purpose digital computers. Programs may be written in a symbolic language called DAP and may be assembled by a standard software component into binary object programs. These programs may be loaded into core memory for execution at any location specified by the user or by standard loader programs.

It should be noted that the standard instruction set for a DDP-224 computer does not include any instructions for the implementation of an efficient table search procedure or for the performance of one's complement arithmetic. Without a fast table search procedure the time required to find the subroutine that simulates any particular CMC operation code would take so long that a real-time simulation would be impossible. In addition, the simulation of one's complement arithmetic by using sign-magnitude arithmetic would add significantly to the overhead required in any CMC simulation. Thus it can be easily seen that a normal DDP-224 computer is not practically suited for the real-time simulation of a CMC computer.

<u>The Interpretive Simulation</u>:

The full requirements for performing in an interpretive sense the activities of the CMC during flight program execution are briefly discussed in the following paragraphs. (The generic acronym "ISCMC" will be used to refer to the interpretive simulation being described). A specific description of the ISCMC as it is currently being implemented will also be given.

A. Special Hardware Design - The manufacturers of the DDP-224 computer, the Computer Control Company of Framingham, Massachusetts, introduced the idea of implementing hardware modifications to circumvent the problems of an interpretive simulation related above. The idea was to add instructions to the basic code set standard in the DDP-224 which could do an efficient table search and could simulate the arithmetic capabilities of the CMC.

All the available bits for basic instructions are now used by the standard code set of the DDP-224. However, the computers in the Apollo trainers operate such that floating point arithmetic is not used, and the elimination of these instructions provided six (6) operation code bit patterns that are used in the implementation of new operation codes. A switch is provided to allow the computer to operate in a standard (floating point) mode or in the interpretive simulation (ISCMC) mode.

The final modifications that were made to the DDP-224 computer are numerous. All are additions of new basic operational capabilities, and all make the DDP-224 operate more like the basic CMC AGC operates.

A total of ten new instructions were created.

The other major modifications that were made to the standard DDP-224 computer added a facility for processing the time-based counters that the ISCMC must have to operate its multi-processing mode. In addition, a facility was supplied which allows the ISCMC to sample data on a timed basis for its E-Memory counter and channel locations at the common core interface of the AMS. A facility is alos provided that allows the AMS to interrupt the ISCMC computer to initiate processing of standard spacecraft and other interrupts.

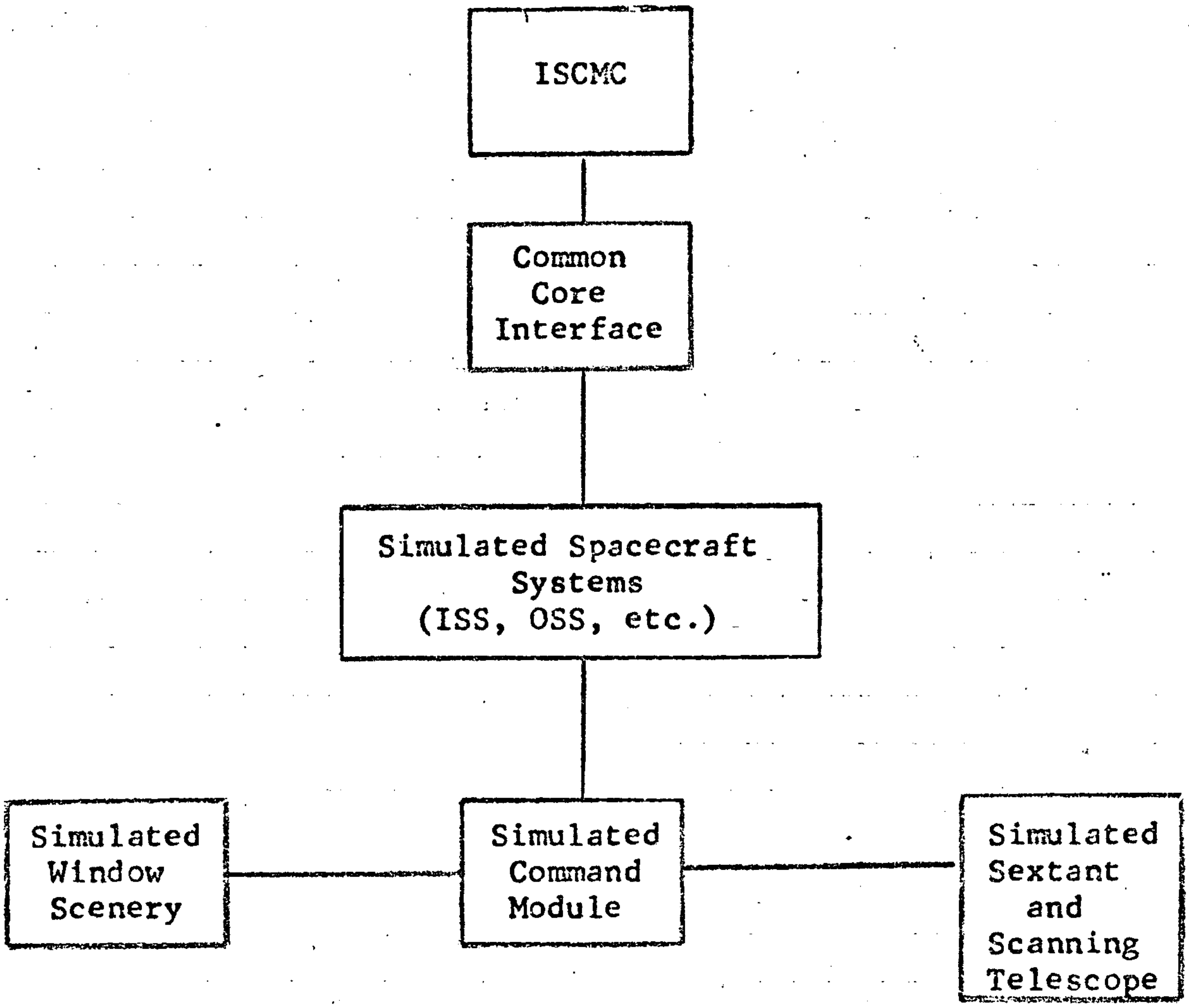

Figure 3.2.3.-1 The AMS System

B. Simulation of the CMC Central Processing Unit - The CMC has special registers associated with its CPU that perform arithmetic, program control, and other operations. The registers which may not be directly addressed are not simulated. The addressable registers are simulated, and the ISCMC executes a bit-by-bit simulation of the activities of the CMC by a proper simulation of the CPU registers of that computer.

3.2.3.4 Advantages

An interpretive simulation of an OBC offers much the same advantages as use of the real OBC hardware.

1) The CPU time and core memory loading in the main simulation computer will be reduced.

2) Flight programs may be used without modification.

3) New modified flight programs can be loaded at any time without modification to main simulation computer load.

4) Effort necessary to maintaining correct documentation and configuration control for changes in the flight program would not be duplicated.

The interpretive simulation also provides an opportunity for effective validation of the interpreted program by comparing its performance with that of the actual flight program. The input data used during test runs on the flight program could be made available for similar runs on the interpreted program. A comparison of outputs from the two programs could be very useful in detecting errors.

3.2.3.5 Disadvantages

Interpretive Simulation - In its purest form, an interpretive simulation requires the dedicated use of the host computer. Thus, one or more digital computers must be added to the simulation facility.

The interpretation process for a single OBC program instruction requires that the computer load the instruction, isolate and interpret the operation code, and decode the operand address based on the interpretation of the operation code. Then the interpreter must execute one or more instructions to perform the function intended by that OBC instruction. Therefore, the host computer must be several times faster than the OBC which it is simulating.

The development cost of such an additional computer with special modifications plus the cost of interface hardware may be prohibitive.

3.2.3.6 Prospects for Improvement

Succeeding generations of on-board computers have followed the development trends characteristic of commercial computers in terms of becoming more similar in their I/O architecture, instruction sets, and programming languages (assemblers, compilers, and operating system software).

The difficulties encountered in the development of the interpreter for the Apollo Guidance Computer program,both in terms of DDP-224 computer hardware modifications, and in terms of interpreter software development, will hopefully be alleviated in the short term future by the availability of minicomputers with microprogramming capability and I/O structures and programming language capabilities more similar to the subject OBC being simulated.

3 2.3.7 Applicability to SMS

The interpretive approach to OBC simulation is applicable to SMS OBC simulation.

3.2.3 8 Cost/Complexity and Risk

Costs of the interpretive simulation can be attributed to the dedicated computer and interface hardware plus the non-recurring costs of interpreter software and interface software development. If, as appears likely, a special processor is required, additional logistic requirements are also imposed.

From an overall simulation viewpoint, it is believed that an interpreter is more difficult to implement than a translator, but is considered to be potentially more efficient in terms of total CPU time and memory required.

3.2.3.9 Implications

As for the real hardware approach and the translative approach, the interpretive approach to OBC simulation requires flight programs in time for simulator test and crew training. Again, as for the translative approach, the computer dedicated to the interpreter must be several times faster and have a larger memory capacity than the OBC which is being simulated.

F

3.2.4 Functional Simulation

3.2.4.1 Description

Developing a functional simulation of an on-board computer requires:

a) an in depth analysis of the OBC computer hardware and the programs which it executes.

b) creating mathematical models describing the hardware function and the programs, and their interaction.

c) programming effort to convert the mathematical models to computer programs in the language of the simulation computer.

d) testing and verifying these programs, independently and in conjunction with the other simulation programs and with associated control and display hardware.

3.2.4.2 Current Usage

Functional simulations of on-board computers have been successfully achieved on a wide range of military and commercial aircraft simulators including the C-130, the F-4 and F-111 series, and the AJ37 military aircraft,and the Boeing 707, 747, and the Lockheed L-1011 commercial airliners.

3.2.4.3 Characteristics

A functional simulation is characterized by the requirement for simulation data in a well defined form available early in the simulator development program. Data which identifies changes to the OBC programs must also be available a fairly long period of time before these must be available for training a flight crew.

3.2.4.4 Advantages

The functional simulation approach is attractive from the viewpoint of total simulation development. Where OBC flight programs are relatively firm, and only minor changes are anticipated, it may prove to be the most cost effective approach. This method requires no special interface hardware, permits a minimum total computation system load, and can be more adaptable to pre-established frequencies of solution. It is the most straight forward to develop and debug, and has the highest probability of real time execution.

3.2.4.5 Disadvantages

Funtional simulation - A functional simulation of the on-board computer requires an in-depth analysis of the task and a detailed programming effort to model that task in the simulation computer. Full advantage must be taken of the simulation computer programming features to insure a fast and efficient functional simulation.

Excessive turn-around time may be required to implement changes to the simulated OBC program when changes to the operational OBC flight program occur.

3.2.4.6 Prospects for Improvement

The advent of use of higher level language programming for OBC software, combined with potentially available microprogrammable computers, indicates a possible merger of functional and translative simulation techniques which may be most cost effective from a total simulation point of view.

Operational flight programs which are most likely to change can be programmed using the translative method, while special programs such as I/O handlers and OBC display hardware drivers which seldom change could be developed optimumly by a combination of microprogramming and functional program development to minimize cost.

3.2.4.7 Applicability to SMS

In its pure form, a functional simulation of on-board computers does not appear applicable to the SMS unless it can be proven that the flight programs are well defined and not subject to change. Except for the main engine computers and the air data computers, this does not seem at all probable.

A combination of functional simulation programs and translated programs may prove to be a viable approach as more data becomes available.

3.2.4.8 Cost/Complexity and Risk

Compared to the other methods of simulation discussed herein, and assuming early available and well defined data on the OBC programs, the functional simulation is a cost effective and relatively straight forward method with low risk.

In a multi simulator procurement, the major cost of software development is non-recurring, and computer hardware (CPU time and core memory) can be minimized.

The major risk, as is well known, lies in the area related to OBC program availability and possibility of changes.

3.2.4.9 Implications

As mentioned previously, a functional simulation requires well defined data very early in the program and, to minimize recurring costs, the programs must not be subject to extensive changes throughout the useful life of the simulator.

3.2.5 Microprogramming

3.2.5.1 Description

Functionally, a computer is comprised of four major sections.

a) the memory section

b) the arithmetic logic section

c) the control section

d) the input/output section

From the viewpoint of microprogramming, the section of the computer of prime interest is the control section.

In the conventional processor, the control section normally consists of large assemblies of gates and flip flops interconnected to form timing counters, sequencers, and decoders to perform the following functions as required by the specific instruction set:

. fetch instructions from memory

. decode machine instructions

. enable appropriate data paths

. change the state of the computer to that required by the next operation

In a microprogrammed processor, the control section is implemented in a less random fashion. All control signals are derived from information stored in a memory device (usually a read only memory). This memory, together with its buffers and control logic, form the control sections. The control words stored in the memory are known as microinstructions. Preparation of these instructions is known as microprogramming. These microinstructions bear no resemblance to the computer's own instruction set, as they manipulate and control data at the most elementary level. A microprogram then is a program structured sequence of commands which reside in hardware and which are translated by hardware into hardware controls.

Major operations performed by microinstructions are:

- data path manipulation
- address sequencing
- I/O and memory control
- specification of processor status
- instruction register field selection
- miscellaneous control function

3.2.5.2 Current Usage

So far as is known, microprogramming techniques have not yet been employed for real time OBC simulations.

3.2.5.3 Characteristics

Four of the elements of the microprogrammed computer are nearly identical to the fixed instruction computer. The significant difference is in the control unit. The basic control sequences of a microprogrammed computer originate in a separate "control memory", usually a read-only memory (ROM) which operates at speeds many times faster than the main memory section of the computer. Thus the simplified block diagram (Figure 3.2.5-1) of the microprogrammed computer has one more element than the fixed instruction computer.

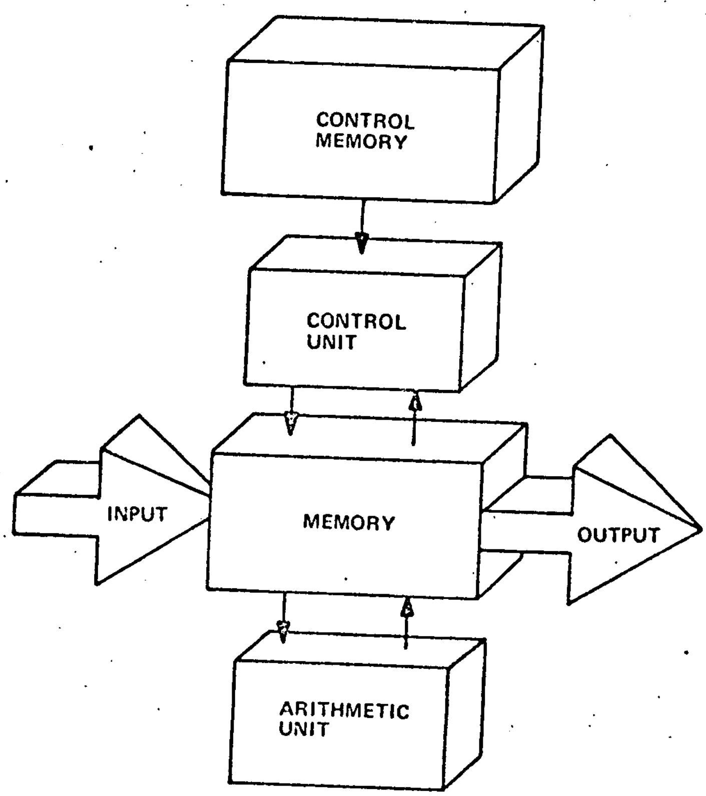

Figure 3.2.5-1

Simplified Block Diagram
Microprogrammed Computer

Memory: The random access main memory of the microprogrammed computer differs little from the fixed instruction computer. It is implemented with magnetic core or semiconductor systems in similar sizes and speeds to the fixed instruction computer. The basic difference is the timing and control of the memory system. The control unit of the microprogrammed computer is clocked to a significant higher speed separate memory system. Hence, the main memory speed is essentially independent of the processor speed and is operated in a manner similar to an input/output device.

Arithmetic Unit: The arithmetic and logic unit in a microprogrammed computer operates on fixed data lengths, typically 8 bits. The speed of the unit is 10 to 50 times faster than fixed instruction computer arithmetic units operating on smaller portions of arithmetic problems at each step. Microcommands are much more intimately related to the computer architecture and to bit patterns. This allows high versatility in problem solution and minimizes the restrictions usually encountered at the software level.

Input/Output: Microprogrammed computers provide extremely fast elementary I/O capabilities. Data paths are fixed length, typically 8 bits, and the I/O control functions are simple elements sequenced by high speed control memory firmware. This permits special I/O systems to be designed for the users' requirements. The microprogrammed computer offers all of the I/O capabilities found in fixed instruction compu-coupled with the unique advantage of providing only the capabilities needed, and the versatility to be changed when required.

Control Unit: The control unit of the microprogrammed computer is simple and straightforward. It operates and controls all elements of the computer system, including two levels of memory. Because it is more basic than the control units in fixed instruction computers it provides capability to solve problems in an added dimension. The control unit is programmable, not fixed. Programs operating upon the control unit are called microprograms, and are referred to as firmware.

Control Memory: The control memory is the element that most dramatically distinguishes the microprogrammed computer. The control memory contains the stored sequence of control functions that dictate end user architecture of the microprogrammed computer. These stored sequences are called "microprograms" or "firmware" corresponding to fixed instruction computer sequences called "programs" or "software".

The control memory has been called many other names including read-only store (ROS), read-only memory (ROM) and control store. Terminology relating to the control memory of microprogrammed computers is most complex because of many misnomers coined by computer and semiconductor manufacturers. Present terminology that relates to the mechanization of control memory are:

ROM: Read-only Memory: Any memory system in which the bit patterns of each word are fixed, and unalterable.

In application, few ROM's can be modified after manufacture. Those ROM's that can, may be called modifiable. To make any change requires a hardware modification such as adding or deleting diodes in a diode matrix ROM or rerouting of wires in a core ROM.

BROM: Bipolar Read Only Memory: Large scale integration (LSI) bipolar devices are used for volume manufacture. Original setup masking is expensive. Cost for manufactured elements is low.

PROM: Programmable Read Only Memory: A semiconductor diode array is programmed by fusing or burning out diode junctions. Cost for setup is minimal. Manufacturing cost is moderate to high. The PROM is usually used for final shake down of a system prior to investing in the BROM setup.

AROM: Alterable Read Only Memory: A true misnomer. The AROM is actually a read-write memory that is used for initial checkout of firmware. The firmware is typically loaded into the AROM via a paper tape input device. Once loaded the AROM operates the control unit as does any ROM control memory. The advantage of the AROM is programming within a few minutes rather than a manufacturing process. Cost is high; however, the devices are used indefinitely for checkout and analysis of numerous firmware implementations. See WCS.

WCS:Writeable Control Store: A programmable read write semiconductor memory, modifiable under software control.

There are four classes of applications which are established for Microprogrammed computers. Each class contains several sub classes which are implemented by control unit programming (firmware) variation.

Any class, augmentation of, or variation of, represents a computer architecture different from another; each offering specific advantages to the intended end application.

(A) General Purpose Computers

1) General Purpose Computers With Standard Instruction Set

2) General Purpose Computers With Added Special Instructions

3) General Purpose Computers With Background for Special Data Processing or Input/Output Functions

4) General Purpose Computer With Addition of Special Microprogram Which is Entered and Exits From the Software Program, and Remains Active for a Relatively Long Period of Time

(B) Special Purpose Computers

1) Special Instruction Set

2) Direct Application Microprogram

3) Direct Sequence of Subroutines

4) Interlaced Microprogram Instructions and/or Subroutines With Partial Processing

5) Subroutine Branching According to System States

(C) Emulator Computers

1) Duplication or Approaching Equal Functional Capability With a Pre-existing Fixed Instruction Stored Program General Purpose Computer

2) Duplication or Approaching Equal Functional Capability With a Pre-existing Special Purpose Computer

In the truest sense all applications of the microprogrammed computer can be considered emulation. However, as defined here, the emulator computer is the microprogrammed computer with its firmware allowing functional duplication of another computer. Direct emulation of a preexisting general purpose or special purpose computer is practical only if an advantage results. Usually a cost advantage is realized if the preexisting computer is several years old. In many cases a speed advantage will result.

Many parameters need be considered to determine feasibility and efficiency of a microprogrammed computer emulating any specific general purpose or special purpose computer. Essentially these parameters are:

Complexity and Number of Logical Elements.

Word Size and Number of Hardware Registers.

Maximum Main Memory (Core) Size and Word Length.

Execution Time Required Per Operation.

Input/Output Requirements.

Detailed knowledge of both the preexisting computer and the microprogrammed computer is needed to properly evaluate the feasibility and fit of emulation.

(D) Language Processor

1) Direct Execution of High Level Language Statements

2) Partial Execution of High Level Language Statements

The instruction set configuration of a special purpose computer which is to be programmed at the assembler language level is usually a "hostile" environment to the implementation of compiler level languages. The microprogrammed processor permits the configuration of a minicomputer architecture which is efficient in a compiler language environment. In essence, the utilization of an assembler may be minimized and the compiler statements are in effect interpreted more directly.

3.2.5.4 Advantages

Advantages of microprogramming are:

a) Provides an orderly method of implementing modifications and extensions to existing processor instructions sets.

b) Permits easier processor trouble shooting through minimization of random logic.

c) Permits optimum tailoring of computer systems to a specific task by implementing frequently used operations in microinstructions.

d) Microprogramming can increase system speed.

Microprogrammable computers are faster than fixed instruction computers for the following reasons:

1. Instruction execution times are from 5 to 30 times faster in a microprogrammed computer.

2. File registers can be used for data storage, and pointers, where core is required in a fixed instruction computer, thus program execution time can be sped up by avoiding memory access cycles.

3. Subroutines are closely tailored to specific requirements and data word lengths, thus improving computer efficiency and speed.

4. Input/output routines can be simplified for the application to increase I/O speed.

4. Special time-consuming algorithms (math, logic, etc.), which are not available in the general purpose processor can be easily incorporated into a microprogrammed processor.

e) Memory space can be reduced.

In the general purpose fixed instruction computer, the instructions are stored in core memory along with data. Both instructions and data can be altered by the program. In a microprogrammable computer, the instructions are stored in a read only memory along with permanent (or constant) data. Only variable data, pointer, and flags are stored in core memory.

G

In the general purpose fixed instruction computer there is usually a limited instruction repertoire with variations of instruction, and memory reference instructions having limited addressing modes.

In the microprogrammable computer there is usually a smaller number of instructions, which are more compact and specialized than the fixed instructional computer. Memory addressing and I/O functions usually are built up by assembling a group of microinstructions. The microinstructions are closely related to the internal architecture and I/O structure of the basic computer.

3.2.5.5 Disadvantages

Disadvantages of microprogramming relate primarily to cost and time.

Considerable cost is involved in the hardware investment, primarily for new control store hardware. In addition there are time requirements for a microprogrammer to acquire sufficient knowledge to be able to generate micro code, and then to write, debug and implement microprograms. Also to be borne in mind is the fact that much existing software will require modification to recognize new function codes.

3.2.5.6 Prospects for Improvement

Microprogramming is still going through some major evolutions which will make it more and more the most important system architectural tool.

The ultimate promise is the natural language computer. High level programming languages such as FORTRAN, COBOL, PL and JOVIAL and application oriented languages can be interpreted directly without compilers and assemblers. Programming and operation of a system and debugging a program then becomes highly simplified and more efficient, and thus much more aconomical.

3.2.5.7 Applicability

Microprogramming techniques will have applicability to the Space Shuttle program to the extent that the benefits to be gained outweigh cost considerations.

3.2.5.8 Cost/Complexity and Risk

Fixed instruction computers are basically application sensitive. Even with numerous models to choose from only a few offer good price performance for any specific application. Even more important to note is the fact that if a specific fixed instruction computers offers the best price performance for a given application at one level of complexity it may offer less relative value as the complexity changes.

Typically, to increase the performance of the fixed instruction computer the main memory (usually core memory) is increased in size.

In the final analysis, the performance of any computer is measured by its ability to solve a specific problem within a given period of time.

The prime criteria for selection of the appropriate computer is time and cost of implementation over the entire project life. In this light, the microprogrammed computer offers answer to this enigma. The user selects the cost/performance lines between three elements; hardware, firmware, and software for his specific application.

Within any capability level numerous trade-offs between control memory size and core memory size can be established for the microprogrammable computer. As the size of the control memory increases advantages result in price and relative speed. In addition, programming costs and implementation time can be significantly reduced once the users' needs are established in firmware. Now, with the availability of supporting systems, firmware development is in the same dimension in price and turn-around time normally associated with fixed instruction computers. The result: computer users can benefit from microprogramming along with the computer manufacturer.

3.2.5.9 Implications

As mentioned previously, the primary constraints to the use of microprogramming techniques relate to cost.

The benefits to be gained by microprogramming must outweigh the cost considerations.

Deciding whether to use a Writable Control Store or a permanent Read Only Memory again involves the factor of cost. WCS is convenient but more costly than ROM. Although ROM involves a manufacturing step, the cost factor is usually decisive when a quantity of units are made. For small quantities a WCS is often a suitable compromise.

3.3 Tradeoffs and Recommendations

As indicated in section 3.1, the Space Shuttle vehicle incorporates a total of 18 digital computers of four different types and for application in six different operational configurations.

1) Primary Guidance and Navigation
2) GN&C and Performance Monitor, Modular Display Electronics
3) Back Up Guidance and Navigation and Performance Monitor, MDE
4) Payload Management and Payload Handling MDE
5) Main Engine Control
6) Air Data Computations

For each of these systems and functions, a tradeoff study is required to determine the optimum simulation method.

The basis for these tradeoff studies must include such factors as data requirements vs availability and changeability, training requirements and training value, and the impact on total simulation cost, complexity, scheduled delivery, and simulator availability of these factors and other factors such as:

- Logistic Support Requirements, including Ground Support Equipment and Spare Parts
- Testing Requirements
- Maintainability, and Reliability, MTTR, and MTBF

Table 3.3-1 summarizes these considerations for the various on-board computers and simulation approaches, based on data available and assumptions as given in section 3.4.2.

Table 3.3-2 is a risk comparison for the shuttle OBC requirements for the various simulation approaches under consideration.

Table 3.3-3 compares the relative costs of each method of simulation for the on-board computers. Table 3.3-4 gives a resultant overall grade for each approach.

It is seen that for the GN&C and the MDE computers, a translative approach is preferred; primarily because of the availability of a high level source language for the OBC programs.

Because the HDC-601 computer used in the Main Engine Control system is nearly identical to the Honeywell H-316/H-516, an emulative technique can be utilized incorporating a H-316 as a substitute for the HDC-601.

Because of the small size and low risk involved, the functional simulation is recommended for the air data computer.

REFERENCES:	ENGINEER	REV.	THE SINGER COMPANY SIMULATION PRODUCTS DIVISION BINGHAMTON, NEW YORK	TITLE SIMULATOR	REP. NO.	PAGE NO.	OF
	NAME						
	DATE						

	DATA REQUIREMENTS FOR SIMULATOR DESIGN & DEVELOPMENT	IMPACT OF OBC SOFTWARE PROGRAM CHANGE ON TRNG	EFFECT ON SIMULATOR MAINTAINABILITY		EFFECT ON SIMULATOR RELIABILITY		SIMULATOR LOGISTIC SUPPORT REQUIREMENT	SIMULATOR FIDELITY TECHNICAL GRADE
			MTTR	GRADE	MTBF	GRADE		
REAL HARDWARE	Hardware data early. Software for test and training.	Reload new program and test.	Added special hardware.	5	Added special hardware.	5	New additional spare parts and test equipment.	A
TRANSLATOR	Hardware and Programmer data required to develop Translator. Software test and training.	Recompile, load new program and test.	Same as functional.	3	Increase in CPU Memory	3	Slight additional software support for source and object programs control.	D
INTERPRETER	Hardware and Programmer data required to develop Interpreter. Software for test and training.	Reload new program and test.	Same as functional.	2	Slight increase in CPU Memory.	2	Minimum software support as for Real Hardware or Emulator.	C
FUNCTIONAL SIMULATION	All hardware and software data early in program.	New simulation software development and test.	Minimum CPU configuration.	1	Minimum CPU configuration.	1	Extensive software configuration control required.	E
MICROPROGRAM EMULATION	Hardware and Programmer data to define microprograms. Software for test and training.	Reload new program and test.	Added special hardware	4	Added special hardware	4	Additional spare parts.	B

TABLE 3.3-1

SPACE SHUTTLE OBC SIMULATION COMPARISON

	DATA REQUIREMENTS FOR SIMULATOR DESIGN & DEVELOPMENT	IMPACT OF OBC SOFTWARE PROGRAM CHANGE ON TRNG	EFFECT ON SIMULATOR MAINTAINABILITY MTTR	GRADE	EFFECT ON SIMULATOR RELIABILITY MTBF	GRADE	SIMULATOR LOGISTIC SUPPORT REQUIREMENT	SIMULATOR FIDELITY TECHNICAL GRADE
REAL HARDWARE	Hardware data early. Software for test and training.	Reload new program and test.	Added special hardware.	5	Added special hardware.	5	New additional spare parts and test equipment.	A
TRANSLATOR	Hardware and Programmer data required to develop Translator. Software test and training.	Recompile, load new program and test.	Same as functional.	3	Increase in CPU Memory	3	Slight additional software support for source and object programs control.	D
INTERPRETER	Hardware and Programmer data required to develop Interpreter. Software for test and training.	Reload new program and test.	Same as functional.	2	Slight increase in CPU Memory.	2	Minimum software support as for Real Hardware or Emulator.	C
FUNCTIONAL SIMULATION	All hardware and software data early in program.	New simulation software development and test.	Minimum CPU configuration.	1	Minimum CPU configuration.	1	Extensive software configuration control required.	E
MICROPROGRAM EMULATION	Hardware and Programmer data to define microprograms. Software for test and training.	Reload new program and test.	Added special hardware	4	Added special hardware	4	Additional spare parts.	B

TABLE 3.3-1

SPACE SHUTTLE OBC SIMULATION COMPARISON

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TABLE 3.3-2 OBC SIMULATION RISK COMPARISON

	PROBABILITY OF DATA AVAILABLE FOR SIMULATOR	ESTIMATED % DATA CHANGE VS. MISSION	RISK VS. SIMULATION APPROACH				
			REAL HARDWARE	TRANSLATOR	INTERPRETER	FUNCTIONAL SIMULATION	EMULATION OR (MICROPROGRAM)
GN&C	2	40	1	3	2	10	5
GN&C MDE	3	30	1	3	2	9	5
PM MDE	4	40	1	3	2	9	6
PLH MDE	1	80	1	3	2	10	6
ENGINE CONTROL	7	<10	1	2	2	3	2 (Using H-316/516)
AIR DATA	8	<10	1	2	2	2	3

1-3 LOW
4-6 MEDIUM
7-8 HIGH
9-10 VERY HIGH

	ESTIMATED NON-RECURRING COST			1ST SIMULATOR		RECURRING COST		2ND SIMULATION			RECURRING COST/MISSION PROGRAM CHANGE				
	REAL HARDWARE	TRANSLATOR	INTERPRETER	FUNCTIONAL SIMULATION	EMULATION OR MICROPROGRAM	REAL HARDWARE	TRANSLATOR	INTERPRETER	FUNCTIONAL SIMULATION	EMULATION OR MICROPROGRAM	REAL HARDWARE	TRANSLATOR	INTERPRETER	FUNCTIONAL SIMULATION	EMULATION MICROPROGRAM
GN&C	5	2	2	5	4	4	1	1	1	1	<1	<1	<1	3	1
GN&C MDE	4	2	2	4	3	3	1	1	1	1	<1	<1	<1	3	1
TM MDE	4	2	2	4	3	3	1	1	1	1	<1	<1	<1	3	1
PLM MDE	5	2	2	5	4	4	1	1	1	1	<1	<1	<1	3	1
ENGINE CONTROL	6	2	2	3	2 (Using 3-316/516)	5	1	1	1	1	<1	<1	<1	<1	<1
AIR DATA	1	2	2	<1	1	1	<1	1	1	1	<1	<1	<1	1	1

1 -3 Low
4 -6 Medium
7 -8 High
9-10 Very High

TABLE 3.3-3
OBC SIMULATION RELATIVE COSTS

REFERENCES:	ENGINEER	REV.	THE SINGER COMPANY SIMULATION PRODUCTS DIVISION BINGHAMTON, NEW YORK	TITLE SIMULATOR	REP. NO.	PAGE NO.	OF
	NAME						
	DATE						

	ESTIMATED NON-RECURRING COST 1ST SIMULATOR					RECURRING COST 2ND SIMULATION					RECURRING COST/MISSION PROGRAM CHANGE				
	REAL HARDWARE	TRANSLATOR	INTERPRETER	FUNCTIONAL SIMULATION	EMULATION OR MICROPROGRAM	REAL HARDWARE	TRANSLATOR	INTERPRETER	FUNCTIONAL SIMULATION	EMULATION OR MICROPROGRAM	REAL HARDWARE	TRANSLATOR	INTERPRETER	FUNCTIONAL SIMULATION	EMULATION MICROPROGRAM
GN&C	5	2	2	5	4	4	1	1	1	1	<1	<1	<1	3	1
GN&C DE	4	2	2	4	3	3	1	1	1	1	<1	<1	<1	3	1
CM DE	4	2	2	4	3	3	1	1	1	1	<1	<1	<1	3	1
PLM DE	5	2	2	5	4	4	1	1	1	1	<1	<1	<1	3	1
ENGINE CONTROL	6	2	2	3	2 (Using H-316/516)	5	1	1	1	1	<1	<1	<1	<1	<1
AIR DATA	1	2	2	<1	1	1	<1	1	1	1	<1	<1	<1	1	1

1 -3 Low
4 -6 Medium
7 -8 High
9-10 Very High

TABLE 3.3-3
OBC SIMULATION RELATIVE COSTS

11/17/72

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	OVERALL GRADE				
	REAL HARDWARE	TRANSLATOR	INTERPRETER	FUNCTIONAL	EMULATION OR MICROPROGRAM
GN&C	B	A	D	E	C
GN&C MDE	B	A	D	E	C
PM MDE	B	A	D	E	C
PLM MDE	B	A	D	E	C
ENGINE CONTROL	E	D	C	B	A
AIR DATA	C	D	E	A	B

TABLE 3.3-4
SIMULATION APPROACH
OVERALL GRADE

3.4 References and Assumptions

3.4.1 References

The following references were used in the development of this section of the Simulation Techniques Survey.

Doc. No. 41 Space Shuttle Phase B Final Avionics Report NAS910960 March 8, 1972

Doc. No. 65 Aerospace Digital Computer SKC-2000 No. SKC-2000 Nov. 30, 1970

Doc. No. 151 SDC Proposal Microprogram Processors in Avionics

Doc. No. 166 Space Shuttle Program Technical Proposal Vol. III SD 72-SH-50-3 May 12, 1972

Doc. No. 172 Digital Computer General Description HDC-601 August 23, 1972

Doc. No. 187 IBM OBC Candidates for Shuttle AP101/SPI

Doc. No. 232 Alternate Avionics System Study, Phase B Extension MSC-03329 Nov. 12, 1971

Doc. No. 239 Role of Microprogramming in Fourth Generation Computers

Doc. No. 240 Aerospace Systems Implications of Microprogramming

Hewlitt Packard 2100 Computer Microprogramming Guide Feb. 1972

Varion 73 System Handbook June, 1972

Microdata Corporation Microprogramming Handbook, 2nd Edition Nov.,1971

3.4.2 Assumptions

In order to make effective recommendations on the approach to be implemented for each on-board computer simulation, certain assumptions were made.

These assumptions are as follows:

1. For simulation approaches, employing real OBC hardware, where the real vehicle computers are redundant, it will not be necessary to provide redundant OBC computer simulation, e.g., the GN&C system utilizes 3 redundant on-board computers in the Space Shuttle. It is assumed that the simulation can be accomplished with one real OBC by implementing special simulation techniques in the simulated OBC interface software and/or its hardware interfaces.

2. A high level language will be utilized for software development for the OBC computers utilized for the GN&C, MDE, and Engine Control. It is also assumed the Air Data computer will be programmed in assembly language.

4.0 SYSTEMS SIMULATION

This technique's survey discusses methods of simulation. A detailed evaluation of all possible techniques is not possible within the scope of the study; however, as many techniques are discussed as possible with data available. Present usage of the various techniques is pointed out, but an advantage - disadvantage approach is highly dependent upon the general math model structuring and is therefore omitted. To do otherwise could lead to contradictory conclusions.

4.1 AXIS SYSTEMS

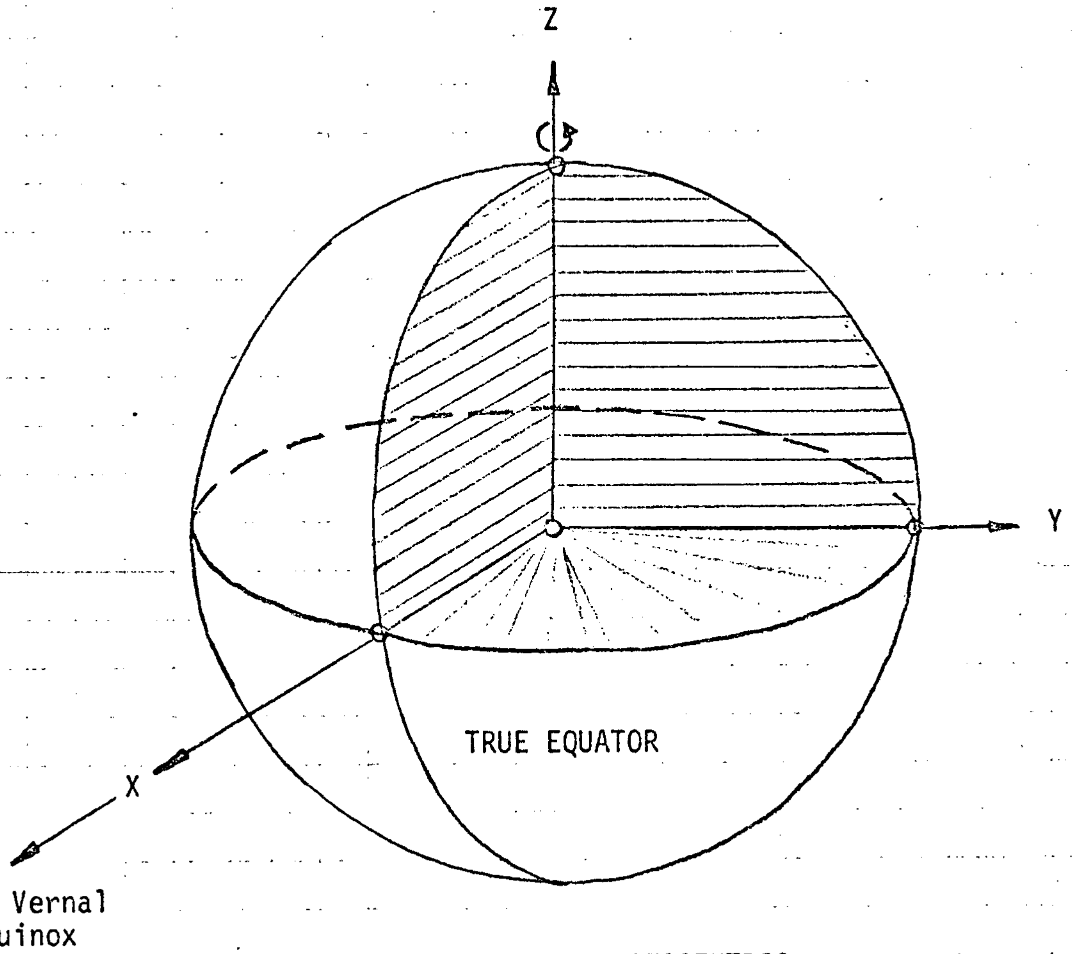
4.1.1 OVERVIEW

The selection of coordinate systems for simulation must consider a number of external influences.

- Reference frame in which mission dependent data is supplied.
- Numbers and ease of transformations.
- Accuracy requirements.
- Mission requirements.
- Simulator hardware requirements (external to simulator computer).

By consideration of the reference frame of supplied data, a possible problem with verification can be avoided. This does not dictate that the simulator contain the supplied reference frame but does present a possible problem. The solution could be to have the data supplied in another coordinate system. The number and ease of transformation to other coordinate systems has an impact on both computer sizing and cost of software development. The accuracy and resolution requirements may vary for different mission phases. For instance, on approaching a landing site, the resolution of the out-the-window presentation requirements is a factor inversely proportional to range. Any coordinate systems selected must be capable of accomplishing the mission requirements. An example is the SMS payload simulation. Once the payload is moved from its stowed position in the payload bay where it is a part of the orbiter vehicle, additional information about the payload is required by several systems including Guidance, Control and Visual.

The real world standards for the Space Shuttle Program are recommended in reference (1). Additional requirements are dictated by the simulator, the visual system for example.



TRUE-OF-DATE INERTIAL GEOCENTRIC

Type: Non-rotating, Earth referenced

Origin: Center of the Earth

Orientation and Labeling:

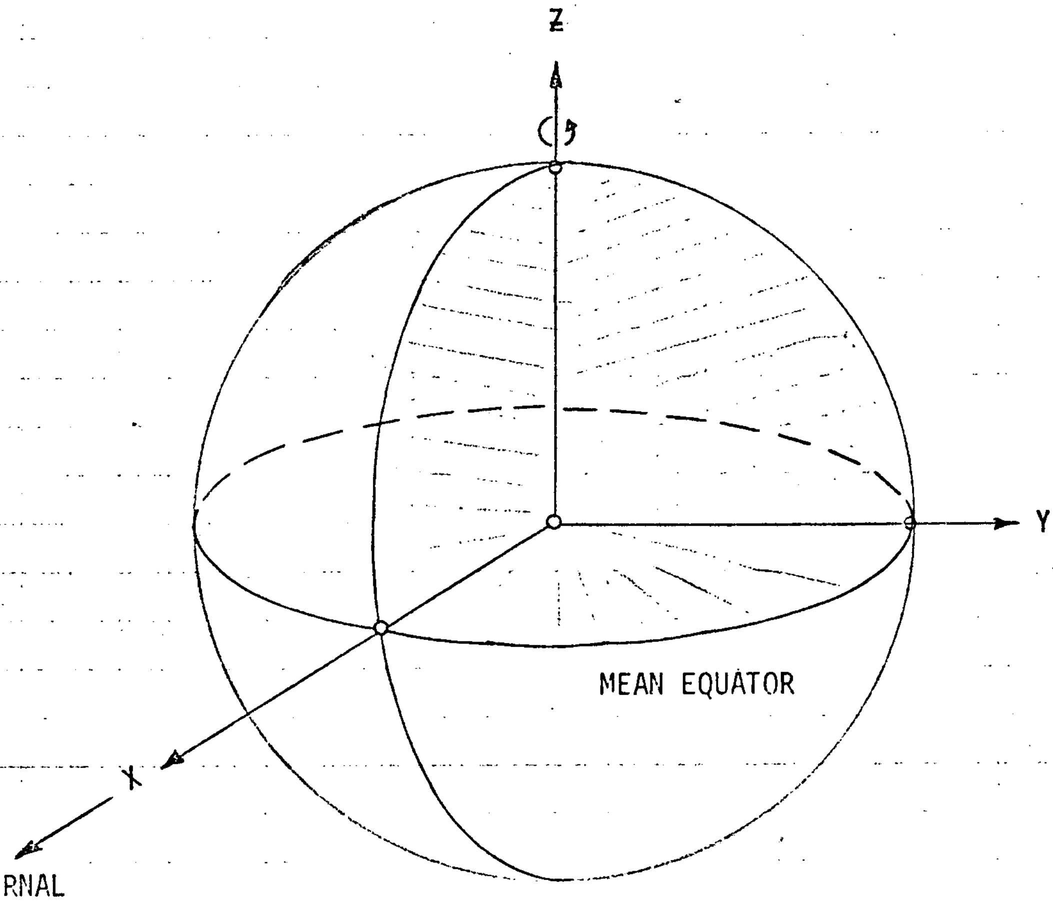
Z - True Earth north polar axis on date

X - True vernal Equinox on date

Y - Completes standard right-hand system

Subscript: T

Usage: State vectors are maintained in this system except for approach and landing. Simplifies calculations involving position relative to earth geometry.



GEOCENTRIC INERTIAL

Type: Inertially fixed, Earth-Referenced.

Origin: Center of the Earth.

Orientation and Labeling:

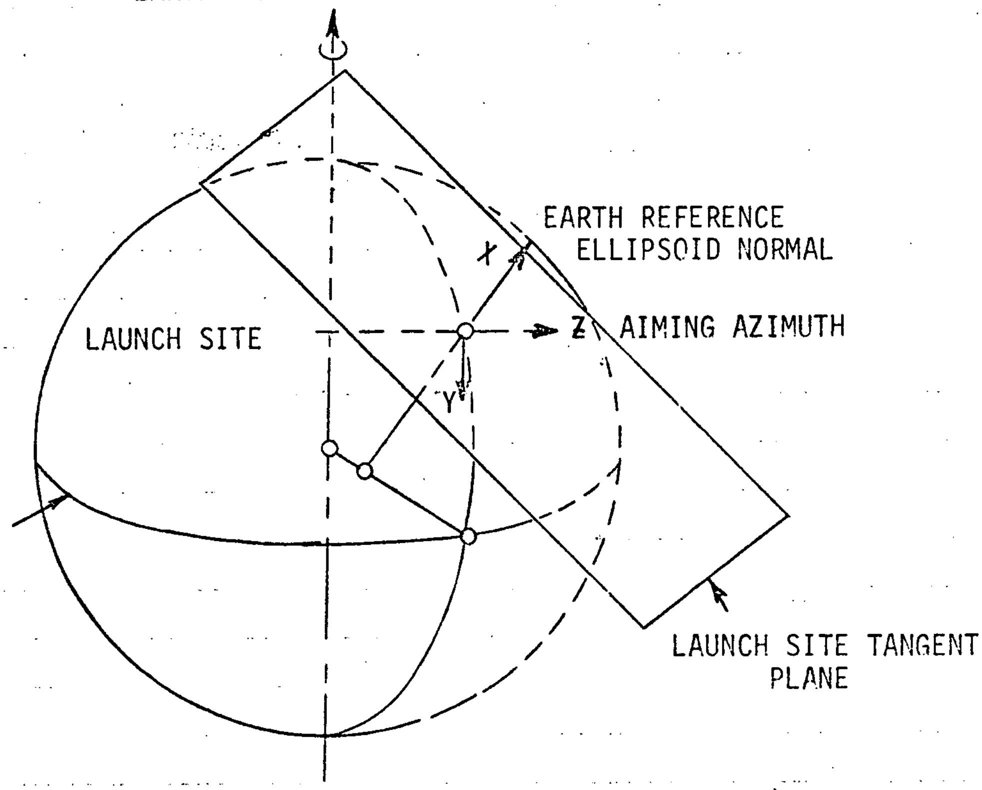
Z - Perpendicular to earth's mean equator of 1950.0, positive north.

X - Directed along intersection of ecliptic and mean equator of 1950.0, toward the vernal equinox.

Y - Completes standard right-hand triad system.

Subscript: I

Usage: Used as the basic coordinate system. State vectors are maintained in this system for all phases of the mission, except for approach and landing. Initial conditions data is presently supplied in this frame.



EARTH FIXED LAUNCH SITE

Type: Rotating-With Respect To Inertial, Earth-Referenced.

Origin: Intersection of Earth-reference ellipsoid and the normal to it passing through the launch site.

Orientation and Labeling:

X - Coincident with the earth-reference ellipsoid normal passing through the site, positive outward from earth.

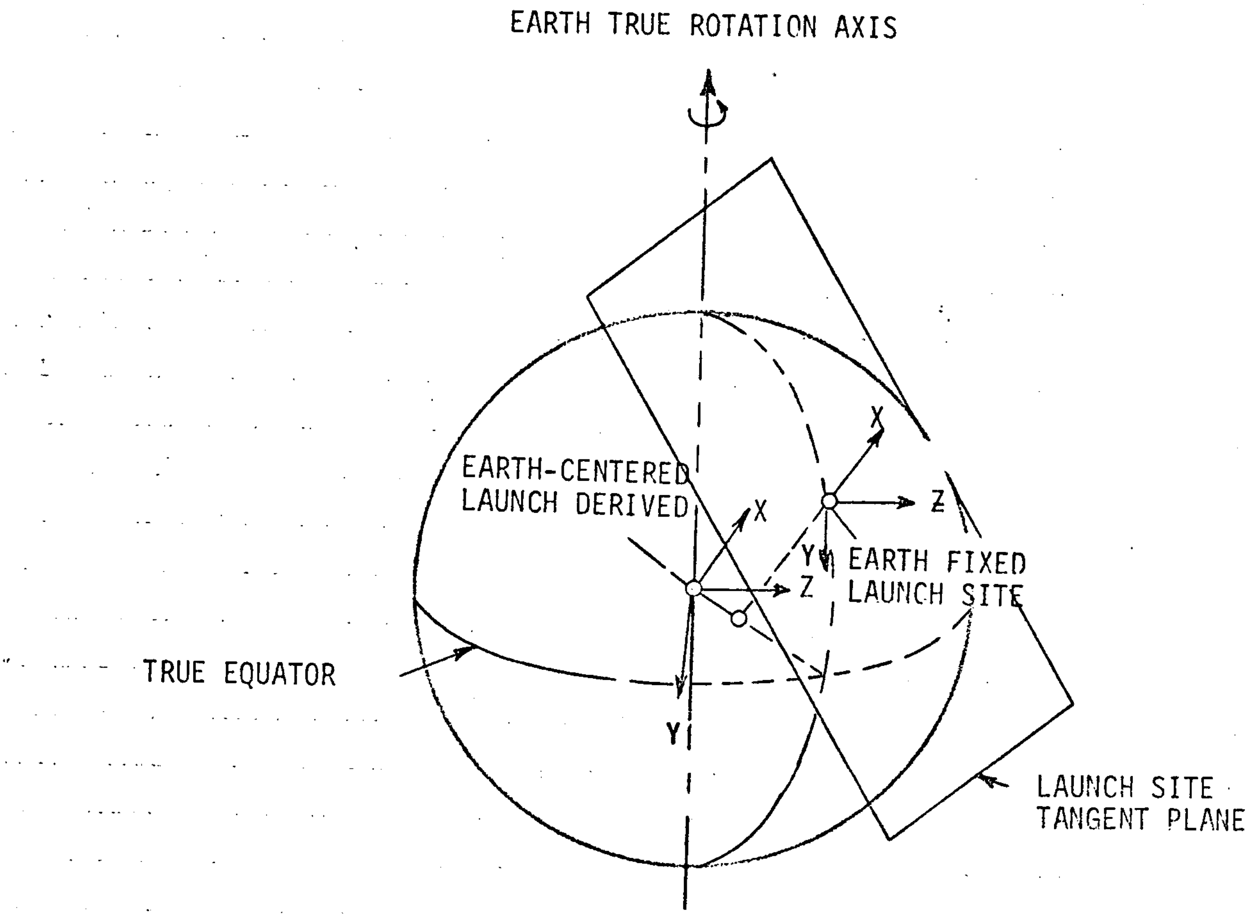
Z - Parallel to Earth-fixed aiming azimuth defined at guidance reference release time, positive downrange.

Y - Completes a standard right-handed triad system.

(The Y-Z plane is the launch site tangent plane.)

Subscript: L

Usage: None



EARTH-CENTERED LAUNCH DERIVED

Type: Rotating with respect to Inertial, Earth-referenced.

Origin: Center of the Earth.

Orientation and Labeling:

X - Parallel to the earth-reference ellipsoid normal passing through launch site, positive toward the site.

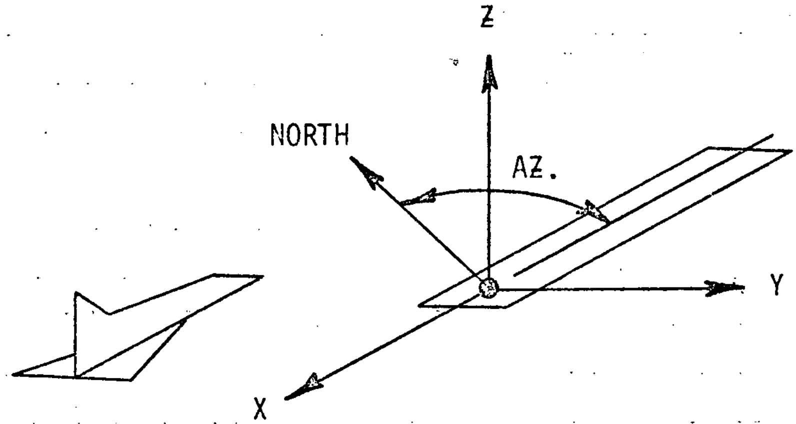
Z - Parallel to the Earth-fixed aiming azimuth, positive toward aiming azimuth.

Y - Completes standard right-handed triad system.

(The Y-Z plane is parallel to the launch site tangent plane.)

Subscript: K

Usage: The system is translatable with the Earth-fixed launch site system.



EARTH-FIXED LANDING SITE

Type: Rotating with respect to Inertial, Earth-Referenced.

Origin: End of Runway.

Orientation and Labeling:

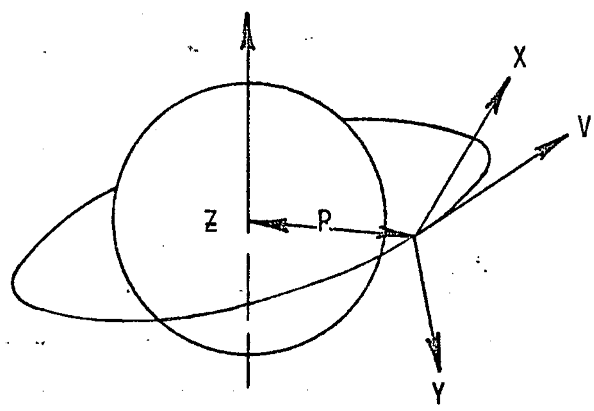
+X - Along the reciprocal of the runway centerline azimuth.

+Z - Local vertical, positive up.

Y - Completes right-hand triad system.

Subscript: F

Usage: Used during approach and landing.



LOCAL ORBITAL

Type: Orbit-Referenced, Rotating with respect to Inertial.

Origin: Vehicle center of mass.

Orientation and Labeling:

Z - Positive toward center of the Earth along vehicle earth-centered position vector.

Y - Positive along normal to the orbit plane in direction of V X R.*

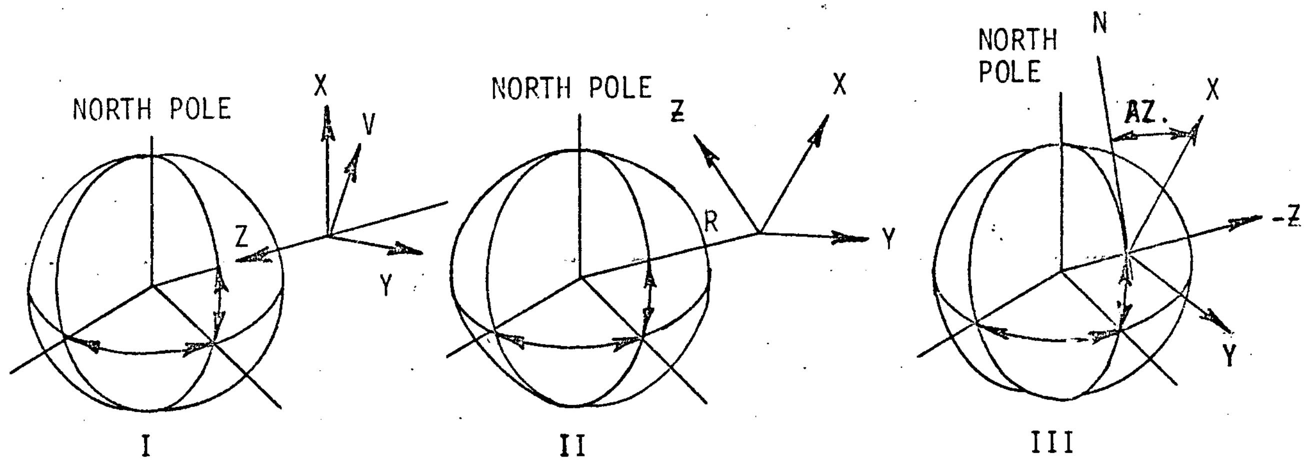
X - Completes standard right-hand triad system.

