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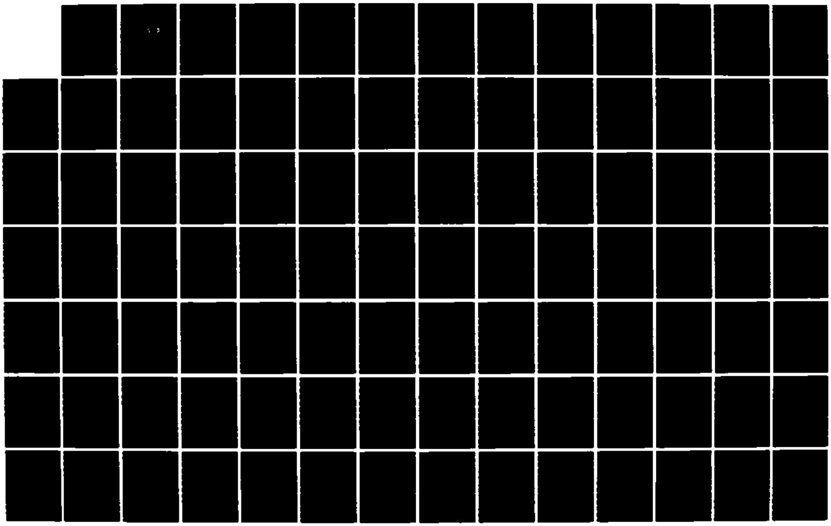

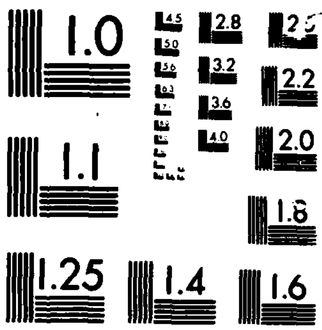

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AN ANALYSIS OF THE CENTAUR GROUND PROCESSING SYSTEM AT THE KENNEDY SPACE CENTER/CAPE CANAVERAL AFS

THESIS

John Timothy Brock, B.S.
Major, USAF

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AN ANALYSIS
OF
THE CENTAUR GROUND PROCESSING SYSTEM
AT THE
KENNEDY SPACE CENTER/CAPE CANAVERAL AFS

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Space Operations

John Timothy Brock, B.S.

Major, USAF

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ABSTRACT

This project determined the capability and limitations of the new Shuttle/Centaur ground processing system at the Kennedy Space Center/ Cape Canaveral AFS FL. In particular, it investigates whether or not the system could process four Centaur vehicles in a one year period.

To determine the system's capability two tools were developed: a PERT network graph and a SLAM simulation model of the system. The output from these two sources formed the basis for the analysis of the system.

The PERT network was constructed using data from the Centaur Program Office and from Cape Canaveral AFS FL. The critical path through the network was also identified. Analysis of the PERT network indicated that it will take over 230 days to process one Centaur vehicle and that there is no slack time in the processing schedule.

The SLAM model was built for the proposed system and simulation runs were conducted using versions of the processing system with modified elements, i.e. increased facilities. These runs indicated that additional resources must be procured if the system is to reach a four flight per year processing rate. As currently configured, the system can only support two flights a year.

PREFACE

When any major space system is first initiated, it seems that the attention of the program's management is focused on the flight hardware. Unfortunately, this can lead to serious defincies in the system's ground system. I experienced this situation in 1977, when the first Defense Meterological Satellite Program Block 5D vehicle was launched. We had a marvolous "state-of-the-art" spacecraft; however, the supporting ground system was unable to keep pace with the satellite. This situation was later remedied when a "new and improved" ground control system, equal to our flight hardware, was introduced.

Fortunately, today's program managers recognize the importance of a modern, up-to-date ground system to control and manage their space systems. When the Shuttle-Centaur program was established, management determined that a flexible ground processing system must be developed at the launch site. This involved the modification of several existing structures as well as the construction of new facilities to insure that any and all variancies in the processing of the new shuttle-compatable Centaur upper stages.

The purpose of this study is to determine if the Centaur ground processing system is capable of handling the projected loading of the systems. To do this, I used a computer model to simulate the critical systems of the

system. This allowed me to saturate the system and find the points where the system "log jams" occur. Hopefully, with these point identified, steps can be taken now to correct these deficiencies before they lead to delays which will cost large amounts of time and money.

As one would expect, no one could complete a project of this size without the assistance of many individuals. I received help from many varied sources, a few of which I wish to recognize.

First, my thanks go out to Major Mike Carpenter of Space Division/YOX, Los Angeles AFS, CA for sponsoring this project. Mike provided much needed financial and technical support.

Next, I received much technical and documentation support from the Centaur Program Office at the NASA Lewis Research Center, Cleveland, OH. Lt Col Bill Files, Assistant Program Director, was instrumental in the transfer of this documentation to me and was of great assistance in determining the scope of this project.

A great deal of thanks must go to the personnel of the General Dynamics Corporation, builders of the Centaur vehicles. In particluar, Mr. Dick Combs and Mr. Tom Edmonds must be singled out for special recognition. Dick provided valuable information on the Complex 36A operations. Tom came to my rescue early in the life of this project, when it appeared that I had run into a dead end. He was able to provided me with enough data to keep the project going and is ultimately responsible for the success of this project. Thanks, Tom.

Other personnel and organizations providing support to this project include Mr. Mike Olive of the 6555 Aerospace Test Group, Cape Canaveral AFS, FL; Mr. Irv Cohen of the Aerospace Corporation, Los Angeles, CA; Mr. Bob Lahs of the TRW Corporation, Redondo Beach, CA; Mr. Steve Whitemarsh of the Martin Marietta Corporation, Cocoa Beach, FL; Mr. Steve Black of the Lockheed Space Operations Company, Cape Canaveral, FL; Mr. John Washburn of the General Dynamics Corporation, Cocoa Beach, FL; and Mr. Bill Coleman and Mr. Dick Hover of the McDonnell Douglas Corporation of Cocoa Beach, FL.

A great deal of thanks must go to my advisor, Col Mike O'Connell, who was able to keep my shoulder to the wheel and forced me to complete this project on time.

Finally, my loving thanks go out to three people: my parents, Mr. and Mrs. Jack Brock, who encouraged me to get my master's degree, and my fiancee, Jackie Rolly, who had to organize the entire wedding by herself so I could work on this project. I couldn't have made it without them.

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List of Tables

List of Abbreviations/Acronyms

a	PERT Optimistic Time Estimate
ACCUM	SLAM Accumulate Node
ACT	SLAM Activity Statement
AFSCF	Air Force Satellite Control Facility
ASE	Airborne Support Equipment
ASSIGN	SLAM Assign Node
ATRIB	SLAM Entity Attribute
AWAIT	SLAM Await Node
b	PERT Pessimistic Time Estimate
CC	Communications Center @ CPOCC
CCA	Centaur/CISS Assembly (Centaur & CISS)
CCAFS	Cape Canaveral Air Force Station
CCE	Centaur Cargo Element (Centaur,CISS & Spacecraft)
CCLS	Computer-Controlled Launch Set @ CPOCC
CCT	Centaur CISS Transporter
CCVAPS	Computer-Controlled Vent and Pressurization System
CISS	Centaur Integrated Support Structure
CLCC	Centaur Launch Control Center @ CPOCC
CMCC	Centaur Mission Control Center @ CPOCC
COLCT	SLAM Statistics Collection Node
CPM	Critical Path Method
CPOCC	Centaur Payload Operations Control Center
CREATE	SLAM Entity Generation Node
CRPT	Centaur Transport Pallet
CRT	Cathode Ray Tube

CSS	Centaur Support Structure
CSTP	CISS Transport Pallet
CTGS	Centaur Telemetry Ground Station
CX 36A	Centaur Complex 36A
DOD	Department of Defense
DUFTAS	Dual-Failure-Tolerant Arm/Safe Sequencer
ELS	Eastern Launch Site
FCR	Flight Control Room @ JSC
FREE	SLAM Resoure Release Node
FSE	Fixed Support Equipment @ LC-39
GCS	Ground Computer System @ CPOCC
GDC	General Dynamics Corporation
GEO	Geosynchronous Orbit
GH2	Gaseous Hydrogen
GHe	Gaseous Helium
GN2	Gaseous Nitrogen
GOON	SLAM Go On Node
GSE	Ground Support Equipment
HER	Hardware Exersion Remote
IMG	Inertial Measurement Group
IUS	Inertial Upper Stage
IVE	Interface Verification Equipment
JIS	Joint Integrated Simulation
JSC	Johnson Space Center
KSC	Kennedy Space Center
LCC	Launch Control Center @ LC-39
L-	Number of Days Before Shuttle Launch

LC-39	Shuttle Launch Complex 39
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LO2	Liquid Oxygen
LRD	Launch Readiness Demonstration
LSOC	Lockheed Space Operations Company
m	PERT Most Likely Time Estimate
MCC	Mission Control Center @ JSC
MDAC	McDonnell Douglas Astronautics Company
MDP	Manual Drain Panel
MES	Main Engine Start
MLP	Mobile Launch Platform @ LC-39
MMSE	Multi-use Mission Support Equipment
MSE	Mobile Support Equipment
MUX	Multiplexer
NASA	National Aeronautics and Space Administration
NM	Nautical Mile
N2H4	Hydrazine
OAS	Orbiter Avionics Simulator @ SPIF
OPF	Orbiter Processing Facility
PAVCS	Pneumatic Actuation Valve Control System
PCR	Payload Changeout Room @ LC-39
PERT	Program Evaluation Review Technique
PGHM	Payload Ground Handling Mechanism @ LC-39
PHF	Payload Handling Fixture @ SPIF
POCC	Payload Operations Control Center for Spacecraft
QUEUE	SLAM Queue Node

RES	SLAM Resource Block
RSS	Rotating Service Structure @ LC-39
RTDS	Real Time Data System @ CPOCC
RTGS	RTDS Telemetry Ground Station @ CPOCC
S	PERT Slack Time
S/CGPS	Shuttle/Centaur Ground Processing System
SGLS	Space Ground Link System
SLAM	Simulation Language for Alternative Modeling
SMAB	Solid Motor Assembly Building
SPIF	Shuttle Payload Integration Facility
St,e	Standard Deviation
STOP	Standard Power Turn On Profile
STS	Space Transportation System
TERM	SLAM Termination Node
TCD	Terminal Countdown Demonstration
TDRSS	Tracking and Data Relay Satellite System
te	PERT Expected Completion Time
Te	PERT Earliest Completion Time
Te*	PERT Earliest Completion Time for Entire S/CGPS
TGS	Telemetry Ground Station @ CPOCC
Tl	PERT Latest Completion Time
TNOW	SLAM Current System Time
TTF	Test and Transport Fixture
USAF	United States Air Force
VAR	Variance
VPF	Vertical Processing Facility

ABSTRACT

This project determined the capability and limitations of the new Shuttle/Centaur ground processing system at the Kennedy Space Center/Cape Canaveral AFS FL. In particular, it investigates whether or not the system could process four Centaur vehicles in a one year period.

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AN ANALYSIS OF THE
CENTAUR GROUND PROCESSING SYSTEM
AT THE
KENNEDY SPACE CENTER/CAPE CANAVERAL AFS, FL

I. INTRODUCTION

This chapter presents an overview of the project to the reader. It includes a description of the events which lead to the requirement for the Shuttle/Centaur system, a short description of the system, a statement of the project's problem statement and objectives, an outline of the methodology used to conduct the project, and an outline of the material presented in this paper.

A. Background

In the 28 years since the launch of Sputnik, the United States has grown more and more dependent on space systems for important functions. These systems handle many varied tasks such as communication, weather observation, interplanetary research, and national defense. The Space Transportation System (STS) or space shuttle is the primary means of launching these systems into earth orbit. However, the STS can only place these spacecraft into "low" earth orbit (LEO). These orbits range in altitude from 130 nautical miles (NM) to 320 NM, which is the maximum capability of the STS (3:13-3). Unfortunately, only a few of our space systems operate at LEO altitudes.

Some space systems, such as communications satellites must operate at geosysynchronous earth orbit (GEO) altitude of 19,360 NM. At this altitude, the velocity of the satellite matches the rotational velocity of the earth, thus the satellite will remain above the same point on the ground. To reach this orbit, an additional propulsion system or upper stage must be used.

In addition to the GEO-based satellites, spacecraft are sent on scientific missions to other planets. These vehicles must be propelled to trajectories which take them completely out of the earth's gravititional pull. To reach these interplanetary trajectories, an upper stage booster must be used once again to propel the spacecraft from the shuttle's LEO "parking" orbit.

1. Upper Stage Development

As the National Aeronautics and Space Administration (NASA) developed the STS, the United States Air Force (USAF) accepted the challenge of developing a shuttle-compatible upper stage booster. This booster is the Inertial Upper Stage (IUS). In August 1976, the Boeing Aerospace Company was selected to develop the IUS. Initially, the IUS consisted of a family of solid-propellant vehicles. The vehicles were designed in four sizes, using common components: two versions using two stages, one version with three stages, and one version using four stages (33:724-725).

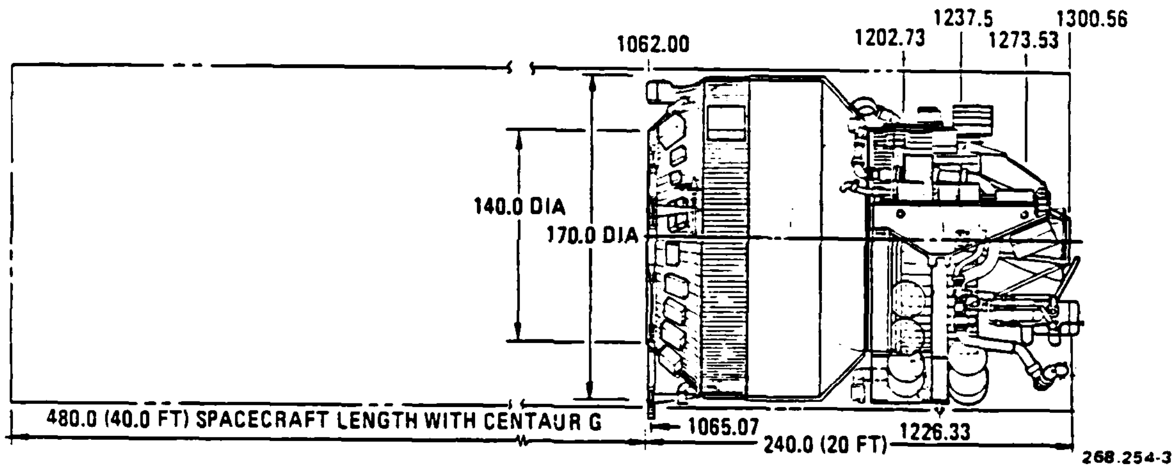
As the program progressed, two of the variants (one of the two stage versions and the four stage version) were eliminated. Remaining were a two-stage version which would place satellites weighing up to 5,000 pounds into GEO (2:166) and a three-stage version which would launch satellites into interplanetary trajectories.

Unfortunately, the IUS program ran into severe technical and financial difficulties, and only the two-stage IUS was developed (7:16). This restriction forced NASA and the USAF to look for an alternative upper stage booster for use in interplanetary missions and also capable of placing satellites weighing more than 5,000 pounds into GEO.

2. Shuttle/Centaur Upper Stage

In 1983, USAF and NASA signed a memorandum of understanding to jointly fund and develop the General Dynamics Centaur upper stage for use on the STS (30:23). The Centaur replaces the three-stage IUS. Originally developed in the mid-1960's for use with expendable launch vehicles such as the Atlas and Titan rockets, the Centaur is a high-energy, liquid-fueled upper stage (13:1-1). Under the USAF/NASA agreement, two space shuttle compatible versions of the Centaur will be produced. For the USAF, a 20-foot-long version, called Centaur G, will be capable of placing a 40-foot-long, 10,000 pound payload into GEO. A

30-foot-long NASA version, called Centaur G-Prime, will be used to launch interplanetary probes to Jupiter. The design of the NASA version is driven by the interplanetary performance requirement. The USAF version is driven by the 40-foot-long payload requirement and the 65-foot shuttle cargo bay length (Figure 1-1). Therefore, the Centaur G is shorter that the G-Prime (30:24). Target date of the first launch of the Shuttle/Centaur upper stage, a G-Prime version, is 23 May 1986 (20:60).



(Adapted from 13:2-2)

Figure 1-1

Centaur G and Spacecraft Length Capability

The Shuttle/Centaur Ground Processing System (S/CGPS) is being developed to manage and process the Centaur vehicle at Cape Canaveral AFS (CCAFS) and the Kennedy Space Center (KSC) (13:1-1). Tasks to be supported by this system include pre-launch checkout, launch support, on-orbit operations, and post-flight equipment recovery.

3. Launch Processing Overview

The pre-launch phase of the ground processing begins with the arrival of the Centaur vehicle at CCAFS and concludes at the start of the shuttle countdown. Upon arrival, the Centaur vehicle and its launch cradle, called the Centaur Integrated Support Structure (CISS), are moved to a hangar and checked for superficial damage. The Centaur and CISS are then moved to Centaur Complex 36A (CX 36A), where they are mated together. A complete systems check is conducted. This check includes a systems build-up,a check for leaks, functional testing, tanking, and a terminal countdown demonstration (12:3-2). These tests verify that the Centaur can support the flight. All checkouts are controlled from the Centaur Payload Operations Control Center (CPOCC) located on CCAFS (13:3-80). After the checkout at CX 36A, the Centaur/CISS vehicle is moved to either the Vertical Processing Facility (VPF) for NASA payloads or the Shuttle Payload Integration Facility (SPIF) for USAF payloads. At these facilities, the vehicle is mated to the mission spacecraft and a combined systems compatibilty test is conducted. The combined Centaur/CISS/ spacecraft assembly is then moved to shuttle Launch Complex 39 (LC-39) for installation into the shuttle cargo bay. Once installed in the shuttle, a final combined STS-Centaur-spacecraft compatibility test is conducted (12:3-2). This test completes the pre-launch phase.

During the launch phase, the final servicing of the Centaur is completed in the shuttle cargo bay. The Centaur fuel tanks are loaded at the same time as the STS tanks (12:3-17,3-21). The status of all Centaur systems is monitored from the CPOCC during the final countdown and launch of the STS. If Centaur problems are discovered during this phase, the CPOCC relays the information to either the Launch Control Center at KSC (pre-launch) or the Mission Control Center at the Johnson Space Center, TX (post-launch) for resolution (13:3-83).

The CPOCC directs all Centaur on-orbit operations. A complete checkout of the Centaur vehicle is completed prior to deployment from the shuttle. If all Centaur systems are working, the CPOCC gives the go-ahead to proceed with the Centaur deployment (13:3-90). The CPOCC continues to monitor the Centaur's performance during its engine firings and through deployment of the spacecraft into its final "operational" orbit (13:3-88).

When the shuttle returns to KSC, ground processing personnel remove the CISS from the shuttle cargo bay. The CISS is then moved to a hangar and refurbished (12:3-18). After refurbishment, the CISS will be capable of supporting another Centaur flight.

The preceding has shown that there are many, varied tasks which the Shuttle/Centaur Ground Processing System must conduct. Since the system is being designed to support up to four Centaur flights a year, it is important if the Centaur system has the capability or ability to conduct these operations on-time to meet all launch schedule requirements. If limitations, such as long system delays or equipment shortages, prevent the system from supporting the four flight per year goal, additional capability may be required.

B. Problem Statement

A key element of the Shuttle/Centaur Program is the ground processing system at the Kennedy Space Center/Cape Canaveral AFS, Florida. If the ground processing system is incapable of supporting up to four Centaur flights a year, there could be major delays in the deployment of important Department of Defense spacecraft.

C. Research Question

What are the capabilities and limitations of the Shuttle/Centaur Ground Processing System to support the preparation, launch and on-orbit operation of the Centaur upper stage booster?

D. Objectives of The Research

The specific objectives of the research are listed below:

1) Specify all necessary activities performed by the S/CGPS and their interrelationships.

2) Determine the amount of time required to process one Centaur vehicle by the processing system.

3) Determine the critical path and bottlenecks within the processing system.

4) Determine the limitations placed on the processing system by the equipment.

5) Determine the maximum number of Centaur vehicles that the S/CGPS can support in one year using the proposed set of equipment.

E. Methodology

In order to determine the capabilities and limitations of the S/CGPS, an analysis of the system was performed. To perform this analysis, both a Program Evaluation Review Technique (PERT) Network and a computer simulation model of the ground processing system were developed.

1. The PERT Network

The PERT Network identifies the activities that must be completed on schedule if the Centaur vehicle processing is to be concluded on-time. A PERT chart is like a map; once the route is drawn, one can easily follow progress against a checklist of keypoints or milestones (32:11). It was used on this project to identify the longest, or "critical" path within the system (17:46-47).

The Critical Path is the sequence of activities or events in the S/GCPS which take the grestest amount of time to complete and which has the least amount of "slack" or catch-up time (1:437). If a failure or delay occurs along this path, potentially disastrous delays in the launch of the Centaur and its spacecraft could occur.

2. <u>The SLAM Model</u>

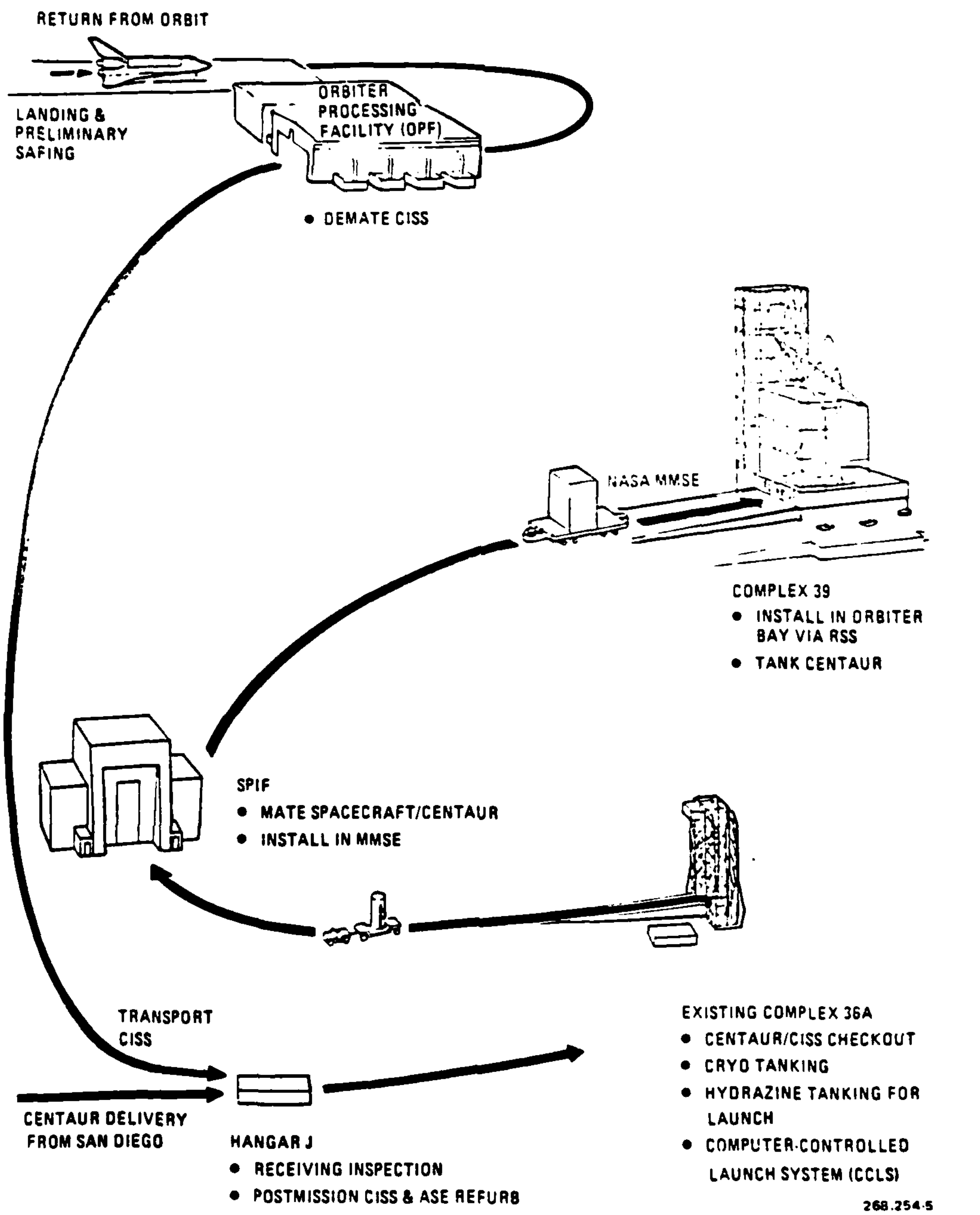
A simulation model enables the study of and the experimentation with the internal interactions of the processing system. Changes to the system were simulated, and the effects of these alternations on the system's ability to process Centaur vehicles were observed. By changing the simulation inputs and observing the resulting outputs, valuable insight was obtained into which of the system variables, such as ground support equipment, has the greatest impact on the ground system's performance (4:4).

The computer simulation model for this research was developed using the Simulation Language for Alternative Modeling (SLAM). SLAM is an advanced FORTRAN based language that allows simulation models to be built based on three different world views. It allows the analyst to develop models from a process-interaction, next-event, or activity-scanning perspective. SLAM is portable and runs on a wide variety of computing systems (27:ix).

Classically, simulation model-building is a four phase process. In the first phase, a statement of the problem is developed, objectives are set, and an overall plan is established. The second phase involves the building of the model, including data collection, coding, verification, and validation of the software. The third phase is running the model. The model runs are used to estimate measures of performance for the system being simulated. The fourth and final phase is implementation, which involves documentation of the model itself and a report of the results of the simulation. This last phase will hopefully result in implementation of changes to the actual system to improve its performance (4:11-16). The methodology to be used for this project was based on this four phase process.

Specifically, the simulation model included only those elements of the S/CGPS that will be used in support of Department of Defense (DOD) payloads (Figure 1-2). The following activities were modeled: vehicle arrival and inspection at the hangar (Hangar J), system checkout at CX 36A, satellite mating/checkout at the USAF SPIF, launch support activities at LC-39, on-orbit operation up to Centaur separation from the spacecraft, and return/refurbishment of the CISS at KSC/CCAFS (13:3-85,86).

Information on the S/CGPS was obtained from several different sources. As prime contractor for the Centaur system, the General Dynamics Corporation (GDC) has developed a preliminary outline of the Centaur processing flow. This



(Adapted from 13:2-5)

Figure 1-2

Centaur G Ground Operations at CCAFS/KSC outline describes activities from the arrival of the Centaur at CCAFS through vehicle checkout at CX 36A (16). The McDonnell Douglas Astronautics Corporation (MDAC) handles the ground processing of all DOD payloads at the SPIF. MDAC has prepared documentation outlining Centaur ground processing operations from arrival at the SPIF through the launch at LC-39 (25).

A modified version of the model-building process described above was used for this project. The data collection task involved breaking out the individual activities to be performed by the S/CGPS and determining their interaction with other S/CGPS activities. This information was obtained from the GDC and MDAC documentation described above. The past performance statistics for several activities (that is, how long to do each one) were collected. From this data, a statistical distribution was assigned to each activity in the simulation model. The objective of the model construction task was to build a complete, working model of the S/CGPS which could simulate the process of preparing one Centaur vehicle. This task was completed when the model was validated or determined that the model was an accurate representation of the S/CGPS (4:14). After successful runs with one Centaur, the model loading task was conducted by increasing the number and frequency of Centaur vehicles to be processed. This loading or "stressing" of the system identified bottlenecks in the processing flow. During the data analysis task, the results of the model runs were evaluated to determine performance parameters of the S/CGPS. These parameters were documented and will be sent to CCAFS/KSC.

F. Outline of the Paper

The project has been completed and the results are presented in this paper. The following summary is intended to aid the reader in locating specific topics of the project. They are presented in the order in which they were completed.

Chapter Two presents a detailed summary of all equipment and facilities used by the S/CGPS to perform its mission. This block of data was assembled after reviewing available materials on the S/CGPS and after conducting lengthy interviews with the managers, designers, and intended operartors of the system. The data were the basic building blocks for both the PERT network and the SLAM simulation.

Chapter Three centers on the development of the PERT network. It presents a short discussion of the PERT networking technique. It then outlines the development of the PERT network charts and summarizes the results of the anaylsis to determine the "critical path." Copies of the data used to calulate the activity time and the actual PERT charts are included in an appendix to the report.

Chapter Four highlights the development of the SLAM simulation model. It presents the steps involved in the construction of the model and the actions taken to verify that the model was working properly. The flow charts used to develop the model and the SLAM software coding for the model are included as an appendix to this paper.

Chapter Five is an analysis of the data generated by the SLAM simulation model. The output from the different runs are presented and the numerical analysis used to reach conclusions about the performance of the S/CGPS is discussed. The actual output from one simulation run is presented in an appendix to the paper.

Conclusions and recommendations derived as a result of the research of this project are presented in Chapter Six. Included are some proposed changes to the S/CGPS which should improve its performance and should raise the confidence level that four Centaur vehicles can be processed and launched by the system within one year.

II. THE SHUTTLE/CENTAUR G SYSTEM

This chapter presents a detailed description of the Shuttle/Centaur G system. Included in the discussion are the flight hardware, ground support equipment, facilities, and an outline of the operations (prelaunch, flight, and postlaunch) conducted by the system.

A. Introduction

Before one can begin the arduous task of developing a PERT network or a simulation model, one must have a thorough understanding of the system to be studied. Unfortunately, the information necessary to develop this understanding is not centrally located in one convenient book or document.

The only method of collecting the information necessary for this project was to investigate the sources of data which were produced by the organizations involved in the Shuttle/Centaur program. Additionally, personal interviews were conducted with key personnel working on the program. Individuals interviewed included the Deputy Program Director of the Shuttle/Centaur Program Office, CCAFS and KSC personnel working on the system in Florida, GDC employees developing the equipment and procedures at CCAFS, and members of the Air Force program office at Space Division overseeing the Shuttle/Centaur Project.

The product of this data collection is the following summary of hardware components that comprise the Shuttle Centaur G System. Also, listed are the ground and flight operations which the S/CGPS must conduct in order to achieve the Centaur mission requirements.

B. Shuttle Centaur G Hardware

The hardware used in support of the Shuttle/Centaur program can be divided into two main categories. Airborne hardware, which is placed into the Orbiter for the flight, and the associated ground support equipment at Cape Canaveral Air Force Station (CCAFS) and the Kennedy Space Center (KSC) in Florida to assemble, checkout and monitor the airborne equipment.

1. Centaur Airborne Hardware

The Centaur airborne hardware consists of two main components: the Centaur G upper stage vehicle and the Centaur Integrated Support Structure (CISS).

a. Centaur G Vehicle

The Centaur G vehicle is capable of injecting a 40-foot-long spacecraft, weighing approximately 10,000 pounds, into a geosynchronous orbit (GEO). This capability assumes launch of the Orbiter vehicle into a 28.5 degree inclined, 130 NM, circular parking orbit, and deployment of the Centaur within eight hours after liftoff from KSC.

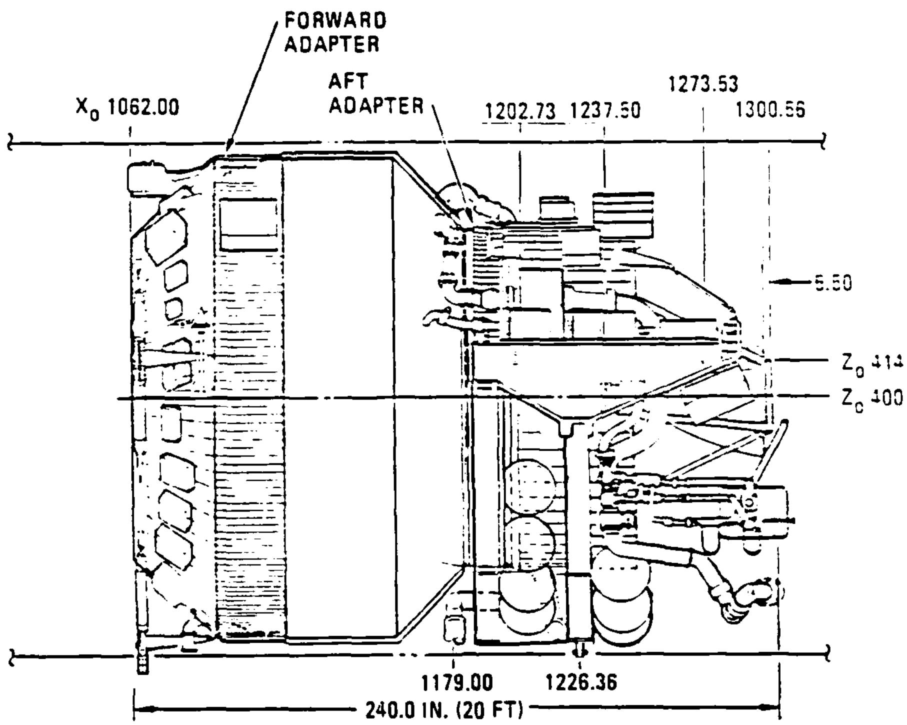
Separation from the shuttle orbiter can, however, be delayed up to 84 hours after liftoff with a corresponding performance degradation due to evaporation of liquid hydrogen (LH2) and liquid oxygen (LO2) propellants (13:2-2).

To achieve the GEO, the mission flight plan incorporates two firings or "burns" of the Centaur's main engines to inject the mission spacecraft into it's final GEO position. Centaur predeployment events are controlled automatically by the airborne support equipment in the Orbiter, with orbiter crew functions used, as necessary, to initiate on-orbit deployment or caution/warning safety functions. The first burn occurs nominally 46 minutes after separation from the Orbiter. The capability of delaying the first engine firing one orbit revolution after separation is also available (13:2-2).

The second Centaur engine firing occurs after a five and one-quarter Hohmann transfer orbit. After separation of the satellite vehicle, the Centaur will execute a collision/contamination avoidance maneuver. Under a nominal timeline, the avoidance maneuver, final event of the Centaur's mission, should be performed within 12 hours of the liftoff from KSC.

The Centaur G vehicle is 19.5 feet long. It consists of a forward 170-inch diameter LH2 tank that transitions to a 120-inch diameter aft LO2 tank (Figure 2-1). External protuberances (rings, stringers, insulation, harnessing, fluid lines, and avionics) do not violate the

180-inch payload envelope of the Orbiter payload bay. The Centaur G vehicle includes a forward adapter attached to the LH2 tank. This adapter provides mountings for most of the Centaur electronic avionics packages. It also provides a



(Adapted from 13:2-6)

Figure 2-1

Shuttle/Centaur G, Adapters, and Mechanisms

mounting interface for the spacecraft and distributes the loads between the Centaur and the Orbiter forward attachments. An aft adapter and separation ring is attached to the aft end of the Centaur to distribute acceptable circumferential line loads into the tank and to provide pyrotechnic-actuated separation for Centaur deployment from the CISS and the Orbiter (13:2-6).

The pressure-stabilized Centaur propellant tanks are constructed in a manner similar to the earlier Atlas Centaur D1A vehicle. These tanks must be kept under constant positive pressure in order to maintain the structural integrity of the vehicle. Loss of tank pressure would result in the collaspe of the vehicle structure and distruction of the Centaur. For this reason, maintenance of tank pressure receives top priority.

The Centaur's insulation system consists of polymide, fire-resistant foam blankets enclosed by a multilayer radiation shield/helium containment membrane over the entire LH2 tank (13:2-8). This insulation blanket acts in a manner similar to a Thermos bottle. Its prevents the very cold, cryogenic propellant, LH2, in the tank from evaporating or "boiling off." Loss of a significance amount of LH2 to "boil off" would reduce the performace of the Centaur vehicle, i.e. reduce the length of the burns. The LH2 tank insulation blanket is purged with helium before launch and during abort. The helium purge prevents the built up of explosive hydrogen gas in the insulation blankets.

The Centaur LO2 tank aft bulkhead supports the two Pratt & Whitney Aircraft RL10A-3-3B engines and the associated LO2 and LH2 propellant supply systems. The RL10 engines will operate at a thrust of 15,000 pounds and a specific impulse of 440.4 seconds. LH2 and LO2 are supplied to the engines through flexible feed ducts that allow for engine gimballing. The engines are capable of being restarted on orbit (13:3-2).

In addition, the aft bulkhead supports the hydrazine (N2H4) monopropellant reaction control system, the pneumatic storage and supply systems, and the tank vent system used to control tank pressures. The reaction control system consists of two N2H4 storage spheres, four propellant settling motors, and eight attitude control motors. The system is pressurized by regulated helium pressure. Separate independent hydraulic systems are mounted on each engine. Each system is capable of providing hydraulic power to gimbal the main engines to effect flight guidance.

Propellant tank pressure is controlled by a computer-controlled vent and pressurization system (CCVAPS), which injects helium into the propellant tanks before engine start in response to sensed tank pressures. After engine start, the LH2 tank is pressurized with gaseous hydrogen (GH2) bled off the engines. The LO2 tank is presurized with helium (13:2-8).

The Centaur G avionics system consists of a 16k core memory digital computer unit, a gimballed-platform Inertial Measurement Group (IMG), a Sequence Control Unit (SCU), two signal conditioners, pyrotechnic initiator control unit (PICU), propellant utilization and level-sensing system, CCVAPS, telemetry systems, and an electrical power system with batteries. These systems/units operate together to control all vehicle functions. They perform all the functions necessary for autonomous operation of the Centaur vehicle from Orbiter separation through the post-satellite vehicle separation maneuver.

A command link permits data command and data uplink via the Orbiter when the Centaur is attached. After separation from the Orbiter, no data uplink is available. Only downlink health and status telemetry is transmitted to the ground. The secure telemetry system is compatible with the Orbiter payload interrogator, tracking and data relay satellite system (TDRSS), and the USAF space ground link system (SGLS) (13:3-52).

Shuttle integration and safety requirements have caused a few minor component changes from the Atlas Centaur avionics system. One was the addition of a Dual-Failure-Tolerant Arm/Safe Sequencer (DUFTAS) which precludes premature arming of critical Centaur safety-related functions while attached to the Orbiter.

The applicable weights for the Centaur G vehicle are summarized in Table 2-1.

b. Centaur Integrated Support System

The Centaur vehicle is supported and serviced within the Orbiter payload bay via the Centaur Integrated Support Structure (CISS). The CISS consists of the Centaur support structure (CSS), a deployment adapter, and associated CISS electronics and fluid systems (Figure 2-2). The CSS connects the Centaur vehicle and deployment adapter to the Orbiter through a five-point support system. The deployment adapter attaches to the aft end of the Centaur at the

TABLE 2-1

Centaur G Weight Summary

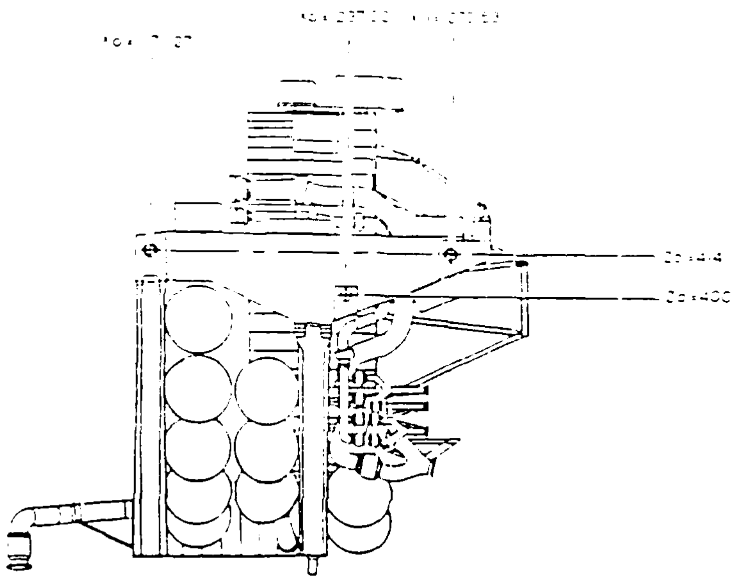
Item	Weight (Lbs)
Centaur Tanker Weight	37,517
Centaur Dry Weight	7,384
Centaur Expendanbles	30,133
Propellants	30,009
Hydrogen	4,155
Oxygen	25,265
Residuals	589
Hydrazine	120
Helium	4

(Adapted from 13:3-72)

separation ring and to the CSS throught two rotation trunnions and a guide keel pin.

During deployment, the vehicle is rotated 45 degrees to its separation attitude by a rotation mechanism attached to the deployment adapter.

Fluid system ducting and gimbals are provided to interconnect the various propellant tank service lines to their Orbiter overboard service ports. The gimbals permit the Centaur to be rotated to the deployment position while maintaining all safety-related systems in the connected and functional state.



(Adapted from 29:2-3)

Figure 2-2

Centaur Integrated Support Structure

CISS helium storage spheres, single-failure tolerant pressurization systems, and two-failure-tolerant pressure regulation systems supply all helium for pressurizing the Centaur tanks, actuating vent and dump system valves, and providing the necessary system purges to manage Centaur propellants safely.

CISS avionics perform all control functions for vehicle safety while the Centaur is attached to the Orbiter and for deployment. Two-failure-tolerant control is achieved with five strings of micro processor-controlled avionics, associated sensors, and controllers (13:3-3).

The applicable weights for the CISS are summarized in Table 2-2.

After deployment of the Centaur vehicle, most of the CISS systems are placed in a standby mode. The status of all CISS systems are continually monitored for the rest of the Orbiter's flight. If a hazardous situation should arise the Orbiter's crew can be directed to take action to make the CISS systems safe.

When the flight ends, the CISS will be removed from the Orbiter and returned to Hangar J for refurbishment. Each CISS will be capable of six flights before the structure and its electronics must be scraped (11).

TABLE 2-2

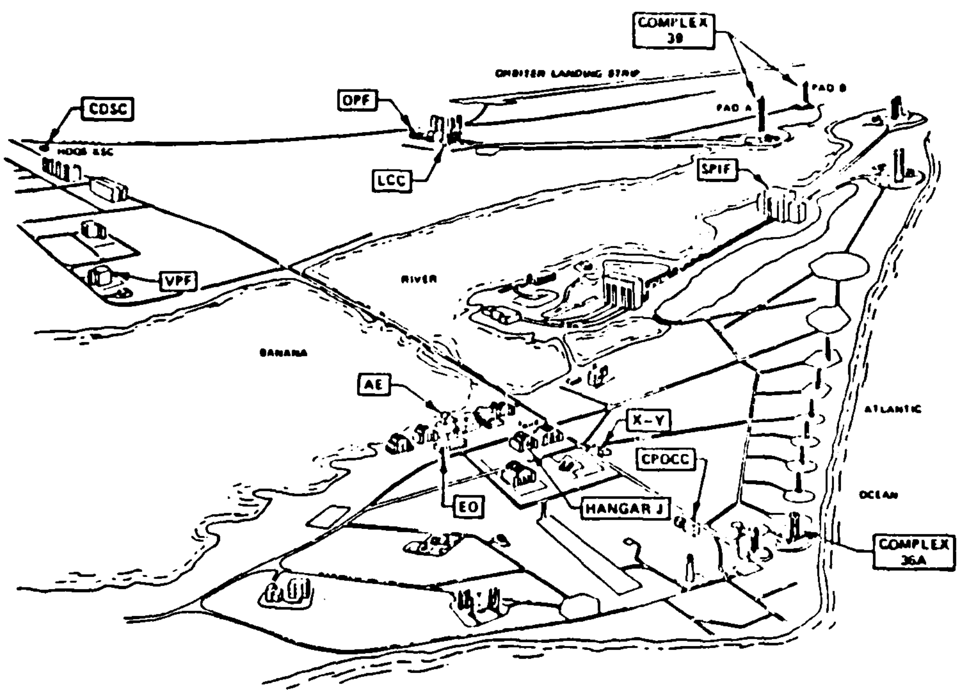
CISS Weight Summary

Item	Weight (Lbs)
Total CISS	6,476
CISS Dry Weight	6,363
CISS Residuals	113
Propellants	43
Helium	70

(Adapted from 13:3-73)

2. Centaur Associated Ground Support Equipment

The major facilities and equipment used to support the integration of the Centaur into the STS are located at several locations around CCAFS and KSC (Figure 2-3). The facilities include Hangar J, Complex 36A, the USAF Shuttle Payload Integration Facility, Shuttle Launch Complex 39, the Orbiter Processing Facility, and, the heart of the S/CPGS, the Centaur Payload Operations and Control Center. Mechanical Ground Support Equipment (GSE) required to integrate the Centaur with the Orbiter consists primarily of structural and fluid control items.



(Adapted from 10:18)

Figure 2-3

Shuttle/Centaur Facilities

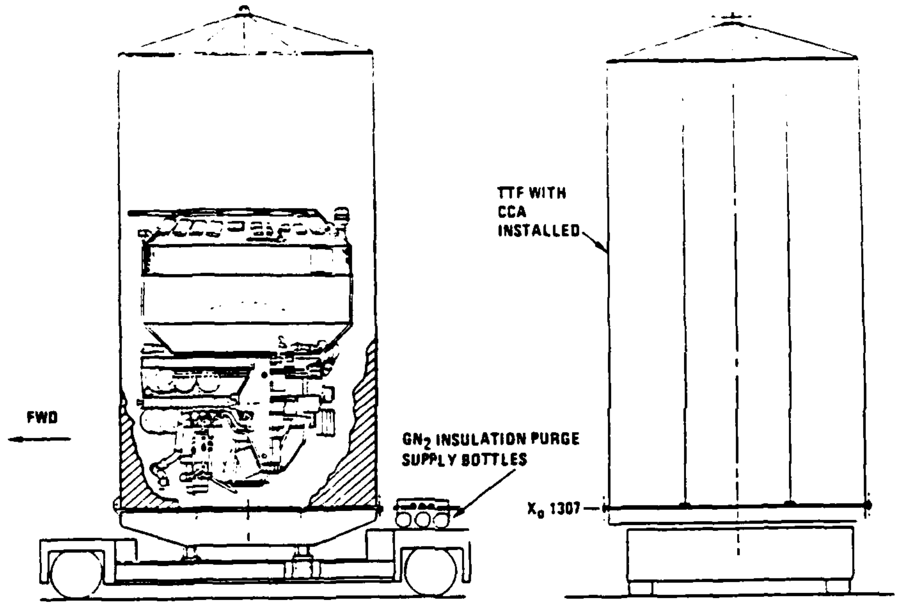
a. Hangar J

The Centaur G vehicle and CISS will be transported from the GDC factory in San Diego, California to CCAFS on the NASA Super Guppy aircraft. After arrival at CCAFS, the Centaur equipment is transported to Hangar J for receiving and inspection. No major modifications will be required at Hangar J (12:3-1).

b. Complex 36A

CX 36A has been used for years to support launches of the Atlas/Centaur vehicle. It will be modified to allow assembly of the Centaur, CISS, and insulation system and to perform checkout of the combined Centaur/CISS Assembly (CCA). The Atlas Centaur launch stand will remain in place and an adapter will be installed to hold the CCA in the vertical position using the Test and Transport Fixture (TTF) (Figure 2-4). The TTF provides an air conditioned environmental enclosure and it also simulates the actual Orbiter payload bay environment (12:3-7). Included in the TTF is the Orbiter payload bay nitrogen purge; the transfer lines connecting the LO2 supply tank, LH2 supply tank, and helium supply tank to the CISS; and portions of the Centaur LO2 and LH2 tank ground vent systems. The TTF is also used to transport the CCA to the SPIF.

Fluid control items required to support the Centaur G include LO2, LH2, and helium control skids and the standby pneumatic control unit. The control skids will be used for propellant transfer operations at CX 36A and launch operations at LC-39. The standby pneumatic control unit maintains the Centaur tank pressures after installation of the Centaur into the CCIS whenever the airborne pressuration system is not in control (12:3-5).



(Adapted from 13:3-79)

Figure 2-4

Centaur/CISS in TTF

c. <u>Shuttle Payload Integration Facility</u>

Modification and new installations will be made at the USAF's Shuttle Payload Integration Facility (SPIF) to allow for Centaur operations. These changes will include the capability to mate the Centaur with the spacecraft, the addition of helium fluid lines to maintain Centaur pressuration, and equipment to perform the required integration tests prior to going to LC 39.

d. Launch Complex 39

At LC-39, the CCA will use existing handing equipment. Access to the vehicle will be provided by existing work platforms with small portable workstands provided where necessary. The Centaur/CISS/spacecraft will be transported between the SPIF and LC-39 in the multi-use mission support equipment (MMSE) canister provided by KSC.

Centaur propellants will be loaded and the airborne helium bottles charged during the launch countdown at LC-39. All fluids will come from Shuttle supply sources and will be controlled by Centaur-dedicated LO2, LH2 and helium control skids (13:3-18). N2H4 will be loaded at the SPIF.

e. Orbiter Processing Facility

Following a normal mission, the CISS will be removed from the Orbiter payload bay in the Orbiter Processing Facility (OPF) using the OPF crane and placed in the TTF on the Centaur/CISS transporter (CCT) for return to Hangar J. No modifications will be required at the OPF to support the S/GPCS (13:3-18).

f. Centaur Payload Operations and Control Center

The Centaur Payload Operations Control Center (CPOCC) is the focal point for all Centaur operations at CCAFS and KSC. Its function to control and monitor the Centaur vehicle, CISS and spacecraft for the mission include the following operations:

a. Centaur and CISS integration and testing at CX 36A.

b. Spacecraft and Centaur/CISS integration and testing at the SPIF.

c. Prelaunch checkout and cryogenic loading at LC-39.

d. Postlaunch analysis until deployment.

e. Monitor Centaur burn through spacecraft deployment.

f. Analysis of CISS data until return of the Orbiter.

The CPOCC will be located in the Deep Space Instrumentation Facility at CCAFS which is being modified and expanded to accommodate CPOCC requirements. The major CPOCC subsystems are as listed below:

a. Communications Center

b. Ground Computer System (GCS)

(1) Computer Controlled Launch Set (CCLS)

(2) CCLS Telemetry Ground System (CTGS)

c. Real Time Data System

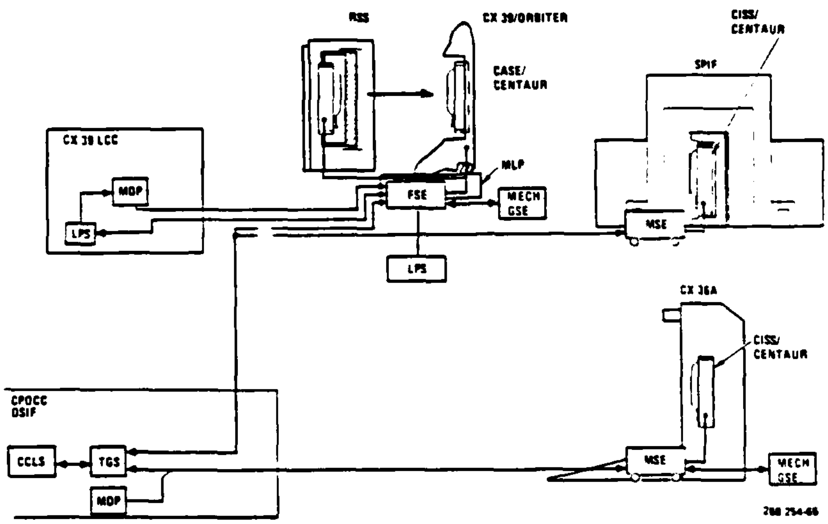
d. Centaur Launch Control Center (CLCC)

e. Centaur Mission Control Center (CMCC) (18:1-1).

The target Operational Readiness Date for completion of the new CPOCC is 1 January 1987 (31:11). Note: the first two Shuttle/Centaur G-Prime missions will be controlled from interim CPOCC facilities located at several locations around CCAFS (10). However, for purposes of this project, the new

CPOCC will be used.

The monitor and control interface between the CPOCC and the Centaur vehicle will be via either m ile or fixed support equipment (MSE/FSE), which will house landline instrumentation and remote launch control equipment. The MSE will be transportable and capable of supporting operations at CX 36A and the SPIF. FSE will be permanently installed in a test area at LC-39. Communications between the CPOCC and the MSE/FSE will be via existing wide-band transmission networks located throughout CCAFS and KSC (13:3-82). Figure 2-5 shows the Shuttle/Centaur electrical ground system.



(Adapted from 13:3-81)

Figure 2-5

Shuttle/Centaur Electrical Ground Systems

A manual detanking panel (MDP) located in the LC-39 Launch Control Center is hardwired into the FSE to permit draining of the vehicle propellants in a safe and timely manner should circumstances dicatate.

(1) Communications Center

The Communications Center (CC) is the central focal point of all incoming and outgoing video, audio, and data communications. All data requirements for encryption or decryption are performed at the CC (18:4-1).

The new, secure CPOCC facility will provide secure communications links from the CPOCC computers to the Centaur/CISS computers. Centaur and CISS telemetry links will be encrypted onboard prior to transmission. This will allow verification as well as uplink loading of classified information in a secure environment.

(2) Ground Computer System

The GCS at the CPOCC commands and controls all CISS/Centaur ground functions. The mains components of the GCS are the Computer Controlled Launch Set (CCLS) and the CCLS Telemetry Ground Station (CTGS) (18:4-4).

The CCLS consists of two computers located in the CPOCC. These computers monitor and control the Centaur and CISS during component testing, combined vehicle tests and prelaunch activities. During the Orbiter attached mode and the Centaur free flyer mode, the CCLS monitors the health of the Centaur.

During major testing and launch activities, one computer is required for direct support and the other for backup (19:4-74). The backup CCLS will be in the a standby-backup configuration where the operator can switch to the backup system within one minute of a detect failure in the primary CCLS unit (13:3-82).

Each CCLS consists of a general purpose computer with standard peripherals, a standard operating system, and test program. Each computer will interface with two operator consoles.

The avionics console will control and test the Centaur and CISS avionics systems. The fluids console will control all fluids and tanking operations.

Commands to the vehicle from the CCLS will be sent via long-distance land lines. The long distance reciever will be in the MSE/FSE which is colocated with the Centaur/CISS vehicle at the facility (CX 36A, SPIF, or LC-39) handling it.

The CCLS, working in conjuction with other GSE, will control the vehicle avionics, the CISS avionics, and the tanking and pressurization skids. In addition to monitoring and controlling the CISS/Centaur vehicle operations, the CCLS will be used to develop and test all Centaur and CISS computer software.

The lineline MSE/FSE system has been developed for Shuttle/Centaur to monitor performance of the tanking and helium skids at CX 36A and LC-39. The remote measurements are multiplexed into the a data stream in the MSE/FSE for transmission to the CPOCC. At the CPOCC, the data stream will be recorded on magnetic tape and, at the same time, displayed real-time by the CCLS Telemetry Ground System (CTGS). The CTGS provides input/output interfacing with wideband transmission lines, recording of the data signals, and display of this data.

(3) Real Time Data System

The Real Time Data System (RTDS) is comprised of interface equipment, computer equipment, and computer terminals/CRT monitors. The purpose of this system is to provide the capability for real time processing of CISS, Centaur vehicle, and ground support equipment equipment data for evaluation and analysis by engineering and management personnel. Thr RTDS has no control capability; all control is via the CCLS discussed above.

Vehicle and GSE telemetry data for the RTDS are received through a data bus from the telemetry interface equipment. The data are converted and processed in real time and displayed on terminal/CRT monitors located throughout the CPOCC. The data are recorded on mass storage devices for real time history recall and CRT display, and on magnetic tape for post-test data processing and evaluation by engineering personnel (18:4-8).

The CPOCC has two main operating areas: the CLCC and the CMCC.

(4) Centaur Launch Control Center

The CLCC is the central operating location in the CPOCC during systems test, major tests, and prelaunch activities. The CLCC controls the Centaur during all prelaunch operations, operates the ground station and CPOCC computer systems, and interfaces with the STS launch control center at KSC (10:7). The NASA and GDC launch directors are located in this area during major tests and prelaunch activities. The avionics consoles that control the CCLS computer are located here along with its printer and recorders. There are also two fluids consoles (primary and backup) for propellant loading (18:8-1).

(5) Centaur Mission Control Center

The CMCC is the management control center of the CPOCC, where all phases of ground and flight operations are monitored by management and engineering personnel. It monitors Centaur systems, particularily after launch. There are 75 monitoring consoles for personnel that provide various monitoring displays for support and decision making. These consoles retrieve data for display from the RTDS and CCLS (18:4-9). The CMCC performs interface functions of the CPOCC with the Orbiter mission control center at the Johnson Space center, the mission spacecraft's payload operations control center, and the Air Force Satellite Control Facility (AFSCF) for mission operations (10:9).

3. Other Ground Support Equipment

A TV system permits remote visual observations of tanking operations at CX 36A and LC 39. Television cameras will be mounted in the TTF in addition to the camera mounted on the structure at CX 36A. This system will also tie into the existing television system at LC-39.

An RF system will provide for reradiation of the Centaur S-band telemetry signal from CX 36A and the SPIF. The system will also provide for reception, demodulation, and parameter measurements of the Centaur S-band telemetry signals in the CPOCC telemetry ground station.

C. SHUTTLE/CENTAUR G OPERATIONS

Assembly and verification testing of the Centaur will be accomplished in stages in facilities described above. The operations from the recieving inspection in Hangar J to the final launch preparations on Complex 39 will contribute to the assurance that the vehicle is ready for flight.

For this project, the operations will be broken down into six phases: receiving & inspection, system buildup & checkout, spacecraft mate & test, launch, flight, and recovery.

1. Receiving & Inspection

The Centaur, CISS, and supporting loose equipment will be delivered to the USAF skid strip at CCAFS. Shipment of these elements from the GDC factory in San Diego will be by the NASA Super Guppy aircraft. During transport, the Centaur is mounted on a transportation pallet (CRTP) and the

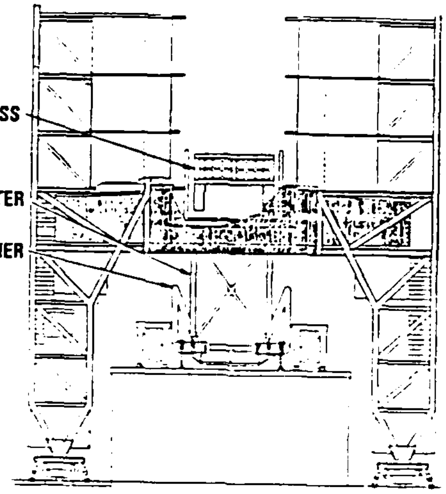
CISS is installed in the lower portion of the test and transport fixture (TTF) for stability. After unloading from the aircraft, the Centaur/pallet combination is placed on a flat-bed trailer and moved to Hangar J. The CISS/TTF is transported to Hangar J on a modified transporter previously used during for an earlier space program .

The receiving tasks and Centaur tests performed in Hangar J are general in nature and are to prepare the vehicle for installation at CX 36A. An inventory of the shipped equipment is made and the Centaur and CISS are checked for any superficial damage incurred during shipment. Provisions are also available in Hangar J for tank purging, minor assembly, and preliminary cleaning (13:3-1).

2. System Buildup & Checkout

Ground system checkouts will be performed on the CX 36A ground and facility systems prior to installation of the CISS and Centaur. These test ensure that the complex/ vehicle interfaces are compatible.

The CISS/TTF combination is transported to CX36A via the modified Viking transporter and installed on the launcher adapter (Figure 2-6). After the CISS has been secured to the adapter, interface lines and harnesses between the facility and the CISS are connected. Orbiter bay simulation hardware is used to make the interface connections. Components shipped from San Diego as loose equipment are installed during this period. Electrical and



(Adapted from 12:3-4)

Figure 2-6

CISS Installation at CX 36A

mechanical level tests are performed to prepare the CISS systems for CISS avionics subsystem functional test and overboard cryogenic flow tests. These tests consist of pre-power turn on, CCLS interface checks, GCS control of CISS/skid components, leak and functional tests, and a CISS/deployment adapter rotation test. A flow test of LH2 and LO2 through the ground support equipment and propellant control skids, associated transfer lines, and the CISS components will be the final major test to verify the system is ready to accept the installation of the Centaur Vehicle.

The TTF-upper structure will be mated to the lower portion prior to Centaur installation. The outside panels for the TTF are removed as required to provide access to the Centaur during the mating operation.

The Centaur vehicle is transported from Hangar J to CX 36A for direct installation into the CISS/TTF. The CX 36A bridge crane is used to rotate the Centaur to the vertical attitude, remove it from the pallet, and position it into the CISS.

The major Centaur/CISS integrated tests performed at CX 36A are intended to simulate the conditions expected at LC-39. The CX 36A electrical and mechanical systems have been modified to have near the same lenght and size of cabling and plumbing as installed at LC-39. Semi-permanently installed hardware at CX 36A and LC-39 will be of identical design (12:3-1,3-5).

Cr. .genic tankings of the Centaur vehicle are the all-up systems test performed at CX 36A. For one test, all airborne systems will be assembled as close to flight configuration as possible at this stage of the processing. Flight batteries and pyrotechnics will not be installed. The propellant flows and gas supply systems will simulate the LC-39 installations. Simulated countdown to lift-off (T-0) will be performed with the propellant tanks and the helium storage bottles at flight level. Propellant boil-off rates, purge flows, and power levels are monitored throughout the test at the CPOCC. The total environment of the CISS/Centaur combination will be controlled to maintain the various compartments within the launch parameters. After satisfactorily completing the cryogenic testing requirements, the vehicle tanks are drained, purged to an inert condition, and all systems are returned to a standby position (12:3-7,3-11).

Leak and functional tests of the Centaur attitude control system will be accomplished at CX 36A. However, no operation, i.e. firings, of the attitude control motors will be performed. Loading of the attitude control system propellant, N2H4, will be delayed until arrival at the SPIF. At this point the CISS and Centaur systems are secured and prepared for loading on the transporter.

After completing the cryogenic tanking tests, and simulated countdown tests, the Centaur processing moves into a different phase. The vehicle has demonstrated its capability to withstand the cryogenic environment and to perform as a single element with all systems functioning. The remaining processing operation verify interfaces with the spacecraft and the Orbiter and securing all systems.

3. Spacecraft Mate & Tests

The Centaur will remains enclosed in the TTF for transfer to the SPIF. The combination will be remove from the CX 36A service tower, placed on the CCT and transported directly to the SPIF (Figure 2-4).

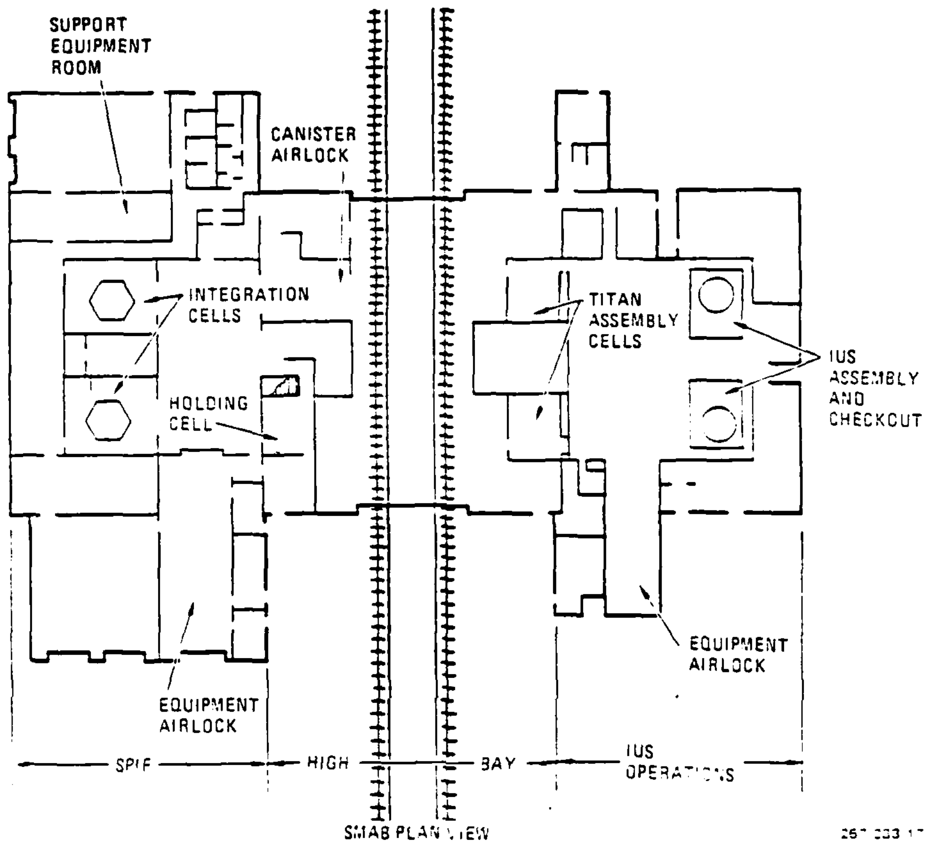
The SPIF facility is the location at which the Centaur enters into the integration flow for the STS. The purpose of the activities at this location is to integrate the spacecraft with the Centaur, off-line from the main Shuttle processing flow. Mating of the spacecraft to Centaur and the following activities will verify that the combination is ready to be installed into the Orbiter payload bay and proceed on to launching (12:3-11).

Upon arrival at the SPIF, the transporter/vehicle will be positioned in a holding area and prepared for moving into the cleanroom. The external surfaces of the TTF and transporter will be cleaned or bagged.

The SPIF is located in the west bay of the solid rocket motor assembly building (SMAB) in the Titan intrgrated launch area on CCAFS (Figure 2-7). The SMAB facility was modified to provide the SPIF capability which includes an environmentally conditioned and contamination controlled area inside the bay. The bay contains two integrated test cells for vehicle mating and combined testing (12:3-15).

After cleaning, the transporter will be positioned on an air bearing pallet for transporting into the transfer aisle via the canister airlock. Additional cleaning may be accomplished as the vehicle is passed through the airlock.

The TTF cover will be removed to allow access to the forward end of the Centaur. The SPIF overhead crane will be used to lift the Centaur/CISS assembly from the TTF and place the combination directly into one of the integration cells. The facility pneumatic connections will be made to the vehicle as soon as possible in order to reestablish tank



(Adapted from 12:3-16)

Figure 2-7

SPIF Floor Plan in SMAB

pressures and the insulation purge.

Electrical, instrumentation, and environmental connection will be made to the Centaur/CISS to support the SPIF activities. Preliminary power-on tests will be accomplished to verify the communications links to the CPOCC. These checks will also verify the health of the systems after their overland move from CX 36A prior to the spacecraft being mated.

After completing the Centaur/CISS prepartions, the spacecraft will be mated to the Centaur. Any spacecraft stand-alone tests will be performed after mating with the Centaur. The SPIF facility uses the interface verification equipment (IVE) to perform off-line verification of the interfaces between Centaur/CISS/spacecraft and the Orbiter. Some of the IVE components include the Orbiter Avionics Simulator (OAS), Orbiter aft flight deck simulator, Orbiter mechanical simulator, and the T-0 interface rack. The IVE will be used to accomplish the major spacecraft/Centaur/Orbiter integration tests: the functional interface test, the mission simulation test, and the system end-to-end test. The mission simulation test verifies the prelaunch, ascent, predepolyment and postdeployment modes of the Centaur/spacecraft/OAS. The end-to-end test verifies the telemetry and command links between Centaur/spacecraft, OAS, KSC ground stations, TDRSS, Johnson Space Center (JSC), CPOCC, and Air Force Satellite Control Facility (AFSCF). This test is intended to encompass all of the control and monitoring centers for the mission (12:3-15,3-16).

The Centaur attitude control system propellant, N2H4, will be loaded for the flight at this point. The system will be continually monitored during the remaining processing until launch (6).

After completing the SPIF operations, the Centaur/CISS/

spacecraft assembly is prepared for transporting to LC 39. Ordinance will be installed, support equipment disconnected, and the areas will be secured. The entire cargo element is placed into the multi-use mission support equipment (MMSE) canister by the payload handling fixture (PHF). The canister is moved from the canister airloack into the SMAB high bay. The 300-ton bridge crane is used to lift the canister from the air bearing pallet and to place it onto its transporter. The integrated cargo is then transported to the rotating service structure (RSS) at LC-39 for installation into the Orbiter payload bay (12:3-17,3-18).

4. Launch

The LC39 RSS will be in the rolled-back position with the payload changeout room doors opened in preparation for receiving the Centaur/spacecraft. The MMSE canister transporter will position the canister at the base of the RSS. Using the fixed servide structure crane, the canister will be hoisted to the open doors of the RSS. The canister doors will be opened and the cargo will be removed by the payload ground handling mechanism (PGHM) in the RSS. The PGHM supports the cargo, removes it from the cannister and holds it in the PCR. The PCR will be a holding area for final cleaning and other cargo preparations prior to installation into the cargo bay. The facility will be configured to supply vehicle power to the Centaur. The capability will also be available to service the Centaur hydraulic system and to dump the hydrazine system.

After the Orbiter is on the pad and the mobile launch platform (MLP) is locked down, the RSS is rotated to the Orbiter for cargo installation. The cargo will be installed into the payload bay by the PGHM. Structural, fluids, and electrical connections tests will be performed on the mechanical systems and power-on tests will verify the integrity of the Centaur/CISS to Orbiter interfaces.

After completing the interface and system level tests, an end-to-end test will be accomplished to verify the communication links between the STS and the command and control centers. Stray voltage tests will be performed to support final ordinance connections. The Centaur will support the spacecraft with any mission peculiar tasks required for final closeout. These tasks may include electrical power, purges, or installation of special equipment. Centaur and CISS batteries will be installed as part of the final cargo bay closeout. The propulsion, hydraulic, pneumatic, and hydrazine systems will also be configured for flight prior to closing the payload bay doors. The manual pressuration system that monitors and controls Centaur tank pressures will be secured and this function will be transferred to the ground computer system (GCS) at the CPOCC which communicates with the CISS for the remaining launch preparations. Once the cargo bay doors are closed, the Centaur is in the launch standby mode and ready to begin final launch day tasks. Only remote or monitoring functions are performed during this period from the CPOCC.

The final countdown operations for Centaur will start approximately 12 hours prior to liftoff. Guidance calibration will be accomplished prior to the start of cryogenic loading. Propellant tanking of the Centaur will be controlled throught the LH2 and LO2 control skids. The Centaur propellant and pneumatic supplies are supply from the facilities supplying the Orbiter systems. The flow of propellants to the Centaur/CISS is controlled from the CPOCC via the system control skids (12:3-18).

Status communications is maintained between the Centaur and the CPOCC by the 16 CCLS/GCS interface lines. Centaur will indicate a "GO" at approximately T-20 minutes prior to launch.

5. Flight

Centaur G flight operations, plans and procedures completement those for the Orbiter Mission Control Center (MCC) and the Orbiter crew. The Centaur will accomplish a baseline mission with a 60-day call-up period. Preflight planning will coordinate training, operations control, operations support, and flight plans for nominal, contingency, and abort missions (13:3-87).

Flight operations actually begin many weeks prior to the launch of the Shuttle/Centaur with the rehearsals and Joint Integrated Simulations (JIS). The purpose of the JIS's are to exercise the impacts of the STS on the

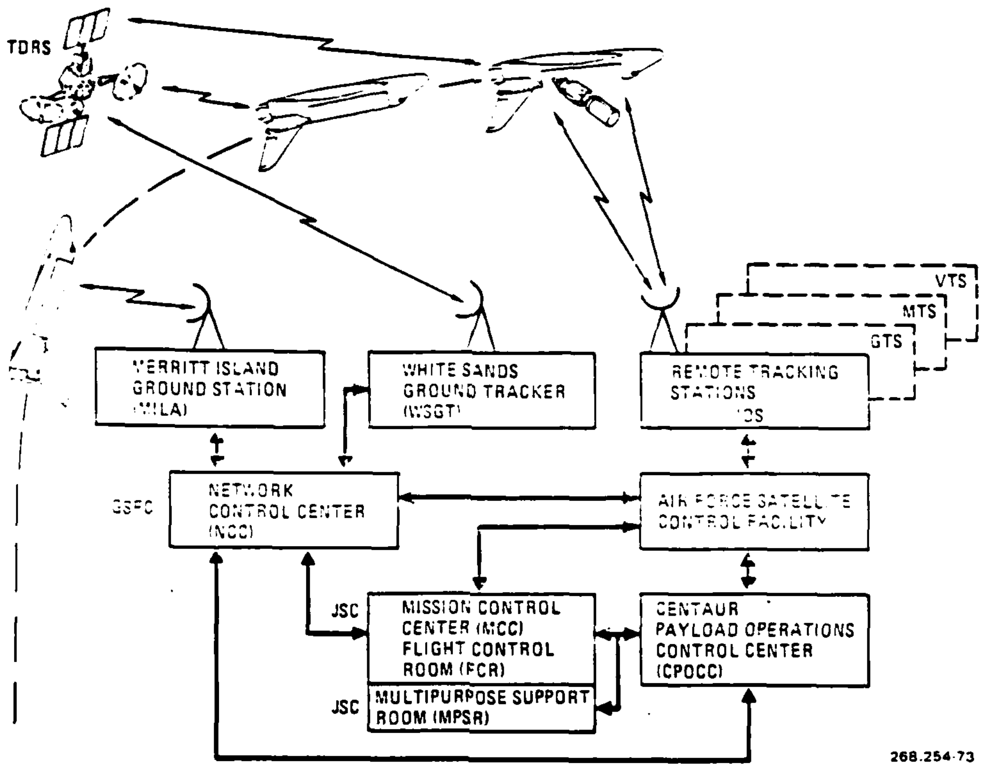
Centaur/spacecraft, to exercise the impacts of the Centaure/spacecraft on the STS, and to exercise the managemennt interfaces of all control centers involved in the operation of the mission (10).

Flight operation, during flight, support the command and control for Shuttle/Centaur. This includes ground-based activities ranging from data processing and monitoring to operational support to the MCC.

During ascent and Orbiter-attached operations, mission and flight operations will be control from the MCC at the Johnson Space Center (JSC), as shown in Figure 2-8. The CPOCC will monitor the Centaur and will be in close communication with the MCC and the AFSCF to provide Centaur analysis and support.

Within the MCC, the Flight Control Room (FCR) will control Orbiter mission operations. Centaur flight controllers in MCC support rooms support the activities of the FCR during Orbiter/Centaur attached operations. After separation, when the Orbiter has maneuvered out of the zone of safety around the Centaur, responsibility of the Centaur will be assumed by the CPOCC. The CPOCC will then control Centaur flight operations through Centaur burn, spacecraft separation, and Centaur postseparation maneuvers.

During the ascent phase of the flight, flight operations support consists primarily of monitoring Centaur/CISS health status until the Orbiter payload bay doors are opened. On-orbit operations then begin with



(Adapted From 13:3-90)

Figure 2-8

CPOCC Support for Mission Flight Operations

initiation of Centaur and spacecraft checkouts.

Flight operations support continues on-orbit with ground analysis of checkout data, continuous real-time analysis of health status, and providing advice regarding Centaur as necessary to the FCR. The latter includes "GO"/"NOGO" decisions for Centaur rotation and separation from the Orbiter.

Flight operations support of the Centaur vehicle after handover to the CPOCC consists primarily of monitoring

Centaur automatic sequences, data recording, evaluating anomalies, and providing tracking acquisition data to AFSCF.

Nominal flight operations are continuous from launch through orbit injection and post-separation maneuvers. The Centaur Cargo Element (CCE) is limited to such safe, automatic activities as passive navigation, vent control, and pressurization control until the Orbiter crew assumes an active role in CCE on-orbit predeployment operations. Based on Shuttle flight requirements for ascent phase and on-orbit reconfiguration, the earliest time CCE on-orbit predeployment operations can begin is 2 hours 30 minutes after liftoff.

From liftoff through Centaur post-separation operations, the MCC and CPOCC will monitor the health and safety of the CCE via the telemetry link. The Orbiter crew also has independent access to vehicle status information via a CRT display and can act as a backup source during attached operations.

There are two key go/no-go decision points: 1) to initiate the rotation operation at about 20 minutes before Centaur separation, and 2) to proceed with the separation at about four minutes before the event. (13:3-88,3-90).

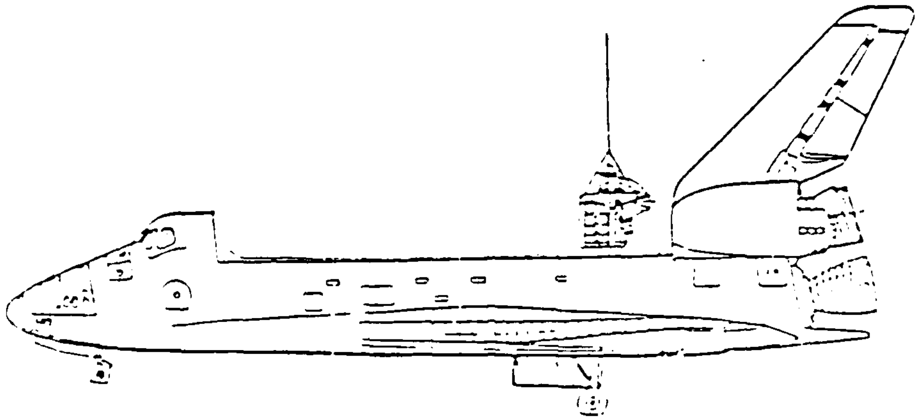
Two Orbiter operations are required following Centaur/Orbiter separation: 1) the Orbiter maneuvers away from the Centaur without contaminating the spacecraft, and 2) the CISS will be secured for atmospheric reentry and landing. Tasks include venting the helium pressurant tanks and pressurizing propellant lines to atmospheric levels.

Centaur coast attitude and events are designed to meet spacecraft thermal constraints. Centaur separation time is planned sufficiently early to ensure Orbiter safety before the Centaur's first Main Engine Start (MES1). After MES1, the Centaur provides passive thermal control and telemetry readout, as required by the spacecraft. At about 5 hours and 15 minutes after MES1, the Centaur will prepare for the second burn (MES2).

A 26-degree plane change and geosynchronous orbit insertation occur during the two minute duration of the MES2. The Centaur establishes the spacecraft separation attitude and initiates separation from the spacecraft. The Centaur then performs orbit deflection maneuvers to ensure no contamination of, or recontact with, the spacecraft. This orbit deflection maneuver takes place approximately 40 minutes after MES2 (13:91,3-92).

6. Recovery

After a successful mission, the CISS will be returned to KSC still in the payload bay. When the Orbiter arrives at the Orbiter Processing Facility (OPF), the mechanical and electrical systems on the CISS will be disconnected to allow removal from the Orbiter. The CISS will be removed from the payload bay by the OPF bridge crane and installed in the TTF (Figure 2-9). The same handling equipment will be used to rotate the CISS to the vertical position and for



(Adapted from 29:6-2)

Figure 2-9

CISS Removal From Orbiter

transporting to Hangar J (13:3-18).

At Hangar J, the CISS will be removed from the TTF and be refurbished to support another flight. Reburbishment ends the duties of the S/CGPS to support this mission. Another mission begins with the arrival of a new Centaur vehicle from San Diego.

D. Summary

As is apparent from the discussion above, the S/CGPS is a very complex system. However, the PERT and simulation models were developed during the same six phase approach as outlined in the previous sections. This should enable the reader to follow the flow of the S/CGPS in whatever form it is presented.

III. THE PERT/CPM NETWORK

This chapter presents a short discussion of the PERT/CPM network process and describes the development of a PERT network for the S/CGPS. An analysis of the PERT network is conducted including determination of the system's "critical path."

A. Introduction

Network theory is not a new concept. Scientists and engineers have been using it for centuries (32:9). For example, network analysis has been an important tool in the study of electrical networks. Recently however, there has been a growing awareness that various concepts and techniques of network theory are also very useful in business and economic analysis. Important applications of network theory have been made in information retrieval and processing, in the study of subways, highways, and transportation systems, and in the planning and control of research and development projects (24:379).

One typical network analysis problem involves the planning and control of activities or projects that can be reprensented as time-dimensioned networks. The network analysis procedures of the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM) have been widely employed by managers in the planning and control of such time-diminsioned networks (24:380)

Few management tools have been the subject of so many discussions, have received as much publicity, or have been the target for so much scrutiny as have CPM and PERT. Both systems were developed in the late 1950's.

In 1956, E.I.DuPont undertook a thorough investigation into the extent to which a computer might be used to improve planning, scheduling, rescheduling, and progress reporting of the company's engineering programs. In late 1957, consultants from the Remington Rand UNIVAC Division of the Sperry Rand Corporation ran a pilot test of a system using a unique arrow-diagram or network method which came to be known as the Critical Path method (1:12-13).

At about the same time, the U.S.Navy Special Projects (SP) Office, established a research team composed of the members of SP and the management consulting firm of Booz, Allen, and Hamilton. Their assignment was known as project PERT, and was aimed at finding a solution to the management problems posed by the POLARIS Fleet Ballistic Missile Program. POLARIS was a huge, complicated development program, being conducted at or beyond the state of the art in many areas, and had activities proceeding concurrently in hundreds of industrial and scientific organizations around the country. What emerged from the study was an integrated management planning and control technique: PERT (1:13-14). Simply put, PERT was developed as a planning technique and a tool of management control which uses network theory (32:9).

CPM is typically used for construction projects in which a single, or deterministic, time estimate is made for each job or activity.

PERT is used for projects that involve research and development work in which the planning effort and the manufacturing of component parts are new and are usually being attempted for the first time. Hence, the time estimates cannot be predicted with certainty, and probabilistic concepts are employed. Since no Centaur vehicle has been processed in this manner before, the S/CGPS would certainly fall into this latter category (9:9).

B. The Basics of a PERT/CPM Network

Before beginning, the basic terms and prinicles used in the PERT as well as the CPM networks are presented. These terms will be used consistently throughout the remainder of the project.