*R - Radius vector of vehicle position from center of the Earth.

*V - Vehicle velocity vector.

Subscript: 0

Usage: Attitude reference, displays.



IRU STABLE MEMBER

Type: Earth-Referenced, Non-Rotating inertially fixed.

Origin: Center of IRU Stable Member.

Orientation and Labeling:

I - Local Vertical

+Z - Direction of the negative position vector (-R).

+Y - Direction of cross-product of velocity vector (V) into the position vector (R).

+X - Completes standard right-hand triad system.

II - Thrust Alignment

+X - Parallel to vehicle +X axis in preferred attitude for engine start.

+Y - Direction of the cross product of +X and the position vector (R).

+Z - Completes right-hand system.

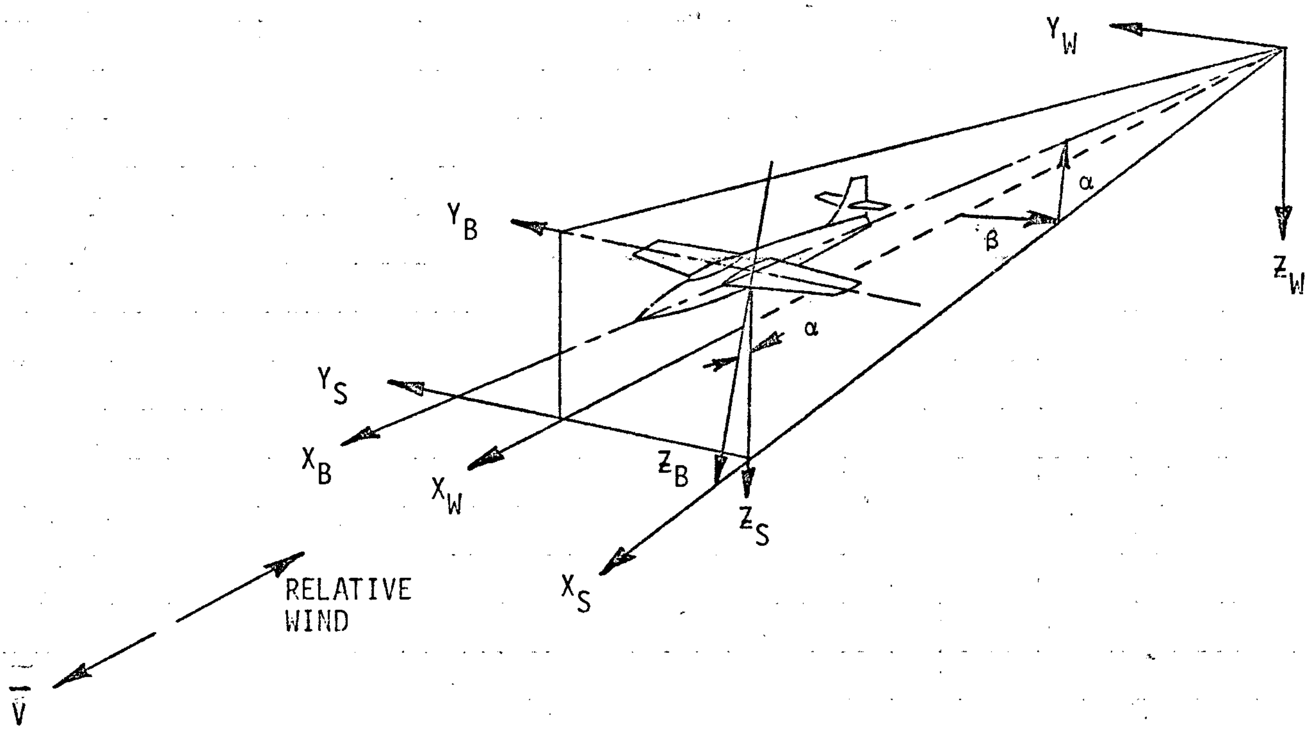
III - Prelaunch

+Z - Direction of the idealized plumbline vector (-R) at GRR.

+X - Direction of the derived launch azimuth angle (A_Z) at GRR.

+Y - Completes right-hand system.

SUBSCRIPT: S



DYNAMICAL BODY

Type: Vehicle-Referenced, Rotating with respect to inertial.

Origin: Vehicle center of mass.

Orientation and Labeling:

X and Z lie in the plane of symmetry with +X forward in the longitudinal direction.

Y completes right-hand triad system.

$\bar{V}$ - Velocity relative to the atmosphere.

X_B, Y_B, Z_B - Body axis system coordinates. X-Z is the plane of symmetry. Origin is the center of mass. Y completes right-hand triad system.

X_S, Y_S, Z_S - Stability axis coordinates. X-Z is the plane of symmetry parallel to body axis. Origin is center of mass or other convenient point.

X_W, Y_W, Z_W - Wind axis system coordinates. Origin is center of mass or other convenient point.

α - Angle of attack.

β - Angle of sideslip.

DYNAMICAL BODY - Continued

Transformation from Body Axes to Dynamical:

$$X_B = X_{V(C.G.)} - X_V$$

$$Y_B = Y_V - Y_{V(C.G.)}$$

$$Z_B = Z_{V(C.G.)} - Z_V$$

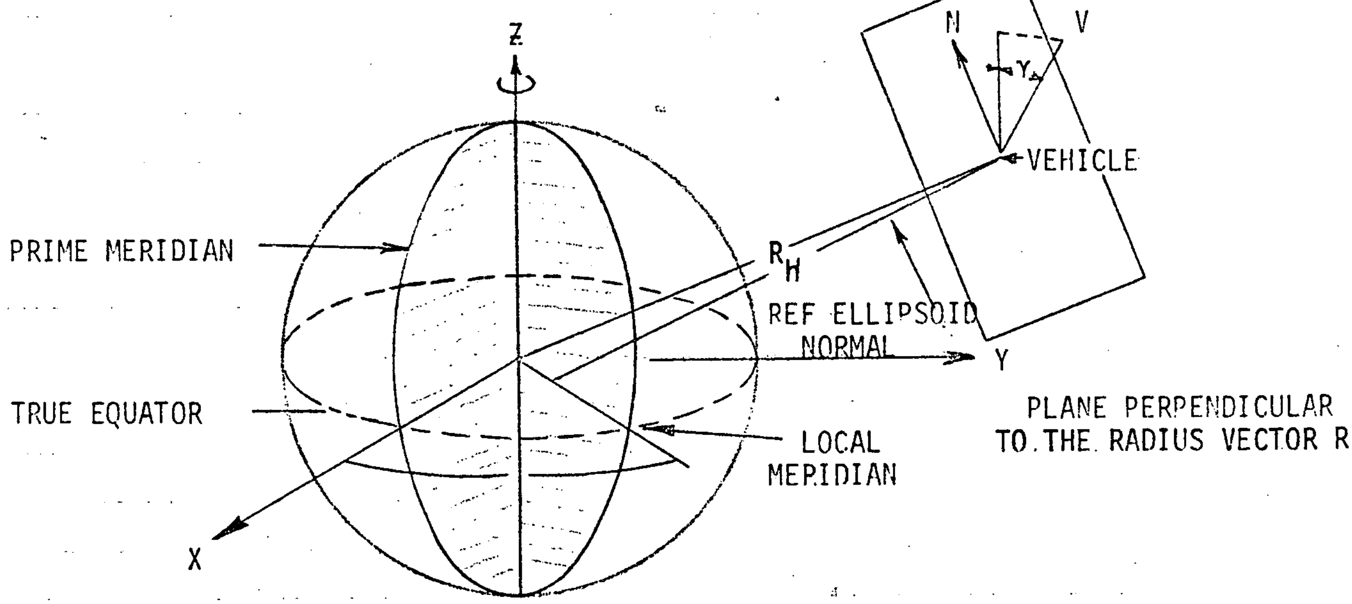
Where X_B, Y_B, Z_B are dynamical body coordinates

X_V, Y_V, Z_V are launch config. structural body coordinates.

$X_{V(C.G.)}$, $Y_{V(C.G.)}$, $Z_{V(C.G.)}$ are the structural body coordinates of the center of mass.

SUBSCRIPT: D

Usage: Aerodynamics.



GEOGRAPHIC

Type: Rotating, with respect to Inertial frame, Earth-Referenced.

Origin: Center of the Earth.

Orientation and Labeling:

λ - Longitude measured eastward from the Greenwich meridian to the meridian of interest, positive-east.

δ - Geocentric declination measured from the equatorial plane to the geocentric radius vector, positive north.

L - Geographic latitude measured from the equatorial plane and the radius vector at the point of intersection with the earth surface, positive north.

h - Altitude is the perpendicular distance from the Earth-reference ellipsoid to the point of interest.

R - Radius vector magnitude measured between the center of the earth and the point of interest.

V - Velocity magnitude of the vehicle (inertial).

γ - Flight path angle measured positive upward to the velocity vector from the plane normal to the geocentric radius vector.

GEOGRAPHIC - Continued

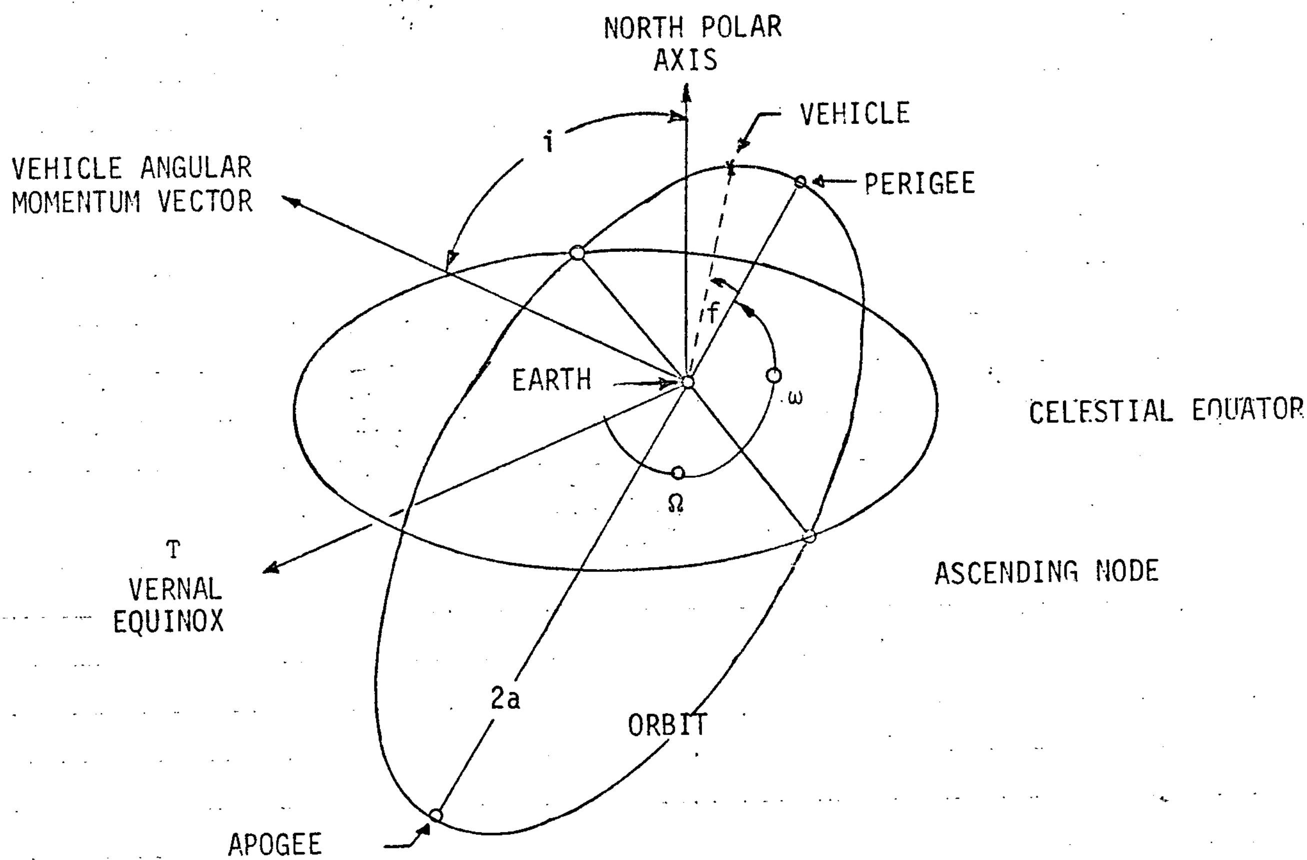
+Z - Directed along the Earth's true rotational axis, positive north.

+X - Directed through the Greenwich meridian and the true equator.

Y - Completes standard right-handed triad system.

Subscript: E

Usage: Used for ground station locations, tracking, and communications.



ORBITAL ELEMENTS

Type: Non-Rotating, Earth-Referenced.

Origin: The Center of the Earth.

Orientation and Labeling:

a - Semimajor axis of the orbit.

e - Eccentricity of the orbit.

ω - Argument of perigee, the angle measured in the orbit plane from the ascending node to perigee, positive in the direction of the orbit.

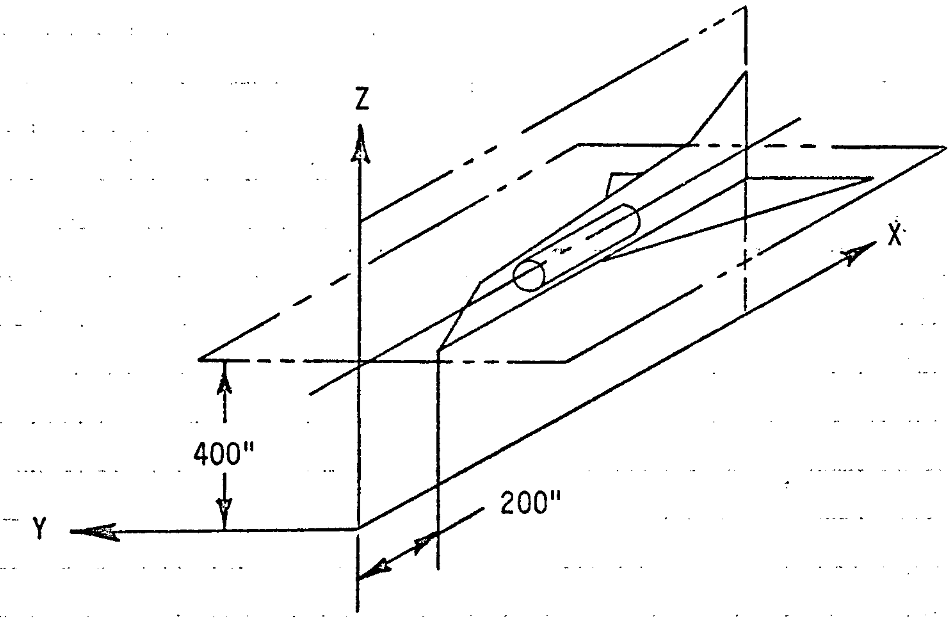
i - Inclination angle is the angle between the north polar axis (mean 1950.0) and the vehicle angular momentum vector.

Ω - Right ascension of the ascending node is the angle measured eastward from the vernal equinox (mean 1950.0) along the equator to ascending node.

f - True anomaly is the geocentric angular displacement of the vehicle measured in the orbit plane from perigee positive in the direction of travel in the orbit.

ORBITAL ELEMENTS - Continued

Usage: Used to compute orbital elements.



ORBITER STRUCTURAL BODY

Type: Vehicle referenced, rotating with respect to inertial frame, fixed with respect to body.

Origin: 200 inches ahead of the vehicle nose and 400 inches below the payload bay centerline.

Orientation and Labeling:

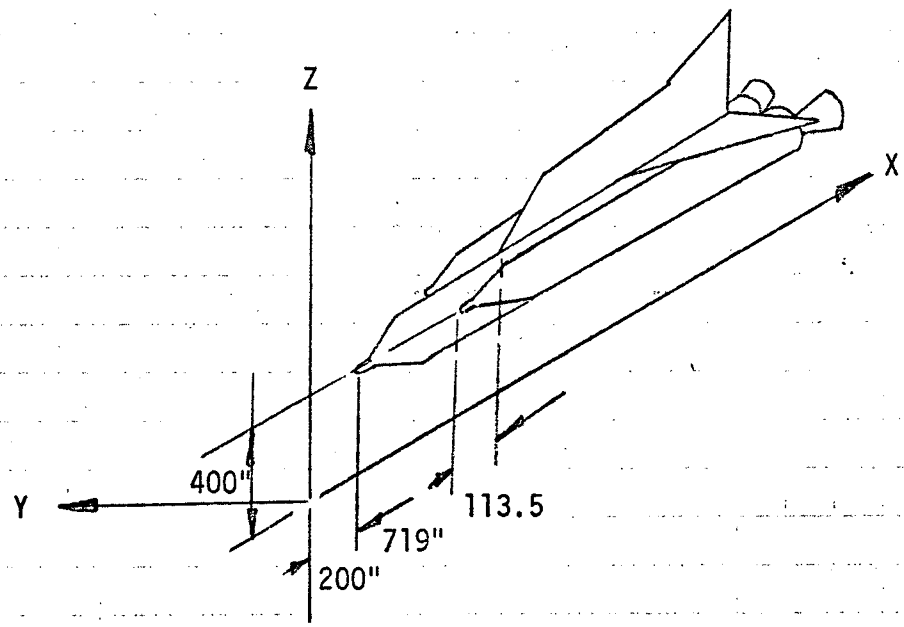
X - Parallel to payload bay centerline, positive aft

Z - Positive upward

Y - Completes right-hand triad system.

Subscript: V_o

Usage: Vehicle geometry, weights and balance.



LAUNCH CONFIGURATION STRUCTURAL BODY

Type: Vehicle reference, rotating with respect to inertial frame, fixed with respect to body.

Origin: 200 inches ahead of the External Tank nose and 400 inches below the External Tank centerline.

Orientation and Labeling:

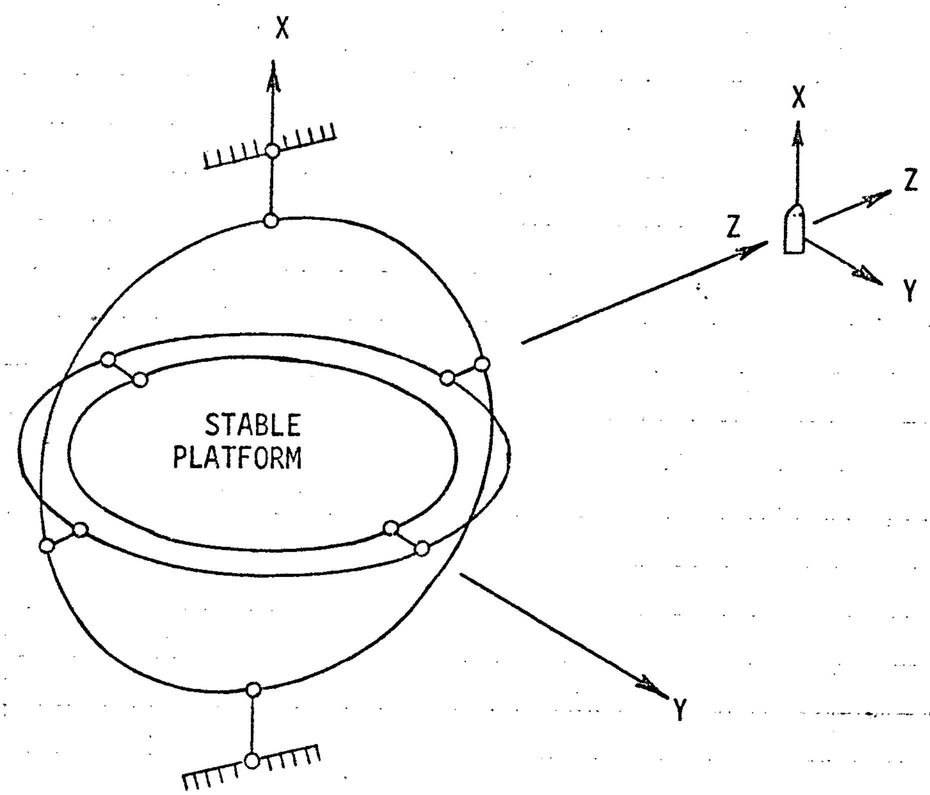
X - Parallel to the External Tank longitudinal structural element, positive aft.

Z - Positive upward

Y - Completes right-hand triad system.

Subscript: V

Usage: Vehicle geometry, weights and balance



NAVIGATION BASE

Type: Vehicle referenced, fixed WRT body rotating WRT inertial frame.

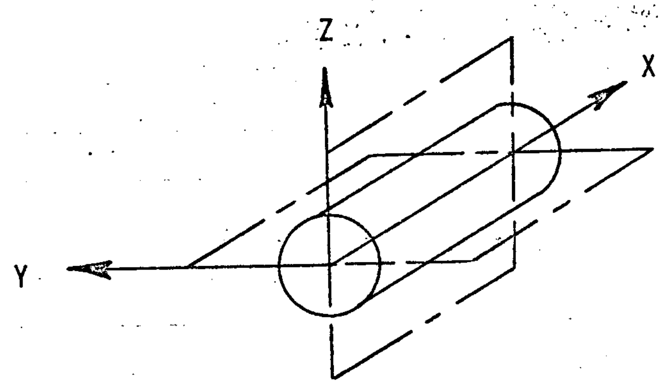
Origin: Mounting points of IRU and Navigation Base

Orientation and Labeling:

Navigation base coordinates shall be orthogonal and parallel to the vehicle coordinates.

Subscript: N

Usage: Guidance and Navigation



PAYLOAD STRUCTURAL BODY

Type: Payload referenced, fixed WRT payload rotating WRT inertial frame.

Origin: Payload centerline at front end of payload

Orientation and Labeling:

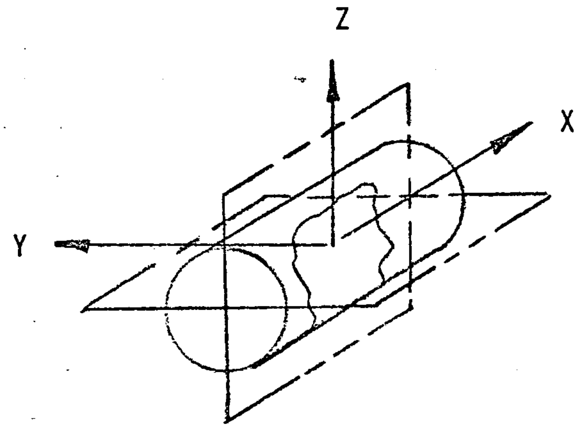
X - Negative in the direction of launch, parallel to the payload bay centerline, while attached.

Z - Positive upward in the orbiter landed position, parallel to the orbiter Z axis, while attached.

Y - Completes right-hand time system.

Subscript: P

Usage: Visual, vehicle geometry, mass properties summation.



PAYLOAD

Type: Payload referenced, non-rotating WRT payload, rotating WRT inertial frame.

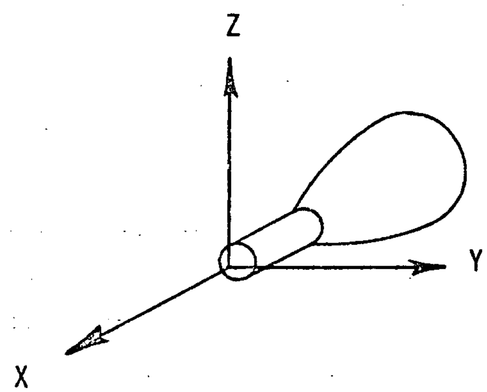
Origin: Payload center of mass.

Orientation and Labeling:

Axes are parallel to the Payload Structural Body.

Subscript: Q

Usage: Payload control dynamics



SHUTTLE ENGINE

Type: Engine referenced, fixed WRT body, rotating WRT inertial frame.

Origin: Gimbal stage mounting surface on Engine Centerline

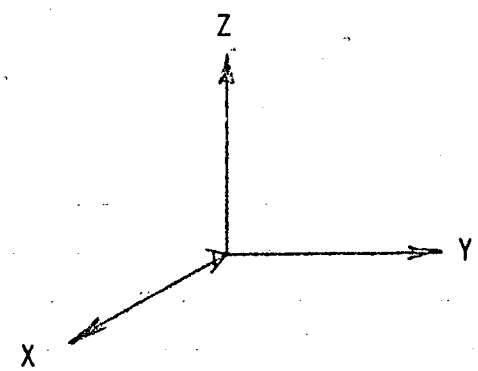
Orientation and Labeling:

X - longitudinal, positive opposite to engine nozzle exit

Y, Z - orthogonal with + X right hand time system.

Subscript: $N_{1...N}$

Usage: Main Engines and OMS, and SRM's.



VISUAL

Type: Vehicle referenced, rotating

Origin: Viewer Eyeball

Orientation and Labeling:

TBD after Visual System hardware selection

Subscript: V

Usage: Visual simulation

4.1.3 RECOMMENDATIONS AND ASSUMPTIONS

Except for simulator hardware unique requirements, the coordinate systems surveyed are now represented on existing simulations. These math models should be considered for direct implementation on the SMS.

The basic coordinate system for equations of motion should be the mean 1950 based inertial system as presently implemented on both the CMS and SLS simulators except for the approach and landing phases. Resolution accuracy requirements for approach and landing will probably require use of the landing site centered system as implemented on the HFTS.

A requirement exists for approach and landing navigation for multiple ground based navigational aids stations. The earth centered and earth fixed landing axes systems appear best adaptable for this requirement.

The requirements for the payload have been discussed in the techniques, however, the manipulator has not. As data is received to allow specification of these devices, coordination systems for the shoulder, elbow and wrist can be defined.

4.1.4 REFERENCES AND ASSUMPTIONS

(1) Recommended Space Shuttle Coordinate System Standards. NASA Internal Note No. 71-EW-5. May, 1971.

(2) Proposed Coordinate Systems Standards For The Space Shuttle Vehicle MSC-04315 May 21, 1971.

(3) HFTS, SLS, CMS, T-27 Survey.

4.2 Integration Schemes

4.2.1 Overview

The problem of choosing integration schemes for aerospace training simulation is compounded by the requirements for extremely high accuracy, frequency response bandwidth and cost. In training simulations, the input/output to computer/training station. The bandwidth requirements are generally below 2 HZ, however, loops internal to the simulation of a given system may require much higher response to maintain accuracy and stability. A 2 HZ limitation in the trainee loop has been used in the past to justify lower requirements on the computation schemes and with good justification for functional simulations requiring only the stimulus-response loop including the trainee. The costs of approaching real world fidelity is generally prohibitive and therefore, techniques have been developed to circumvent many of the problems. These techniques are advantageous only after analysis of the requirements of the simulation. Recognition must be made of the change in requirements when non real-time is used. "Fast" time and "Slow" time as well as discrete initial conditions insertion must also be considered in the selection of the scheme to be used for simulation of the time-dependent parameters. Finally, the computation rate and computer must be considered in the selection of an integration scheme due to the impact on errors. Errors which must be considered are defined as follows:

Round-Off Error - This is caused by programming techniques, the computer used and type of arithmetic (fixed or floating point). The round-off error is usually not significant unless the computer word length is marginally small.

Truncation Error - This error is caused by approximating the solution to differential equations by difference equations. Judicious selection of integration method coefficients is the major control.

Propagated Error - The total error (the sum of round-off and truncation) may be insignificantly small at an instant in the integration process. However, these small errors may, if allowed to accumulate without bound, become the over-riding consideration. The propagated error is a function of integration step size, other errors, integration scheme and characteristics of the system simulated.

Stability - Stability is normally tested by response to a step-function input. The ability of the system to respond to accept the input and return to a nominal steady-state condition is a function of the integration scheme selected, the computation rate selected and characteristics of the system simulated.

Phase Shift - The function may function accurately in duplication of excursions of the system simulated but be shifted on time. This shift is generally small but the effects of the shift can have serious consequences, especially in the interface between systems and result in instability. Analysis of the systems and implementation methods can minimize these effects although the discrete nature of digital computation does not allow absolute relief from the problem.

4.2.2 Techniques

Table I lists a number of integration methods. The characteristics of each method are sufficiently different as relates to errors to warrant inclusion in the survey. As examples of use of the table, the formulas for the parabolic O_{13}, the trapezoidal and the second order Adams are written as follows:

Parabolic (O_{13})

$$X_{N+1} = X_N + \Delta t \left(\frac{23}{12} \dot{X}_N - \frac{4}{3} \dot{X}_{N-1} + \frac{5}{12} \dot{X}_{N-2}\right)$$

Trapezoidal (C_{12})

$$X_{N+1} = X_N + \Delta t \left(\frac{1}{2} \dot{X}_{N+1} = \frac{1}{2} \dot{X}_N\right)$$

2nd Order Adams (O_{12})

$$X_{N+1} = X_N + \Delta t \left(\frac{3}{2} \dot{X}_N - \frac{1}{2} \dot{X}_{N-1}\right)$$

TABLE I

TABLE OF POPULAR NUMERICAL INTEGRATION TECHNIQUES

$$Y_n = \sum_{i=1}^{3} a_i \; Y_{n-i} + h \sum_{i=0}^{3} b_i \; Y_{n-i}$$

Method	Type	a_1	a_2	a_3	b_0	b_1	b_2	b_3
Euler	O_{11}	1				1		
Backward Rectangular	C_{11}	1			1			
2nd Order Adams	O_{12}	1				3/2	-1/2	
Trapezoidal	C_{12}	1			1/2	1/2		
O_{33} Mod Gurk*	O_{33}	1.1462	-0.2011	0.0549		1.6416	-1.0080	0.2751
Classic O_{33}	O_{33}	-18	9	10		9	18	3
Simpson	C_{13}		1		1/3	4/3	1/3	
O_{30} C_{31} Mod Gurk*	O_{30}	1.807	-1.109	0.303				
	C_{31}	1.146	-0.201	0.055	0.909			
Classic O_{30}	O_{30}	3	-3	1				
Classic C_{31}	C_{31}	18/11	-9/11	2/11	6/11			
3/8 Rule	C_{14}			1	3/8	9/8	9/8	3/8
Adams - Bashforth	C_{14}	1			9/24	19/24	-5/24	1/24
Best O_{12} Method Based* on Stability Alone	O_{12}	1				3/4	1/4	
1/2 Rule	C_{24}	1/2	1/2		17/48	51/48	3/48	1/48
Parabolic	O_{13}	1				23/12	-4/3	5/12
Classic	O_{11}		1			2		
Classic	O_{22}	-4	5			4	2	
Classic	C_{22}	8/10	2/10		4/10	8/10		
Classic	C_{13}	1			5/12	2/3	-1/12	
Classic	C_{32}	9/17	9/17	-1/17	6/17	18/17		
1/3 Rule	C_{34}	1/3	1/3	1/3	13/36	39/36	15/36	5/36
2/3 Rule	C_{24}		2/3	1/3	25/72	91/72	43/72	9/72

* Denotes a non-classic method

TABLE I

Abbreviation	Meaning
O_{nm}	An open integration method (i.e. one not using the present value of the derivative) which uses n past values of the dependent variable and m past values of the derivative of the dependent variable.
C_{nm}	A closed integration method (i.e. one which uses the present value of the derivative) which uses n past values of the dependent variable and m-1 past values of the derivative of the dependent variable.

Table II lists figures of merit for eight integration methods as defined in reference (1). The method of arriving at the figures of merit are shown in the reference. The note with respect to the trapezoidal method is taken from the reference. The trapezoidal method has been successfully implemented for flight simulation in conjunction with an "Open" technique, as the corrector half of a predictor - corrector, as the second integrator in a double integral, etc.

TABLE II

INDIVIDUAL FIGURES OF MERIT FOR EIGHT INTEGRATION METHODS

Method	W_1	W_2	W_3	W_4	W_5
O_{33}Mod Gurk	0.56014	0.21678	0.56009	0.00006	0.000003
Rectangular	0.86466	0.34963	0.86466	0.000007	0.117023
Trapezoidal*	1.0	0.92008	0.99996	0.00173	0.00183
Parabolic	0	0	0	0	0
Second-Step	0.99817	0.18860	0.99813	0.00001	0.00673
$O_{30}C_{31}$	0.56014	0.21678	0.56008	0.00006	0.000001
Classical O_{13}	0.42305	0.23261	0.42305	0.00002	0.00014
2nd Order Adams	0.63212	0.16613	0.63212	0	0.01580

W_1 = Stability

W_2 = Truncation Error

W_3 = Round-off Error

W_4 = Propagated Error

W_5 = Computing Time

*The Trapezoidal Method, being closed technique, is not normally practical for flight simulation applications. However, because of its popularity for other applications, it is included in the analysis.

Table III shows a method of selection of a "correct" integration scheme by assigning weights to the criteria for the system. The cases shown should be used as examples only since characteristics of the system being simulated is the overriding criteria in the selection.

TABLE III

TOTAL FIGURES OF MERIT USING THREE SEPARATE WEIGHTING CONFIGURATIONS FOR EIGHT INTEGRATION METHODS

Method	Case A	Case B	Case C
O_{33}Mod Gurk	1.33707	0.94862	2.61086
Rectangular	2.1960	1.70586	4.13373
Trapezoidal	2.9237	1.96539	6.26623
Parabolic	0	0	0
Second Step	2.1916	1.60499	4.06286
$O_{30}C_{31}$	1.33706	0.94861	2.61083
Classical O_{13}	1.07887	0.75119	2.17864
2nd Order Adams	1.44617	1.06285	2.71871

Case A: $W_1 = W_2 = W_3 = W_4 = W_5 = 1 \quad \Sigma W_i = 5$

Case B: $W_1 = 1/2;\ W_2 = 1/2;\ W_3 = 1;\ W_4 = 1;\ W_5 = 2 \quad \Sigma W_i = 5$

Case C: $W_1 = 1/2;\ W_2 = 3;\ W_3 = 3;\ W_4 = 3;\ W_5 = 1/2 \quad \Sigma W_i = 10$

The techniques for open and closed integration formulas were evaluated on a 6400 computer (reference 2). The 6400 computer has a 48 bit mantissa floating point word length making the round-off error negligible. This is found to be generally true of round-off error in that as long as round-off error does not approach that of the propagated error, round off error can be ignored for it will be dominated by truncation errors. As an example (reference 1), an analysis was applied to a linear first order differential equation using the O_{33} Mod Gurk method for integration. This resulted in truncation error bounds of $.62 \times 10^{-3}$ and local round-off error of $.62 \times 10^{-10}$.

A natural frequency of 2 Hz, assuming a linear second order system step response to the system was used. The calculation of W_N (Natural frequency) and W_d (damped natural frequency) and ξ from the time history of the system were assumed to be perfect damped sinusoid.

In all cases the open form was used for integration of the highest order derivative ($\ddot{y}$) and the closed forms used for the lower order derivative ($\dot{y}$). The open form is a predictor in that the value of the integral is based on data at time N, N-1, N-2 etc. The closed form is a corrector in that the value of the integral is based on data including time N + 1. Figures 1 through 8 show the results of these computer implementation.

Table 4 is a representative list of integration schemes implemented for aerospace simulations.

TABLE 4

USE \ SIMULATOR	CMS	T-27	SLS	HFTS
TRANSLATIONAL EOM	BOOST: 812 ORBIT: O_{13}-O_{12}	O_{13}/C_{13}	O_{13}	O_{13}/O_{13}
ROTATIONAL EOM	O_{12}/Trapezoidal	O_{12}/C_{12} O_{11}/C_{11}	O_{12}	O_{12}/O_{12}
RCS	O_{11}	O_{11}	N/A	C_{11}/Rectangular
CRYOGENICS	O_{11}	N/A	N/A	N/A
STABILITY AND CONTROL	Z Transform	O_{11}	N/A	N/A
TARGETING	Runge-Kutta	O_{12}/C_{12}	N/A	Z Transform
FLIGHT CONTROL COMPUTER	Z Transform	N/A	N/A	Z Transform
PLATFORM	Trapezoidal	N/A	N/A	C_{11} Trapezoidal

4.2.3 Trade-Offs and Recommendations

A final step in the survey should be a computer evaluation of the various techniques using representative shuttle systems programmed representative of the SMS program language and computer. This approach is beyond the scope of the Simulation Techniques Survey.

In determining the integration scheme to be used for each SMS system, strong consideration should be given to the proven techniques now being used on other aerospace training simulations. In so doing, the difference in the computer and possibly different program languages should be considered as these factors may materially effect the results obtained.

It must be remenbered that to accomplish all simulation modes required, even the well-behaved functions may be required to undergo off nominal changes. This is illustrated by analyzing the requirements for "fast" time, "slow" time and "reset". These off-nominal modes can not be ignored.

Consideration should be given to including more than one integration scheme for time dependent parameters under different mission modes. The dynamic response, stability and numerical accuracy emphasis is not the same for all phases of the mission nor for all modes of operation of the simulator. For instance, on "reset", while in "freeze" mode, particular on-board systems may require integrations schemes resulting in rapid stability convergence (without use of consummables).

In general, formulas using a minimum of past data like O_{11} C_{11} perform better for the lightly damped case such as rotational EOM while for the heavily damped case, more part data like O_{13} C_{13} performs better (Translational EOM).

Sophisticated computing algorithms involving the use of Z transforms can extend the bandwidth using integration schemes of the predictor-corrector and Runge-Kutta type. These schemes require multiple derivative evaluations of each integration step.

SYSTEM PARAMETERS

$$g(s) = \frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}$$

$$\zeta = .005$$

$$\omega_n = 4\pi$$

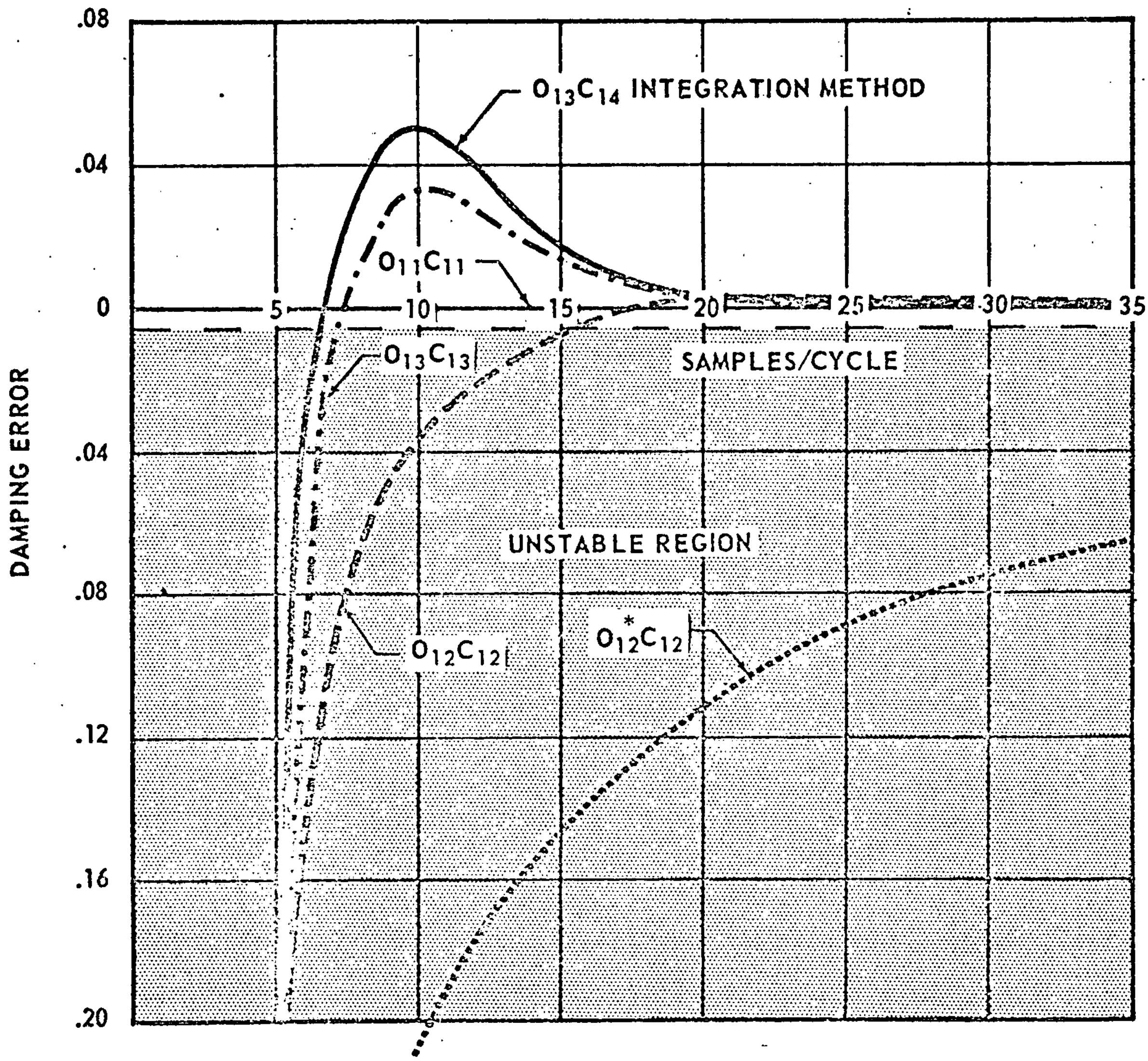


Figure 1 - Damping Error vs Samples/Cycle for .005 Damping Ratio

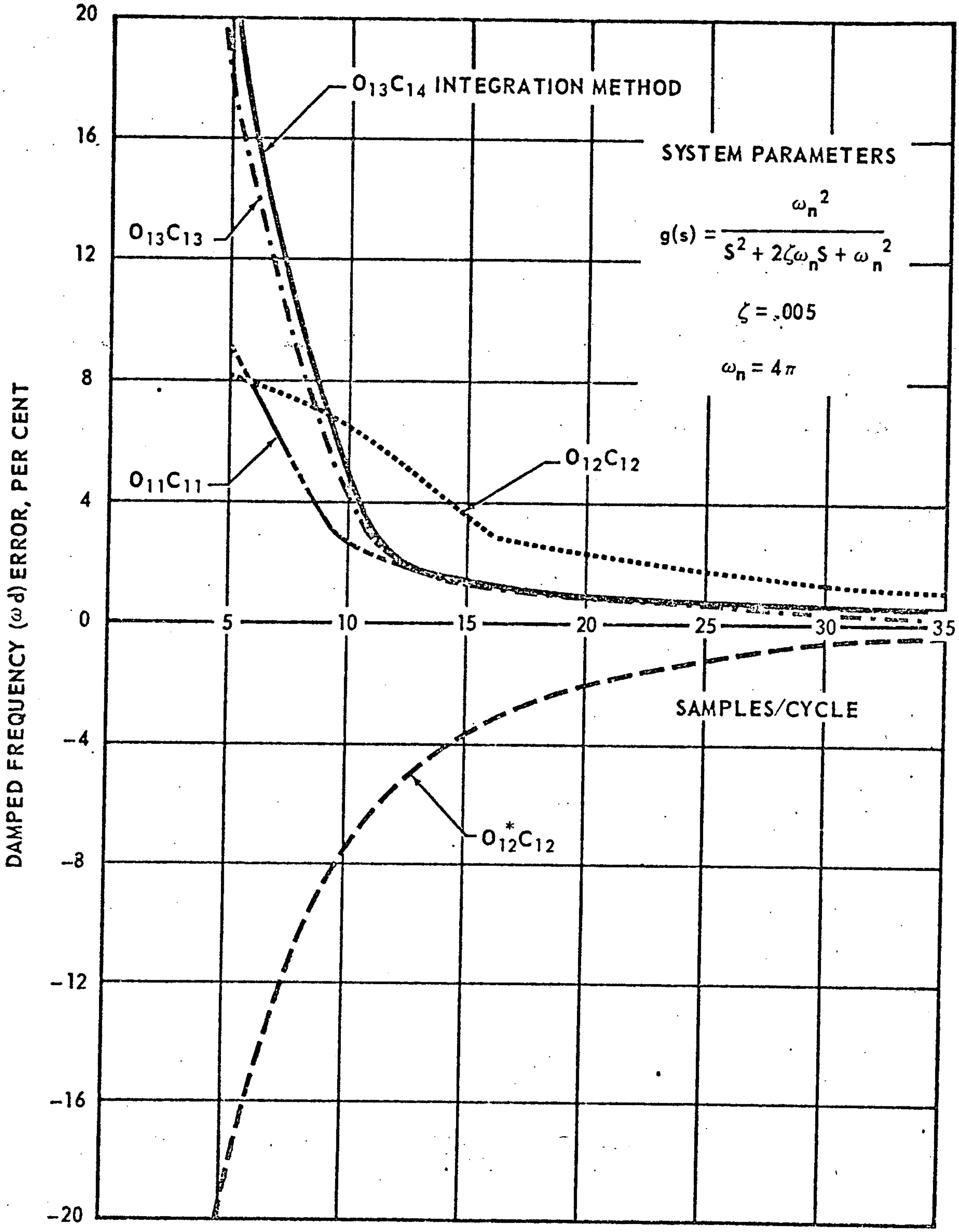


Figure 2 - Frequency Error vs Samples/Cycle for .005 Damping Ratio

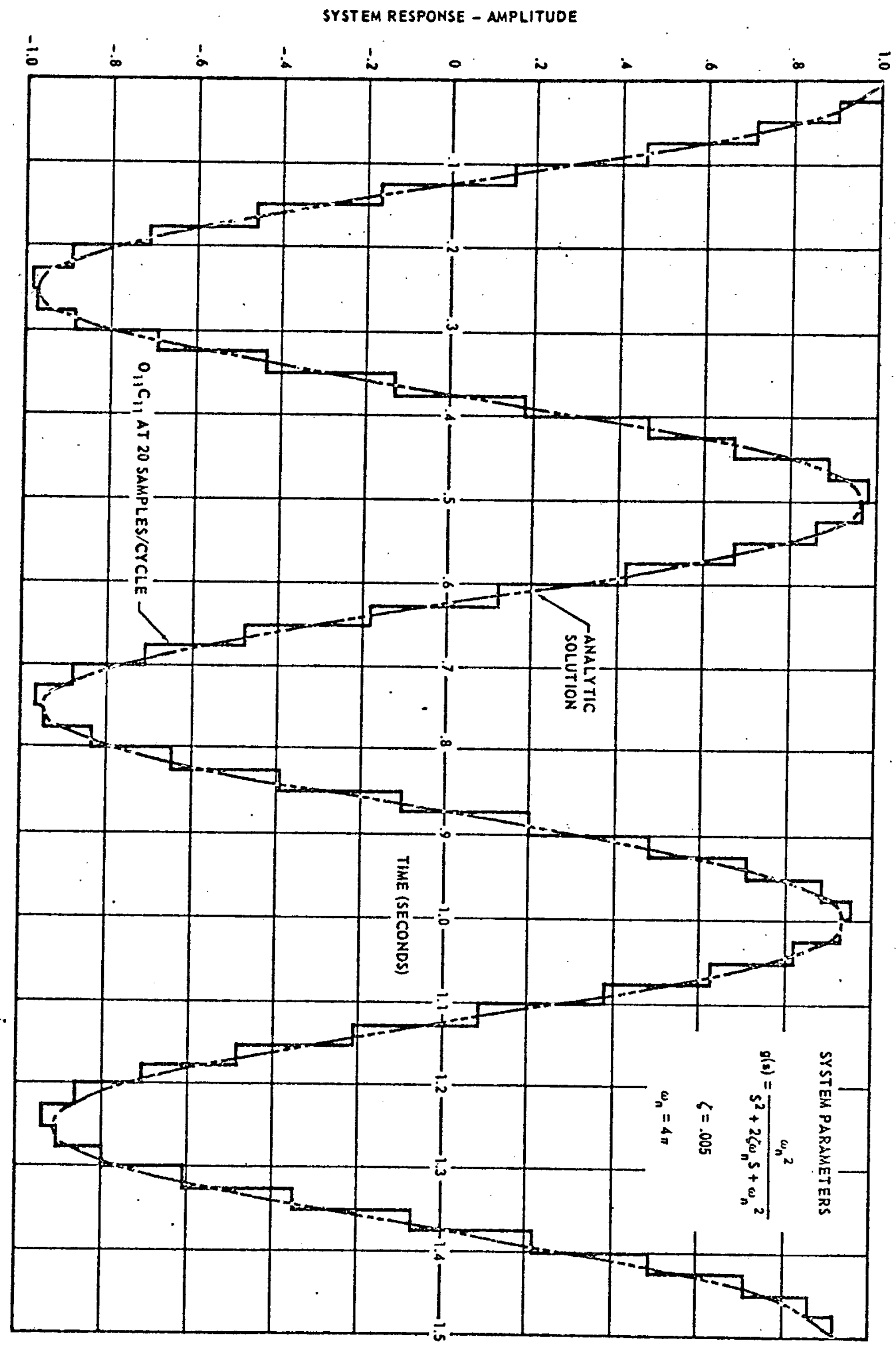


Figure 3 - Transient Response of O_{11} C_{11} Integration Method at 20 Samples/Cycle for .005 Damping Ratio

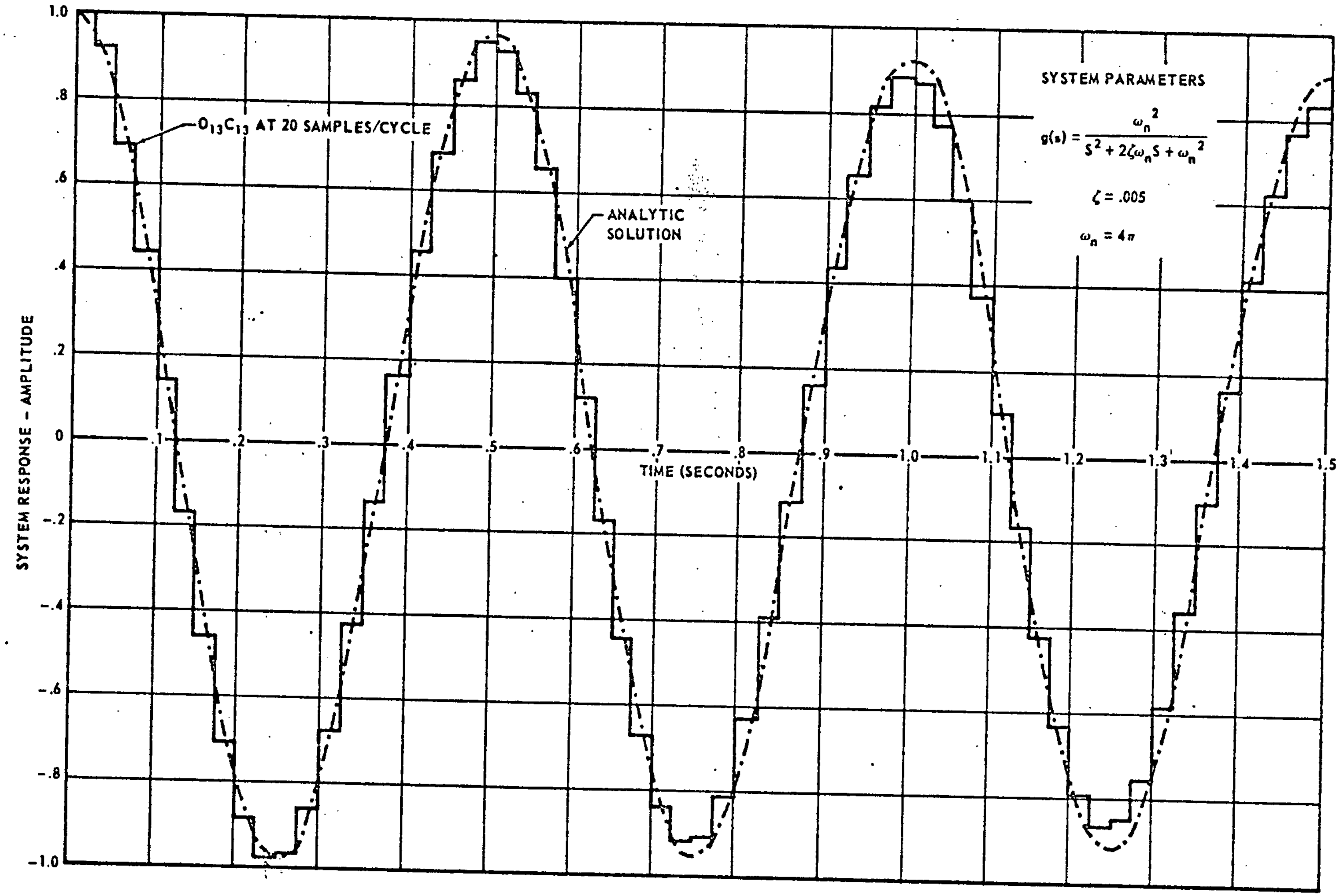


Figure 4 - Transient Response of O_{13} C_{13} Integration Method at 20 Samples/Cycle for .005 Damping Ratio

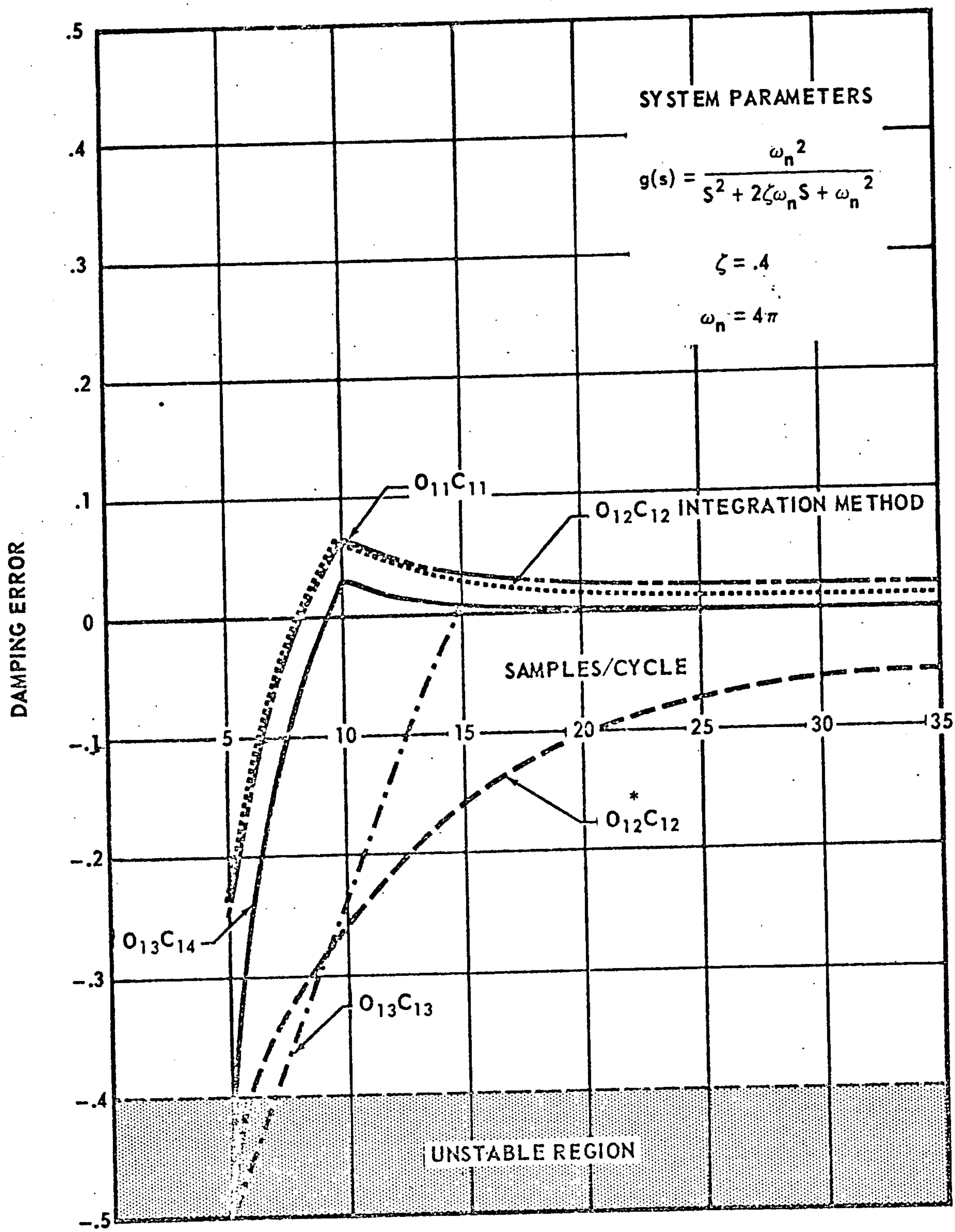


Figure 5 - Damping Error vs Samples/Cycle for .4 Damping Ratio

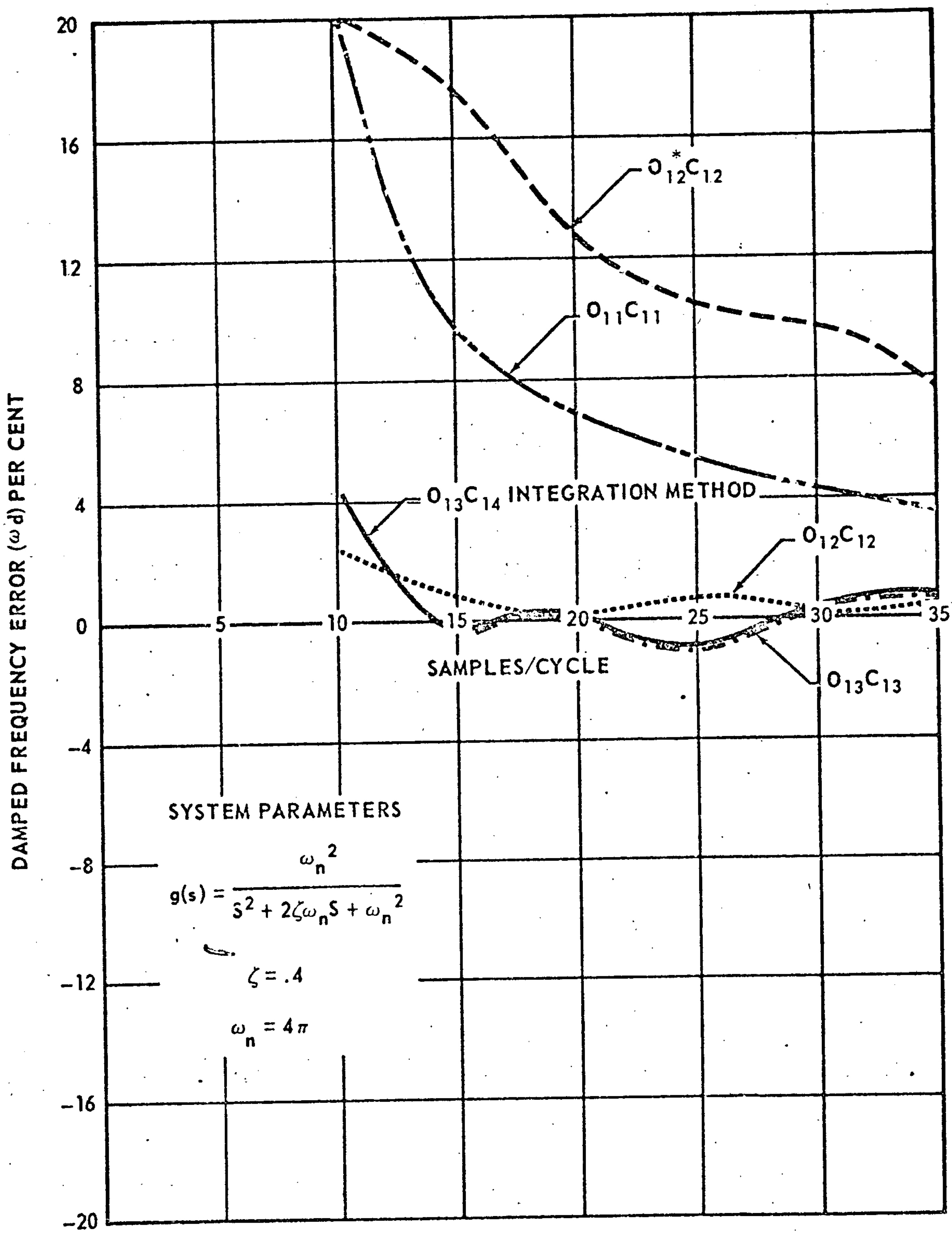


Figure 6 - Frequency Error vs Samples/Cycle for .4 Damping Ratio

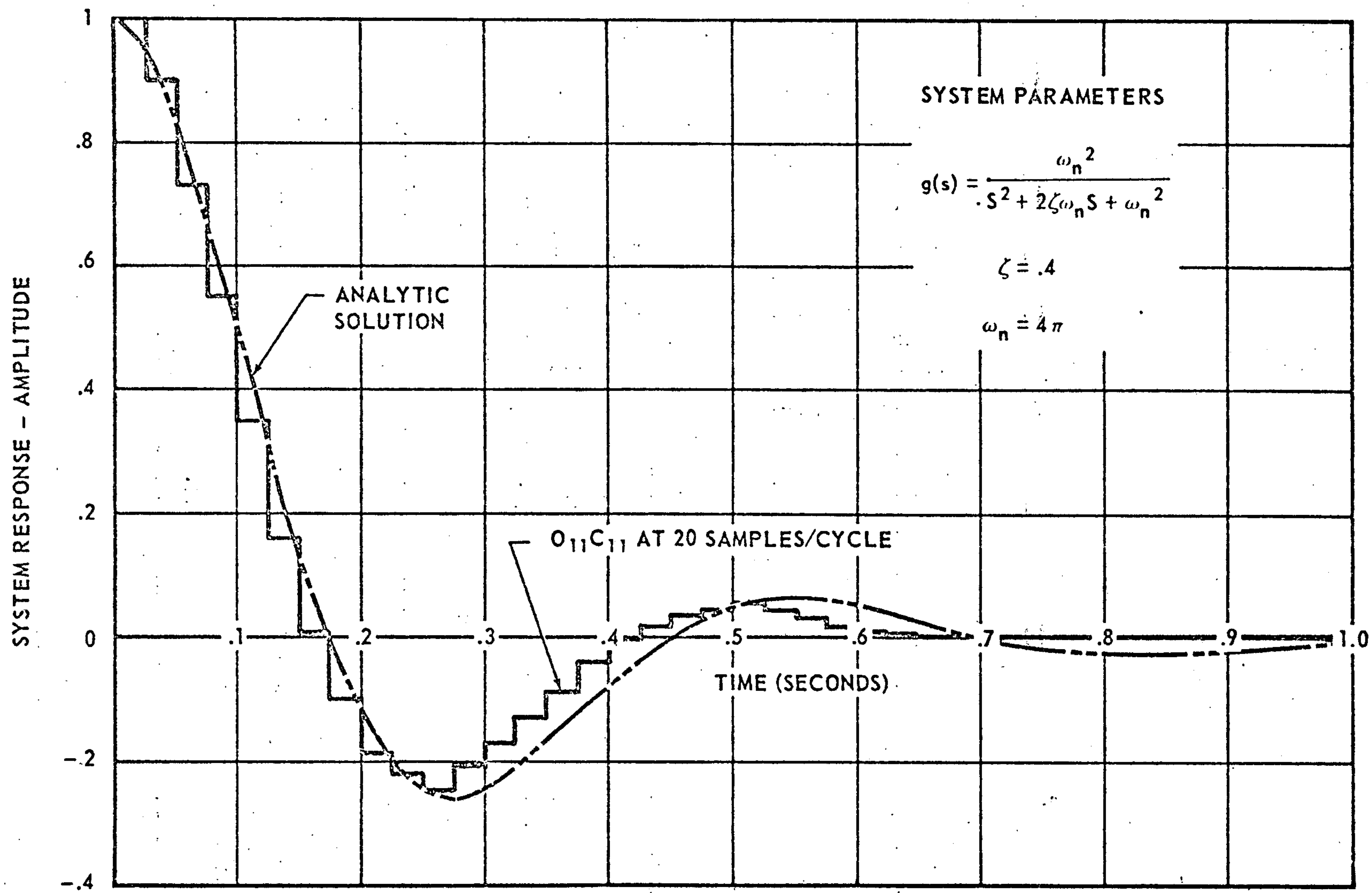


Figure 7 – Transient Response of O_{11} C_{11} Integration Method at 20 Samples/Cycle for .4 Damping Ratio

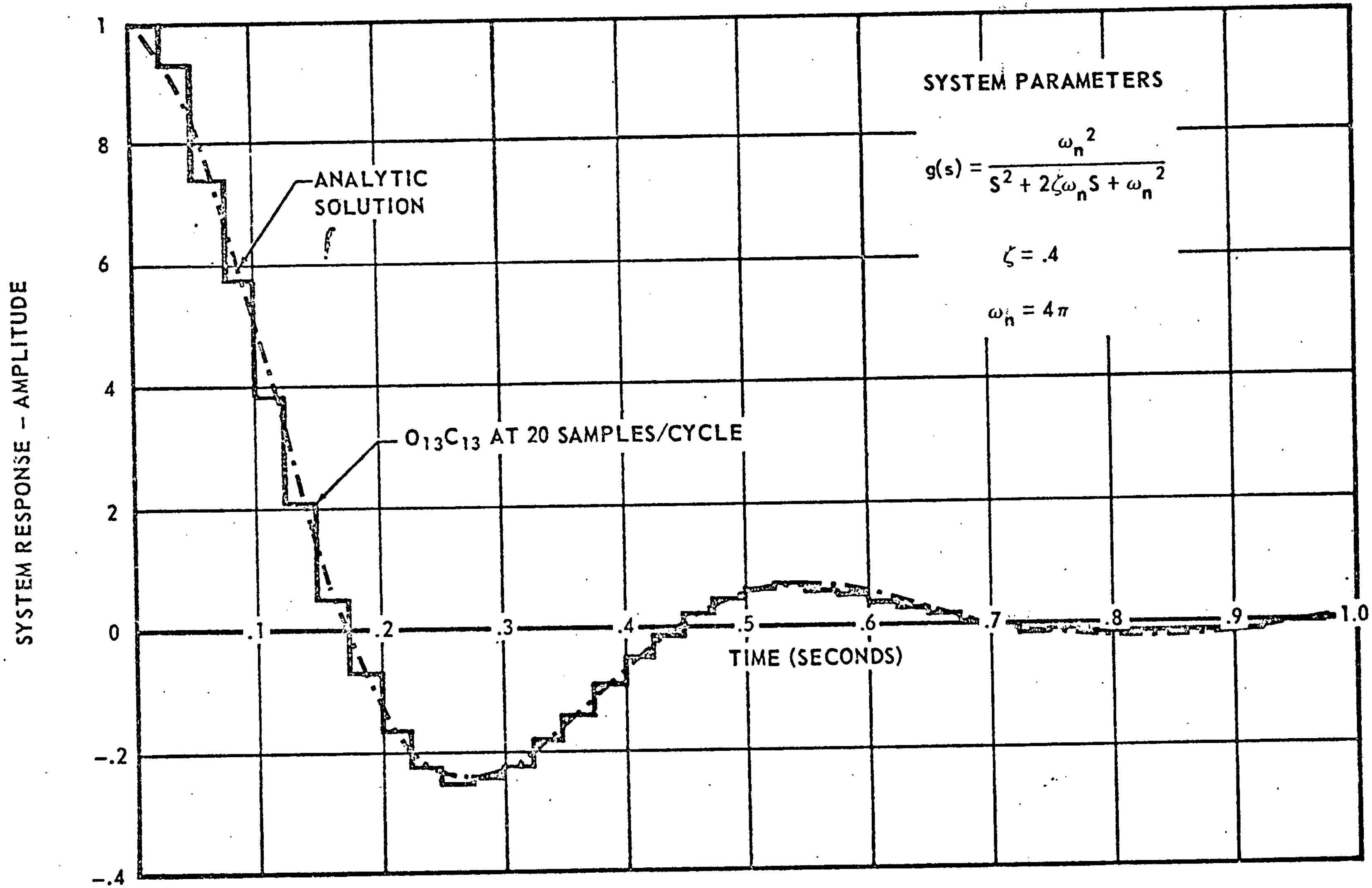


Figure 8 – Transient Response of O_{13} C_{13} Integration Method at 20 Samples/Cycle for .4 Damping Ratio

4.2.4 References and Assumptions

1. Study of Numerical Integration Techniques for Real-Time Digital Flight Simulation. Bart J. Nigro, Bell Aerosystems Co. March, 1967. N67-35630

2. Facility Definition Study for a Universal Aircraft Flight Simulator Trainer. FTC-TR-68-6. Air Force Flight Test Center. April, 1968.

3. Application of the Hybrid Analogy to the SLV Flight Control Computer Simulation. CMS-ER-091. September, 1971

4. Numerical Integration Method for Apollo Mission Simulator Trajectory Computation. Link Division, General Precision, Inc. April, 1964.

5. SLV EOM Integration Study, CMS-ER-041. May 8, 1970.

6. Space Trajectories Program for the IBM 7090 Computer. J.P.L. September 1, 1962

4.3 Computation Rates

4.3.1 Overview

The overriding requirement in determining computation rates for aerospace flight simulation is that the trainee be unaware of any lags or dicontinuities either in his displays and cues, or his inputs to the simulation. The trainee inputs are usually not critical due to the less time critical nature of the inputs. Notable exceptions are continuous manual control inputs and, to a lesser degree, certain discrete inputs (switches). Lagged control display outputs could result in pilot induced oscillations, while excessive lags within the control dynamics loops usually result in the simulated vehicle possessing erroneous handling qualities. Momentary action switches should closely match the real world response. The displays and cues to the trainee should closely match the real world responses. This requirement is essential if the trainee has many displays to monitor, such as during aerodynamic flight, since the monitoring is normally accomplished by way of a well-defined scan pattern. Lags and stepping action by continuous indicators can result in negative training. Behind the scenes, as far as the trainee is concerned, the simulated systems can have much more stringent requirements, as indicated in Paragraph 4.2.1 regarding computation errors.

Since sizing of the computer in terms of computing speed is directly related to this subject, care must be taken that computation rates higher than those necessary to accomplish the simulator requirements not be specified. In determining these requirements, the system to be simulated should not be considered only in nominal operational modes because it may be found that off-nominal or malfunction cases may dictate the required computation rates.

4.3.2 Techniques

Computation rates used by several simulations are shown by subsystem in Table 1. The computation rate shown indicates the basic rate for the principle equations to be solved. It does not necessarily include the rates for supporting programs such as the logic for mode determination.

TABLE 1

SIMULATOR / MATH MODEL	CMS	SLS	T-27	HFTS*
Rotational Equations of Motion	20/sec.	10/sec. 1/sec.	20/sec.	20/sec.
Translational Equations of Motion	10/sec. 5/sec.	10/sec. .25/sec.	20/sec.	10/sec.
Aerodynamics Forces	20/sec.	N/A	10/sec.	10/sec.
Aerodynamics Moments	20/sec.	N/A	20/sec.	20/sec.
Weight and Balance	10/sec.	N/A (Constants)	5/sec.	5/sec.
Ephemeris	20/sec. 5/sec.	2/sec.	20/sec.	Part of E.O.M.
Stability and Control	20/sec. 5/sec.	10/sec. 5/sec.	20/sec.	20/sec.
Guidance, Navigation and Control	20/sec. 10/sec. 5/sec. 2/sec.	10/sec. 5/sec.	20/sec.	20/sec.
Reaction Control System	20/sec. 10/sec. 5/sec.	10/sec. 5/sec. 1/sec.	20/sec.	20/sec.
Air Breathing Engine	N/A	N/A	5/sec.	5/sec.
Nose Wheel Steering	N/A	N/A	N/A	20/sec.
EXEC	20/sec. 10/sec. 5/sec. 1.25/sec.	20/sec.	Special Purpose Hardware	20/sec.
I/O	20/sec.	20/sec.	80/sec.	20/sec.

TABLE 1 (Continued)

MATH MODEL \ SIMULATOR	CMS	SLS	T-27	HFTS*
NAVAIDS	N/A	N/A	10/sec.	10/sec.
VISUAL	20/sec. 10/sec. 5/sec.	10/sec. 5/sec. 1/sec.	20/sec. 10/sec. 5/sec.	20/sec.
ENVIRONMENTAL CONTROL SYSTEM	5/sec. 1.25/sec.	1/sec.	2.5/sec.	N/A
ELECTRICAL POWER SYSTEM	2.5/sec. 1.25/sec.	2/sec.	2.5/sec.	N/A
ROCKET PROPULSION	10/sec.	N/A	5/sec.	N/A
ORBITAL MANEUVERING SYSTEM	20/sec. 5/sec.	N/A	5/sec.	N/A

*Aerodynamic Flight Only

4.3.3 Trade-Offs and Recommendations

Computation rates for the SMS must first be evaluated on a per-system basis to meet the accuracy and stability requirements of that system. Systems interaction must then be evaluated as the effect on other systems may be the determining factor in selection of the computation rate. Finally, the input-output requirements outside the computer must be evaluated.

Selection of computation rates for the SMS should make use of the experiences on other aerospace simulations. In making this selection, the unique requirements of the SMS systems should be considered. The computation rate should not be selected simply because that rate was successfully implemented on another simulator.

A general rule presented by reference (1) is that 15 samples per cycle are required to maintain reasonably good results; however, Z transform methods where applicable and under good conditions (e.g., minimal non-linearity) often show good frequency response at frequencies up to 1/4 the sampling frequency.

4.3.4 References and Assumptions

1. Study of Numerical Integration Techniques for Real-Time Digital Flight Simulation. Bart J. Nigro, Bell Aerosystems Co., March, 1967. N67-35630
2. Facility Definition Study for a Universal Aircraft Flight Simulator Trainer. FTC-TR-68-6. Air Force Flight Test Center. April, 1968.
3. Application of the Hybrid Analogy to the SLV Flight Control Computer Simulation. CMS-ER-091. September, 1971.

4. Numerical Integration Method for Apollo Mission Simulator Trajectory Computation. Link Division, General Precision, Inc. April, 1964.

5. SLV EOM Integration Study, CMS-ER-041. May 8, 1970.

6. Space Trajectories Program for the IBM 7090 Computer. J.P.L. September 1, 1962.

REF. KEY

4.4 Aerodynamic Coefficients

4.4.1 Overview

Aerodynamic coefficients are commonly obtained from wind tunnel tests and test flights of the vehicle to be simulated. Initially a simulation is usually limited to wind tunnel data. This data may not be accurate due to test design and testing limitations. Therefore, this data is refined as test flights produce more accurate coefficients. This refinement does not represent absolute accuracy since each vehicle is built within a set of tolerances and is unique. In any case, the data produced is emperical and volumous. It represents both well behaved functions (e.g. atmospheric density) and ill-behaved functions (e.g. compressibility effects).

The problems to be solved then are:

1) Representation of this data for a simulation in an efficient method from computer core and time considerations while maintaining acceptable tolerances.
2) Representing this data in a manner that can be easily adapted to changes as refinements can be expected.

4.4.2 Techniques

There are many techniques available for producing a function representative of empirical data in a computer. Due to the large number or techniques this discussion shall limit itself to some of the more common techniques that have proved useful in previous simulations.

In choosing a technique an intimate knowledge of the computer capabilities available is necessary. For instance there are always

REF. KEY

core and time tradeoffs to be considered. Many functions are mission phase dependent and need not occupy resident core except in particular regions. Therefore, it may be advantageous to use storage capabilities of the computer other than resident core if they exist and if the computer time required to access this data is not prohibitive.

The method or methods selected to produce the function representing the data can, in general, be divided into two methods. The first of these will be referred to as "curve-fitting" and the second as "data-interpolation".

4.4.2.1 Function Approximation

This method of generating a function is well adapted to representing well-behaved curves. This technique results in a smooth, algorithm with well defined accuracies and without a large penalty in computer requirements.

Some of the more common "curve fitting" techniques employed include:

1) Trignometric representations of curves where techniques such as fourier series may be employed. These usually assume the form: $f(x) \approx g(x) = a_0 + a_1 \cos x + a_2 \cos 2x + \ldots + a_n \cos nx + b_1 \sin x + b_2 \sin 2x + \ldots + b_n \sin nx$

2) Monomial representation of curves where techniques such as least-squares and minimax polynomials are employed to generate polynomials which represent the raw data. These assume the form: $f(x) \approx g(x) = a_0 + a_1 x + a_2 x^2 + \ldots + a_n x^n$

REF. KEY

3) Exponential and logarithmic functions are used which lead to techniques employing such things as Laplace and Z transforms. These usually assume the form: $f(x) \approx g(x) = a_0 e^{b_0 x} + a_1 e^{b_1 x} + \ldots + a_n e^{b_n x}$

In any case, each set of data that is a candidate for one of these or several other methods must be evaluated on its own merit and behavior.

4.4.2.2 Interpolation

Many types of raw data cannot be economically represented by any of the previously discussed methods. Aerodynamic coefficients represent data that usually fits into this category. When this is true it becomes necessary to tabularize the data in some manner and resort to one of many available interpolation schemes. The scheme employed in this situation is usually to segmentize the function to be represented into a series of functions that can more readily be approximated by strings of straight lines, quadratics or curves of higher degree. The choice made is usually based on computer core and time requirements necessary to approximate the function within a given tolerance band.

A review of previous simulations reveals that aerodynamic coefficients functions are generally approximated by tabularizing data and performing straight line interpolations on this data.

Generally each method yields a different tolerable "approximation error". Figures 1, 2, and 3 illustrate the error function E(x) for three different methods of piecewise linearization. These are the tangent method, chord method, and secant method, respectively.

Figure 1 illustrates a tangential approximation to a curve. The sign of the error function is positive where the curve is concave

REF. KEY

and negative where the curve is convex. The error function achieves its peak absolute values at the breakpoints of the function. The integral of the error function, reflecting possible accumulative error effects, behaves badly. It changes its direction only when the curve changes its direction of curvature.

Figure 2 illustrates a chord approximation to the curve. The sign of the error function is negative where the curve is concave and positive where the curve is convex. The error function achieves its zero values at the breakpoints of the function. The integral of the error function also behaves badly, changing its direction only when the curve changes its direction of curvature.

Figure 3 illustrates a secant approximation to a curve. The error function alternates in sign. It changes sign twice between adjacent breakpoints, thus forming an alternating function. The integral of the error function also has this alternating character.

Of the three approximation types illustrated, the secant method is generally the most favorable for minimum average error, for minimum maximum error, and for minimum number of line segments. The best selection, however, depends upon the behavior of the curve to be approximated.

REF.
KEY

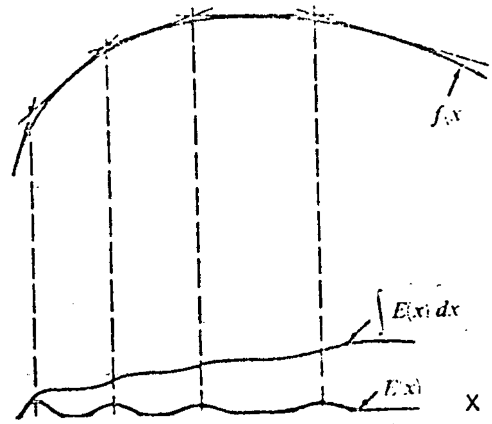


Figure 1 - Tangent piecewise linear approximation.

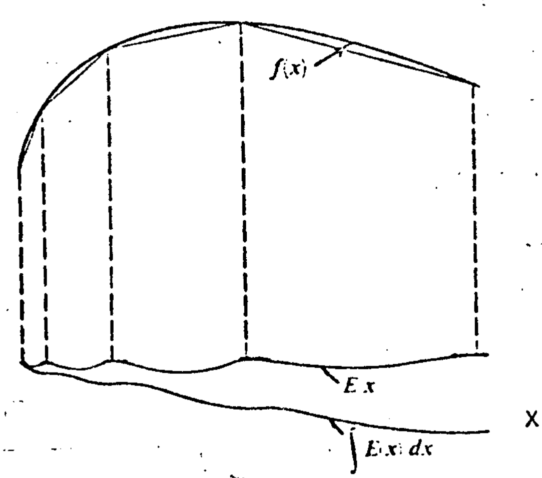


Figure 2 - Chord piecewise linear approximation.

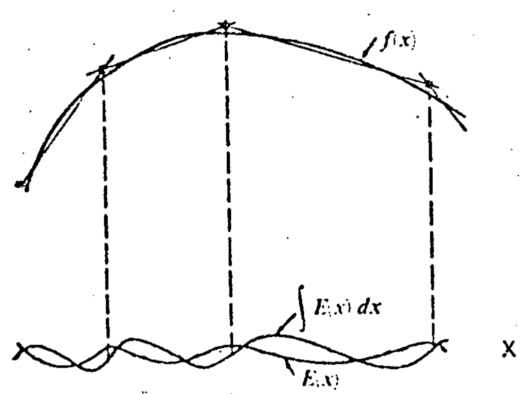


Figure 3 - Secant piecewise linear approximation.

REF. KEY

Once the method has been selected, there are several interpolation formulas to be considered:

Slope-intercept:

$$y = xmi + bi$$

Slope-point:

$$y = (x - xi)\, mi + yi$$

Point-point:

$$y = \frac{yi + 1 - yi}{xi + 1 - xi}(x - xi) + yi$$

An added advantage that is not obvious in interpolation schemes is that often, if breakpoints can be conveniently picked such that they number some even power of two and the data is then normalized, great time advantages can be realized by taking advantage of a computer's shifting capability for table searches, multiplying and dividing. Therefore, the time necessary to implement the above equations is often less than the usual operations would indicate.

4.4.3 Trade-offs and Recommendations

The primary objectives in choosing a scheme to represent a function in a computer are to minimize core and time requirements while maintaining sufficient accuracy and refinement capabilities to avoid degrading the simulation. Usually time is the most critical simulation parameter but in some cases core may be the constraint. This must be defined before a scheme can be selected.

The following statements can be false for a given computer or particular function, however, for as a general rule:

REF. KEY

1) A function approximation usually has a core advantage over an interpolation scheme and its associated tables.
2) An interpolation scheme is usually advantageous from a computer time viewpoint.
3) An interpolation scheme is usually more readily refinable than a function approximation.
4) A function approximation will give a better representation of simple well-behaved functions.
5) An interpolation scheme has been found to be the most desirable for representing complex aero data.

4.4.4 References and Assumptions

1) Brice Carnahan, H. A. Luther, James O. Wilkes; "Applied Numerical Methods"; Wiley; 1969.
2) Bruce W. Arden; "An Introduction to Digital Computing"; Addison-Wesley; 1963.
3) Isadore L. Goldhirsh; "Automatic Techniques for Economic Computer Computation of Continuous Functions"; Simulation; July, 1968.

4.5 Gust/Turbulence Simulation

4.5.1 Overview

In the past, the Gust/Turbulence model used in aircraft simulation was based on a discrete gust profile. This gust profile could take on different shapes thus representing various types of gusts. Examples of these profiles are the sharp-edged gust, the triangular gust and the ramp-type gust. In conjunction with these gust profiles, an arbitrary alleviation curve was used to adjust for certain aircraft characteristics. Recent developments, however, have contributed to a more realistic approach to the description and simulation of atmospheric turbulence. Measured data indicates that turbulence is a continuing phenomenon and that unique gust profiles do not exist. Since the structure of the gust profile is completely random, its shape cannot be defined as a function of distance or time. The gust profile then can only be described in a statistical sense. The statistical characteristics of atmospheric turbulence are described as follows:

Random Nature - The term random refers to a lack of definiteness, that is, there is no fixed pattern to the frequency or velocity of the gusts that may be encountered in any turbulence penetration. Because of this statistical nature, all velocities and accerlerations are represented on a probability scale of occurrence.

Stationarity and Homogeneity - Properties of stationarity and homogeneity of a random process specify an invariance in the statistical characteristics of turbulence with time and distance. Inasmuch as the intensity of turbulence is dependent upon the broader weather conditions, these properties can only apply in a limited sense. Weather conditions generally involve large scale organized flow patterns which cover hundreds of miles and change slowly with time. As of consequence, stationarity and homogeneous conditions might at best, be expected to apply within regions of 100 miles and time duration of one hour.

Gaussian - The Gaussian conditions implies that the gust fluctuations have a Gaussian probability distribution. A Gaussian random process is one in which the distribution of velocity fluctuations of several points has a normal distribution.

Isotropy - There are two properties associated with the Isotropic conditions of turbulence. The first property being the invariances of the statistical characteristics of turbulence with vehicle flight direction. The second is the relation between the statistical characteristics of various turbulence components. For isotropic turbulence, both the vertical and side components of turbulence sensed by a vehicle would be expected to have the same intensity. The longitudinal components, while having the same mean-square gust velocity does differ in intensity. It appears that the conditions of isotropy apply to atmospheric turbulence in only a limited sense. In particularly isotropy may be approximated only at the higher frequencies.

To further illustrate the structure of turbulence, consideration must be given to the different types that are proposed for simulation. Of the many types, all fall into one of the four following categories:

Mechanical Turbulence - Mechanical turbulence dominates the lowest few thousand feet of the atmosphere. Sometimes considered to be clear air turbulence, it ranges in intensity from a RMS (room mean square) of 0 to 6 ft/sec. It is mainly a function of surface wind and terrain roughness.

Thunderstorm - Thunderstorm turbulence is characterized by cumliform clouds. It ranges from the middle troposphere and in periods of severe activity extends as high as 60,000 ft. Thunderstorm turbulence intensity ranges from a RMS of 6.0 ft/sec to 16 ft/sec.

Cumulus Cloud - As the name implies, it is characterized by cumulus clouds. It's altitude of most occurances ranges about 15,000 ft. Intensity varies from a RMS of 3.4 ft/sec to 9.2 ft/sec.

Clear Air Turbulence - Since clear air turbulence can neither be seen nor easily forecast, it is considered to be the most serious of turbulence encounters. It dominates the upper troposphere and stratosphere. Although it is infrequent between 50,000 and 80,000 ft. no upper limit is known. It is found in thin horizontal sheets and is oriented with the wind flow pattern. It ranges from a RMS of 0 to 6 ft/sec.

The problem of choosing a method for the simulation of atmospheric turbulence is dependent on the fidelity required to meet training objectives. In general, state-of-the-art simulators used in pilot training are not capable of reproducing a realistic turbulent atmosphere. Neither can they reproduce adequate aircraft dynamics and control response characteristics beyond the normal operating envelope which is necessary to allow for training in recovery from unusual attitudes that may be attained in a severe turbulence encounter.

Regarding aircraft response, a number of response characteristics must be considered. An aircraft in turbulence can experience extreme changes in angle-of-attack and sideslip. If the simulator is to respond properly to these extreme excursions, it is necessary that the aerodynamic equations in the simulator be capable of accurately reproducing these extreme values. That is, should an aircraft angle-of-attack of 30^{o} be required, but data stored in the simulator be valid for only 25^{o}, then proper simulation response cannot be expected. This points out the importance of recognizing and resolving some of the problems of turbulence simulation in the early design stages of the simulator.

In evaluating the different methods of simulating atmospheric turbulence the following requirements should be considered to assure maximum simulation fidelity.

1) Simulation of turbulence must be modeled as a random fluctuating quantity.

2) The model must contain all the statistical characteristics of a random process.

3) Both High and Low frequencies of turbulence must be derived as a time varying signal, and

4) The total simulation must account for the problems of maneuvering flight through a gust field at speeds over the subsonic and supersonic flight regime. Also, the effects of compressibility, wing sweep, pilot response, automatic control systems, positive and negative high or low speed stall, dynamic stability and the flexible response of the vehicle must be considered.

4.5.2 Techniques

There are several existing methods by which atmospheric turbulence can be simulated with a high degree of fidelity. Four of them will be summarized in this discussion.

Before describing the methods, it is necessary to point out one characteristic which is common to all four. This one characteristic is the requirement for a random number (noise) generator whose outputs approximate a Gaussian probability distribution of the type shown in figure 1.

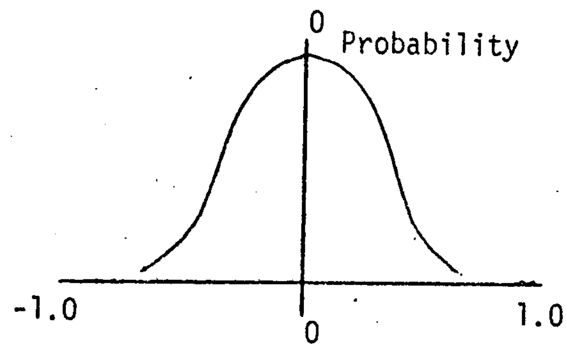


Figure 1 GAUSSIAN DISTRIBUTION

As described in paragraph 4.5, atmospheric turbulence has Gaussian characteristics. Since turbulence is a continuious random fluctuating quantity the probability of obtaining an equal number of positive and negative equal valued gust velocities must be the same. To further illustrate this point consider a time history plot of a turbulence encounter. (Reference figure 2.). If several samples of gust velocities are taken and plotted on a probability scale, the results would approximate a Gaussian distribution.

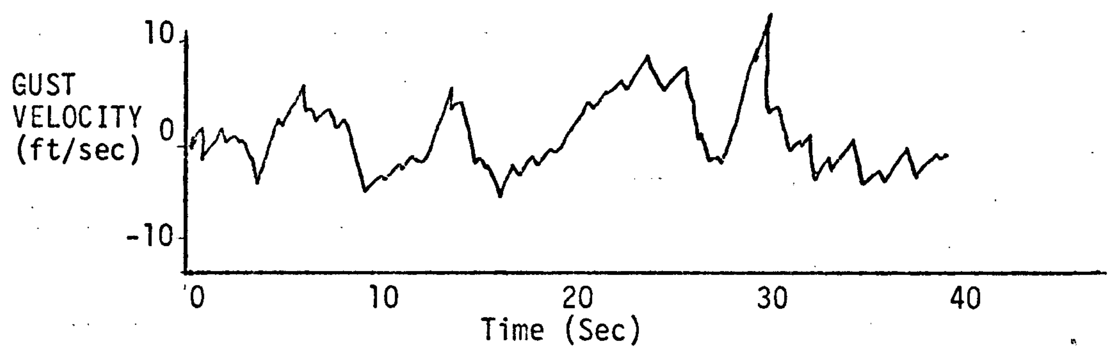


Figure 2 TIME HISTORY PLOT

The equation which will describe a normal distribution of values is given by:

$$P = \frac{1}{\delta\sqrt{2\pi}} e^{\frac{-Wg^2}{2\delta^2}}$$

where,

P = Probability (%)

δ = Root mean square of gust velocity (ft/sec)

Wg = Gust velocity component (ft/sec)

The methods for generating random numbers which approximate a normal distribution are numerous and well documented, therefore, they will not be presented as part of this discussion.

Method 1 - Electronic - Electronic simulation of atmospheric turbulence requires filtering the output of a white noise generator. It is basically a hardware orientated system composed of complex filters and power amplifiers. The frequency characteristics of the filter(s) would have to be continuously variable because of the dependence of spectral content on vehicle forward velocity. A power amplification facility would be required to adjust the high frequency content of the random noise signal. Signal outputs of the system would be used to perturb vehicle pitch, yaw and roll rates. Instructor control of the system consists of selecting a gust level and frequency of occurrence.

Method 2 - Digital Filtering of White Noise - This method uses a random "White Noise" generator and a simple digital output filtering technique. In this method the output of a random noise generator is filtered through an integrator or first order filter. The integrator can be expressed by the following:

$$S(t) = \int_{-\infty}^{+} W_1 (t - \tau)\, n(\tau)\, d\tau$$

Where,

$$W_1 (t) = .5 \int_{-\infty}^{\infty} P(W)\, e^{-wt}\, dt$$

$n(\tau)$ = the white noise signal

$P(w)$ = Power spectral density

ST = Total Gust Velocity

t = time

By continuously analyzing the output from the random noise generator and computing the integral for S(t), an estimate for S(t) is obtained.

Instructor control would consist of selecting a power spectral density to correspond to the type and intensity of turbulence required. Power Spectral

Density plots of turbulence normalized with respect to velocity fit an expression of the form:

$$P(W) = \sigma^2 \frac{L}{\pi} \frac{(1+3W^2L^2)}{(1+W^2L^2)^2}$$

where,

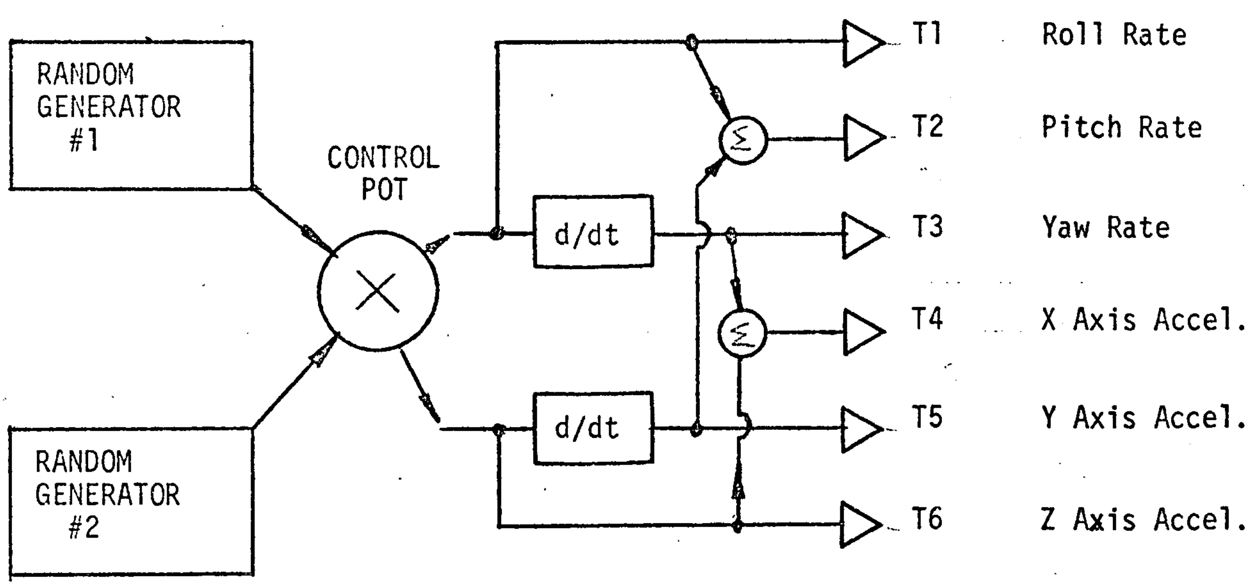
$W = 2\pi / \lambda$

λ = Wave length

σ^2 = mean square of gust velocity

L = scale of turbulence

Figure 3.0 shows a typical system configuration utilizing the digital filtering technique.



DIGITAL FILTERING

Figure 3.0 TYPICAL CONFIGURATION

<u>Method 3 - Fourier Series Expansion</u> - The fourier series expansion method is a periodic function utilizing a random number generator. This method is represented by the expression.

$$S(t) = \sum_{0}^{M} (\text{an SIN nwt} + \text{bn cos nwt})$$

where,

an, bn = random variables

t = time

w = total forward velocity

n = number of intervals in time history record

By using the above expression for S(t), the turbulence can be computed by generating an and bn using a random noise generator with a constant RMS output. The correct RMS level for an, bn would be obtained by magnifying digitally. The computation time required will govern the number of terms contained in S(t) and also the value of W. To meet the power spectral density requirements of turbulence using this method, the an and bn values must be amplified to account for the spectral content at frequencies corresponding to the turbulence encounter.

This method is further expanded to account for the statistical nature of turbulence and instructor control of the RMS of turbulence. The expanded method can be expressed by:

$$S(t) = \frac{\sigma(100)}{\pi\sigma\sqrt{M(M-1)}} \sqrt{\frac{1+3\left(\frac{100M}{M}\right)^2}{\left(1+\left(\frac{100m}{M}\right)^2\right)^2}} \left(\frac{S(t)}{TOM}\right)$$

where,

σ = RMS of turbulence (instructor input)

M = mach no.

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When three separate samples have been generated they are equated to a delta velocity component in the X, Y and Z axis respectively. These are then added to the X, Y and Z body axis velocity components in the simulators equations of motion.

Method 4 - Discrete/Continuous - The approach taken in this method is to apply a discrete gust profile to a continuous function whose characteristic limits of wavelength, frequency and amplitude are contingent on the turbulence selected for training.

This method can best be expressed by the following equation.

$$Wg = .5(Wo)\ (1\text{-Cos}\ \frac{(Vp\ \pi\ t1)}{.5(LTURB)} + PHZ) + LTAMP\ (\frac{SIN\ Vp\ \pi\ t2}{LTWAV})$$

where,

Wg = Gust velocity

Vp = Total aircraft velocity

t1 = time for short term wavelength

t2 = time for long term wavelength

PHZ = phase angle shift

Wo = Maximum gust encountered (short term)

LTURB = Short term wave length

LTWAV = Long term wave length

LTAMP = Maximum gust encountered (long term)

The characteristic parameters of short and long term amplitude frequency and wave length are random variables with a defined maximum and minimum limit. By limiting these parameters to a specified value(s), the statistical characteristics of light, moderate, severe and extreme atmospheric turbulence can be simulated with accuracy.

These random variables with defined limits are obtained in the following ways.

1) Assume a minimum of twelve random numbers are obtained from a generator which approximates a normal distribution.

2) The limitations on the random numbers can be expressed in terms of standard deviations and arithmetic means as follows. (Ref. Figure 4.0)

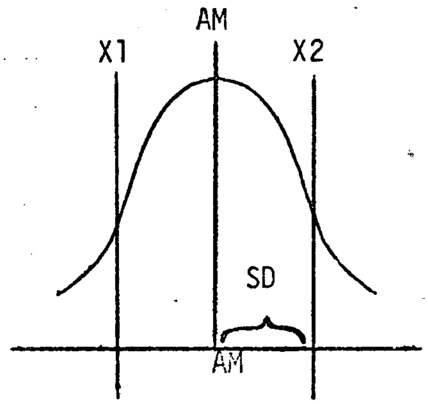

FIGURE 4.0

$$AM = \frac{X1 + X2}{2}$$

$$SD = \frac{AM - X1}{12}$$

where,

SD = standard deviation

AM = Arithmetic means

X1, X2 = Min and Max limits of gust velocity or wave length

3) By taking a random number whose absolute value is less than one, multiplying it by the parameter AM and SD, then adding the two results, a random number with defined limits will be obtained.

This method will generate the type of Gust time history as illustrated in Figure 5.0.

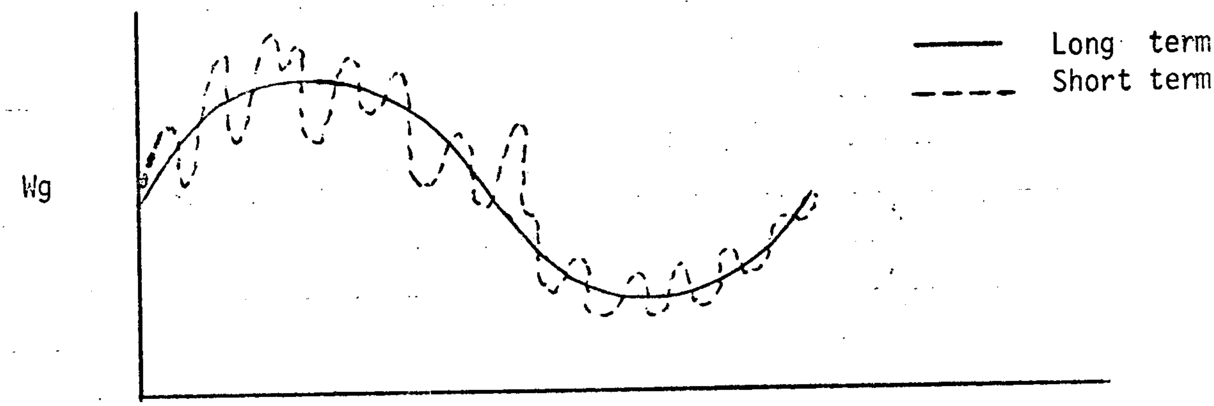

FIGURE 5.0

Once a value of Wg is obtained, an incremented angle-of-attack due to Wg is generated as follows:

$$\Delta\alpha g = \text{ARCTAN} \frac{Wg}{Vp} - \alpha N\text{-}1$$

$$\alpha N = \alpha n\text{-}1 + \Delta\alpha + \Delta\alpha g$$

where,

$\Delta\alpha g$ = change in angle of attack due to the gust

$\alpha N\text{-}1$ = Previous aircraft angle of attack

$\Delta\alpha$ = change in angle of attack due to aerodynamics of the aircraft.

αN = New angle of attack

For the lateral dynamics of the aircraft, the gust input is used to obtain a new sideslip angle as follows:

$$\Delta\beta g = \arctan \frac{Wg}{Vp} - \beta n\text{-}1$$

$$\beta n = \beta n\text{-}1 + \Delta\beta + \Delta\beta g$$

where,

ΔBg = change in sideslip angle due to the gust input

$Bn-1$ = previous sideslip angle

Bn = new sideslip angle

ΔB = change in sideslip due to the aerodynamics of the aircraft.

4.5.3 Trade-Offs and Recommendations

As stated previously, the problem of recommending one specific method for simulating atmospheric turbulence is dependent on the fidelity required to meet training objectives. Defining a simulation technique as per training objectives is beyond the scope of this write-up. However, a summarization of the different methods as to their advantages and disadvantages is possible. The following is a summarization of the four methods described previously.

Method 1

Advantages: 1) It is completely hardware orientated

Disadvantages: 1) Constructing the required filters would require extensive development work.

2) Peaks in the random noise signal could cause overloading of the power amplifier.

3) Amplification would modify the spectral characteristics and possibly the gaussian nature of the signal.

Method 2

Advantages: 1) Method gives considerable flexibility in that problems are restricted to a integration technique and approximation to exponential functions.

2) It will compare with spectral density criteria with a high degree of accuracy.

3) Proven method.

Disadvantages: 1) The integral must be computed over a wide range in limited computation time.

2) Instructor control over selection of turbulence intensities would be limited.

<u>Method 3</u>

Advantages: 1) Ease of implementation

2) Instructor control over a wide range of turbulence intensities.

Disadvantages: 1) It is an approximation method

2) Divergence from expected results when compared to power spectral density data.

<u>Method 4</u>

Advantages: 1) Instructor control over a wide range of turbulence intensities.

2) It will compare with power spectral density criteria with a high degree of accuracy.

3) Method gives considerable flexibility

4) Dynamic response of a vehicle is similiar to the real world environment.

Disadvantages: 1) It would require extensive system analysis to formulate a model in which vehicle dynamics were included.

4.5.4 <u>References and Assumptions</u>

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5.0 Equipment Interface

5.1 Computer Interfacing

5.1.1 Overview

Based on the Hardware Designs of presently available computers, the available techniques for achieving a satisfactory interface with a large Digital Conversion System are limited. To a very great extent, the actual hardware interface is dependent on the design of the computer and its interface options

Because of the simulation requirement to transfer large numbers of digital words per unit time, both into and out of CPU core memory, the established practical norm has become a Bit Parallel, Word Serial Format.

Due to the variability of simulator customer preference as to a particular computer and/or computer manufacturer, most DCE system designs are tailored to satisfy the requirements of the particular computer chosen.

Techniques which are reviewed herein are:

1) The Direct Memory Access (DMA) using data block transfers under real time I/O program control from the main CPU.

2) DCE Service Interrupt Interface

3) DCE Interface via a satellite computer

5.1.2 Techniques

5.1.2.1 DMA, Data Block Transfers Under Real Time I/O Program Control from Main CPU

5.1.2.1.1 Description

This technique permits data transfer via direct memory access. The I/O Program controls device type (D/A, A/D, DI, DO) selected, and basic update rate. A DMA controller contains registers used to:

a. Store the word count for each block transfer

b. Store DCE status and commands

c. Store input and/or output data

The I/O Program then commands a particular transfer operation of X words (or Bytes) to or from a specified starting core location, for a particular DCE device type. The command is implemented as follows:

a. The number of words to be transferred are stored in the Word counter of the DMA Device Controller.

b. The DMA Device Controller, independent of the CPU, but in a priority, cycle stealing architecture, then commences the sequential word transfer to or from the starting core location and decrements its word counter until the block transfer is completed. Each transfer is carried out via a hand shaking operation between the Device Controller and the DCE System Controller. This assures the necessary control and synchronization between the two devices, which generally have completely independent clocks.

c. When the Device Controller word counter reaches zero it flags the CPU (via an interrupt) that it has completed its operation and is ready for the next command.

5.1.2.1.2 Current Usage

Vitually all simulation DCE is designed to operate in this Basic Mode. The only known exception being very small systems (under 100 digital words) which operate directly from the computer I/O Bus under program control for each input or output word transfer. (Also refer to actual DCE systems described in following paragraphs).

5.1.2.1.3 Characteristics

With large quantities of data required to be transferred and the update rates also required to maintain faithful "Real Time" simulation, this technique is utilized since it enables the block transfer to take place on a "cycle stealing" basis without tying up the CPU for each word transfer. The chief characteristic of DMA Transfer is its inherent high speed and the fact it allows the CPU to be used at maximum efficiency for I/O transfers.

5.1.2.1.4 Advantages

1. Allows large quantities of digital data to be transferred with minimum impact on CPU timing and software complexity.

2. "Cycle-stealing" in no way disturbs the program execution sequence in the processor.

5.1.2.1.5 Disadvantages

1. Time required to execute resident programs and real time I/O must still be controlled by design to assure that total allowable frame time is not exceeded. Exceeding total allowable time will result in loss of "real-time" simulation and the average update rate will be reduced.

2. The design of some DMA Controllers is byte oriented only, and therefore for that particular computer, the maximum data transfer rate is effectively reduced since the controller can only transfer one byte at a time instead of the full word. (Example: Consider a 32-bit (4-byte) machine. Where it is desired to uitlize the full 32-bit data word, it is necessary to make 4 byte transfers in lieu of one full 32-bit data word.

5.1.2.1.6 Prospects for Improvement

The only foreseeable improvement to this technique lies in the development of faster computer systems with reduced cycle times.

5.1.2.1.7 Applicability to SMS

This basic technique has high application potential for the SMS since it is a proven interface method and permits the high speed data transfer rates required for the SMS.

5.1.2.1.8 Cost/Complexity and Risk

1. The cost and complexity related to this technique are not directly relevant since there is no comparative means of accomplishing the same performance. However, cost of a particular computer I/O

DMA channel may affect the choice of computer for some particular simulation application.

2. Design and other risk factors are low by comparison to other techniques assuming the I/O DMA channel has been field demonstrated by the computer manufacturers. If not, the program schedule risk can be quite high as well as an expensive procedure.

5.1.2.1.9 Implications

1. This is a well demonstrated technique.

2. Risk is related to unproven designs.

5.1.2.2 DCE Service Interrupt Interface

5.1.2.2.1 Description

This technique is not applicable to output transfers since these are basically under Program Control full time. However, for input transfers the CPU remains unencumbered with input transfers except if some or all of the input data has changed since the last update to the CPU. When input data changes, a device or subdevice service interrupt signal is generated and the CPU satisfies the interrupt by doing a device or subdevice input transfer to update data in core. The program then resumes its instruction execution routine in normal sequence.

5.1.2.2.2 Current Usage

This technique is presently implemented in the hardware and software for the Skylab Simulator DCE System.

5.1.2.2.3 Characteristics

Used only for discrete digital inputs. Could be used for analog inputs also if update rates were extremely low and equivalant analog input system band pass was comparable. Therefore, analog input transfers executed by this type service interrupt are not used for simulation type DCE because "Real-Time" Simulation could never be realized.

5.1.2.2.4 Advantages

Average input data transfer service time is reduced and becomes a direct function of the variability of the data itself per unit time.

5.1.2.2.5 Disadvantages

1. Requires more complex programming to satisfy branch requirements for the service interrupt.

2. Software changes above a baseline become more tedious due to the presence of the service interrupt control functions.

3. Basic DCE hardware related to digital input data must have provisions to double buffer all data plus control logic necessary to generate and transmit service interrupt signals to the CPU.

4. Detailed design requirements are different for each computer interfaced due to differences in how the computer manufacturer has designed his particular I/O interface timing and control.

5. More difficult to isolate malfunctions in the DCE, therefore could have an adverse effect on DCE mean-time-to-repair.

6. Makes estimating CPU time difficult because of the variability of input transfer time prediction.

5.1.2.2.6 Prospects for Improvement

It is believed the prospects for improvement of this technique are low since in the past most DCE systems have not relied on the scheme. Also, the fact that it is costly and only a partial solution to DCE related CPU timing problems would indicate that not much would be gained from any improvement.

5.1.2.2.7 Applicability to SMS

It is not considered particularly relevant to the SMS, basically due to the large number of disadvantages. This is true especially in light of the fact that SMS will no doubt require software and hardware update as the overall program moves forward in time. Therefore, added software change difficulties should be avoided or at least minimized.

5.1.2.2.8 Cost/Complexity Risk

1. Cost will definitely be higher than for comparable more straightforward systems.

2. In terms of quantity of hardware and more rigorous timing requirements this technique is more complex.

3. Design risk is also higher due chiefly to the increased complexity of the system.

5.1.2.2.9 Implications

The implications of using this technique are added operational complexity and cost and practically no positive benefit to the overall simulation.

5.1.2.3 DCE Interface Via a Satellite CPU

5.1.2.3.1 Description

This technique is based on the use of a small Satellite CPU as a very versatile interface between the main CPU and the DCE equipment. All I/O data would reside in core in the Satellite CPU and be transferred to and from the main CPU by the combined program control of both main and Satellite CPU's. The DCE equipment proper would interface the Satellite CPU via a DMA channel or equivalent just as in the case of direct DCE interface with the main CPU.

5.1.2.3.2 Current Usage

This technique presently has limited usage as a DCE interface and is mainly utilized in the area of interfacing DCE to hybrid computer complexes for scientific research work and the gathering, statistical analysis, and display of experimental trial data. These systems are quite small by comparison to a simulation DCE and computer system.

5.1.2.3.3 Characteristics

1. Data organization and control are maintained by programs resident in the Satellite CPU.

2. The basic technique can be implemented in two ways:

a) Two independent CPU's transferring data to each other via a separate computer/computer buffer.

b) Two independent CPU's, each with dedicated memory and a quantity of common memory utilized to implement transfers between the two CPU's.

Use of the common memory method of interface is inherently a higher speed technique.

5.1.2.3.4 Advantages

1. Provides great flexibility in data handling and formatting.

2. Provides capability of system operational changes by Software revision.

3. Can be used to free the main CPU of more routine data housekeeping chores,thus conserving main CPU time and core.

4. Can be used as a bit processor to pack and/or unpack digital inputs and outputs,thus saving CPU time in doing the same task required to collect and/or distribute booleans.

5. Provides the capability of controlling and executing DCE and trainer static and dynamic testing while in a non-integrated mode with the main CPU, thus freeing the main CPU for preventive maintenance or program verification.

5.1.2.3.5 Disadvantages

1. Represents a major cost item.

2. Average data propagation time through the overall system is effectively increased by the succession of data transfer interfaces.

3. Basic interface with the main CPU is still required for virtually the same quantities of data.

4. Additional interfacing hardware is required to tie the two CPU's together (computer/computer buffer or common memory).

5.1.2.3.6 Prospects for Improvement

The prospects for improvement are directly related to the development of the state-of-the-art in digital computers and high speed computer-computer data transfers.

5.1.2.3.7 Applicability to SMS

This technique has high application potential to the SMS because of the versatility it offers both in the area of system flexibility and in overall simulator utilization efficiency.

5.1.2.3.8 Cost/Complexity Risk

1. While initial costs would be higher, the overall lifetime costs (value) of the system using this technique appear to justify the initial expense.

2. There is no question that the computational hardware and software package required to implement this technique is complex by comparison to existing simulation standards. However, neither is considered beyond the state-of-the-art.