Using the terminology of the theory of graphs, a **graph** is defined as a set of junction points called **nodes** that are connected by lines called **branches**.

Many times a graph is used to represent some type of physical flow or movement. A **network** is defined as a graph in which a flow can take place in the branches of the graph (17:3). In this project, the actual flow will consist of Centaur flight hardware flowing through the ground processing system.

Therefore, the S/CGPS can be viewed as a group of jobs or operations that are performed in a certain sequence to reach an objective, the launch of the Centaur and its spacecraft payload. Each one of the jobs or operations that make up the S/CGPS is time and resource consumming and is usually referred to as an **activity**. Each activity has a beginning and an end point that are points in time. These points in time are known as **events**, and can be considered as milestones in the launch processing flow.

A mathematical model of the S/CGPS satisfying the previous definitions can then be visualized as a "network" in which "events," corresponding to "nodes," are joined by "activities" corresponding to "branches." This network thus becomes a convenient method of expressing the sequential nature of the processing system.

The two basic elements in a network plan are the line or arrow which represents a time-consuming **activity** or branch, and the circle or rectangle which represents the **event** or node marking the beginning or end of an activity. When all activities and events are linked together sequentially in proper relationship, they form the S/CGPS network. This network is the basic planning document in a network-based management system (1:16).

The "event" is described as a discrete point in time. An event denotes the specific starting or ending time point for an activity or a group of activities. Events do not consume time or resources, and are represented in the network diagram by circles or rectangles containing an identifying letter (Figure 3-1).

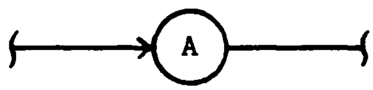


Figure 3-1

A PERT Event

An "activity" is defined as the work necessary to progress from one event (point in time) to another. Activities are operations which consume time, money or manpower and are characterized by a specific initiating event and a terminal event. In the S/CGPS network, activities are represented as solid lines joining these events and are labeled with an activity number, i.e. (2.1.13), unique to that activity (1:16).

One can attribute a sense of direction to an activity by indicating which event is to be considered the point of origin. Such a activity is called "directed" (Figure 3-2)

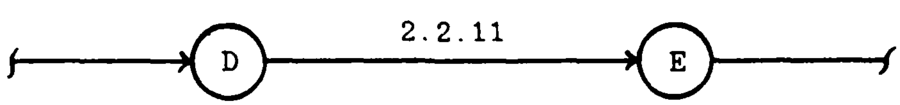


Figure 3-2

A PERT Activity

and when drawing a diagram the orientation of the activity is indicated by use of an arrowhead.

A sequence of connecting activities between events **I** and **K** is called a **chain** from **I** and to **K**. If the direction of travel, or flow, along a chain between two events is specified, it is called a "path" (Figure 3-3). A "cycle" is a chain that begins and ends at the same event.

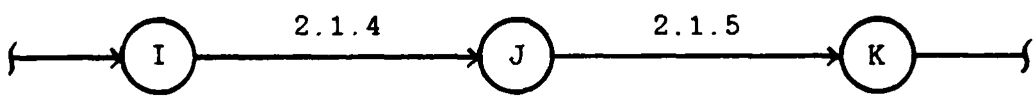


Figure 3-3

A PERT Path

Several important ground rules connected with the handling of events and activities in a network will be followed in order to maintain the correct structure for the network:

1. Each defined activity is shown by a unique branch of the graph.
2. Branches show only the relationship between different activities. The length of the branches have no significance.
3. Branch direction indicates the general progression of time. The branch arrowhead represents the point in time at which an "activity completion event" takes place. In a similar manner, the branch tail

represents the time at which an "activity start event" occurs.

4. When a number of activities terminate at one event, this indicates that no activity starting from that event may commence before all activities terminating at this event have been completed.

5. If one event takes precedence over another event that is not connected by a specific activity, a **dummy activity** is used to join the two events (Figure 3-4). Dummy activities have no duration or cost. Dashed lines indicate a dummy activity. (24:405).

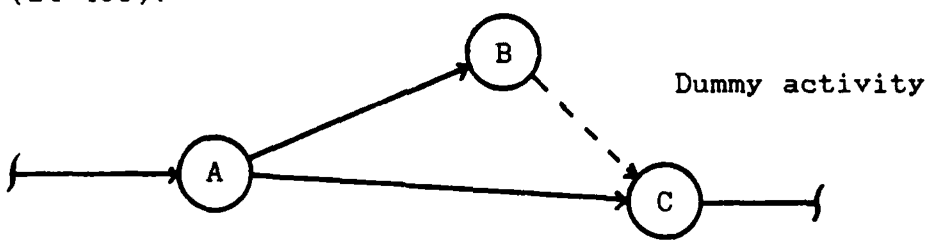


Figure 3-4

A PERT Dummy Activity

As previously mentioned, CPM deals with deterministic situations. Thus, only one time estimate for the completion of an activity is required. However, PERT is commonly employed for projects having a significant amount of time uncertainty. Therefore, three time estimates are employed, as follows:

1. **Optimistic.** This is an estimate of the shortest possible time in which an activity can be completed

under optimum conditions. The optimistic estimate assumes that the activity is accomplished in an ideal environment, free of even the normal amount of delays or setbacks.

2. **Pessimistic**. This is the estimate of the longest time it might take to complete an activity. The pessimistic estimate assumes that everything goes wrong, all possible delays or setbacks occur, and everything in general goes badly. However, the possibility of a catastrophic event (strikes, acts of God, etc.) is not considered.

3. **Most likey**. This estimate lies between the optimistic and the pessimistic. It assumes normal conditions will be encountered in the activity (24:407). The most-likely estimate assumes that the "normal" amount of things will go wrong, the "normal" amount of things go right. It anticipates a satisfactory rate of progress but no dramatic breakthroughs: in short, "business as usual" (1:80).

In developing these three time estimates for the activities, the statistical judgment of competent personnel was employed. Individuals directly involved with the S/CGPS were interviewed. Most had many years of experience dealing with space systems and launch processing at CCAFS and KSC (5) (6) (8). The three time estimates are considered to be related in the form of a unimodal probability distribution, with **m**, the most likely time, being the modal value. Because **a**, the optimistic time, and **b**, the pessimistic time, may vary in their relationship to **m**, this probability distribution may be skewed to the right or to the left.

After considerable research into the relationships between these three times, the original PERT research team decided that the **beta distribution** seemed to fit these general properties. Thus, the beta distribution was chosen for determining the **mean** or **expected time**, **te**, and the **standard deviation**, **St,e**, associated with the three time estimates.

Two basic assumptions were made in order to covert **m**, **a**, and **b** into estimates of the expected value and variance of the elapsed time required by the activity. The first of these assumptions is the **St,e**, the standard deviation of the elapsed time required by the activity, is equal to one-sixth of the range of the reasonably possible time requirements.

$$St,e = (1/6)[b-a] \qquad (3\text{-}1)$$

The underlying rationale for this assumption is that the tails of many probability distributions are known to lie at about three times the standard deviation from the mean, so that there would be a range of about six standard deviations between the tails.

The second basic assumption is that the activity time are beta distributed. Under this assumption, the expected activity time can be approximated as:

$$te = (1/6)[a+4m+b] \qquad (3\text{-}2)$$

This equation is thus used to compute the estimated expected value of the elaped time required for an activity (24:408).

PERT was used to analyze S/CGPS management problems. The estimated completion time of all S/CGPS activities and the sequence in which they needed to be accomplished were known. Using these techniques, the minimum time in which one Centaur vehicle could flow through the processing system was calulated and the crucial jobs that can delay the entire processing sequence were identified.

The longest time path through the S/CGPS network was computed. How this was achieved will now be explained. Once the time estimates for each activity were made, the longest or **critical path** was calulated. For any particular event, its **earliest time**, **Te** was defined as the time at which the event will occur if the preceding activities were started as early as possible. Similarly, the **latest time** for an event,**Tl**, was defined as the latest time at which the event can occur without delaying the completion of the Centaur processing beyond its earliest time. Now, the slack concept defines the **slack**, S, for an event as the difference betweeen its latest time and its earliest time,

$$S = Tl - Te. \qquad (3\text{-}3)$$

Thus, the slack value indicates how much delay in reaching an event can be tolerated without delaying the completion of the Centaur processing (24:410-411).

When the S/CGPS activities were plotted according to the branch-diagramming techniques described above, there were numerous paths existing between the "start" and the "end" of the processing system. By adding the duration of all the various activities forming a path, various "durations for S/CGPS completion" were obtained. The longest of these durations is the critical time for S/CGPS processing, and the path associated with it is the **critical path**. Therefore, the critical path controls the processing time for each Centaur vehicle.

The **critical path** for the network can be defined as that path through the system whose events path have zero slack time. It is important to note that, in determining the critical path for the S/CGPS, nothing was optimized. Rather, only the set of activities in the S/CGPS which were most critical in terms of the time required for completion were identified.

These terms and principles were used and followed to generate the S/CGPS network. The next section of this paper outlines the development of this network.

C. The S/CGPS PERT Network

The construction of the S/CGPS network was accomplished in three steps. The first step was to identify the individual activities required to process one Centaur vehicle through the system. Next, the estimated completion times (optimistic, pessimistic, and most likely) were determined. With these estimates, determination of the expected completion time, **te**, and the standard deviation, **St,e**, were calulated. This information was then used to derived the output information for the S/CGPS PERT network. Finally, by adding together the time estimates of the activities all along the paths of the network, the path that will consume the most time or "critical path" through the system was identified (1:19).

1. Activities of the S/CGPS

As can be seen from the information in Chapter Two, hundreds of individual tasks must be completed to process a Centaur vehicle from receipt at the CCAFS landing strip to mission completion on-orbit. To make identification of these tasks manageable, a system was developed to break the six phases of the S/CGPS into subtasks. The subtasks were then divided into the individuals tasks or activities accomplished by each subtask.

A numbering system was established to keep track of each activity. Each activity has a unique three digit number. The first value identifies the processing phase in which the activity is located. The second number specifies the subtask containing the activity; and the third number identifies the activity within the subtask. For example, the activity, **Fill LH2 Storage Tank**, is the fourth activity conducted during the first subtask, **CISS @ CX 36A**, of the second phase, **System Buildup & Checkout**, of the processing cycle. Therefore, the activity number for **Fill LH2 Storage Tank** is **2.1.4** for Phase 2, Subtask 1, Activity 4.

The available documentation on the S/CGPS was reviewed and personal interviews were conducted with key individuals involved with the Centaur program. From this data, the S/CGPS's six phases, outlined in Chapter Two, were divided into 24 seperate subtasks. Table 3-1 is a list of all Phases and Subtasks of the S/CGPS.

These subtasks were then broken down into the individual activities performed to complete each subtask. A list of all activities in the S/CGPS is contained in Appendix A of this paper.

After identifying the specific activities of the S/CGPS, the relationship of one activity to another had to be specified. This was accomplhished by means of a PERT network graph. The graph indicates which activities can be conducted in parallel and which must be done in a serial (one-at-a-time) method. If there are several activities which must be completed prior to start of a new activity, this is indicated on the graph by several activities meeting at the starting node of the next activity. The graph guidelines outlined in section B of this chapter were

TABLE 3-1

SHUTTLE/CENTAUR PHASES & SUBTASKS

1. RECEIVING & INSPECTION

    1.1 CISS @ HANGAR J
    1.2 CENTAUR @ HANGAR J

2. SYSTEM BUILDUP & CHECKOUT

    2.1 CISS @ CX 36A
    2.2 CENTAUR/CISS @ CX 36A (PART I)
    2.3 CENTAUR/CISS @ CX 36A (PART II)

3. SPACECRAFT MATE & TEST

    3.1 SPIF PREPARATIONS
    3.2 CENTAUR/CISS ASSEMBLY CHECKOUT
    3.3 MOVE SPACECRAFT TO SPIF
    3.4 CENTAUR CARGO ELEMENT MATE & CHECKOUT
    3.5 CENTAUR CARGO ELEMENT MAJOR SYSTEMS TEST
    3.6 FINAL CENTAUR CARGO ELEMENT PREPARATIONS

4. LAUNCH

    4.1 LAUNCH COMPLEX 39 PREPARATIONS
    4.2 CENTAUR CARGO ELEMENT CHECKOUT
    4.3 INSTALLATION IN ORBITER & CHECKOUT
    4.4 CENTAUR CARGO ELEMENT PRELAUNCH CLOSEOUT
    4.5 LAUNCH COUNTDOWN

5. FLIGHT

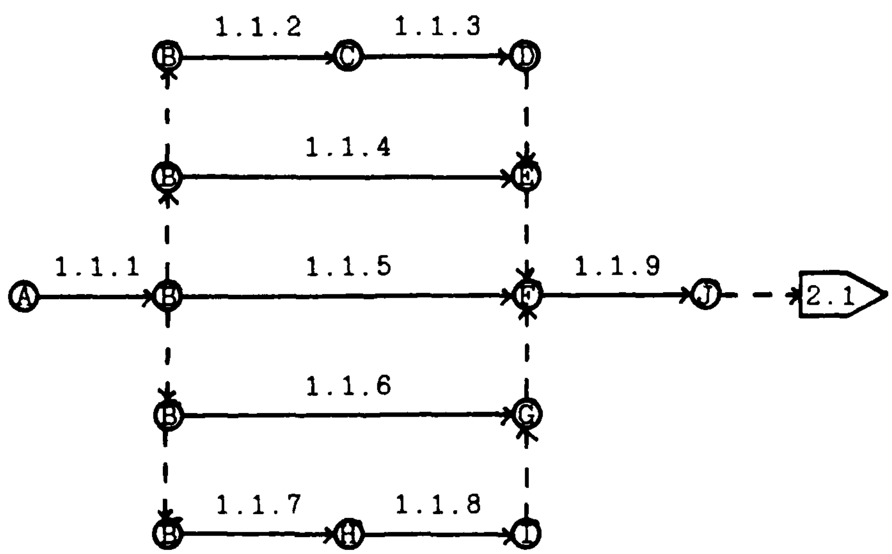
    5.1 EXERCISES & SIMULATIONS
    5.2 ASCENT
    5.3 CENTAUR CARGO ELEMENT CHECKOUT & DEPLOYMENT
    5.4 CENTAUR FLIGHT

6. RECOVERY

    6.1 MONITOR CISS
    6.2 REMOVE CISS
    6.3 CISS REFURBISHMENT

followed during development of the S/CGPS network graphs.

The graph for Subtask 1.1, **CISS @ Hangar J**, is presented in Figure 3-5. Notice that all activites are numbered using the activity numbering system described above. Each of the event nodes has its own unique alpha-numeric identifier, i.e. A, B, C, etc. These node identifiers are used to specify a particular path through the subtask. For example, one path is [A,B,C,D,J] using activites 1.1.1, 1.1.2, 1.1.3, and 1.1.9. Another path is [A,B,G,J] using activities 1.1.1, 1.1.6, and 1.1.9. Note: dummy activity nodes, [D,E,F] AND [G,F], are not included in the path listing.



(Adapted from 16)

Figure 3-5

SUBTASK 1.1: CISS @ HANGAR J Network Graph

The starting and completion points of each subtask is indicated by the following figure: 1.2 This indicates the subtasks which preceeds and follows the current subtask. If an activity is continued from one page to a different page of the network graph a triangle, A , with an alpha-numeric character is used to connect the activity to the other page. The triangle is also used to continue an activity on the same page.

After evaluating the interaction of all system activities, the PERT Network Master Graph of the S/CGPS was developed. This graph is presented in Figure 3-6.

The Master Graph shows the overall flow and relationship of all subtasks of the processing system. Each subtask was also graphed into its component activities. The complete set of PERT network graphs for the S/CGPS are contained in Appendix B of this paper.

2. <u>Estimating S/CGPS Completion Times</u>

The determination of estimated completion times (optimistic, pessimistic, and most likely) for the S/CGPS activities proved to be a more difficult problem. The engineers working on the project had made estimates on the "most likely" completion times, **m** for the individual activities. These times are listed with their specific activities in Appendix A. Unfortunately, no one had made estimates on the optimistic, **a**, and pessimistic, **b**,

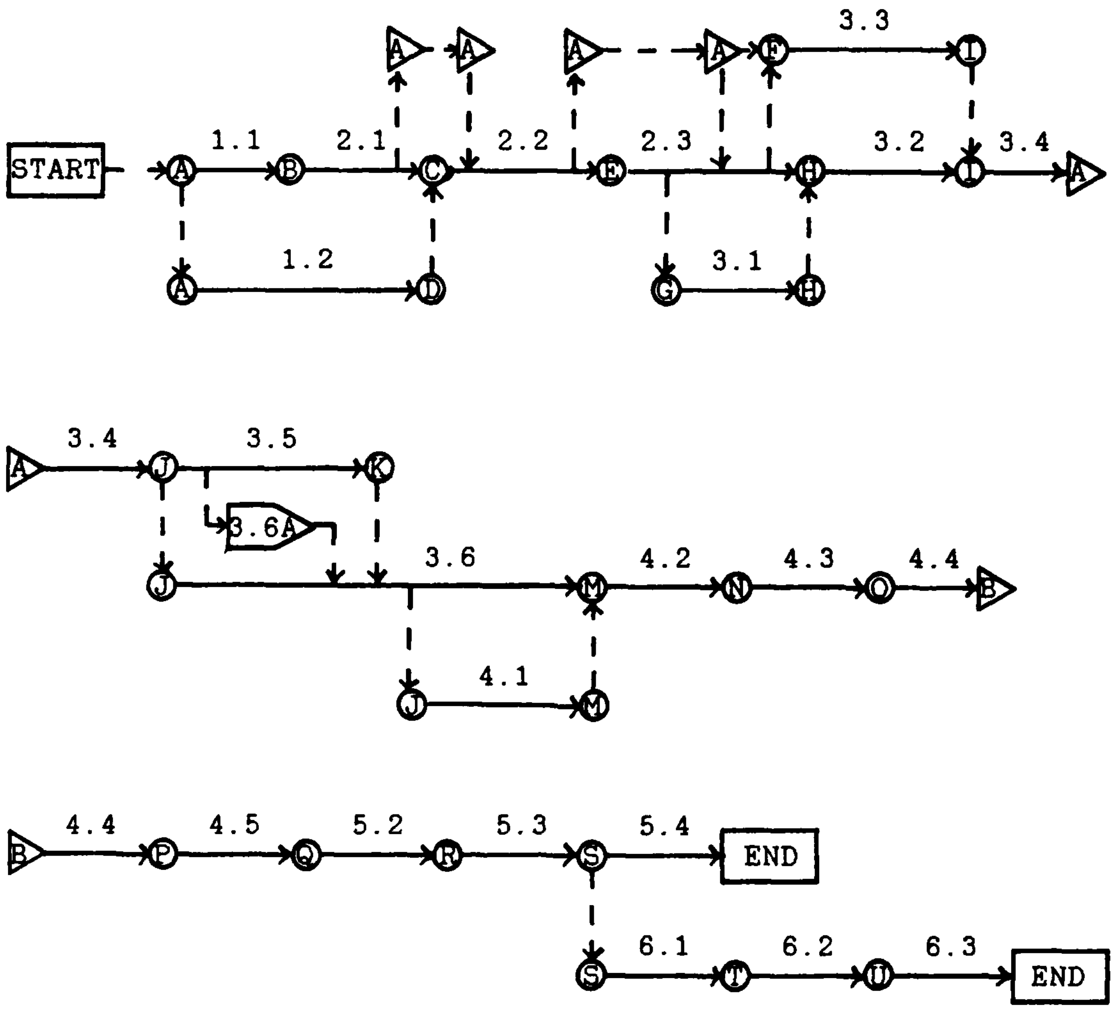


Figure 3-6

PERT Network Master Graph of all S/CGPS Subtasks

times for the hundreds of activities. Another method for calculating these times had to be developed.

The General Dynamics Corportation made a majority of the completion time estimates for the S/CGPS activities. To make these estimates, GDC used the same procedures which they have employed for years to make time estimates for launches of the GDC-produced Atlas launch vehicle. It was assumed that the errors in their time estimate for the S/CGPS would be approximately the same as those for the Atlas system. Fortunately, data is available for the actual performance of the launch processing crews verses the estimated times for these tasks. It was decided that ten typical activities for the Atlas processing system would be selected as a data base for estimating optimistic and pessimistic times for the S/CGPS (8). The actual performance times for each activity during ten Atlas launches would be collected and used to determine the times for the S/CGPS. This data is presented in Table 3-2. For

TABLE 3-2

SCHEDULED ACTIVITY TIME VS. ACTUAL COMPLETION TIMES ON TEN ATLAS LAUNCHES (IN DAYS)

		ACTUAL DAYS TO PERFORM									
ACTIVITY	SCH	39E	41E	58E	42E	14E	73E	87E	50F	6002	6003
Prop C/O	13	15	13	18	11	12	12	21	15	11	17
Gnd Pneu	1	2	1	3	1	2	2	1	2	2	2
Hydraulics	2	1	2	4	2	2	2	5	7	2	5
PLS Turn	2	3	4	4	4	3	3	3	4	5	4
Launcher	4	4	8	4	6	3	4	7	5	5	4
A/B Pneu	2	2	2	5	3	1	3	2	3	14	6
Umbilical	2	2	3	3	1	3	3	2	4	3	2
Logic Val	3	3	4	3	3	4	4	5	5	4	7
PU Sys C/O	1	1	2	3	1	[illegible]	1	3	1	4	3
Autopilot	2	2	4	2	3	2	4	4	5	2	3

(Adapted from 15)

example, the Atlas activity, **Propellant Checkout**, was estimated to be completed in 13 days. However, for Atlas vehicle 37E it actually took 15 days and for Atlas vehicle 87E it took 21 days.

With this information, one can calculate how early (optimistic) or how late (pessimistic) the activities were performed. To do this, each performed activity was converted to an early or late completion time. In other words, if an activity was estimated to be completed in four days but was actually completed in eight days, then its early/late time was +4. Conversely, if the activity was completed in three days, its early/late time was -1. The information from these calculation is shown in Table 3-3.

TABLE 3-3

EARLY/LATE COMPLETION TIMES FOR TEN ATLAS LAUNCHES (IN DAYS)

		ACTUAL DAYS TO PERFORM									
ACTIVITY	SCH	39E	41E	58E	42E	14E	73E	87E	50F	6002	6003
Prop C/O	13	+2	0	+5	-2	-1	-1	+8	+2	-2	+4
Gnd Pneu	1	+1	0	+2	0	+1	+1	0	+1	+1	+1
Hydraulics	2	-1	0	+2	0	0	0	+3	+5	0	+3
PLS Turn	2	+1	+2	+2	+2	+1	+1	+1	+2	+3	+2
Launcher	4	0	+4	0	+2	-1	0	+3	+1	+1	0
A/B Pneu	2	0	0	+3	+1	-1	+1	0	+1	+12	+4
Umbilical	2	0	+1	+1	-1	+1	+1	0	+2	+1	0
Logic Val	3	0	+1	0	0	+1	+1	+2	+2	+1	+4
PU Sys C/O	1	0	+1	+2	0	+3	0	+2	0	+3	+2
Autopilot	2	0	+2	0	+1	0	+2	+2	+3	0	+1

All the early/late completion times were then normalize by dividing each time by its estimated completion time. In the previous example, the late time is now +.5 or 2/4 and the early time is -.25 or -1/4. These normalized early/late times are displayed in Table 3-4.

TABLE 3-4

NORMALIZED EARLY/LATE TIMES FOR TEN ATLAS LAUNCHES (IN DAYS)

	ACTUAL NORMILIZED DAYS TO PERFORM									
ACTIVITY	39E	41E	58E	42E	14E	73E	87E	50F	6002	6003
Prop C/O	+.15	0	+.38	-.15	-.08	-.1	+.62	+.15	-.15	+.31
Gnd Pneu	+1	0	+2	0	+1	+1	0	+1	+1	+1
Hydraul	-.5	0	+1	0	0	0	+1.5	+2.5	0	+1.5
PLS Turn	+.5	+1	+1	+1	+.5	+.5	+.5	+1	+1.5	+1
Launcher	0	+1	0	+.5	-.25	0	+.75	+.25	+.25	0
A/B Pneu	0	0	+1.5	+.5	-.5	+.5	0	+.5	+6	+2
Umbilica	0	+.5	+.5	-.5	+.5	+.5	0	+1	+.5	0
Logic Vl	0	+.33	0	0	+.33	+.3	+.66	+.66	+.33	+1.3
PU C/O	0	+1	+2	0	+3	0	+2	0	+3	+2
Autoplt	0	+1	0	+.5	0	+1	+1	+1.5	0	+.5

An analysis of this data reveals that, as one would expect, most of the activities (30 of them) were completed on-time (normalized time = 0). The other normalized performance times were distributed about zero with more values skewed to the late side (late-62, early-8). The earliest normalized time was -.5 and this became the value used to calculate the S/CGPS optimistic time, **a**. All calculations used the following formula:

$$\mathbf{a} = \mathbf{m} + (-.5)\mathbf{m} \qquad (3\text{-}4)$$

where **m** is the most likely time which is listed for each S/CGPS activity in Appendix A.

The latest time in the normalized early/late table is +6.0; therefore, the S/CGPS pessimistic time, **b**, was based on the following formula:

$$\mathbf{b} = (6)\mathbf{m} \qquad (3\text{-}5)$$

These formulas were used to calculate **a** and **b** for all GDC Centaur activities in the S/CGPS. However, the values for the shuttle-only related activites were not calculated in this manner.

Discussions were held with personnel from Lockheed Space Operations Corporation (5). LSOC is NASA's prime contractor for integration of the shuttle vehicle. There is actual data available for performance of LSOC's shuttle processing system (LC-39, flight, OPF). It was decided that most shuttle processing activities would be calulated using the following formulas:

$$\mathbf{a} = (.90)\mathbf{m} \qquad (3\text{-}6)$$

$$\mathbf{b} = (1.10)\mathbf{m} \qquad (3\text{-}7)$$

These formulas were based on the fact that shuttle processing activities have been completed in some cases as early as 90% of their estimated completion times. Converserly, some activities have exceeded their estimated time by 10%. These activities are in phase 4., phase 5., and phase 6. of the S/CGPS.

Some shuttle activities, such as the final countdown, have optimistic times equal to their most likely times, since it is not possible to complete the activity early. Also, activities such as the shuttle ascent phase are of fixed lenght with no variation and thus they have the same value for optimistic, most likely, and pessimistic times.

Now that the three time estimates are available for all activities of the S/CGPS, the PERT network can be developed. Computations for the expected time, **te**, and the standard deviation, **St,e**, were made using formulas 3-3 and 3-2.

For example, Activity 2.1.11, **Rotation Test**, had a most likely time, **m**, of two days. Using formula 3-4, an optimistic time, **a**, of 1 day was calculated.

$$\mathbf{a} = \mathbf{m} + (-.5)\mathbf{m} = 2 + (-.5)(2) = 1$$

Using formula 3-4, a pessimistic time, **b**, of 12 days was calculated.

$$\mathbf{b} = (6)\mathbf{m} = (6)(2) = 12$$

After using formula 3-2, the expected activity time, **te** was 3.5 days.

$$Te = (1/6)[a+4m+b] = (1/6)[1+4(2)+12] = 3.5$$

The standard deviation, **St,e**, was determined to be 1.833 after using formula 3-1.

$$St,e = (1/6)[b-a] = (1/6)[12-1] = 1.833$$

The variance, **VAR**, for each activity can be determined by squaring the standard deviation, **St,e**. In this case, the variance is 3.36.

$$VAR = (St,e)(St,e) = (1.83)(1.83) = 3.36$$

These procedures were used to calculate the expected time, standard deviation and variance for the 400 plus S/CGPS activities. The results of these calculations are are presented in Appendix C of this paper.

3. Determining the S/CGPS Critical Path

With two essential elements, the PERT network graph and expected completion times available, the critical path through the S/CGPS could be calculated. This was a rather lenghty process since there are hundreds of possible paths throught the system and each one had to be evaluated.

The first step was to identify all possible paths through each of the subtasks. A few subtasks, such as Subtask 5.4 (**Centaur Flight**), had only one possible path. Unfortunately, most subtasks had many possible paths. For example, Subtask 2.1 (**Centaur/CISS @ CX 36A, Part II**) had seventy possible paths through the subtask. Each one had to identified and labeled. The path labeling system described earlier in this chapter was used consistently throughout this process. All S/CGPS paths are listed in Appendix D of this paper.

Several subtasks proved to be very challenging to evaluate since they had interactions with other subtasks. These unique interacting subtasks were seperated from the other subtasks and their paths determined. For example, one branch of Subtask 2.1 (**CISS @ CX 36A**) splits out from the normal flow and re-appears within Subtask 2.2 (**Centaur/CISS @ CX 36A, Part** I). This branch by-passes many of the activities of both subtasks. Therefore, this branch has its own unique path.

Another subtask which proved difficult to evaluate was Subtask 5.1 (**Exercises & Simulations**). This subtask interacts with eleven other subtasks spread throughout the network. The exercises and simulations are geared to be performed at certain times prior to the Centaur launch, i.e. L-14 or 14 days before launch (34). To accommodate the phasing of the 5.1 activities, activities in other subtasks were used as trigger to initiate the exercise tasks.

For example, activity 5.1.9 (**Joint Integrated Simulation #3**) is performed at L-18 days (14:14). Activity 4.2.11 (**Launch Pad Validation**) is completed approximately 18 days before launch. Therefore, completion of activity 4.2.11 (**Pad Validation**) acts as the starter for activity

5.1.9 (**JIS#3**). All exercises and simulations of Subtask 5.1 were set up in this manner. To facilitate the identification of these interactive subtask paths, the paths leading to Subtask 5.1 are listed separately at the bottom of each subtask listing in Appendix D.

After identification of the subtask paths, the next step is to calculate the expected completion time, **te**, of each path. To determine this path earliest time, the expected times, **te**, for all activities in the path are added together. The sum of the activity **te**'s is the **te** for that path. The **te** for each S/CGPS subtask path is listed in Appendix D.

The longest path through each S/CGPS subtask was identified. These times are listed in Table 3-5.

Unfortunately, the longest path through each subtask is not necessarily the critical path through the entire

TABLE 3-5

LONGEST PATH THROUGH EACH SUBTASK

SUBTASK	**te**	SUBTASK	**te**
1.1	14.00	4.1	10.00
1.2	36.75	4.2	7.003
2.1	42.00	4.3	4.48
2.2	56.00	4.4	9.295
2.3	22.75	4.5	4.052
3.1	11.375	5.1	224.931
3.2	13.563	5.2	0.07
3.3	15.75	5.3	0.26
3.4	20.985	5.4	0.2821
3.5	14.002	6.1	6.715
3.6	33.25	6.2	6.675
		6.3	47.292

network. The interactive subtask path times must be calculated and compared to the times of the longest paths listed above. For example, the interactive subtask path [A,F,B,B,C, ▷A,J,Q,M,R] which begins in Subtask 2.2 (**Centaur/CISS @ CX 36A, Part I**) and ends in Subtask 2.3 (**Centaur/CISS @ CX 36A, Part II**) is 19.25 days long. This path must be compared to the sum of the longest paths in both Subtask 2.2 (56.00 days) and Subtask 2.3 (22.75 days). Since the 78.75 days of Subtasks 2.2 and 2.3 are longer than the 19.25 days of the interactive path, the interactive path can be eliminated from consideration as the critical path.

Subtasks which are paralleling other subtasks must be compared. The subtask path with the shorter time would not be on the critical path. In Figure 3-6, one observes that Subtasks 1.1 (**CISS @ Hangar J**) and Subtasks 1.2 (**CISS @ CX 36A**) parallels Subtask 1.2 (**Centaur @ Hangar J**). Therefore, the expected times of the two paths must be calculated and compared. The total sum of the 1.2 and 2.1 paths is 56.00 days, while the 1.2 path is only 36.75 days. This means that since there are no other possible paths in this segment of the network, the paths through Subtask 1.1 and 2.1 are part of the critical path.

After comparing the expected times of all possible paths through the S/CGPS network, the subtask paths which comprise the critical path were determined. These path are summarizes in Table 3-6. Several of the subtasks have more

TABLE 3-6

SUBTASK PATHS ON THE S/CGPS CRITICAL PATH

SUBTASK	PATH	te	VAR
1.1	[A,B,E,F,J]	14.0	31.93
	[A,B,F,J]	14.0	31.93
	[A,B,G,F,J]	14.0	31.93
2.1	[A,I,J,K,L,M,N,O,P,Q,W]	42.00	60.49
2.2	[A,Y,Z,a,b,c,j,l,q,r,+]	56.00	115.94
2.3	[A,C,D,E,G,J,M]	21.00	30.24
	[A,C,D,E,G,J,P,M]	21.00	30.24
	[A,C,D,E,G,J,Q,M]	21.00	30.24
	[A,C,H,G,J,M]	21.00	35.28
	[A,C,H,G,J,P,M]	21.00	35.28
	[A,C,H,G,J,Q,M]	21.00	35.28
	[A,C,I,G,J,M]	21.00	35.28
	[A,C,I,G,J,P,M]	21.00	35.28
	[A,C,I,G,J,Q,M]	21.00	35.28
3.3	[A,B,C,D,E,F,G,H,R]	15.75	17.64
	[A,B,C,E,F,G,H,R]	15.75	17.64
3.4	[A,B,C,D,F,H,I,J,K,L,M,O]	20.986	21.37
3.5	[A,B,C,D,E,F,G,H,I,J,K,L,M]	14.002	5.25
3.6	[E,F,G,H,I,J,K,L,M,N,O,P,Q,R,S,T,U]	22.75	13.95
4.2	[A,B,C,D,E,F,G,H,L,M,N,O]	7.003	2.58
	[A,B,C,D,E,G,H,L,M,N,O]	7.003	2.58
4.3	[A,B,C,E,F,G,H,I,J,K,L]	4.48	0.00
	[A,B,C,E,F,G,H,I,K,L]	4.48	0.00
4.4	[A,B,C,D,E,F,G,H,I,J,M,N,O,R]	9.295	2.85
	[A,B,C,D,E,F,G,H,I,J,M,N,Q,R]	9.295	2.85
	[A,B,C,D,E,F,G,H,I,J,M,N,R]	9.295	2.85
	[A,B,C,D,E,F,G,H,I,M,N,O,R]	9.295	2.85
	[A,B,C,D,E,F,G,H,I,M,N,Q,R]	9.295	2.85
	[A,B,C,D,E,F,G,H,I,M,N,R]	9.295	2.85
4.5	[A,C,D,E,F,G,H,I,P]	4.052	0.00
5.2	[A,B]	.07	0.00
5.3	[A,B,C,E]	.26	0.00
	[A,B,D,C,E]	.26	0.00
5.4	[A,B,C,D,E,F,G]	.2821	0.00
6.1	[A,B,C,D,E]	6.715	0.12
6.2	[A,B,C,D,F,G,H,I,J]	6.675	3.57
6.3	[A,B,C,D,I,J,K,L,M,N,O]	47.292	82.80
	[A,B,C,E,D,I,J,K,L,M,N,O]	47.292	82.80

than one path identified. Each path's time is equal to the longest time of the subtask; therefore, each is a critical path through that subtask. Subtask 2.3 (**Centaur/CISS @ CX 36A, Part** II) has nine separate paths which are 22.75 days long. Since this path lenght is the critical path throught this portion of the network, there are actually nine critical paths through Subtask 2.3. This means that there is not one critical path through the network; but in fact by multiplying all possible combinations together, there are actually 5,184 possible critical paths (3•9•2•2•2•6•2•2) in the S/CGPS network.

A visual representation of the S/CGPS critical path is presented in Figure 3-7. The critical path is indicated by the hatched lines, ~~//////////~~. Notice that the critical path terminates at two points: completion of the Centaur vehicle's mission in space and refurbishment of the CISS on the ground.

D. Analysis of the S/CGPS PERT Network

After the PERT network was constructed and the critical path identified, an analysis of the data was completed. The earliest completion time for the entire S/CGPS was calculated, along with the latest completion times, and slack times. The probability of meeting the estimated schedule was determined.

The earliest completion time, **Te**, for each S/CGPS subtask path was determined. The **Te** times are calculated

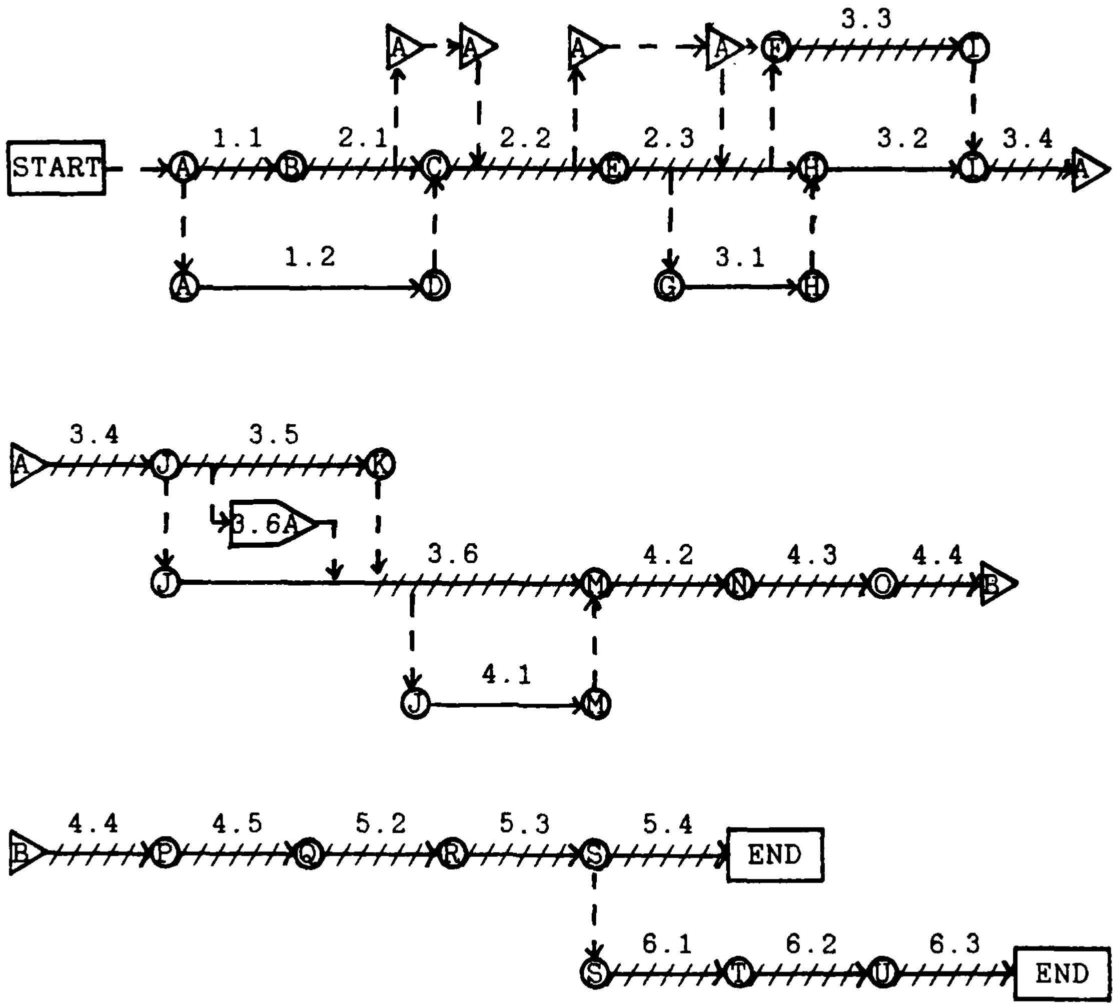


Figure 3-7

The Critical Path of the S/CGPS

by starting at time equal to zero and adding together the expected completion times, **te**, of each subtask activity. The **Te** times are added together in the order in which the subtasks are performed. For example, the first subtask in the S/CGPS is Subtask 1.1, **CISS @ Hangar J**. Its **Te** time is zero. Since Subtask 1.1 has an expected completion time,

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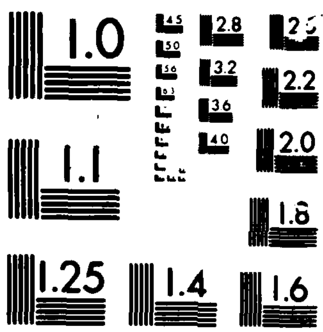

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te, of 14 days, the earliest start time for Subtask 1.2, **CISS @ CX 36A**, is 14 days (0 + 14 days). This procedure continues through the entire network.

The earliest completion time for the entire S/CGPS network, **Te#**, is an accumulation of the **te** times of all paths that lie along the critical path. Two S/CGPS **Te#**'s were produced: #1 for the end of the Centaur vehicle's flight and #2 for the completion of CISS refurbishment. S/CGPS **Te#1** was 231.9291 days with a variance of 304.35 and S/CGPS **Te#2** was 292.329 days with a variance of 390.84 The variances for the S/CGPS **Te#**'s were determined by adding the variances of all critical path activities together.