3. Overall SMS program risk could be appreciably reduced by use of this technique since many areas of development and testing can be pursued independently.

5.1.2.3.9 Implications

Higher initial hardware cost but a probability of reduced program risk and associated lower overall cost.

5.1.3 Tradeoffs and Recommendations

The principle tradeoffs worthy of serious consideration are:

General

1. Non-recurring and recurring cost and complexity

2. Reliability/Maintainability requirements

3. SMS requirements in terms of layout, growth potential, versatility, etc.

4. Program risk, both in the area of technical development and maintaining an optimum program plan as established.

Specific

1. Operational speed

2. Long term system versatility

3. Minimization of long term operating cost and complexity with respect to changes which may be required in the SMS hardware and software above an initial delivered configuration.

Therefore, in light of all possible considerations which it is feasible to evaluate at this time, it is recommended that computer interfacing of the DCE equipment be accomplished utilizing two separate multiplexed DMA device controller channels (one for input data and one for output data transfer; Bit parallel word serial). This scheme effectively splits the data and time loading as opposed to using only one DMA channel for the entire DCE system. Also, it permits the highest average through put-rate and is considered adequate in light of the cost and risk of developing more exotic techniques.

In terms of the DCE system exclusively, use of a satellite computer cannot be justified without more detailed design effort to establish cost and complexity tradeoffs related to the choice of computer hardware and software complexity, both of which affect computer loading and overall system versatility.

5.1.4 References and Assumptions

5.1.4.1 References

See Section 5.5.

5.1.4.2 Assumptions

1. The SMS will be required in small or single quantities, therefore, non-recurring development should be minimized, but not beyond the point of sacrificing required technical performance excellence.

2. The prevailing design philosophies must enable growth and change in the most economically feasible manner possible in order to keep pace with changes in flight hardware if or when they become necessary or desirable.

3. The SMS should be designed and constructed to provide maximum utilization and, therefore, determining faults, isolating them, and repairing them should be carried out as expeditiously as possible.

4. The SMS DCE system will fall in the category of being considered a "large" system in terms of the number of digital and analog DCE word channels.

5. The SMS DCE system will fall in the category of being considered a "fast" system in terms of the data through-put rates required to maintain accurate "real-time-simulation" with no apparent slipping or time lags.

5.2 DCE Configurations

5.2.1 Overview

At the present time nearly all simulation applications utilize a centralized DCE system of one form or another. Until recently, it has been impractical to segment sections of DCE equipment due to physical size and weight limitations of equipment packaging especially where these electronic assemblies have an adverse effect on the usable payload capabilities of motion systems. The centralized DCE system has utilized the highest packaging efficiency practical. This is due primarily to the following:

1. DCE has been supplied by Computer Manufacturers who, having had no specific knowledge of the simulator application, have packaged their equipment in their classical manner and in a highly modular form.

2. Where simulator manufacturers have designed their own systems, the modular approach has been adhered to principally to minimize costs for large numbers of like devices.

A search of current literature shows the only readily purchasable off-the-shelf DCE equipment to be in the form of specilized modules sold by computer and computer peripheral manufacturers, or "Black Box" A/D or D/A converters, which must be used in conjunction with user designed and built interface and control circuitry to achieve an integrated computer I/O system.

With the rapidly expanding availability of specialized LSI & MSI circuitry and analog to digital and digital to analog converter modules, a great wealth of "Bits and Pieces" hardware exists for structuring DCE systems. It is true, however, that the user has been left largely to his own initiative to design, configure and build systems from this hardware. Therefore, Distributed DCE systems exist mainly as special purpose configurations in particular applications.

In the area of simulation, Distributed DCE has been mainly the result of the simulator manufacturer's efforts to improve performance and reduce system costs while still maintaining some degree of flexibility. Therefore, the simulator complex configuration has dictated the degree of modularity since a simulator is made up of physically separable sections. Example:

1) Instructors Console (Indicators, Controls, Switches, Instruments, Displays, etc.)
2) Cockpit (Indicators, Controls, Switches, Instruments, Control Loading Servos
3) Motion System
4) Visual System
5) Where applicalbe, Advanced training and performance evaluation console.

It is not difficult to realize that the I/O Device types and quantities attributable to each section change radically in going from one type aircraft or spacecraft to another. Also, the I/O Device types and quantities are a function of the Basic Motion and Visual systems anticipated to be used.

5.2.2 Techniques

5.2.2.1 Centralized DCE

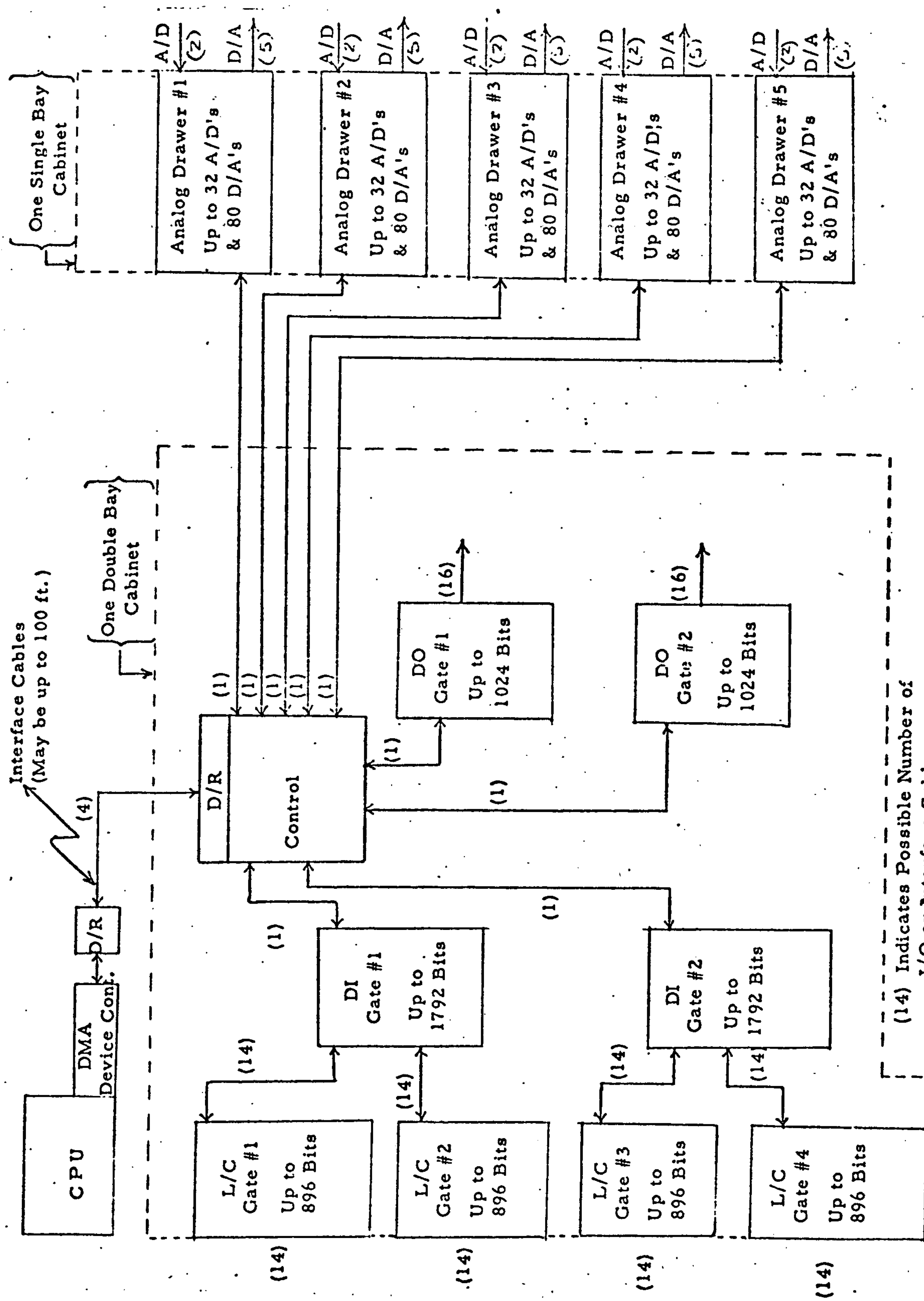
5.2.2.1.1 Description

In the broadest sense, the technique of centralized DCE is based primarily on a packaging scheme and only indirectly results in the addition or omission of electronic hardware because of the packaging methodology. A centralized DCE System consists of all the necessary electronics hardware (A/D's, D/A's, DI's, DO's, control and steering logic, etc.) housed in one or more equipment cabinets in close proximity to each other and generally also in close proximity to the simulator's computer complex.

5.2.2.1.2 Current Usage

1. Virtually all simulation DCE equipment produced to date tends toward the centralized DCE technique. A minor variation to this is the placement of some particular quantity of DCE hardware located physically closer to the using devices. (This technique is used on some of Singer Com.'s large commercial simulators, namely, the 747's and L-1011's where some DI and DO P/C card gates are located in the cockpit atop the 60-inch stroke, synergistic motion system.

2. Most recently, Singer-SPD has developed and produced a Centralized DCE System being used on its current 727 and C-130 Simulators, known as the "T-Linkage". A significant cost reduction was realized along with reduction in system volume through the use of wire-wrapped, DIP Socket back plane gates for the entire digital and control



Gate Dimensions are nominally 19" x 34" x 4"

FIGURE 1 SINGER SPD "T" LINKAGE

portion of the DCE system, thus eliminating all printed circuit cards from that section. Logistical support problems were consequently reduced since the most probable item requiring replacement has now become the IC itself. A block diagram of the system is shown in Figure 1.

The system can be configured as follows:

a. DI: Modules of 8 16-bit words expandable to a total of 224 words.

(May be TTL or 28 V DI's chosen in Blocks of 8 words.)

b. DO: Modules of 8 16-bit words expandable to a total of 128 words.

(may be TTL or Lamp Driver DO's chosen in blocks of 8 words.)

c. A/D: Modules of 16 channels expandable to a system total of 192 channels. (±10V range, 10 bits + sign)

The A/D subsystem utilizes one ADC and 4 8-channels multiplexers for each 32 channels and has low pass filters with a 50 Hz cutoff on each channel.

d. D/A: Modules of 16 channels expandable to a system total of 400 channels. (±10V range, 10 bits + Sign.)

The analog subsystem is made up of drawers and P/C cards, each drawer having the capability of 32 A/D's and 80 D/A's. The D/A subsystem utilizes a sample/hold technique, with two DAC's utilized for each 80 channels and either 7 Hz or 320 Hz low pass filters on each channel. Filtering selection is applicable to 16-channel blocks.

The Main DCE Controller is configured for full system ecpansion.

Other features of the system include:

a. High speed, dual differential line driver/receiver system, allowing the DCE system to be up to 100 feet away from the CPU I/O DMA Device Controller.

b. DO & D/A Update fail indication and override (used to interlock simulator DC power and main simulator status).

c. Hardware DI & DO Bit Processor for packing and unpacking Boolean Bits of DI & DO.

d. Starting channel address and range feature.

e. Analog subsystem also provides $\pm$10 volt reference voltage for simulator A/D signal generation hardware.

Presently used in conjunction with the Basic DCE system is a hardware sine converter which operates as an independent peripheral to the CPU (PDP-11/45), interfaced via a Program controlled I/O Device Controller.

5.2.2.1.3 Characteristics

1. High speed digital conversion equipment - 32 μ sec average A/D conversion time. 64 μ sec average D/A conversion time. Digital Input & Output transfers at the rate of 1 μ sec per word transfer (exclusive of Computer Overhead).

2. Requires a large quantity of long cables (up to 150 ft.) to acquire and distribute analog and digital signals around the trainer complex.

3. By attention to proper hardware and software design considerations it is possible to design a system which is directly DCE channel addressable through the use of control words in the I/O programs (starting channel address and range).

5.2.2.1.4 Advantages

1. Requires a comparatively simple and efficient method of obtaining and distributing DC power.

2. Permits single point maintenance for all sections of the DCE.

3. Avoids the necessity of hardware and driver/receiver electronics to distribute high-frequency Digital Data and Control signals around the simulator complex over long lines and also the electronic logic required to multiplex and demultiplex the data transferred in bit parallel, word serial format.

4. Simplifies the addition of such optional DCE features as closed-loop self-test since all the DCE Equipment inputs and outputs are centrally located for ease of accessibility.

5. Location in close proximity to the computer complex minimizes the payload required to be carried on the Motion System for DCE related to devices in the trainer areas.

6. Requires the least amount of packaging designs and hardware variations.

5.2.2.1.5 Disadvantages

1. Requires long cable runs to the trainer electronics assemblies with consequent analog noise susceptibility problem considerations.

2. Requires several cabinets worth of floor space in the trainer floor plan.

5.2.2.1.6 Prospects for Improvement

1. There are almost continuous opportunities to reduce the total volume and cost of any given DCE System with the development of new LSI/MSI Electronics and related packaging schemes. The limiting element here, however, is the efficiency with which I/O Signal cabling and cable distribution can be integrated into electronic packaging designs.

2. Presently, the cost of small modular D/A converters has been reduced to the level where it is economically feasible to design and build a DCE analog output subsystem having a dedicated converter and buffer register for each channel. (Refer also to paragraph 5.3.2.2 where this particular topic is covered in greater depth.)

5.2.2.1.7 Applicability to SMS

This technique has high application potential to the SMS.

5.2.2.1.8 Cost/Complexity Risk

1. From an operational standpoint, this technique is the least complex of all possible methods.

3. Because it is the most straightforward system operationally, it offers the minimum risk in regard to design, testing, and reliability.

5.2.2.1.9 Implications

In terms of DCE System Configurations a Centralized DCE System should be considered on its merits for use in the SMS.

5.2.2.2 Distributed DCE

5.2.2.2.1 Description

The technique of Distributed DCE is again based primarily on a packaging scheme, and only indirectly results in the addition or omission of electronics hardware because of a particular packaging and Distribution Methodology. The Basic Distributed DCE System still consists of the necessary electronics hardware (A/D's, D/A's, DO's, Control and steering logic, etc.). However, based on a particular desired configuration, additional multiplexing and demultiplexing electronics and control logic is required for data steering for each "black box" module of DCE equipment around the simulator complex. There are a number of Design philosophies which can be considered in the design of a Distributed DCE System.

1. A central controller and a number of DCE subpackages where each subpackage has the capability of housing all DCE Device Types (D/A, A/D, DI, DO) in various quantities. See Fig. #1.

2. A central controller and a number of DCE subpackages where each subpackage has the capability of housing a variable quantity of only one Device Type. See Fig. #2.

3. A direct interface to the computer with a controller for each Device type plus a number of DCE subpackages where each subpackage has the capability of housing a variable quantity of the particular Devices. See Fig. #3.

4. Fig. 4 partially illustrates that, without regard to

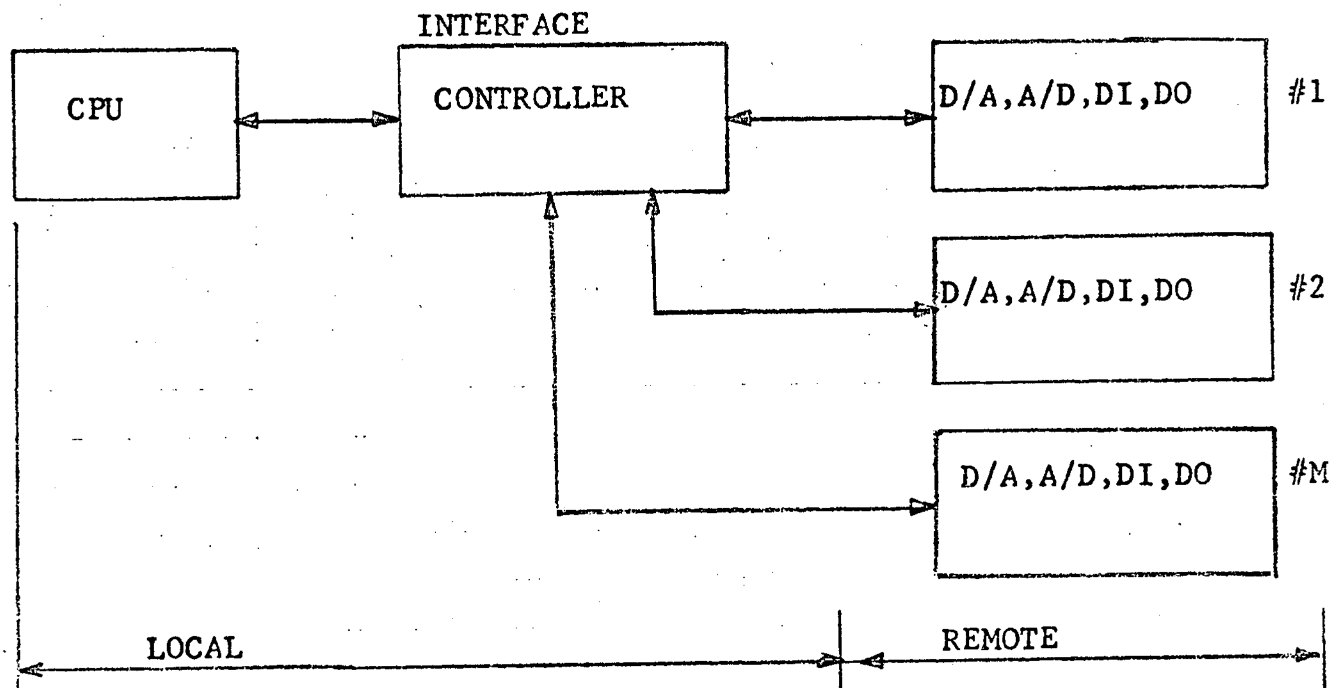


FIGURE 1

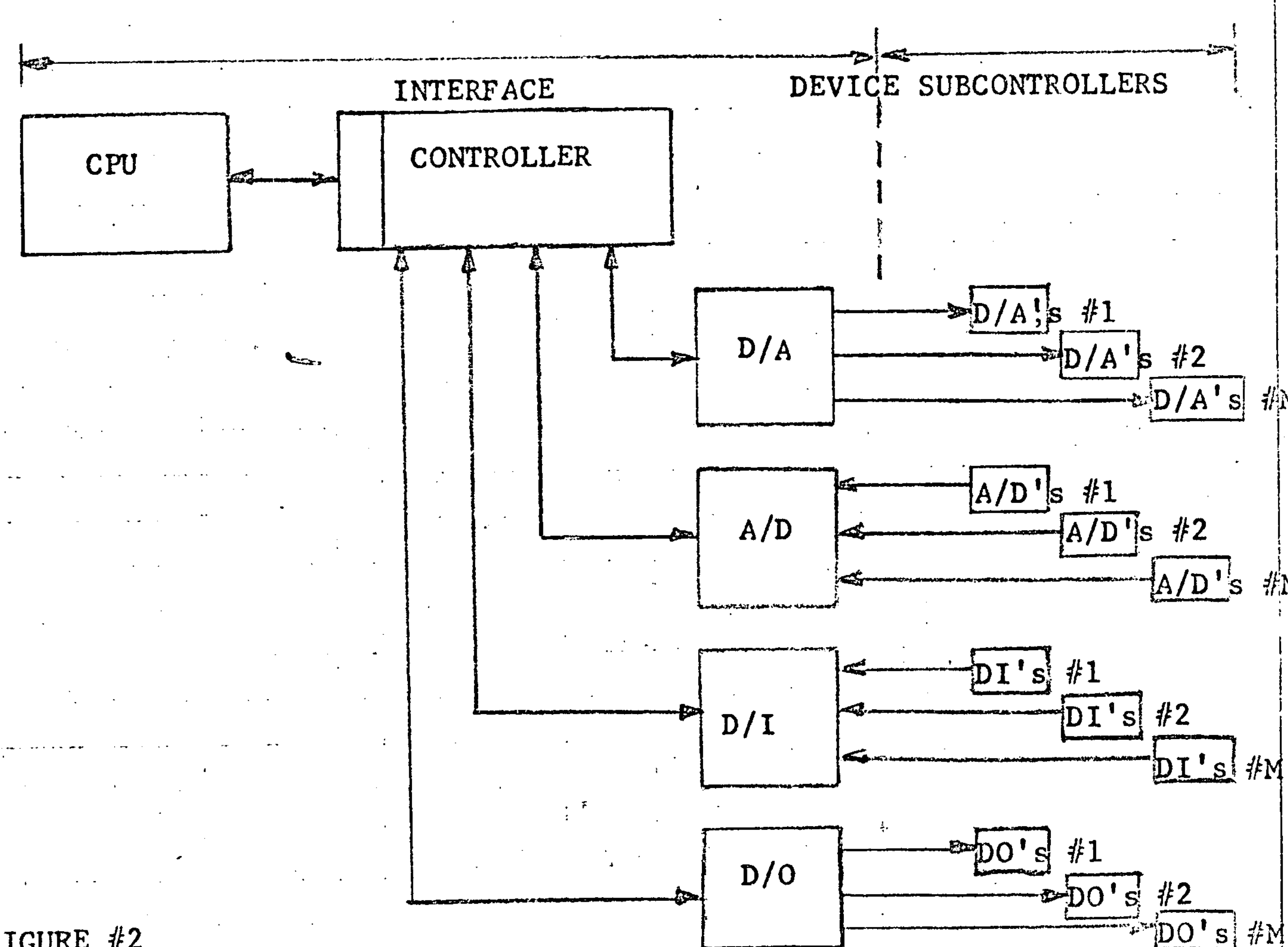


FIGURE #2

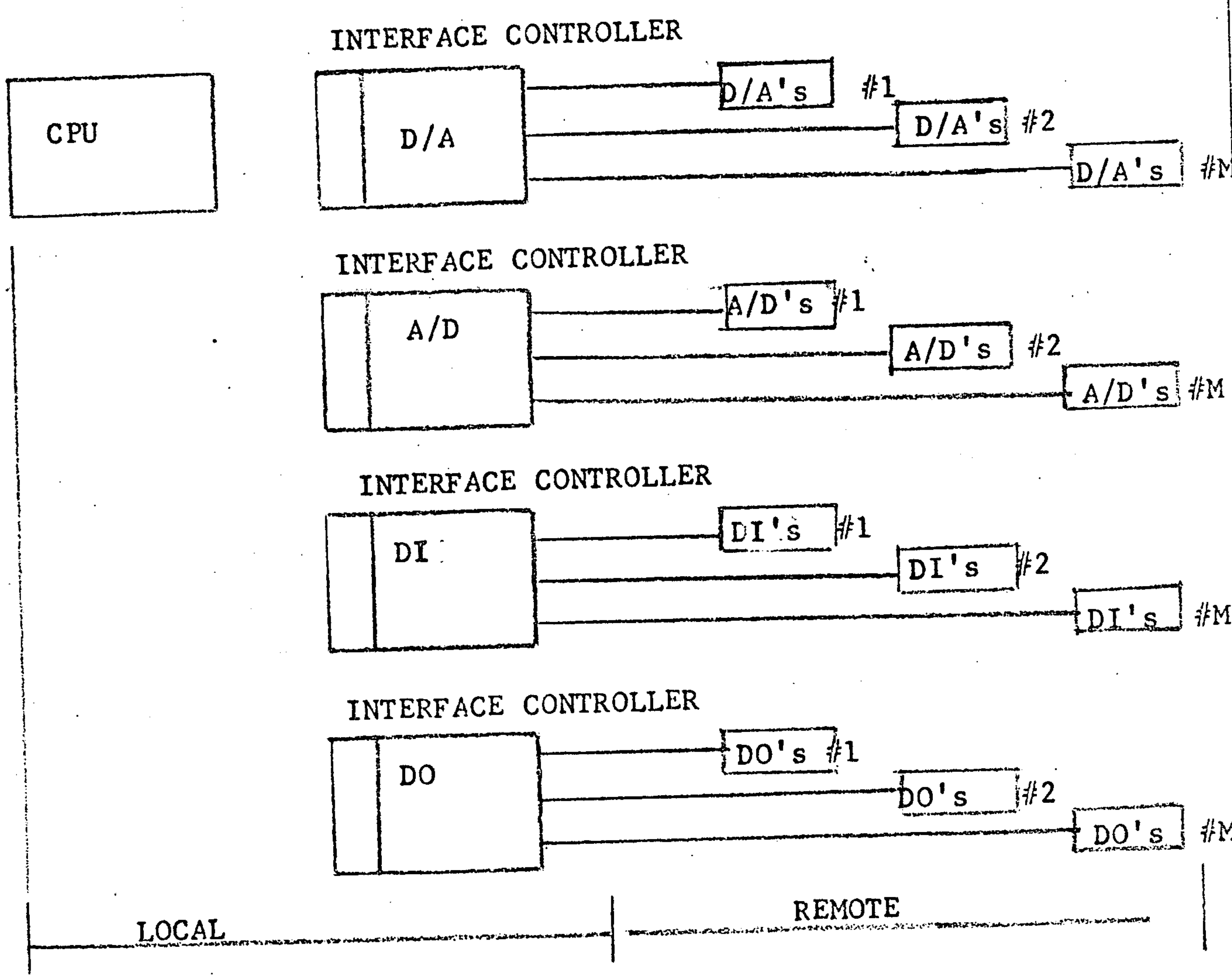


FIGURE 3

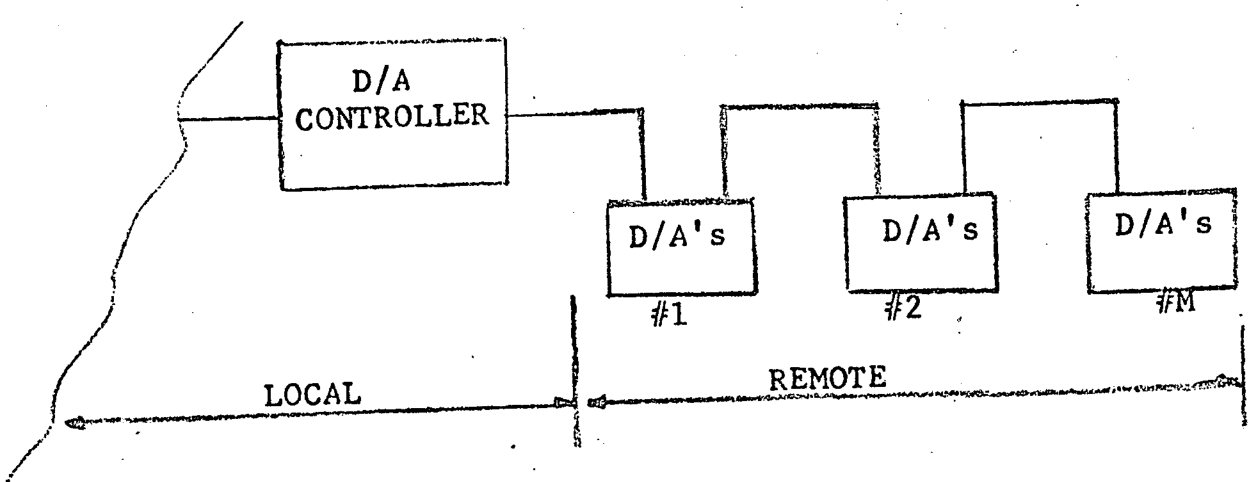


FIGURE 4

interface/control configuration, the Remote Functional Devices can be daisy chain connected with respect to the Distribution/Collection of Digital Data.

5.2.2.2.2 Current Usage

1. Singer-SPD's (Simulation Products Division's) MUFIN*/ MINI-LINKAGE 1000 system as utilized in the ASUPT Simulator is configured as the system depicted in Fig. 1. The system is configured as a main CPU (SEL-86) Interface via two 32-bit parallel device channels and is composed of five (5) sub Linkages, each Mini-Linkage 1000 being capable of the following I/O expansion - D/A -400, A/D-32, DI-512 Bits (16 Bit Words), DO-512 Bits (16 bit words). The total system has a form of self test for verifying operability but not for discrete analog calibration. Each of the Linkages can be up to 100 feet away from the control/interface section which is located adjacent to the CPU. In addition to the rudimentary interface/control functions, the SEL 86 interface unit has the following special features.

a. Fixed to floating and floating to fixed point conversions.

b. Bit processing for packing and unpacking Boolean bits of DI and DO.

c. Channel addressable hardware sine conversion for D/A channels used for resolver or synchro output drives.

*Multiple Unit Fanout Interface = MUFIN

2. Singer-SPD's AJ-37 Simulator for the Swedish Government also uses a MUFIN*/MINI-LINKAGE 1000 DCE System. However, this system differs in that it is interfaced to an SPD,GP-4 computer via two device channels and does not utilize the Self-test option. Also, because of design expediency, the system was packaged more as a centralized DCE system than a distributed DCE system in that the entire system is contained in two adjacent double-bay cabinets located next to the GP-4 computer. All DCE signals are distributed to the simulator via a central interface cabinet.

5.2.2.2.3 Characteristics

1. Update rates and effective data throughput constrained by specific interface and control techniques and by the total data path length around the simulator complex.

2. Possible to create an infinite combination of configurations.

3. By attention to proper hardware and software design considerations, it is possible to design a system which is directly DCE channel addressable through the use of control words in the I/O Programs. (Starting channel address and range.)

5.2.2.2.4 Advantages

1. This technique provides most versatile design flexibility.

2. In large systems, it can significantly reduce the complexity and bulk of long, signal distribution cables. This can be an important weight and cost factor especially with regard to a large,

complex, simulator cockpit/trainee station atop a motion system.

3. By placing the analog conversion devices close to their sources and loads, the overall noise susceptibility of the analog systems can be reduced. Therefore, high resolution and accuracy conversion devices can then be utilized to their fullest potential in the system design sense.

4. Eliminates need for special interface cabinets.

5. Overall simulator costs (recurring plus non-recurring) may be minimized for one or two unique products.

5.2.2.2.5 Disadvantages

1. Additional digital transmission electronics, connectors, and more exotic cable types are required.

2. Imposes space and weight penalties in the trainee area.

3. Based on system design and modularity considerations may require a more complex device subaddressing scheme.

4. Where DCE self test or calibration features must be made an integral part of the DCE system, the self test design becomes unwieldy and more expensive than in a centralized DCE system.

5. It becomes more difficult at initial design to adequately address the problem of spare channel provisioning for potential growth of the simulator.

6. Design effort and risk increase due to the necessity of evaluating and making provisions for data and control propagation delays through the overall system.

7. Multipotential and ground, DC power must be distributed to, and decoupled at, each and every subsystem of DCE.

The alternate to this approach is a large number of small DC power supplies and the consequent requirement for an AC power distribution system.

5.2.2.2.6 Prospects for Improvement

The various distributed DCE techniques mentioned are all subject to improvement, technically, through the development of digital and basic DCE equipment and modules (higher speed, greater resolution and accuracy, etc.). With the development of higher density LSI/MSI electronics the overall costs would be expected to come down.

5.2.2.2.7 Applicability to SMS

Distributed DCE is considered to be technically applicable to SMS.

5.2.2.2.8 Cost/Complexity Risk

1. A highrecurring cost system results due to the practical consideration of having many digital driver/receiver combinations distributed throughout the system.

2. For equivalent systems, a Distributed DCE system is operationally more complex.

3. As mentioned previously, design and configuration risk is higher due to the problems of evaluating and controlling system timing. Also it would logically be expected that as the SMS program moves forward in time, changes and expansion would of necessity be

required to be made. Therefore, this flexibility should be considered in initial design effort.

5.2.2.2.9 Implications

A higher non-recurring engineering design effort is required to provide an optimized DCE system for each particular simulator system.

5.2.3 Tradeoffs and Recommendations

The principle tradeoffs worthy of serious consideration are:

General

1. Non-recurring and recurring cost and complexity

2. Reliability/Maintainability requirements

3. SMS requirements in terms of layout, growth potential, versatility, etc.

4. Program risk, both in the area of technical development and maintaining an optimum program plan as established.

Specific

1. Operational speed

2. Long term system versatility

3. Minimization of long term operating cost and complexity with respect to changes which may be required in the SMS hardware and software above an initial delivered configuration.

The DCE system should have the potential of satisfying both short and long term growth potential, with the growth potential being additive at minimum cost and calendar schedule impact.

At the present point in time, and based on the state-of-the-art of development of centralized and distributed DCE systems, it is recommended that a centralized DCE system configuration be utilized in the SMS. Fugure developments in MSI and LSI circuitry in the next year or two may allow development of a distributed DCE system capable of closed loop test economically and with lower risk than at present.

5.2.4 References and Assumptions

5.2.4.1 References

See Section 5.5.

5.2.4.2 Assumptions

1. The SMS will be required in small or single quantities, therefore, non-recurring development should be minimized, but not beyond the point of sacrificing required technical performance excellence.

2. The prevailing design philosophies must enable growth and change in the most economically feasible manner possible in order to keep pace with changes in flight hardware if or when they become necessary or desirable.

3. The SMS should be designed and constructed to provide maximum utilization and, therefore, determining faults, isolating them, and repairing them should be carried out as expeditiously as possible.

4. The SMS DCE system will fall in the category of being considered a "large" system in terms of the number of digital and analog DCE word channels.

5. The SMS DCE system will fall in the category of being considered a "fast" system in terms of the data through put rates required to maintain accurate "real-time-simulation" with no apparent slippage or time lags.

5.3 Specialized DCE Hardware, Data Handling Techniques

5.3.1 Overview

Because of some unique system design goals related to digital simulators, certain techniques have evolved which increase the flexibility of system design and economically provide more powerful means of accomplishing tasks than would otherwise be possible. As can be easily understood, while the digital computer has great versatility in implementing a simulation system, there are certain mundane, but necessary tasks which can be carried out more efficiently outside the computer rather than within. The more salient of these items are:

1. Hardware bit processing to pack and unpack digital words in order to collect or distribute boolean bits.

2. Providing, external to the computer, word storage registers containing analog output data for ultimate conversion to analog signals.

5.3.2 Techniques

5.3.2.1 Bit Processing

5.3.2.1.1 Description

Under software control, via the control lines from the CPU to the DCE system, the particular device type is selected for a block transfer in the normal way except the additional device types are added as noted -

DBI (Digital Bit Input)

DBO (Digital Bit Output)

For input transfers, the DCE control logic thus enables the DCE controller to take one DCE DI word of n bits and input it to the computer on a one bit per CPU Byte or one bit per CPU word basis.

For output transfer, the DCE control logic thus enables the DCE controller to accept n Bytes or n words from the CPU and form them into one n bit DCE word for output transfer to the simulator interface.

Particular design details must, of course, be based on the actual computer and its hardware design features.

5.3.2.1.2 Current Usage

This technique is utilized fully in the Singer-SPD "T" Linkag mentioned previously as well as the SPD Linkage system being used on the 2F101 (T-2C) simulator. Present existing designs provide for a transformation of each 16-bit linkage DI word into 8, 16-bit computer (PDP-11 series) words. Each computer word is composed of 2 8-bit bytes.

5.3.2.1.3 Characteristics

1. Basic transfer rate is 1μsec for each 16-bit digital input or output word (DWI or DWO) and 8μsec for each block of 16 digital bit inputs or digital bit outputs (DBI or DBO).

2. DBI's and DBO's must be transferred in blocks of 16 Linkage Word bits.

3. Packing and unpacking is completely under software control.

4. Based on specific design detail and computer instruction implementation, DCE can accept computer bytes or whole words set to the Boolean value, or only most or least significant bit of the computer byte or word. The converse is also true for input formats.

5.3.2.1.4 Advantages

1. Relieves the CPU hardware and software of the necessity of packing and unpacking boolean bits. Therefore, reduces total CPU time otherwise required.

2. Provides increased overall system flexibility.

5.3.2.1.5 Disadvantages

1. Increases I/O core required.

2. Partially reduces overall DCE data throughput rate. (However, this is not considered significant in relation to the total data transfer accomplished each frame.)

5.3.2.1.6 Prospects for Improvement

Prospects for improvement of the technique are not considered relevant except in the sense of reducing cost of the required hardware.

5.3.2.1.7 Applicability to SMS

Because of the nature of all simulators and their use of large numbers of booleans, this technique is definitely technically applicable to the SMS.

5.3.2.1.8 Cost/Complexity Risk

While the cost of non-recurring design effort may be of some minor significance in application of this technique for a particular computer complex, the recurring cost of the required hardware and the technical and program schedule risk are considered negligible. Implementation of the required hardware adds very little to overall system complexity.

5.3.2.1.9 Implications

Minor reduction of effective throughput is a valid tradeoff against the saving in program time otherwise required to unpack DI words or pack DO words within the CPU.

5.3.2.2 Analog Output Channel Data Storage

5.3.2.2.1 Description

Until recently, with the advent of low cost D/A converter modules, the cost of D/A converters was such that a sample and hold technique was the only cost effective way to design and build analog output DCE systems having the large numbers of channels required by a large simulator (100 to 400 channels.)

It is now economically sound to configure an analog output system having modular D/A converters and digital word holding registers for each channel. By designing packaging to permit the necessary flexibility, the resolution of the digital data can be economically maintained at 16 bits for all channels. However, less expensive 12, 10, 8, or 6 bit converter modules can be utilized in discretely selected channels as required, to provide a more cost effective total system.

5.3.2.2.2 Current Usage

Singer-SPD's S3A simulator currently utilizes an analog output subsystem configured as described. It is basically a pluggable system in that the basic resolution and accuracy of any particular channel can be chosen merely by selecting the appropriate converter module. All interconnected package interfaces are standardized within the system.

5.3.2.2.3 Characteristics

1. Currently designed to accept 8, 10, or 12 bit resolution converters interchangeably.

2. Currently designed with a 16-bit holding register for each channel.

3. Basic digital data transfer time increased to 1 μsec per channel exclusive of actual converter settling times.

5.3.2.2.4 Advantages

1. Results in an extremely cost effective system by comparison to other techniques.

2. Assuming a DCE Controller with the capability of analog output starting channel address and range, this technique overcomes a strong disadvantage of a sample and hold technique in that continuous update is not required to prevent drift. With starting channel address and range, and with individual holding registers for each analog output channel, increased software efficiencies can, at least potentially, be realized.

3. With the addition of the individual holding registers it is possible to halt the CPU or single step without the consequent analog output signal ambiguities that result in a simulation DCE system using the sample and hold technique.

4. With the addition of the individual holding registers it is technically feasible to increase the basic throughput rate to the analog output subsystem.

5.3.2.2.5 Disadvantages

With respect to utilization of high resolution (greater than 12 bit) and accuracy converters in this scheme it is not possible to establish a single set of ±10V references for the total system since each converter module presently available has its own internal reference and these cannot be slaved to a common system reference as would be expected in a total system design utilizing a large number of high resolution and accuracy converters.

5.3.2.2.6 Prospects for Improvement

It is presently considered feasible to obtain families of converters having integral storage registers and it is reasonable to expect that new development will yield higher resolution units off-the-shelf in which a single 10 volt system reference can be utilized to improve overall system performance while reducing both long and short term drift.

5.3.2.2.7 Applicability to SMS

Because of its advantages,this technique is considered to have high application potential to the SMS.

5.3.2.2.8 Cost/Complexity Risk

As previously mentioned, this technique results in an extremely cost effective system. It is presently feasible to reduce recurring costs even further through the use of converters with integral holding registers. Overall system complexity is effectively reduced in comparison to sample and hold techniques. Program technical and schedule risk is considered negligible.

5.3.2.2.9 Implications

Problems associated with a requirement to have a common 10 volt system reference are not considered to be necessarily relevant to most simulator applications since accuracies normally required are not as stringent as those encountered in such high precision systems.

B

5.3.2.3 Starting Channel Address and Ranging

5.3.2.3.1 Description

This technique permits Block Transfers into or out of the CPU to any appropriate DCE Device type with input or output commencing at any program selected DCE channel. The transfer is then carried on via the CPU DMA controller until its word count register is decremented to zero or the program issues a "transfer terminate command".

5.3.2.3.2 Current Usage

This technique is currently implemented in the Basic Designs of Singer-SPD's "T-Linkage" and the Linkage used for the 2F101 (T-2C) simulator.

5.3.2.3.3 Characteristics

1. In the specific DCE systems mentioned, the technique is implemented by utilizing a 16 Bit (PDP-11 series computer) control word as the first word of each Block Transfer from core to establish the starting channel address.

2. Requires additional I/O time of approximately 1 μsec for each block of data transferred, in order to transfer the control word required.

3. Range is established via I/O program control of the word count loaded in the DMA device controller of the CPU.

4. Real Time I/O Program can override the flag from the Device Controller and terminate the Block Transfer at any time.

5.3.2.3.4 Advantages

1. Provides overall system flexibility in that update rates for the various DCE hardware channels can be made a function of software control only. (If Block Transfers to a particular DCE Device type must always start at channel 0, then devices in the simulator which require the highest update rate must always be hard wired as the lowest numbered channels since only range is a controllable parameter.)

2. Provides software change flexibility in terms of multi-vehicle configuration simulation, growth potential of the DCE system itself and automatic DCE testing.

5.3.2.3.5 Disadvantages

1. Very slight increased recurring cost of the DCE system.

2. The I/O Data Blocks must have an additional control word. (The starting channel number must be in the I/O Data pool.)

5.3.2.3.6 Prospects for Improvement

The only known prospect for improvement is considered to be availability of a DMA Device Controller unit with sufficient externally available control lines to enable transferring the starting address via a path other than the data lines. This could potentially allow a system design capable of minor increased speed. (However, this scheme could turn out to be less practical in terms of recurring cost.)

5.3.2.3.7 Applicability to SMS

This technique has very high application potential for the SMS.

5.3.2.3.8 Cost/Complexity Risk

The cost, complexity and risk involved in implementation of this technique is considered negligible.

5.3.2.3.9 Implications

Considered to be virtually a mandatory requirement for a simulator such as the SMS.

5.3.2.4 Hardware Sine Conversion

5.3.2.4.1 Description

The hardware device consists of the necessary digital logic to accept a digital word representing an angle in degrees as an input from the computer and provide the sine of that angle as a digital word at its output back to the computer.

The hardware converter is thus functionally utilized in place of a software subroutine.

In simulation applications, the device is applicable to computing the digital data words required for D/A/R (Digital to Analog to Resolver) and D/A/S (Digital to Analog to Synchro) conversion devices.

5.3.2.4.2 Current Usage

Singer-SPD's simulators currently utilizing the SPD "T-Linkage" also use a hardware sine converter operating as a CPU peripheral device interfaced to a program controlled device channel on the CPU (PDP-11 series).

5.3.2.4.3 Characteristics

1. Present device described has 14 Bit input and output. Directly TTL compatible to the DR-11A controller of the PDP-11 computer.

2. DR-11A has a 16 Bit output word register loaded under program control and a 16 Bit input word register accessed by the CPU under program control. There are no timing or control interfaces required between the CPU and the Hardware Sine Converter.

3. The Hardware Sine Converter operates on a ripple down principle. Therefore, the CPU transfers a word to the DR-11A output register, waits or executes other instructions to accomplish a 2 sec settling time, and then reads the result back in from the DR-11A input register.

5.3.2.4.4 Advantages

1. High Accuracy (for simulation purposes)

2. Minimizes computer time in direct proportion to the number of Resolver/Synchro Devices in the simulator.

3. Can also be used for other sine subroutine computations not directly related to the DCE equipment.

5.3.2.4.5 Disadvantages

1. Recurring cost of the Hardware Sine Converter itself plus the device controller required for the CPU.

5.3.2.4.6 Prospects for Improvement

1. Reduction of recurring cost through the use of LSI Logic Packs. (Present system described uses basic 7400 series DIP packs.)

2. Increased speed through the use of more advanced logic hardware barring reduced propogation delay.

3. Increased accuracy based on expansion of the basic word length of the device.

5.3.2.4.7 Applicability to SMS

Considered to have high technical application potential to the SMS.

5.3.2.4.8 Cost/Complexity Risk

Considered to have some cost impact which must be weighed against increased system versatility and reduced computer loading. Overall complexity and risk are considered negligible.

5.3.2.4.9 Implications

Implementation of the technique can substantially reduce computer loading in simulators utilizing large numbers of D/A/R's and/or D/A/S's.

5.3.3 Tradeoffs and Recommendations

The principle tradeoffs worthy of serious consideration are:

General

1. Non-recurring and recurring cost and complexity

2. Reliability/Maintainability requirements

3. SMS requirements in terms of layout, growth potential, versatility, etc.

4. Program risk, both in the area of technical development and maintaining an optimum program plan as established.

Specific

1. Computer loading (time and core).

Therefore, in light of all possible considerations which it is feasible to evaluate at this time, it is recommended that:

1. Hardware Bit processing be included as an integral part of the DCE hardware unless a satellite computer is included in the overall SMS. Depending on the choice of a particular Main CPU and its instruction flexibility and operating speed, the hardware bit processor can economically relieve the CPU of the time consuming task of packing and unpacking Boolean bits and thus reduce design risk in the software development area of design.

2. The analog output system utilize the buffered storage technique to provide increased performance flexibility and at least potentially, reduce software loading.

3. Starting channel address and ranging be considered a mandatory requirement of the DCE system to provide the inherent system flexibility it offers in comparison to cost or complexity.

4. Based on its relative advantages and modest cost, a hardware sine converter should be included in the SMS computer complex in order to provide system flexibility and minimize computer loading.

5.3.4 References and Assumptions

5.3.4.1 References

See Section 5.5.

5.3.4.2 Assumptions

1. The SMS will be required in small or single quantities, therefore, non-recurring development should be minimized, but not beyond the point of sacrificing required technical performance excellence.

2. The prevailing design philosophies must enable growth and change in the most economically feasible manner possible in order to keep pace with changes in flight hardware if or when they become necessary or desirable.

3. The SMS should be designed and constructed to provide maximum utilization and, therefore, determining faults, isolating them, and repairing them should be carried out as expeditiously as possible.

4. The SMS DCE system will fall in the category of being considered a "large" system in terms of the number of digital and analog DCE word channels.

5. The SMS DCE system will fall in the category of being considered a "fast" system in terms of the data throughput rates required to maintain accurate "real-time simulation" with no apparent slippage or time lags.

6.0 Automatic Test Features

6.1 DCE Testing & Calibration Techniques

6.1.1 Overview

The need for some automated or semi-automated means of testing a large simulation DCE system comes about because of the shear complexity of the system and the requirement to identify and isolate a malfunction in the shortest practical time to enable optimum utilization of the simulator. All currently utilized testing techniques rely on the versatility of the computer itself and the complementary duality of the basic DCE devices. The cost of the additional test hardware and software for any particular sized system must be weighed against the versatility it provides since for small DCE systems, the self test feature may not be economically feasible.

Essentially all hardware systems for DCE testing and calibration are specialized designs produced for unique DCE systems by simulator manufacturers. These types of systems tend to be not readily available commercially from computer and computer peripheral manufacturers as off-the-shelf items.

The most obvious deficiency in all current DCE testing schemes is the fact that it is both costly and difficult to produce a test system (hardware and software), capable of directly isolating faults in the complex control section of the DCE system. However, utilizing existing techniques, in conjunction with the development of diagnostic software, an operational test system package to isolate faults to major areas of the controller can be produced which is more powerful than anything presently available.

6.1.2 Techniques

6.1.2.1 Integral DCE Electronic Closed-Loop Testing

6.1.2.1.1 Description

Implementation of this technique relies on additional integral electronics contained in the DCE hardware for either sensing or forcing responses independent of the simulator status or signal levels.

6.1.2.1.2 Current Usage

Singer-SPD's F-111, 747, L-1011, and DC-10 DCE systems use the basic techniques noted.

a. DI's - Under software control, (Unique Control Words) the DI inputs are forced to all "1" or all "0" regardless of the simulator signals. Simulator inputs & test inputs are isolated from each other to prevent interaction.

b. DO's - Under software control, (Unique Control Words) the DO's are forced to all "0" and then to "1" one bit at a time. Each 32 bits are diode "OR" tied and the output is fed to an analog input channel.

c. D/A's and A/D's - Under software control,(Unique control words) the D/A's and A/D's are electronically connected. A group of 8 D/A channel outputs are used as inputs to a ladder network whose output is fed to one A/D channel. Software sets up output signal pattern and compares expected nominal results with actual results.

6.1.2.1.3 Characteristics

1. Integral to the DCE system hardware design.

2. High operational speed.

6.1.2.1.4 Advantages

1. Testing can be carried out completely under software control.

2. Provides hard copy printout via necessary software and TTY or line printer.

3. Pass/fail criteria can be easily altered via use of software constants.

4. Avoids the cost and complexity of interconnect cables and connectors, otherwise required to connect self test hardware to the basic DCE system.

5. Is not dependent on the mix of I/O types in a given configuration.

6. Is the most easily applied test technique in distributed DCE systems.

7. Assuming no control malfunctions exist, allows DI & DO testing to the bit level.

6.1.2.1.5 Disadvantages

1. Requires comparatively complex software to evaluate analog DCE system performance.

2. Requires added control and decode logic in the system controller.

3. Does not lend itself to configuring self test as a hardware option to the basic DCE system.

4. Requires major engineering effort for redesign if DCE signal ranges are modified for a specific application (28 volt DI's vs TTL level DI's.)

5. Does not permit testing of the DCE system all the way to its own external interfaces with the simulator.

6. Added functional electronics reduces the overall reliability of the basic DCE system. (An operational malfunction in the test portion of the system could prevent even degraded operation of the basic DCE system with the simulator.)

7, Generally requires additional DC voltage levels in order to establish signals used as override or forcing functions.

8. Does not provide direct absolute calibration of the analog DCE equipment.

6.1.2.1.6 Prospects for Improvement

It is believed the basic technique could be greatly simplified and the cost reduced through use of electronic devices (LSI/MSI logic, Multiplexer Modules, etc.) now available. (Also refer to paragraph 5.4.1 for comments on diagnostic techniques.)

6.1.2.1.7 Applicability to SMS

Considered to have equal technical applicability as other techniques.

6.1.2.1.8 Cost/Complexity Risk

1. Relatively high cost and complexity by comparison to the other feasible techniques.

2. Considered to have higher new design risk than some other feasible techniques.

6.1.2.1.9 Implications

Results in substantially increased electronic hardware and software complexity, but lacks other essential basic desirable features such as direct assessment of analog DCE calibration.

c

6.1.2.2 Wraparound Self-Test Via Patch Boards

6.1.2.2.1 Description

Implementation of this technique relies on the use of one or more patch panels and two or more sets of patch boards. All DCE I/O signals are routed to and from the patch panels. One set of patch boards are configured for straight-through signal transmission between the DCE system and the simulator. Additional sets of patch boards are used to effectively connect blocks of digital outputs to digital inputs and analog outputs to analog inputs.

6.1.2.2.2 Current Usage

Singer-SPD's S3A simulator DCE system utilizes this patch board technique. Several other SPD simulators which have also used the technique are:

a. The 2B24 simulator
b. The SFTS simulator
c. The 14B44 simulator
d. The Skylab simulator

6.1.2.2.3 Characteristics

1. Technique requires only passive hardware.

2. Enables great system interface flexibility

3. Requires operator intervention to change patch boards in order to run tests.

4. Unless multiple input/output pairing is implemented, the technique allows fault isolation only to the signal pair level. (for a no go pair of D/A & A/D channels, malfunction could be in either or both.)

5. The simulator is totally isolated from the DCE equipment during testing. Therefore, malfunctions in the simulator can have no adverse effect on the DCE testing.

6.1.2.2.4 Advantages

1. Is extremely straightforward in design and consists of totally passive elements.

2. Provides an added extra feature to the DCE system in that the normal operating patch boards comprise an easily changeable interface for the simulator.

6.1.2.2.5 Disadvantages

1. Requires I/O signal levels, accuracies, and ranges which are directly compatible with each other.

2. Requires additional cabling.

3. Does not provide direct, absolute calibration of the analog DCE equipment.

4. Because of the high density of analog and digital signals passing through the patch panel, the signals generally are required to be shielded to prevent noise pickup and cross talk.

5. Analog to synchro/resolver conversion devices are not tested by this technique.

6. Does not permit precise fault isolation in the DCE control logic electronics to the component level.

6.1.2.2.6 Prospects for Improvement

The only foreseeable prospect for improvement in this technique is in the area of cost reduction resulting from the availability of lower cost hardware elements. (Also refer to paragraph 5.4.1 for comments on diagnostic techniques.)

6.1.2.2.7 Applicability to SMS

Considered to have equal technical applicability as the other techniques. For SMS, the capability of altering the signal distribution interface to the simulator could be a great asset.

6.1.2.2.8 Cost/Complexity Risk

1. Assuming the consequent technical tradeoffs do not preclude use of the technique, it is considered to be one of the most cost-effective of all techniques.

2. In general terms, the complexity is high, but not considered any worse than the other techniques.

3. The only design risk is believed to be in the proper sizing of the total DCE system from its inception including a true projection of the ultimate growth.

4. The system has proven to be highly reliable in field use.

6.1.2.2.9 Implications

Results in a compact, reliable cost effective system but requires operator intervention to run tests. Therefore, overall test time is greater than some of the other techniques. Also, absolute analog calibration must be verified using external test equipment.

6.1.2.3 Wraparound Self Test Via Multipole Relay Multiplexing

6.1.2.3.1 Description

Implementation of this technique relies on the use of two functional banks of Form C contact, multipole relays. One bank being used to connect or disconnect the simulator from the DCE system. The second bank used to alternately connect DCE inputs and outputs together via a relay tree configuration. The complexity of the relay tree is a function of the ratio of input to output devices and is not absolutely required if the ratio is 1:1. If the I/O ratio is 1:1, and it is only necessary to isolate faults to the channel or bit pair level, no tree is required.

6.1.2.3.2 Current Usage

This technique is implemented in the current design of Singer-SPD's 2F101 (T-2C) simulators. The I/O counts for this system are:

DI	256 bits (16, 16 bit words)
DO	256 bits (15, 16 bit words)
D/A	128 channels
A/D	32 channels

The same set of Form C contact, Multipole relays are used to open the signal path to the simulator and to connect DI's to DO's. The analog signals are disconnected from the trainer by one set of Form C contact, multipole relays, and the A/D's are connected to the 128 D/A channels, 32 at a time, via a relay tree.

Full software control of the system is implemented through the use of three dedicated, relay buffered DO bits. While not implemented in this particular system, it is feasible to control the relays by a manually controlled selectro switch. All analog signals are shielded and digital signals are transferred via twisted wire to preclude noise and crosstalk.

This system uses bifurcated gold plated contact relays and is enclosed to prevent contamination by dust. All cables to the DCE system are an integral part of the self test unit, avoiding the necessity for two complete sets of connectors otherwise required.

6.1.2.3.3 Characteristics

1. Fully automatic via software control.

2. Use of dedicated DO bits for control precludes requirement for special control words and decode logic in the control and interface section of the DCE.

3. For the 2F101 system described, digital I/O faults are isolated to the bit pair level and analog I/O faults are isolated to the particular input or output device channel.

4. High speed in relation to any technique requiring operator intervention to change connections, move cables, etc.

6.1.2.3.4 Advantages

1. Is extremely straightforward in design and consists of totally passive elements with the exception of the relays.

2. By proper attention to design, can be configured to provide an easily modifiable signal interface between the DCE system and the simulator.

3. Use of low contact resistance relays prevents live impedance matching problems and effective alterations in source impedances which would otherwise have an adverse effect on scaling and accuracy.

4. Failure of a critical relay coil has no adverse effect on the performance of the basic DCE system or the simulator as a whole. By attention to design philosophy it is possible to design and provide a patch cable to bypass a section of the self test system while it is being repaired.

6.1.2.3.5 Disadvantages

1. Requires I/O signal levels, accuracies and ranges which are directly compatible with each other.

2. Requires additional cabling.

3. Does not provide direct, absolute calibration of the analog DCE equipment.

4. Because of the high density of analog and digital signals passing through the multipole relays, the signals generally are required to be shielded to prevent noise pickup and cross talk.

5. Analog to synchro/resolver conversion devices are not tested by this technique. (These could be implemented by the addition

of a synchro/resolver to digital converter and a means of electronically or electromechanically connecting outputs to input, one device at a time.)

6. Does not permit precise fault isolation in the DCE control logic electronics to the component level.

6.1.2.3.6 Prospects for Improvement

The only foreseeable prospect for improvement in this technique is in the area of cost reduction resulting from the availability of lower cost hardware elements. (Also refer to paragraph 6.1.1 for comments on diagnostic techniques.

6.1.2.3.7 Applicability to SMS

Considered to have equal technical applicability as the other techniques. For SMS, the feature of not having to manipulate hardware is a great asset to the overall maintainability of the simulator.

6.1.2.3.8 Cost/Complexity Risk

1. Assuming the consequent technical tradeoffs do not preclude use of the technique, it is considered to be one of the most cost effective of all techniques.

2. In general terms, the complexity is high, but not considered any worse than the other techniques.

3. The only design risk is believed to be in the proper sizing of the total DCE system from its inception including a true projection of the ultimate growth.

4. The system has proven to be highly reliable in field use.

6.1.2.3.9 Implications

Results in a compact, fully automatic, reliable, cost effective system. This technique yields a system which, from the practical operating standpoint, is as fast as any fully electronic system. Absolute analog calibration must be verified using external test equipment.

6.1.2.4 Wraparound Self Test Via Electronic Multiplexing

6.1.2.4.1 Description

Implementation of this technique is accomplished basically the same as with Multipole relays except all interconnections are made via electronic switches.

6.1.2.4.2 Current Usage

There is no known DCE system fully utilizing this technique in current operation.

6.1.2.4.3 Characteristics

1. Avoids the use of any electromechanical devices for signal switching, multiplexing or demultiplexing.

2. Inherent high speed.

6.1.2.4.4 Advantages

1. By judicious choice of components and design philosophy it is possible that this technique can result in a more cost effective system than any yet designed or produced.

2. By proper attention to design, can be configured to provide an easily modifiable signal interface between the DCE system and this simulator.

3. No hardware has to be physically manipulated to set up for testing.

6.1.2.4.5 Disadvantages

1. Requires I/O signal levels, accuracies and ranges which are directly compatible with each other.

2. Requires additional cabling.

3. Does not provide direct, absolute calibration of the analog DCE equipment.

4. Because of the high density of analog and digital signals passing through the electronic switches, the signals generally are required to be shielded to prevent noise pickup and cross talk.

5. Analog to synchro/resolver conversion devices are not tested by this technique. (Could be implemented by the addition of a synchro/resolver to digital converter and a means of electronically connecting outputs to input, one device at a time.)

6. Does not permit precise fault isolation in the DCE control logic electronics to the component level.

7. Added functional electronics reduces the overall reliability of the basic DCE system. (An operational malfunction in the test portion of the system could prevent even degraded operation of the basic DCE system with the simulator.)

6.1.2.4.6 Prospects for Improvement

It is believed the basic technique could be more effectively implemented through the use of LSI/MSI development to provide devices which could be packaged more cost effectively than components currently available. (Also, refer to paragraph 5.4.1 for comments on diagnostic techniques.)

6.1.2.4.7 Applicability to SMS

Considered to have equal technical applicability as the other techniques. However, the technique requires further development before its performance parameters can compete with other existing systems.

6.1.2.4.8 Cost/Complexity Risk

1. By comparison to other currently used techniques, electronic wraparound switching is considered to be costly and complex.

2. Design Risk is considered high since there are functional requirements which can be difficult to meet using purely electronic components. (Example: Switches with extremely low feed through capacitance in the off state to prevent output to input analog cross talk).

6.1.2.4.9 Implications

Application of this technique requires use of electronic "switches" which have extremely low "on" impedances to enable, in the applicable instance:

1. handling lamp driver current levels. (Typically 250-300 MA steady state & 500-600 MA peak.)

2. Maintaining low effective analog output channel impedance (typically less than one ohm for the output amplifier itself.)

Development of this technique requires detailed design development in several areas.

6.1.2.5 Analog DCE Testing and Calibration Via a Multiplexed, High Accuracy Complementary Conversion Device

6.1.2.5.1 Description

This technique is the only one described herein which permits calibration of analog inputs and outputs in the true sense. It may be combined with any one of several other basic closed loop or wrap-around schemes. Implementation requires the presence of at least one DAC and ADC having sufficient resolution and accuracy to be considered a secondary type standard by comparison to the devices actually utilized to supply signals to, and accept signals from, the simulator. Also required to implement the technique are the means of connecting, electronically or electromechanically, each of the operational devices to the calibration device one channel at a time.

6.1.2.5.2 Current Usage

No known simulation DCE system presently utilizes this technique. However, it is used for highly specialized scientific applications where calibration curves are utilized for error correction prior to calculation of final results.

6.1.2.5.3 Characteristics

1. High degree of sophistication added to basic DCE system.

2. Relatively more complex software required to provide point by point error curve.

3. Operational test time is increased by a factor of the number of channels in the total system since each type device must be

tested individually and the conversion settling times of the high accuracy and resolution converters must be taken into account.

6.1.2.5.4 Advantages

1. Provides an absolute means of assessing the accuracy of each channel in the analog DCE system, over its entire range.

2. Enables fault isolation of an operational analog device to the channel level as opposed to the channel pair.

6.1.2.5.5 Disadvantages

1. Adds substantially to the cost of the system.

2. If channel to channel wraparound test mentioned earlier is omitted in favor of this technique, significantly more time is required to fully test all of the analog DCE system since only one channel can be tested at a time.

3. Requires complementary software to fully implement the technique.

6.1.2.5.6 Prospects for Improvement

The only foreseeable prospect for improvement in this technique is in the area of cost reduction resulting from the availability of lower cost elements. Also, higher speed high resolution converters would reduce the overall required test times. (Also, refer to paragraph 5.4.1 for comments on diagnostic techniques.)

6.1.2.5.7 Applicability to SMS

Considered to have high technical applicability primarily in the following areas:

1. As a means of predictive failure analysis based on the previous calibration history of a particular device.

2. As a means of quickly isolating a latent deficiency in overall trainer performance.

6.1.2.5.8 Cost/Complexity Risk

1. Considered to be a relatively high cost item.

2. Complexity of the total DCE system would be increased only moderately either in hardware or software.

3. Very little risk is associated with implementation of this technique.

6.1.2.5.9 Implications

DCE controller operational modifications would be required over and above its basic functions to fully implement the high accuracy and resolution converters into the system (unique device selection and perhaps full world data transfers in the DCE for these particular devices.)

6.1.3 Tradeoffs and Recommendations

The principle tradeoffs worthy of serious consideration are:

General

1. Non-recurring cost and complexity
2. Reliability/Maintainability requirements
3. SMS requirements in terms of layout, growth potential, versatility, etc.
4. Program risk both in the area of technical development and maintaining an optimum program plan as established.

Specific

1. Signal cabling required
2. Operational speed

Therefore, in light of all possible considerations which it is feasible to evaluate at this time, it is recommended that:

1. Closed loop DCE testing definitely be incorporated as a part of the SMS.
2. The multipole relay technique be employed because of its reliability, simplicity and advantages.
3. The high accuracy calibration technique should be considered for incorporation in the overall system but only in light of its advantages compared against cost and the added savings it can provide in a long term operating environment.

6.1.4 References and Assumptions

6.1.4.1 References

Refer to Section 5.5.

6.1.4.2 Assumptions

1. The SMS will be required in small or single quantities, therefore non-recurring development should be minimized, but not beyond the point of sacrificing required technical performance excellence.

2. The prevailing design philosophies must enable growth and change in the most economically feasible manner possible in order to keep pace with changes in flight hardware if or when they become necessary or desirable.

3. The SMS should be designed and constructed to provide maximum utilization and, therefore, determining faults, isolating them, and repairing them should be carried out as expeditiously as possible.

4. The SMS DCE system will fall in the category of being considered a "large" system in terms of the number of digital and analog DCE word channels.

5. The SMS DCE system will fall in the category of being considered a "fast" system in terms of the data throughput rates required to maintain accurate "real-time-simulation" with no apparent slippage or time lags.

6.1.5 General Reference Material

General Reference Material

1) Simulator User Survey
2) Singer SPD's Linkage Designs (many) (Binghamton, SSO, APO)
3) Singer SPD Linkage Technical Specifications (many) (Computer Interfaces, Linkage Hardware Specs., Software Interface Specs., Self-Test Hardware Specs., Self-Test Software Specs.)
4) Various Computer Manufacturer Tech Pubs relevent to DCE Interfacing (H-316, H-516, H-716, DDP-224, DDP-324)(2, 3, 5, 7) (GP-4) (PDP-11/15, /20, /45) (Data Craft 1620/1, /5)(SEL-86)
5) In house Technical and Cost Studies (Formal and Informal) Centralized DCE, Distributed DCE, Self Test, DCE Packaging
6) Various Commercial DCE Components Tech Pubs, Data Sheets, etc. - (Data Device Corp.) (Micro Networks) (Analog Devices) (Burr-Brown) (Zeltex) (Datel) (Transmagnetics) (Kearfott) (Texas Inst.) (Motorola) (Signetics) (Fairchild) (Sprague) (Corning) (Raytheon) (Beckman) (T-Bar) (North Electric) (Electronic Engineering Co. of Calif.) (Stanford Applied Engineering) (Augat) (AMP) (Scanbe) (Teledyne Philbreck)
7) Various Commercial DCE Systems, Tech Pubs, Data Sheets, etc. (Xerox Data Systems) (Honeywell) (Computer Products)
8) NASA Publications
    1) Technology Utilization NASA SP-5498(01) Title - "Electronic Switches and Control Circuits"
    2) Technology Utilization NASA SP-5949(01) Title - "Digital Circuits for Computer Applications"
9) Proceedings No. 67, NATO Advisory Group for Aerospace Research and Development
   Avionics Panel Technical Symposium on "Data Handling Devices" held in Instanbul, Turkey on 1 to 4 June 1970.

6.2 Dynamic Computer Test

6.2.1 Overview

There are three types of computer test systems in general use on computer systems today.

1) Vendor supplied basic tests - which are stand alone tests used to provide a basic test capability as well as total system test but require the computer system to be taken off line. These tests are supplied with all computer systems.

2) Vendor supplied background mode test system - provides for running tests for system verification in a background mode while continuing with operational software in foreground mode. This type system is strongly recommended for use on SMS.

3) Special test systems - which are developed to meet special test requirements. No special test requirements are foreseen for SMS.

6.2.2 Techniques

6.2.2.1 Vendor Supplied Basic Tests

6.2.2.1.1 Description

This category of tests includes the basic fundamental tests for each piece of hardware supplied by the computer vendor.

6.2.2.1.2 Current Usage

Tests of this type are supplied by all computer vendors.

6.2.2.1.3 Characteristics

Tests in this category are intended to check a particular piece of hardware or a specific function of a piece of hardware. They typically are stand-alone tests and are loaded with a simple bootstrap type of loader such that a minimum of computer hardware is required for loading. The tests are usually in a set. Each test uses hardware tested by the previous test to verify proper operation of a new portion of the total hardware. The tests are usually run in sequence when a problem of unknown nature is suspected or if a thorough system test is desired.

Usually a system test is also provided by the computer vendor which combines all or most of the basic tests (perhaps in an abbreviated form). This test usually includes concurrent operation of the CPU, Memory, and peripheral devices. A basic computer system capability is assumed and then proper operation verified.

Often a test monitor is provided which allows the test routines to be individually selected from a magnetic tape or disc. The tests may be run individually or chained with other tests for execution.

6.2.2.1.4 Advantages

These tests perform the detailed hardware testing in a stand-alone mode which aids the maintenance personnel in isolating and correcting the problem.

6.2.2.1.5 Disadvantages

These tests require total control of the CPU which means the computer system must be taken off-line for running the tests.

6.2.2.1.6 Prospects for Improvement

None.

6.2.2.1.7 Applicability to SMS

These tests are mandatory on SMS for their intended purpose. They do not, however, exclude requirements for other tests for other purposes.

6.2.2.1.8 Cost Complexity and Risk

These tests are normally bundled with the computer hardware and are supplied at no additional cost by the computer vendor.

6.2.2.1.9 Implications

None.

6.2.2.2 Vendor Supplied Background Mode Test System

6.2.2.2.1 Description

This type of test system provides for running computer system tests in a background mode while continuing with operational (e.g., simulation, batch processing) software in foreground mode.

6.2.2.2.2 Current Usage

This type system is in use on many large computer systems today including among others, XDS Sigma 6 & 9, CDC 6000/7000 Series, and IBM 360/370 Series.

This capability is planned for such systems as the SEL 86 and XDS Sigma 5 within the next 2 years.

6.2.2.2.3 Characteristics

This type of test is intended to verify proper system operation. It operates in background mode (Spare Computer time) and is usually initiated by the computer operator. Testing may include CPU, Memory, and/or any peripheral device at the operator's option.

6.2.2.2.4 Advantages

The primary advantage of this type of test system is that the computer system does not have to be taken off-line in order to verify proper system operation. Another advantage is the ease in which a test routine may be called up for execution in the background mode to aid in corrective or preventative maintenance on elements of the computer system.

6.2.2.2.5 Disadvantages

There are no disadvantages although the system is limited in its capabilities to diagnose fundamental problems. Obviously, if a fundamental problem exists, the monitor software which supports the foreground/background modes will not function properly and the test routines would not be executed. Thus, the need for the basic stand-alone tests.

6.2.2.2.6 Prospects for Improvement

Minor improvements will probably be made but there are no major improvements foreseen.

6.2.2.2.7 Applicability to SMS

This type of test system is definitely applicable to SMS and is extremely desirable but not mandatory.

6.2.2.2.8 Cost Complexity and Risk

This system is normally supplied by the computer vendor.

6.2.2.2.9 Implications

None.

6.2.2.3 Special Test Systems

6.2.2.3.1 Description

Special test systems may be developed to meet special test requirements such as depth of test or diagnostic printouts.

6.2.2.3.2 Current Usage

Special test systems for general purpose computer systems are not in general usage.

6.2.2.3.3 Characteristics

The characteristics of special tests are designed to meet the special requirements of special users. The special requirements often include one or more of the following:

a) more thorough testing

b) better diagnostic printouts

c) easier or faster testing

d) special testing modes

6.2.2.3.4 Advantages

The special test system will meet the users special test requirements.

6.2.2.3.5 Disadvantages

The cost of development of special test systems is usually quite high and the rather limited use causes a relatively low level of confidence on the part of the using personnel.

6.2.2.3.6 Prospects for Improvement

There are no particular prospects for improvement.

6.2.2.3.7 Applicability

There are no special testing requirements foreseen for SMS.

6.2.2.3.8 Cost Complexity and Risk

The cost of special test systems is very high and if the personnel doing the development are not intimately familiar with the detailed hardware operation there is considerable risk that the test system will be useless.

6.2.3 Tradeoffs and Recommendations

Basic computer system tests will be supplied by the computer vendor.

A background mode system test should be obtained for the SMS if available from the computer vendor. The availability of this type system should be considered when selecting the SMS computer system.

No special tests should be developed for the SMS computer system. The mean-time-to-repair (MTTR) of most computer systems is acceptable using tests supplied by the computer vendor.

6.2.4 References & Assumptions

None.

6.3 Hardware Diagnostics

6.3.1 Overview

The objective of simulator hardware diagnostics is quick determination of a simulator's operational status. The emphasis is on speed. Obviously complete verification of a simulator's status can only be achieved by running the complete test guide which is anything but quick. The rationale of hardware diagnostics is essentially that software doesn't fail and therefore, if the hardware checks out, the simulator is operational. Hardware diagnostics can also be a maintenance aid both by isolating faults and by establishing calibration pre-conditions

6.3.2 Techniques

6.3.2.1 Simulator Off Line Diagnostics

6.3.2.1.1 Description

Special software is created to exercise all of the DCE and DCE associated hardware. This software is not intended to run in conjunction with the operational software, hence "off line".

In operation, various tests are initiated by typewriter or keyboard control. The procedure requires that input devices be operated in a predetermined sequence or pattern and that predetermined outputs be observed. The exact details vary as the software must be developed for the particular simulator but a typical test sequence might, when initiated, cycle the lamp driver DCE outputs which activate lamps on the IOS thru a pattern. Observation of this pattern would provide the operator a check of this portion of the hardware.

6.3.2.1.2 Current Usage

FB-111A and F-111D simulators.

6.3.2.1.3 Characteristics

See 6.3.2.1.1

6.3.2.1.4 Advantages

This technique permits localization of faults to a very low level in the hardware.

6.3.2.1.5 Disadvantages

Creation of the software is a significant effort. Modifications in hardware often necessitate changes in this software as well as in the operational software thus increasing modification costs. The complete procedure requires more simulator time than can be allocated on a daily basis. Operation can be cumbersome.

6.3.2.1.6 Prospects for Improvement

There is a likelihood of modest improvement, primarily in programming technique.

6.3.2.1.7 Applicability to SMS

This could be applied to SMS.

6.3.2.1.8 Cost/Complexity and Risk

Risk is minimal as the technique works. Complexity is strictly software and has no impact on computer loading or size. Cost is significant. The software required is comparable from a standpoint of effort to a major simulator operational system.

6.3.2.2 Simulator Test

6.3.2.2.1 Description

"Simulator Test" by convention refers to various "built in test" features imbedded in the operational hardware and software. This is done primarily to expedite the test phase of the simulator. Some of these test features are a form of hardware diagnostics. An example of this is "Instrument Test". Initiation of this test mode causes all instruments to drive to either a pre-programmed value or a value selected by the operator. This is accomplished by means of software incorporated into each instrument drive program. This provides a means of quickly determining the status of all instruments both on a go/no-go basis and on an accuracy basis with minimum disturbance of the overall simulator. Software controlled "Lamp Test" is another example. This is typically used for part or all of the indicator lites at a conventional IOS. It has the advantage of testing the DCE as well as the lamps themselves.

6.3.2.2.2 Current Usage

Essentially all simulators have some form of simulator test. The degree and sophistication varies widely.

6.3.2.2.3 Characteristics

Not applicable.

6.3.2.2.4 Advantages

Generally tests are only implemented for hardware which is known from experience to be potentially troublesome. This avoids the expenditure of effort in areas where little return can be anticipated. Since the test features are "resident" (part of the operational hardware/software) they can be used without precluding simultaneous maintenance or checkout effort on other areas of the simulator. Modification effort is often reduced. If for example an instrument is changed and this caused changes in the instrument drive program, the instrument test feature change is made in that same program rather than in some other body of software.

6.3.2.2.5 Disadvantages

The computer load is increased. Test features are often disjointed and fragmentary.

6.3.2.2.6 Prospects for Improvement

The technique has shown steady improvement for some time and this trend can be expected to continue. Automated Test Guide in some respects has evolved from this technique.

6.3.2.2.7 Applicability to SMS

This technique is applicable to SMS.

6.3.2.2.8 Cost/Complexity and Risk

Risk is negligible. Cost and complexity are small.

6.3.2.3 Automated Test Guide

See 6.4. To some extent automated test guide can be used as a hardware diagnostic technique.

6.3.2.4 Daily Readiness

6.3.2.4.1 Description

This technique is rather similar to the use of an aircraft "check list". Software is created to provide sets of initialization parameters and to maintain various conditions while the test personnel go thru a "check list" procedure. By way of example one of these tests might position the simulated vehicle on certain latitude, longitude and altitude and the test personnel would operate all of the navigation avionics to obtain bearings, ranges and the like for comparison with check list values.

The daily readiness software is a part of the operational software. This technique therefore provides an overall check of the simulator, both hardware and software.

6.3.2.4.2 Current Usage

F-111A, FB-111, F-111D.

6.3.2.4.3 Characteristics

Not applicable.

6.3.2.4.4 Advantages

Properly implemented, this technique can provide some assurance of the operational status of the simulator.

6.3.2.4.5 Disadvantages

This technique tends to be expensive both in initial cost and in usage compared to the benefits it provides. Use tends to be time consuming.

6.3.2.4.6 Prospects for Improvement

No great improvement is likely.

6.3.2.4.7 Applicability to SMS

This technique could be applied to SMS.

6.3.2.4.8 Cost/Complexity and Risk

Risk is small. Cost and complexity are large by comparison to usefulness.

6.3.3 Tradeoffs and Recommendations

The tradeoff in this area is one of completeness of checkout versus the time required to use the checkout procedure and the cost of implementation. The recommendation is to use a combination of "Simulator Test" and "Automated Test Guide" techniques and to concentrate on the areas most likely to have problems.

6.3.4 References and Assumptions

None.

6.4 Automated Test Guide

6.4.1 Overview

The trend over the past several years has been toward more extensive use of the simulator computer complex itself in developing, perfecting and debugging the simulators' operation. Automated test guide is a further extension in this direction.

Total automation of test guide verification is neither a realistic nor desirable goal. Instead, the goal is automation of those portions of the test guide verification process which might otherwise be influenced by the proprioceptive skills of those running the test guide and those which involve a number of repetitive operations. Examples of the former are rate of climb tests, steady state side slip tests, dynamic stability tests and the like. Examples of the latter are speed/thrust tests and engine performance vs. altitude, mach number and power setting.

Automation in areas which do not meet those criteria will, in general, require a greater expenditure of effort to accomplish than the automation can save. Those other areas, on-board systems, navigation and communication, and the like are susceptible to some semi-automation which is cost effective. This semi-automation takes the form of computer techniques which facilitate quick setup of the test guide conditions.

6.4.2 Techniques

Since the techniques of implementing automated test guide are not sharply delineated they will be treated as one general technique.

6.4.2.1 Automated Test Guide

6.4.2.1.1 Description

By means of software (software not necessary to the operation of the simulator), the conditions for a test guide procedure are initialized and maintained. In addition, the results of the test are output on a line printer or teletype.

This places some constraints on the operational software. If, for example, the engine test guide is to be automated, it must be readily possible to substitute test guide values for parameters normally obtained from the flight environment computations and from hardware inputs. Therefore, the engine computations must consistently obtain their data from a buffered interface data pool and ideally this buffered interface should be of minimum size.

It must be stressed that the automated test guide driver programs must be limited to manipulating the input data to a system if the results are to be credible. Thus in the case where the automatic test guide software must maintain some system output during a test, it must do it by adjusting inputs to the system. An example of this could be a rate of climb test where one of the test conditions might be a specified airspeed or mach number. This must be maintained by control surface position, not by freezing airspeed.

6.4.2.1.2 Current Usage

This has been employed on the Advanced Simulator for Undergraduate Pilot Training, L-1011 simulators, 747 simulators and will be used on the S-3A Weapon System Trainer.

6.4.2.1.3 Characteristics

N/A.

6.4.2.1.4 Advantages

Where the technique is truly applicable, it can often provide a significant savings in the time required to run test guide. As an example, engine test guide can be run on an L-1011 simulator in one day (including data reduction) as opposed to the two weeks it would normally take. Only two hours of simulator time is required. Since the simulator test guide is typically run several times, these savings are multiplied by the number of times the test guide is run.

On a simulator which is subject to continuing modification and change, automated test guide is valuable through the life of the simulator. It provides an expedient means both of evaluating modifications and of verifying the performance of areas which have not been modified.

The results are repeatable. This is particularly significant in the area of flying qualities where actually flying the test guide procedures typically leads to a large variance in the results as a function of the skills of the "pilot".

The number of anomalies introduced by errors on the part of the test personnel is reduced.

Hard copy output facilitates maintenance of simulator performance history records.

6.4.2.1.5 Disadvantages

The technique poses a possible problem of credibility. Avoidance of this problem requires that the automated test guide procedures can be shown to produce the same results as actual operation of the simulator.

Application of the technique where it is not suitable could lead to gross inefficiencies. That is to say that design of the automated test guide software could require much more effort than just running the test guide in traditional fashion.

6.4.2.1.6 Prospects for Improvement

Since this is a rather new technique, improvement should be expected. It will probably be extended into some parts of the navigation area in the near future.

6.4.2.1.7 Applicability to SMS

This technique is applicable to SMS.

6.4.2.1.8 Cost/Complexity and Risk

Risk is negligible if the technique is applied in areas where it has proven effective. Cost and complexity cannot be assessed at this time since it is highly dependent on the specific test guide to be automated. It must be noted, however, that this technique has come into being in the interest of cost reduction.

6.4.2.1.9 Implications

Successful implementation depends, to a large extent, on the organization of the operational software. Interfaces between major systems such as Air Breathing Engines, Flight, Navigation, etc., must be clear, clean and minimal.

6.4.3 Tradeoffs and Recommendations

The tradeoff involved in this technique is engineering design effort versus test and maintenance effort. The test and maintenance effort estimate should include that involved with the original configuration and that involved with modifications and performance assurance. The cost of simulator time, both in final test and on-site, should be factored into the tradeoff.

It is recommended that the automated test guide be used in the flight and engine areas and that the technique be extended into other areas to the extent practicable.

7.0 Instructor-Operator/Machine Interface and Training Aids

7.1 Aural Feedback

7.1.1 Overview

Aural Feedback refers to messages under computer control that provide the trainee with the same kind of information concerning his simulator performance as is normally provided by the instructor. Having such feedback under computer control can provide the following advantages:

a) The instructor is unburdened

b) Feedback is faster, more accurate, fully standardized and more certain since the hardware system used is faster and more reliable than the instructor.

c) The impersonal critique by the computer may be less damaging to the trainee's ego.

d) Under certain conditions, it may allow practice in the absence of an instructor.

However, even with sophisticated programming, computer control of feedback will lack the judgement and flexibility of a competent instructor, and may interrupt the trainee with feedback of low value while omitting more pertinent information.

This feature is found on the 2B24 (SFTS), which is used for training large numbers of helicopter pilots in instrument flight. While no separate evaluation of this feature was made, the 2B24 has proven to be a very effective training device, and audio feedback is believed to contribute to its effectiveness (Caro, 1972).

7.1.2 Techniques

7.1.2.1 Multiple Cassettes

7.1.2.1.1 Description

Each message is stored on a separate cassette, which is triggered by the computer at an appropriate time.

7.1.2.1.2 Current Usage

A system of this kind is employed in the 2B24 (SFTS) referred to earlier.

7.1.2.1.3 Characteristics - Self Evident

7.1.2.1.4 Advantages

Simplicity

Moderate Cost

Message can be reprogrammed without modification of computer program

Modest demands on computer storage

Lengthy messages possible

Messages can be of different lengths

7.1.2.1.5 Disadvantages

Only a small number of messages can be provided economically since the cost is nearly proportional to the number of messages (cassettes).

7.1.2.1.6 Prospects for Improvement

Mature technology; no significant improvement forseen.

7.1.2.1.7 Applicability to SMS

Because of the limited number of messages this technique can provide at reasonable cost, it does not appear appropriate for SMS.

7.1.2.1.8 Cost/Complexity and Risk

N/A

7.1.2.1.9 Implications

None.

7.1.2.2 Word Assemblers

7.1.2.2.1 Description

This technique stores audio in the form of discrete words or syllables, and assemblies permutations and combinations of these speech units under computer control to from the desired messages. Both optical (film) and magnetic (tape) techniques are used.

7.1.2.2.2 Current Usage

A Cognitronics unit employing this technique is employed on the ASUPT, now under development. Similar systems are being marketed by IBM, Brobeck, Metrolab, Honeywell, and Periphonics as computer output devices.

7.1.2.2.3 Characteristics

Vocabularies typically number 31 to several hundred words. Some units allow words of random times duration to be assembled; others have one or a few fixed durations.

7.1.2.2.4 Advantages

Almost unlimited number of different messages possible.

7.1.2.2.5 Disadvantages

Unnatural sounding, because words are not inflected as function of context.

Vocabulary limited.

7.1.2.2.6 Prospects for Improvement

Cost, reliability, and vocabulary size should improve.

7.1.2.2.7 Applicability to SMS

Any of the word assemblers systems would be applicable to SMS.

7.1.2.2.8 Cost, Complexity and Risk

These devices are well proven and available off-the-shelf; there is no technical risk involved. Their complexity is of the same order as many other simulator assemblies.

7.1.2.2.9 Implications

Substantial computer space is required for message generation, storage, and control.

7.1.2.3 Formant Generators

7.1.2.3.1 Description

These devices synthesize speed sounds (formants) by manipulating an analog of the human larynx.

7.1.2.3.2 Current Usage

Until recently, these devices (e.g., Vocoder) were laboratory curiousities. A commercial unit (Votrax) was recently advertised; an attempt is now under way to obtain performance data on it.

7.1.2.3.3 Characteristics

"It accepts digital commands from a variety of sources, including any computer, and converts them into completely understandable English. In fact, when programmed for the purpose, it can speak any language" (From Votrax ad in Scientific American, September 1972, pg. 165).

7.1.2.3.4 Advantages

Limitless vocabulary

More natural sounding speech

Foreign language capability

Low Cost

7.1.2.3.5 Disadvantages

Lack of experience in use of device

7.1.2.3.6 Prospects for Improvement

Improvements in performance, reliability, and price are highly probable. More important, however, will be the off-the-shelf availability of suitable programs to drive it.

7.1.2.3.7 Applicability to SMS

If a suitable program could be developed, this technique would meet SMS requirements.

7.1.2.3.8 Cost/Complexity and Risk

The device is not especially costly, and hence not overly complex; however, the computer program needed to make it work is likely to require a substantial effort.

7.1.2.3.9 Implications

As noted earlier, use of this device would impact both computer and programming requirements.

7.1.3 Tradeoffs and Recommendations

Aural feedback should be useful for procedural tasks, and for training in use of the manipulator arms. It does not appear relevant for the tracking tasks involved in control of the vehicle's flight path. A vocabulary of 200-300 words should be adequate; the size of the vocabulary needed, and other desired characteristics (e.g., variability in word duration, ease of vocabulary change) need to be determined before a procurement specification is written. The word assembler technique provides the needed capability at acceptable cost without the technical risk associated with formant generators.

7.1.4 Assumptions and References

7.1.4.1 Assumptions

None

7.1.4.2 Reference

Caro, Paul W. "Transfer of Instrument Training and the Synthetic Flight Training System". In Proceedings of the Fifth Naval Training Device Center and Industry Conference. NAVTRADEVCEN IH-206, 1972.

7.2 Visual Feedback

7.2.1 Overview

Visual feedback refers to computer generated graphic, numeric, or verbal data that provides the trainee with the same kind of information concerning his aimulator performance as is normally provided by the instructor. The advantages of having such feedback under computer control are discussed in 7.1.1. The choice of the modulity for feedback (auditory or visual) depends on the nature, complexity, and urgency of the information.

7.2.2 Techniques

7.2.2.1 Plotters

7.2.2.1.1 Description

Plotters are two types: XY, used for applications such as ground track or glide path, and XT, which provides a time history of a given parameter.

7.2.2.1.2 Current Usage

Both XY and XT are commonly used in simulators; XT recorders are used (e.g., on SFTS) for such parameters as altitude and airspeed.

7.2.2.1.3 Characteristics

Too well known to require elucidation.

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7.2.2.1.4 Advantages

Hard copy.

Background information (e.g., maps, tolerance bands) can be preprinted (or projected) and thus displayed without exercising the computer.

Inexpensive.

7.2.2.1.5 Disadvantages

Bulky

Requires maintenance, such as replenishing ink and paper, erasing glass.

Inflexible - gross changes difficult.

7.2.2.1.6 Prospects for Improvement

Mature technique - no substantial improvements likely.

7.2.2.1.7 Applicability to SMS

Could be used as ground path recorder, glide slope recorder.

7.2.2.1.8 Cost/Complexity and Risk

Modest cost/complexity, low risk.

7.2.2.1.9 Implications

Space must be provided.

7.2.2.2 Readouts

7.2.2.2.1 Description

A readout is a device that displays an alphanumeric or numeric character upon computer demand. Included in this category are segmented displays, a subset of the segments being used illuminate to form a given character; projection displays, in which one of a set of characters is projected on a rear-projection screen, liquid crystals, etc.

7.2.2.2.2 Current Usage

Such readouts are widely used at simulator instructor/operator stations as well as for other display purposes; a five digit readout in the

SFTS cockpit presents the student with information on his progress when in the adaptive training mode.

7.2.2.2.3 Characteristics

Table 7.2 (from Information Displays, May/June 72, pg. 6,) summarizes the characteristics of more types of readouts.

7.2.2.2.4 Advantages

Legibility

Easily driven

7.2.2.2.5 Disadvantages

High cost when many characters are required

Inflexibility

High ratio of panel area to display area required.

7.2.2.2.6 Prospects for Improvement

Anticipated improvements will not eliminate any of the cited disadvantages.

7.2.2.2.7 Applicability to SMS

Could provide trainee with information on a few aspects of his performance.

7.2.2.2.8 Cost/Complexity and Risk

These devices are comparatively simple and reliable, but are costly when many characters are needed, since one device is needed per character. Risk is minimal.

7.2.2.2.9 Implications

None.

7.2.2.3 CRTs

7.2.2.3.1 Description

This category includes CRTs that display alphanumerics, graphics, or both.

7.2.2.3.2 Current Usage

A CRT for student feedback is in each ASUPT cockpit. Large numbers of CRTs are used as computer outputs in a variety of applications.

7.2.2.3.3 Characteristics

Too well known to require elucidation.

7.2.2.3.4 Advantages

Versatility - Flexibility

High information content

7.2.2.3.5 Disadvantages

Space required

Legibility may be inferior to that of other displays.

7.2.2.3.6 Prospects for Improvement

Many small incremental improvements can be expected in this highly competitive field. Flat tubes may become generally available, drastically reducing volumetric requirements.

7.2.2.3.7 Applicability to SMS

CRTs may be useful in providing trainee feedback in three areas: procedures, flight data, and manipulator handling. For procedures and manipulator handling, if the amount of information to be presented is small, use of aural feedback would be preferable, since it would not require looking away from the job.

7.2.2.3.8 Cost/Complexity and Risk

The cost of CRT systems has gone down significantly in the last several years, and is now quite modest. No technical risk is involved.

7.2.2.3.9 Implications

Considerable space is required for a CRT.

7.2.3 Tradeoffs and Recommendations

A CRT system possessing both graphic and alphanumeric capability is recommended for visual feedback; it can easily perform the functions of both plotters and readouts, and has a great deal of flexibility.

7.2.4 References and Assumptions

7.2.4.1 Reference

Jacobs, Lesley D. CRT Graphics Consoles - An Aid to Selection. RADC-TR-71-61, November 1971. AD 734 247

7.2.4.2 Assumptions

None.

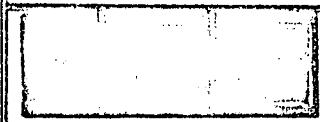
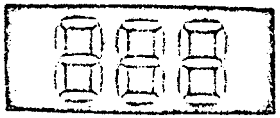
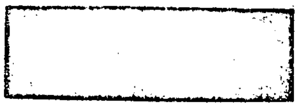
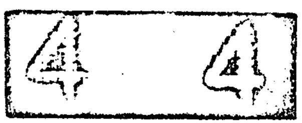
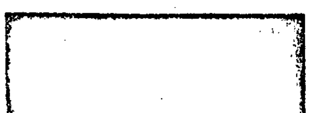
readout system		technology	intensity rise-time constant T_R [msec]	maximal intensity (asb)	letter generation	color	width to height ratio W/H (H = 24')	space between numeral positions
	a)	incandescent bulb	150	12 000	7 segments	white	0,60	1.45 · H
	b)	incandescent bulb	40	16 500	modified 7 segments dot resolved	white	0,55	1.16 · H
	c)	incandescent bulb	150	25 500	7 segments	white	0,60	0.79 · H
	d)	LED (light emitting diodes)	< 1	9	5 x 7 x-y-array	red	0,70	1.46 · H
	e)	LED	< 1	145	7 segments dot resolved	red	0,90	1.69 · H
	f)	incandescent bulb	200	295	projected arabic numerals	white	0,80	1.38 · H
	g)	glow-discharge tube	< 1	4 200	arabic numerals incandescent filaments	red-orange	0,70	2.09 · H
	h)	glow-discharge tube	< 1	2 300	arabic numerals incandescent filaments	red-orange	0,65	1.15 · H
	i)	incandescent bulb	100	330	arabic numerals dot resolved	white	0,80	1.39 · H

TABLE 1. Relevant parameters of the read-out-systems

7.3 Aural Commands

7.3.1 Overview

By aural commands is meant all aural information given to the trainee other than feedback on his performance. It thus includes mission briefings, instructions on what to do and how to do it, etc. It does not include sounds heard as a consequence of the mission itself - aural cues (Sec. 8.0) or ground communication.

7.3.2 Techniques

See Section 7.1.2.

7.3.3 Tradeoffs and Recommendations

In view of the small number of crews to be trained, it does not appear worthwhile to invest in any additional hardware for aural commands, but rather to use the hardware selected for aural feedback.

7.4 Scoring

7.4.1 Overview

By scoring is meant the sensing, processing, and display of indices of man/machine performance using the simulator computer and needed I/O devices. The indices of performance can be relatively unprocessed (e.g., location of touchdown point) or highly processed (e.g., probability of mission success). Display can be to the student, to the instructor, or to both. When given in real time, scoring is almost synonymous with aural and visual feedback; the remainder of this discussion will treat scores displayed at the completion of an instructional unit such as a mission segment. Scoring is useful not only to improve learning and motivation, but can aid in evaluating crew procedures, trainee readiness, and training program effectiveness.

There are seven basic classifications of measures useful in evaluating trainee performance:

1) Time: Measures dealing with time periods in production of performance.

2) Accuracy: Measures dealing with the correctness and adequacy of production of performance.

3) Frequency of Occurrence: Measures dealing with the rate of repetition of behavior.

4) Amount achieved or accomplished: Measures dealing with the amount of output or accomplishment in performance.

5) Consumption or Quantity used: Measures dealing with resources expended in performance in terms of standard references.

6) Behavior classification by observers: Measures dealing with classifying more complex behaviors into operationally defined subjective categories. Observations are placed into discrete classes on a continuum for the event observed.

7) Condition or state of the individual in relation to the task: Measures dealing directly with the state of the individual which describe behavior and/or results of acts that have occurred.

These classes of measures are graded on a quantative-qualitative continuum, with precise quantities (time, accuracy, frequency) at one end and more qualitative interpretations (categorization, descriptive reports) at the other. Each class or group includes a variety of subgroups and specific measures. These are listed in detail in Table 7.4.

As in other areas of psychometrics, the more objective, easier-to-obtain measures usually reflect but a single facet of the trainee's performance; more global measures tend to be unreliable, difficult to obtain, or both. In general, combinations of discrete scores are required; the task of combining separate scores into a useful overall score is often a demanding one. Since a given overall score can be achieved in a variety of ways, it is usually necessary to utilize sub-scores as well as the overall score in interpreting trainee performance.

Table 7.4

A Classification of Measures

TIME

1. Time to Initiate an Activity from the Onset of a Signal or Related Events
   - Time to perceive event
   - Reaction time
   - Time to initiate a correction
   - Time to initiate a subsequent activity (following completion of a prior activity)
   - Time to initiate a course of action
   - Time to detect trend of multiple related events
2. Time to Complete an Initiated Activity
   - Time to acquire, to lock-on, to identify
   - Time to complete single message
   - Time to complete a computational problem
   - Time to make an adjustment/manipulation/control positioning
   - Time to reach a criterion
3. Overall Time from Signal Onset to Activity Completion
   - Percent time-on-target
   - Time spent in an activity (communicating, repairing, computing, etc.)
   - Time to complete a sequence of activities
   - Build-up of time (cue length)
4. Distribution of Part Task Times in Completing an Activity
   - Time-sharing among events

ACCURACY

1. Correctness of Observation or Perception (Discrete/sequential)
   - Accuracy in identifying display readout
   - Accuracy in identifying extra-cockpit objects (environment, ground terrain, celestial navigation objects)
   - Accuracy in estimating distance, direction, speed

Table 7.4 (Cont'd)

Time estimating accuracy
Detection of a trend based on multiple related events
Detection of change in presence of noise
Correctness of observation sequence

2. Correctness of Response or Output
   - Accuracy in control positioning (pressures, direction, amplitude, rate, and duration)
   - Accuracy of in-flight maneuvers
   - Accuracy of retrofire maneuvers
   - Accuracy of intercept
   - Computing accuracy
   - Selection of action from among alternates
   - Correct symbol usage
   - Accuracy in spatial positioning (navigation)
   - Accuracy in weapon delivery
   - Accuracy in landing
3. Error Magnitude
   - Error amplitude measures
   - Error frequency measures
   - Error in bomb drop
4. Correctness of Response Sequence
   - Sequence of response
   - Sequential-manipulative accuracy (serial response, one activity; coordinated response with several controls)
5. Adequacy of Probability Estimation (Relative to an "Ideal Observer")
   - Accuracy in using unreliable information
   - Recognition of signal in noise
   - Recognition of out-of-tolerance condition

FREQUENCY OF OCCURRENCE

1. Number of Responses Per Activity or Interval
   - Number of actions made per unit
   - Number of communications per activity or interval
   - Number of adjustments to maintain in-tolerance (number of checks, replacements, problems solved)
   - Number of interactions with other members
   - Number of gross/significant errors per unit
2. Number of Defined Consequences of Performance Per Activity
   - Number of out-of-tolerance conditions
3. Number of Observing or Data-Gathering Responses
   - Number of requests for information
   - Number of interrogations/observations made
   - Number of discrete recordings/reportings made

AMOUNT ACHIEVED OR ACCOMPLISHED

1. Response Magnitude or Quantity Achieved
   - Degree or proportion of success (intercepts, information collection, weapon delivery, rescue, landing, etc.)
   - Cumulative response output
   - Written test of knowledge (scores)
2. Man-Machine System Achievement
   - Attainment of training objectives
   - Assessment of "merit" in performance (influenced by man-machine interactions)

CONSUMPTION OR QUANTITY USED

1. Resources Consumed Per Activity
   - Fuel/energy conservation
   - Units consumed in activity accomplishment
2. Resources Consumed Per Time
   - Rate of consumption

BEHAVIOR CATEGORIZATION BY OBSERVERS

1. Classifying Activities or Handling of Events
   - Impromptu response invention (improvising)
   - Communication effectiveness
   - Redundant communications
   - Emotional content of communication
   - Priority assignment to an activity or among activities
2. Overall Judgments of Performance
   - Coordination of effort/movement
   - Procedural synchronization of action
   - Relevance of response
   - Substantive content of communication
   - Intelligibility of voice report
   - Use made of available references, job information, test equipment
   - Visual-perceptual orientation
   - Crew cohesiveness
   - Quality of checks (fault location)
   - Use made of performance information available from symptons/checks/errors
   - Adequacy/goodness of behavior (gross rating of a complex performance)
   - Adherence to safety procedures (handling of equipment)

CONDITION OR STATE OF THE INDIVIDUAL IN RELATION TO THE TASK

1. Description of Behavior at Prescribed Times
   - Response perseveration
   - Anticipation of probable events
   - Alertness to events
2. Description of Condition
   - Behavioral intactness of individuals/crew
   - Physiological condition of individual/crew (life support) (by means of attachment on body surface or equipment near the body: electrocardiogram, electroencephalogram, temperature, galvanic skin response, sound at ear drum, etc.)

Table 7.4 (Cont'd)

3. Self Report of Experience
   - Report of illusory phenomena (apparent movements; quality and duration of illusory movements)
   - Protocols of experience

7.4.2 Techniques

There do not exist a plurality of scoring techniques: all scoring of the kind discussed here is performed in the same manner. Hence, the subsections under the Techniques heading will be omitted.

7.4.3 Tradeoffs and Recommendations

The provision of scoring capability is recommended to serve the purpose noted in 7.4.1.

7.4.4 References and Assumptions

7.4.4.1 References

Faconti, V., Mortimer, C.P.L.C and Simpson, D.W. Automatic Instruction and Performance Monitoring in Flight Simulator Training. AFHRL-TR-69-29, February 1970.

Society of Automotive Engineers. The Measurement of Trainee Performance in Simulators and Part-Task Trainers. Aerospace Information Report 1054, December 1968.

7.4.4.2 Assumptions

None.

7.5 Malfunction Insertion and Display

7.5.1 Overview

The simulator has long been recognized as providing a safe place for practicing how to cope with a wide variety of malfunctions. A malfunction insertion and display system should

a) display to the instructor all the malfunctions that are available for insertion. Such a display should be highly legible, and require little or (preferably) no manipulation to access any data.

b) allow selection of the chosen malfunction for insertion or removal with little or (preferably) no reference to tables, such as insertion by malfunction number.

c) allow selection with a minimum of key depressions, preferably one or two.

d) show the status of all active malfunctions in a clear way (i.e., not by malfunction number).

e) allow malfunctions to be preprogrammed to occur as a function of time or event.

f) alert the instructor when a preprogrammed malfunction is about to be inserted.

g) allow the instructor to inhibit or cancel such preprogrammed malfunctions.

h) allow modifications to be made to the malfunction <u>repertoire</u> without hardware changes (software only).

i) allow for a large malfunction repertoire

j) be compact

k) be reasonable in cost

l) be highly reliable

Current simulators use a wide variety of malfunction insertion and display system, including

a) A lighted push button switch for each malfunction

b) switches that identify the x and y positions of the malfunction name on a matrix display

c) switches that identify the particular 12 position readouts containing the name of the malfunction, and its position (1 - 12) on that readout.

d) systems in which malfunctions are inserted by number, using a table giving the number of each malfunction (display is by number also).

e) alphanumeric tabular CRTs and associated keyboards.

Of these methods, the CRT-keyboard system is so far superior to the rest that no other is worth considering.

7.5.2 Techniques

7.5.2.1 CRT - Keyboard System

7.5.2.1.1 Description

A typical CRT-keyboard system used for malfunction insertion and display is time-shared with other simulator functions, such as parameter insertion and trainee performance monitoring.

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Since all malfunctions cannot be displayed simultaneously, the instructor uses the keyboard to work through one or two levels of index pages to bring the desired malfunction to the screen, and then uses the keyboard again to select, inhibit, or preprogram the desired malfunction. Active and impending malfunctions are displayed on a dedicated portion of the CRT.

7.5.2.1.2 Current Usage

Such systems are currently employed on the Skylab Simulator, as well as on the 2F101 and ASUPT.

7.5.2.1.3 Characteristics

Typical CRTs have 20-40 lines of 80-150 characters per line. Some systems are not capable of providing as many characters on a "PAGE" as there are spaces.

7.5.2.1.4 Advantages

Flexibility

Compactness

Software modifiability

7.5.2.1.5 Disadvantages

Full malfunction repertoire cannot be displayed simultaneously. Several keystrokes are typically required to insert a malfunction.

7.5.2.1.6 Prospects for Improvement

Incremental improvements in hardware are likely. Substantial improvements in software, making possible easier accession of malfunctions, is possible.

7.5.2.1.7 Applicability to SMS

Such a system is definitely applicable to SMS.

7.5.2.1.8 Cost/Complexity and Risk

See 7.2.2.3.8

7.5.2.1.9 Implications

Integration with other CRT/keyboard needs at the IOS is needed.

7.5.3 Tradeoffs and Recommendations

A CRT/keyboard system, time-shared with other instructor/operator functions, is recommended.

7.5.4 References and Assumptions

7.5.4.1 References

None.

7.5.4.2 Assumptions

1. The number of malfunctions to be incorporated in the simulator is upwards of several hundred.

7.6 Record/Playback

7.6.1 Overview

A record/playback capability in a simulator serves two functions: it allows standardized demonstrations to be made to trainees, and it permits the trainee to examine his own performance. Both standardized demonstrations and self-confrontation have been recognized in other contexts to be valuable for training; only recently has digital simulation provided the technology that made them practical for vehicle simulators.

7.6.2 Techniques

7.6.2.1 Record Inputs

7.6.2.1.1 Description

A history of the crew's inputs to the simulator is recorded in digital form. The playback is produced by functionally disabling the control inputs from the crew station(s) and replacing them in the computer with the previously recorded inputs. The normal computational functions of the computer are exercised as if the crew were operating the simulator. The system using this technique requires programs to handle the I/O and disable the controls during playback. This necessitates running the playback program during spare computer time. Some form of bulk storage device is required. Additional hardware is required to control the system.

7.6.2.1.2 Current Usage

No known application.

7.6.2.1.3 Characteristics

See 7.6.2.1.1

7.6.2.1.4 Advantages

Straight forward technique.

7.6.2.1.5 Disadvantages

Bulk storage device needed.

7.6.2.1.6 Prospects for Improvement

None foreseen.

7.6.2.1.7 Applicability to SMS

This technique meets SMS requirements.

7.6.2.1.8 Cost/Complexity and Risk

Modest cost/complexity, little risk.

7.6.2.1.9 Implications

None.

7.6.2.2 Record Inputs and Selected Outputs and Internal Variables

7.6.2.2.1 Description

This technique is the same as 7.6.2.1. Record Inputs except that certain equation outputs are also recorded, and during playback the computed value of parameters are replaced by the recorded values at a rate that prevents errors from propagating.

7.6.2.2.2 Current Usage

Used on ASUPT, 2F101, 747

7.6.2.2.3 Characteristics

See 7.6.2.2.1

7.6.2.2.4 Advantages

Lower input rate to the computer from the recording medium.

7.6.2.2.5 Disadvantages

Somewhat more complex.

7.6.2.2.6 Prospects for Improvement

None foreseen.

7.6.2.2.7 Applicability to SMS

This technique meets SMS requirements.

7.6.2.2.8 Cost/Complexity and Risk

Modest cost/complexity, little risk.

7.6.2.2.9 Implications

None.

7.6.2.3 Record Inputs and All Outputs

7.6.2.3.1 Description

In this approach, all the outputs to the simulator are recorded in addition to the inputs. During playback, the values of the recorded inputs are used to drive selected controls, while the outputs are used to drive the displays. The computational function of the computer is bypassed. Programs are required to handle the I/O and perform the executive function. Hardware requirements are the same as for the previous technique.

7.6.2.3.2 Current Usage

None known.

7.6.2.3.3 Characteristics

See 7.6.2.3.1

7.6.2.3.4 Advantages

Little programming effort.

7.6.2.3.5 Disadvantages

Large hardware requirement.

May be difficult to match the state of the crew compartment to the internal state of the computer when shifting from playback to real time simulation.

7.6.2.3.6 Prospects for Improvement

None foreseen.

7.6.2.3.7 Applicability to SMS

This technique meets SMS requirements.

7.6.2.3.8 Cost/Complexity and Risk

Modest cost/complexity, little risk.

7.6.2.3.9 Implications

None.

7.6.2.4 Record Outputs

7.6.2.4.1 Description

The outputs driving the instruments, motion system, etc., are recorded, and then played back, bypassing the computational function of the computer.

7.6.2.4.2 Current Usage

None known.

7.6.2.4.3 Characteristics

See 7.6.2.4.1

7.6.2.4.4 Advantages

Instruments go through exact replay, without relying on recomputation for the displayed values.

7.6.2.4.5 Disadvantages

Large hardware requirement.

May be difficult to match the state of the crew compartment to the internal state of the computer when shifting from playback to real time simulation.

7.6.2.4.6 Prospects for Improvement

None foreseen.

7.6.2.4.7 Applicability to SMS

This technique meets SMS requirements.

7.6.2.4.8 Cost/Complexity and Risk

Modest cost/complexity, little risk.

7.6.2.4.9 Implications

None.

7.6.3 Tradeoffs and Recommendations

Recording inputs, together with selected internal values and outputs is the most cost-effective approach; it provides a high-fidelity playback with minimal complications because it utilizes the computer to provide selections.

7.6.4 References and Assumptions

7.6.4.1 References

Faconti, et al (sec. 7.4.4.1)

7.6.4.2 Assumptions

None.

7.7 Simulator Initialization

7.7.1 Overview

Prior to each simulator exercise, the state variables for both the simulator vehicle and its environment must be set to values appropriate for that exercise. The number of variables to be initialized in the SMS will be greater than that for current flight or space vehicle simulators, since the Orbiter operates in both atmospheric flight and space environments. Both the vehicle variables (e.g., systems status) and the environmental variables (e.g., sea level barometric pressure, ephemeris data) partake of this added complexity.

7.7.2 Techniques

7.7.2.1 Discrete Controls

7.7.2.1.1 Description

By Discrete Controls is meant having a separate control, often a knob or switch, for setting the value of each vehicle and environment parameter.

7.7.2.1.2 Current Usage

Most current simulators, require initialization to be performed parameter by parameter.

7.7.2.1.3 Characteristics

Panel space, cost of panel hardware, and time needed for initialization functions are roughly proportional to the number of parameters that have to be initialized.

7.7.2.1.4 Advantages

Simple and well understood.

Graceful degradation; failure of a control associated with one parameter does not affect others.

Controls can be customized to the particular parameter.

7.7.2.1.5 Disadvantages

When a large number of parameters need to be initialized, much panel space and instructor time is required.

7.7.2.1.6 Prospects for Improvement

Only minor improvements, comparable to the substitution of thumbwheel for rotary switches, are foreseen.

7.7.2.1.7 Applicability to SMS

The large number of parameters to be initialized in SMS makes this method very cumbersome.

7.7.2.1.8 Cost/Complexity and Risk

With the large number of parameters to be initialized, this kind of system becomes fairly costly and complex. The technique is well proven, and involves no technical risk.

7.7.2.1.9 Implications

None.

7.7.2.2. Keyboard

7.7.2.2.1 Description

This technique uses a keyboard, such as that of a teletypewriter or CRT terminal, to identify the parameter being initialized, and its value.

7.7.2.2.2 Current Usage

ASUPT, 2F101

7.7.2.2.3 Characteristics

A fixed amount of hardware, and panel space is required irrespective of the number of parameters to be set.

7.7.2.2.4 Advantages

Small amount of hardware required.

Keyboard can be time-shared with other functions.

7.7.2.2.5 Disadvantages

More effort often required to set a given parameter.

When a large number of parameters need to be initialized, considerable time and effort is required of the instructor.

7.7.2.2.6 Prospects for Improvement

Human engineering of the coding process together with improved programming will lead to a reduction in the number of keystrokes required to identify the parameter, and to perform any auxilliary functions. Where the value of a parameter is numerical (as opposed to one of a few states), one key will have to be pressed per digit.

7.7.2.2.7 Applicability to SMS

The large number of parameters to be initialized makes this a very time-consuming method.

7.7.2.2.8 Cost/Complixity and Risk

Low cost/complexity, negligible risk.

7.7.2.2.9 Implications

None.

7.7.2.3 Stored Sets of Parameter Values

7.7.2.3.1 Description

With this technique, parameters are not set one by one, but rather the simulator is initialized with a pre-assembled set of parameter values. This technique is part of the concept of Preprogrammed Missions (PM); with PM parameters modified as required during the course of the problem, switches malfunctions inserted scores obtained, etc.

7.7.2.3.2 Current Usage

ASUPT, 2F101, Skylab.

7.7.2.3.3 Characteristics

See 7.7.3.1

7.7.2.3.4 Advantages

Allows rapid initialization

Eliminates instructor error

Standardizes exercise

7.7.2.3.5 Disadvantages

Constrains instructor to set up parameter values which may not include the exact initialization conditions he desires.

7.7.2.3.6 Prospects for Improvement

None foreseen.

7.7.2.3.7 Applicability for SMS

This technique is applicable for SMS use.

7.7.2.3.8 Cost/Complexity and Risk

Low cost/complexity, negligible risk. Some effort needed to define sets of initial conditions.

7.7.2.3.9 Implications

None.

7.7.3 Tradeoffs and Recommendations

A combination of Stored Sets of Parameter Values (7.7.2.3) with the override capability of Keyboard (7.7.2.2) will provide the advantages of both approaches without any of their disadvantages.

7.7.4 References and Assumptions

None.

7.8 Setup Verification

7.8.1 Overview

Before a problem starts, it is necessary to be sure that initial conditions (sec. 7.7) are set appropriately. In addition, if the training exercise does not involve all crew stations, each of the controls at the uninvolved stations must be in a suitable position or state; it is most desirable that this be rapidly verified at the IOS.

7.8.2 Techniques

7.8.2.1 Local Verification

7.8.2.1.1 Description

With this technique, the position of each relevant switch or other control is verified by direct inspection - at the IOS for discrete initialization controls, and at various crew station locations for vehicle and system controls.

7.8.2.1.2 Current Usage

Almost all current flight simulators.

7.8.2.1.3 Characteristics

See 7.8.1.1.

7.8.2.1.4 Advantages

No extra hardware or software required.