Table 3-7 lists the **Te** data for the entire S/CGPS. The table includes the expected completion time, **te**, the variances, **VAR**, and the earliest start time, **Te**, for the important paths and partial paths of the S/CGPS. A partial path is defined as a segment of a subtask path which connects the subtask to another subtask before reaching its end. Partial paths are denoted by their subtask number and the starting and ending nodes of the partial path, e.g. 3.5[A-F]. Paths and partial paths situated along the critical path are identified with an asterisk, *.

Table 3-7 also includes the latest starting time, **Tl**, for these S/CGPS paths. The latest time for each path was computed using the earliest completion time, **Te#**, for the network. The **Te#** is the terminal event of the processing

TABLE 3-7

S/CGPS PERT NETWORK OUTPUT INFORMATION

SUBTASK	te	VAR	Te	Tl	S
* 1.1	14.0	31.93	0.0	0.0	0.0
1.2	36.75	76.45	0.0	19.25	19.25
* 2.1	42.00	60.49	14.00	14.00	0.0
* 2.2	56.00	115.94	56.00	56.00	0.0
2.3[A-C]	7.00	13.44	12.00	112.00	0.0
* 2.3[A-M]	21.00	35.28	112.00	112.00	0.0
2.3	22.75	36.12	112.00	112.00	0.0
3.1	11.375	15.33	119.00	123.812	4.812
3.2	13.563	6.35	134.75	135.187	0.437
* 3.3	15.75	17.64	133.00	133.00	0.0
* 3.4	20.985	21.37	148.75	148.75	0.0
3.5[A-F]	6.125	2.32	169.735	169.735	0.0
* 3.5	14.002	5.25	169.735	169.735	0.0
3.6[A-F]	12.25	11.19	169.735	173.237	3.502
3.6[C-F]	8.75	9.24	175.86	176.737	0.877
3.6[E-F]	1.75	0.84	183.737	183.737	0.0
3.6	33.25	24.3	169.735	173.237	3.502
3.6[C-U]	29.75	22.35	175.86	176.737	0.877
* 3.6[E-U]	22.75	13.95	183.737	183.737	0.0
4.1	10.00	0.14	185.487	196.487	11.00
* 4.2	7.003	2.58	206.487	206.487	0.0
* 4.3	4.48	0.0	213.490	213.490	0.0
* 4.4	9.295	2.85	217.970	217.970	0.0
* 4.5	4.052	0.0	227.265	227.265	0.0
* 5.2	0.07	0.0	231.317	231.317	0.0
* 5.3	0.26	0.0	231.387	231.387	0.0
Subtotal	231.647	304.35	0.0	0.0	0.0
Subtotal	231.647	304.35	0.0	0.0	0.0
* 5.4	0.2821	0.0	231.647	231.647	0.0
Te#1	231.9291	304.35	0.0	0.0	0.0
Subtotal	231.647	304.35	0.0	0.0	0.0
* 6.1	6.715	0.12	231.647	231.647	0.0
* 6.2	6.675	3.57	238.362	238.362	0.0
* 6.3	47.292	82.80	245.037	245.037	0.0
Te#2	292.329	390.84	0.0	0.0	0.0

* - **Critical Path** Route

system. It is defined as the earliest time as which the processing cycle can be completed. By subtracting the expected completion times, **te**, of each subtask path in reverse order, i.e. subtract the last paths first, the **Tl** was determined. The **Tl** is defined as the latest time at which its particular subtask path can be started and still meet the minimum completion time, **Te***, for the S/CGPS.

Care had to be observed when calculating the **Tl**'s to insure that parallel paths and partial paths did not produce a latest time for a particular node which was earlier than the latest time for the same node via another path. For example, calculations for Subtask 2.3 revealed that one path, 2.3[A-C], had a **Tl** time of 116.812 days (123.812 days - 7.00 days, via Subtask 3.1). However, another path, 2.3[A-M] had a **Tl** time of 112.00 days (133.00 days - 21.00 days, via Subtask 3.3). Since the **Tl** time of 112 is more than 4 days earlier than the other **Tl**, 112 was used as the latest time for the start of Subtask 2.3

With the earliest time and latest time available for all paths, the slack time, **S**, for each subtask path could be calculated. The slack time is determined by subtracting the earliest time, **Te**, from the latest time, **Tl**, for each node. Notice that subtask paths along the critical path have zero slack time.

A review of the slack time data reveals that the system was very little slack time available. In fact, slack time is so small on several paths that they should probably be considered for inclusion on in the critical path. Subtask path 3.2, **Centaur/CISS Assembly Checkout**, has a slack time of 0.437 days or approximately 10 hours. This 10 hour reserve for a subtask which lasts more than 13 days allows little margin for error. Any major delay in the accomplishment of a subtask activity would result in the extention of the path lenght beyond the critical path's lenght. Therefore, activities along this subtask, as well as along a parallel subtask, 3.3 - **Move Spacecraft to SPIF**, must be monitored to ensure on-time completion of the S/CGPS master schedule.

This output information can also be used to compute the probability that each S/CGPS subtask will meet its original schedule. This was accomplished using the following procedure. First, the probability distribution of the **Te**'s was specified. This distribution was assumed to be normal. This assumption was reasonable, since the earliest time is the sum of many random variables (system activities). Under the Central Limit Theorem of classical probability theory, the distribution of the sum of independent variables (not necessarily randomly distributed) tends toward normality. From the S/CGPS PERT network output, the mean and variance of the earliest times were available. It was possible to calculate the probability that the earliest time would be less than the originally scheduled time, **Ts**, for each subtask (24:412).

The probability of meeting the original schedule,

P(Ts<Te), was determined using a standardized normal table. First, a calculation was performed using the following formula:

Probility (meet schedule) =

$$P(Z < [Ts-Te]/St,e) \qquad (3\text{-}8)$$

where **Z** is a standard normal deviate. After a numerical value using formula 3-8 was determined, it was used to determine a probability from the standard normal distribution table. This probability number is the probability that the subtask will be completed at or earlier than the originally scheduled time (24:413).

For example, Subtask 1.1, **CISS @ Hangar J**, was orignally scheduled to be completed in 8 days. The expected completion time, **te**, for this subtask was 14 days with a variance, **VAR**, of 31.93. Using formula 3-8 above,

$$P(Z<[Ts-Te]/St,e) = P(Z<[8-14]/5.56)$$
$$= P(Z<-1.061)$$

Using the standard normal distribution table for P(**Z**<-1.061), a probability of 0.14437 or 14.437% was determined.

Table 3-8 lists the probability that the important subtasks of the S/CGPS can meet their originally scheduled completion times. The original schedule times, **Ts**, used for this calculation were the times provided by GDC, MDAC, and LSOC.

TABLE 3-8

PROBABILITY S/CGPS SUBTASKS WILL MEET ORIGINAL SCHEDULE

SUBTASK	Te	VAR	Ts	P(Z<X)	Prob
* 1.1	14.0	31.93	8.0	-1.061	14.43%
1.2	36.75	76.45	21.0	-1.801	3.58%
* 2.1	42.00	60.49	24.0	-2.314	1.03%
* 2.2	56.00	115.94	32.0	-2.229	1.29%
2.3[A-C]	7.00	13.44	4.0	-0.818	20.66%
* 2.3[A-M]	21.00	35.28	12.0	-1.515	6.49%
2.3	22.75	36.12	13.0	-1.622	5.24%
3.1	11.375	15.33	6.5	-1.245	10.65%
3.2	13.563	6.35	7.75	-2.307	1.04%
* 3.3	15.75	17.64	9.0	-1.607	5.40%
* 3.4	20.985	21.37	11.99	-1.946	2.58%
3.5[A-F]	6.125	2.32	3.5	-1.723	4.24%
* 3.5	14.002	5.25	8.0	-2.619	0.44%
3.6[A-F]	12.25	11.19	7.0	-1.569	5.83%
3.6[C-F]	8.75	9.24	5.0	-1.234	10.85%
3.6[E-F]	1.75	0.84	1.0	-0.818	20.66%
3.6	33.25	24.3	19.0	-2.891	0.19%
3.6[C-U]	29.75	22.35	17.0	-2.697	0.35%
* 3.6[E-U]	22.75	13.95	13.0	-2.610	0.45%
4.1	10.00	0.14	10.0	0.0	50.00%
* 4.2	7.003	2.58	4.0	-1.870	3.07%
* 4.3	4.48	0.0	4.48	0.0	50.00%
* 4.4	9.295	2.85	5.3	-2.366	0.89%
* 4.5	4.052	0.0	4.0	0.0	50.0 %
* 5.2	0.07	0.0	0.07	0.0	50.0 %
* 5.3	0.26	0.0	0.26	0.0	50.0 %
Subtotal	231.647	304.35	136.382	-5.461	0.003%
Subtotal	231.647	304.35	136.10	-5.461	0.003
* 5.4	0.2821	0.0	0.2821	0.0	50.0 %
Te#1	231.9291	304.35	136.382	-5.447	.003%
Subtotal	231.647	304.35	136.10	-5.461	0.003%
* 6.1	6.715	0.12	6.64	-0.217	41.40%
* 6.2	6.675	3.57	4.8	-0.992	16.06%
* 6.3	47.292	82.80	27.5	-2.175	1.48%
Te#2	292.329	390.84	175.04	-5.932	.003%

* - **Critical Path** Route

A review of the probability data reveals that there is a very low probability that the S/CGPS will be able to process the Centaur vehicle on-time. Some of the system's subtasks {4.1-**Launch Complex 39 Preparations**, 4.3-**Installation in Orbiter & Checkout**, 5.2-**Orbiter Ascent**, 4.5-**Launch Countdown**, 5.3-**Centaur Cargo Element Checkout & Deployment**, and 5.4-**Centaur Flight**} have a probability of 50%, the S/CGPS's best probability. These subtasks relate to either the shuttle orbiter processing, which is based on past performance data, or on-orbit operations, which use fixed, non-variable time lines.

However, the other subtasks have a very low probability of completing their activities on schedule. The probabilities are scattered between 10% to 0%. In fact, a significant number of the subtasks (13 out of 30) have a less than 5% chance of on-time completion.

Data for the S/CGPS critical path, **Te#1** & **Te#2**, is even more pessimistic. Both **Te#1** & **Te#2** have virtually zero probability of completing their processing cycles in the scheduled times.

The reason that these probabilities are so low is due to the fact that the initial time estimates for completion of the Centaur processing tasks contained a large range of possible outcomes. This is particularily true of the pessimistic completion time estimates, **b**. The **b** estimates for Centaur processing were based on processing times which were six times greater than the activity's most likey completion times, m. This procedure generated a large range for the values and a large value for both standard deviation and variance. These values caused the probabilities to be extremely low.

A better technique for estimating these times is required. After the S/CGPS is operational and has had the opportunity to actually process several Centaur vehicles, a better estimate of the on-time probabilities can be made using actual performance data as a basis.

E. Summary

The PERT procedures and an analysis of its network output has determined the critical path through the S/CGPS. It has also revealed that there is very little slack time available within the system. This would seem to suggest that the system will be unable to meet its basic goal of processing four Centaur vehicles per year. Any delays or slips in the processing of one vehicle would result in an equal delay in the completion of the mission since there is no slack time available in many of the subtask paths to allow "catch-up" time.

Unfortunately, the PERT network does not permit anaylsis of the system's ability to process two Centaur vehicles simultaneously. PERT is only capable of determining the lenght of time required to process one vehicle from start to end of the system processing cycle. It can not evaluate the effect of several Centaur vehicles completing for the same limited resoures, such as CX 36A or SPIF cells. Delays incurred while waying for availabile facilities are not calculated by the PERT network; it assumes the when one activity ends the next activity can begin immediately. In the real world, this is rarely the case.

In order to determine the system's capability of processing multiple vehicles and evaluate resource delays, another tool was used. For this project, the computer simulation model was developed for this task. The remainer of this paper deals with the development and anaylsis of the SLAM simulation model.

IV. THE SLAM MODEL DEVELOPMENT

This chapter presents a short overview of the computer simulation model technique, reviews terms used in simulation modeling, and discusses the commands used in SLAM simulation modeling. It describes the development of the S/CGPS simulation model using the SLAM.

A. Introduction

Simulation is one of the most powerful analysis tools available to those responsible for the design and operation of complex processes or systems. The concept of simulation is both simple and appealing. It allows a user to experiment with systems (real and proposed) where it would be impossible or impractical otherwise.

Simulation modeling is heavily based upon computer science, mathematics, probability, and statistics. The modeler must be skilled in each of these basic sciences; however, simulation modeling and experimentation remain very much intuitive processes (28,ix). A modeler must develop a "feel" for the system being modeling. This can only be done only after he has cultivated a thorough understanding of the system to be modeled.

The starting point of any simulation is the system being modeled. However, before beginning a discussion of the formulation of the S/CGPS model, a list of terms and procedures used in simulation modeling is presented.

3. Simulation Modeling

A **simulation** is the imitation of the operation of a real-world system over time. Whether done by hand or on a computer, simulation involves the generation of an artifical history of a system, and the observation of that artifical history to draw inferences concerning the operating characteristics of the real system.

The behavior of a system as it evolves over time is studied by developing a simulation **model**. This model usually takes the form of a set of assumptions concerning the operation of the system. These assumptions are expressed in mathematical, logical, and symbolic relationships between the **entities**, or objects of intrest, of the system (4:2). In the case of the S/CGPS, these entities are the Centaur vehicles as they flow through the processing system. Once developed and validated, a model can be used to investigate a wide variety of "what if" questions about the real-world system. Potential changes to the system can first be simulated in order to predict their impact on system performance.

A simulation can also be used to study systems in the design stage, before such systems are built. Since the S/CGPS will not complete processing of its first vehicle until May 1986, it would fall into this category. Thus, simulation modeling can be used both as an analysis tool for predicting the effects of changes to existing systems, and as a design tool to predict the performance of new systems under varying sets of circumstances.

In some instances, a model can be developed which is simple enough to be "solved" by mathematical methods. Such solutions may be found by use of differential calculus, probability theory, algebraic methods, or other mathematical techniques. The solution usually consists of one or more numerical parameters which are called **measures of performance** off the system. However, many real-world systems are so complex that models of these systems are virtually impossible to solve mathematically. In these instances, numberical computer-based simulation must be used to imitate the behavior of the system over time. From the simulation, data are collected as if the a real system were being observed. This simulation is used to estimate the measures of performance of the system (4:2-3).

A **system** is defined as a group of objects that are joined together in some regular interaction or interdependence toward the accomplishment of some purpose. The S/CGPS falls within the parameters of this definition. The computers, ground support equipment, and workers operate jointly during the processing cycle to achieve the launch of the vehicle at the scheduled time.

A system is often affected by changes occurring outside the system. Such changes are said to occur in the **system**

environment. In modeling systems, it is necessary to decide on the **boundry** between the system and its environment. In the case of the S/CGPS, activities conducted at locations other than CCAFS and KSC, such as operations at the production factory at San Diego, are outside the influence of the processing system and, therefore, are part of the environment. The boundary of the S/CGPS was defined to be only the elements at CCAFS and KSC that directly support the preparation and operation support of Department of Defense Centaur missions.

An **entity** is an object of interest in the system, such as the Centaur booster itself. An **attribute** is a properity of an entity. An example of an attribute for the Centaur vehicle is the time the vehicle entered the S/CGPS. An **activity** represents a time period of specified lenght. In this case, it could be the lenght of time required to install the Centaur vehicle into the Orbiter's main payload bay.

The collection of entities that compose a system might only be a subset of another overall system. For example, the Centaur processing system could be considered to a subsystem of the space shuttle launch processing system. However, for this project, only the S/CGPS was modeled. Other processing systems were assume to have no effect on the ability of the S/CGPS to complete processing on the Centaur systems.

The **state** of a system is defined to be that collection of variables necessary to describe the system at any time, relative to the objectives of the study. In the study of the S/CGPS, some state variables include number of Centaur vehicles being processed and the number in storage awaiting processing. An **event** is defined as an instantaneous occurrence that may change the state of the system. The term **endogenous** is used to describe activities and events occurring within a system, and the term **exogenous** is used to describe activities and events in the evnvironment that affect the system. In the S/CGPS model, the completion of vehicle fabrication at the factory is an exogenous event (outside the system, in the environment), and the launch of a vehicle from Launch Complex 39 is an endogenous event (within the system).

A **discrete system** is one in which the state variables change only a discrete set of points in time. A discrete change model utilize a next event type of time keeping. In this type of model, whenever simulation time is changed it is advanced to the exact time of the earliest of all future event occurrences. In other words, the models does not use fixed time increments to measure activities. The S/CGPS simulation is a discrete-event system simulation (4:6-7).

Somtimes it is of interest to study a system to understand the relationships between its components or to predict how the system will operate under a new policy. To study the system, it is sometime possible to experiment with the real-world system itself. However, in the case of the

S/CGPS , this is not possible. Since the real-world system is still being constructed, a model of the S/CGPS had to be developed.

A **model** is the representation of a system for the purpose of studying the system. For most studies, it is not necessary to consider all the details of a system. Thus, a model is not only a substitute for a system, it is simplification of the system (26:3). On the other hand, the model should be sufficiently detailed to permit valid conclusions to be drawn about the real system (4:9).

Just as the components of the real system are entities, attributes, and activities, the model is represented similarly. However, the model contains only those components that are relevant to the study.

The S/CGPS simulation model is a mathematical model. I. uses symbolic notation and mathematical equations to represent the real S/CGPS. It is a **dynamic** model because it represents the system as it changes over time.

A **stochastic** simulation model has one or more random variables as inputs. Random inputs lead to random outputs. Since the output are random, they can be considered only as estimates of the true characteristics of a model. The simulation of the S/CGPS involves random processing times. Thus, in this stochastic simulation, the output measures, such as the lenght of time to process each Centaur vehicle or the number of vehicle in the system, must be treated as statistical estimates of the true characteristics of the actual S/CGPS (4:10).

As mentioned above, the S/CGPS simulation model is a discrete-event simulation model. In this type of model, the system's state variables change only at a discrete set of points in time. The simulation model is analyzed by numerical methods rather than by analytical methods. **Numerical** methods employ computational procedures to "solve" mathematical models (4:11). In this case, the model is "run" rather than solved; that is, an artifical history of the S/CGPS is generated based on assumptions made about the system. Observations are collected and analyzed to estimate the true system performance measures.

To assemble the S/CGPS model, the SLAM simulation language was used adhering to the principles outlined above. The SLAM commands and statement described in the following section were the basic building blocks in the S/CGPS simulation model.

C. SLAM Simulation Language

SLAM, a new Simulation Language for Alternative Modeling, is an advanced FORTRAN based language that allows simulation models to be built based on three different world views: network, discrete event, and continuous. It provides network elements for building simulation models that are easily translated into input statements for direct computer processing. It contains subprograms that support discrete event model developments, and specifies the organizational structure for building such models. By combining network and discrete event modeling capabilities, SLAM allows the systems analysis to develop models from a process-interaction, next-event, or activity-scanning perspective (27:ix). SLAM was developed and is maintained by Pritsker & Associates, Inc., P.O. Box 2413, West Lafayette, Indiana 47906.

The process orientation of SLAM employs a **network** comprised of specialized elements called **nodes** and **branches**. These elements model the processes such as queues, work stations, and decision points. The modeling task consists of combining these elements into a network model which represents the S/CGPS. The entities in the system, the Centaur vehicles, flow through the network model. The representation of the S/CGPS is transcribed into the SLAM computer system and the simulation model output is generated.

In the event orientation of SLAM, one defines the events and the potential changes to the the system when an event occurs. For example, the completion of vehicle processing at the SPIF is an event in the S/CGPS; and upon completion of this processing, an integration cell in the SPIF is freed, resulting in a change in the status of the processing system. The mathematical-logical relationships prescribing the changes associated with each event type are coded as FORTRAN subroutines. A set of standard subprograms is provided by SLAM to perform common discrete event functions such as event scheduling, file manipulations, statistics collection, and random sample generation.

The executive control program of SLAM controls the simulation by advancing time and initiating calls to the appropriate event subroutines at the proper points in simulated time. Hence, one is completely relieved of the task of sequencing events to occur chronologically.

The sequence of events, activities, and decisions that comprise the S/CGPS is referred to as a **process**. **Entities** flow through the process. An entity can be assigned **attribute** values that enable one to distinguish between individual entities of the same type or between entities of different types. For example, the time a Centaur vehicle enters the processing system is an attribute, ATRIB(1), of that entity. Such attributes are attached to the entity as it flows through the network. The resources of the S/CGPS are the vehicle checkout facilites and computer systems for which the entities compete while flowing through the system. A resource is busy when processing an entity, otherwise it is idle.

SLAM provides a framework for modeling the flow of entities through processes. The framework is a network structure consisting of specialized nodes and branches that are used to model resources, queues for resources, activities, and entity flow decisions. In short, a SLAM network model is a representation of a process and the flow of entities through the process (27:78-79).

To illustrate the basic network concepts and symbols of SLAM, the following pages will discuss some of the key SLAM elements used in the S/CGPS simulation model.

The model is based on a multiple resource queueing system. The Centaur vehicles and CISS's are the system's entities. Entities are routed along the branches eminating from the nodes. The **activity** is the actual work done to complete the Centaur processing.

The passage of time is represented by a **branch**, as was done in the PERT/CPM network model. Branches are the graphical representation of activities. The service operation (checkout of the vehicles) is an activity and, hence, is modeled by a branch. If the service activity is ongoing, that is, the server (SPIF cell) is busy, arriving entities (Centaurs) must wait (27:80).

The processing system's equipment, such as the CX 36A checkout facility, the CCLS computer systems, and the SPIF integration cells, are the network resources and are modeled as limited resources. A Centaur spacecraft awaiting processing is placed in a **queue**.

The S/CGPS model consists of a set of interconnected elements that depict the operation of the processing system. The elements were converted into a form for input to a computer program that analyzes the model using simulation techniques. The input corresponding to a SLAM model element were in the form of **statements**. In the statements, a semicolon was used to indicate the end of the SLAM statement. Comments were insert followi-g the semicolon. These comments describe the function of each statement (27:84).

The SLAM statements listed below were used in the S/CGPS model. They are included here to provide the reader with the ability to read and follow the logic flow of the SLAM coding of the simulation model.

1. CREATE NODE

In SLAM, entities are inserted into a network by CREATE nodes. The CREATE node generates the entities and routes them into the system over activities that emanate from the CREATE node. A time for the first entity to be created by the CREATE node is specified. In the S/CGPS model, this time is the start of the simulation, TNOW = 0. The time at which the entity was created is assigned as an attribute of the entity.

The time between creations of entities after the first is also specified. A second entity is created by the node every 90 days. Therfore, time between arrivals of Centaur vehicles at CCAFS is every ninty days. Entities will continue to be generated until the simulation is stopped. An example of thsi statement is shown below:

```
CREATE,90,,1;
```

where an entity is created every 90 days. Since field three of the statement is blank (,,) the the first entity is generated at the default time of zero. The final number indicates that the creation time is stored in atribute (ATRIB) 1 (27:86-87).

2. TERMINATE NODE

Centaur vehicles leave the system following completion of their flights. The modeling of the departure of an entity is accomplished by use of a TERMINATE node. Entities are terminated or distroyed when they reach this node. TERMINATE nodes can be used to stop the SLAM simulation. Once a specified number of entities have reached a TERMINATE node, the software can be commanded to halt the simulation run. This technique was used for some of the model development runs, where the simulation was terminated after one Centaur completed processing. However, the stopping condition can also be based on a time period. For example, the data collection runs of the S/CGPS simulation runs were terminated after five years of simulated operation (27:91).

3. ACTIVITY Statements

Branches are used to model activities. Activity branches are used to route entities from one node to another node. Only at activity branches are explicit time delays prescribed for entities flowing through the system. The duration of an activity is the time delay that the entity encounters as it flows through the branch representing the activity. Activity duration are specified by an expression containing one of several variables. The duration can be a constant, such as one day. It could be determined from a probablity distribution. For example, the lenght of time to mate the Centaur vehicle with the CISS, Activity 2.1.22, could be distributed along a log normal curve with a mean of 1.61 days and a standard deviation of 0.7782. This information was inserted into the model such that when an entity reached this activity the computer automatically selected a delay based on this log normal distribution curve. The activity branch for this example would be:

```
ACT,RLOGN (1.610,0.7782);            MATE CENTAUR
```

where ACT stand for an activity branch, the log normal distribution is selected with a mean of 1.610 days and a standard deviation of 0.7782. The "MATE CENTAUR" label is included in the left column for information only.

Activity statements are also used to route entities to a node which is not the next node listed on the SLAM computer listing. For example, to send an entity to node N35A, the following statement was used:

```
ACT,,,N35A;
```

Notice that this activity only routes the entity directly to node N35A and no time delay is incurred, since field two of the statement if left blank (27:96-100).

4. GOON NODE

The GO ON or GOON node is a continue type node. In the S/CGPS, the GOON is used to model a sequence of activities since the start of one activity must be separated from the end of the preceding activity by a node. The GOON node act as a buffer node between these two activities (27:109).

5. ACCUMULATE NODE

The ACCUMULATE node releases an entity to proceed to the next node only when a specified number on entities have arrived at the node. The ACCUM node is used extensively to model points in the S/CGPS where multiple activities must be completed prior to the initiation of the next activity. For example, 14 separate activities must be completed at node N22A, before the **Terminal Countdown Demonstration** can begin. Therefore, the following statement was inserted just before the TCD activity statement:

ACCUM,14,14;

where ACCUM indicates an Accumulate node which requires the collection of 14 entities for the first release on a single entity and the collection of another 14 entities for every subsequent entity release. Notice that in each entity release transaction 13 entities are terminated (27:108-109).

6. QUEUE NODE

A QUEUE node is the location where entities wait for service. The QUEUE nodes used in the S/CGPS simulation use the first-in, first-out queueing method. In other words, the Centaur vehicle that has waited the longest in the queue is the first to be served when a server becomes free.

There are two queues in the S/CGPS model. Each is identified numberically. Entities waiting at queues are maintained in files, and a file number is associated with that queue. An example of these queues is listed below:

QUEUE(16),,,,MATE;

where entities in the queue are stored in file number 16 and after release from the queue the entities proceed to node lable MATE (27:88-89).

7. ASSEMBLY SELECT NODE

A SELECT node is a point in the network where a decision regarding the routing of an entity is made and the decision concerns a QUEUE node. In the S/CGPS model the decision invole the ASSEMBLY queue selection rule. This involves the combining of two entities into an assembled entity. The selection process requires that at least one entity be in each QUEUE node before any entity will be routed to an activity branch. In this case a Centaur vehicle must be at the CENT QUEUE node and a CISS must be at the CISS QUEUE node before the combined Centaur/CISS entity can continue through the processing system. The statement used to perform the assembly is shown below:

SELECT,ASM,,,CISS,CENT;

where ASM defines an ASSEMBLY SELECT node and the entities must come the QUEUE node: CISS and CENT (27:111,117-118).

8. RESOURCE BLOCK

The RESOURCE block is used to identify: the resource name, the number of resource units available, and the order in file files associated with AWAIT nodes are to be polled to allocate freed units of the resource to the entities. In the S/CGPS, there is only one Complex 36A facility available. Therefore, the RESOURCE block for the computer controlled launch set, CCLS, is:

RESOURCE/CCLS(2),1,2,3,4,5,6;

where the name of the resource is CCLS, two units of the resource are available, and the entities in await files are polled in the following order: File #1 - first, file #2 - second, file #3 - third, etc (27:123-124).

9. AWAIT NODE

An AWAIT node is used to store entities waiting for units of a resource. When an entity, Centaur and/or CISS, arrives at an AWAIT node and the resource, such as CX 36A, is available, the entity passes directly through the node and is routed to the node. If the entity has to wait at the node, it is placed in a file in accordance with a priority assigned to that file. Regular activities emanate from the AWAIT node. An example of an AWAIT is shown below:

AWAIT(10),CX36;

where the resource resuired is CX 36A, and entities wait to use CX 36A ait in file number 10 (27:124-125).

10. FREE NODE

FREE nodes are used to release resources when an entity arrives at the node. Every entity arriving at a FREE node releases a specified number of the resources being used. The freed resources are then allocated to entities waiting in AWAIT nodes in the order or precedent prescribed by the RESOUCE block. The entity arriving to the FREE node is then routed to the next activity or node (27:126). To release the SPIF cell after completion of all SPIF activites, the following statement was used:

FREE,SPIF CELL;

11. ASSIGN NODE

The ASSIGN node is used to prescribe values to the attributes of an entity passing through the node. For example, the ASSIGN node is requently used to prescribe the time that the Centaur enters another phase of its processing, such as when it is move to CX 36A. The following statement,

ASSIGN,XX(2)=TNOW;

assigns the value of current system time, TNOW, to the system variable XX(2) (27:92).

12. COLCT NODE

Statistics are collected on variables at a COLCT node. The variables refer to the time or times at which an entity arrives at the COLCT. Estimates for the mean and standard deviation of the variables are obtained. In addition, a histogram of the values collected at the COLCT node can be obtained. For example, the following statement,

COLCT,TNOW-ATRIB(1),SUBTASK 2.1;

instructs the SLAM program to collect statistics on the value, TNOW-ATRIB (the current system time minus the time the Centaur was created), and label the data as "SUBTASK 2.1" (27:109-111).

These twelve SLAM network input statements were used to construct the simulation model of the S/CGPS. Separate SLAM control statements were used to control the operation of the simulation, i.e. number of runs, statistics to be collected. The next section of this chapter describes the actual construction of the model from its beginning as a system concept to the final validated computer code.

D. Construction of the SLAM Model

The construction of the S/CGPS model involved making decisions on what were the essential features of the S/CGPS. These features were converted into basic assumptions that characterized the system and encoded into the SLAM computer coding. This meant that the model began rather simple; however, it became more and more complex as more details of the complexity of the actual S/CGPS were included.

There was a direct interplay between the construction of the model and the collection of the needed input data. Initial data collection began early in the project's life, April 1985, and has continued through the life of the project. Information was collected from many sources, such as the prime Centaur contractor, GDC, in San Diego, California, the USAF launch site processing contactor, MDAC, at CCAFS, and the Centaur Program Office in Cleveland, Ohio, to name only a few.

The model was programmed for use using the SLAM II general-purpose simulation language on a VAX/VMS computer system. Verification of the computer program being prepared for the simulation model involved a check to see if the computer program was performing properly. If it was not, the computer coding had to be "debugged", or the logic used to form the structure of the model had to be re-evaluated.

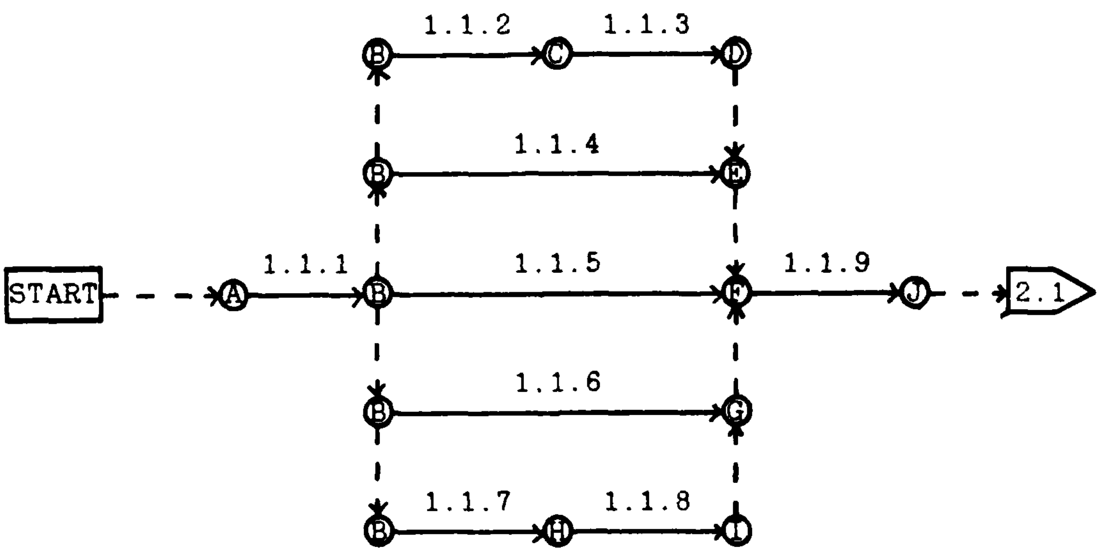
The final step of model construction process involved validation. Validation was the determination that the simulation model was an accurate representation of the real S/CGPS. Usually, this involves comparing the output of the model to the actual behavior of the real system; then, using the discrepancies between the two, and the insights gained, to improve the model. However, since the S/CGPS does not yet exist, the step proved some what difficult to accomplish.

The model under went many variations. The data collected and analyzed during the PERT/CPM formulation phase of the project was used to construct the first versions of the SLAM model. The first model built modeled only the operation of the S/CGPS's major Subtasks (CISS @ Hangar J, Launch Complex 39 Preparations, etc.). Later a more detailed verision of the model was developed to included the individual activities which comprised the systems's subtasks. The resources required to conduct the activities, such as CX 36A and CCLS computers, were added to simulatate the systems delays caused by "busy" limited resources. Finally, a probability distribution of the completion times of all activities was calculated and inserted into the model. The probability distributions are used to calcuate a completion time for each of the activities.

1. S/CGPS Activity Modeling

To construct the detailed activities involved in the conduct of the S/CGPS's subtasks, the previously developed

PERT charts were used. The PERT charts are a graphic representation of the network of interdependent activities that must be completed in order for the subtask activity to be considered finished. Each subtask PERT chart, such as the one in Figure 4-1 (**SUBTASK 1.1 CISS @ HANGAR J**) was used to formulate a corresponding SLAM flow chart to represent that subtask. The SLAM flow charts uses symbols



(Adapted from 16)

Figure 4-1

PERT CHART FOR SUBTASK 1.1: CISS @ HANGAR J

for the different SLAM network statements to be employed and it is used to establish the type and order of the SLAM network statements. The development of Subtask 1.1 is outlined below.

Subtask 1.1 includes nine activities which must be conducted in a specific order to complete processing of this subtask. When the first activity, 1.1.1, is completed, five separate activities (1.1.2, 1.1.4, 1.1.5, 1.1.6, and 1.1.7) are all begun simulatneously. Each of these activites is independent of the others and completes its own processing flow. However, prior to initiation of Activity 1.1.9, the work of the five activity paths must be complete. This is indicated at node Ⓕ, where all five activity lines rejoin. The completion of Activity 1.1.9 signals the end of Subtask 1.1 and the processing proceeds on to the next subtask (2.1).

Figure 4-2 is the SLAM flow chart for Subtask 1.1,

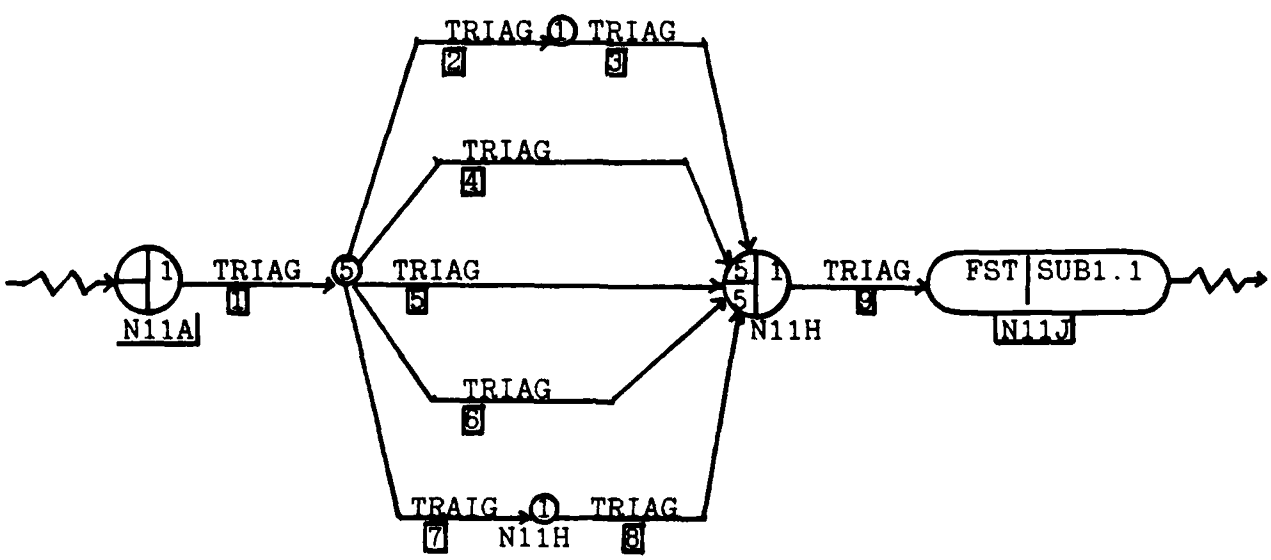


Figure 4-2

SLAM FLOW CHART FOR SUBTASK 1.1: CISS @ HANGAR J which was generated from the Subtask 1.1 PERT chart. As one can observe, the PERT chart and the SLAM flow chart appear somewhat similar.

To interpert the SLAM chart, the flow moves from left to right across the page. The wavy line and segemented circle,  , indicate a CREATE node. In this case, the CREATE node generates only one entity. The solid lines following the nodes are activities. The boxed number, [3] , below the activity line is number of the activity. The numbers correspond to the activity numbers in the PERT charts. For example, Activity 1.1.6 and a SLAM activity number [6] .

The TRIAG remark indicates the a triangular probability distribution was used to determine the duration of the activity. The triangular distribution was selected to provide an easy to implement and consistent probability distribution. At a later time, an in-depth analysis of available performance data was conducted to select a more realistic probability distribution. However, early model versions used the TRIAG distribution function. Parameters used in the triangular distribution were based on the the most optimistic time, **a**, most likely time, **m**, and most pessimistic time, **b**, of the PERT calculations. These values were used to define the interval, **a** to **b**, and the mode, **m**, of the distribution.

The circle which contain numbers, ② , are GOON nodes.

The GOON is used to separate sequentially performed activities. For example, activity 8 is performed immediately after activity 7. Therefore, a GOON node is used to separate activities 7 and 8. A ① indicates that one entity is released from the GOON node for every entity that reaches it. The GOON node after activity 1 releases five entities every time one entity reaches this point. The five entities follow the five activity paths which emanate from the node.

An important element of the PERT to SLAM conversion was use of the ACCUMULATE node, indicated on the flow chart by the three segment circle,  . The ACCUM node is used to model activity precedent relations. In other words, an entity proceeds from this node only after a specified number of entities have reached the node. In this particular instance, five entities, one from each activity path, must reach the ACCUM node before activity number 9 can begin. After an entity is released from the node, the remaining four entities are distroyed.

The four digit alpha-numberic characters, N11A, below the segmented circle is the node label for that particular node. No two nodes have the same four-digit node label. The numbering convention for nodes in the PERT chart was used to identify the SLAM node labels. For example, the PERT node label **1.1[H]** translates into a SLAM node label of **N11H**. The "N" character begins each node label because SLAM requires that the node labels begin with a letter and not a number.

The elongated circle,  , is used for a COLCT node. The COLCT node is used to gather statictics on the entities that reach this node. In this case, data is collected on the time-of-first arrival at the node.

The wavy line,, after the COLCT node indicates use of the TERMINATE node. The TERM destroys the entities that reach it; therefore, the TERM node ends the flow of this particular processing subtask.

Using the SLAM flow chart above the following SLAM code was written to simulate the activities of S/CGPS Subtask 1.1

```
      CREATE;
      ACT/1,TRIAG(.5,1,6);              TAKE CISS FM AIRCRAFT
      GOON,5;
      ACT/2,TRIAG(1.5,3,36),,N11C;      PREP FOR STD TURN ON
      ACT/4,TRIAG(3,6,36),,N11F;        MECHANICAL INSPECTION
      ACT/5,TRIAG(3,6,36),,N11F;        ELECTRICAL INSPECTION
      ACT/6,TRIAG(3,6,36),,N11F;        INSTRUMENT INSPECTION
      ACT/7,TRIAG(1,2,12);              TRANSDUCER POWER OFF
      GOON;
      ACT/8,TRIAG(1.5,3,18),,N11F;      TRANSDUCER POWER ON
N11C  GOON;
      ACT/3,TRIAG(.5 1,6);              STANDARD TURN ON
      ACCUM,5,5;
N11F  ACT/9,TRIAG(.5,1,6);              TRANSPORT TO CX 36A
      COLCT,FIRST,SUBTASK 1.1;
      TERM;
      ENDNETWORK;
```

The ENDNETWORK statement signals to the computer that it has reached the end of the SLAM network input statements. Note that the node labels at the end of the activity statements, ACT/6,TRIAG(3,6,36),,**N11F**; , identifies the node to which the entity is routed after the activity is completed. This means that after activity 6 was complete its entity is sent to node N11F, ACCUM, to wait for the other four activity paths to finish their tasks.

The comment statement,i.e. ELECTRICAL INSPECTION, to the left of each activity states the work being accomplished during that activity. This information does not affect the computer program and is included so that the programmer can locate specific tasks being performed by the S/CGPS.