7.8.2.1.5 Disadvantage

Time consuming.

Human error likely.

7.8.2.1.6 Prospects for Improvement

None.

7.8.2.1.7 Applicability to SMS

Applicable to SMS, but undesirable in view of its time-consuming nature.

7.8.2.1.8 Cost/Complexity

No added simulator case or complexity; some costs associated with time consumed in verification.

7.8.2.1.9 Implications

None.

7.8.2.2 Central Verification

7.8.2.2.1 Description

As the title implies, central verification provides at a single location (usually a CRT, although a TTY or other computer output device would also serve) the required information, usually, if not always, in exception form.

7.8.2.2.2 Current Usage

Skylab.

7.8.2.2.3 Characteristics

Prior to the beginning of an exercise, one of the CRT pages of the Skylab IOS displays, in tabular form, the identity and state of controls not in the appropriate state for that exercise.

7.8.2.2.4 Advantages

Speed of verification.

Unburdening of instructor.

High reliability of operation.

7.8.2.2.5 Disadvantages

Requires access to CRT.

Requires programming.

7.8.2.2.6 Prospects for Improvement

Minor improvements are in prospect for human-engineering the CRT display and its call-up, and for programming verification more efficiently.

7.8.2.2.7 Applicability to SMS

Very appropriate for SMS.

7.8.2.2.8 Cost/Complexity and Risk

Modest cost/complexity, negligible risk.

7.8.2.2.9 Implications

None.

7.8.3 Tradeoffs and Recommendations

A system, similar to that of the Skylab Simulator for setup verification, is recommended. Such a system, using a CRT, should be human-engineered for easy call-up of needed data, and reading and interpreting the data with minimum effort.

7.8.4 References and Assumptions

7.8.4.1 References

None.

7.8.4.2 Assumptions

A significant amount of training will occur with one or more crew station unmanned, but still in the simulation loop.

7.9 Fast - and Slow-Time

7.9.1 Overview

In an extended mission of the kind the Shuttle will accomplish, certain periods of time will contain flurries of activity, while other periods will require little or no crew activity. When things are happening very fast, it may be of considerable training value to slow the action so that the inexperienced trainee can get a better handle on it. When things are happening very slowly, or not at all, training time can be saved by simulating such arid expanses in fast time, or by skipping or jumping time.

7.9.2 Techniques

7.9.2.1 Fast Time

7.9.2.1.1 Description

Running an exercise at fast time requires either performing more computational iterations per second (upping the iteration rate), or else integrating over a longer time period per iteration (using the normal iteration rate). The former is almost impossible, since simulator computers are invariably working near capacity, and it would be quite costly to size a simulator computer so that it loafs during normal simulation in order to allow capacity for it to run fast time.

Having the computer, during each of a smaller number iterations, perform integration over a longer time period, cannot produce the same result as a larger number of iterations each of which covers a shorter time interval. Errors due to inferior curve fitting and rounding off will degrade such fast time results.

7.9.2.1.2 Current Usage

None identified.

7.9.2.1.3 Characteristics

See 7.9.2.1.1.

7.9.2.1.4 Advantages

See 7.9.1.

7.9.2.1.5 Disadvantages

See 7.9.2.1.1.

7.9.2.1.6 Prospects for Improvement

As computation becomes cheaper, it may become economically feasible to procure a simulator computer whose speed is geared to fast-time simulation.

7.9.2.1.7 Applicability to SMS

Because of the integration errors, fast-time will not be applicable for SMS.

7.9.2.1.8 Cost/Complexity and Risk

Not applicable.

7.9.2.1.9 Implications

Not applicable.

7.9.2.2 Jump-Ahead

7.9.2.2.1 Description

Jump-ahead is concerned with rapidly updating simulator state to a given time or position, without regard for intermediate values.

7.9.2.2.2 Current Usage

Skylab Simulator.

7.9.2.2.3 Characteristics

With jump-ahead a limited number of parameters is affected, typically those parameters involving time, location, and quantity of consumables. No training takes place until the jump-ahead process is completed.

7.9.2.2.4 Advantages

Periods of little training value are bypassed.

No significant computational anomolies are introduced.

7.9.2.2.5 Disadvantages

None.

7.9.2.2.6 Prospects for Improvement

None foreseen.

7.9.2.2.7 Applicability to SMS

Desirable and feasible for SMS.

7.9.2.2.8 Cost/Complexity and Risk

Low cost/complexity; low risk. Integrations are more complex than on Skylab, involving atmospheric, in addition to space flight.

7.9.2.2.9 Implications

None.

7.9.2.3 Slow Time

7.9.2.3.1 Description

Slow time computation is accomplished by integrating solutions on every nth iteration, rather than on every iteration, as is normally done.

7.9.2.3.2 Current Usage

Skylab Simulator.

7.9.2.3.3 Characteristics

Simulation proceeds at 1/nth the normal speed.

7.9.2.3.4 Advantages

For some control tasks, there may be some advantage in being able to practice under the easier, slow time conditions. During replay, it may be easier to spot and analyse mistakes. Slow time can also make program debugging easier.

7.9.2.3.5 Disadvantages

None.

7.9.2.3.6 Prospects for Improvement

None foreseen.

7.9.2.3.7 Applicability to SMS

Desirable and feasible for SMS.

7.9.2.3.8 Cost/Complexity and Risk

Low cost/complexity; negligible risk.

7.9.2.3.9 Implications

None.

7.9.3 Tradeoffs and Recommendations

Jump-ahead and slow time are desirable and feasible for SMS. A capability in these areas similar to that of the Skylab Simulator would be satisfactory.

7.9.4 References and Assumptions

None.

8.0 Aural Cue Simulation

8.1 Vehicle Sounds

8.1.1 Overview

In the present context, vehicle sounds refers to all inadvertent sounds generated by the vehicle and its equipment. This includes sounds of engines, hydraulic pumps, power units, landing gear, air noise, tire screech and all other sounds of this type.

Computer controlled sound generation represents the traditional technique of simulating characteristic vehicle sounds. There are some recent variations in this time honored technique, one of which is computer synthesis of the desired audio wave form.

Certain aspects of the available techniques are common to all and indeed will probably be common to future techniques. These common considerations are the establishment of the parameters and characteristics of the sounds to be simulated and the design of the transducer system which is driven by the audio generation equipment.

Once the source of the sound has been established (what vehicle, what engine, what equipment, etc.), it becomes necessary to acquire data about the sound. In order to achieve the best fidelity, a recording of the sound should be obtained and the actual sound source should be listened to by several observers. Obviously, care must be taken in making the recordings and notes should be made as to impressions obtained by the aural observations.

In theory, it is possible to analyze the recording by means of various equipment, physical data about the sound source, the characteristics of the recording/playback equipment, and by critical (and repetitive) listening. In general, the less data obtained by electronics and mathematical means, the greater the burden that is placed upon the listening. Probably the worst case from the viewpoint of analysis by equipment is where the "cocktail party effect" exists. (See Journal of the Acoustic Society, Vol. 32, No. 7 July 1960, C. Cherry, J. Bowles, Study of Cocktail Party Problem). This effect results from the simultaneous occurrence of a number of different sounds. This is due to the fact that real systems require the simultaneous functioning of several sound producing subsystems to fulfill the overall system function. For example, airplane engine noise, aerodynamic noise, and airframe vibration noise occur together to fulfill the flying function. It is extremely difficult to separate one particular sound of interest for analysis from all the others by means of analyzers. This is usually because the spectrums of the many sounds completely overlap each other. Fortunately, most individuals (to varying degrees) are capable of listening to one conversation while effectively "tuning out" the background conversations. This ability is, of course, affected by the relative intensities of the wanted and unwanted conversations, but is remarkably efficient, especially when enhanced by the repetition allowed by tape recordings.

It is often possible to establish criteria for some of the required sounds without having really adequate data. This of course hinges on assumptions which relate the desired sound to sounds of known characteristics. If this is done, however, the simulated sound system must be extremely flexible so as to accommodate the almost certain changes that will result when adequate data becomes available. This has been a key influencing factor in the development of sound simulation systems. The obvious ultimate goal is a system which can simulate any sound without requiring hardware modification.

The transducer system, in the present context, refers to the equipment which performs the conversion from electrical to acoustical signals. The design of the system consists primarily of selecting the types of transducers required and their physical placement in the trainer compartment. The design of the transducer system largely establishes the maximum simulation fidelity the overall system will be capable of producing.

Selection of the types of transducers in effect sets the limits on the sound quality. Traditionally, the transducers have been loudspeakers. The recent trend, however, is toward structurally mounted sound transducers which in effect use the simulated vehicle hull as a sounding board. This has the advantage of coupling sub-sonic components into the controls, seats, panels, etc. providing "feel" of the sounds. In some applications combinations of conventional loudspeakers and sound transducers are used. Determination of their locations sets the limits for the simulation of directionality. The importance of the latter consideration is often underrated but in fact simulation of the directional characteristics of an aural cue is as important as the sound quality of the cue. The design goal is a layout which will facilitate generation of a 3 dimensional sound environment. This will, in general, require a minimum of 6 transducers for a high quality system. As an aid to visualizing this, consider a typical "sterographic" sound reproduction system. The illusion of directionality is created by the relative amplitudes of sound coming from the two loudspeakers. The apparent sound source will lie on a line connecting the two speakers. Extension of this by one step leads to the "quadraphonic" system now in vogue with hi-fi buffs. Four sound sources are used and the system is capable of creating an apparent source anywhere on the plane defined by the real sources. Further extension to 8 real sources provides the capability of generating an apparent source anywhere in the cube defined by the sources. Mechanical configuration often makes the use of 8 sources difficult in a vehicle simulator, however, and a compromise system using 6 sources will probably be adequate. In fact, good results have been obtained using four sources in a non-planar arrangement. It should be noted that the transducer system must be a consideration in the basic design of the cockpit or trainer compartment. Failure to observe this rule will result in the transducers being placed where space permits rather than being an integral part of the cockpit and the resulting sound system cannot be expected to give best results.

8.1.2 Techniques

8.1.2.1 Traditional Approach

8.1.2.1.1 Description

Basically this approach can be viewed as the use of a group of hardware subsystems each generating one of the required simulated signals. The outputs of the subsystems are combined appropriately and used to drive the transducers. Thru a process which can best be described as evolutionary, it has been established that the overwhelming majority of sounds that must be produced in a simulator can be generated by the use of relatively few standard modular circuits. Subsystems based on this modular concept have also evolved to a point where few sounds fall outside the area of previous experience.

In general, the hardware subsystems can be designed in such a way that a reasonable range of change in the end result sound can be accomplished by modifying the simulator software which controls the hardware system. With this technique, however, the system design emphasis is definitely in the hardware area.

A subsystem typical of this approach is shown in Fig. 8.1.2.1.1.

8.1.2.1.2 Current Usage

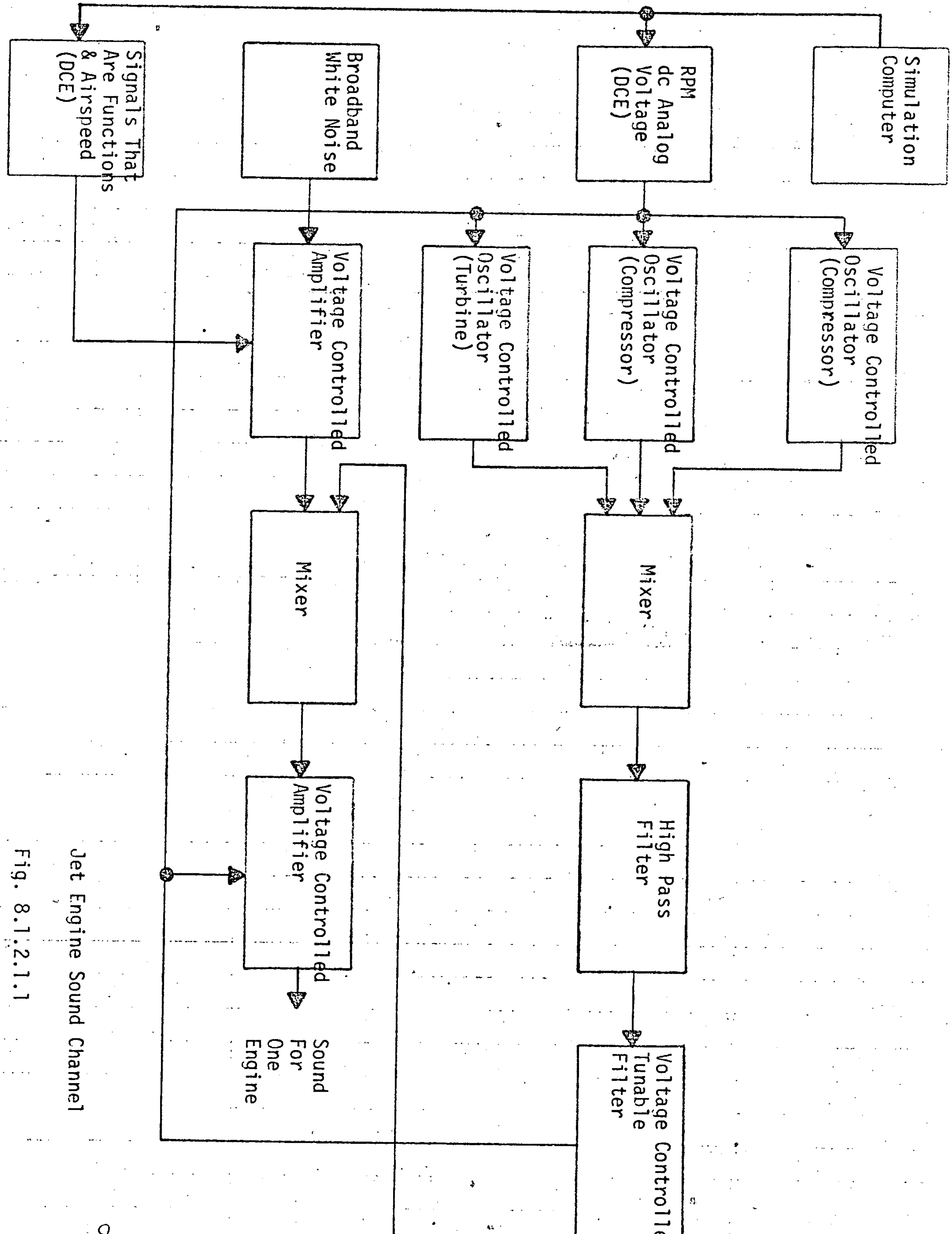
This technique has been used on nearly all flight simulators.

8.1.2.1.3 Characteristics

Detail characteristics depend on the actual hardware configuration but in general this technique can produce aural cues thru the entire audio spectrum including sub and super sonic components.

8.1.2.1.4 Advantages

The straight forward nature of this approach is a distinct advantage. It is easily understood by design, test, and maintenance personnel. The modular



Jet Engine Sound Channel

Fig. 8.1.2.1.1

nature of the system makes it possible to design the system from a varied data base. That is to say, the data for each sound may be of different form. A further advantage of this technique is its proven performance.

8.1.2.1.5 Disadvantages

The dependence of this approach on specifically designed hardware tends to make the implementation of major changes cumbersome. The complexity of the hardware increases at least linearly with the number of different sounds simulated. New circuit design is typically required in designing a system for a new vehicle. On occasion the cost of quality simulation of a sound is such that compromises must be made.

8.1.2.1.6 Prospects for Improvement

Since this technique has evolved over a period of perhaps twenty years, it is doubtful that vast improvement can be made.

8.1.2.1.7 Applicability to SMS

This technique is fully applicable to SMS.

8.1.2.1.8 Cost/Complexity and Risk

Risk is minimal using this approach. No new technological breakthroughs are required. The technique has been used on a wide range of vehicle simulators. The hardware complexity for a system for SMS can be approximated as one full electronics cabinet. DCE would be of the order of 30 D/A channels and 20 D/O bits.

8.1.2.2 Poly-Voice*

The Poly-Voice Sound System is a real time acoustic effects generator particularly suited to the production of computer controlled sound effects. Although specifically designed with aircraft flight simulation in mind, the unit is capable of synthesizing almost any sound that can be math-modeled within the limitations of the controlling computer.

The system is a multichannel synthesizer that simultaneously responds to

*Pat. applied for.

multiple time dependent math models. Each event to be synthesized is generated by producing acoustic signals characteristic of the proper frequency (pitch), intensity (loudness), timbre (sound color or wave shape), density (energy or events per unit time), and timing. Both transient and steady-state acoustic phenomena can be generated.

While Poly-Voice has a strong family resemblance to the traditional system, it is different in several significant respects. A single channel can be time-division-multiplexed. That is to say that the same channel is capable of producing a variety of different sounds at different times. Of course there is still the restriction that the number of channels must equal the number of unique sounds which must be generated simultaneously. Even so, the number of sound generation channels is small compared to a traditional system. A typical commercial or military simulator would require four separate channels. SMS will probably require six.

Generation of the directional aspect of aural cues is another important standard feature of Poly-Voice. While this could be incorporated into other sound system designs, it has not been done previously.

An overall block diagram is shown in Fig. 8.1.2.2.

8.1.2.2.1 Current Usage

AJ-37 Weapon System Trainer

Advanced Simulator for Undergraduate Pilot Training

DLH-727 Commercial Airline Simulator

8.1.2.2.2 Characteristics

Tone Parameters

Frequence	0.25 Hz to 20 KHz
Control Voltage	0.2 to 10 volts
Control Voltage Freq. Response	140 Hz

B

Noise Parameters

Special Weight Control Range (3db)	60 Hz to 112 KHz
Control Voltage	.2 to 10 volts
Control Voltage Freq. Response	140 Hz

8.1.2.2.3 Advantages

The technique uses hardware which is extremely versatile. This places the system design and implementation effort primarily in the software area. This also facilitates the handling of modifications over a wide range without hardware changes. Because of the flexibility of this approach, it is possible to provide fidelity simulation in areas where the cost increment of a conventional system of equal performance would be unjustifiable. Since unique hardware is not required for each sound the total amount of hardware is less than a conventional system would require.

The number of different circuit module types is reduced with Poly-Voice, which is an advantage from a logistics support viewpoint.

8.1.2.2.4 Disadvantages

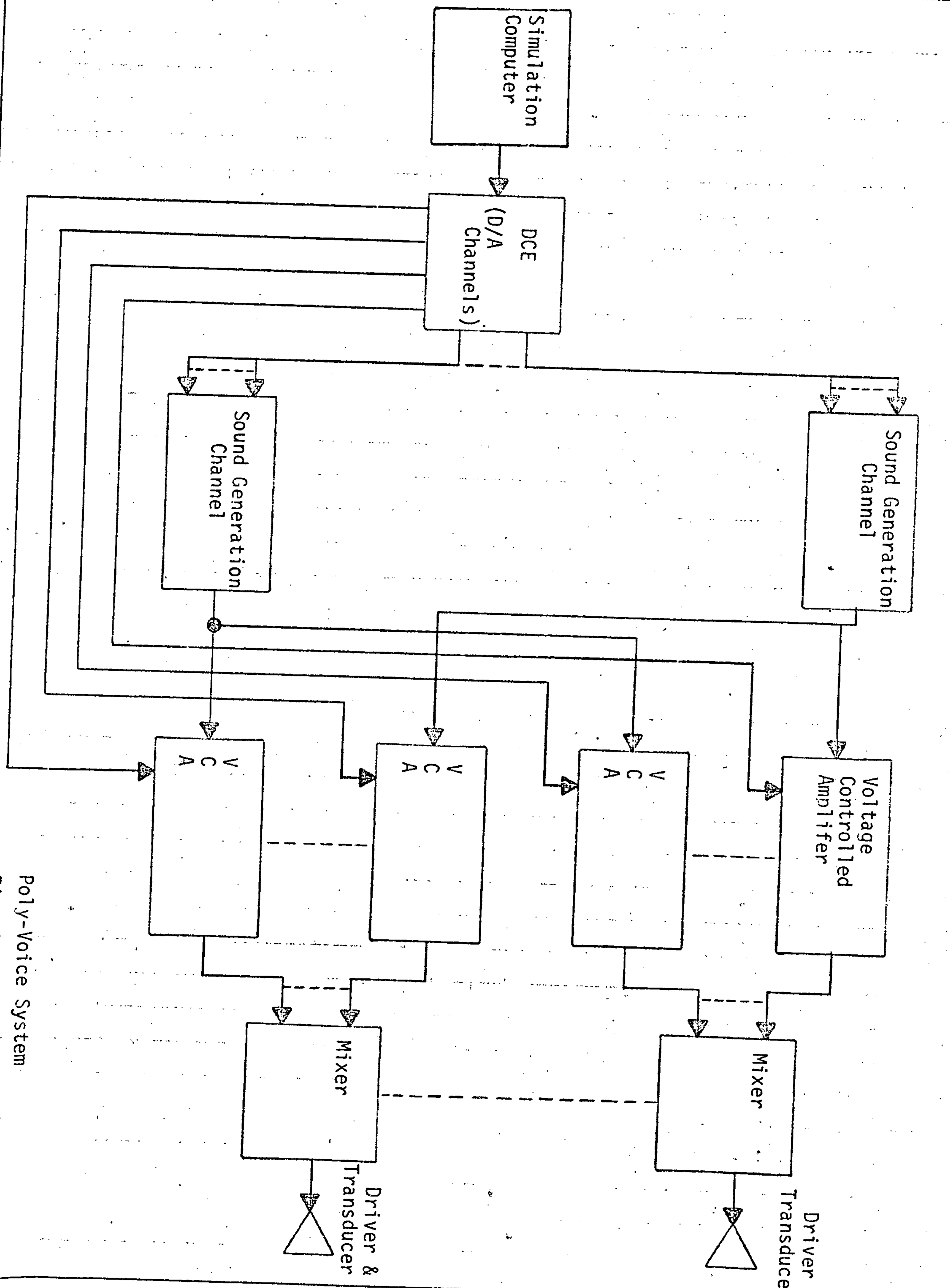
This system is not as straight forward as one based on the traditional approach, which means it is not as easily understood by design, test and maintenance personnel. More extensive software and more DCE is required to implement this approach than the traditional approach.

8.1.2.2.5 Prospects for Improvement

Since this technique is relatively new, improvement should be anticipated. Improvement is most likely in the area of software efficiency. Performance vs. cost improvement is probable based on experience to date.

8.1.2.2.6 Applicability to SMS

This technique is fully applicable to SMS.



Poly-Voice System
Fig. 8.1.2.2

8.1.2.2.7 Cost/Complexity and Risk

Risk using this technique is minimal despite its newness. Usage has been sufficient to preclude the chance of serious deficiencies appearing. A system for SMS utilizing this technique would require approximately one-half an electronic cabinet in hardware complexity. DCE requirements would be approximately 40 D/A channels.

8.1.2.3 Time Domain Waveform Synthesizing Method (Pat. No. 3,676,565)

8.1.2.3.1 Description

This technique represents a radical departure from the traditional approach. Simulation computation is performed in the frequency domain. Frequency data is broken down into groups and each group processed through an inverse Fourier or fast Fourier transform to obtain time domain data which is then processed by special purpose digital hardware. The resulting composite digital information is then passed through a digital to analog converter to provide an analog time domain waveform. The above process must be done independently for each transducer. In summary, the desired spectral density of the output of each transducer is computed in real time. Further standard computation combined with special purpose hardware produces a time domain signal or waveform which is used to drive the transducer.

8.1.2.3.2 Current Usage

This approach is under development for use in ASW (Anti-Submarine Warfare) simulation, notably the S-3A WST.

8.1.2.3.3 Characteristics

Characteristics are determined by the detail design. This technique has been shown capable of precise simulation of sounds with spectral components from .01 HZ to 20 KHZ.

8.1.2.3.4 Advantages

Hardware design, with this approach, can be completely independent of the sounds to be simulated. This is a two-fold benefit. All changes or modifications can be accomplished with software. In original simulator design, the hardware can be defined with minimal system analysis. This has significant schedule advantages. Simulation fidelity is strictly a function of the sophistication of the software.

8.1.2.3.5 Disadvantages

Data for the simulation should be in the form of spectral density. Data in this form may be difficult or even impossible to obtain. This may not be too serious if the data can be analyzed with respect to spectral density.

The real time computation load imposed by this technique is large. Indeed, a dedicated high-speed mini-computer in addition to the dedicated digital and digital-to-analog hardware may be required for each transducer to maintain the high I/O rates required. The programming effort in implementing this approach for SMS application would be extreme.

8.1.2.3.6 Prospects for Improvement

Due to the developmental nature of this approach, the prospects for improvement are difficult to assess, particularly for SMS application.

8.1.2.3.7 Applicability to SMS

The applicability of this technique to SMS is doubtful. Its application would constitute a development program in itself.

8.1.2.4 Tape Playback

8.1.2.4.1 Description

A continuous loop of tape (or in some cases a magnetic disc or drum) is played on command. This would constitute a subsystem in a system conforming to the traditional approach.

8.1.2.4.2 Current Usage

AMS booster sound.

8.1.2.4.3 Characteristics

Characteristics are determined by the detail design. The limitations are self evident.

8.1.2.4.4 Advantages

This approach permits the direct recording of the desired aural cue.

8.1.2.4.5 Disadvantages

Aural cues of a varying nature cannot be adequately simulated. The electro-mechanical nature of the equipment is a reliability/maintenance detriment. If the actual aural cue is not readily recordable, generation of the tape becomes a problem. Flexibility (ease of modification) is restricted which is a severe disability on any new vehicle simulation program.

8.1.2.4.6 Prospects for Improvement

Reliability/maintenance is the only area susceptible to improvement.

8.1.2.4.7 Applicability to SMS

None at this time.

8.1.3 Tradeoffs and Recommendations

The most attractive approach to vehicle sound simulation at this time appears to be the Poly-Voice technique. Initial cost should be lower than for any other technique and updates and modifications will involve primarily software changes. Simulation fidelity using this approach should be more than adequate in SMS application.

8.1.4 References and Assumptions

It has been assumed that the following are representative of the vehicle sounds which will be simulated in the SMS.

Speed brake deployment

Air noise (including air nose changes due to speed brakes, landing gear, and flaps)

Hydraulic Motor hum (controls)

Pyrotechnic separators

Fuel and oxidizer venting

Separation

Pressurization sys.

Air conditioning sys.

Reaction control thruster jets

Drag chute

Electrical generators

DC motors

Auxillary power units

Docking

Hydraulic actuators

Air breathing engine (including deployment & start)

Main rocket engine

Solid rocket motors

Hull noises (turbulence & buffeting)

Landing gear

Tire vibration

Tire screech

Reference:

Sound Generator Handbook SSPD-SSO

Patent 3,676,565 11 July 72 - Time Domain Waveform Synthesizing Method

Sound Systems - Brian Lynch SSPD-FSO

Commercial Poly-Voice Aircraft Sound System - Wavetek

Abstract - AJ-37 Flight Simulator Sound System
Neil McCanney SSPD-FSO

8.2 Avionics Sounds

8.2.1 Overview

Avionics sounds are those which are generated electronically in the actual vehicle. This includes all tones, station identification keying, voice communication, warnings and the like which are heard over speakers and headsets.

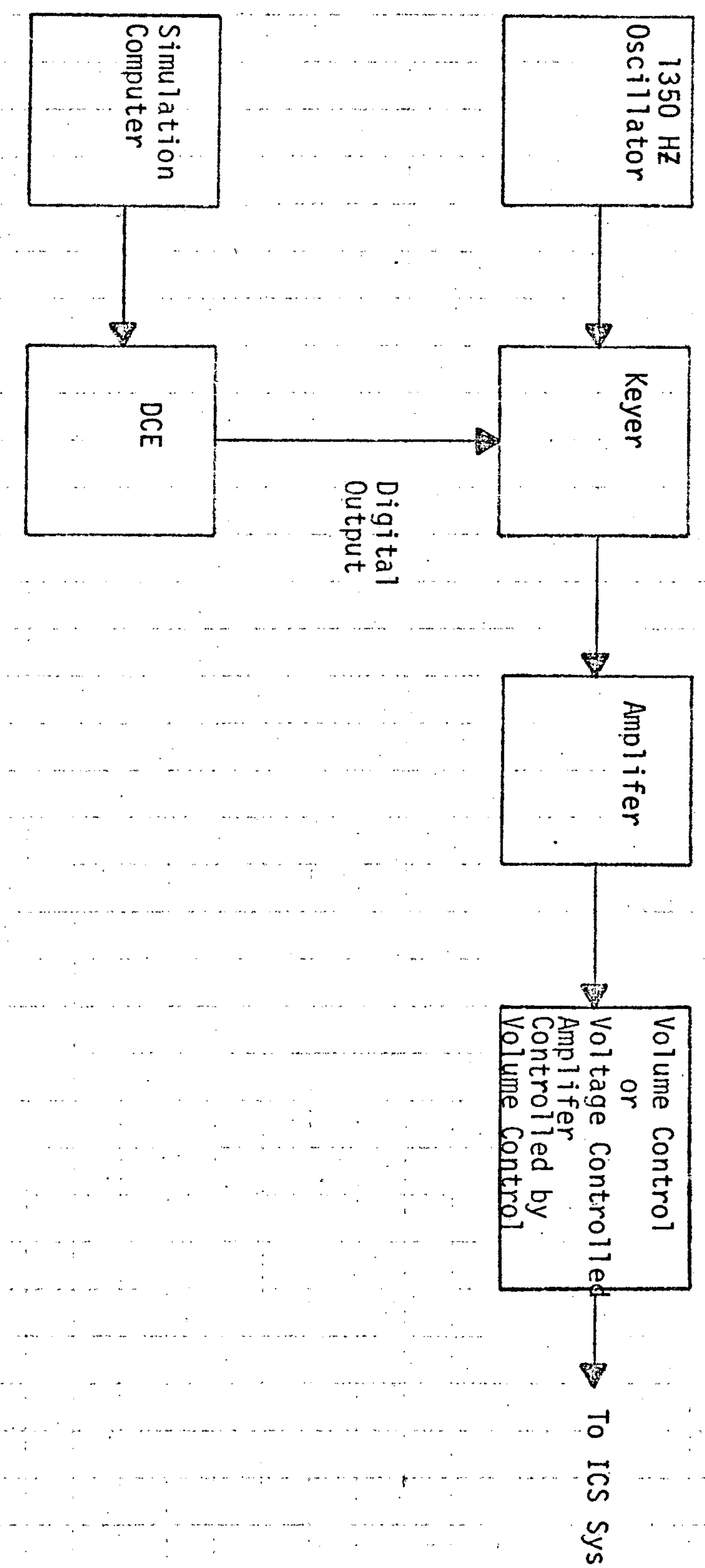
Computer controlled sound generation has been the historical method in this area of simulation for all sounds except voice communication. Two-way voice communication requires and will probably continue to require a human operator playing the part of the remote communication station. Tape playback techniques have been used to provide simulation of one-way voice communication such as VOR voice identification, A transmissions (scheduled weather broadcasts), AB transmissions (continuous weather broadcasts), and ATIS's (Air Traffic Information Station). Recent developments in the field of computer interface equipment indicate the feasibility of computer generated speech techniques which could replace tapes.

8.2.2 Techniques

8.2.2.1 Computer Controlled Sound Generators

8.2.2.1.1 Description

This technique differs only in detail from the "Traditional Approach" " of vehicle sound simulation covered in 8.1.2.1. Oscillators, keyers, attenuators and the like are combined to create hardware subsystems which under computer control via DCE generate the required signals. Those signals are then routed to



Tacan Ident. Subsystem

Fig. 8.2.2.1.1

8-15

F-398-8-A

the appropriate speakers and headsets. Figure 8.2.2.1.1 shows a typical subsystem.

8.2.2.1.2 Current Usage

This technique has been used on essentially all flight simulators.

8.2.2.1.3 Characteristics

Characteristics are determined by the detail design. This technique is fully capable of simulation of avionics sounds to real world tolerances.

8.2.2.1.4 Advantages

The approach is straight forward. It is a well-developed technique which, with the exceptions of ECM and ASW simulation, which are not applicable to SMS, has proven to be quite adequate. The standard nature of many of the avionics sounds permits carryover from previous designs.

8.2.2.1.5 Disadvantages

An apparent disadvantage is the complexity of the necessary hardware. In general, however, the hardware required is a small increment to that required to handle the voice communication problem and is easily integrated with the latter.

8.2.2.1.6 Prospects for Improvement

Improvement of this technique will primarily be in the area of exploiting the newer electronic devices such as FET gates, IC multipliers, and the like.

8.2.2.1.7 Applicability to SMS

This technique is fully applicable to SMS.

8.2.2.1.8 Cost/Complexity and Risk

Risk with this technique is essentially zero. Any sound which is generated electronically in a vehicle can certainly be generated electronically in a simulator. Cost and complexity are hard to estimate as both the hardware and software required are typically integral parts of larger systems and are not meaningful when isolated.

8.2.2.2 Tape Playback

8.2.2.2.1 Description

Tape playback has been used as a means of simulating the voice transmissions of radio stations where these transmissions are of a non-interactive nature. These implementations have been basically of two types. Some systems use a combination of both types.

One scheme utilizes multiple tape playback units. One tape unit is used per message. The units are of a type in which the tape is positioned at the beginning of the message, either by means of rapid rewind to a cue mark or by means of loop which continues to a cue mark. Computer control starts the appropriate tape unit at the appropriate time and further computer control gates the tape unit output to the appropriate channel of the avionics audio system.

The other variation employs a master tape (or drum or disc) which is searched under computer control for the desired message. The message is then transferred to a slave tape unit to free the master unit for further searches. The number of slaves required is a function of the number of messages the crew can hear simultaneously (typically two).

8.2.2.2.2 Current Usage

These techniques have been used on several commercial simulators (L-1011, 727, 747, etc.) and on the E-2C Tactics Trainer.

8.2.2.2.3 Characteristics

Characteristics are determined by the detail design.

8.2.2.2.4 Advantages

Tape playback offers good simulation in some applications as noted.

8.2.2.2.5 Disadvantages

Tape playback is an expensive approach. It involves a large amount of expensive hardware. Flexibility is limited. Quality tape equipment is subject to constant model changes, making it often impossible to obtain the same model even a year later.

8.2.2.2.6 Prospects for Improvement

Material improvement of this approach is unlikely.

8.2.2.2.7 Applicability to SMS

Applicability is contingent on the tuning range of the VHF Communication equipment used in SMS. It is further contingent on SMS simulator requirements definition.

If these considerations mandate simulation of any of the voice communication situations which tape playback can handle, then the technique is applicable.

8.2.2.2.8 Cost/Complexity and Risk

Risk in using this technique is probably low despite problems that have been encountered in the past. The equipment tends to be bulky and these systems have required full double electronics cabinets.

8.2.2.3 Computer Controlled Voice Synthesis

8.2.2.3.1 Description

Recently developed techniques permit voice synthesis under computer control. One device that has just become available simulates electronically the human speech apparatus. Input to the device is digital data representing the phonemes which are desired in the vocal output. Output is an electrical signal which can then be interfaced to any audio distribution/transducer system. Application of the device involves essentially the same computer techniques required to output text on typewriters. In this case, however, the alphabet is one of phonemes instead of type symbols. The device contains an internal digital data buffer which operates on a first-in/first-out basis. This facilitates the computer interface by making the computer output timing less critical. A block diagram of this approach is shown in Figure 8.2.2.3.1.

8.2.2.3.2 Current Usage

This technique has not yet been used in flight simulation.

8.2.2.3.3 Characteristics

Input: Serial or parallel digital data

8 bits/phoneme two of the 8 bits establish

Inflection

Serial computer interface conforms to RS232

Parallel computer interface TTL compatible

Data rate required - 300 baud

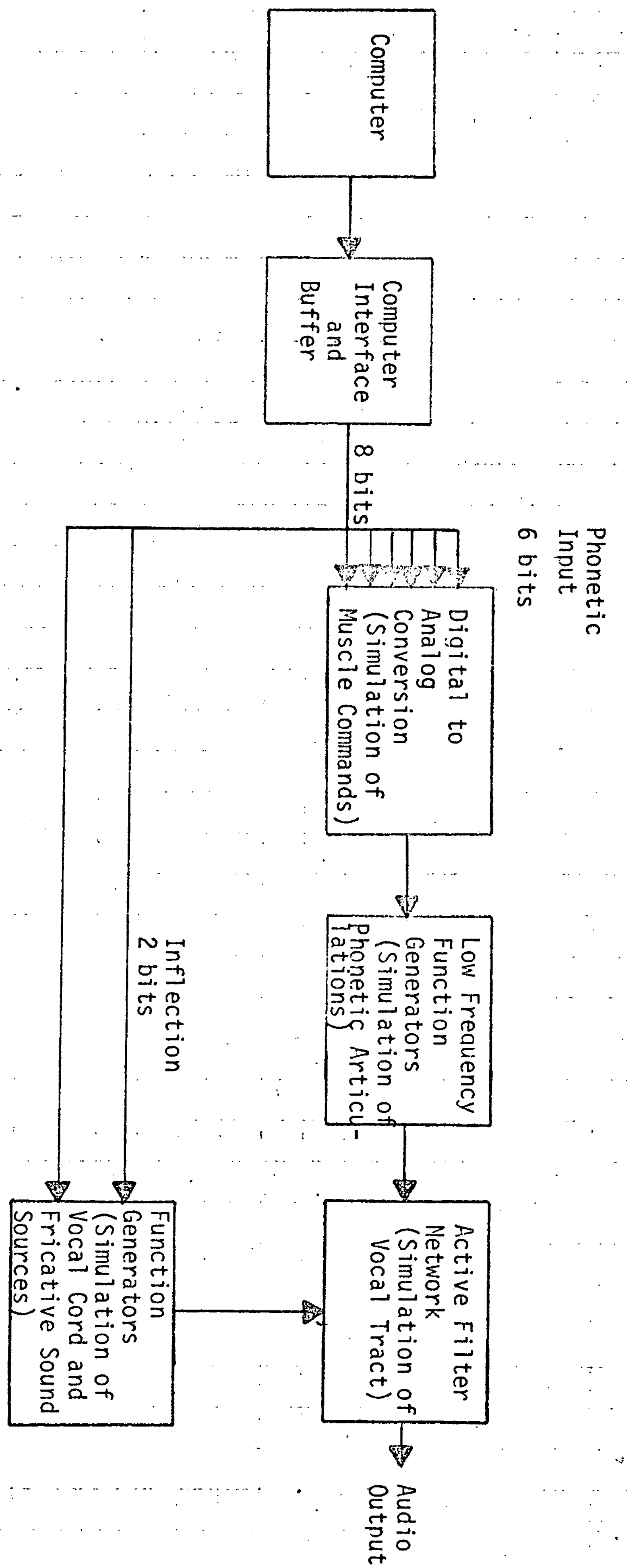
Output: Electrical signal representing human speech.

8.2.2.3.4 Advantages

This approach has marked advantages vice tape playback. Flexibility in terms of number of messages and timing is greater. The amount of hardware is greatly reduced and the hardware is of a type which is inherently more reliable.

8.2.2.3.5 Disadvantages

Messages must be programmed instead of being directly recorded. A phonetic keyboard, including its own computer interface, is available to facilitate this effort.



Voice Synthesis
Fig. 8.2.2.3.1

8.20

8.2.2.3.6 Prospects for Improvement

Due to the newness of this approach, this is unknown.

8.2.2.3.7 Applicability to SMS

Applicability is contingent on the same factors as tape playback.

8.2.2.3.8 Cost/Complexity and Risk

Since this technique has not yet been used, there is risk. Evaluation of the device will doubtless have been made for other applications prior to the design of SMS.

8.2.3 Tradeoffs and Recommendations

If a requirement develops for voice simulation, computer controlled voice synthesis should be explored in depth as it is potentially a better technique than tape playback.

8.2.4 References and Assumptions

Computer controller voice synthesis

VOTRAX®, Vocal Interface Div., Federal Screw Works, Detroit Michigan.

9.0 IOS Hardware

The purpose of the IOS is to support the instructional functions of simulator and problem setup and control including setting environment and vehicle states; malfunctions; monitoring trainer performance; and briefing, coaching, and debriefing of trainees.

9.1 Placement of IOS

9.1.1 Overview

Inasmuch as the Orbiter engages in both atmospheric and space flight, the placement of the SMS IOS is governed by considerations relating to both transport type aircraft and spacecraft. The analogy with transport aircraft simulation holds both for the cockpit configuration and many flying tasks, especially those associated with approach and landing, and with ferry flight, and with the high experience level of the trainees. However, there are significant differences between transport pilot and SMS pilot training, both in the numbers of crewmen to be trained and in the economics of the training enterprise. Extrapolation from previous spacecraft training experience must also be done with care, not only because of the aircraft-like training component just mentioned, but also because of the number of crews to be trained, a number larger by far than on earlier space programs.

9.1.2 Techniques

9.1.2.1 Remote IOS

9.1.2.1.1 Description

By a remote IOS is meant one from which the instructor cannot see the trainee(s) nor any of the displays and controls at the crew station.

9.1.2.1.2 Current Usage

Remote IOS's have been used in all U.S. spacecraft simulators to date, as well as in simulators for tactical fighter aircraft, such as the F-4 and F-111.

9.1.2.1.3 Characteristics

Remote IOS's do not intrude on the crew area, the crew stations of the vehicles whose simulators have remote IOS's almost invariably cannot fit an IOS near the crew without greatly distorting the crew station environment. Being remote, these IOS's require a host of "repeaters " of crew station displays and control positions to enable the instructor to follow the training problem.

9.1.2.1.4 Advantages

Realism of simulator crew station environment, undisturbed by instructor intrusion.

IOS design not constrained by space limitations.

IOS displays optimized for instructional functions.

9.1.2.1.5 Disadvantages

Extra hardware needed for "repeaters".

Instructor cannot see trainee's actions directly (CCTV can make up for part of deficit).

9.1.2.1.6 Prospects for Improvement

The improvement of interactive CRT systems promise to provide the remote instructor with better information and easier problem control.

9.1.2.1.7 Applicability to SMS

Remote IOS's are feasible for instructors relating to all crew positions.

9.1.2.1.8 Cost/Complexity and Risk

The technology of remote IOS's, while in rapid evolution due to improvements in CRT systems and other IOS elements, is nevertheless a well developed one, with low technical risk. As the capability required of the IOS is increased, its cost and complexity can constitute a significant fraction of the total simulator.

9.1.2.1.9 Implications

Floor space must be allocated to remote IOS's.

9.1.2.2 Fixed IOS Near Crew Station

9.1.2.2.1 Description

This kind of IOS provdes the instructor with a direct view of the student's instruments and controls, so that "repeaters" are not required, except in unusual cases, i.e., if the student's body occults the instructor's view. The IOS contains controls and associated displays for problem control, malfunction insertion, and the like.

9.1.2.2.2 Current Usage

Most simulators of transport aircraft, both commercial and military, employ fixed IOS's near the crew station; the flight instructor is usually located behind the left hand seat, in a position analogous to that of the jump seat used by instructor or check-pilots in the aircraft.

9.1.2.2.3 Characteristics

Since limited space is available, IOS design emphasizes efficient utilization of space. The positioning of the instructor seat to provide direct viewing of trainee instruments and controls can be critical.

9.1.2.2.4 Advantages

"Repeaters" not required.

Instructor's physical presence makes training more personal.

Instructor can see trainee reaching for control, in addition to observing results of control action.

Instructor experiences motion cues.

9.1.2.2.5 Disadvantages

Instructor, being at greater than designed viewing distance from instruments, may have a hard time reading them. Trainee's body may occult critical instruments from instructor's view.

Instructor may be outside best viewing envelope for visual system.

Instructor may have hard time inserting malfunctions unobtrusively.

Simulator motion may interfere with instructor's reading of displays, taking control action.

Instructor cannot enter and egress while motion is "on".

9.1.2.2.6 Prospects for Improvement

Progress in miniaturization and packaging of CRT systems promises a modest decrement in the intrusiveness of this kind of IOS.

9.1.2.2.7 Applicability to SMS

This kind of IOS is certainly feasible for the spacecraft commander and pilot; it is probably also feasible for the cargo and systems specialists.

9.1.2.2.8 Cost/Complexity and Risk

Although fewer controls and displays are required with this type of IOS, positioning them in the crew station, atop the motion system, tends to make for higher cost and complexity per display or control. Technical risk is very low.

9.1.2.2.9 Implications

The motion system sizing must take account of the weight of the instructor and IOS. Entrance and egress is also affected.

9.1.2.3 Portable IOS

9.1.2.3.1 Description

A portable IOS is a plug-in device that provides the instructor, while seated in one of the crew seats in the simulator, with limited control capability, typically control of initial conditions and malfunctions insertion. Thus when the trainee is flying from the left hand seat, the instructor, in the right hand seat can act as copilot while performing simulator instructor functions.

9.1.2.3.2 Current Usage

Commercial simulators, such as 747, L1011.

9.1.2.3.3 Characteristics

Because of size and cabling limitations, these units are generally limited to a few switches (often of the thumbwheel variety) and a set of numeric readouts.

9.1.2.3.4 Advantages

Allows the instructor control capability from right hand seat without compromising regular crew training.

9.1.2.3.5 Disadvantages

This control is quite limited, compared with that at conventional stations.

9.1.2.3.6 Prospects for Improvement

Improved display technology, such as flat CRTs, may enable scope of control and display to be broadened.

9.1.2.3.7 Applicability to SMS

Definitely feasible for SMS, especially for training of the spacecraft commander with the instructor in the right hand seat.

9.1.2.3.8 Cost/Complexity and Risk

Low cost/complexity, negligible technical risk.

9.1.2.3.9 Implications

None.

9.1.3 Tradeoffs and Recommendations

For maximum training effectiveness, a combination of the three techniques discussed above is desirable. The fixed instructor stations near crew positions need not have all the capabilities of the remote IOS, but should permit initialization, monitoring and malfunction insertion. The portable unit should have at least the capability to initialize to one of a half dozen sets of initial conditions, to monitor performance on selected parameters (one parameter at a time), and to insert malfunctions.

9.1.4 References and Assumptions

9.1.4.1 References

Cohen, E. Tools for the Man Behind the Man. Connecting Link 1966, Vol. 3 No. 2, pp 5-9.

Murphy, G.L. Advancements in Instructor Station Design. In Regan, J.J. & Amico, G.V. (Eds.) Naval Training Device Center 25th Anniversay Commenorative Journal, 1972.

9.1.4.2 Assumptions.

None.

9.2 Location, Mix, and Type of Displays and Controls

9.2.1 Overview

Instructor console displays serve the following basic functions:

a) indicators of simulator status

b) identification of instructor/operator control actions that have been or can be taken

c) indicators of the performance and status of the simulated vehicle, from which trainee performance can be inferred

d) display of material from data bank, e.g., spacecraft data, lesson plans, mission profiles, trainee background and performance history. This category covers data not nearly as volatile as the first three.

Certain limited data may require a dedicated display position, either a special indicator (e.g., MOTION ON) or a reserved or dedicated position on a CRT (e.g., LAT-LONG). Other data are not required throughout the training exercise, just during selected portions. Similarly, some control actions need to be available throughout the exercise, while others are not needed except during selected portions. There is also a criticality factor associated with controls; some, such as EMERGENCY STOP, must be capable of immediate actuation, while others, such as

BARO SET, are not as time-critical. Even with simulators of less complex vehicles than the Orbiter, there is a severe problem in making available to the instructor the displays and controls needed, at the appropriate time, and without requiring excess effort that would degrade the instructional function.

9.2.2 Techniques

9.2.2.1 Descrete Controls and Displays

9.2.2.1.1 Description

This technique, which can utilize a wide variety of controls and displays, uses each hardware item on a panel for a single function, and is thus characterized by fixed labels for each switch, knob, light, instrument, etc.

9.2.2.1.2 Current Usage

This technique is used exclusively on older simulators, and is predominant on most simulators delivered in the sixties.

9.2.2.1.3 Characteristics

Switch or knob for each control function

Separate display for each item of information

9.2.2.1.4 Advantages

Easy to learn

Function-position association

Graceful degradation - one item can fail without disrupting remainder

Every item is available full time

9.2.2.1.5 Disadvantages

Large space requirements make some items difficult to see or reach

Modifications require hardware changes

System checkout time-consuming

9.2.2.1.6 Propsects for Improvement

Modest improvements, such as in numerical readout, likely.

9.2.2.1.7 Applicability to SMS

This technique is applicable to SMS, but will lead to an IOS of unmanageable size and dubious reliability if used exclusively.

9.2.2.1.8 Cost/Complexity and Risk

An IOS for SMS constructed exclusively with discrete controls and displays will be costly and complex, because of the large number of controls and displays required. Little technical risk is involved, however.

9.2.2.1.9 Implications

Substantial floor space requirements

Extensive checkout requirements

9.2.2.2 Multiplexed Controls and Displays

9.2.2.2.1 Description

As the name implies, this approach permits a control or display to serve different functions at different times; a control will determine what information a display will show or what control function another control will serve. In the past, this concept was frequently applied by having a single set of comparatively expensive numerical readouts be able to display, at different times, a variety of parameters, such as latitude, longitude, airspeed, altitude, etc. Today multiplexing is best exemplified by an interactive CRT-keyboard system, in which keyboard actions control both what is displayed on the CRT and what is inputted to the simulation, such as initial conditions, malfunctions, freeze, etc.

9.2.2.2.2 Current Usage

Skylab

2F-101

ASUPT

9.2.2.2.3 Characteristics

Such a system is extremely flexible, but requires that the instructor seeks out the data he requires; some of this selection can be under computer control, so that information displayed is a function of mission phase, or exception data are displayed.

9.2.2.2.4 Advantages

Compact - no reaching needed

Almost limitless number of control functions

Almost limitless library of information can be displayed

Content and format of displays and controls modifiable by software change only.

9.2.2.2.5 Disadvantages

Instructor must learn how to execute control actions or call up displays; not self evident.

No association of function with position

Data generally not available full-time; must be called up, requiring effort by instructor

Degradation not graceful; if CRT malfunctions, IOS is useless.

9.2.2.2.6 Prospects for Improvement

Improvements can be expected both in CRT hardware (flatter, cheaper, more reliable, less flicker, better legibility) and in software (easier call-up, better graphics).

9.2.2.2.7 Applicability to SMS

Very applicable to SMS.

9.2.2.2.8 Cost/Complexity and Risk

Modest cost and complexity (software, primarily); low risk.

9.2.2.2.9 Implications

None.

9.2.3 Tradeoffs and Recommendations

A system using CRTs and keyboards for almost all functions is recommended; dedicated controls should be used for only a few functions - those involving safety (e.g., MOTION OFF) and very frequently used controls. The need for dedicated displays can be met largely or entirely by using a portion of the CRT for such data. However, cockpit instruments which are associated with the dynamic response of the vehicle such as the HSI, FDAI, etc., should be dedicated displays. More than one CRT will probably be required.

9.2.4 References and Assumptions

None.

9.3 Peripheral Equipment

9.3.1 Overview

By peripheral equipment is meant devices that enable the instructor to make inputs to the simulator computer, and to sense outputs. This section will restrict coverage of output devices to those producing permanent records, since non-permanent outputs, such as those of CRTs, are treated elsewhere. The treatment will be from a functional, rather than engineering viewpoint, discussing instructional features of various kinds of devices, rather than details of their construction. Completely omitted from this discussion will be simulator peripheral equipment, such as disks, tape transports, etc., that support the simulator generally, but are not candidates for the IOS.

9.3.2 Techniques

9.3.2.1 Hard Copy Alphanumeric Devices

9.3.2.1.1 Description

These devices are of three kinds: character-at-a-time printers (e.g., TTY), line printers, and CRT hard copy devices.

9.3.2.1.2 Current Usage

Numerous simulators as well as other computer facilities utilize character and line printers; teletype devices predominate among simulators. Devices to make a permanent record of CRT contents are less common, but are found on the 2F-101 and ASUPT.

9.3.2.1.3. Characteristics

Parameters of interest includes speed of printing (for printers), cycle time (for CRT hard copy devices), legibility, permanence of record, noisiness, initial cost, and upkeep.

9.3.2.1.4 Advantages

Not applicable.

9.3.2.1.5 Disadvantages

Not applicable.

9.3.2.1.6 Prospects for Improvement

Significant improvements in performance and in cost-effectiveness can be anticipated with all three varieties of devices.

9.3.2.1.7 Applicability to SMS

These devices could be used for verification of initial condition, including status of controls at unmanned stations, and for recording trainee performance.

9.3.2.1.8 Cost/Complexity and Risk

Low cost/complexity for printers (CRT hard copy devices are fairly costly); no risk.

9.3.2.1.9 Implications

None.

9.3.2.2 <u>Hard Copy Plotters</u>

9.3.2.2.1 Description

These devices are of two kinds: XY plotters and XT plotters, sometimes called time history recorders.

9.3.2.2.2 Current Usage

Most flight simulators employ XY plotters as ground track and/or glide slope deviation recorders. A few simulators, such as the F-4, provide time histories of selected parameters, such as steering error.

9.3.2.2.3 Characteristics

Self-evident.

9.3.2.2.4 Advantages

Plots of the kind provided by these devices furnish the instructor with needed information concerning trainee performance is a most natural and easily assimilable manner.

9.3.2.2.5 Disadvantages

The hard-copy aspect of these plots is of little use to the instructor (although it may be of some use for trainee feedback); such records tend to accumulate and get in the way.

9.3.2.2.6 Prospects for Improvement

Plotters represent a fairly mature technology; only modest increases in performance or cost-effectiveness are anticipated.

9.3.2.2.7 Applicability to SMS

XY plotters could be used for cross-country and glide slope deviation recorders. XT recorders may have some applicability with respect to manipulator arm performance.

9.3.2.2.8 Cost/Complexity and Risk

These recorders are generally low to moderate in cost/complexity, and constitute negligible technical risk.

9.3.2.2.9 Implications

These recorders are somewhat bulky; if used, space must be provided for them at the IOS.

9.3.2.3 Computer Input Devices

9.3.2.3.1 Description

Input devices fall in two categories: digital and analog. Digital devices are switches and keyboards; analog devices include potentiometers, joysticks, track balls, and RAND tablets.

9.3.2.3.2 Current Usage

Switches, keyboards, potentiometers and joysticks are in common use in current simulators; track balls and RAND tablets are rarely if ever used in simulators, but are used in other computer input applications.

9.3.2.3.3 Characteristics

Self-explanatory.

9.3.2.3.4 Advantages

Self-evident.

9.3.2.3.5 Disadvantages

Self-evident.

9.3.2.3.6 Prospects for Improvement

Very mature technologies; no significant prospects for improvement.

9.3.2.3.7 Applicability to SMS

Switches and keyboards are certainly required for SMS; the need for analog input devices (and the types of analog input devices) cannot be determined at this time.

9.3.2.3.8 Cost/Complexity and Risk

Low cost/complexity; neglible risk.

9.3.2.3.9 Implications

None.

9.3.3 <u>Tradeoffs and Recommendations</u>

A CRT-centered IOS is recommended, with the CRTs having graphic as well as alphanumeric capability. This eliminates the need for separate plotters; if permanent records of these plots are required, a CRT copying device would be effective and flexible, but probably would be more costly than the plotters. Permanent records of alphanumeric data are accomplished most cost-effectively with a TTY or line printer.

9.3.4 <u>References and Assumptions</u>

None.

10.0 SIMULATION SOFTWARE ENVIRONMENT

10.1 Programming Language

10.1.1 Overview

A major consideration in the implementation of the applications software for the SMS is the programming language to be used. The choice can have possible impact on the design, development and checkout of the simulation programs.

10.1.2 Techniques

10.1.2.1 Symbolic Languages

10.1.2.1.1 Description

Typically each family of computers has its own "assembly" language because of the closeness of symbolic languages to machine languages and because of the similarity between members of the same family of computers, occasionally, translations or simulators are prepared which make it possible for the symbolic language for one family to serve an equivalent role for another family of computers.

10.1.2.1.2 Current Usage

Symbolic languages have been used extensively in the design of simulation software systems for most current simulators.

10.1.2.1.3 Characteristics

Syntax - Reflects closely the underlying character of the machine language. Structure and rules for usage are well defined.

Semantics - The operations specified in the Syntax are usually of two groups: The imperative and the declarative. The imperative afford the programmer the capability to utilize each command built into the hardware.