After verifing the accuracy of the SLAM code, i.e. no typing errors, the code was placed in the computer and the simulation model run. The results of the run were then reviewed to verify the performance of the model. The output of the SLAM program includes statistics on all the activites in the model. If the model was performing correctly each activity should have had an entity count (number of entities passing throught the activity) of one, a maximun utilization count of one and a current utilization count of zero. Any subtask output not conforming to these statistics resulted in a review of the coding to check for improper routing of the SLAM entities.

Additionally, statistics were collected on 400 individual one entity runs of each model. These statistics were gathered via the COLCT node in the SLAM coding. The output of the COLCT node is maximum, minimum, and mean values of the 400 one entity runs. These values are checked against the expected completion times of the subtask. For example, from the earlier PERT calculations. The earliest completion time for Subtask 1.1 is 4.0 days and the latest completion time is 48 days. Since the triangular distribution used the PERT values, the output of the COLCT should result in maximum and minimum completion times within the interval established by the earliest and latest PERT completion times.

The final step to verify operation of the subtask model was to run a SLAM TRACE. The TRACE function traces the movement of the entity through the subtask model. The SLAM TRACE report details the event time, the event code, and the varibles for each event that is executed during the trace period (27:156). The output of the TRACE program was checked to verify the proper number and timing of the entity across the nodes of the model.

This step completes the verification of the preformance of all the activities of the subtask. Simulation models of all 23 subtasks of the S/CGPS were constructed in this manner.

The next step in the model construction process was to assemble each on the subtask activity models together. This assembly was completed in several increments. First, the SLAM coding for each of the subtasks which comprise one phase of the processing system was merged into one computer file. For example, the SLAM code files for Subtask 2.1, Subtask 2.2 and Subtask 2.3 were merged into a single file which became the SLAM code for S/CGPS Phase 2, **SYSTEM BUILDUP & CHECKOUT**. The file contained the merged SLAM code was then edited to insert the SLAM network statements to allow transition of the entities from the end of one subtask to the beginning of the next subtask. This editing would usually include the replacement of the TERM nodes at the end of each subtask, except the last subtask, with activity statements to route the entity to the proper starting node in the next subtask.

Also at this point, the activity paths which branch out of one subtask prior to the end of the subtask were identified and modeled. This procedure involved the identification of the point where the branch "break-out" occurs and the location where the branch merges back into the processing flow. This breakout was usually accomplished by insertion of a GOON node, to generate additional entities, and a "dummy" activity, to route the newly generated entity along the breakout branch.

After completion of the editing of the SLAM code for each phase, the competed phase model was placed into the computer and simulation runs were accomplished. As was the case for the subtask models, the model for each phase was validated using the output from the simulation run. Once again, the activity statistics, the COLCT statistics, and the TRACE record were reviewed to determine if the output produced was in agreement with the expected output for that phase.

After the six phases of the S/CGPS were built and verified, the next step in the model construction was begun.

In this step, the phases of the S/CGPS were merged together in a manner similar to the procedures used for construction of the individual phase models.

First, Phase One, **RECEIVING & INSPECTION**, and Phase Two, **SYSTEM BUILDUP & TEST**, were merged into one model for both phases. Again, the combined phase model was checked and validated using the model output checks described above. Unfortunately, at this point there were more than 100 activities in the model. SLAM restricts the model builder to only 100 numbered activity. Since it was not possible to number all the activities, none were numbered. The SLAM program does not collect statistics on un-numbered activities. Therefore, the activity statistics output could not be used to verify operation of all activities in the combined phase model. However, since the phases were previously validated in the subtask model and again in the phase model, the inability to verify activities once again was not considered critical. If an area of the model did not appear to be performing correctly, the activities in that area of the code were numbered and statistics on their function were collected and analyzed.

These procedures were used again to combine Phase 3 and Phase 4 into a single model. Next, Phase 5 and Phase 6 were combined. Note: Subtask 5.1, **Exercises & Simulations**, was not included at this time. Subtask 5.1 was added last. The reason for this will be explained later.

Finally, the three combined phases models were merged together into one final S/CGPS activity model. This model contained all activities of the S/CGPS except those in Subtask 5.1. This combined activity model was once again checked and verified using the procedures outlined above.

After the combined activity model was validated, Subtask 5.1 was inserted into the model. Subtask 5.1 was not included earliest in the model integration because of the extensive interaction that this subtask has with other subtasks throughout the S/CGPS. For example, 12 activities from 10 other subtasks interact with this subtask. The only time that this subtask could be totally integrated into the model was after all other activities were together in one model. Subtask 5.1 was inserted into the model and the final S/CGPS activity model was checked and verified.

2. S/CGPS Resource Modeling

At this point, a complete model of all S/CGPS activities existed. However, this model did not included any resource limitations. In other words, if an entity (Centaur) needed a resource (CX 36A), the resource was always available. Obviously, the limitation of the resource had to be inserted into the model.

The first step in this phase of the model construction was to identify the limited resources of the S/CGPS and the how many units of the resource would be available. A review of Centaur program documentation determined that the items listed in Table 4-1 would be modeled as limited resources.

Next, the activities which require use of these resources were identified. Table 4-2 indicates the numbers of activites which require S/CGPS resources. SLAM allows the model designer to specify the order in which the AWAIT

TABLE 4-1

Limited Resources of the S/CGPS

Resource	Number Available
Centaur Complex 36A (CX36)	One
SPIF Integration Cell (SPIF CELL)	Two
Shuttle Launch Complex 39 (LC 39)	Two
Computer Controlled Launch Set (CCLS)	Two
Test & Transport Fixture	One
Multiuse Mission Support Equipment (MMSE)	Two

node are polled to satisfy resource requests. Therefore, a priority list for use of the resources had to be determined. As can be seen in Table 4-2, only two resources, CCLS and TTF, required priority decisions. For the TTF, the activities at the OPF, Subtask 6.2, take precedence over the activities at Hangar J, Subtask 1.1. The reason for this

TABLE 4-2

Number of Activities Requiring S/CGPS Resources

Resources	Number of Activities
CX36	1
SPIF CELL	1
LC 39	1
CCLS	39
TTF	2
MMSE	1

decision is that at the OPF, the TTF is used only to transport the CISS back to Hangar J. This should take only 1.25 days. On the other hand, the activity at Hangar J should tie up the TTF for over 80 days, since the TTF must be used for testing at CX 36. Therefore, the short activity (OPF) was given priority.

Use of the CCLS was prioritized along the following guidlines. Activities supporting launch and flight operations are given first priority. Pre-launch testing at LC-39 and the end-to-end systems test at the SPIF has second precedence. Third precedence was given to Spacecraft-Centaur and Shuttle-Centaur interface testing at SPIF and the Terminal Countdown Demonistration Test at CX 36A. Centaur testing at SPIF was assigned priority four. All Centaur and CISS testing, except the TCD, at CX 36A were priority five. Finally, priority six was given to CISS refurbishment at Hangar J.

After establishment of the resource requirements, the RESOURCE blocks, AWAIT nodes, FREE nodes and PREEMPT nodes were inserted into the model. The model was run and the output statistics for the resource utilization were reviewed. This data indicates how much of the resources were being used.

Care had to be taken that the resource statement were inserted correctly into the model. Unfortunatly, several runs were required to correct errors in this area. At this point, the model was now reaching a level of complexity such that many different paths to the resource requirements were available. The additional runs were required to add resource requests to activity paths which had been overlooked earlier.

The model now included all S/CGPS activities and all resource utilization requirements needed to process one Centaur vehicle through the system. At this point, an analysis was undertaken to identify the correct probability distribution for determing the duration of the S/CGPS activities. The procedures to accomplish this determination are outlined in the following paragraphs.

3. Probability Distribution Function

Normally, a probabilty distribution function for the duration time of a system's activities would be determined using actual performance data for the system. However, as discussed earlier, the S/CGPS has not yet processed its first Centaur vehicle. Therefore, an alternate method of determining a probability distribution function had to be developed. As was the case in the PERT anaylsis, performance data from Altas launch operations were used to determine the probablity function for Centaur activities.

Since General Dynamics perform launch processing for the Atlas launch vehicle as well as the Centaur upper stage, it was assumed that S/CGPS's activity performance would approximate the activity performance observed for the Atlas. Therefore, the probability distribution function calculated for the Altas data would be applied to the Centaur processing activities in the S/CGPS model. Activities for non-Centaur activities, such as standard shuttle processing operations, would be estimated using earlier shuttle performace data.

The Atlas data used to calculate the probability distribution function is displayed in Table 4-3. The scheduled performance time for each Atlas activity is listed in column one of Table 4-3. The actual times required to

TABLE 4-3

SCHEDULED ACTIVITY TIME FOR TEN ATLAS LAUNCH ACTIVITIES COMPARED TO THE ACTUAL PERFORMANCE OF THESE ACTIVITIES FOR TEN ATLAS LAUNCHES (IN DAYS)

ACTIVITY	SCH	ACTUAL PERFORMANCE ON TEN ATLAS LAUNCHES									
		39E	41E	58E	42E	14E	73E	87E	50F	6002	6003
Prop C/O	13	15	13	18	11	12	12	21	15	11	17
Gnd Pneu	1	2	1	3	1	2	2	1	2	2	2
Hydraulics	2	1	2	4	2	2	2	5	7	2	5
PLS Turn	2	3	4	4	4	3	3	3	4	5	4
Launcher	4	4	8	4	6	3	4	7	5	5	4
A/B Pneu	2	2	2	5	3	1	3	2	3	14	6
Umbilical	2	2	3	3	1	3	3	2	4	3	2
Logic Val	3	3	4	3	3	4	4	5	5	4	7
PU Sys C/O	1	1	2	3	1	4	1	3	1	4	3
Autopilot	2	2	4	2	3	2	4	4	5	2	3

(Adapted from 15)

complete the activity on ten Atlas launches is displayed in the next ten columns of the table. In this analysis, all data in the chart will be utilized. During the PERT calculations, the Beta distribution was used. Beta only used the data from the best performance, worst performance, and most likely performance times to determine the distribution. To accurately determine the correct probability distribution all data point were utilized. This procedure should reduce any bias in the data caused by a spurious data sample, i.e. one activity taking six times longer than the scheduled time to perform.

The first step in the analysis was to normalized all the Atlas data so that the scheduled performance times for all activites were equal to one. Observe from Table 4-3 that some activities are scheduled to be completed in 13 days, whereas, other activites are scheduled for completion in 1 day. By dividing the scheduled and actual performance data of each activity by its scheduled performance time, the resulting data is now equivalent to the performance of an activity of scheduled lenght equal to one day. For example, the performance data for the activity **Logic Validation**:

Logic Val	3	4	3	3	4	4	5	5	4	7

is divided by the scheduled time of 3 days to produce the following list of normalized performance data:

Logic Val	1.0	1.33	1.0	1.0	1.33	1.33	1.67	1.67	1.33	2.33

Table 4-4 contains the normalized performance data for all ten Atlas launches. This data was used to determine the probability distribution function for the Centaur activities using the AIDS computer program.

The AIDS program enables an operator to enter a set of

TABLE 4-4

NORMALIZED PERFORMANCE DATA FOR TEN ATLAS LAUNCHES (IN DAYS)

	NORMALIZED ACTUAL TIMES TO PERFORM ACTIVITIES									
ACTIVITY	39E	41E	58E	42E	14E	73E	87E	50F	6002	6003
Prop C/O	1.15	1.0	1.38	0.84	0.92	0.92	1.62	1.15	0.84	0.84
Gnd Pneu	2.0	1.0	3.0	1.0	2.0	2.0	1.0	2.0	2.0	2.0
Hydraul	0.5	1.0	2.0	1.0	1.0	1.0	2.5	3.5	1.0	2.5
PLS Turn	1.5	2.0	2.0	2.0	1.5	1.5	1.5	2.0	2.5	2.0
Launcher	1.0	2.0	1.0	1.5	0.75	1.0	1.75	1.25	1.25	1.0
A/B Pneu	1.0	1.0	+2.5	1.5	0.5	1.5	1.0	1.5	7.0	3.0
Umbilica	1.0	1.5	1.5	0.5	1.5	1.5	1.0	2.0	1.5	1.0
Logic Vl	1.0	1.33	1.0	1.0	1.33	1.33	1.66	1.66	1.33	2.33
PU C/O	1.0	2.0	2.0	1.0	4.3	1.0	3.0	1.0	4.0	3.0
Autoplt	1.0	2.0	1.0	1.5	1.0	2.0	2.0	2.5	1.0	1.5

data points and generate a histogram of the distribution of the data points. The program will attempt to fit a theoretical probability distribution to the data set and will conduct a goodness-of-test for the proposed probability distribution.

The normalized Atlas performance data was loaded into the AIDS program and the following statistics were calculated by the computer:

MEAN VALUE:	1.622
STANDARD DEVIATION:	0.8987
MINIMUM VALUE:	0.500
MAXIMUM VALUE:	7.000

The program generated a histogram with seven cells and a cell interval equal to 0.929 Figure 4-3 is the histogram generated by the AIDS program for this data.

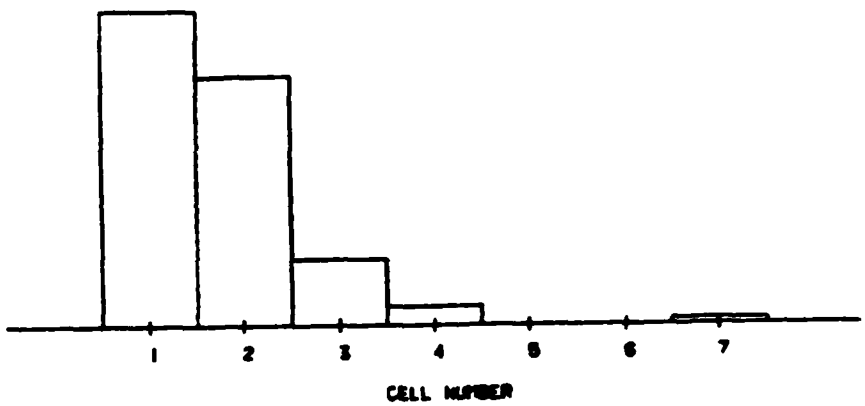


Figure 4-3

AIDS Histogram for Normalized Atlas Data

The AIDS program will attempt to fit the data set to any of the following probability distributions: Triangular, Normal, Lognormal, Exponential, Erlang, Gamma, Weibull, Beta, and Beta-PERT. The Atlas data distribution was compared to all of these distributions.

A goodness-of-fit test was conducted on each of the theoretical data distributions proposed by the computer.

Goodness-of-fit tests are a means of statistically determining if the tentatively selected probability distribution is an adequate characterization of the data set. The Kolmogorov-Smirnov (K-S) test was conducted to determine the validity of the proposed distribution. The K-S test is a nonparametric test because it uses a test statistic which makes no assumptions about the distribution. It tests for the degree of agreement between the sample cumulative and a known continuous distribution. The test consisted of comparing the maximum absolute difference between these two functions at each of the sample observations. A level of significance (alpha) equal to 0.05 was used for all K-S testing. Table 4-5 shows the results of K-S tests for all nine theorical distributions.

TABLE 4-5

K-S TEST RESULTS FOR PROPOSED PROBABILITY DISTRIBUTIONS

DISTRIBUTION	TEST STATISTIC	CRITICAL VALUE	RESULTS
TRIAGULAR	.450	.1367	FAIL
NORMAL	.1868	.1367	FAIL
LOGNORMAL	.1711	.1367	FAIL
EXPONENTIAL	.380	.1367	FAIL
ERLANG	.2454	.1367	FAIL
GAMMA	.1893	.1367	FAIL
WEIBULL	.1963	.1367	FAIL
BETA	.2186	.1367	FAIL
BETA-PERT	.3002	.1367	FAIL

Unfortunately, none of the proposed distributions meet the requirement (test statistic less than the critical value) to accept the hypothesis that the data set is from the specified distribution. Even when the alpha value was changed to 0.01 and the critical value for the K-S test was now equal to 0.1638, none of the distributions were able to pass the hypothesis test.

However, a review of the test data shows that the Lognormal test statistic of 0.1711 is the closest to the K-S critical statistic of 0.1367 Therefore, the Lognormal probability distribution function was selected for use with the Centaur activity duration calculations. The AIDS program proposed use of the following values with the Lognormal probability distribution function: MEAN = 1.610; STANDARD DEVIATION = 0.778 Figure 4-4 is the proposed Lognormal distribution superimposed over the Atlas normalized performance data histogram.

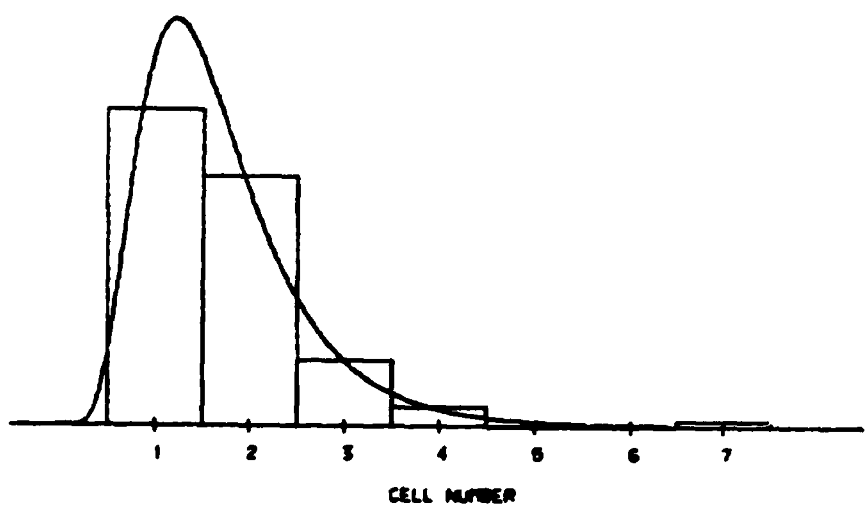


Figure 4-4

Lognormal Distribution vs. Atlas Data Histogram

Figure 4-5 is the AIDS graphic resentation of the K-S test. The polygonal line moving from the lower left to the upper right depicts the cumulative distribution fuction (CDF) for the Atlas normalized performance data. The two dashed lines which run in a similar fashion form an envelop which indicates the amount of permissible deviation from the Lognormal cumulative distribution function. Since the Atlas CDF crosses the dashed lines at the value 1.0 (horizonal scale), the distribution hypothesis was rejected. However, as can be observed the CDF does not significantly violate the envelop. Therefore, it was felt that this distribution would present an reasonable estimate of the duration of the Centaur activities.

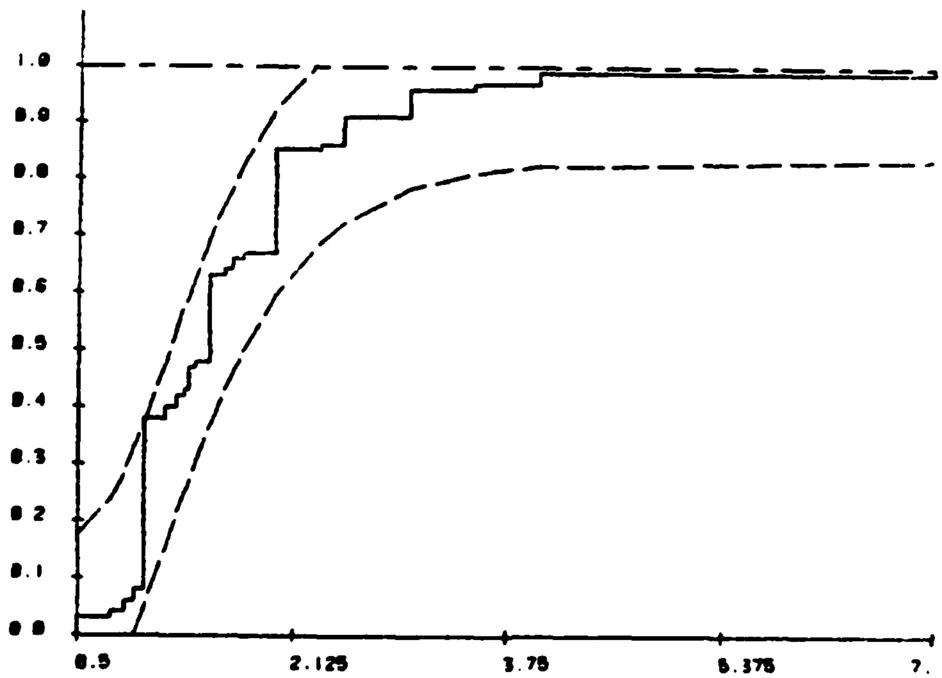


Figure 4-5

Results of the K-S Test for the Lognormal Distribution

As mentioned earlier, the distribution for shuttle processing activities was based on past performace data. Personnel working on the shuttle processing system estimated that shuttle procressing activities were completed on-time with a deviation of plus or minus ten percent (5). Therefore, it was decided to used the Triangular distribution to calculate duration of shuttle processing activities. The interval to be used for the triangular distribution begins at the early completion time (90% of schedule completion time) and runs to the latest completion time (110% of schedule completion time). The mode for the triangular distribution was the scheduled completion time.

With the probability distribution function for all activities determined, the next step was to insert these distribution functions into the model. Early model versions used the triangular function (TRIAG) and PERT beta values to estimate activity durations. For Centaur processing activities, the TRIAG function was replaced by the following function:

RLOGN (1.610, 0.7782) * X

where RLOGN defines the SLAM Lognormal distribution function with a mean equal to 1.610 and a standard deviation equal to 0.7782. The mean and standard distribution values were the proposed values from the AIDS program. The "X" value is the scheduled completion time for the Centaur activity. For example, Centaur activity **CISS Mechanical Receiving Inspection** is scheduled to last six days. Therefore, the SLAM activity statement for this task would be:

ACT,RLOG(1.610,0.7782)*6;

Shuttle processing activities were placed into the model using the plus/minus ten percent deviation described above. For example, shuttle processing activity, **Shuttle Rollout to LC 39** is scheduled to last 0.5 days. Therefore, the SLAM activity statement for the task would be:

ACT,TRIAG(0.45,0.5,0.55);

After insertion into the SLAM code, the model was run once again and the new model checked and validated using the same procedures followed earlier. At this point, the model was an accurate representation of the S/CGPS's capability to process one Centaur vehicle. The final step in the model construction effort was to configure the model to process several Centaurs at the same time.

4. Final Model Modifications

The first area of the model to be changed to accommodate the processing of multiple Centaur vehicles was the entity generation portion of the SLAM code. The early models had a CREATE statement which generated only one entity which represented both the Centaur and the CISS. The new CREATE statement generates an entity every 90 days to test the S/CGPS ability to process 4 Centaur vehicle a year (one every 90 Days).

Current plans for the Centaur Program state that only two CISSs will be produced initially. Therefore, the S/CGPS model inserts a CISS entity along with each of the first two Centaur entities entering the system. After the first two Centaur have entered into the system, all other entity generations produce only a Centaur entity and no CISS entity. These Centaur vehicles will be processed and flown using one of the refurbished CISS structures.

After nine CISS flights, the CISS structure is considered to be not flight worthy. It is therefore not refurbished and flown again. A new CISS is shipped from the GDC factory at San Diego to replaced the used CISS. The model simulates this function by use of an attribute counter, ATRIB(3), for each CISS entity. At the end of each flight, ATRIB(3) is incremented one count. When ATRIB(3) reaches nine the entity is routed to a CISS termination phase, N71A, where the CISS entity is destroyed and a flag, XX(8) = 1, is set to request a new CISS entity generation.

At the occurrence of the next scheduled Centaur entity generation, the model notes that the CISS flag is set and it generates a new CISS entity along with the Centaur entity. After generation, the program resets the CISS flag back to zero.

It is possible that later (after the first two) Centaur entities could be generated and ready for processing, i.e.

mate with the CISS at CX 36A, prior to completion of the CISS refurbishment at Hangar J. To prevent a Centaur entity from continuing its processing without a CISS entity, a SELECT ASSEMBLY statement was insert into the model at the point where the Centaur and CISS are mated together. This SELECT node makes the Centaur entities wait at a QUEUE node for the arrival of a CISS entity at a parallel QUEUE node. Once an entity is waiting at each node, they are combined (Centaur/CISS mate) into one entity and the processing flow can continue.

SLAM network statements were insert at the end of the **CISS Refurbushment**, Subtask 6.3, to route the CISS entity back to the start of the processing flow at Subtask 2.1, **CISS @ Hangar J**. The lenght of the simulation run is now controlled by a timer, rather than by the completion of processing of one entity. The model was programmed to terminate at the end of a ten year period (3650 days).

After insertion of these network statements the model was run once again and the output checked and verified to insure correct operation of the model. This final validation completes construction of the S/CGPS SLAM simulation model. The model was now ready to begin production runs to determine where the short falls in the processing system are located. A complete listing of the SLAM code for the S/CGPS model is presented in Appendix E of this paper.

E. Conclusion

The SLAM simulation model was constructed in a multiple phase process. At every step of the process, the model was checked and validated to insure that the output was consistent with the expected output from the real S/CGPS. This caused the builder to have a high degree of confidence that the model was a good representation of the the real S/CGPS.

Key attributes and variables of the S/CGPS SLAM model are included in Tables 4-6 and 4-7 shown below.

TABLE 4-6

S/CGPS SLAM ENTITY ATTRIBUTES

ATTRIBUTE	FUNCTION
ATRIB(1)	TIME ENTITY GENERATED
ATRIB(2)	VEHICLE COUNT
ATRIB(3)	FLIGHT COUNT

TABLE 4-7

S/CGPS SLAM VARIABLES

VARIABLES	FUNCTION
XX(1)	TIME CISS ENTERED CX 36A
XX(2)	TIME CENTAUR/CISS ENTERED SPIF
XX(3)	TIME CENTAUR/CISS ENTERED LC 39
XX(4)	TIME SHUTTLE WITH CENTAUR LAUNCHED
XX(5)	TIME SHUTTLE FLIGHT ENDS
XX(6)	TIME CISS REFURBISHMENT BEGINS
XX(7)	VEHICLE NUMBER
XX(8)	NEW CISS FLAG (1=NEED NEW CISS, 0=NO CISS)
XX(9)	CISS VEHICLE COUNT

With the validation of the SLAM model, production runs of the S/CGPS model were begun. The next chapter of this report discusses the results of the analysis of these production runs.

V. ANALYSIS OF THE S/CGPS SLAM MODEL

This chapter discusses an analysis of the output of the S/CGPS simulation model. The output is reviewed to determine weakness and deficiencies in the operation of the model and in turn the real-world processing system. The goal of this analysis is to determine whether or not the S/CGPS will be capable of meeting the goal of four Centaur flights per year.

A. Introduction

As a result of the construction process outlined in Chapter IV, the SLAM model of the S/CGPS was now configured to perform its the main purpose: the determination of the capabilities of the system. In this system anaylsis phase, the verified and validated S/CGPS model will be iterated in order to make inferences regarding the possibility of alternative configurations of the operating conditions.

The simulation model portrays the dynamics behavior of the Centaur processing system over time. It was built to produce results that resemble the outputs from the real S/CGPS. The main difference between the model and the real system is that an analyst has more control over the running of the simulation model than is possible with the real-world system. By using multiple simulation runs, the sensitivity of the model inputs to changes in the model parameters can be determined. For example, if the number of test stands at CX 36A were increased would the number of Centaur vehicle processed in given lenght of time change significantly.

B. Establishing a System Baseline

Before one can evaluate the effect any change may have on a system, a system base line must be established. The system baseline is defined to be the performance of the simulation model as currently designed. In other words, the simulation model was built to replicate the real world system as accurately as possible. Therfore, the output of the simulation model should approximate the real S/CGPS. Multiple runs of the model were conducted and the output statistic collected and analysed to determine the capabilities of the S/CGPS as its is currently designed.

Before continuing, the techinque used to collect the output statistics will be discussed. To ensure the accuracy of the output data, fifty separate simulation runs of each system model configuration were conducted. Each run began at a system time (TNOW) equal to zero and terminated at TNOW equal to 3650 days or 10 years.

The starting conditions for each run were as follows: There are no Centaur vehicles in the system at the start of the run. The first vehicle arrives as soon as the run begins (TNOW=0). After that, a Centaur vehicle is entered into the system every 90 days no matter what other events are happening within the system. This input rate continues until the run is terminated. All Centaur facilities, such as CX 36, SPIF CELLS, and CCLS, are initially idle and can immediately accept a Centaur vehicle for processing.

At the end of the ten year simulated time period, the run is terminated and a statistical summary of the status of the system is produced. An example of the output of one of these simulation runs is displayed in Appendix F. At this point, the SLAM program clears all system statistical counters, the system time is reset to zero, and another simulation runs is initiated. The subsequent simulation runs all begin with the same initial starting condition described above. The only difference between the simulation runs is the use of a different set of random numbers to generate the completion times of the S/CGPS subtask activities.

At the completion of the fifty simulated runs, the computer terminates the simulation program and outputs the statistical data on each of the fifty runs into a computer file. The data from these fifty runs are then analyzed to product a statistical summary of the performance of the system in its model configuration. The statistical summary includes the sample mean, **M**, the sample variance, **S**, and a 95% confidence interval for several significant variables of the model. The key variables which were used to evaluate the performance of the model are listed in Table 5-1.

TABLE 5-1

SIGNIFICANT VARIABLES OF THE S/CGPS MODEL

NAME	VARIABLE
#CISS	NUMBER OF CISS IN SYSTEM
#CENT	NUMBER OF CENTAUR VEHICLES IN SYSTEM
#FLTS	NUMBER OF CENTAUR FLIGHTS
FLT TIME	AVERAGE TIME TIL END OF FLIGHT
#REFURB	NUMBER OF CISS REFURBISHMENTS
REF TIME	AVERAGE TIME TIL END OF REFURBISHMENT
AWAIT(1)	AVERAGE WAIT TIME FOR CCLS
AWAIT(8)	AVERAGE WAIT TIME FOR CX 36
# WAIT CX36	NUMBER WAITING FOR CX 36
AWAIT(12)	AVERAGE WAIT TIME FOR TTF AT HANGAR J
# TTF HANG	NUMBER WAITING FOR TTF AT HANGAR J
AWAIT(13)	AVERAGE WAIT TIME FOR TTF AT OPF
# TTF OPF	NUMBER WAITING FOR TTF AT OPF
QUEUE(14)	AVERAGE WAIT TIME FOR CISS
# FOR CISS	NUMBER OF CENTAURS WAITING FOR CISS
CCLS USE	PERCENT OF CCLS UTILIZATION
CX36 USE	PERCENT OF CX 36 UTILIZATION
TTF USE	PERCENT OF TTF UTILIZATION

The mean was calculated by adding the value of the variables from each run together and dividing by the number of simulation runs (50 runs). The standard deviation was calculated using the following formula:

$$S = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - M)} \qquad (5\text{-}1)$$

where n is the number of simulation runs, and X represents the individual variable value from each simulation run. The

95% confidence interval is a range of values with an upper and lower limit, such that there is a 95% probability that the true mean of the variable would be contained within the defined interval (26:271). The confidence interval was calulated using the following formula:

$$M \pm t \, S/\sqrt{n} \qquad (5\text{-}2)$$

where t is the student t percentage point. In this case, t equals 2.01 because of the 95% confidence level (t0.025) and the degrees of freedom equal 49 (number of runs minus one) (4:496).

Sometimes, data from the first few time periods of a simulation run are not included in the statistical summary. This "warm-up" period is used to reduce bias in estimating a steady-state mean by eliminating values during the transient "start-up" period of the simulation (27:54). However, this rechnique was not used for the S/CGPS simulation runs. The early run data of the S/CGPS is included in the statistical summary. This was done because the early performance of the CISS/Centaur mating activity can result in significant delays in later Centaur processing. It was thought that the data from this period would provide valuable insight into the overall operation of the system; therefore, it was included in the summary.

The S/CGPS simulation model was now ready for a simulation run to establish the system's baseline performance. The results of the simulation run using the model of the current S/CGPS configuration is presented in Table 5-2. This table includes some key data points of the S/CGPS. A definition of these data points and their importance are listed below.

#CISS is the number of CISS structures that have been delivered to the launching site. This data is indicative of the rate at which the CISSs are be used.

CENT# is the number of Centaur boosters that have delivered to the launch site. This number is constant (40) because the input rate is a constant one every 90 days or 40 vehicles in 5 years.

#FLTS is the number of flights that occur in the five year period. This counter is incremented at the completion of Subtask 5.4 ,**Centaur Flight**. The FLT TIME is the average lenght of time from receipt of the Centaur vehicle to completion of the flight, Subtask 5.4

#REFURB is the number of times a CISS was refurbished. The REF TIME is the average lenght of time from start of CISS testing at CX 36 until completion of CISS refurbishment at Hangar J, Subtask 6.3

AWAIT(1) is the average time a Centaur vehicle must wait for two CCLS to become available before the final launch coutdown begins, Subtask 4.5 This point was selected to evaluated the loading of the CCLS system because it requires both CCLS to be dedicated to one task.

AWAIT(8) is the average time a CISS structure must wait before the CX 36 test stand is available for testing. The number of CISS wait for CX 36 at the termination of the run is displayed as # FOR CX.

AWAIT(12) is the average time a CISS structure, AWAIT (12), must wait for a TTF before proceeding to CX 36 and the number of CISS, # FOR TTF/CX, waiting for CX 36 at the end of the simulation. This point displays TTF useage and backlogs which can occur at this point.

The points AWAIT (13) and # FOR TTF/OPF displays the average waiting time for a TTF by a CISS at the OPF and the number of CISS awaiting a TTF at the OPF at the end of the run. These point show another point in the model where backlogs can occur due to lack of the TTF resource.

The average wait time, QUEUE(16), by a Centaur vehicle for a CISS to be refurbished is calulated and the number of Centaurs, # FOR CISS, awaiting a CISS at that point at the end of the simulation is displayed. This is a critical point because it indicates whether the ground processing system can keep up with the Centaur delivery rate to the launch site. If a large number of Centaur are waiting at this queue then something must be done to make more CISSs available to handle the Centaurs be delivered.

The utilization rate of three key resources is calculated and displayed: the CCLS system (CCLS USE), the CX 36 test stand (CX36 USE), and the TTF (TTF USE). The utilization rate is the average utilization of the resources is the model during the runs. For example, the one unit of the resouces is used 50 percent of the run, then the average utilization is 0.50 If two units of the resource are available and they are utilized 75 percent of the time during the run, then thhe average utilization rate is 1.50 or 75% of the 2 units.

The data displayed in Table 5-2 became the baseline data against which the performance of modified S/CGPS model configurations was evaluated.

TABLE 5-2

BASELINE PERFORMANCE DATA FOR THE S/CGPS SIMULATION MODEL

VARIABLE	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	4.28	0.61	4.107	4.453
#CENT	41.0	0.0	41.0	41.0
#FLTS	15.9	2.07	15.312	16.488
FLT TIME	236.0	14.6	231.850	240.150
#REFURB	14.0	2.07	13.412	14.588
REFURB TIME	365.0	22.3	358.661	371.339
AWAIT(1)	3.02	1.15	2.693	3.346
AWAIT(8)	86.5	16.3	81.866	91.133
# FOR CX	1.4	0.64	1.218	1.582
AWAIT(12)	71.3	22.6	64.875	77.724
# FOR TTF/CX	1.00	0.33	0.906	1.094
AWAIT(13)	195.0	29.9	186.500	203.499
# FOR TTF/OPF	1.04	0.59	0.872	1.208
QUEUE(14)	907.0	50.50	892.645	921.355
# FOR CISS	25.7	2.26	25.058	26.342
CCLS USE	0.533	0.019	0.527	0.538
CX36 USE	0.812	0.052	0.797	0.827
TTF USE	0.851	0.053	0.836	0.866

A review of the baseline data reveals some rather depressing information. One observes that after ten years of launch processing only an average of approximately 16 Centaurs vehicles have been launched. The average time to process one Centaur vehicle from arrival at CCAFS until it is place on orbit was between 232 to 240 days. Even if one allows for no Centaur launches in the first year of the processing cycle, there should have been approximately 32 to 36 Centaurs placed in orbit. This assumption is based on a target figure of four flights per year for a nine year period (first year ignored). It is apparent that the S/CGPS, as it is currently configured will be unable, to meet the four flights per year launch rate. Modifications to the processing system must be made to reach the target launch rate. The next phase of the analysis involves the evaluation of different configurations of the S/CGPS to determine if the system can be modified to meet the four per year launch rate.

C. Alternate S/CGPS Configurations

To ascertain what modifications should be made to the proposed S/CGPS configuration, the baseline data was reviewed again to determine what system resources were causing the Centaur processing backlogs. Once the causes of these backlogs were identified, modifications were made to the S/CGPS model and the simulation runs were reaccomplished. These modifications were usually in the form of increased system resources and assets.

The baseline data reveals that a significant backlog of Centaur vehicles occurs at QUEUE(14), where the Centaurs wait to be mated with the CISS. There were an average of 25 Centaur vehicles waiting at this point to continue their processing. These 25 vehicles are more than 60% of the 41 vehicles which arrived at CCAFS for launch. Obviously, the queue must be freed up if a significant increase in the processing rate is to be achieved. What are the potential causes of the backlog?

The baseline S/CGPS provides for only two CISS structures to be initially deliever with the Centaur vehicles. If only two CISSs are available and the Centaur processing cycle time is averaging 365 days from CISS arrival to completion of the CISS refurbushment at Hangar J, then several Centaur vehicles will arrive for processing before the first CISS has completed refurbishment and is ready to support another flight. The delay will cause the processing system to immediately fall behind when the third Centaur vehicle (the first to use a refurbished CISS) arrives at the launch site. In order to alleviate this problem, additional CISS structures must be delivered at the start of the processing. To test this proposal, two simulation runs were conducted: one with an initial delivery of three CISS structures and one with an initial delivery of four CISS structures.

Another potential cause of this backlog is the fact that only one Centaur Transport & Test Fixture (TTF) is available. The TTF is used to transport the CISS from Hangar J to CX 36A and is used to move the assembled Centaur/CISS vehicle from CX 36A to the SPIF. It also ferries the used CISS structure from the Orbiter Processing Facility (OPF) back to Hangar J for refurbishment. However, the TTF is also used to enclose the combined Centaur/CISS vehicle during its test and checkout phase at CX 36A. During the baseline simulation runs, the CX36A testing was averaging 120 days to complete. This means that if a CISS were ready for transport back to Hangar J for start of refurbishment but the TTF was involved in testing at CX 36A, the CISS must wait at the OPF for the TTF to become available. The baseline data shows that the average wait at the OPF for a TTF was 195 days.

A possible solution to this problem would be the addition of another TTF to handle the simulatneous requirements at CX 36A and the OPF. To test this theory, one run was made with two TTFs available and another run with three TTFs at the launch site.

As noted above, the average time to complete testing at CX 36 was 120 days. This means that before testing of the first Centaur is complete at CX 36, a second Centaur is already at Hangar J waiting for the first vehicle to clear the facility. The addition of a second test stand at CX 36A would hopefully reduce the cause of this delay. A simulation run was conducted with two test stands available at CX 36A to test this theory.

The simulation runs of these modified S/CGPS configurations were conducted in the following manner. The baseline S/CGPS model was changed only in the one aspect being tested. All other parameters remained the same as the baseline. For example, the simulation model in which two CX 36A test stands were available was created by changing one line of the SLAM computer code: RESOURCE CX36(1) to RESOURCE CX36(2). The other varables of the model were unchanged. When the modified model was run on the computer, the same random number stream which was used for the baseline run was reused for this version of the model. By using the same group of random numbers for this modified C/GGPS model, any changes which occur the output data must be attributed solely to the modification of the system variable and not to some random occurrence of the number stream. The simulation runs for each of the modified system configuration was conducted using exactly the same starting conditions, SLAM code execution procedures, and data analysis techinques described above. A fifty simulation run sequence was accomplished for each model modification.

After completion of the simulation runs, in which only one aspect of the model was changed, another set of simulation runs was conducted in which combinations of these proposed system modifications were used. For example, the proposal to initally deliver three CISS structures to CCAFS was combined with the requirement to have two TTF available at the launch site. This two variable modification of the model was constructed by changing only the two variables of concern in the baseline model. The simulation run was then performed using the same exact procedures used for tne baseline and one variable modified simulation runs.

A list of all simulation runs which were initally conducted is displayed in Table 5-3. This list includes the combination of variables which were selected for evaluation. A summary of these results of these runs and the complete statistical summary for each set of runs are listed in Appendix G of this paper. Only the significant results of the runs will be high-lighted in next section of this chapter.

D. Simulation Run Output

The output of the simulation runs produced some interesting and unexpected results. A change in a system variable at times would improve the backlog at one point of the S/CGPS, while identifing a new backlog at some other location of the system. By comparing the output of each of the simulation runs, the modifications which resulted in the most improved performance of the S/CGPS were identified. Table 5-4 displays the results of several key statistics from each of the runs.