The declaratives provide directions to the translation program to direct the way it does the translation work (e.g., macros).

Data Structures - are usually defined at the field, word, byte, character, and bit levels.

Binding Time - makes it possible for the programmer to specify operations that will result in delaying the performance of the operation until execution.

10.1.2.1.4 Advantages

The symbolic language provides the programmer with the greatest degree of control over the computer's operations.

The use of the symbolic language is beneficial when operating speed and use of storage space are critical.

It is also beneficial when the programmer needs to call upon the computer resources and direct them meticulously.

10.1.2.1.5 Disadvantages

Usually more experienced programmers are required to work in this language.

The time to code and checkout a program is a function of the number of instructions that have been coded.

10.1.2.1.6 New Advances

None foreseen at this time.

10.1.2.1.7 Applicability to SMS

The symbolic language is applicable in the supervisory, executive and bit manipulation software.

10.1.2.1.8 Cost/Complexity and Risk

Coding and checkout time are increased as the number of instructions increases.

10.1.2.2 High Level Languages

10.1.2.2.1 Description

These languages are more distant from the computer, and give specific attention to the sequence of operations that the computer is to perform. The following paragraphs will be directed to Fortran and Cobol since they are most common.

10.1.2.2.2 Current Usage

These languages are currently used in the SLS Simulation and Support Software.

10.1.2.3 Characteristics

Syntax

Cobol - Programs are written in four divisions: Identification, environment, data, and procedure. The Syntax provides for data manipulation in one-coordinate arrays and in tables, and the ability to handle sequential input and output. The Syntax also provides for sort capability, overlay and segmentation, library call, and random access processing.

Fortran - Programs are written in series of statements. The imperative statements are arithmetic and control. The arithmetic statements resemble formulas and direct the computer to take action. The arithmetic operations are exponentiation, division, multiplication, subtraction, and addition in order of precedence. The control statements afford looping, conditional testing, and branching. The declarative statements afford for input and output data formatting.

Semantics

Cobol - The language has at a minimum twenty-one verbs grouped as follows: arithmetic, input/output, data movement, and transfer of control.

It permits options in the statement form, together with redefinition on declaration of fields of storage. The input/output operations are reading/writing operations on files.

Fortran - Reflects arithmetic orientation. The language provides for input/output operations. The language also allows for transfer of control. Because of its arithmetic orientation, most implementations have a large supply of mathematical subroutines.

Data Structure

Cobol - Centers around ordered files. File access is normally sequential, but random access is available. All numbers are assumed to be fixed point integers. Special provisions for editing data are made.

Fortran - Vectors and matrices can be handled with little difficulty. Declaratives are used for defining arrays. The language provides no facilities for handling files, strings, or lists. This is usually done through user subroutines.

Binding Time - Both Fortran and Cobol do not provide any convenient provisions to help the programmer delay binding of computer instruction execution.

10.1.2.2.4 Advantages

Cobol can effectively be used where the arithmetic burden is light. The logic burden can be handled by a series of comparisons on fields. The language is very effective in file manipulation and maintenance.

The Fortran language is relatively easy to learn. Fortran can effectively be used where the file manipulation burden is light and the arithmetic burden is great.

Both languages are in wide use, and they are supported by every major computer manufacturer.

10.1.2.2.5 Disadvantages

Both of these high level languages provide code which requires more core storage than if the program were written in a symbolic language.

10.1.2.2.6 New Advances

No major new advances are anticipated at this time.

10.1.2.2.7 Applicability to SMS

Cobol is applicable for the following support software: data base generation; reset data generation; file manipulation and maintenance.

Fortran is applicable for most of the simulation software systems such as flight mechanics, on-board systems, and life support.

10.1.2.2.8 Cost/Complexity and Risk

The implementation of these languages would reduce coding and checkout time.

10.1.3 Trade-Offs and Assumptions

The three languages should be implemented where applicable during the SMS Program Development.

10.2 Operating Systems

10.2.1 Overview

An operating system consists of a set of programs that assist the user in obtaining better operating performance from the computer, faster preparation of programs, and less difficult management of the computer's time availability and resources. The complexity and capability of the operating system will be in proportion to the task requirements and the computer resources available.

10.2.2 Techniques

Since the techniques of implementing an operating system vary from computer manufacturer to computer manufacturer, they will be treated as one technique.

10.2.2.1 Current Usage

Operating systems with varying capability and complexity are supplied by every major computer manufacturer.

10.2.2.2 Description

The components of an operating system vary due to the differences in the work load to be handled. Also, different operating systems distribute the basic work functions to different components. The major components of an operating system are defined in the following paragraphs.

Monitor - Coordinates and controls the activities and operations of the other components of the operating system.

Scheduler - Establishes queues on stacks of jobs waiting to be done and maintains them as their priority status changes where they are waiting and during execution.

Dispatcher - Arranges the performance of the necessary operations required for the completion of a job.

Interrupt Handler - Maintains the status of the other components of the operating systems as well as the type of operations being carried on.

Peripheral Driver - Handles and schedules all input and output requests from programs in execution.

Storage Allocator - Controls the use of main and mass storage by jobs in execution.

Communication - Maintains tables, queues, and stacks used for communication between the components of the operating system.

Library Manager - Inserts and deletes programs from the library and maintains a directory in order to locate items when they are needed.

10.2.2.3 Characteristics

The following tables list the functions that an operating system should contain. Some of the functions listed may be unique to a particular operating system, and the presence or lack of a specific function should not be assumed to represent a superiority of one system over another.

Where a checkmark appears in the table, the operating system has some form of the associated feature. In some cases, a number appears in the table. This number references a note which further defines how the operating system handles that function. Some entries are preceded by a hyphen (-), and these are examples of the function. The occurrence of a checkmark by such an entry means that the principal feature exists and the example was specifically noted in the documentation.

The investigation of the operating systems was made with reasonable care; but due to the scope of current operating systems, some features may be present but description of them may be hidden in the bulk of the documentation. As an example, the IBM systems earned a check for 'card stacking', not because the system description stated it would stack cards, but because the feature was found in the data control block macro definition.

EXECUTIVE/CONTROL FUNCTIONS

Job Management

Job Control

Scheduling

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Algorithmic Scheduling						
- Priority Recognition	X	1	1	X	X	X
- Resource Availability	X	2	2	X	X	X
Time Initiated Scheduling						
- Elapsed Interval	1	X	X	X	X	X
- Periodic Interval				X	X	X
- Time of Day	X	X	X	X		
Event Initiated Scheduling						
- Interrupt Initiated	X	X	X	X	X	X
- Unsolicited Inputs				X	X	X
Program Initiated Scheduling			3			
- Subsequent Execution	X			X	X	X
- Asynchronous Execution	X		X	X	X	
Conditional Scheduling						
- Prior Task/Job Completion	X	X	X	X		X
- Prior Task Error Code	X	X	X			X
Scheduling Queue Maintenance						
Single Input Queue Control					1	
Multiple Input Queue Control	2	4	5			X

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EXECUTIVE/CONTROL FUNCTIONS

Job Management

Job Control

Resource Allocation

OPERATING SYSTEM	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Internal Storage Allocation		7	6	2	2	1
Fixed Block Allocation						
Dynamic Allocation	4	8	8		3	X
- Buffer Pools	X	X	X	X		X
- Free Pools of Internal Storage	X			X		
- Program Expansion Area Pools	X		X	X		X
Page Allocation		X	X			
Common (Shared) Storage Allocation			X	X		X
Internal Storage Access Control						
- Storage Protection	3	10	10	3	4	2
- Fetch Protection		10	10			
I/O Device Allocation					5	
Allocation by Specific Device	5	X	X	X	X	X
Allocation by Device Type		X	X	X	X	X
- Card Reader		X	X	X	X	X
- Tape	X	X	X	X	X	X
- Disk	X	X	X	X	X	X
Allocation by Device Category		X	X	X	X	X
- Sequential	X	X	X	X	X	X
- Direct Access	X	X	X	X	X	X

EXECUTIVE/CONTROL FUNCTIONS Job Management Job Control Resource Allocation I/O Device Allocation	OPERATING SYSTEM: UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Shared Device Allocation		X	X	X	X	
- Operator's Console Display				X		
- Common I/O Files	X	11	11	X		X
Dynamic Allocation						
- Temporary Files	X	X	X	X	X	X
- System Work Files	X	X	X	X	X	X
Common Subroutine Allocation		12	12			
Re-entrant Routine Control	X	X	X			X
Serially Reusable Routine Control		X	X			
Lock/Unlock Facilities	X					
Request Queue Control	6	X	X			

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EXECUTIVE CONTROL FUNCTIONS — OPERATING SYSTEM

Job Management

Job Control

Program Loading

	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Structure Control						
- Paged		X	X			X
- Overlay		X	X	X	X	X
- Dynamic	X	X	X	X		X
Loading Control						
Program Relocating	X	X	X	X	X	
Storage Compacting	X	X	X	X		
Swapping Control						
Roll Out/Roll In Control	19		X	X	X	X
Paging Control						
- Static						
- Demand		X	X			X

EXECUTIVE CONTROL FUNCTIONS

Job Management

Job Control

Event Monitoring

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Dispatching Control						
Time Slicing Control	X	X	X	X		X
Contention (Priority) Dispatching	X	X	X	X	X	X
Dispatcher Queue Maintenance	X	13	14	X	6	X
Event Synchronization						
- I/O Device Completion	X	X	X	X	X	X
- Time Interval Interrupts	X	X	X	X	X	X
- Sub-Task Execution/Completion			X	X		X
Interrupt Processing Control						
Interrupt Priority Recognition	X	X	X	X	X	X
Interrupt Masking/Disabling	7	X	X		X	X
Interrupt Stacking		X	X	X	X	X
Program Limit Monitoring						3
- Output Record Limits	8					X
- Execution Time Limits	8	15	15	X		X

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EXECUTIVE CONTROL FUNCTIONS — Job Management — Job Control — Program Termination Processing

EXECUTIVE CONTROL FUNCTIONS / Job Management / Job Control / Program Termination Processing	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Resource Deallocation						
- Closing Files	X	X	X	X	X	X
- Releasing Devices	X	X	X	X	X	X
- Releasing Core	X	X	X	X	X	X
Summary Information Outputting						
- Record Counts	X					X
- Run Times	X	X	X	X		X
- Error Summarization				X		X
Abnormal Termination						
- Core Dumps	X	X	X	X	X	X
- File Dumps	X					
- Error Codes	X	X	X	X	X	X
- Program Recovery Initiation						

EXECUTIVE/CONTROL FUNCTIONS

Job Management

I/O Control

I/O Scheduling

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Device Resolution	X	X	X	X	X	X
Request Stacking						
- Device Queue Maintenance	X	X	X	X	X	X
- Channel Queue Maintenance						
- I/O Initiation						
- Priority Recognition	X	X	X	X	X	X
- Arm Optimization		X	X			
Alternate Routine Control						
- Alternate Channels to Device						
- Alternate Devices						

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EXECUTIVE/CONTROL FUNCTIONS

Job Management

I/O Control

Date Transfer

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Buffering Control						
- Buffer Pool Maintenance	X	X	X	X		X
- Buffering Handling						
- Simple Buffering	X	X	X		X	X
- Exchange Buffering	X	X	X			
- Chained Segment Buffering		X	X	X		X
Data Code Translation						
- Compressed Formats					X	X
- Character Code Conversion	X	X	X	X	X	X
- Paper Tape Formats		X	X			X
- Teleprocessing Code Conversion		X	X	X		X

EXECUTIVE/CONTROL FUNCTIONS — OPERATING SYSTEM

Job Management

I/O Control

Device Manipulation

	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Tape/Disk Positioning	X	X	X	X	X	X
Card Stacking		X	X	X		X
Page Ejecting	X	X	X	X	X	X

EXECUTIVE/CONTROL FUNCTIONS

Job Management

I/O Control

Remote Terminal Support

	OPERATING SYSTEM: UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Interactive Communication Control	X			X		X
Terminal-to-Terminal Communication Control	X			X		X
Control of Remote Job Initiation	X	X	X	X		X

EXECUTIVE/CONTROL FUNCTIONS

Job Management

System Communication

System Startup

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
System Initialization						
- Batch Job Initialization	9	16	16	X	7	4
- Foreground Initialization	9				7	X
- Standard Option Modification	10			X		X
- Resource Specification						
- Peripheral Devices	X	X	X	X		X
- Partition Sizes		X	X			
- Input/Output Symboints	9	X	X			X
- Parameter Specification						
- Date	X	X	X	X	X	X
- Time	X	X	X	X	X	X
System Restart						
- Suspended Queue Resumption	11	X	X	X		X
- Parameter Respecification	X	X	X	X		X

EXECUTIVE/CONTROL FUNCTIONS

Job Management

System Communication

Job Control Communication

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Non-Interactive Control						
- Input Stream Control Cards	12	X	X	X	X	X
- Cataloged Procedures	X	X	X			
- Operator Console Commands	X	X	X	X	X	X
Interactive Control						
- On-Line/Remote Terminal Dialogue	X	X	X	X		X
- Operator Console Dialogue	X	X	X	X		X

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EXECUTIVE/CONTROL FUNCTIONS Job Management System Communication Input/Output Stream Control	OPERATING SYSTEM UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Symboint Processing	X	X	X	X	X	X
Input/Output Queue Maintenance	X	X	X	X	X	X
Control Command Analysis	X	X	X	X	X	X

EXECUTIVE/CONTROL FUNCTIONS — OPERATING SYSTEM

Job Management

System Communication

Resource Status Modification

	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Addition/Deletion of System Resources	X	X	X	X	X	X
Partition Size Modification		X				
Substitute Device Identification						X

EXECUTIVE/CONTROL FUNCTIONS

Job Management

System Communication

System Status Interrogation

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Current User Display	X	X	X	X		X
Resource Status Display	X	17	17	X	X	X
Job Status Display	X	X	X	X	X	X

EXECUTIVE/CONTROL FUNCTIONS — OPERATING SYSTEM

Job Management

Recovery Processing

Checkpointing

	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Program Initiated Checkpointing	13	X	X	X		X
System Initiated Checkpointing	X				8	
- Roll-Out/Roll-In	X	X	X	X		X
Externally Initiated Checkpointing						
- Input Stream Control Card	X			X		
- Operator Console	X			X		X
- On-Line/Remote Terminal	14			X		X
Checkpoint Notification						
- Operator Console	X	X	X	X		X
- Job Output Log	X			X		

EXECUTIVE/CONTROL FUNCTIONS

Job Management

Recovery Processing

Restarting

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Program Initiated Restarting	X					X
System Initiated Restarting	X					
- Roll-Out/Roll-In	X			X		X
- Error Detection Occurrence	X			X		
Externally Initiated Restarting						
- Input Stream Control Card	X	18	18	X		
- Operator Console	X	X	X	X		X
- On-Line/Remote Terminal	X			X		X
Device Repositioning						
- Input Stream	X	X	X	X		X
- Output Stream	X	X	X	X		X
- Peripheral Devices	X	X	X	X		
- Teleprocessing Devices				X		

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EXECUTIVE/CONTROL FUNCTIONS Diagnostic Error Processing Hardware Error Control Error Correction	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Fault Analysis	X	X	X	X	X	X
Event Retry/Retransmission	X	X	X	X	X	X
- Retransmission Threshold						
Controlled Linkage to User Error Routines	X	X	X	X	X	X

EXECUTIVE/CONTROL FUNCTIONS

Diagnostic Error Processing

Hardware Error Control

Error Notification

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Operator Notification	X	X	X	X	X	X
Program Notification	X	19	19		X	X
Device Error Statistic Accumulation	X	X	X	X		
Diagnostic Logout of Permanent Errors	X	X	X	X		X

EXECUTIVE/CONTROL FUNCTIONS

Diagnostic Error Processing

Hardware Error Control

Error Recovery

OPERATING SYSTEM	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
System Reconfiguration						
Alternate Device Utilization	15			X	9	
Controlled System Degradation	X	X	X	X	X	X
Manual Reconfiguration	15	20	20			X
On-Line Diagnostic Testing Control		X	X	X		

EXECUTIVE/CONTROL FUNCTIONS

Diagnostic Error Processing

Program Error Control

Error Correction

		OPERATING SYSTEM					
		UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Controlled Linkage to User Error Routines	16	X	X	X			X
Simulation of Non-Hardware Implemented Opers.	17						
- Non-Implemented OP Codes							5

EXECUTIVE/CONTROL FUNCTIONS Diagnostic Error Processing Program Error Control Error Notification	OPERATING SYSTEM UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Operator Notification	X	X	X	X	X	X
Program Notification	X	X	X	X	X	
Diagnostic Error Log-Out	X	X	X	X		

EXECUTIVE/CONTROL FUNCTIONS

Diagnostic Error Processing

Program Error Control

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Program Termination	X	X	X	X	X	X

EXECUTIVE/CONTROL FUNCTIONS

Diagnostic Error Processing

Interface Error Control

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Operator Key-In Editing	X	X	X	X	X	X
Control Command Editing	X	X	X	X	X	X
Remote Terminal Communication Editing	X			X		X
Program-to-System Link Verification	X				X	X

EXECUTIVE/CONTROL FUNCTIONS

Processing Support

Timing Service

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Real-Time Clock Service						6
- Date	X	X	X	X	X	X
- Time of Day	X	X	X	X	X	X
Interval Timer Service						
Scheduling Periodic Interrupts	X	X	X	X	X	X
- Loop Control	X					
- Timing Analysis	X					
Temporary Task Suspension Control	X	X	X	X	X	X

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EXECUTIVE/CONTROL FUNCTIONS

Processing Support

Testing/Debugging Service

	OPERATING SYSTEM					
	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Storage Dump Control						
Snapshot Control	X	X	X	X	X	X
Partial Dump Control	X	X	X	X	X	X
Tracing Control		21	21			
- Data Tracing				X	X	X
- Instruction Tracing		22	22	X	X	X
- Logic Tracing				X	X	X
- Supervisor Entry Tracing		22	22			

EXECUTIVE/CONTROL FUNCTIONS — OPERATING SYSTEM

Processing Support

Testing/Debugging Service

System Test Mode Control

	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
I/O Simulation						7
- Error Simulation						
- I/O Re-routing						
Abnormal Termination Service						
- Storage Dumps	X	X	X	X	X	X
- File Dumps	X			X		
- Subsequent Task Execution				X		X
Interactive Testing Service						
- Breakpoints				X		X
- Memory Searching						
- Memory Modification						X
- Interrupt or Error Notification						X

EXECUTIVE/CONTROL FUNCTIONS

Processing Support

Logging and Accounting

	OPERATING SYSTEM: UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Maintaining Job Charge Information						
CPU Time Recording	X	X	X	X		X
I/O Channel and Device Time Recording	X	X	X	X		X
Resource Utilization Recording	X	X	X	X		X
Controlled Linkage to User-Supplied Accounting Routines	18	X	X	X		X
Maintaining Error Statistics						
Hardware Error Summary Accumulation	X	X	X	X		X
Program Error Summary Accumulation				X		
Hardware Log-out Storage and Maintenance		X	X	X	X	X
Error Statistic Retrieval	X			X		
Maintaining System Utilization Statistics						
User Account Summary Recording	X	X	X	X		X
File Access Summary Recording	X			X		X
System Service Request Recording				X		
System Performance Monitoring	X			X		X

EXECUTIVE/CONTROL FUNCTIONS

Processing Support

Program Accessible System Description Maintenance

OPERATING SYSTEM	UNIVAC 1100	IBM MFT/VS1	IBM MVT/VS2	CDC SCOPE	SEL RTM	XDS BTM
Current System Status Interrogation						
- Number of Other Users				X	X	
- Core Storage in Use	X			X	X	X
- Device Status	X			X	X	X
- Elapsed Program Execution Time	X	X	X	X		X
System Definition Interrogation						
- System Components						
- Maximum Number of Users						
- Generation Optics Selected						

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UNIVAC 1100 NOTES

1. Interval determined by program that caused sub-task to be created.
2. Two queues are maintained, one for batch, one for teleprocessing.
3. Storage protect is implemented by address limit registers, and by a transparent base register.
4. Requesting program may be rolled out until enough free core is available, or another program may be rolled out to satisfy the request.
5. Only tape units may be requested by specific address.
6. Use of test and set instruction, which will cause an interrupt if target word has high order bit set (implying that service is in use). System will lower dispatch priority until test and set instruction will execute without interruption.
7. No interrupts are permitted during processing of a previous interrupt.
8. Values set at system generation but may be over-ridden for any single job.
9. Initiated via key in from operator.
10. Some standard options may be modified from system generation values. Modifications will remain valid until changed or system re-initialization.
11. No data found directly indicating that system could be restarted with jobs in queues. However, the system will re-initialize system files if any exist. Since input queues are in the form of system files, a 'warm' restart may be inferred.
12. Control statements are not limited to card format only. System is unique in that it will allow an executing program to submit an executive control statement image for processing.
13. Two types of check point are allowed, complete and partial. A complete check point saves temporary files and certain catalogued files in addition to the program and program status. A partial check point only saves the

UNIVAC 1100 NOTES

program and program status. Thus a partial checkpoint only rolls the program out. Any files used, except symboint input/output are lost. A real time program may not be checkpointed.

14. Only partial checkpoint allowed for teleprocessing.
15. System will attempt to find another device which can replace the failing one. If one can be found and the medium can be transferred, the system will attempt to proceed using the alternate device. This may call for manual intervention by the operator. Program may continue.
16. Error conditions a user program may process include: illegal operation codes, privileged instructions, core storage violations, floating point overflow and underflow, divide overflow, and test and set interrupts (see 6 about test and set).
17. If any, can be handled by user error routines. See 16 above.
18. System maintains master accounting log which is updated until user supplied accounting program purges information from log.
19. Program rolled in may not occupy same memory area it had prior to rollout.

IBM MFT/VS1 and MVT/VS2 NOTES

The IBM operating systems VS1 and VS2 are system 370 upgrades of system 360 MFT and MVT respectively. Both systems have only been recently released by IBM and full documentation on the systems have not been procurable from the vendor. Therefore, the function analysis of the two systems have been based upon the 360 system and what limited data is available on the S/370 systems.

Because of the commonality of the two systems, notes on both systems are presented here.

1. System recognizes up to 15 classes of job stream input. Within a class, execution is determined by priority. If all jobs are of same priority, execution is first in, first out.
2. Jobs are initiated only when all data sets, I/O devices, and sufficient core memory are available.
3. A program can initiate another task. This task can run at the same, or different, priority of the originating task. All such sub-tasks can operate asynchronously of each other.
4. Up to 15 partitions may be active. Each partition may select jobs from 3 of the 15 possible input queues. Within a partition, only one job can be active at one time.
5. Each job class may have one or more initiators selecting jobs from the input queue. Each initiator will process one job to completion, then move to the next job in that queue. Up to 63 initiators may be active at one time.
6. Required storage limits may be specified by job or by job step. If neither, the default limit at system generation is used. Unless additional core is requested by program, the required memory is determined by physical size of module.

IBM NOTES

7. Partition size determines maximum amount of memory that is available to program.
8. Available storage is maintained by the system and may be requested by the program up to job limits.
9. If required, programs may be rolled out to satisfy core requirement.
10. Provided by storage lock and key arrangement.
11. For read only data sets. If data set is to be updated, only one job at a time may use the data set.
12. Selected re-entrant routines are placed in common area for simultaneous use by all tasks.
13. Priority of partition determines dispatch priority of task.
14. Determined by job priority.
15. Can be changed from default time by control card input.
16. Started by initialization of initiator.
17. Core allocation only.
18. Total job step restart only.
19. For user written I/O access method only, and then limited to certain cases.
20. System will attempt to have failing device, if in use by task, taken out of service and tape or disk pack mounted on another drive. Reconfiguration is also under operator control.
21. The powerful debugging and testran is not supported in the VS systems.
22. Trace table capability is function of system generation. By use of macros, the problem program can make entries in trace table.

CDC NOTES

1. Two classes of jobs: job source and rollout.
2. Allocates by 512 word blocks.
3. By limit registers.

SYSTEMS ENGINEERING LABORATORIES (SEL) 85/86 RTM NOTES

1. Although several jobs may be in execution at the same time, no data was found which would indicate multiple input classes are available.
2. System will attempt a 'Best Fit' for required memory. If memory cannot be allocated and lower priority job occupies sufficient core to satisfy the request, the lower priority job may be rolled out.
3. Additional core cannot be dynamically allocated via monitor services.
4. Memory lock and key.
5. Additional peripherals may be dynamically allocated.
6. Dispatch queue may contain up to 255 entries.
7. Under operator control.
8. For core requirements only. See 2 above.
9. Since a user program can be made aware of a failed device, and a user can request additional peripheral equipment, it is assumed that an alternate device can be assigned. However, it appears to be the user programs responsibility.

XDS NOTES

1. Storage is divided into three areas: monitor, resident foreground, and background. Batch and nonresident foreground compete for background area.
2. Lock and key method.
3. Limits which may be imposed include temporary and permanent disk storage and number of scratch tapes used.
4. Under operator control.
5. Monitor may contain simulation routines for non-implemented operations. Function of system generation.
6. System may monitor two or four real-time clocks.
7. System allows user to request that an interrupt be simulated, allowing checkout of interrupt routines independent of existance of actual interrupt.

10.2.2.4 Advantages

None can be made at this time.

10.2.2.5 Disadvantages

None can be made at this time.

10.2.2.6 New Advances

No major advances are foreseen at this time.

10.2.2.7 Applicability to SMS

An operating system will be required for the SMS, but the complexity and capability depends upon the computer type selected and the task requirements.

10.2.2.8 Cost/Complexity and Risk

It is essential that an operating system that has been in use for a while be implemented to reduce the risk of major problems that will hinder development and checkout of the simulation system.

10.2.3 Trade-Offs and Recommendations

The preceding function check list does not include all of the computer systems that may be utilized in the SMS computer complex. It does cover three operating systems from the 'Multiprocessor' configuration and two from the operating systems from the 'Multiprocessor' configuration and two from the 'Dedicated' configuration.

As stated elsewhere, the 'Super Computer' configuration was not recommended. It is recommended that no effort be spent on investigation of any 'Super Computer' operating system.

The preceding check list covered only the executive and control functions of the operating systems which are the essential elements. These functions by no means cover all of the services an operating system should provide.

During the hardware/software conceptual design phase, additional emphasis will be placed upon the following general items: system generation, system file creation (compilers, utilities), authorized user declaration (passwords, priorities, accounting controls), system maintenance, program maintenance, load module generation, compiler interfaces, program libraries, peripheral device support. Additionally, investigation will be directed toward areas of data manipulation functions, such as file management facilities, data access, data file maintenance, and sort/merge as required.

10.2.4 References

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7. OS/VS2 Planning Guide, GC28-0600-1, IBM Corp., July 1972.
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10.3 Simulation Software Structure

10.3.1 Overview

A major concern in the implementation of the simulation system for the SMS is the efficient use of computer complex resources. Various candidate solutions exist for the task structure for the simulation software of the SMS.

10.3.2 Techniques

10.3.2.1 Disc Overlay

10.3.2.1.1 Description

Application programs executed at a low iteration rate are read in from mass storage into an assigned area in main storage in order to be executed.

10.3.2.1.2 Current Usage

This technique is currently being utilized in the SLS.

10.3.2.1.3 Characteristics

The low iteration rate programs share main storage and reside on mass storage. The size of the main storage buffer(s) is a function of mass storage access time (transfer rate) and simulation system response fidelities.

10.3.2.1.4 Advantages

Minimizes the amount of main storage required for the application programs.

10.3.2.1.5 Disadvantages

Debugging facilities are difficult to implement for the application software.

10.3.2.1.6 New Advances

Application programs of a higher iteration rate might be treated the same way if proper computer resources were available.

10.3.2.1.7 Applicability to SMS

Directly applicable if computer resources are adequate.

10.3.2.1.8 Risk

System fidelity and response might be lacking in some instances.

10.3.2.2 Compute-on-Demand

10.3.2.2.1 Description

Applicable simulation software is read in from mass storage and executed only when required.

10.3.2.2.2 Current Usage

This technique is currently being used in the SLS.

10.3.2.2.3 Characteristics

The application software is read in and executed only when there is a change of state in crew station on IOS inputs.

10.3.2.2.4 Advantages

Effective utilization of computer complex execution time and main storage.

10.3.2.2.5 Disadvantages

Math models would have to be divided into logic and transient equations, and steady state equations. The communications between them could be problematic.

10.3.2.2.6 New Advances

New advances would be predicated on computer complex requirements and Simulation system requirements.

10.3.2.2.7 Applicability to SMS

This technique is as applicable to SMS as SMS requirements and computer complex resources allow.

10.3.2.2.8 Complexity and Risk

The complexity cannot be fully evaluated until all SMS requirements and computer resources are known.

10.3.2.3 Mission Phase Dependence

10.3.2.3.1 Description

The total SMS application software would be resident in mass storage. Only the programs which represent a defined mission phase would be read in and executed.

10.3.2.3.2 Current Usage

This type of scheme is utilized in the current CRT system in SLS.

10.3.2.3.3 Characteristics

See 10.3.2.3.1

10.3.2.3.4 Advantages

Very efficient use of computer complex resources.

10.3.2.3.5 Disadvantages

Continuous training across mission phases the programs for which are not in main storage may produce transients and meter fluctuations.

10.3.2.3.6 New Advances

None

10.3.2.3.7 Applicability to SMS

Very applicable depending upon computer resources available, and mission phase requirements.

10.3.2.3.8 Complexity and Risk

Major complexity and risk is associated with mission phase transients and computer complex resources available.

10.3.3 Tradeoffs and Recommendations

No recommendations can be made at this time because computer complex resources are not known.

10.3.4 References

None

10.4 Debugging Techniques

10.4.1 Overview

Techniques other than those supplied in an operating system (e.g., dump trace, and diagnostic messages) are available for debugging and supporting the simulation software.

10.4.2 Techniques

10.4.2.1 CRT Pages

10.4.2.1.1 Description

This technique uses small programs to compute and/or display one or more parameters on the CRT screens at the CRT screen update rate.

10.4.2.1.2 Current Usage

This technique is currently being utilized in the SLS.

10.4.2.1.3 Characteristics

The CRT pages are small selectable programs which reside on mass storage when not in use and are transferred to main storage when requested. The amount and rate of data available is a function of screen update rate and the number of allowable display positions on the screen.

10.4.2.1.4 Advantages

Allows the monitoring of several parameters in real-time without resorting to recording all changes on hard copy.

10.4.2.1.5 Disadvantages

The number of parameters which may be displayed is limited by the physical number of display positions on the screen, and parameters computed at faster rates than that the CRT screen is updated cannot be effectively monitored.

10.4.2.1.6 New Advances

As larger CRT screens with faster refresh rates become available the number and rate of parameters that can be monitored increases.

10.4.2.1.7 Applicability to SMS

Directly applicable if large enough and fast enough CRT's are available.

10.4.2.1.8 Complexity and Risk

The complexity of CRT pages is proportional to the difficulties of supporting any peculiarities of the CRT hardware. The risk is associated with the dependability of the CRT system and types of backup debug facilities available in case of failure.

10.4.2.2 Numerical Read Out

10.4.2.2.1 Description

This technique is the use of a small real-time routine to sample a selected parameter, convert the data to a suitable form, and output to a digital display device.

10.4.2.2.2 Current Usage

This technique is currently in use in CMS and LMS.

10.4.2.2.3 Characteristics

One parameter is selected with a display format and is monitored on a digital display device.

10.4.2.2.4 Advantage

Since only one parameter is monitored the rate of sampling is high and overhead of formatting is low.

10.4.2.2.5 Disadvantages

The amount of data and accuracy are highly limited and require specialized DCE requirements.

10.4.2.2.6 New Advances

The development of faster and simpler hardware may result in gains in sample rates and accuracy.

10.4.2.2.7 Applicability to SMS

The applicability to SMS is constrained by data pool organization and availability of conversion equipment required.

10.4.2.2.8 Complexity and Risk

The complexity involves the requirements of the hardware necessary to make the read out work, and the method of data pool organization. The risks are those of dependability of equipment and the effects of erroneous data displays caused by failure.

10.4.2.3 Real-Time Logging/Real-Time Print

10.4.2.3.1 Description

The technique of real-time logging consists of collecting data in real-time and outputting this data to some external magnetic recording device (e.g., tape) and later converting with an off-line program the recorded data to readable hard copy. The technique of real-time print is similar to logging except the data is converted and outputted to hard copy in real-time.

10.4.2.3.2 Current Usage

This technique is currently in use in SLS, CMS, and LMS.

10.4.2.3.3 Characteristics

The particular parameters and sampling rates are selected by the user and sampled in real-time. The data is then either in the case of logging outputted unconverted to a magnetic recording device or in the case of print converted and outputted as hard copy. The maximum rate of sampling is usually that of the fastest parameter calculations in the simulation. In the case of real-time logging, an off-line program reads the recorded data and converts the data to a suitable format for hard copy.

10.4.2.3.4 Advantages

Large amounts of data at high rates may be gathered for eventual hard copy.

10.4.2.3.5 Disadvantages

The gathering of data and outputting uses central processor and channel time; this function also controls the use of external recording media.

10.4.2.3.6 New Advances

As central processors, channels, and recording media increase in speed, the number of parameters and rate of sampling may increase.

10.4.2.3.7 Applicability to SMS

This technique is applicable to SMS in the debugging of programs using large amounts of data at high computation rates.

10.4.2.3.8 Complexity and Risk

The complexity involves data gathering, service of recording equipment, and the degree of sophistication in the hard copy format. The risk involves the dependability of the recording media and the possibility of some simulation degradation due to a large number of parameters and high sampling rates.

10.4.2.4 Slow Time

10.4.2.4.1 Description

This technique consisting of slowing down the basic synchronous execution rates of the simulator to one slower than required for normal simulation.

10.4.2.4.2 Current Usage

This technique is available in the SLS.

10.4.2.4.3 Characteristics

This technique involves the selectable alteration of the synchronous exectuion rate of the basic simulation to one slower than normal.

10.4.2.4.4 Advantages

This allows for closer monitoring of some simulator functions which normally happen too fast. Also the effects of one function interrupting another may be eliminated.

10.4.2.4.5 Disadvantages

The true state of the computer during normal simulator operations is not present and a distorted effect of the interaction of some functions may be presented.

10.4.2.4.6 New Advances

New advances in timers and clocks allow for better selection of the degree of slow time performance desirable.

10.4.2.4.7 Applicability of SMS

This technique is applicable to SMS as a facility to evaluate the responce of systems to external actions.

10.4.2.4.8 Complexity and Risk

The complexity of implementation and use is proportional to the method that drives the basic simulator cycle. The risk involved is that of obtaining a distorted image of the effect of the interaction of simulator functions which take place in normal operation.

11.0 COMPUTATION SYSTEM

11.1 Overview

11.1.1 Statement of Problem

Past experience with simulations of complexity similar to the SMS has revealed that the computer system is one of the key elements, if not the heart of the simulation device. The SMS Computer Complex must be comprised essentially of capabilities which will afford adequate performance of the simulation task as well as time-sharing support functions. The complex must also possess sufficient spare in the capabilities to support additional simulation requirements as they arise as well as ease of expansion if and where necessary.

11.1.2 Definition of Applicable Areas

The major areas for consideration in the determination of the capabilities for the computer complex are: Simulation Software, Simulation Hardware, Time Sharing, System Software, and Flight Computer Simulation. The following paragraphs attempt to delineate the general requirements that must be satisfied.

11.1.2.1 Simulation Software

11.1.2.1.1 Supervisory

- Executive Functions - the executive functions of task priority management, program loading and sequencing, program and data pool linkage, frame timing and synchronization.
- Real Time I/O Functions - special or non-standard device access methods, intra-computer interface and I/O access, digital conversion equipment I/O routines, data conversion and/or formatting routines.
- Simulator Control Functions - the definition of simulation moding functions, flight computer control functions, master timing

capability, proposed handling of asynchronous demand functions, and special processing request handling.

11.1.2.1.2 Application

- Iteration Rates - the number of executions per second necessary to achieve the best system fidelity and response.
- Accuracy - the amount of significance required for system computations.
- Size - the amount of mainframe and external storage required by the simulation software.
- Bit Manipulation - bit oriented computations within the simulation software (e.g. boolean algebra, packing and unpacking).

11.1.2.1.3 Miscellaneous

- Data Base - data base generation and configuration control, data base modification, data base to program linkage, proposed data base listings, reports, and documentation.
- Reset Generator - methods for reset point generation and configuration control, reset point modification, and descriptions of reset generator reports.
- Simulation Software Support - data set generation, data set update and modification, simulation software maintenance, and simulation software configuration control.
- Hardware Diagnostics - hardware diagnostic routines, hardware failure reports, and hardware configuration control.
- Software Debug Aids - data log/delog, computer data snaps/dumps, program trace, and simulation software timing.
- Off-line CRT Display Support - CRT page compiler, CRT to data base linkage, CRT page test drivers, display data file maintenance and configuration control.

11.1.2.1.4 Micro/Macro Programming

11.1.2.1.4.1 Micro Programming

- Arithmetic Computations - the use of hardware to do actual arithmetic evaluations which require several normal computer instructions.
- Packing/Unpacking Data - the use of hardware to do the actual packing and unpacking of data consisting of bits.
- Data Conversions - the use of hardware to convert data of one type to data of another type.
- Speed - the amount of time required to complete a function.
- Complexity - the difficulty of implementing a function through micro programming.

11.1.2.1.4.2 Macro Programming

- Redundant Manipulations - recursive computations of basically the same set of operations.
- Data Conversions - changing data from one data type to another.
- Packing/Unpacking - merging or unmerging data consisting of information bits.
- Subroutine Replacement - the use of in-line macro expansion to replace the use of subroutines.
- Conditional Assembly - the ability to alter the source code generated dependent upon conditions existing at assembly time.

11.1.2.2 Simulation Hardware

11.1.2.2.1 IOS

- Crew Station Monitoring - factors such as proximity of IOS to crew station, duplicated crew station displays and controls, CRT display of crew station controls, student/instructor communications, and part task monitoring.

- Simulator Controls and Displays - simulator moding controls, simulation parameter display, hardware configuration/status display, control panel layout/placement, and external interface control and monitoring.
- Simulator Malfunctions - malfunction insertion/deletion, malfunction display, and crew response monitoring.
- Configuration Control and Display - part task configuration control, backup modes of operation, peripheral and DCE configuration control, and degraded configuration.

11.1.2.2.2 Crew Station

- Work Stations - instrument panel definition, instrumentation, primary/secondary flight controls, emergency egress, auxiliary furnishings, cabling, environmental controls, and work station inter/intra relationships.
- Simulator Features - part task work stations, IOS stations, simulator displays and controls, control response, control feedback, visual cues, aural cues, and IOS communications.

11.1.2.2.3 DCE

- Speed - the amount of time necessary to transfer and convert data.
- Packed/Unpacked Data - data consisting of many bits or of one bit per unit of transfer or conversion.
- Noise - the effect on data validity due to electrical impulse.
- Scaling - the conversion and limiting of data of one type to a type suitable for hardware use.

- Multiplexed/Non-Multiplexed Messages - data units to or from the hardware may or may not have data for one device merged with data for another device.
- Amount - the physical total of data to or from the hardware.

11.1.2.2.4 Visual

- Response - the amount of time required for best response of the visual system to crew station actions.
- Smoothness of Motion - the degree of evenness of visual image movement without jerkiness.
- Data Format - the form which data driving the visual equipment must assume.
- Data Computation Complexity - the intricacy of the equations necessary to compute the data required to drive the visual equipment.
- Phase Transition - the changing of from one display form to another.

11.1.2.2.5 Motion Base

- Response - the amount of time required for best response of the motion base to crew station and other external demands.
- Smoothness of Motion - the degree of evenness of motion without jerkiness.
- Data Format - the form which data driving the motion base must assume.
- Data Computation Complexity - the intricacy of the equations necessary to compute the data required to drive the motion base.

11.1.2.2.6 Control Surface/Auto Throttle Loading

- Response - the amount of time required to give best response to changes in the loading of control surfaces and auto throttle.
- Smoothness of Load Change - the degree of evenness of changes in loading without jerkiness.
- Data Format - the form which the data for the loading equipment must assume.
- Data Computation Complexity - the intricacy of the equations necessary to compute the data required for loading.

11.1.2.3 Time Sharing

11.1.2.3.1 Remote Terminal Processing

- Terminal Equipment - peripheral devices, display equipment, and terminal I/O channel hardware.
- Terminal Capability - remote job entry, file update features, priority interrupt, and response time.
- Terminal Interfaces - the terminal/CPU interface, file access capability, and terminal-to-terminal communications.

11.1.2.3.2 Batch Processing

- Job Entry - input and output medium/equipment, job collection and storage facilities, and batch job queue control capability.
- Job Initiation and Execution - job scheduling, job priority, computer and terminal resource management, and peripheral device allocation.
- Batch Job Accounting/Output - resource utilization, CPU utilization, output scheduling, and batch priority control.

11.1.2.3.3 Management Information System

- Inquiry/Response Time - the amount of time required for a reasonable inquiry and response.
- Inquiry/Response Data - the format and amount of data required for an inquiry and response.
- Size - the amount of mainframe and mass storage required.
- Execution Time - the amount of processor time required to execute.
- Data Sets - the complexity of data organization and amount required to support the system.
- Terminal Control - the processing of inquiry and responses from the various local and remote terminals.

11.1.2.3.4 Interactive Programming

- Inquiry/Response Time - the amount of time required for a reasonable inquiry and response.
- Inquiry/Response Data - the format and amount of data required for an inquiry and response.
- Size - the amount of mainframe and mass storage required.
- Execution Time - the amount of processor time required to execute.
- Data Sets - the complexity of data organization and amount required to support the system.
- Terminal Control - the processing of inquiry and responses from the various local and remote terminals.

11.1.2.4 System Software

11.1.2.4.1 Operating System

- Job Management - job scheduling, job initiation, and job termination.

- Task Management -task queuing priority interrupt, and task switching.
- Contents Supervision - program loading, overlay support, and program linkages.
- Real Time I/O - I/O interrupt servicing I/O access methods, data buffering, and device switching and independence.
- Resource Management - main storage supervision, device allocation, storage protect support, and task priority supervision.
- Extended Capabilities - time shared processing, background processing, device sharing, debug facilities, local/remote batch processing, terminal servicing, time management, and external interrupt handling.

11.1.2.4.2 Language Processors

- Efficiency of Object Code - the amount of storage and time required for the object code produced from the source code.
- Processing Speed - the amount of time required to produce object code from source code.
- Size Requirements - the amount of mainframe and mass storage required by the processor to operate.
- Symbol Capabilities - the number, length, and types of symbols allowed by the processor.
- Conditional Assembly/Compile - the ability to alter source code at assembly or compile time.
- External Referencing - the ability to reference from one separate program to another.
- Data Sets - the organization and number of data groups required for the processor to operate.

- Supervisory Requests - the ability of the processor to use and allow requests to the system supervisor.
- Processor Perculiarity - items which are unique to a specific processor which may offer advantages or disadvantages.
- Debug Aids - facilities in the processor which allow trouble shooting of the processed program.

11.1.2.4.3 Peripheral Equipment Support

- Interface Complexity - the intricacy of interfacing with equipment which is considered standard or non-standard to the computer system.
- Multiplexed/Non-Multiplexed Data Transfer - the facility for merging or non-merging data to or from various equipment.
- Servicing Overhead - the amount of storage and time required in the main processor to control the equipment.
- Data Compatibility - the amount of difference between the data format of device and computer or device and device data.
- Peripheral Device Speed - the speed with which the peripheral devices can process and transfer data.

11.1.2.5 Flight Computer Simulation

11.1.2.5.1 Flight Hardware Interface

- Data Exchange - compatibility of data between the flight computer and the simulation computer.
- Flight Computer Loading - method for loading the flight program. This would also include modification of the flight program.
- Commands and Moding - provision for communicating flight computer commands and moding sequences to the Flight Computer.

- Flight Program Debug - Facility for dumping and/or monitoring the Flight Computer and Flight Program.

11.1.2.5.2 Interpretive Computer Interface

- Data Exchange Rates - the number of times per second data must be exchanged between the simulation environment computer and the on-board computer.
- Data Exchange Formats - the complexity of converting from the data format of the simulation environment computer to the on-board computer or reverse.
- Moding Control - the amount and complexity of communicating moding control information between the environment computer and the on-board computer.

11.1.2.5.3 Host Computer

- Flight Computer Speed - the relative differences in execution speed between the real world flight computer and the host computer.
- Instruction Translation - the process of producing host computer instructions to flight computer instructions.
- Data Type Compatibility - the differences between flight computer data and host computer data.
- Interrupts - the interrupts that are peculiar to the flight computer.
- Synchronous/Asynchronous Operations - the performance of the host computer during the cyclic and non-cyclic flight computer operations.
- Hardware Modifications to Host Computer - any changes to the host computer required by peculiarities to the flight computer.

- Modification/Generation of Languages Processors - changes to existing or development of new processors to translate flight computer instructions to host computer or to recognize new hardware modifications to the host computer.
- Micro Programming - the use in the host or flight computer of micro programmed functions.

11.2 Techniques

11.2.1 Supercomputer/Uni-processor

11.2.1.1 Description

This technique is one using a large, fast computer to perform all simulator computations, all simulator support functions, and all time-sharing functions. This technique is represented in Figure A.

3

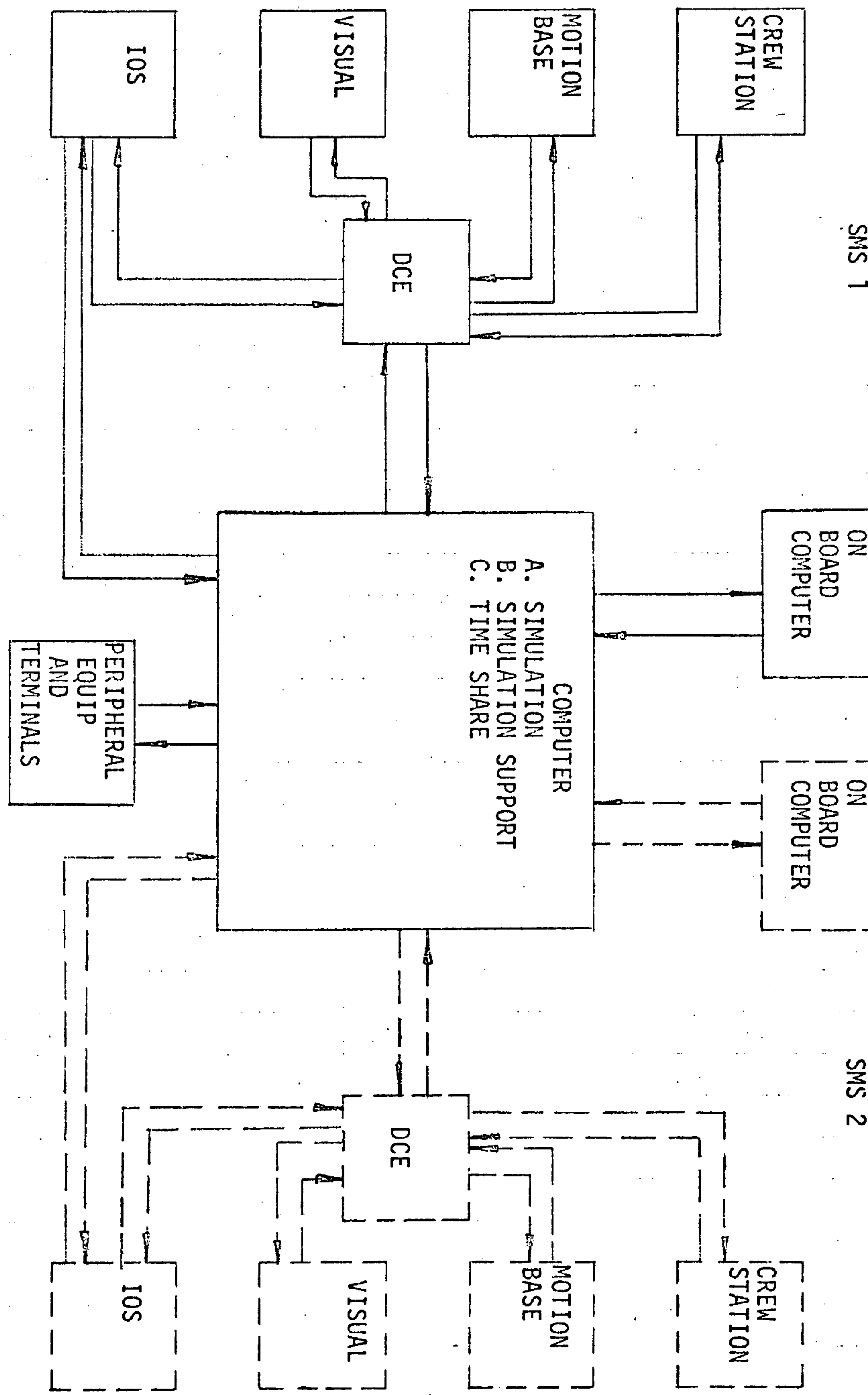


FIGURE A SUPERCOMPUTER/UNI-PROCESSOR

11.2.1.2 Current Usage

A supercomputer is not currently in use.

11.2.1.3 Characteristics

The general characteristics of the supercomputer are contained in the following table:

		CDC STAR 100
COST:		No Information Available
Central Processor:		
Memory:	Cycle Time	1.2 Microsecond
	No. of Words	1,048,576 (64 bit)
Number Base		Binary, decimal
Execution Speed		100,000 million results/second
Index Registers:	Number	Available, but number not known
	Hardware or Memory	Hardware
Indirect Addressing	(Yes, No)	No
Floating Point	None	
Hardware	Standard	X
	Optional	
Number of Instructions		220
Addresses/Instruction		1 or 3
Interrupt Control:	No. of Lines	17
	No. of Registers	--

Special Features: Virtual memory, large array processing, string processing.

Communication Controls: No data available.

Peripheral Devices No data available.

11.2.1.4 Advantages

The major advantage to this technique is that all computer functions are housed in one computer; thus, all problems inherent in synchronization and interfacing of several computers are avoided.

11.2.1.5 Disadvantages

The major disadvantages to this approach are:

a) A single failure in the computer will result in the entire computer complex being down.

b) If the data being operated on by the computer is not arranged in large arrays and strings, the actual instruction execution time of the computer will degrade to an average of approximately 1.3 microseconds for the supercomputer.

11.2.1.6 New Advances

There is currently no information available or any new advances which may be pending.

11.2.1.7 Applicability to SMS

The supercomputer has three major disadvantages which make it not applicable to SMS. These are:

a) A single point failure will result in losing both simulation and time-sharing ability. Also, if two (2) simulators are driven by the same computer, then both simulators will be down with no backup.

b). The data used in SMS will not be arranged in large arrays and strings. The type of basic equations to the simulation are most efficient with single unit data; then the average execution speed is degraded to an average of 1.3 microseconds per second.

c) The addition of a second SMS may overload the computer and the result could require the addition of another computer.

11.2.1.8 Cost/Complexity and Risk

- Cost - The initial cost of the supercomputer will be in the tens of millions of dollars, making the money investment higher than other possible techniques.

- Complexity - The complexity of the supercomputer configuration is less than the multiprocessor configuration; however, the software complexity of communication between possibly two (2) simulators and the time-sharing system is high.

- Risk - The major risk to the supercomputer arises from the consideration that there are currently none in use. This involves all problems inherent in any new hardware/software system which is not in wide use. Thus, many problems, which are usually eradicated from a system which has been in use, may appear.

11.2.1.9 Expansion Capability

Two methods of expansion are available in this approach.

a) Expand to full memory capability, if possible.

b) Add a second computer.

11.2.1.10 Environmental Constraints

The major environmental constraints are:

a) Available floor space.

b) Available power.

c) Air-conditioning requirement.

d) Water cooling/condensing facilities.

11.2.2 Multiprocessor

11.2.2.1 Description

This technique involves the use of two or more integrated processors which make a total CPU resource (see Figure B). The processing requirements of the total job would be divided between these processors in some logical manner. In the SMS case, this might result in one processor to handle the requirements of each SMS and one processor for batch and terminal requirements. This does not mean, however, that the processors could not be functionally interchanged or accept other responsibilities.

11.2.1.2 Current Usage

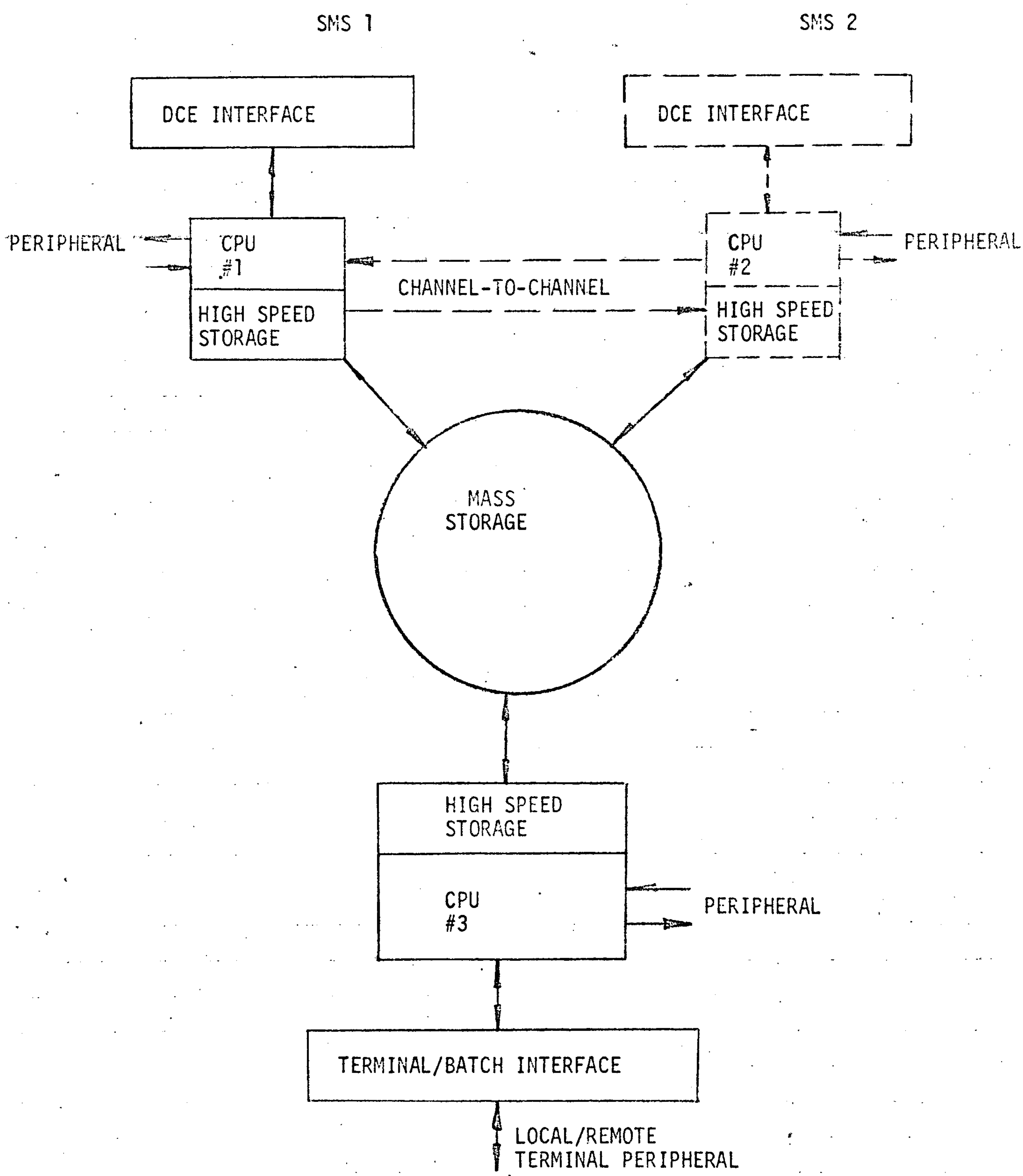
Multiprocessor systems are widely used over a variety of applications such as Airline Reservation Systems, Hospital Administration and Management, Hybrid/Simulation systems, Nuclear Applications, Real-time Operations, and Simulation of Continuous Dynamic Systems.