The delivery of additional CISS structures to the

TABLE 5-3

VERSIONS OF THE S/CGPS MODEL EVALUATED

NO VARIABLES MODIFIED:

STANDARD BASELINE MODEL

ONE VARIABLE MODIFIED:

THREE CISS DELIVERED MODEL
FOUR CISS DELIVERED MODEL

TWO CX 36A MODEL

TWO TTF MODEL
THREE TTF MODEL

TWO VARIABLES MODIFIED:

TWO CX36, THREE CISS MODEL
TWO CX36, FOUR CISS MODEL
TWO CX36, TWO TTF MODEL
TWO CX36, THREE TTF MODEL
TWO TTF, THREE CISS MODEL
TWO TTF, FOUR CISS MODEL

THREE VARIABLES MODIFIED:

TWO CX36, TWO TTF, THREE CISS MODEL
TWO CX36, TWO TTF, FOUR CISS MODEL
TWO CX36, THREE TTF, FOUR CISS MODEL

launch site marginally improved the performance of the system. The 3 CISS model processed only 18 flights, an increase of 2 over the baseline, and the 4 CISS model improved to 22 flights, an increase of 6. It appears that that the limiting factors in this model are the availability of CX36 and the TTF. One observes that both of these resourses have utilization factors of approximately 90%.

TABLE 5-4

SUMMARY OF KEY STATISTICS FOR THE SIMULATION RUNS

MODEL VERSION	# OF FLTS	WAIT CX36	WAIT TTF	WAIT CISS	CX36 USE	TTF USE
BASELINE	15.9	1.3	1.0	25.7	0.81	0.85
3 CISS	18.0	1.5	1.9	22.5	0.88	0.91
4 CISS	22.6	2.2	1.9	17.7	0.89	0.92
2 CX36	22.0	0.9	1.7	18.1	1.03	0.83
2 TTF	26.1	4.2	1.1	14.1	0.93	1.37
3 TTF	26.9	5.9	0.4	12.5	0.93	1.65
2 CX36/3 CISS	23.7	1.1	1.1	15.6	1.25	0.89
2 CX36/4 CISS	24.8	0.8	2.1	15.0	1.38	0.92
2 CX36/2 TTF	27.2	1.9	2.2	18.0	1.40	1.45
2 CX36/3 TTF	33.8	3.0	0.7	4.6	1.43	1.63
2 TTF/3 CISS	28.4	4.0	1.9	11.2	1.00	1.41
2 TTF/4 CISS	28.6	2.7	1.9	10.6	1.00	1.35
2 CX36/2 TTF/3 CISS	31.5	2.2	2.0	5.2	1.54	1.61
2 CX36/2 TTF/4 CISS	23.9	1.8	1.6	13.7	1.76	1.80
2 CX36/3 TTF/3 CISS	36.4	3.7	0.4	2.0	1.64	2.01

The Centaur vehicles are having to wait for the one unit of each resource, TTF and CX 36, to become available before continuing their processing.

The simulation model with two CX 36 test stands available had a system output of only 22 flight in the ten year period, a increase of 6 flights above the baseline system. System limitations in this case are due to the lack of enought CISS structures of keep up with the arriving Centaur vehicles. The one TTF with an 83% utilization factor is also causing some processing delays.

Making additional TTF available at the launch site resulted in the most dramatic improvements in S/CGPS performance. With two TTFs available for CX 36 testing and Centaur/CISS movement, the system output increase by 10 above the baseline system to 25 flights. With three TTFs, 27 flights were completed, a marginal increase. One observes that TTF utilization in both cases is well above the proposed one TTF availablity in the baseline system to 1.37 and 1.65, repectfully. In these S/CGPS configurations, CX 36 utilization is approaching maximum capacity with a 93% use rate. The fact that only two CISS structures are available to support launch processing probably prevents the output of these models from being even higher.

It is apparent that using only one variable modification at a time will not provide sufficient system improvement to product a launch rate that approaches the target goal of four flights per year. At least two variable modification will be required to attain further system improvements.

The combination of increased CX 36 resources and additional CISS structure deliveries provided little improvement over the one variable modification variants of the model. In fact, they failed to equal the performance of the multiple TTF models. The lack of TTFs is definitely the cause of some backlogs in the processing cycle. Output of the two CX 36/three CISS model was 23 flights. The two CX 36 /four CISS model had an output of 24 flights. Both models had TTF utilization rates of approximately 90%. An increase in TTF resource must be involved in any final solution to raise the S/CGPS flight output.

The two CX 36/three TTF model produced the best performance of any two variable modification models. Its output of 33 flight is within the previously determine acceptable system performace target of 32 to 36 flight in the model time period. Therefore, at least one configuration of the model has achieved a level of output that meets the launch goals.

Unfortunately, the two TTF and multiple CISS models do not achieve the level of performance of the two CX 36/three TTF model. Both the two TTF/three CISS and two TTF/four CISS models have system outputs of approximately 28 flights. The reason for this poor performance is due to the lack of sufficient CX 36 resources. The CX 36 resource utilization factor in both models is 100%. Therfore, an upper limit has been reached for S/CGPS performance with only one CX 36 test stand. Any improvement above the 28 flight level performance must include an increase in the CX 36 resource.

It has been determined that for system performance to approach the goal of 4 flights per year additional TTFs and a second CX 36 facility must be available. Since it is known that these system variables must be increased, the only model configuration which can improve system performance any higher are the three variable modified programs.

The three variable modified models offered several configurations which meet the target goal of four flights per year. The two CX 36/three TTF/three CISS model produces an output of 36 flights. This certainly meets the target criteria of 32 to 36 flights. The two CX 36/three TTF/four CISS model did even better with an output of 38 flights. This configuration was processing Centaur vehicles as fast as they arrived as CCAFS. In fact, this simulation model has CISS entities in QUEUE(15) waiting for Centaur vehicles to be off-load from the aircraft.

In an unusual case, the two CX 36/two TTF/four CISS model had poorer performance the the two CX 36/two TTF/three CISS model. This result is the exact opposite of what one would expect. An anylsis of the statistical summary indicates that several of the simulation runs of this model resulted in a large backlog of Centaur vehicles at QUEUE(14) awaiting mating with the CISS. It appears that in these runs, eventhought two CX36 facilities are available and two TTF are present, the system falls behind the procesing schedule and is unable to furnish support to move the CISS structure from the OPF back to Hangar J to begin the refurbishment effort. This is due to the fact that both TTFs are busy supporting Centaur checkout activites at both CX 36 test stands. Therefore, no TTF is available to move the CISS back to Hangar J. This pushes the schedule even further behind and the system never has an opportunity of catch up.

The analysis seems to indicate that the models in which the TTF and/or CX 36 resoucres are operated near maximum utilization do not provide any opportunity to recover from schedule slips. In other words, as long as the system is operating at or near schedule, the S/CGPS will be capable of meeting the schedule. However, a perturbation in the processing flow can results in systems delay from which the S/CGPS can never recover.

At the conclusion of the analysis outlined above, one last set of simulation runs was conducted. The purpose of these last runs was to determine what the Centaur input level that the baseline S/CGPS model could support. To perform these runs, the baseline model was modified to reduce the input level from one Centaur vehile every 90 days to one Centaur every 120 days or 3 vehicles per year. An additional run was conducted at the input level of one vehicle every 180 days or two vehicles a year.

The results of these runs in displayed is Table 5-5. A review indicates that at the 120 days input level the system

TABLE 5-5

SUMMARY OF KEY STATISTICS FOR REDUCED INPUT RUNS

MODEL VERSION	# OF FLTS	WAIT CX36	WAIT TTF	WAIT CISS	CX36 USE	TTF USE
BASELINE	15.9	1.3	1.8	25.7	0.81	0.85
120 DAY INPUT	15.7	1.4	1.9	15.1	0.81	0.85
180 DAY INPUT	14.9	1.0	2.0	6.00	0.79	0.84

output is almost identical to the baseline. Therefore, even at this input level the lack of TTF and CX 36 resources is limiting the systems performance.

At the 180 day input level, the statistical summary seems to indicate that the system has reached a steady-state level of operation. All fifty runs had the same number of entities awaiting sevice at the major AWAIT and QUEUE nodes of the model. The CX 36 and TTF utilization rate are slightly lower than at the baseline and 120 day input levels. Therefore, it appears that the baseline S/CGPS can support two Centaur vehicles a year. However, a small increase in the TTF resourse would probably result in an increase system output.

E. Summary

The SLAM model proved to be an invaluable tool for a system analyst. Proposed chages to the S/CGPS could be easily and quickly made to the model and the resulting output data was available within minutes of the orginal configuration concept. This rapid model turnaround provided an opportunity to explore many different system options and configurations.

The results of these many simulation runs was the determination that the S/CGPS was not performing at a level which is capable of meeting the target launch rate. Fortunately however, the anaylsis of the S/CGPS simulation model indicates that modifications can be made to the proposed system configuration which should result in improved performance of the entire system. This analysis directly lead to the recommendations which are outlined in the next chapter.

VI. CONCLUSION & RECOMMENDATIONS

This chapter summarizes the research conducted for this project. It discusses the conclusions reached from this research amd make some recommendations to further the research and to improve the Centaur ground processing system.

A. Introduction

The results of this project have produced some unexpected results. The PERT nerwork and the SLAM simulations identified areas where system performance restrictions or resoure limitations have caused the system to fall short of its launch goals. The inability of the system to process Centaurs more rapidly or to handle more vehicles simultaneously proved to be the ultimate limitation of the system's capability.

Fortunately however, the results have produced some specific recommendations for future activity. These recommendations are divided into two categories: areas where the research conducted in support of this project can be enhansed by further research, and areas where changes in the proposed C/SGPS can improve the systems's performance. These results and recommendations are listed in the next two sections of this chapter.

B. Areas of Further Research

Any anaylsis is only as good as the data upon which it is based. This anaylsis, unfortunately, had to be based upon data which had to be modified to fit the Centaur model being developed. It is impossible to determine at this time how accurately this information reflects the actual performance of the C/SGPS. The only way to insure an accurate replication of the C/SGPS is to collect actual performance data from the system. Since the first two Centaur vehicles are currently beginning processing at CCAFS for launches scheduled in May 1986, the first actual data is only now being collected. However, as more Centaur vehicles are sent through the processing cycle a data base will become available upon which to improve the PERT network and SLAM model. This data will enable a researcher to update the probability distributions used in the SLAM model with distribution fuctions which more accurately reflect the S/CGPS's performance.

Unfortunately, time constraints prevented the completion of some anaylsis which was envision to be accomplished when the research began. Any follow-on research should include a sensitivity analysis to complete an in-pepth study of the S/CGPS. In a sensitivity analysis, parameters which affect the performance of a system are changed and the resulting effects of these changes are observed. For example, if the amount of time required to process the Centaur at CX 36 could be reducted by 50 percent what would be the effect of the output of the entire system.

Time limits to perform this research required that some of the activities of the S/CGPS has to be combined into one activity for inclusion into the PERT and SLAM models. For example, Subtask Activity 3.2.3 (**Remove CCA from TTF**) actually is a combination of the following activities: open integration cell, remove top cover from TTF, attach Centaur lifting slings, and perform Centaur weight/center of gravity checks. A more accurate model of the system would include each of these separate activities as individual tasks. If all these activities were included in the PERT and SLAM models, some currently unobserved relationships between the activites may become apparent. This more detailed model would also allow the researcher to make more subtle modifications to the model and observe their effect.

C. Proposed Modifications to the S/CGPS

Data from both the PERT network analysis and the SLAM simulation runs indicate that the S/CGPS, in its currently proposed configuration, will be unable to launch four Centaur vehicle per year. The PERT anaylsis estimates that it will take approximately 232 days to process one Centaur vehicle from arrival at CCAFS until the vehicle completes its mission of placing a spacecraft on-orbit. The SLAM simulation runs of the propsed S/CGPS produced a similar value of 236 days for vehicle processing. Turn-around times for the CISS refurbishment were 292 days (PERT network) and 365 days (SLAM simulation). The increase in CISS refurbishment time from the PERT to the SLAM estimates is due to the fact that the CISS must wait for resources, such as CX 36, to be available for the proccessing to continue. These lenghts of time devoted to one vehicle in terms facilities, material, and manpower make it clear that to achieve a processing rate of four flight per year changes in the current method of operations will have to be mode.

The PERT analysis indicated that there is very little slack time available in the S/CGPS subtask processing to handle problems which arise. Of the 30 different subtask path segments in the PERT network only eight had any slack time whatsoever. Two of these had slack of less than one day and the maximum slack time was 19 days. With these types of time constrains the system will have difficulty meeting the times calculated by this analysis. Something must be done to reduce the lenght of time it take to prepare one of these vehicles.

The operators of the S/CGPS should determine if some of the processing activities will actually require all the tests and checks proposed. The elimination of unneccessary or redundant testing could produce a large reduction the amount of time required to complete the processing cycle. On the other hand, care must be taken to make sure all necessary testing is accomplished to make sure the vehicle is ready for the flight. It appears however, that some of the extensive testing performed at CX 36 could have been done at the factory in San Diego. By conducting the main portion of the test at the factory and only conducting a shorter "verification" test at the launch site, the processing time of the entire system might be significally reduce and thus enabling more vehicles to be processed by the S/CGPS.

Without modifying the processing time described above, the results of the SLAM simulation runs indicate that additional resources will be required if the processing goal of four flights per year is to be attained. It is proposed that the following resources be procured to increase the output level of the S/CGPS.

Two additional Centaur Test and Transport Fixtures (TTF) should be bought for the S/CGPS. These structures are relatively inexpensive and an increase in the number of TTF available in the SLAM model produced a significant increase in the output of the system. Centaur output from the simulation runs increased 60 percent when another TTF was added to the system. By having three TTFs at the launch site, there should be no significant details due to the lack of an available TTF. For example, if one TTF were being used at CX 36 for Centaur testing and a second were moving a Centaur into the SPIF, the third TTF could be used to move a previously flown CISS from the OPF back to Hangar J. These three TTFs could cover all TTF tasks performed at the launch site. If additional CISS (more than the currently planned two CISS) or additional CX 36 test stands were procured, then additional TTF should also be acquired to ensure no delays are caused by this inexpensive item.

A third CISS should be procured and delivered to the launch site with the third Centaur vehicle. Current plans are to procure only two CISS structures to cover all Centaur flight requirements. The long processing time required to refurbish the CISS (on average over 100 days) results in the delay in the start of comnbined Centaur-CISS testing at CX 36. By making a third CISS available for the third flight instead of having to wait for completion of refurbishment of the first flight CISS, the initial delays from which the system never recovers can be avoided. It appears from the SLAM output data that procurement of a fourth CISS would provide little improvement in system processing capability. Therfore, it is recommended that only one addition CISS be procured at this time.

The addition of these resources, two TTFs and one CISS, are relatively inexpensive methods of increasing the output of the S/CGPS. However, as the SLAM data revealed, if the four flight per year goal is to be achieved and the current processing activity time periods remains, a second test stand, similar to the one at CX 36, must be built. This is a rather expensive requirement which would push the finanical resources of the Centaur Program Office to attain.

It is recommended that a serious review of the recommendations made above, as well as the four flight per year requirement, be performed before committing the large sums of money required to build a second Centaur test stand. The test stand is a major undertaking which will take several years to accomplish. Other system modifications, especially reduction of the processing times, would be more cost effective to implement.

However, if future system requirements dictate four Centaur flights or more in a one year period, then the only method of attaining the processing rate will be to construct another CX 36 test stand at some location at CCAFS. This will require either the conversion of another Atlas launch pad (CX 36B or CX 11) or the construction of an entire new facility to duplicate the CX 36A facility. Either alternative will be an expensive and lenghty project.

D. Conclusion

The Centaur upper stage booster has been and will continue to be a key element of this nation's space program. If this system is to be utilized to its maximum capacity, it will have to have a ground processing system up to the task. The research presented in this paper has identified the areas for potential improvement in the ground system. With this information, the managers of the Centaur program can establish a ground system capable of meeting the challenges facing the Shuttle-Centaur system.

ADDENDIX A:

SUBTASKS & ACTIVITIES OF THE S/CGPS

SUBTASK 1.1

CISS @ HANGAR J
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
1.1. 1	Unload CISS from Aircraft	1
1.1. 2	Preparations for Standard Turn On	3
1.1. 3	Standard Turn On	1
1.1. 4	CISS Mechanical Receiving/Inspection	6
1.1. 5	CISS Electrical Receiving/Inspection	6
1.1. 6	CISS Instrumentation Receiving/Inspect	6
1.1. 7	CISS Transducer Ringout (Power Off)	2
1.1. 8	CISS Transducer Ringout (Power On)	3
1.1. 9	Transport CISS to CX 36A	1

SUBTASK 1.2

CENTAUR @ HANGAR J
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
1.2. 1	Unload Centaur from Aircraft	1
1.2. 2	Centaur Electrical Receiving/Inspection	11
1.2. 3	Propellant Probe/Cable Checks	3
1.2. 4	Pneumatic Subsystem Receiving	4
1.2. 5	Propellant Tank Purge & Sample	4
1.2. 6	Vent Subsystem Functional Checks	2
1.2. 7	Centaur Mechanical Receiving/Inspection	4
1.2. 8	Cryogenic Flange Bolt Torque Check	3
1.2. 9	Propellant/Hydraulic Receiving Preps	3
1.2.10	Fill & Drain Subsystem Checkout	2
1.2.11	Preparations for Transport	2
1.2.12	Centaur Propellant/Hydraulic Preps	6
1.2.13	Hydraulic Subsystem Loop Press Check	2
1.2.14	Transport Centaur to CX 36A	1

(Adapted from 16)

SUBTASK 2.1

CISS @ CX 36A
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
2.1. 1	Remove Protective Covers	4
2.1. 2	Prepare CISS for Mate	3
2.1. 3	Check CX 36A Bridge Crane	1
2.1. 4	Fill LH2 Storage Tank	1
2.1. 5	Fill LO2 Storage Tank	3
2.1. 6	Install CX 36A Fluid Interfaces	2
2.1. 7	Install Fluid Line Insulation	4
2.1. 8	Preparations for Standard Turn On	2
2.1. 9	Standard Turn On	1
2.1.10	Avionics Subsystem Functional Check	3
2.1.11	Rotation Test	2
2.1.12	Pressure System Functional Test	5
2.1.13	CISS Vent System Checkout	4
2.1.14	Helium Storage Pressure Check	2
2.1.15	LO2 System Validation	2
2.1.16	LH2 System Validation	2
2.1.17	PAVCS Functional Checkout	4
2.1.18	Purge System Check	2
2.1.19	Helium Stage Pressure	2
2.1.20	Airborne Instrumentation Measurement C/O	10
2.1.21	Pressure Changeover	1
2.1.22	Mate Centaur	1

(Adapted from 16)

SUBTASK 2.2

CENTAUR/CISS @ CX 36A (PART I)
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
2.2. 1	PU & PLIS Probe Checkout	2
2.2. 2	CX 36A Electrical Readiness	3
2.2. 3	Blockhouse Blast Door Checkout	1
2.2. 4	Facility Electrical Readiness	2
2.2. 5	Engine Electrical Readiness	2
2.2. 6	N2H4 System Electrical Checks	2
2.2. 7	Servo Harness Checks	2
2.2. 8	Purge System Checkout	2
2.2. 9	Intermediate Bulkhead Checkout	5
2.2.10	Clean Tank Walls	2
2.2.11	Install LO2 Insulation	2
2.2.12	Install LH2 Insulation	5
2.2.13	Align & Install Trunnion	2
2.2.14	Electrical Interface Test	2
2.2.15	Check CX 36A Bridge Crane	1
2.2.16	Erect TTF	1
2.2.17	Install TTF Insulation Panels	3
2.2.18	Verify Structures	5
2.2.19	Vent Door Checkout	1
2.2.20	Install Separation Springs	2
2.2.21	ECS System Connection	3
2.2.22	Structural Preparations for TCD	4
2.2.23	Preparations for Standard Turn On	2
2.2.24	Standard Turn On	1
2.2.25	Avionics Subsystem Functional Checkout	8
2.2.26	PAVCS Subsystem Checkout	3
2.2.27	Vent System Functional Checks	3
2.2.28	Pressure System Functional Checks	3
2.2.29	Helium Storage Pressure	3
2.2.30	Pressure Change Over	1
2.2.31	CCVAPS/APCS Functional Checks	4
2.2.32	Pneumatic Readiness	3
2.2.33	Pressure Change Over	1
2.2.34	Install Forward Bulkhead Insulation	3
2.2.35	Purge System Checkout	4
2.2.36	Foam Vent System Flanges	4
2.2.37	Hazardous Gas Detection System Checkout	2
2.2.38	Fill LH2 Storage Tank	1
2.2.39	Fill LO2 Storage Tank	3
2.2.40	Fluid Sampling	4
2.2.41	Battery Activity	2
2.2.42	Install Batteries	1
2.2.43	Avionics Subsystem Verfication	3
2.2.44	Connect Fluid Lines	2

SUBTASK 2.2 (CONT)

ACT #	ACTIVITY	m
2.2.45	N2H4 System Thruster Loop Pressure	2
2.2.46	N2H4 Leak & Functional Test	3
2.2.47	Cryogenic Flange Bolt Check	3
2.2.48	Remove Engine Supports	1
2.2.49	Main Engine Leak Checks	4
2.2.50	Install Engine Supports	1
2.2.51	Hydraulic Leak & Functional Test	3
2.2.52	Hydraulic End-to-end Test	3
2.2.53	Install Propellant Duct Heat Sheild	4
2.2.54	Foam Propellant System Transducers	5
2.2.55	Install Propellant Heat Shield	5
2.2.56	Propellant/Hydraulic TCD Readiness	2
2.2.57	RF Receiving/Inspection	2
2.2.58	Pump Speed Checkout	2
2.2.59	RF Subsystem Checkout	2
2.2.60	Helium Storage Pressure	1
2.2.61	Transducer Ringout (Power Off)	2
2.2.62	Transducer Ringout (Power On)	3
2.2.63	Airborne Instrumentation Measurements	10
2.2.64	Install Tank TV Camera	3
2.2.65	Terminal Countdown Demonstration	1

(Adapted from 16)

SUBTASK 2.3

CENTAUR/CISS @ CX 36A (PART II)
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
2.3. 1	Post-TCD Checks	3
2.3. 2	TCD Data Review	4
2.3. 3	Activate Batteries	3
2.3. 4	Install Batteries	1
2.3. 5	Calibrate IMG	1
2.3. 6	Mission Sequence Simulation Preparations	3
2.3. 7	Propellant Flight Readiness Operations	4
2.3. 8	Final Cleaning	4
2.3. 9	Mission Sequence Simualtion Test	1
2.3.10	Remove Batteries	2
2.3.11	Check CX 36A Bridge Crane	1
2.3.12	Preparations for De-Erection	3
2.3.13	Propellant/Hydraulic Systems Operations	2
2.3.14	Pressure Change Over	1
2.3.15	Mission Sequence Simulation Data Review	3
2.3.16	Install Ordinance	3
2.3.17	Move to SPIF	1

(Adapted from 16)

SUBTASK 3.1

SPIF PREPARATIONS
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
3.1. 1	Install Standard Switch Panel/Console	.5
3.1. 2	Install & Connect OAS Cables	1.5
3.1. 3	Install & Mate SMCH Cable	3.0
3.1. 4	Validate & Verify OAS/SMCH Connection	3.0
3.1. 5	Verify Comm/Telemetry Interfaces	.5
3.1. 6	Prepare SPIF Cable Tray for Centaur	.5
3.1. 7	Install Payload Retention Fittings	1.5
3.1. 8	Align Payload Retention Fittings	1.0
3.1. 9	Install SPIF Platforms & Barriers	.5
3.1.10	Configure for GN2/GHe Support	.75
3.1.11	Clean Facility	1.0
3.1.12	Install Centaur GSE In Cell	.75
3.1.13	Install Battery Simulation Pack	.75
3.1.14	Perform Payload Integration Test	.5

SUBTASK 3.2

CENTAUR CISS ASSEMBLY CHECKOUT
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
3.2. 1	Clean TTF & Move into SPIF Airlock	.5
3.2. 2	Move TTF into SPIF Transfer Aisle	.5
3.2. 3	Remove Centaur/CISS From TTF	.5
3.2. 4	Install CCA into Integration Cell	.5
3.2. 5	Position Cell Platforms	.5
3.2. 6	Establish Clean Environment in Cell	.5
3.2. 7	Remove TTF from SPIF	.75
3.2. 8	Clean & Inspect Centaur for Damage	1.0
3.2. 9	Connect SMCH & RF Intefaces to CCA	.5
3.2.10	Establish Centaur/CISS Cooling	.5
3.2.11	Install Mission Unique Hardware	2.0
3.2.12	Connect Spacecraft Interface Test Equip	.75
3.2.13	Centaur Avionics Functional Verification	2.0
3.2.14	Centaur/Spacecraft Separation Interface	.5
3.2.15	Review Test Data	2.0

(Adapted from 25)

SUBTASK 3.3

MOVE SPACECRAFT TO SPIF
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
3.3. 1	Off Load Spacecraft EAGE	.5
3.3. 2	Transport EAGE to SPIF & Clean	.5
3.3. 3	Install EAGE in Integration Cell	3.5
3.3. 4	Install EAGE Cabling in Cell	3.5
3.3. 5	Verify EAGE	.5
3.3. 6	EAGE Closed Loop Test	2.0
3.3. 7	EAGE Self Test	2.0
3.3. 8	Move MAGE to SPIF	.5
3.3. 9	Clean MAGE	.5
3.3.10	Move MAGE into Transfer Aisle	.5
3.3.11	Transport Spacecraft to SPIF	.5
3.3.12	Clean S/C Transporter & Move into SPIF	.5
3.3.13	Move S/C Transporter into Transfer Aisle	.5
3.3.14	Review Data	.5
3.3.15	Remove Spacecraft from S/C Transporter	.5
3.3.16	Remove Transporter from SPIF	.5
3.3.17	Inspect Spacecraft	1.0

SUBTASK 3.4

CENTAUR CARGO ELEMENT MATE & CHECKOUT
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
3.4. 1	Prepare Integration Cell for Spacecraft	.6
3.4. 2	Clean S/C Interface on Centaur	.4
3.4. 3	Install Spacecraft onto Centaur	1.0
3.4. 4	Remove Spacecraft Handling Equipment	.6
3.4. 5	Install & Adjust Cell Platforms	1.25
3.4. 6	Connect Battery Charge	.25
3.4. 7	Secure Cell & Establish Environment	.75
3.4. 8	Remove Spacecraft Covers	1.0
3.4. 9	Connect Spacecraft Cooling	.25
3.4.10	Connect Spacecraft to EAGE	.75
3.4.11	Verify Spacecraft/EAGE Interfaces	.66
3.4.12	Perform Spacecraft Testing	4.33
3.4.13	Power Down & Secure Spacecraft	.5
3.4.14	Review Spacecraft Test Data	1.0

(Adapted from 25)

SUBTASK 3.5

CENTAUR CARGO ELEMENT MAJOR SYSTEMS TEST
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
3.5. 1	Preps for Centaur/Orbiter Interface Tst	.4
3.5. 2	Centaur/Orbiter Interface Tests	.6
3.5. 3	Review Centaur/Orbiter Test Data	1.0
3.5. 4	Prepare for Centaur/SC Interface Tests	1.0
3.5. 5	Centaur/Spacecraft Interface Tests	.5
3.5. 6	Review Centaur/Spacecraft Test Data	.5
3.5. 7	Perform Mission Simulation	1.0
3.5. 8	Review Mission Simulation Test Data	1.0
3.5. 9	Preps for End-to-end Test	.25
3.5.10	End-to-end Systems Test	.75
3.5.11	Review End-to-end Test Data	.75
3.5.12	Secure Spacecraft/Centaur	.25

SUBTASK 3.6

FINAL CENTAUR CARGO ELEMENT PREPARATIONS
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
3.6. 1	Prepare Payload Handling Fixture	.6
3.6. 2	Install & Checkout PHF J-Hooks	1.4
3.6. 3	Prepare MMSE Canister	3.0
3.6. 4	Move MMSE Canister to SPIF	1.0
3.6. 5	Servise RCS Propellant System	1.0
3.6. 6	Service Spacecraft Propellant System	3.0
3.6. 7	Perform Stray Voltage Checks	1.0
3.6. 8	Install Small Ordinance	.6
3.6. 9	Verify Ordinance Continuity	.4
3.6.10	Install & Verify Batteries	.6
3.6.11	Disconnect Centaur Cargo Element	.4
3.6.12	Clean & Inspect Centaur Cargo Element	.5
3.6.13	Complete CCE Move Preparations	.5
3.6.14	Centaur Cargo Element Data Review	1.0
3.6.15	Open Integration Cell	1.0
3.6.16	Position PHF & Transfer Pressure System	.3
3.6.17	Transfer CCA to PHF	.7
3.6.18	Transfer CCA to MMSE Canister	1.0
3.6.19	Move MMSE Canister out of SPIF	.5
3.6.20	Move MMSE Canister to LC-39	.5

(Adapted from 25)

SUBTASK 4.1

LAUNCH COMPLEX 39 PREPARATIONS
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
4.1. 1	Clean Payload Changeout Room	7.5
4.1. 2	Secure Payload Changeout Room	.25
4.1. 3	Configure PGHM for Centaur	1.25
4.1. 4	Install Centaur GSE in PCR	.75
4.1. 5	Install Spacecraft GSE IN PCR	1.25
4.1. 6	Position PCR Platforms	.25
4.1. 7	Verify PCR Interface Cables	.75

SUBTASK 4.2

CENTAUR CARGO ELEMENT CHECKOUT
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
4.2. 1	Raise MMSE Canister to RSS Level	.15
4.2. 2	Transfer Centaur/Spacecraft to PGHM	.5
4.2. 3	Secure RSS/Centaur Cargo Element	.2
4.2. 4	Lower & Remove MMSE Canister	.15
4.2. 5	Connect Centaur Interfaces in RSS	.25
4.2. 6	Connect Spacecraft Interfaces in RSS	.25
4.2. 7	Conduct Spacecraft Tests	.25
4.2. 8	Secure Centaur Cargo Element	.2
4.2. 9	Review Spacecraft Test Data	.25
4.2.10	Shuttle Rollout to LC-39	.5
4.2.11	Launch Pad Validation	1.5
4.2.12	Preparations for TCDT	.5
4.2.13	Terminal Countdown Demonstration Test	.25
4.2.14	Secure from TCDT	.25

(Adapted from 25)

SUBTASK 4.3

INSTALLATION IN ORBITER & CHECKOUT
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
4.3. 1	Open Orbiter Payload Bay Doors	.5
4.3. 2	Install CCE in Orbiter Payload Bay	.66
4.3. 3	Install Access Platforms	.25
4.3. 4	Install CISS/SMCH Interfaces	.33
4.3. 5	Install Propellant Dump Lines	.33
4.3. 6	Install LH2 Propellant Lines	.33
4.3. 7	Interface Verification Test (Part 1)	.33
4.3. 8	Leak Check Propellant Lines	.66
4.3. 9	Insulation Foam & Closeout	.66
4.3.10	Interface Verification Test (Part 2)	.66
4.3.11	Centaur End-to-end Verification Test	.66

SUBTASK 4.4

CENTAUR CARGO ELEMENT PRELAUNCH CLOSEOUT
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
4.4. 1	Secure Centaur Cargo Element	.33
4.4. 2	Secure Orbiter	.5
4.4. 3	Load OMS Propellant	1.25
4.4. 4	Load APU Propellant	.66
4.4. 5	Activate CCE/Orbiter Electrical Systems	.25
4.4. 6	Clear Pad/Install Ordnance	.2
4.4. 7	Ordnance Resistance Checks	.2
4.4. 8	Ordnance Closeout	.6
4.4. 9	Final Spacecraft Checks	.33
4.4.10	Load Orbiter Mass Memory Data	.66
4.4.11	Review Spacecraft Data	.25
4.4.12	Orbiter Fuel Cell Closeout	.66
4.4.13	Orbiter Crew Cabin Closeout	.66
4.4.14	Install CISS Flight Batteries	.33
4.4.15	Remove Nonflight Items	.25
4.4.16	Review Centaur Data	.33
4.4.17	Final Centaur Cargo Element Inspection	.33

(Adapted from 25)

SUBTASK 4.5

LAUNCH COUNTDOWN
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
4.5. 1	Connect Ordnance	.33
4.5. 2	Centaur/Spacecraft Stray Voltage Checks	.25
4.5. 3	Check Centaur/Spacecraft Ordnance	.15
4.5. 4	Propellant Load Preparations	.4
4.5. 5	Payload Bay Closeout	.9
4.5. 6	Power Up Centaur & Verify Status	.2
4.5. 7	Disconnect CCE & Close Payload Doors	.33
4.5. 8	CISS/Centaur GHe Pressure to 2000 PSI	1.75
4.5. 9	Prepare LH2 & LO2 Tanking Skids	.15
4.5.10	LH2 & LO2 Cryogenic Propellant Loading	.33
4.5.11	IMG Calibration	.33
4.5.12	CISS/Centaur GHe Pressure to 4000 PSI	.35
4.5.13	IMG Alignment	.25
4.5.14	LO2/LH2 Topoff & Replenishment	.25

(Adapted from 25)

SUBTASK 5.1

EXERCISES & SIMULATIONS
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
5.1. 1	CPOCC In-House Exercise #1	.25
5.1. 2	CPOCC In-House Exercise #2	.25
5.1. 3	CPOCC In-House Exercise #3	.25
5.1. 4	CPOCC/Spacecraft POCC Exercise #1	1.0
5.1. 5	CPOCC/Spacecraft POCC Exercise #2	1.0
5.1. 6	Joint Integrated Simulation #1	1.0
5.1. 7	Joint Integrated Simulation #2	2.0
5.1. 8	Launch Readiness Demonstration #1	1.0
5.1. 9	Joint Integrated Simulation #3	2.0
5.1.10	Launch Readiness Demonstration #2	1.0
5.1.11	Joint Integrated Simulation #4	1.0

(Adapted from 10, 14, 21, 22, 23, 34)

SUBTASK 5.2

ASCENT
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
5.2. 1	Orbiter Ascent Phase	.07

(Adapted from 13:3-92)

SUBTASK 5.3

CENTAUR CARGO ELEMENT CHECKOUT & DEPLOYMENT ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
5.3. 1	Monitor Centaur/CISS Systems	.04
5.3. 2	Centaur/CISS Systems Checkout	.2
5.3. 3	Spacecraft Systems Checkout	.2
5.3. 4	Deploy Centaur/Spacecraft	.02

SUBTASK 5.4

CENTAUR FLIGHT ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
5.4. 1	Maneuver Orbiter away from Centaur	.032
5.4. 2	Centaur Main Engine Start #1	.0055
5.4. 3	Hohmann Transfer Orbit	.2167
5.4. 4	Centaur Main Engine Start #2	.0014
5.4. 5	Separate Spacecraft from Centaur	.0055
5.4. 6	Centaur Orbit Deflection/Blowdown	.021

(Adapted from 13:3-92,3-93)

SUBTASK 6.1

MONITOR CISS ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
6.1. 1	Put CISS Systems into Safe Condition	.1
6.1. 2	Monitor CISS Systems	6.0
6.1. 3	Prepare CISS for Orbiter Re-entry	.5
6.1. 4	Monitor CISS during Re-entry	.04

AD-A167 123 AN ANALYSIS OF THE CENTAUR GROUND PROCESSING SYSTEM AT THE KENNEDY SPACE..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH J T BROCK DEC 85 3/3

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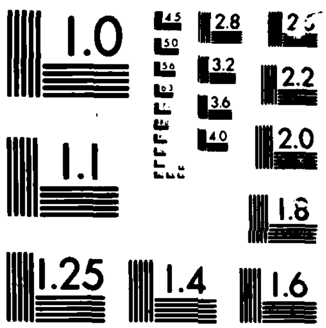

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SUBTASK 6.2

REMOVE CISS
ACTIVITIES & ESTIMATED COMPLETION TIMES

ACT #	ACTIVITY	m
6.2. 1	Orbiter Post-landing Checks	.35
6.2. 2	Move Orbiter to OPF	.2
6.2. 3	Open Orbiter Payload Doors	1.0
6.2. 4	Disconnect CISS Electrical Interfaces	1.0
6.2. 5	Disconnect CISS Fluid Interfaces	2.0
6.2. 6	Disconnect CISS Structural Interfaces	1.0
6.2. 7	Attach CISS Lifting Sling	.5
6.2. 8	Lift CISS from Orbiter	.5
6.2. 9	Place CISS on TTF	.25

(Adapted from 13:3-84)

SUBTASK 6.3

CISS REFURBISHMENT
ACTIVITIES & ESTIMATED COMPLETION TIMES

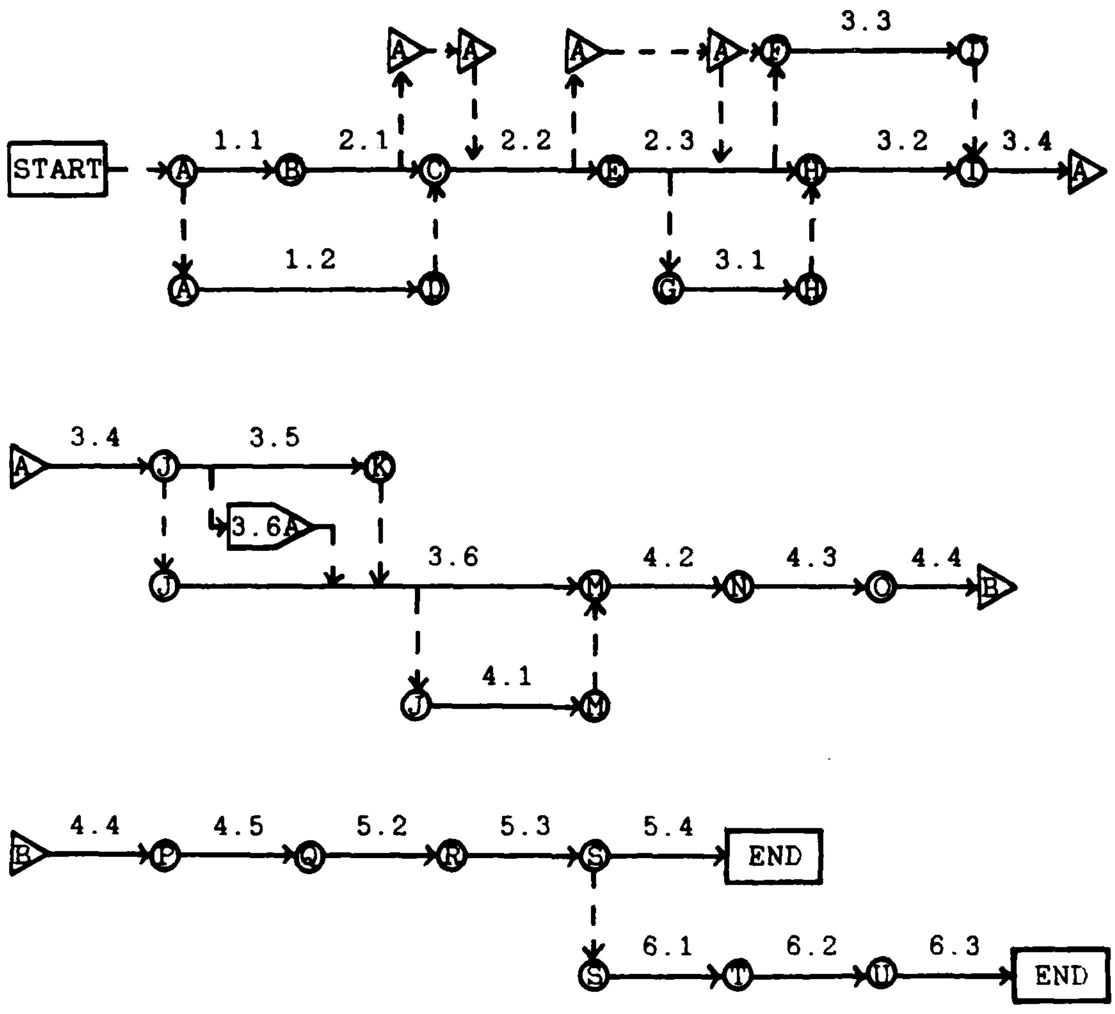
ACT #	ACTIVITY	m
6.3. 1	Transport TTF to Hangar J	1
6.3. 2	Remove CISS from TTF	.5
6.3. 3	CISS Mechanical Receiving/Inspection	6
6.3. 4	CISS Electrical Receiving/Inspection	6
6.3. 5	Inspect Fluid Line Insulation	4
6.3. 6	Preparations for Standard Turn On	3
6.3. 7	Standard Turn On	1
6.3. 8	CISS Transducer Ringout (Power Off)	2
6.3. 9	CISS Transducer Ringout (Power On)	3
6.3.10	Avionics Subsystem Functional Check	3
6.3.11	CISS Vent System Checkout	4
6.3.12	Helium System Check	2
6.3.13	PAVCS Checkout	4
6.3.14	Purge System Check	2

(Adapted from 16)

ADDENDIX B:

PERT NETWORK GRAPHS OF THE S/CGPS

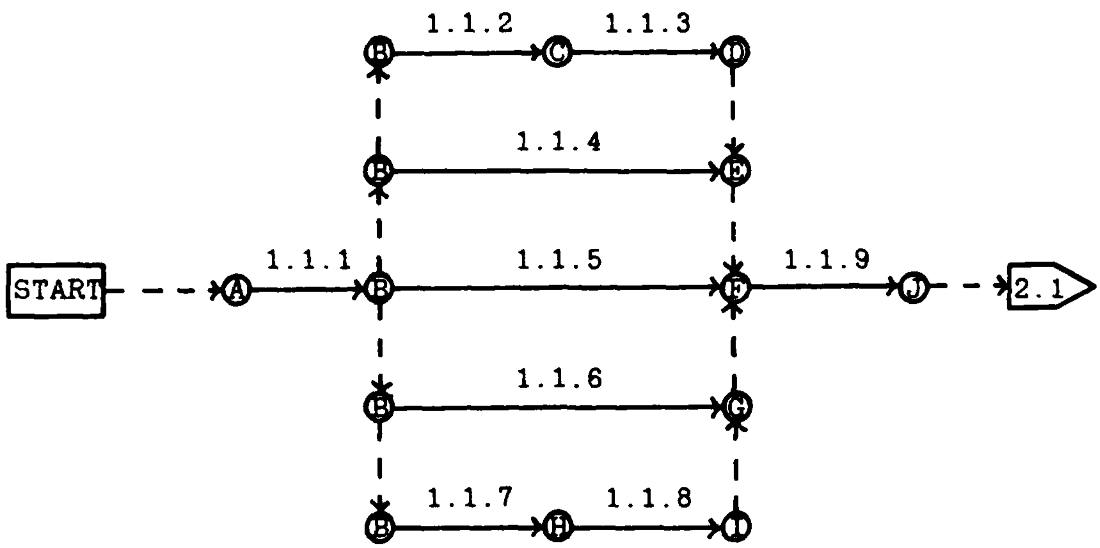
MASTER GRAPH OF ALL S/CGPS SUBTASKS



Note: This graph does not include Subtask 5.1, EXERCISES & SIMULATIONS. See the specific graph for details.