11.2.1.3 Characteristics

The characteristics of several of the candidate configurations is found in attachment 1. It should be noted that the prices are for the central processor only, since the definition of the peripheral requirements is not yet known.

11.2.1.4 Advantages

One of the advantages of a multiprocessor system is the elimination of single point failures. Since most of the equipment is duplexed, the ability to continue critical functions is guaranteed. This is predicated on the assumption that the data conversion equipment for each simulation has an electrical switch for connection to any of the central processors in the computer complex. The ability to expand processing capability in a modular fashion is also of great significance.



MULTIPROCESSOR CONFIGURATION
FIGURE B

11.2.1.5 Disadvantages

Care must be taken in system design to insure that the advantages of a multiprocessing system can be realized. Synchronization between functions and data must be insured where critical to the application.

11.2.1.6 New Advances

The advent of monolithic circuitry has enhanced the speed of communication in a multiprocessing system.

11.2.1.7 Applicability to SMS

The total processing needs and ability to functionally separate processing requirements make the multiprocessing technique particularly attractive to the SMS application. In addition, the ability to provide total SMS processing requirements in a modular fashion may be of significant importance to long term SMS cost and schedule constraints.

11.2.1.8 Cost/Complexity and Risk

Since the multiprocessing technique is widely accepted for a variety of applications, the cost/complexity and risk factors are fairly well defined. The cost/complexity of a multiprocessing system capable of handling the SMS requirements is necessarily high in that it would be an extremely large and powerful complex. The risk associated with implementing such a system, however, is relatively low due to the fact that current state-of-the-art hardware and software technology is involved.

11.2.1.9 Expansion Capability

As previously stated, one of the advantages of a multiprocessing system is its ability to be expanded in building block fashion. Compatibility of the total system can be maintained during all phases of its development.

11.2.1.10 Environmental Constraints

An environment normally expected of a computer complex is the only constraint expected in the SMS complex.

Attachment 1

System: 370/168

COST:

Type	Model/ Special Feature	Description	Monthly Availability Charge (Per Unit)	Purchase Price (Per Unit)
		System 370/168		
3168	J	1 Megabyte CPU	53,800.	2,611,900.
or, 3168	K	2 MB CPU	59,000.	2,841,700.
or, 3168	KJ	3 MB CPU	64,400.	3,081,300.
or, 3168	L	4 MB CPU	69,600.	3,311,100.
2880	2	Two Block MPX Channels	4,640.	218,080.
	#1862	Channel Indirect Data Addressing	300.	14,100.
2870	1	Multiplexer Channel	2,195.	103,500.
	#1861	Channel Indirect Data Addressing	200.	9,430.
3066	2	System Console	3,345.	160,560.
3067	2	Power & Coolant Distribution Unit	2,480.	119,040.

CPU: Memory
Cycle time: 80ns; Buffer = 160 ns/8 bytes; Main Storage = 480NS

#Words: Model = J = 262K, K = 524K, KJ = 786K, L = 1048K

Word Length	
Bits/Char	8
Bits/Word	32
Number Base	binary
Execution Speed	Approximately 20-40% faster than the IBM 360/165.
Fixed Add	(Not Available)
Multiply	"
Divide	"
Index Regs	
Number	15

Attachment 1 continued

Hardware or Memory   Hardware

Indirect Addressing   NO

Floating Pt. Hardware

None

Standard   YES

Optional

No. Instructions   157

Address/Instr   1

Interrup Control   Hardware

No. Int. Levels   8   (2 bytes/code)

Special Features: Virtual Storage (DAT), High Speed Buffer Storage, Extended Control Mode, Extended Multiply/Divide, 4 Way Interleave Storage Reference.

Communications Controls: # Channels: Base = 7, Ext = 12

Max No. of Terminals 3705   (64 - 352) lines

Min. Data Rate (bits/sec)   N/A

Max. Data Rate (bits/sec)   376KB/sec

Buffer Size (bits)   16K - 240K

Full Duplex   Yes

Peripheral Devices:

Mag Tape Density (bits/inch)   556-1600

Tape Speed In/Sec   75-200

Punched Cards Read Speed (Cards/Min)   800-1200

Punch Speed (Cards/Min)   100-500

Paper Tape Punch Speed (Char/Sec)   ---

Read Speed (Char/Sec)   ---

Attachment 1 continued

Line Printer	No. of Columns	120-132
	Speed (lines/min)	600-2000
Disk Storage	Capacity (Char) 2305	5.4-22.4 MB
	Access Time	2.5 - 5 MS
Mag Cards	Capacity (Char)	---
	Access Time	---
Inter-Active Display	Numberic	Yes
	Alphanumeric	Yes
	Graphic	Yes
	Keyboard	Yes
	Light pen	Yes
Console Typewriter		Yes

Attachment 1 continued

System : CDC 7600-18

COST:	Buy	CPU
	Lease	N/A
	Rent	CPU
CPU:	Memory (SCM = Small Core Memory, LCM = Large Core Memory)	
	Cycle Time	275 ns (SCM), 1760ns (LCM)
	#Words	32,768 - 65,536(SCM), 256K - 512K (LCM)
	Word Length	
	Bits/Char	6
	Bits/Word	60
	Number Base	Octal
	Execution Speed	
	Fixed Add	55.0 NS
	Floating Multiply	137.5 NS
	Floating Divide	550,0 NS
	Index Regs	
	Number	8
	Hardware or Memory	Hardware
	Indirect Addressing	Yes
	Floating Pt. Hardware	
	None	
	Standard	Yes
	Optional	
	No. Instructions	82 (CPU), 74 (PPU)
	Address/Instruction	1
	Interrup Control	Yes

Attachment 1 continued

No. Int. Levels	1/PPU (15 Max)	
Special Features	PPU's	
Communications Controls:		7 Channels expandable to 15
Max No. of Terminals		(16-48) lines/subsystem
Min Data Rate (bits/sec)		N/A
Max Data Rate (Bits/sec)		500 KB/sec
Buffer Size (bits)		(128 or 256) 60 bit words
Full Duplex		Yes
Peripheral Devices:		7611 Station
Mag Tape	(Density (bits/inch)	(200-1600) BPI
	Tape Speed	(37.5 - 150) in./sec.
Punched Cards	Read Speed (cards/min)	1200 CPM
	Punch Speed (cards/min)	250
Paper Tape	Punch Speed (Char/sec)	---
	Read Speed (Char/sec)	---
Line Printer	No. of Columns	136
	Speed (lines/min)	1200 LPM
Disk Storage	Capacity (Char)	Approx: 845 Million
	Access Time	Avg. 100 msec.
Mag Cards	Capacity (Char)	---
	Access Time	---
Inter-Active Display	Numeric	Yes
	Alphanumeric	Yes
	Graphic	Yes
	Keyboard	Yes
	Light pen	Yes
Console Typewriter		Yes

c

Attachment 1 continued

	System: Univac 1110
COST: Buy	$3,000,000 Approximately (Full blown CPU)
Lease	N/A
Rent	$75,000 Approximately
CPU: Memory	
Cycle Time	280ns Read, 480ns Write
#Words	(98-262)K Primary, (262-1048)K Extended
Word Length	
Bits/Char	6
Bits/Word	36
Number Base	Octal
Execution Speed	
Fixed Add	300ns
Multiply	2.7us
Divide	5.4us
Index Regs	
Number	15
Hardware or Memory	Storage (hidden)
Indirect Addressing	Yes
Floating Pt. Hardware	
None	
Standard	Yes
Optional	
No. Instructions	200+
Address/Instruction	1
Interrupt Control	Hardware
No. Int. Levels	3

Attachment 1

Special Features		Independent Logic Units, 112 word stack
Communications Controls:		
Maximum number of terminals		16/line modem
Minimum data rate (bits/sec)		
Maximum data rate (bits/sec)		144 KB/sec.
Buffer size (bits)		(32K-131K) Bytes
Full Duplex		Yes (# Max/2)
Peripheral Devices:		
Mag Tape Density (bits/inch)		(200-800) BPI
Tape Speed		120 in/sec
Punched Cards	Read Speed (cards/min)	900
	Punch Speed (cards/min)	300
Paper Tape	Punch Speed (char/sec)	--
	Read Speed (char/sec)	--
Line Printer	No. of Columns	N/A
	Speed (lines/min)	N/A
Disk Storage	Capacity (Char)	29,176K/pack (2-8)/subsystem
	Access Time	82.5ms Avg.
Mag Cards	Capacity (char)	--
	Access Time	--
Interactive Display		
	Numeric	Yes
	Alphanumeric	Yes
	Graphic	Yes
	Keyboard	Yes
	Light Pen	Yes
Console Typewriter		Yes

11.2.3 Dedicated Processor

11.2.3.1 Description

The dedicated processor technique is one that utilizes independent processors for driving the simulator and simulator support/time sharing. This technique is represented in Figure C.

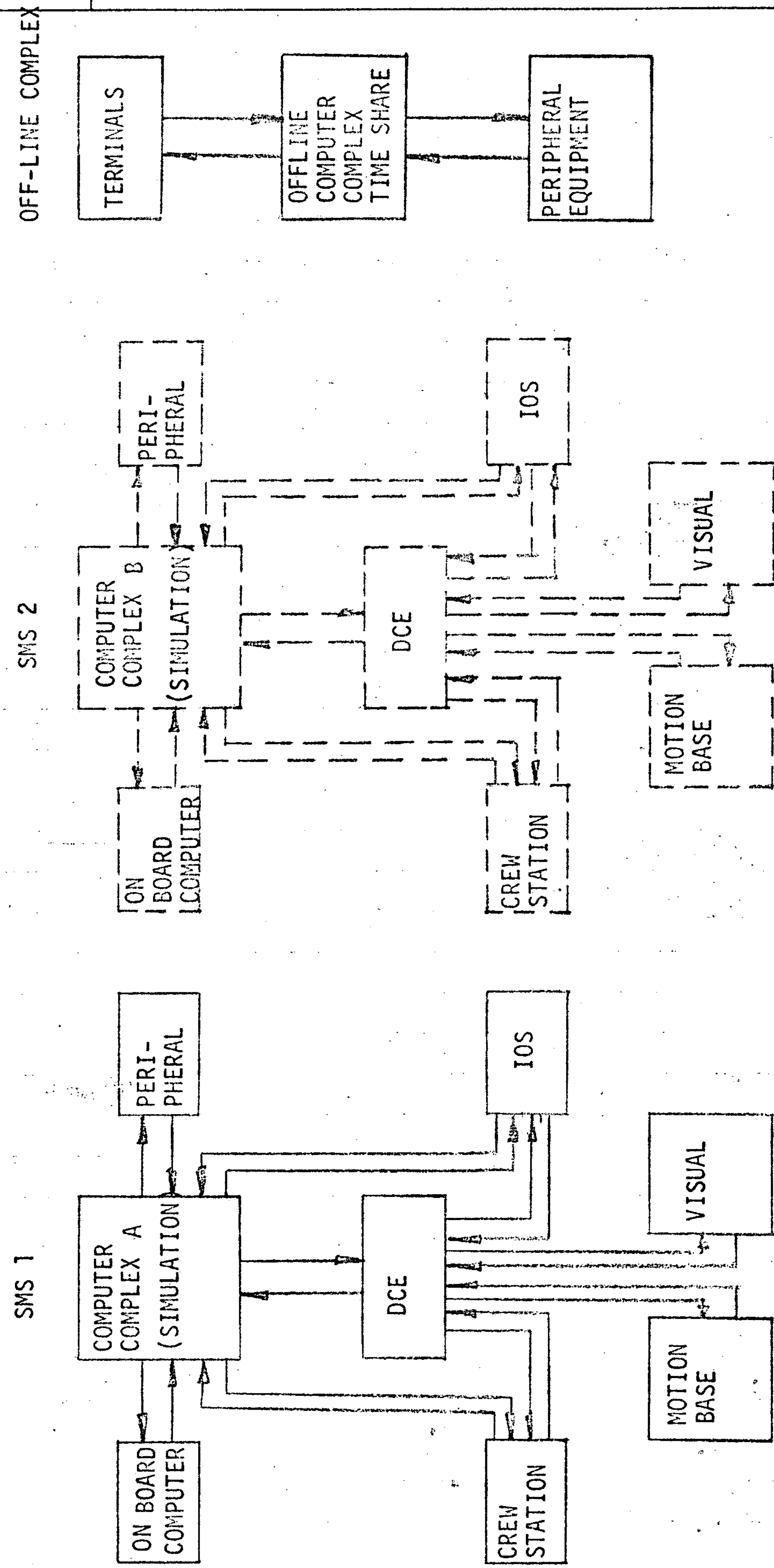
This technique assumes that the on-line/off-line complexes are too electrically distant to allow the incorporation of a unit switching device to allow a rapid reconfiguration of hardware in the event of failure.

11.2.3.2 Current Usage

Current usage of the dedicated processor is illustrated by the Lunar Mission Simulator and the Command Module Simulator with their off-line support complex.

11.2.3.3 Characteristics

The following table illustrates the various characteristics of processors suitable for the dedicated processor technique.



DEDICATED PROCESSORS

FIGURE C

CENTRAL PROCESSOR		Xerox Sigma 8	Xerox Sigma 9	SEL 86
Memory:	Cycle Time	850 NS	850 NS	600 NS
	No. of Words (32 bits/word)	16K - 128K	64K - 512K	8K - 128K
	No. Access Ports/Module	12	12	4
Number Base		Hexidecimal	Hexidecimal/Decimal	Hexidecimal
Execution Speed; Fixed Point	Add	0.73	0.73	1.2
	Multiply	3.32	3.78	6.0
	Divide	9.50	9.48	10.8
Index Registers:	Number	7	7	3
	Hardware or Memory	Hardware	Hardware	Hardware
Indirect Addressing (Yes, No)		Yes	Yes	Yes
Floating Point Hardware	None			
	Standard	X	X	
	Optional	X	X	X
Number of Instructions		102	112	152
Addresses/Instruction		1 or 2	1 or 2	1
Interrupt Control	No. of Lines	224	224	128
	No. of Registers	---	---	---
Special Features		Interpret Instruction Multiprocessors With Shared Memory	Virtual Memory Interpret Instruction Multiprocessors With Shared Memory	Multiprocessors With shared Memory

		Xerox Sigma 8	Xerox Sigma 9	SEL 86
Communication Controls				
Max No. of Terminals		200	200	Not Available
Min Data Rate (Bits/sec)		60	60	Not Available
Max Data Rate (Bits/sec)		120KC	120KC	Not Available
Buffer size (bits)		8	8	Not Available
Full Duplex		Yes	Yes	Not Available
Peripheral Devices				
Magnetic	Density (bits/inch)	200-800	200-800	556-800
Tape	Tape Speed (inches/sec)	20-120KC	20-120KC	75-150
Punched	Read Speed (cards/min)	200-1500	200-1500	300-1000
Cards	Punch Speed (cards/min)	100-300	100-300	100
Paper	Punch Speed (char/sec)	10-150	10-150	1100
Tape	Read Speed (char/sec)	15-300	15-300	600
Link	No of columns	132	132	132
Printer	Speed (lines/min)	225-1500	225-1500	300-600
Disc	Capacity (Char/pack)	24.5MB	24.5MB	260KB - 24MB
Storage	Access Time (msec)	75.0	75.0	8.6 - 32
Interactive	Numeric	Yes	Yes	No
Displays	Alphanumeric	Yes	Yes	No
	Line Drawing	Yes	Yes	No
	Keyboard	Yes	Yes	No
	Light Pen	Yes	Yes	No
Console Typewriter		Yes	Yes	Yes

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11.2.3.4 Advantages

The major advantages to the dedicated processor technique are:

a) cost - the computers used in this technique are usually some of the least expensive on the market.

b) operating system - the operating systems required for this technique are very simple.

c) interfacing and expansion - the interfacing and expansion of additional memory or computers is very simple.

11.2.3.5 Disadvantages

The major disadvantages to the dedicated processor technique are:

a) a single failure in one computer dedicated to the simulation may cause the simulator to be down without a switch to an off-line computer as a backup to keep the simulation going.

b) a single failure in the off-line complex may result in the off-line complex being down without the ability to use the remaining core and time in the simulation computers to act as backup to the off-line.

11.2.3.6 New Advances

There is currently no information available about any new advances which may be pending.

11.2.3.7 Applicability to SMS

The dedicated processor technique is generally applicable to SMS. However, the major drawback to this technique is the availability of instantaneous information from remote inquiry as to the status of the simulation through
information from remote inquiry as to the status of the simulation through
information available to the time sharing organization. Also, online changes to the simulation would not be possible from remote entry. Lastly, a failure in

a simulator complex computer could not receive backup support from the off-line complex.

11.2.3.8 Cost/Complexity and Risk

The cost of a dedicated processor simulator complex and off-line complex will be in the four to six million dollar bracket. The original complexity of interfacing several computers is low due to the specific design to allow this capability. However, as the simulation task continues to grow the amount and complexity of interfacing and synchronizing also grow, the point might be reached which causes the risk of a higher cost than another technique. The risk of a multiprocessor configuration over the dedicated processor should be low, since the concepts and computers used are designed for multiprocessor environments and have been in use for several years.

11.2.3.9 Expansion Capability

The methods of expansion available to the dedicated processor apply to both simulator complexes and the off-line complex. They are:

a) Computer time expansion - addition of one or more computers.
b) Computer storage expansion - addition of memory to existing computers and/or the addition of one or more computers.

11.2.3.10 Environmental Constraints

The major environmental constraints are:

a) available floor space
b) available power
c) air conditioning requirements

11.3 Trade-Offs and Recommendations - The following is the recommendation in order by best technique to use.

11.3.1 Multiprocessor - This approach is the best because it allows for a backup capability from main simulation computer to the time sharing front end computer in the event of a failure. Even though a failure would cause some degradation in the system, training and some time sharing could continue.

11.3.2 Dedicated Processor - This approach is sound due to lowness of cost; however a failure in one complex causes the loss of that complex with no backup capability from another complex.

11.3.3 Uni-Processor - This approach is least desirable due to: a) cost; b) a single failure causes loss of all simulator training and all time sharing facilities; c) possible system overload such that no time sharing could be supported.

The desirability of the configuration techniques as listed in the above paragraphs should not be construed as definite at this time because the computer loading for the SMS Simulation Software is still in a state of flux.

11.4 References and Assumptions

1. The Systems Family of 32 list Price/Performance Leaders, Systems Engineering Laboratories.

2. Reference Manual System 85 Computer, Systems Engineering Laboratories, December, 1971.

3. Authorized Federal Supply Schedule Price List General Services Administration, Federal Supply Service, Systems Engineering Laboratories.

4. Xerox Sigma 9 Computer Reference Manual, Xerox Data Systems, October 1971.

5. Sigma 8 Computer Reference Manual, Xerox Data Systems, January 1971.

6. Control Data Star - 100 Computer System, Control Data Corporation.

7. Xerox Data Systems Authorized Federal Supply Price List, Xerox Data Systems.

8. Univac 1110 System Processor and Storage, Sperry Rand Corp.

9. Control Data Cyber 70 Series - Computer System Applications Guide, CDC

10. System/370 Model 168 - Facts Folder, IBM

11. IBM System/370 Model 168 - Functional Characteristics, IBM

12. IBM Virtual Machine Facility/370: Introduction, IBM

13. OS/VS1 Planning and Use Guide, IBM

14. A guide to the IBM System/370 Model 168, IBM

15. IBM System/370 Principles of Operation, IBM

16. Control Data 7600 Computer Systems, CDC

17. Control Data Corporation - 7600, CDC

18. Univac-Uniscope 100 Display Terminal, Sperry Rand

19. Univac 1100 Series 8414/8411 Disc Subsystems, Sperry Rand

20. Univac-Uniservo VIIIC Mag Tape Subsystem, Sperry Rand

21. Univac-Punched Card Subsystem, Sperry Rand

22. Univac-Advanced Graphic Display System, Sperry Rand

23. IBM System/370 Authorized Federal Supply Schedule Price List, IBM

24. Sperry Rand Authorized Federal Supply Schedule Price List, Sperry Rand

12.0 Control "Feel" Simulation

12.1 Overview

Aircraft control systems comprise all the mechanical, electrical, and hydraulic elements that convert control motions into control surface deflections, gear position or power output. As such, they transmit the pilot's input to the airframe or power plant. The pilot must be provided with some anticipation of the degree to which the aircraft will react to his input. Visual attitude references such as horizon, clouds, and instruments may indicate that a maneuver is too abrupt, but only as the maneuver occurs. A more immediate warning is provided to the pilot, in part, through the response of the primary flight controls (stick, wheel, and pedal).

The pilot is aware of two facets of response to his input to the primary and some secondary controls: namely, movement and force. In some flight conditions, the stick movements can be considerable, but in most cases, particularly at high speed and with aft center of gravity, the stick movement is barely perceptible. For this reason, stick forces are generally conceded to be the most important indication of the violence of a maneuver. This occasionally applies to some secondary controls such as nosewheel steering and stabilizer trim, but generally most secondary controls reflect some type of system friction, return spring, position detent, breakaway or over-center toggle action which is a direct result of the operation of switches, valves, latches, etc. and does not vary with aerodynamic effects.

A prime objective of training utilizing a flight simulator is to familiarize the pilot with control forces required to provide a change in the aircraft attitude or motion. Some of these forces are functions of the aircraft velocity, configuration, and center of gravity. These forces also vary considerably between types of aircraft. Thus, the accurate response of the control loading system is one of the most valuable training features of a flight simulator.

So, it follows, that the simulator system must represent a math model of the aircraft system in order to produce realistic "feel" simulation. It must be capable of producing all of the variables, spring constants, preload, inertia and backlash that the aircraft system is capable of. Each item that is not simulated will reduce the accuracy of response. Each time a constant is used to mathematically simulate a variable, the degree of simulation is compromised. Good simulation requires that the aircraft system be mathematically analyzed for each component and each of these mathematical terms must be duplicated in the simulator system.

12.2 Techniques

Methods for control "feel" simulation that have been tried and evaluated are described in paragraphs 12.2.1 through 12.2.4. Except for the special applications noted, the methods described in paragraphs 12.2.2 through 12.2.4 lack accuracy and the flexibility required for primary control systems. These latter techniques, used singularly or in combinations, have become part of numerous designs for secondary controls, such as throttle, engine start, flap, speed brakes, fuel shutoff, stab, trim, fuel dump, emergency landing gear, landing gear, arresting hook, APV, etc.

12.2.1 Hydraulic Servo

12.2.1.1 Description

The hydraulic servo is the most practical control loading device for primary control applications due, in part, to the advent of reliable solid-state circuitry.

The complete hydraulic system is implemented in such a way that the resultant force of the control is strictly a function of the computer program. This is accomplished by two separate systems working simultaneously.

First, a second-order differential equation for pilot control force (stick, wheel, pedal, etc.) is solved in a computer. The pilot's applied force is sensed by a force transducer (located between the control and the hydraulic cylinder) and is the input to the computer. The computer then solves for the control velocity and control position with reference to the inertia, spring, and friction coefficient data that are programmed.

Second, the hydraulic servo is designed to follow accurately both velocity and position inputs. For example, as the pilot applies a force to a control, at first it cannot be moved because of the hydraulic fluid in the cylinder. The force applied by the pilot is transmitted into the force transducer, which applies a DC input to the computer. The computer then computes velocity and position, which is returned to the servo. The servo amplifier opens the hydraulic valve, allowing the hydraulic fluid to flow into the cylinder, and the control to be driven virtually simultaneously with the applied force.

Because the inertia and friction change under different conditions, means of varying the inertia, viscous friction, and coulomb friction are provided through manually variable adjustment potentiometers. Since, to maintain system stability, control damping is a function of the inertia and spring constants, the system is designed so that the damping coefficient can always be programmed to provide critical damping.

In addition, the mechanical position limits and velocity limits of the control can be simulated and may be varied through adjustment potentiometers. As in the case of the pilot's stick, the control spring force coefficient can be quite complex, being a function of centering spring, Mach number, wing flap deflection, dynamic pressure, and trim. In order to generate this spring force coefficient, to obtain the highest fidelity in simulating control forces, a single digital multiplier to simulate dynamic pressure or a function generator/ multiplier containing three multipliers (including dynamic pressure) can be incorporated in the system.

Because of the large forces available in a hydraulic control loading system and its high frequency response, a hydraulic safety device needs to be provided on each loading unit to provide protection for the pilot. This device should sense the differential pressure in the hydraulic system and, when a preset value is exceeded, will essentially instantaneously lock the cylinder hydraulically. The hydraulic safety device will thus provide positive protection against electronic power supply failure, erroneous transient signals, and any failure in the hydraulic system ranging from servo valve failure to actual rupturing of a hydraulic line. An electronic detector system may also be used to provide this protection. However, the electronic type does not provide 100% protection for all modes of possible failure, such as contaminated valves, blown seals or failed mechanical components. The implementation of both hydraulic and electronic safety devices has also been accomplished. In addition, the system should be equipped with suitable sequence and time-delay circuitry, so that upon turn-on or reactivation of the equipment, the controls will slowly and smoothly seek the computer position and will not be subject to violent and sudden movement. There should be, in other words, absolute fail-safe protection for trainees and maintenance personnel.

12.2.1.2 Current Usage

Most simulator manufacturers use control loading hydraulic servos for primary control applications, as well as certain secondary controls, such as nose wheel steering and stabilizer trim where castering or aerodynamic loads are reflected at the pilot input.

12.2.1.3 Characteristics

Hydraulic control systems possess the stiffness that is required when simulating the preloaded spring force or control limits that exist in most aircraft primary control systems. A cylinder full of oil looks infinitely stiff to

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the piston (not true in practice due to the bulk modulous of the hydraulic oil), while either a cylinder of gas (except at very high pressures) or a magnetic field looks very soft and springy.

12.2.1.4 Advantages

1) The hydraulic servo offers 10-to-20 times higher torque-to-inertia ratio than electrical servos; thus, hydraulic servo systems are more responsive.

2) The hydraulic servo can be made mechanically stiff, in relation to the load and, since the resonant frequency of the load, acting against the equivalent spring force of the driver, introduced a major limitation, the spring force should be as stiff as possible. If it is necessary, as it usually is, to hold the load fixed in position until it is desired to move, less loop gain will be required with a hydraulic servo than with either a low-pressure pneumatic or an electric servo.

3) The hydraulic servo system also has the capability for control movement in response to autopilot input and during "playback" -- a feature which permits the instructor to "replay" a portion of the trainee's flight or to demonstrate maneuvers using "taped" flight during which certain controls move in a "hands-off" mode.

12.2.1.5 Disadvantages

High initial cost and safety considerations.

12.2.1.6 Prospects for Improvement

Continued use of hydraulic servo systems will, no doubt, continue to reflect state-of-the-art improvements as in the past in various areas of mechanical and electrical design and computer application.

12.2.1.7 Applicability to SMS

SMS control requirements might conceivably be comparable to conventional aircraft of equal size and weight, where this type of system "feel" simulation has been applied with great success.

12.2.1.8 Cost/Complexity and Risk

Risk is minimal using this approach. No new technological break-throughs are required. The technique has been used and proved very reliable and effective in reproducing control "feel" and control response experienced on a wide range of vehicle simulators.

The hardware complexity for a system for SMS can be approximated as requiring a servo assembly for each primary control if conventional state-of-the-art type controls are used in the SMS, in addition to those required for certain secondary controls as deemed necessary when these controls are defined. Hydraulic power is generally available from the same hydraulic power unit that is provided for the motion system.

12.2.2 Pneumatic System

12.2.2.1 Description

Closed-loop pneumatic systems are not practical because of the characteristic low-frequency response available from operational low-pressure systems. High-pressure systems would have better low-frequency characteristics, but are not practical because of extremely high cost availability of high pressure hardware components, and safety considerations. This type system will not be discussed further.

Open-loop pneumatic systems have been used for primary control systems where tolerances are liberal, but it becomes very difficult, due to the compress-ibility of air, to generate large forces that are a function of control position. These systems must also be supplemented with actual springs when preloaded springs are used in the aircraft's control system. A variation in the force gradient, due to dynamic pressure, is practical when the accuracy requirement is not string-ent, but simulated control limits are almost impossible with this type of system.

The use of pneumatics in certain secondary controls has proven to be an efficient method of moving a control lever rapidly or simulating the anti-skid feature of some toe brake systems by supplying compressed air to the opposite side of a spring-loaded piston, thereby depleting the effect of the spring at the pedals and allowing them to "drop" or "thump" if the air is supplied in pulsations.

12.2.2.2 Current Usage

Simulators such as 707, 727, DC-8, etc. have used pneumatics to effectively simulate portions of secondary control operations.

12.2.2.3 Characteristics

Low-frequency response, especially with low-pressure pneumatic systems, limits the application of this type of system to areas where accuracy is not critical.

12.2.2.4 Advantages

Low initial cost, high reliability and low maintenance, along with the availability of low-pressure air supplies from such sources as "shop air" or bottled air, make these systems practical for certain applications.

12.2.2.5 Disadvantages

Low-frequency response of low-pressure systems and high cost and safety considerations of high pressure systems.

12.2.2.6 Prospects for Improvement

The inherent characteristics of pneumatic systems, limiting their application in control "feel" simulation, does not suggest much chance for improvement.

12.2.2.7 Applicability to SMS

It is quite possible that some form of pneumatics may be adapted for use in SMS secondary controls.

12.2.2.8 Cost/Complexity and Risk

Considerable risk would be involved in proposing the use of this technique for primary controls, though simple adaptations of low-pressure pneumatics in secondary controls can be found economically feasible, generally risk free.

The hardware complexity for the use of pneumatics in SMS secondary control systems can be approximated as requiring an air compressor, if sufficient "shop air" is not available in the building facility, sized accordingly to supply the various solenoid valve and controlled cylinders that might conceivably be used and, in addition to the pneumatic components, the aircraft control and linkage required for each secondary control system of this type.

12.2.3 Force Spring System

12.2.3.1 Description

The fact that springs are one of the most common and important machine elements makes their use in control "feel" simulation almost indispensible. They are used to absorb energy or shock loads, act as a source of power, and to produce pressure or force.

The force spring system of control loading is ideal for simulation when a vehicle's control system utilizes springs. The irreversible, fully boosted control used on present fighter aircraft is a good example of this type of system. The only force felt by the pilot in this case is from an actual spring loading unit, which is a function of the aircraft's control deflection only and does not include any force variation due to airspeed. In this case, the same aircraft spring or a comparable type may be used in the simulation of such a system.

12.2.3.2 Current Usage

Force spring systems have been universally used by all simulator manufacturers for both primary and secondary control "feel" simulation.

12.2.3.3 Characteristics

Self-evident.

12.2.3.4 Advantages

Low initial cost, low maintenance, and high reliability.

12.2.3.5 Disadvantages

Difficulty of modification, impracticability of reproducing control systems with a complex force curve and the difficulty of implementing the auto-pilot mode or "playback" feature.

12.2.3.6 Prospects for Improvement

The use of springs as a force producing element places certain limitations on this type of system such that improvements tend to complicate the hardware to a point where the selection of some other technique to accomplish the simulation becomes obvious.

12.2.3.7 Applicability to SMS

It is possible that this type of control "feel" simulation would be applicable to SMS primary controls, especially rudder, if the vehicle employs a fully boosted system. If a sidestick controller is employed in lieu of a stick and wheel, some form of a spring would be part of the controller to provide a small force "feel" and/or centering.

12.2.3.8 Cost/Complexity and Risk

The use of this technique to simulate an aircraft control system, of like approach, involves very little risk since the design of the hardware involved is easily defined and relatively simple.

12.2.4 Magnetic Clutch System

12.2.4.1 Description

The magnetic clutch system, used in some early simulators, employed an electric motor-driven actuator that included as the loading device a magnetic-fluid clutch which is a constant-torque device that can be used at either zero or continuous slip. It consists of a driving member enclosed by, and concentric with, the driven member. The gap which separates these two members is filled with the fine magnetic particles suspended in oil. The stationary field coil is located within the clutch housing.

When the clutch is not energized, the driving member rotates freely. When the field is energized, the magnetic particles form a rigid bond which transmits torque. Torque is independent of the speed of either member -- the clutch can transmit torque at zero slip.

12.2.4.2 Current Usage

As other techniques were perfected, this type system was discarded because it was found to have poor repeatability, high maintenance cost, and an unrealistic feel to the pilot.

12.2.4.3 Characteristics

This system provides a "velvety feel" and responds smoothly to changes in force.

12.2.4.4 Advantages

Smooth operation; fairly quick response; high-torque-to-inertia ratio.

12.2.4.5 Disadvantages

High cost; limited heat-dissipation capability; limited life; torque derating required at high slip speeds; relatively poor repeatability and high maintenance.

12.2.4.6 Prospects for Improvements

The fact that this type system has not been used for some time does not provide much hope for improvement.

12.2.4.7 Applicability to SMS

It is highly unlikely that this type system would be used for SMS control "feel" simulation.

12.2.4.8 Cost/Complexity and Risk

Considerable risk would be involved in implementing a system of this type, with a cost similar to that of a pneumatic system.

12.3 Tradeoffs and Recommendations

It would be difficult to recommend a specific type of control "feel" simulation to be used for SMS until the design of the vehicle controls is firm. Past experience would indicate that the hydraulic servo system is the best approach to primary control simulation even though the vehicle control may be a fully boosted system. This approach provides the capability for "autopilot" and "playback" features, plus it is possible to incorporate design modifications more easily than with other types.

Numerous methods have been employed to provide control "feel" simulation for secondary controls ranging from the sophisticated techniques aforementioned to relatively simple types too numerous to expand upon singularly, such as fixed brakes, variable brakes, springs, ball plungers, dash pots, permanent magnets, clutches, solenoids, etc.

The complexity of the simulated control and/or the emphasis placed on its training value dictates the approach that is required to provide adequate simulation.

For example, the simulation of windshield wiper control lever "feel" might be as simple as providing a spring washer at the lever pivot to provide a small resistance to lever movement; whereas, simulation of a stabilizer trim control system can require the use of springs to simulate cable stretch, electric or hydraulic motors for automatic or remote trim, variable brakes for the effect of trim motor stall due to high airload, clutches for mechanical breakouts, etc.

12.4 References and Assumptions

References:

1) "Proposal for Military Aircraft Control Loading System" prepared for the Naval Air Development Center, Warminster, Penna. Proposal No. 877, 8/5/71 Singer.

2) "Specification for Control Loading System" Spec. No. 69-31 Dec. 19, 1969, Rev. 12/29/70 Singer.

3) Evaluation of Four Sidestick Controllers on a Fixed Cockpit Simulation of a Space Shuttle Vehicle Orbiter. By Bedford A. Lampkin, Feb. 10, 1971 Ames Research Center, Moffett Field, California.

4) Preliminary NAR Controls Display Layout Document #92.

Assumptions:

It is assumed that the SMS controls that will require control "feel" simulation will include the following:

Primary Controls

Aileron }
Elevator } Elevon

Rudder

Secondary Controls

Toe Brakes

Power Levers

Speed Brakes

Landing Gear

Parking Brake

Cargo Control Manipulators

Information available at this writing would indicate that the aileron and elevator (elevon) control would be accomplished with a sidestick controller similar to that designed for use in the X-20. The rudder and secondary controls would appear to be of a nature familiar to large conventional aircraft.

13.0 Configuration Management System

13.1 Overview

13.1.1 Statement of Problem

The need to know the simulation configuration at any point in time, together with its prospective configuration, necessitates a comprehensive and flexible configuration management system.

13.1.2 Definition of Applicable Areas

The major areas for consideration in the configuration management system for the SMS during the maintenance and modification cycle of the program are: simulation hardware, simulation software, and logistics. The applicability of any specific configuration management system depends upon the requirements that these areas warrant. The following paragraphs attempt to delineate the more important items and activities of each major area. It should be noted, however, that the items and activities specified may not be complete in all areas, and additional ones will be added, where applicable, as the SMS definition study progresses.

13.1.2.1 Simulation Hardware

The simulation hardware (IOS, Crew Station, DCE, Visual Motion Base and Ancillary Equipment) will present several common configuration control problems. Briefly, these common problems are:

Hardware Prints - That represent the actual electrical and mechanical state of the equipment.

Diagnostic Software - That exercises the equipment must be current with respect to the hardware.

Operations Manual - Which define maintenance and checkout procedures that must be upgraded as the hardware is changed.

13.1.2.1.1 IOS

The Instructor Operator Station will have some unique problems, which will include:

Number of IOS's - If more than one IOS is used, e.g., a "full" IOS and a "Mini" IOS in the crew area, these must be kept compatible.

Configuration of Crew Station Repeaters - Any repeater display on the IOS will also have to be modified when a piece of equipment in the crew station is added or modified.

Supplementary Hardware - Which will include items that are not existent in the spacecraft and are used as instructor-only displays. Examples are Lat/Long indicators or sprills.

Simulator Operations Manual - Which must be updated to include procedural changes, new functions, and malfunction definition changes.

13.1.2.1.2 Crew Station

Configuration control here will include:

Spacecraft Configuration - The actual configuration of the physical vehicle.

Variations from the Spacecraft - Detailing both the systems that are being simulated and those which are unsimulated and represented by dummy hardware.

Spacecraft Changes - Delineating what changes to the vehicle have been reflected in the simulator, changes which are yet to be incorporated, and those changes that will not be implemented.

13.1.2.1.3 Data Conversion Equipment

The simulator configuration will be reflected in the data conversion equipment in the following ways:

Patch Panel Configuration - Which details the way all displays and controls are physically related to the conversion equipment.

Cable Configurations - Which define this relationship of all plugs and sockets between the controls and the conversion equipment.

Channel Allocation - Whether by system, or panel. Included will also be the spare channels available.

Data Pool Relationships - Detailing how the data from the DCE will be mapped into the simulation data pool.

A/D-D/A Scaling - Indicating the relationships between hardware signal levels and the way the simulation models manipulate the values.

13.1.2.1.4 Visual

The visual configuration problem will concern itself with relating the visual media (film, slides, and L&A tables) to the mission profile. Thus, the visual simulation equations may have to perform differently, depending upon what reel of film is used for a terminal approach.

13.1.2.1.5 Motion Base

Although, from a simulation standpoint, a motion base is a simple piece of equipment, there is a lot of physical hardware involved. As such, the motion base is susceptible to the same configuration control procedures as the IOS, Crew Station, or Visual.

13.1.2.1.6 Ancillary Equipment

All Ancillary hardware, (communication, X-T recorders, CRT's, Vidio, Acustic, etc.) is susceptible to the same configuration control procedures as all other items of simulation hardware.

13.1.2.2 Simulation Software

The three main areas of simulation software (supervisory, application, miscellaneous) all share common areas in configuration control, specifically:

Listing Control - The desimination and maintenance of math model and/or program listings.

Levels of Revision - The controls required (source deck, object module, or by patching) to insure that the simulation programs are of a known configuration.

Spacecraft Data - This includes all the data packages received from the spacecraft manufacturer, including curves, system design prints, tables, as well as any assumptions made about the simulation of a system.

Data Set Integrity - This implies the controls required to insure that total recovery can be made in the event of computer system collapse, or loss of a restore tape.

Change Documentation - Using a system of SCR's and/or by indicating the program changes in the source listings.

13.1.2.2.1 Supervisory Software

The simulation supervisory software (Executive, Real-Time I/O, Master Control) has as unique configuration problems:

Jump List Management - Which is the control of program execution and sequencing, addition, and deletion of simulation routines.

Program Timing and Core Loading - Insuring that an accurate time reference base and core loading data is maintained. Also included would be I/O channel usage.

Application Software Requirements - Such as the supply of pointers, constant values, special parameter lists, and initialization control.

Linkage Configuration - Insuring that any DI unpacking, DO packing, or analog quantity conversions are kept up-to-date with respect to the simulator configuration.

13.1.2.2.2 Application Software

This group consists of all the routines required to sustain the simulation. As such, configuration problems will include:

Spacecraft Configuration - Insuring that the math models and/or programs conform to the latest configuration of the vehicle.

Malfunction Configuration - Control over the portions of the simulation routines that reflect malfunctions, and the documentation describing the effects.

On-Board Computer Interfaces - The changes required to maintain a correct interface with the on-board computer programs.

Curve Generation - Insuring that empirical data curves are maintained to the latest data available.

13.1.2.2.3 Miscellaneous

These are, for the most part, off-line software packages that are used in support of the real-time simulation routines. Configuration problems in this area will include:

Data Base Generator - Which will cover I/O channel allocation, addition and deletion of parameters, linking programs to the data pool through "common" statements, and generating data pool maps.

Reset Generator - Which will incorporate new data from Engineering or MPAD into the reset data pool, and will have to insure that the reset data is correct for the simulation configuration.

Diagnositcs - Those routines that exercise the simulation equipment must be maintained at the correct configuration to be compatible with the hardware.

On Board Computer Simulation Utilities - Which will have the responsibility of processing the On Board Computer Flight Program and transforming it into a form useable by the simulation task.

13.1.2.3 Logistics

There exists a large amount of support activities that complement the configuration management of the simulation hardware and software. These activities deal mainly with the reporting and scheduling of the various simulation maintenance and modification functions.

13.1.2.3.1 Task Authorization

Action Memos - From NASA/FCSD and Action Memo Requests by contractor personnel for engineering feasibility and trade-off studies.

Modification Request resulting from contractor-generated simulator changes, NASA/FCSD-generated Modification Requests and Contractor-generated S/C changes.

AVO - Request from NASA for special work to be performed under an approved Action Memo.

13.1.2.3.2 Resource Expenditures

Control of Government property in contractor's possession - Complete inventory of government property.

Control of GFP - Complete inventory of government furnished property.

13.1.2.3.3 Modification Requests

Effectivity - Tracking and statusing the effectivity of the change (i.e., mission, spacecraft, simulator).

Impacts - Estimates of the resources required to implement the simulator design change.

Scheduling - Establishing pertinent milestones that must be tracked through final acceptance.

13.1.2.3.4 Discrepancy Reports (DR's)

Category - The priority of the discrepancies with respect to crew training and simulation reliability.

Simulator Effectivity - The discrepancy is applicable to more than one simulator.

Scheduling - The establishment of schedules for DR clearance from review through acceptance.

13.1.2.3.5 Quality Control (Q.C.)

Modifications - Q.C. acceptance of modifications.

Discrepancy Reports - Q.C. acceptance of DR's.

Failure Tags - Status of failure tags written for hardware components.

Failure Reports - Automated analysis of failure tags.

HCR/ HCN - Status of the various hardware change requests.

Simulator Prints - Status of all hardware prints for a simulator.

13.1.2.3.6 Simulator Complex Utilization

Training - The amount of effective computer time used for crew training.

Other Contractors Utilization - The amount of computer time used by other contractors.

NASA Operations Time - The amount of computer time used by NASA monitors for accepting mods and DR's, system checkout and familiarization training.

Modifications - The amount of computer time used for installation and checkout of modifications.

Discrepancies - The amount of computer time used for clearance of DR's.

Preventative Maintenance - The amount of computer time used to perform preventive maintenance.

Data Processing - The amount of computer time used for the data processing functions that support the simulation task.

Lost Time - The amount of time the simulator complex is down.

13.1.2.3.7 Simulator(s) Configuration

Hardware - Total status of the pending, installed, and accepted changes to the simulator complex hardware.

Software - Total status of the pending, installed, and accepted changes to the simulator complex software.

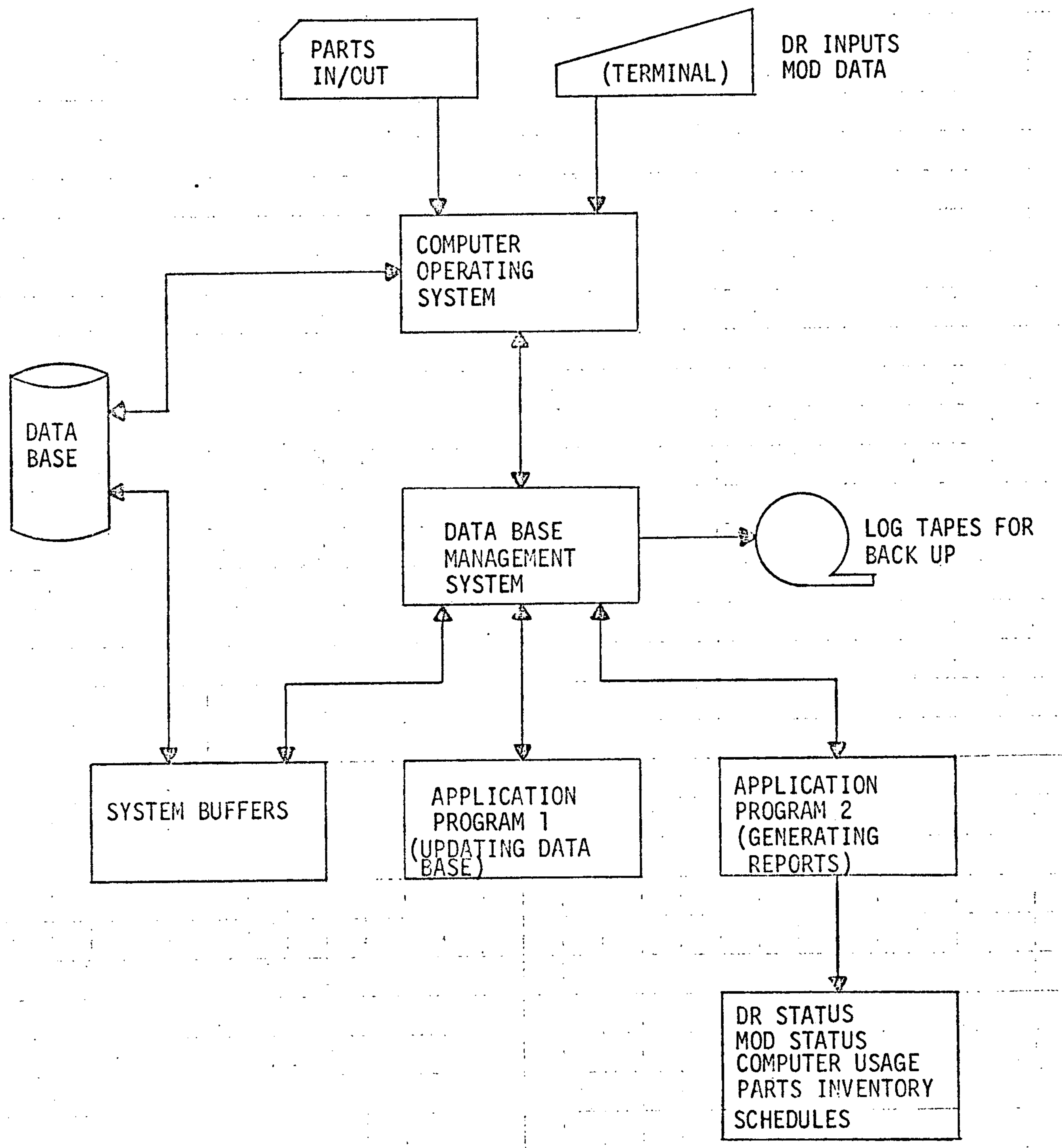
13.2 Automated Configuration Management System

The implementation of a configuration management system may vary from a manual system to one that is fully automated. The two barometers that must be used in the determination of which system should be utilized is the amount of data that must be controlled and statused, and the cost (initial outlay and upkeep) that is acceptable for maintance of the information. Due to the complexity of the configuration management required to support the SMS, a manual system appears to be unfeasible. It is anticipated that an automated system with various manual controls may be more adaptable. The key to the solution of the problem will be ascertaining the proper mix of Human and Automated configuration management that will afford a working, flexible, and reliable management tool.

13.2.3.1 Description

In this section, we are addressing ourselves to a Management Information System, which is also known as a Generalized Data Base Management System. Such a system allows a common data base to exist independently of the numerous application programs that must reference it. A simple example of data bases that are dependant upon application programs would be a data base that relates an employee to payroll information and a data base relating employees to education. Thus we have two data bases that have a common element, the employee. When new personnel are hired, or leave the company, both data bases must be updated. In a company that has a high turnover rate, the probability that, at some point in time, one of the two data bases will not be updated will become 100%. A generalized data base management system will combine both data bases into one unified package that all application programs can process.

Figure 13.1 shows the basic interrelationships that exist between a data base management system, the data base, and user supplied application programs.



PARTS IN/OUT
(TERMINAL)
DR INPUTS
MOD DATA
COMPUTER OPERATING SYSTEM
DATA BASE
DATA BASE MANAGEMENT SYSTEM
LOG TAPES FOR BACK UP
SYSTEM BUFFERS
APPLICATION PROGRAM 1 (UPDATING DATA BASE)
APPLICATION PROGRAM 2 (GENERATING REPORTS)
DR STATUS
MOD STATUS
COMPUTER USAGE
PARTS INVENTORY
SCHEDULES

FIGURE 13.1

13.2.3.2 Current Usage

The advantages of having one or two data bases under the control of one software system are enough to cause more and more data processing installations to turn to such an approach.

The applications in which a data base management system have been utilized cover the whole range of general data processing functions. Banks, public utilities, and credit offices use it to keep their accounts in order; manufacturing uses it to control the flow of an almost infinite number of parts and supplies; one of the large city newspapers is using a data base management system to file and maintain all the facts contained in their 'morgue'.

Whether in a batch or teleprocessing environment, it appears that the industry trend is to unify under one system several data bases that have common elements.

13.2.3.3 Characteristics

In order to satisfy the requirements imposed upon a system that must look at one data base as if it were several, the data base management system must have several characteristics that lend themselves to the end result. Briefly these characteristics are:

- Data Structure

This is the data base organization as viewed by the applications programs, and excludes any storage techniques which are used by the management system. As a characteristic, data structure features are very important since they allow application programs to look at the data base in several different ways; that is, programs can view the data base logically rather than physically. Indeed, no application program need concern itself with actual physical data base organization, the data base management system may be the only package that knows how the data base is really organized.

- Data Definition

This allows the users the capability to define the directories, or tables, which are to be used in processing the data base. Data definition is usually a language that is used to generate the format of the physical data records. Thus, the names, value types, relationships and other attributes of the data base are defined, not only for the data base as a whole, but for each application program. Without a comprehensive data definition facility, the data structure may be limited, which in turn can limit the usefulness of the application programs.

- Interrogation

A data base management system must obviously allow the user to look at the data base and allow elements of it to be extracted for manipulation or display. This characteristic implies that the user is able to make the query without having to detail the steps that are required to access the data element. Thus the system has one or more built in algorithms for finding the data. Within a data base management system there may be many degrees of sophistication possible even within a basic sequential search of the data base. One such level of sophistication would be where the application program places constraints upon the data elements for which he is looking. An example would be to ask the system for the names of all married personnel who have a higher level degree and have no more than two children but not two of the same sex.

- Update

Here we are talking about changing the value content of an element of the data base. Update facilities are usually modeled on the same algorithms as interrogation, including constraint features. The difference being that with updates, we are changing something.

- Creation

These are the features of the data base management system that allow us to perform the initial data base construction. In addition, to the basic data definition and generation of the file, we may also include parameters on data validation, security and control limitations.

- Programmer Facilities

Also referred to as a data manipulation language, these facilities define macros, verbs or other programming statements that the user applications routines may use to interface his program to the data base management system. Covered also in this are are the constraints imposed upon the application programmer defining what, if any, indirectly related data base processing may be performed. An example of this would be where the application program wants to look at a randomly organized data base in a sequential manner. Such a case would apply if a data base dump is required.

- Storage Structure

This is the actual mapping of the data base on some physical media. It usually bears no direct relationship with any specific data structure as used by an application program. This characteristic is conditioned by the requirements of the storage devices and the operating system. Various storage techniques may be used by the system, depending upon how the data is to be accessed.

- Operational Environment

Here we are talking about the actual hardware/software configuration that must exist in which the data base management system will operate. Core memory, mass storage, terminal/batch support, level and type of operating system are included within this area.

13.2.3.4 Advantages

There are many advantages to using a data base management system. A brief summary of the more important would include:

- A Common Data Base, allowing several users to view related elements of the same information.
- Reduction of Paper Work, which may be realized by combining the data on several forms into one concise report.
- Cross Relationships, where one piece of data can be logically related to another in an easy manner.
- Dissemination of Information, more people can be made aware of more information.
- Reliability of Information, everybody is assured of looking at the most current information.
- Recovery in Case of System Loss, usually better than other systems since most data base management systems contain a large amount of trace back and transaction logging features.

13.2.3.5 Disadvantages

A list of disadvantages would include:

- Computer Resources Required may represent a large percentage of all but the largest complexes.
- Not Necessarily Suited to a Particular Application requiring extensive installation generated programs to bend the system to meet specific needs.

13.2.3.6 New Advances

As with any generalized software package that may be put on the market, it is hard to predict what new techniques or features may be incorporated into a data base management system.

One possible advance will be the adoption of the CODASYL system committee report on data base management systems by the American National Standards Institute. Should this occur, then a 'common' set of requirements and specifications can be applied to all data base management systems. This would follow in the path of the COBOL standardization also initiated by CODASL and now accepted by ANSI.

13.2.3.7 Applicability to SMS

The study is concerned with the possibilities of using a data base management system to computerize most of the requirements discussed in the earlier section.

Thus, the question must be answered: Can an automated data management system make a significant reduction in the amount of paper that is required to generate and support a trainer as complex as the SMS?

One specific area of investigation is how can a DR be related to all the activities (ie, a mod, SCR's, missing hardware, documents concerning the logic behind the simulation approach taken, etc.) Required to clear it.

Related also to this, all responsible personnel must be made aware of the DR in the shortest possible time.

13.2.3.8 Cost/Complexity and Risk

As indicated above, the data base management system provides services for an application program to use in accessing the common data base. The data base management system does not include the application-type programs. An analogy thus exists between an operating system and a data base management system. In some installations, due to the complexity of the management system, it is almost a subset of the computer operating system. Such a case exists when the data base management system is used in a teleprocessing environment.

Thus we are discussing a software package that is complicated, at the very least, and can approach the complexity of a full operating system.

Such a system can also be very costly; even the most basic management system will run in the order of hundreds of dollars per month rental. To develop a basic system will require many man-years of effort. Both of these expenses are in addition to the time required to develop the application programs, which will also run to man-years.

Another factor to be considered in a "build or buy" decision is that, although one can rent an off-the-shelf management system (which negates the development cost of a similar system), the user may have no control over the direction that later versions of the system may take. Also, the user may not be able to have specific modifications desired for his installation incorporated into the package.

The other side of the coin is that a data base management system that is generated "in house" may never work as well as required, or that the system cannot be expanded as new requirements are recognized.

In any event, one must be cautious to insure that the data management system remains the servant of the problem, rather than the master of it.

Other factors related to the cost of a Data Base Management system are:

Core Memory Requirements - Which may dictate a larger basic computer complex in addition to the cost of the physical memory.

Computer Time Requirements - Which may require that a larger complex be acquired to contain the management system.

Extra Hardware Required - Such as extra tape units and disk storage devices that are only used by the Data Base Management System.

Initial Procurement and Maintenance - Costs of the system over the life of the complex must be factored against the cost of a manual system over the same period of time.

Transistional Costs - Covering the period of changeover from manual to automated configuration control must be considered. Included here would be the cost of reducing all data currently in various formats to a form acceptable to the system.

13.3 Trade Offs and Recommendations

Recommendations

Data Base Management System

Investigation into this technique should continue. It is recommended that the end result of this study should define the requirements of a Data Base Management System for use in support of the SMS.

It is recommended that vendor-supplied Data Base Management Systems be investigated for direct applicability to SMS, contingent upon computer complex requirements or selection.

It is recommended that a first-level inter-relationship be determined for existing configuration control documentation vehicles (modification requests, DR's, SCR's, etc.)

Software Configuration Control

It is recommended that the current software change procedure be reviewed for possible reduction of effort.

It is recommended that requirements be generated for the software packages which will maintain the "current load" configuration.

Hardware Prints

It is recommended that current state-of-the-art techniques for automated design and drafting be evaluated for feasibility in support of the SMS.

13.4 References and Assumptions

References

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