SUBTASK 1.1

CISS @ HANGAR J

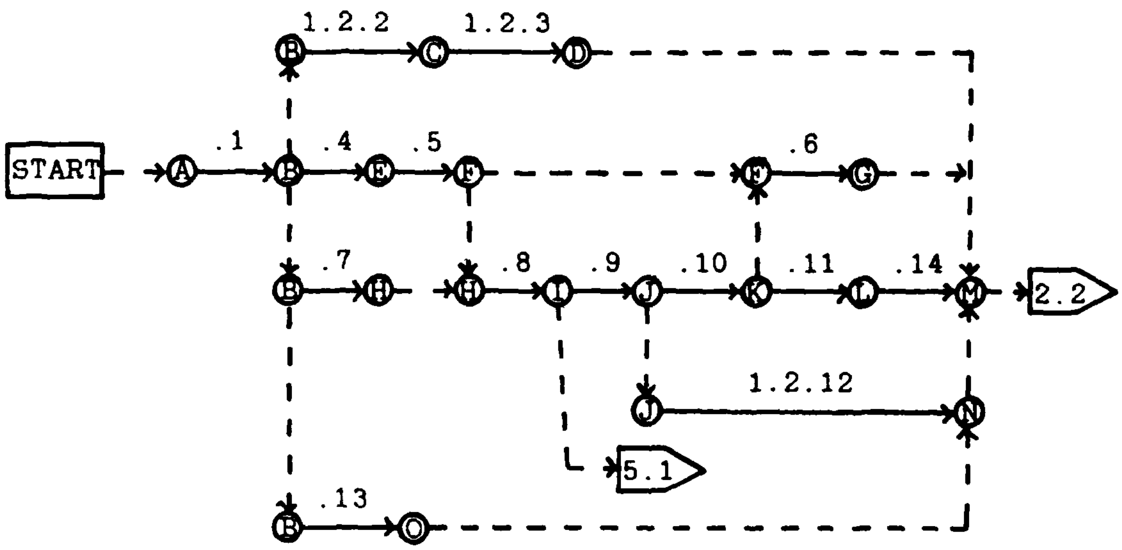


(Adapted from 16)

<u>SUBTASK 1.2</u>

CENTAUR @ HANGAR J

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 2.1.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 2.1.4

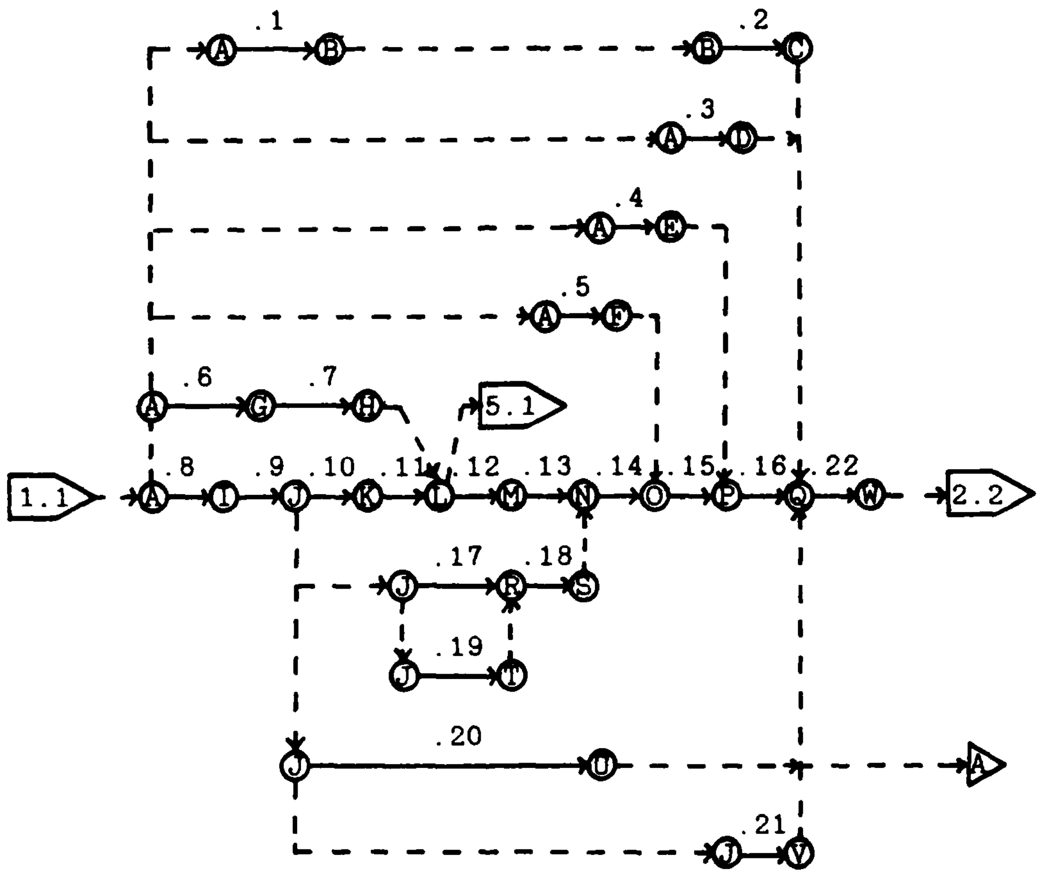


(Adapted from 16)

SUBTASK 2.1

CISS @ CX 36A

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 2.1.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 2.1.4

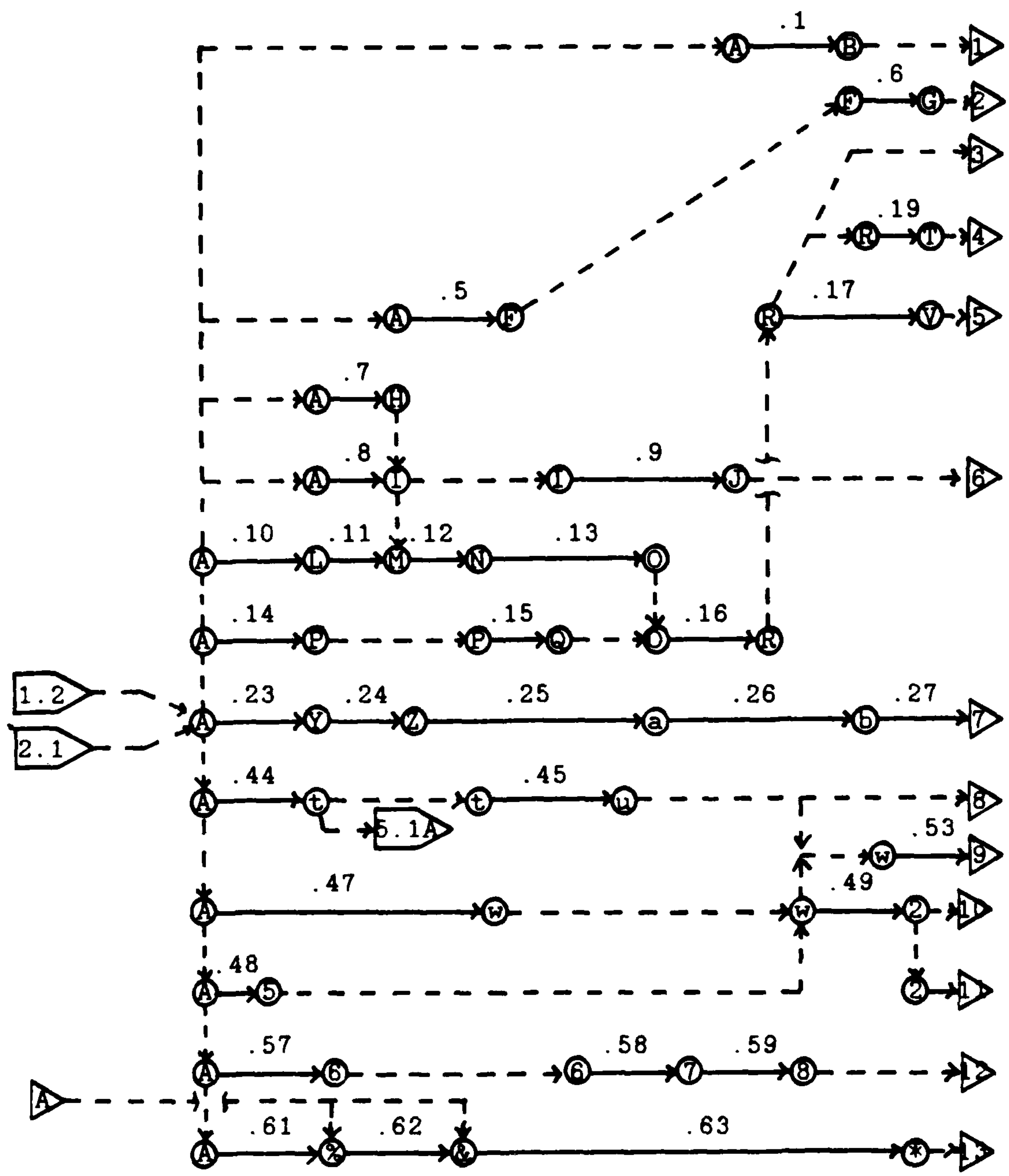


(Adapted from 16)

<u>SUBTASK 2.2</u>

CENTAUR/CISS @ CX 36A (PART I)

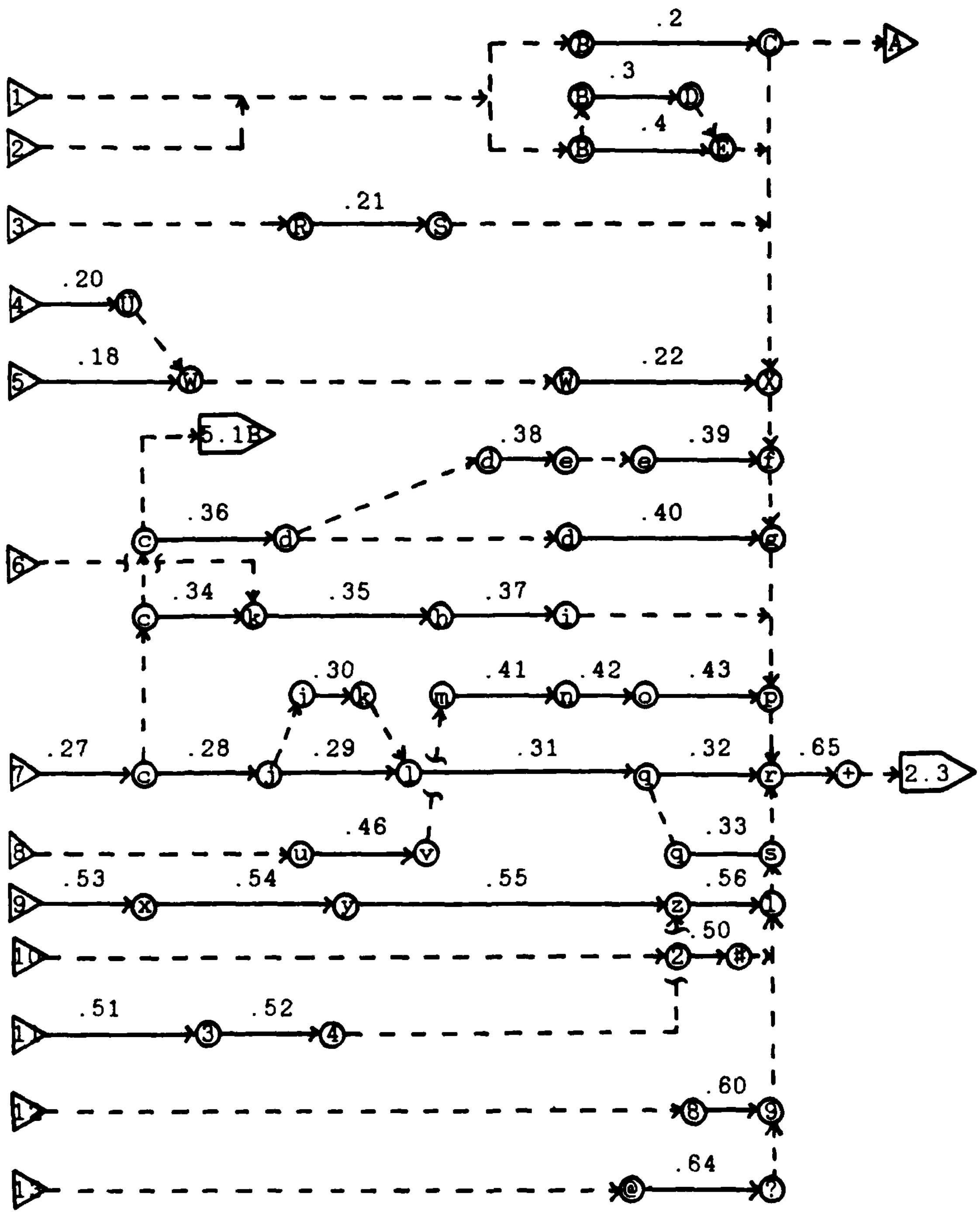
NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 2.2.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 2.2.4



SUBTASK 2.2 (CONT)

CENTAUR/CISS @ CX 36A (PART I)

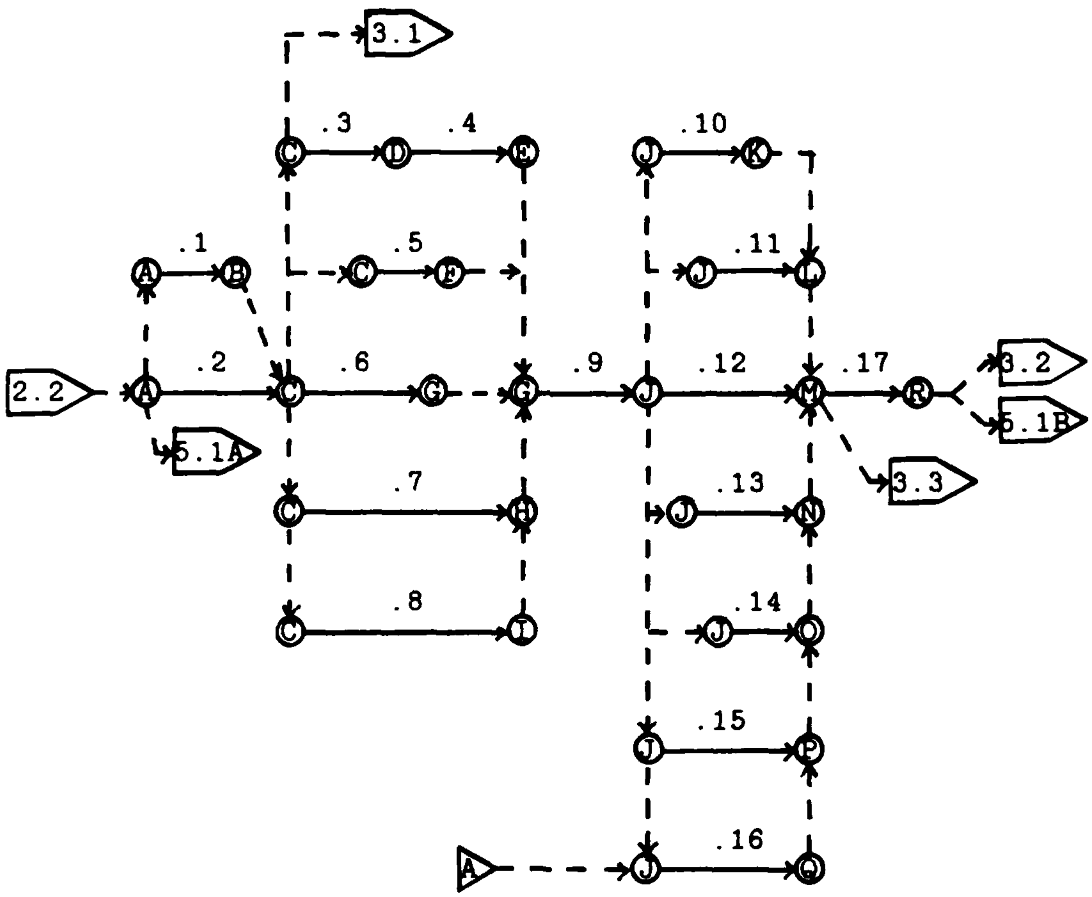
NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 2.2.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 2.2.4



SUBTASK 2.3

CENTAUR/CISS @ CX 36A (PART II)

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 2.3.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 2.3.4

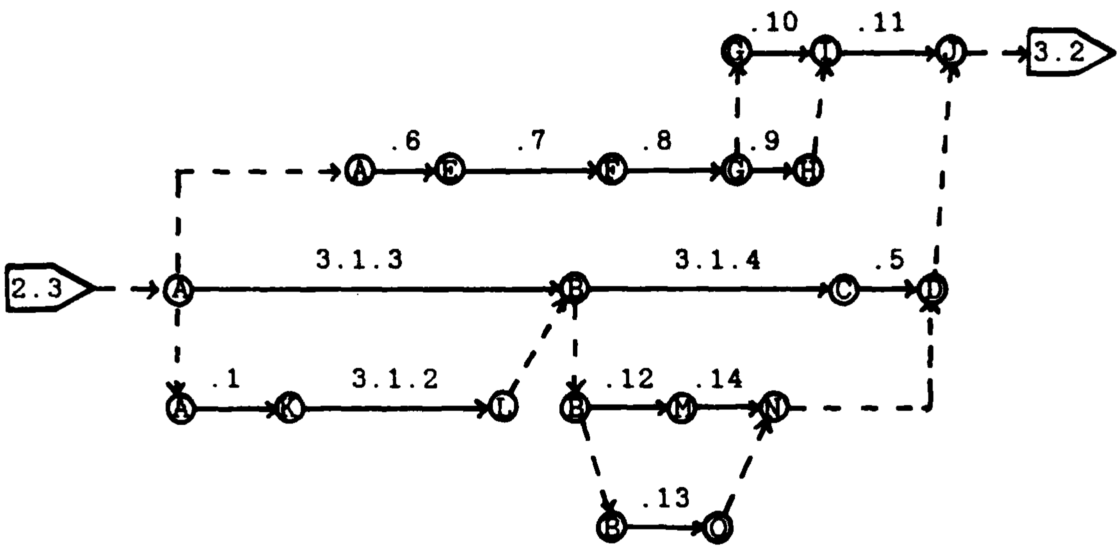


(Adapted from 16)

SUBTASK 3.1

SPIF PREPARATIONS

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 3.1.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 3.1.4

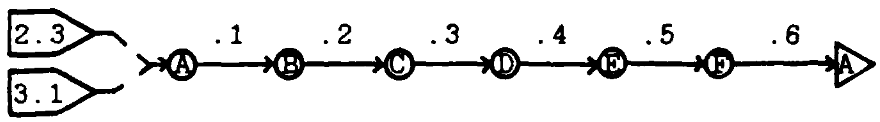


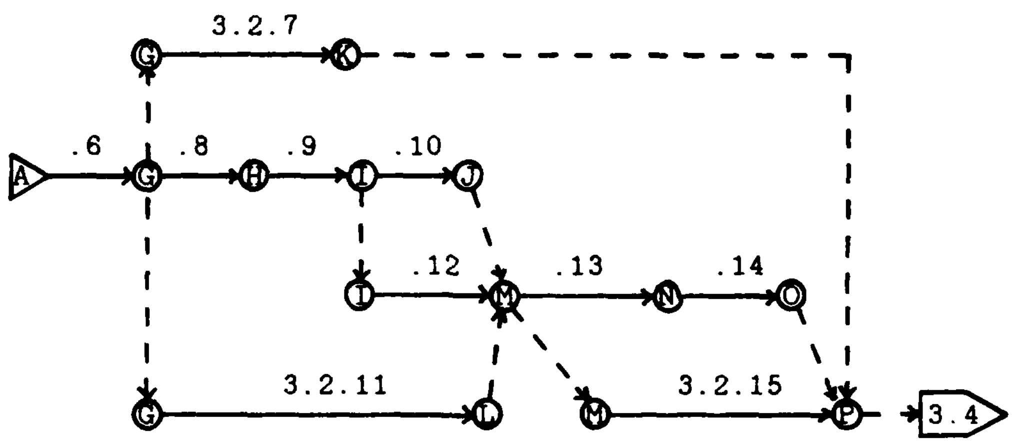
(Adapted from 25)

SUBTASK 3.2

CENTAUR CISS ASSEMBLY CHECKOUT

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 3.2.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 3.2.4



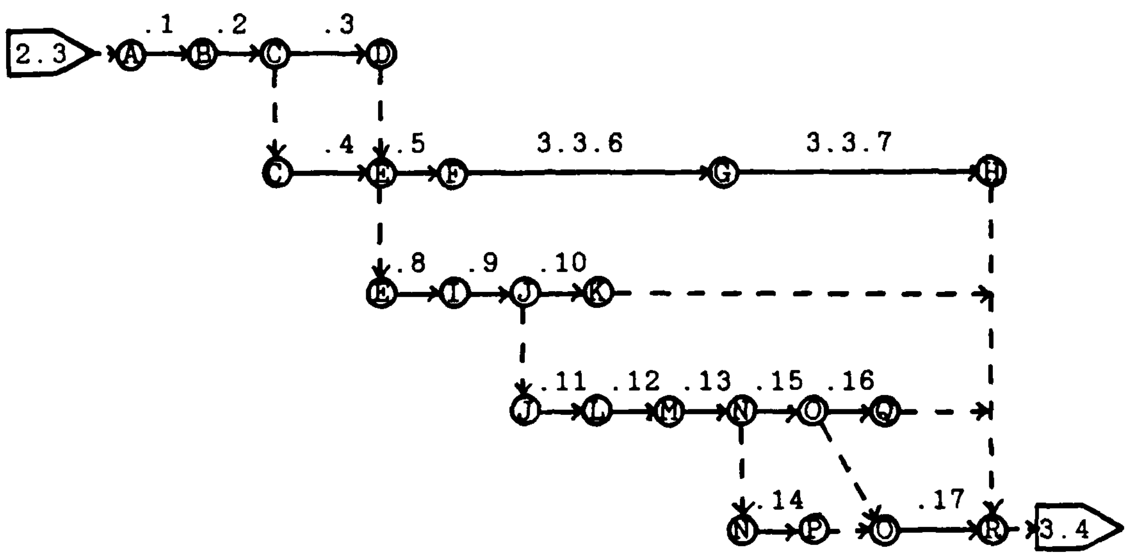


(Adapted from 25)

SUBTASK 3.3

MOVE SPACECRAFT TO SPIF

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 3.3.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 3.3.4

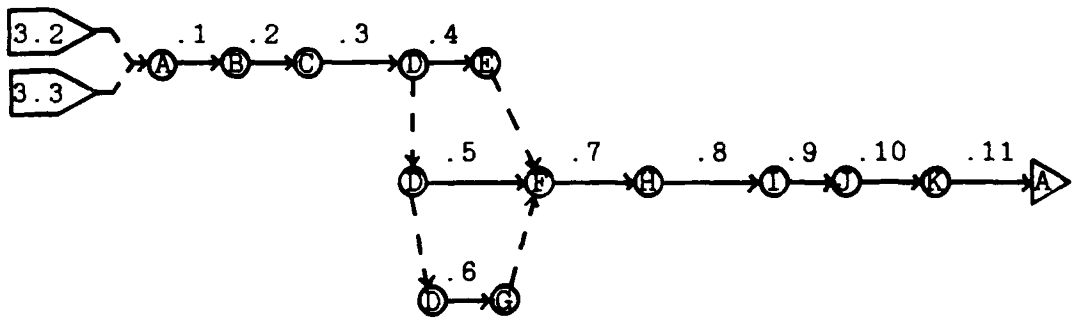


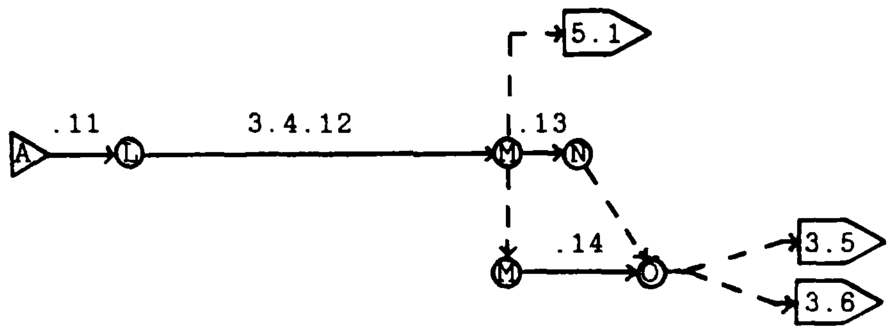
(Adapted from 25)

<u>SUBTASK 3.4</u>

CENTAUR CARGO ELEMENT MATE & CHECKOUT

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 3.4.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 3.4.4

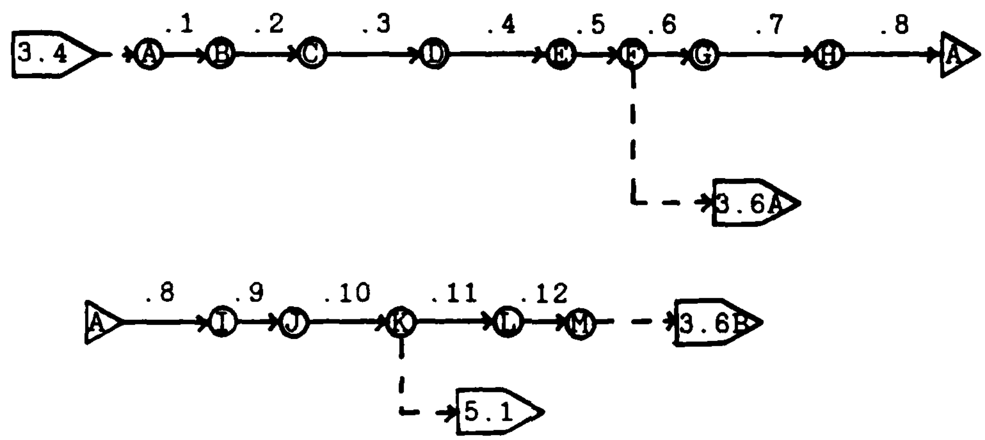




SUBTASK 3.5

CENTAUR CARGO ELEMENT MAJOR SYSTEMS TEST

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 3.5.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 3.5.4

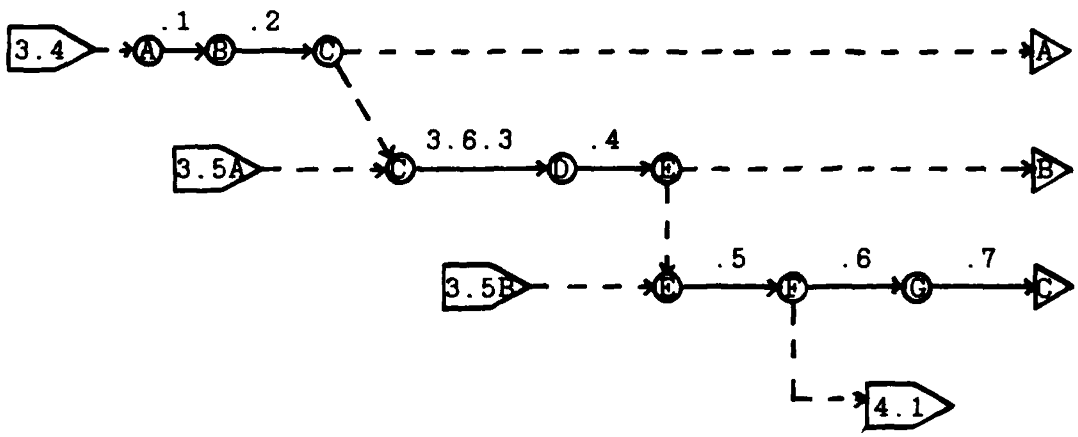


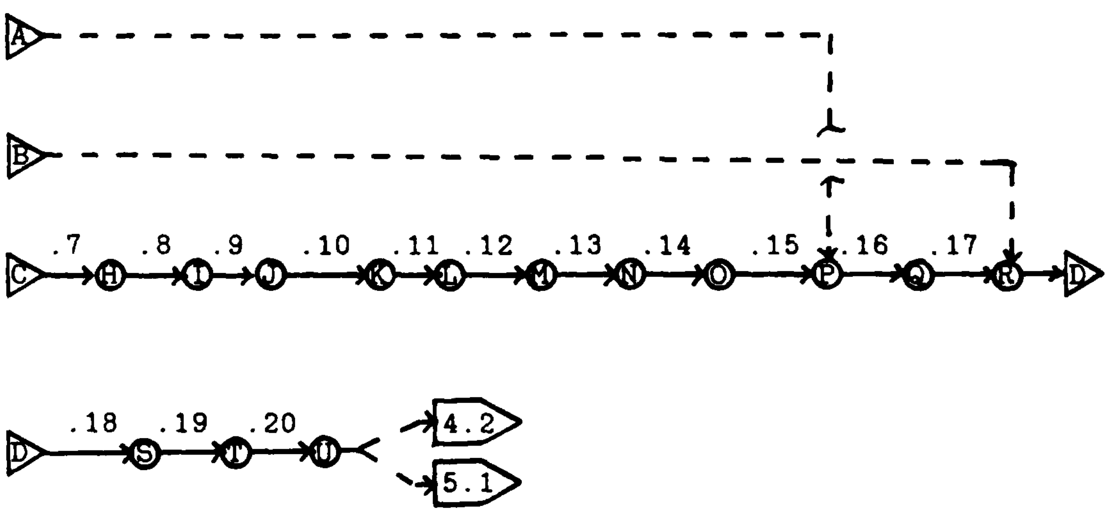
(Adapted from 25)

SUBTASK 3.6

FINAL CENTAUR CARGO ELEMENT PREPARATIONS

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 3.6.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 3.6.4



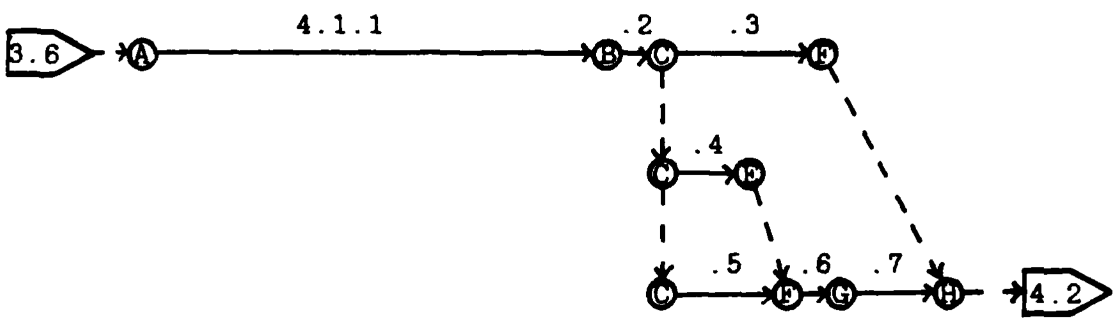


(Adapted from 25)

SUBTASK 4.1

LAUNCH COMPLEX 39 PREPARATIONS

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 4.1.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 4.1.4

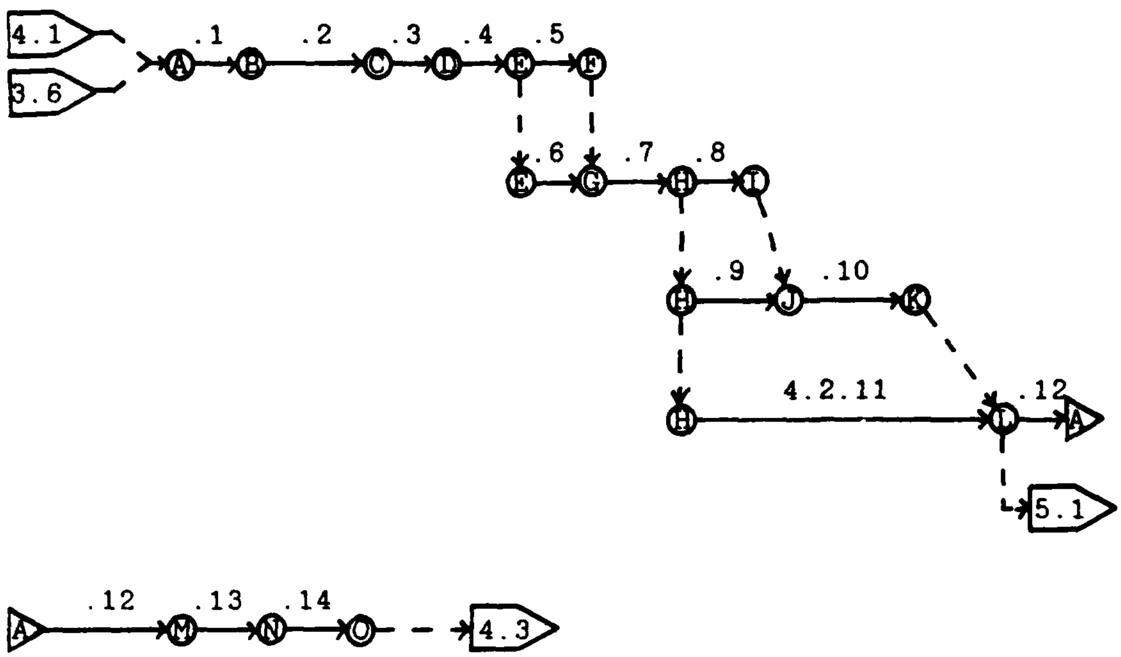


(Adapted from 25)

SUBTASK 4.2

CENTAUR CARGO ELEMENT CHECKOUT

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 4.2.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 4.2.4

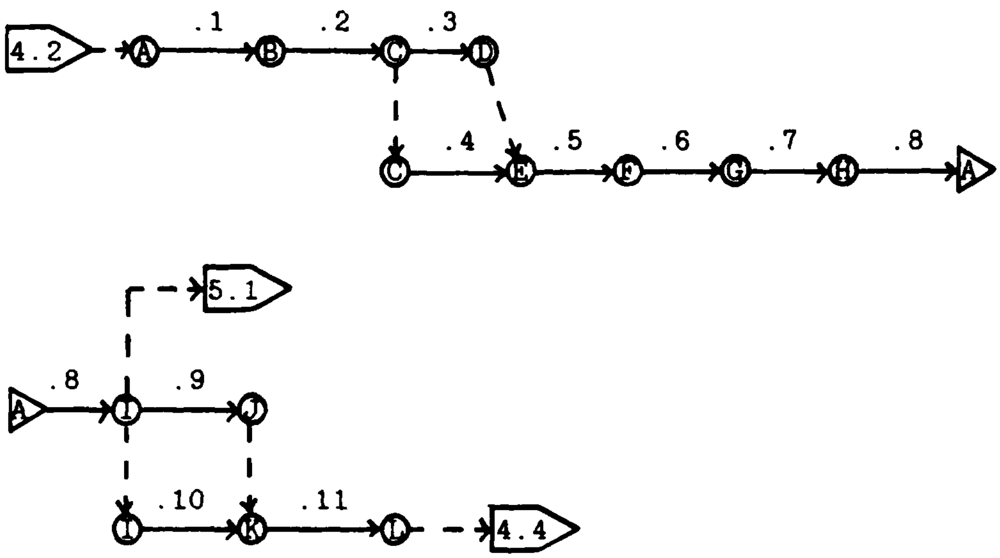


(Adapted from 25)

SUBTASK 4.3

ORBITER INSTALLATION & CHECKOUT

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 4.3.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 4.3.4

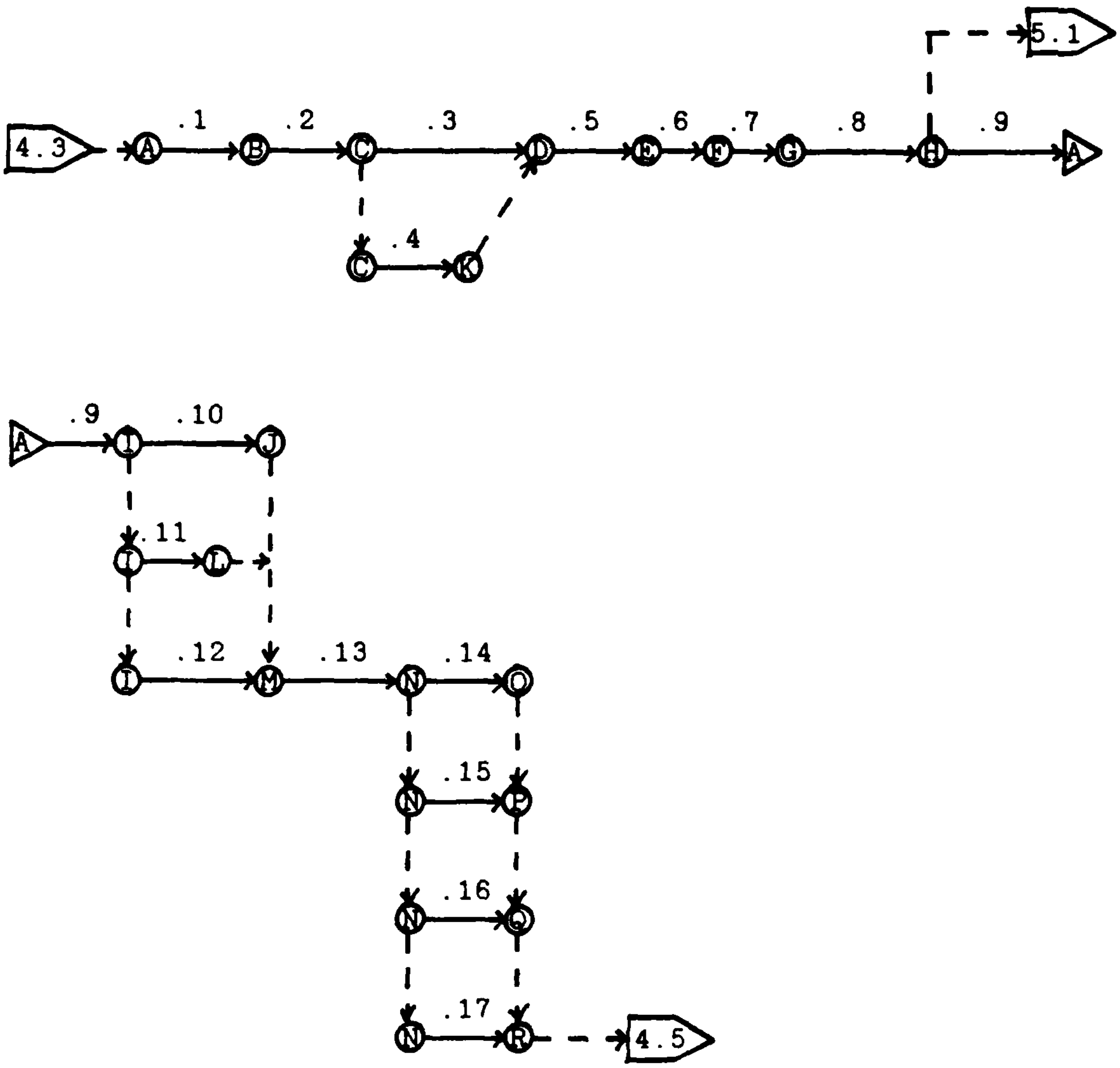


(Adapted from 25)

SUBTASK 4.4

CENTAUR CARGO ELEMENT PRELAUNCH CLOSEOUT

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 4.4.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 4.4.4

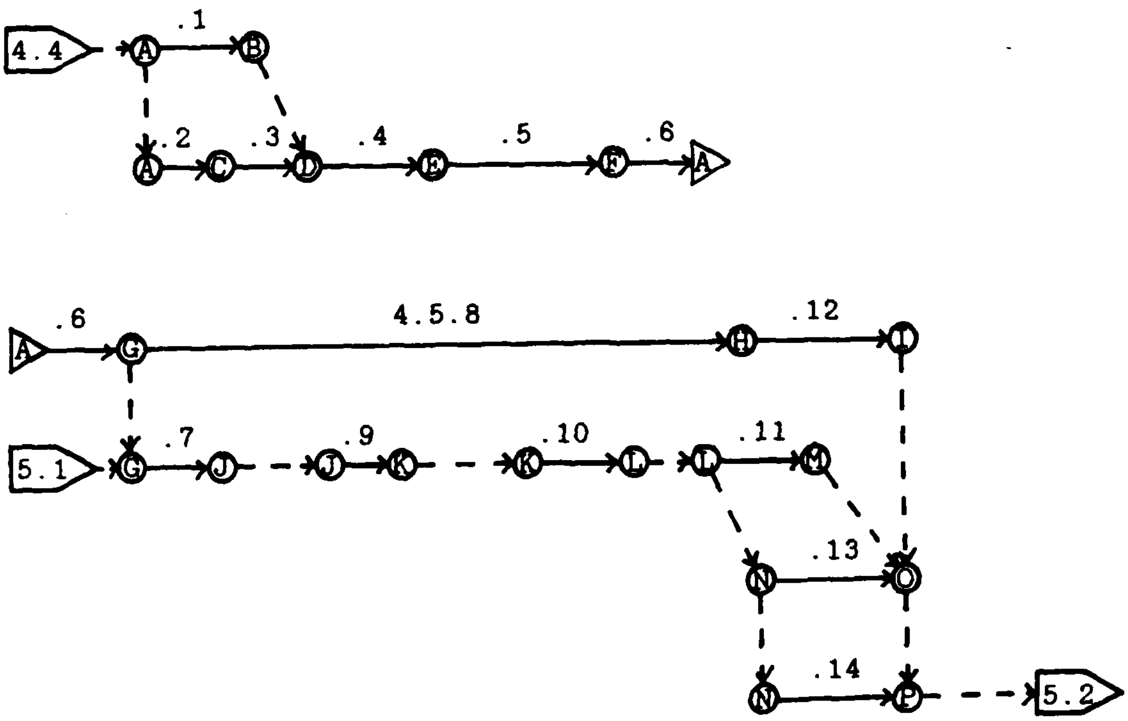


(Adapted from 25)

SUBTASK 4.5

LAUNCH COUNTDOWN

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 4.5.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 4.5.4

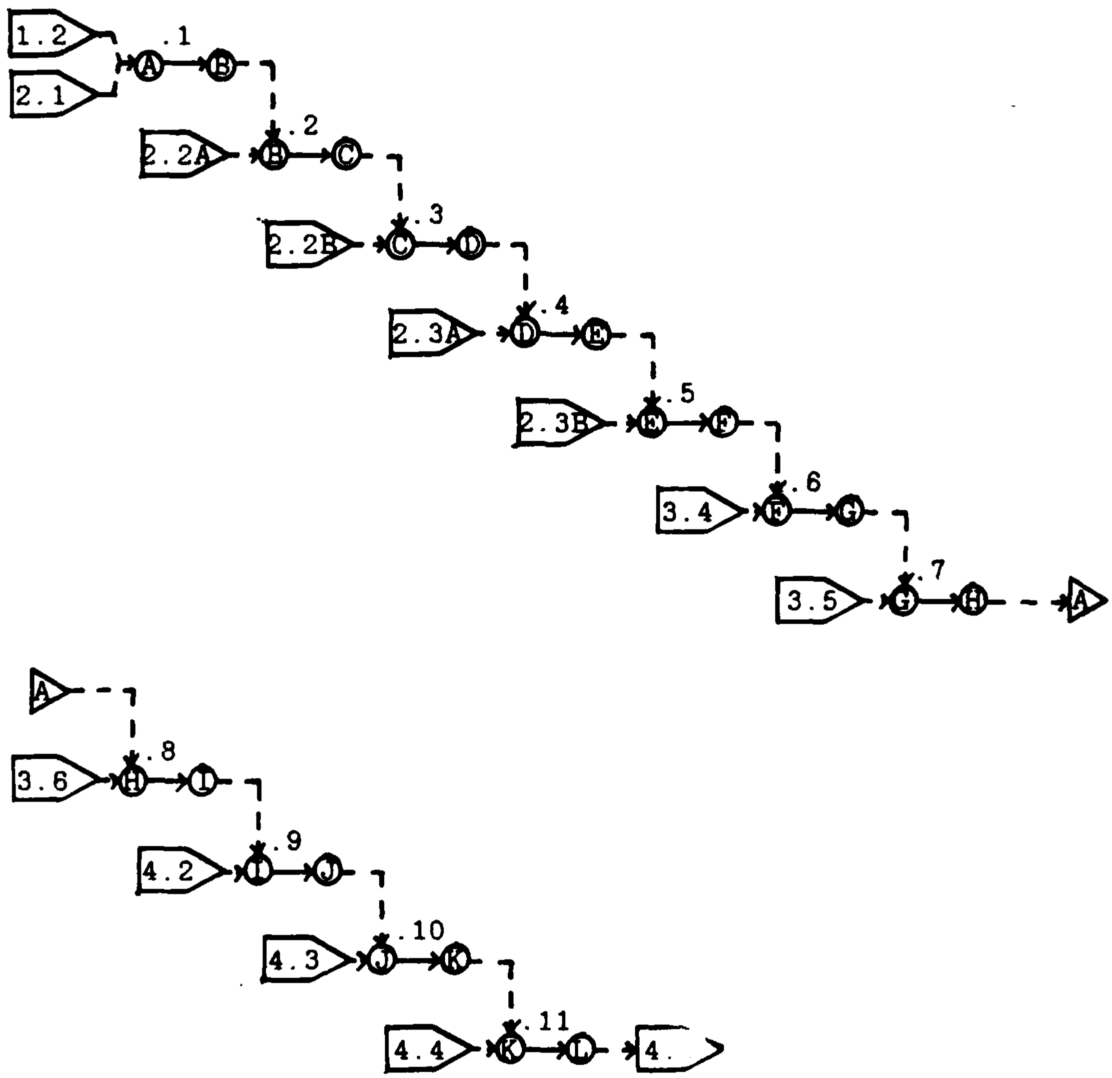


(Adapted from 25)

SUBTASK 5.1

EXERCISES & SIMULATIONS

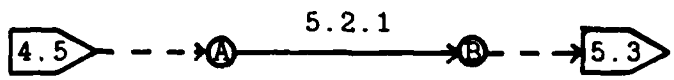
NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 5.1.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 5.1.4



(Adapted from 10, 14, 21, 22, 23, 34)

SUBTASK 5.2

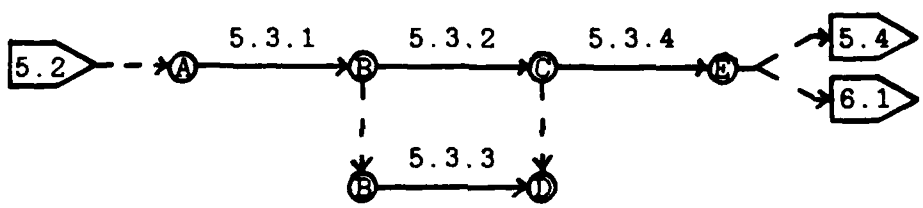
ASCENT



(Adapted from 13:3-92)

SUBTASK 5.3

CENTAUR CARGO ELEMENT CHECKOUT & DEPLOYMENT

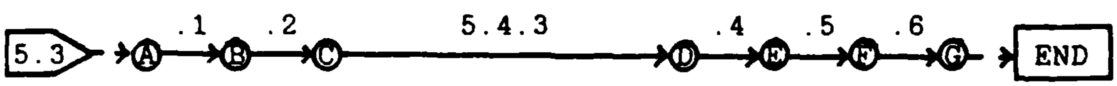


(Adapted from 13:3-92,3-93)

SUBTASK 5.4

CENTAUR FLIGHT

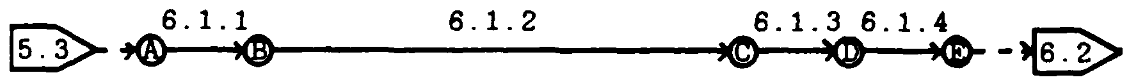
NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 5.4.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 5.4.4



(Adapted from 13:3-94,3-95)

SUBTASK 6.1

MONITOR CISS

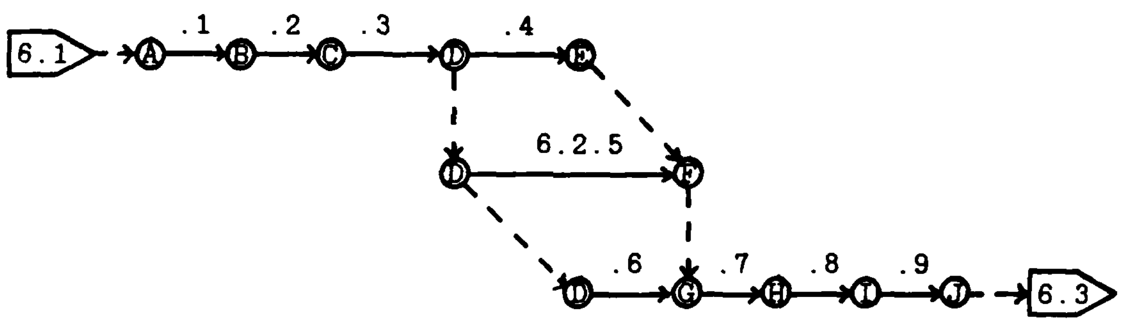


(Adapted from 13:3-90)

SUBTASK 6.2

REMOVE CISS

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 6.2.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 6.2.4

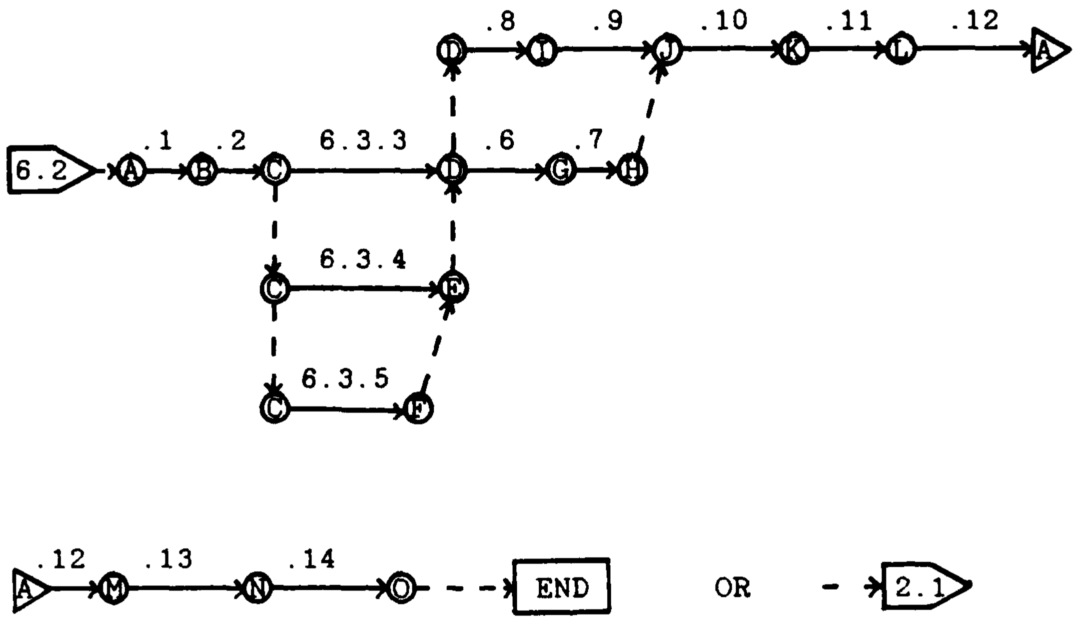


(Adapted from 13:3-84)

SUBTASK 6.3

CISS REFURBISHMENT

NOTE: ALL ACTIVITIES OF THIS SUBTASK ARE NUMBERED: 6.3.XX
WHERE .XX ARE THE NUMBERS BELOW, I.E. 6.3.4



ADDENDIX C:

PERT DISTRIBUTION PARAMETERS FOR THE S/CGPS

SUBTASK 1.1

CISS @ HANGAR J

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
1.1. 1	.5	1	6	1.75	.92	.84
1.1. 2	1.5	3	18	5.25	2.75	7.56
1.1. 3	.5	1	6	1.75	.92	.84
1.1. 4	3.0	6	36	10.5	5.5	30.25
1.1. 5	3.0	6	36	10.5	5.5	30.25
1.1. 6	3.0	6	36	10.5	5.5	30.25
1.1. 7	1.0	2	12	3.5	1.83	3.36
1.1. 8	1.5	3	18	5.25	2.75	7.56
1.1. 9	.5	1	6	1.75	.92	.84

SUBTASK 1.2

CENTAUR @ HANGAR J

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
1.2. 1	.5	1	6	1.75	.92	.84
1.2. 2	5.5	11	66	19.25	10.08	101.67
1.2. 3	1.5	3	18	5.25	2.75	7.56
1.2. 4	2.0	4	24	7.00	3.67	13.44
1.2. 5	2.0	4	24	7.00	3.67	13.44
1.2. 6	1.0	2	12	3.5	1.83	3.36
1.2. 7	2.0	4	24	7.00	3.67	13.44
1.2. 8	1.5	3	18	5.25	2.75	7.56
1.2. 9	1.5	3	18	5.25	2.75	7.56
1.2.10	1.0	2	12	3.5	1.83	3.36
1.2.11	1.0	2	12	3.5	1.83	3.36
1.2.12	3.0	6	36	10.5	5.5	30.25
1.2.13	1.0	2	12	3.5	1.83	3.36
1.2.14	.5	1	6	1.75	.92	.84

SUBTASK 2.1

CISS @ CX 36A

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
2.1. 1	2.0	4	24	7.00	3.67	13.44
2.1. 2	1.5	3	18	5.25	2.75	7.56
2.1. 3	.5	1	6	1.75	.92	.84
2.1. 4	.5	1	6	1.75	.92	.84
2.1. 5	1.5	3	18	5.25	2.75	7.56
2.1. 6	1.0	2	12	3.5	1.83	3.36
2.1. 7	2.0	4	24	7.00	3.67	13.44
2.1. 8	1.0	2	12	3.5	1.83	3.36
2.1. 9	.5	1	6	1.75	.92	.84
2.1.10	1.5	3	18	5.25	2.75	7.56
2.1.11	1.0	2	12	3.5	1.83	3.36
2.1.12	2.5	5	30	8.75	4.58	21.01
2.1.13	2.0	4	24	7.00	3.67	13.44
2.1.14	1.0	2	12	3.5	1.83	3.36
2.1.15	1.0	2	12	3.5	1.83	3.36
2.1.16	1.0	2	12	3.5	1.83	3.36
2.1.17	2.0	4	24	7.00	3.67	13.44
2.1.18	1.0	2	12	3.5	1.83	3.36
2.1.19	1.0	2	12	3.5	1.83	3.36
2.1.20	5.0	10	60	17.5	9.17	84.03
2.1.21	.5	1	6	1.75	.92	.84
2.1.22	.5	1	6	1.75	.92	.84

SUBTASK 2.2

CENTAUR/CISS @ CX 36A (PART I)

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
2.2. 1	1.0	2	12	3.5	1.83	3.36
2.2. 2	1.5	3	18	5.25	2.75	7.56
2.2. 3	.5	1	6	1.75	.92	.84
2.2. 4	1.0	2	12	3.5	1.83	3.36
2.2. 5	1.0	2	12	3.5	1.83	3.36
2.2. 6	1.0	2	12	3.5	1.83	3.36
2.2. 7	1.0	2	12	3.5	1.83	3.36
2.2. 8	1.0	2	12	3.5	1.83	3.36
2.2. 9	2.5	5	30	8.75	4.58	21.01
2.2.10	1.0	2	12	3.5	1.83	3.36
2.2.11	1.0	2	12	3.5	1.83	3.36
2.2.12	2.5	5	30	8.75	4.58	21.01

SUBTASK 2.2 (CONT)

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
2.2.13	1.0	2	12	3.5	1.83	3.36
2.2.14	1.0	2	12	3.5	1.83	3.36
2.2.15	.5	1	6	1.75	.92	.84
2.2.16	.5	1	6	1.75	.92	.84
2.2.17	1.5	3	18	5.25	2.75	7.56
2.2.18	2.5	5	30	8.75	4.58	21.01
2.2.19	.5	1	6	1.75	.92	.84
2.2.20	1.0	2	12	3.5	1.83	3.36
2.2.21	1.5	3	18	5.25	2.75	7.56
2.2.22	2.0	4	24	7.00	3.67	13.44
2.2.23	1.0	2	12	3.5	1.83	3.36
2.2.24	.5	1	6	1.75	.92	.84
2.2.25	4.0	8	48	14.0	7.33	53.78
2.2.26	1.5	3	18	5.25	2.75	7.56
2.2.27	1.5	3	18	5.25	2.75	7.56
2.2.28	1.5	3	18	5.25	2.75	7.56
2.2.29	1.5	3	18	5.25	2.75	7.56
2.2.30	.5	1	6	1.75	.92	.84
2.2.31	2.0	4	24	7.00	3.67	13.44
2.2.32	1.5	3	18	5.25	2.75	7.56
2.2.33	.5	1	6	1.75	.92	.84
2.2.34	1.5	3	18	5.25	2.75	7.56
2.2.35	2.0	4	24	7.00	3.67	13.44
2.2.36	2.0	4	24	7.00	3.67	13.44
2.2.37	1.0	2	12	3.5	1.83	3.36
2.2.38	.5	1	6	1.75	.92	.84
2.2.39	1.5	3	18	5.25	2.75	7.56
2.2.40	2.0	4	24	7.00	3.67	13.44
2.2.41	1.0	2	12	3.5	1.83	3.36
2.2.42	.5	1	6	1.75	.92	.84
2.2.43	1.5	3	18	5.25	2.75	7.56
2.2.44	1.0	2	12	3.5	1.83	3.36
2.2.45	1.0	2	12	3.5	1.83	3.36
2.2.46	1.5	3	18	5.25	2.75	7.56
2.2.47	1.5	3	18	5.25	2.75	7.56
2.2.48	.5	1	6	1.75	.92	.84
2.2.49	2.0	4	24	7.00	3.67	13.44
2.2.50	.5	1	6	1.75	.92	.84
2.2.51	1.5	3	18	5.25	2.75	7.56
2.2.52	1.5	3	18	5.25	2.75	7.56
2.2.53	2.0	4	24	7.00	3.67	13.44
2.2.54	2.5	5	30	8.75	4.58	21.01
2.2.55	2.5	5	30	8.75	4.58	21.01
2.2.56	1.0	2	12	3.5	1.83	3.36
2.2.57	1.0	2	12	3.5	1.83	3.36
2.2.58	1.0	2	12	3.5	1.83	3.36
2.2.59	1.0	2	12	3.5	1.83	3.36
2.2.60	.5	1	6	1.75	.92	.84

SUBTASK 2.2 (CONT)

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
2.2.61	1.0	2	12	3.5	1.83	3.36
2.2.62	1.5	3	18	5.25	2.75	7.56
2.2.63	5.0	10	60	17.5	9.17	84.03
2.2.64	1.5	3	18	5.25	2.75	7.56
2.2.65	.5	1	6	1.75	.92	.84

SUBTASK 2.3

CENTAUR/CISS @ CX 36A (PART II)

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
2.3. 1	1.5	3	18	5.25	2.75	7.56
2.3. 2	2.0	4	24	7.00	3.67	13.44
2.3. 3	1.5	3	18	5.25	2.75	7.56
2.3. 4	.5	1	6	1.75	.92	.84
2.3. 5	.5	1	6	1.75	.92	.84
2.3. 6	1.5	3	18	5.25	2.75	7.56
2.3. 7	2.0	4	24	7.00	3.67	13.44
2.3. 8	2.0	4	24	7.00	3.67	13.44
2.3. 9	.5	1	6	1.75	.92	.84
2.3.10	1.0	2	12	3.5	1.83	3.36
2.3.11	.5	1	6	1.75	.92	.84
2.3.12	1.5	3	18	5.25	2.75	7.56
2.3.13	1.0	2	12	3.5	1.83	3.36
2.3.14	.5	1	6	1.75	.92	.84
2.3.15	1.5	3	18	5.25	2.75	7.56
2.3.16	1.5	3	18	5.25	2.75	7.56
2.3.17	.5	1	6	1.75	.92	.84

SUBTASK 3.1

SPIF PREPARATIONS
ACTIVITIES & ESTIMATED COMPLETI:ON TIMES

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
3.1. 1	.25	.5	3.0	.875	.485	.21
3.1. 2	.75	1.5	9.0	2.625	1.375	1.89
3.1. 3	1.5	3.0	18.0	5.25	2.75	7.56
3.1. 4	1.5	3.0	18.0	5.25	2.75	7.56
3.1. 5	.25	.5	3.0	.875	.485	.21
3.1. 6	.25	.5	3.0	.875	.485	.21
3.1. 7	.75	1.5	9.0	2.625	1.375	1.89
3.1. 8	.5	1.0	6.0	1.75	.917	.84
3.1. 9	.25	.5	3.0	.875	.485	.21
3.1.10	.375	.75	4.5	1.313	.688	.47
3.1.11	.5	1.0	6.0	1.75	.917	.84
3.1.12	.375	.75	4.5	1.313	.688	.47
3.1.13	.375	.75	4.5	1.313	.688	.47
3.1.14	.25	.5	3.0	.875	.485	.21

SUBTASK 3.2

CENTAUR CISS ASSEMBLY CHECKOUT

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
3.1. 1	.25	.5	3.0	.875	.485	.21
3.1. 2	.25	.5	3.0	.875	.485	.21
3.1. 3	.25	.5	3.0	.875	.485	.21
3.1. 4	.25	.5	3.0	.875	.485	.21
3.1. 5	.25	.5	3.0	.875	.485	.21
3.1. 6	.25	.5	3.0	.875	.485	.21
3.2. 7	.375	.75	4.5	1.313	.688	.47
3.2. 8	.5	1.0	6.0	1.75	.917	.84
3.1. 9	.25	.5	3.0	.875	.485	.21
3.1.10	.25	.5	3.0	.875	.485	.21
3.2.11	1.0	2.0	12.0	3.5	1.833	3.36
3.2.12	.375	.75	4.5	1.313	.688	.47
3.2.13	1.0	2.0	12.0	3.5	1.833	3.36
3.1.14	.25	.5	3.0	.875	.485	.21
3.2.15	1.0	2.0	12.0	3.5	1.833	3.36

SUBTASK 3.3

MOVE SPACECRAFT TO SPIF

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
3.3. 1	.25	.5	3.0	.875	.485	.21
3.3. 2	.25	.5	3.0	.875	.485	.21
3.3. 3	1.75	3.5	21.0	6.125	3.208	10.29
3.3. 4	1.75	3.5	21.0	6.125	3.208	10.29
3.3. 5	.25	.5	3.0	.875	.485	.21
3.3. 6	1.0	2.0	12.0	3.5	1.833	3.36
3.3. 7	1.0	2.0	12.0	3.5	1.833	3.36
3.3. 8	.25	.5	3.0	.875	.485	.21
3.3. 9	.25	.5	3.0	.875	.485	.21
3.3.10	.25	.5	3.0	.875	.485	.21
3.3.11	.25	.5	3.0	.875	.485	.21
3.3.12	.25	.5	3.0	.875	.485	.21
3.3.13	.25	.5	3.0	.875	.485	.21
3.3.14	.25	.5	3.0	.875	.485	.21
3.3.15	.25	.5	3.0	.875	.485	.21
3.3.16	.25	.5	3.0	.875	.485	.21
3.3.17	.5	1.0	6.0	1.75	.917	.84

SUBTASK 3.4

CENTAUR CARGO ELEMENT MATE & CHECKOUT

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
3.4. 1	.3	.6	3.6	1.05	.55	.30
3.4. 2	.2	.4	2.4	.7	.367	.13
3.4. 3	.5	1.0	6.0	1.75	.917	.84
3.4. 4	.3	.6	3.6	1.05	.55	.30
3.4. 5	.625	1.25	7.5	2.188	1.146	1.31
3.4. 6	.125	.25	1.5	.438	.229	.05
3.4. 7	.375	.75	4.5	1.313	.686	.47
3.4. 8	.5	1.0	6.0	1.75	.917	.84
3.4. 9	.125	.25	1.5	.438	.229	.05
3.4.10	.375	.75	4.5	1.313	.686	.47
3.4.11	.33	.66	3.96	1.155	.605	.37
3.4.12	2.165	4.33	25.98	7.578	3.969	15.75
3.4.13	.25	.5	3.0	.875	.485	.21
3.4.14	.5	1.0	6.0	1.75	.917	.84

SUBTASK 3.5

CENTAUR CARGO ELEMENT MAJOR SYSTEMS TEST

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
3.5. 1	.2	.4	2.4	.7	.367	.13
3.5. 2	.3	.6	3.6	1.05	.55	.30
3.5. 3	.5	1.0	6.0	1.75	.917	.84
3.5. 4	.5	1.0	6.0	1.75	.917	.84
3.5. 5	.25	.5	3.0	.875	.485	.21
3.5. 6	.25	.5	3.0	.875	.485	.21
3.5. 7	.5	1.0	6.0	1.75	.917	.84
3.5. 8	.5	1.0	6.0	1.75	.917	.84
3.5. 9	.125	.25	1.5	.438	.229	.05
3.5.10	.375	.75	4.5	1.313	.686	.47
3.5.11	.375	.75	4.5	1.313	.686	.47
3.5.12	.125	.25	1.5	.438	.229	.05

SUBTASK 3.6

FINAL CENTAUR CARGO ELEMENT PREPARATIONS

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
3.6. 1	.3	.6	3.6	1.05	.55	.30
3.6. 2	.7	1.4	8.4	2.45	1.283	1.65
3.6. 3	1.5	3.0	18.0	5.25	2.75	7.56
3.6. 4	.5	1.0	6.0	1.75	.917	.84
3.6. 5	.5	1.0	6.0	1.75	.917	.84
3.6. 6	1.5	3.0	18.0	5.25	2.75	7.56
3.6. 7	.5	1.0	6.0	1.75	.917	.84
3.6. 8	.3	.6	3.6	1.05	.55	.30
3.6. 9	.2	.4	2.4	.7	.367	.13
3.6.10	.3	.6	3.6	1.05	.55	.30
3.6.11	.2	.4	2.4	.7	.367	.13
3.6.12	.25	.5	3.0	.875	.485	.21
3.6.13	.25	.5	3.0	.875	.485	.21
3.6.14	.5	1.0	6.0	1.75	.917	.84
3.6.15	.5	1.0	6.0	1.75	.917	.84
3.6.16	.15	.3	1.8	.525	.275	.08
3.6.17	.35	.7	4.2	1.225	.642	.41
3.6.18	.5	1.0	6.0	1.75	.917	.84
3.6.19	.25	.5	3.0	.875	.485	.21
3.6.20	.25	.5	3.0	.875	.485	.21

SUBTASK 4.1

LAUNCH COMPLEX 39 PREPARATIONS

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
4.1. 1	6.375	7.5	8.625	7.5	.375	.14
4.1. 2	.213	.25	.288	.25	.013	.00
4.1. 3	1.063	1.25	1.438	1.25	.063	.00
4.1. 4	.638	.75	.863	.75	.038	.00
4.1. 5	1.063	1.25	1.438	1.25	.063	.00
4.1. 6	.213	.25	.288	.25	.013	.00
4.1. 7	.638	.75	.863	.75	.038	.00

SUBTASK 4.2

CENTAUR CARGO ELEMENT CHECKOUT

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
4.2. 1	.075	.15	.9	.263	.138	.02
4.2. 2	.25	.5	3.0	.875	.485	.21
4.2. 3	.1	.2	1.2	.35	.183	.03
4.2. 4	.075	.15	.9	.263	.138	.02
4.2. 5	.125	.25	1.5	.438	.229	.05
4.2. 6	.125	.25	1.5	.438	.229	.05
4.2. 7	.125	.25	1.5	.438	229	.05
4.2. 8	.1	.2	1.2	.35	.183	.03
4.2. 9	.125	.25	1.5	.438	.229	.05
4.2.10	.25	.5	3.0	.875	.485	.21
4.2.11	.75	1.5	9.0	2.625	1.375	1.89
4.2.12	.25	.5	3.0	.875	.485	.21
4.2.13	.125	.25	1.5	.438	.229	.05
4.2.14	.125	.25	1.5	.438	.229	.05

SUBTASK 4.3

ORBITER INSTALLATION & CHECKOUT

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
4.3. 1	.425	.5	.575	.5	.025	.00
4.3. 2	.561	.66	.759	.66	.033	.00
4.3. 3	.213	.25	.288	.25	.013	.00
4.3. 4	.281	.33	.380	.33	.017	.00
4.3. 5	.281	.33	.380	.33	.017	.00
4.3. 6	.281	.33	.380	.33	.017	.00
4.3. 7	.281	.33	.380	.33	.017	.00
4.3. 8	.561	.66	.759	.66	.033	.00
4.3. 9	.561	.66	.759	.66	.033	.00
4.3.10	.561	.66	.759	.66	.033	.00
4.3.11	.561	.66	.759	.66	.033	.00

SUBTASK 4.4

CENTAUR CARGO ELEMENT PRELAUNCH CLOSEOUT

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
4.4. 1	.165	.33	1.98	.578	.303	.09
4.4. 2	.25	.5	3.0	.875	.485	.21
4.4. 3	.625	1.25	7.5	2.188	1.146	1.31
4.4. 4	.33	.66	3.96	1.155	.605	.37
4.4. 5	.125	.25	1.5	.438	.229	.05
4.4. 6	.1	.2	1.2	.35	.183	.03
4.4. 7	.1	.2	1.2	.35	.183	.03
4.4. 8	.3	.6	3.6	1.05	.55	.30
4.4. 9	.165	.33	1.98	.578	.303	.09
4.4.10	.33	.66	3.96	1.155	.605	.37
4.4.11	.125	.25	1.5	.438	.229	.05
4.4.12	.33	.66	3.96	1.155	.605	.37
4.4.13	.33	.66	3.96	1.155	.605	.37
4.4.14	.165	.33	1.98	.578	.303	.09
4.4.15	.125	.25	1.5	.438	.229	.05
4.4.16	.165	.33	1.98	.578	.303	.09
4.4.17	.165	.33	1.98	.578	.303	.09

SUBTASK 4.5

LAUNCH COUNTDOWN

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
4.5. 1	.281	.33	.380	.33	.017	.00
4.5. 2	.213	.25	.288	.25	.013	.00
4.5. 3	.128	.15	.173	.15	.008	.00
4.5. 4	.34	.4	.46	.4	.02	.00
4.5. 5	.765	.9	1.035	.9	.045	.00
4.5. 6	.17	.2	.23	.2	.01	.00
4.5. 7	.281	.33	.380	.33	.017	.00
4.5. 8	1.75	1.75	2.013	1.794	.044	.00
4.5. 9	.15	.15	.173	.153	.003	.00
4.5.10	.33	.33	.380	.338	.008	.00
4.5.11	.33	.33	.380	.338	.008	.00
4.5.12	.35	.35	.403	.358	.008	.00
4.5.13	.25	.25	.288	.256	.006	.00
4.5.14	.25	.25	.288	.256	.006	.00

SUBTASK 5.1

EXERCISES & SIMULATIONS

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
5.1. 1	.25	.25	.75	.333	.083	.01
5.1. 2	.25	.25	.75	.333	.083	.01
5.1. 3	.25	.25	.75	.333	.083	.01
5.1. 4	1.00	1.00	1.50	1.083	.083	.01
5.1. 5	1.00	1.00	1.50	1.083	.083	.01
5.1. 6	1.00	1.00	1.50	1.083	.083	.01
5.1. 7	2.00	2.00	2.50	2.083	.083	.01
5.1. 8	1.00	1.00	1.50	1.083	.083	.01
5.1. 9	2.00	2.00	2.50	2.083	.083	.01
5.1.10	1.00	1.00	1.50	1.083	.083	.01
5.1.11	1.00	1.00	1.50	1.083	.083	.01

SUBTASK 5.2

ASCENT

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
5.2. 1	.07	.07	.07	.07	0.0	0.0

SUBTASK 5.3

CENTAUR CARGO ELEMENT CHECKOUT & DEPLOYMENT

	TIME ESTIMATES			EXP	D.S.	VAR
ACT #	a	m	b	te	St,e	VAR
5.3. 1	.04	.04	.04	.04	0.0	0.0
5.3. 2	.2	.2	.2	.2	0.0	0.0
5.3. 3	.2	.2	.2	.2	0.0	0.0
5.3. 4	.02	.02	.02	.02	0.0	0.0

SUBTASK 5.4

CENTAUR FLIGHT

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
5.4. 1	.032	.032	.032	.032	0.0	0.0
5.4. 2	.0055	.0055	.0055	.0055	0.0	0.0
5.4. 3	.2167	.2167	.2167	.2167	0.0	0.0
5.4. 4	.0014	.0014	.0014	.0014	0.0	0.0
5.4. 5	.0055	.0055	.0055	.0055	0.0	0.0
5.4. 6	.021	.021	.021	.021	0.0	0.0

SUBTASK 6.1

MONITOR CISS

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
6.1. 1	.05	.1	.6	.175	0.092	0.01
6.1. 2	5.0	6.0	7.0	6.0	0.333	0.11
6.1. 3	.5	.5	.5	.5	0.0	0.0
6.1. 4	.04	.04	.04	.04	0.0	0.0

SUBTASK 6.2

REMOVE CISS

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
6.2. 1	.298	.35	.403	.35	.018	.00
6.2. 2	.17	.2	.23	.2	.01	.00
6.2. 3	.85	1.0	1.15	1.0	.05	.00
6.2. 4	.5	1.0	6.0	1.75	.92	.84
6.2. 5	1.0	2.0	12.0	3.5	1.833	3.36
6.2. 6	.5	1.0	6.0	1.75	.92	.84
6.2. 7	.25	.5	3.0	.875	.485	.21
6.2. 8	.425	.5	.575	.5	..025	.00
6.2. 9	.213	.25	.288	.25	.013	.00

SUBTASK 6.3

CISS REFURBISHMENT

ACT #	TIME ESTIMATES a	m	b	te	St,e	VAR
6.3. 1	.5	1	1	.917	.083	.01
6.3. 2	.25	.5	3.0	.875	.485	.21
6.3. 3	3.0	6	36	10.5	5.5	30.25
6.3. 4	3.0	6	36	10.5	5.5	30.25
6.3. 5	2.0	4	24	7.00	3.67	13.44
6.3. 6	1.5	3	18	5.25	2.75	7.56
6.3. 7	.5	1	6	1.75	.92	.84
6.3. 8	1.0	2	12	3.5	1.83	3.36
6.3. 9	1.5	3	18	5.25	2.75	7.56
6.3.10	1.5	3	18	5.25	2.75	7.56
6.3.11	2.0	4	24	7.00	3.67	13.44
6.3.12	1.0	2	12	3.5	1.83	3.36
6.3.13	2.0	4	24	7.00	3.67	13.44
6.3.14	1.0	2	12	3.5	1.83	3.36

ADDENDIX D:

PERT NETWORK PATHS THROUGH THE S/CGPS

SUBTASK 1.1

CISS @ HANGAR J

PATH	te
[A,B,C,D,F,J]	10.5
[A,B,E,F,J]	*14.0
[A,B,F,J]	*14.0
[A,B,G,F,J]	*14.0
[A,B,H,I,F,J]	12.25

SUBTASK 1.2

CENTAUR @ HANGAR J

PATH	te
[A,B,C,D,M]	26.25
[A,B,E,F,G,M]	19.25
[A,B,E,F,H,I,J,K,F,G,M]	33.25
[A,B,E,F,H,I,J,K,L,M]	33.25
[A,B,E,F,H,I,J,N,M]	36.75
[A,B,H,I,J,K,F,G,M]	22.75
[A,B,H,I,J,K,L,M]	28.00
[A,B,H,I,J,N,M]	19.25
[A,B,O,M]	5.25
[A,B,E,F,H,I] to Subtask 5.1	21.00
[A,B,H,I] to Subtask 5.1	14.00

* - **Critical Path** Route

SUBTASK 2.1

CISS @ CX 36A

PATH	te
[A,B,C,Q,W]	14.00
[A,D,Q,W]	3.5
[A,E,P,Q,W]	7.0
[A,F,O,P,Q,W]	14.00
[A,G,H,L,M,N,O,P,Q,W]	38.5
[A,I,J,K,L,M,N,O,P,Q,W]	*42.00
[A,I,J,R,S,N,O,P,Q,W]	28.00
[A,I,J,T,R,S,N,O,P,Q,W]	24.50
[A,I,J,U,Q,W]	24.50
[A,I,J,V,Q,W]	8.75
[A,G,H,L] to Subtask 5.1	10.50
[A,I,J,K,L] to Subtask 5.1	14.00

SUBTASK 2.2

CENTAUR/CISS @ CX 36A (PART I)

PATH	te
[A,B,C,r,+]	10.5
[A,D,B,E,r,+]	7.00
[A,B,E,r,+]	8.75
[A,B,E,r,+]	14.00
[A,F,G,B,D,E,r,+]	10.50
[A,F,G,B,E,r,+]	12.25
[A,H,I,J,k,h,i,r,+]	24.50
[A,H,M,N,O,R,S,r,+]	24.50
[A,H,M,N,O,R,T,U,W,X,r,+]	31.50
[A,H,M,N,O,R,V,W,X,r,+]	40.25
[A,I,J,k,h,i,r,+]	24.50
[A,I,M,N,O,R,S,r,+]	24.50
[A,I,M,N,O,R,T,U,W,X,r,+]	31.50
[A,I,M,N,O,R,V,W,X,r,+]	35.00
[A,L,M,N,O,R,S,r,+]	28.00
[A,L,M,N,O,R,T,U,W,X,r,+]	35.00
[A,L,M,N,O,R,V,W,X,r,+]	43.75
[A,P,Q,O,R,S,r,+]	14.00
[A,P,Q,O,R,T,U,W,X,r,+]	21.00
[A,P,Q,O,R,V,W,X,r,+]	29.75
[A,Y,Z,a,b,c,d,e,f,r,+]	45.50

* - **Critical Path** Route

SUBTASK 2.2 (CONT)

PATH	te
[A,Y,Z,a,b,c,d,g,r,+]	45.50
[A,Y,Z,a,b,c,k,h,i,r,+]	47.25
[A,Y,Z,a,b,c,j,k,l,q,r,+]	50.75
[A,Y,Z,a,b,c,j,l,q,r,+]	*56.00
[A,Y,Z,a,b,c,j,k,l,q,s,r,+]	47.25
[A,Y,Z,a,b,c,j,l,q,s,r,+]	50.75
[A,t,u,v,m,n,o,p,r,+]	24.50
[A,t,u,w,x,y,z,1,r,+]	36.75
[A,w,x,y,z,1,r,+]	35.00
[A,w,2,#,r,+]	15.75
[A,w,2,3,4,z,1,r,+]	28.00
[A,5,w,x,y,z,1,r,+]	31.50
[A,5,w,2,#,r,+]	12.25
[A,5,w,2,3,4,z,1,r,+]	24.50
[A,6,7,8,9,r,+]	14.00
[A,%,&,*,@,?,r,+]	33.25
[A,B,C] to Subtask 3.1	5.25
[A,C] to Subtask 3.1	7.00
[A,t] to Subtask 5.1	3.5
[A,Y,Z,a,b,c] to Subtask 5.1	29.75

INTER-SUBTASK PATHS BETWEEN 2.1 & 2.2

PATH	te
[A,I,J,U, A ,&,*,@,?,r,+]	47.25

SUBTASK 2.3

CENTAUR/CISS @ CX 36A (PART II)

PATH	te
[A,B,C,D,E,G,J,K,M,R]	19.25
[A,B,C,D,E,G,J,L,M,R]	17.5
[A,B,C,D,E,G,J,M,R]	21.00
[A,B,C,D,E,G,J,N,M,R]	19.25
[A,B,C,D,E,G,J,O,M,R]	17.5
[A,B,C,D,E,G,J,P,M,R]	21.00

* - **Critical Path** Route

SUBTASK 2.3 (CONT)

PATH	te
[A,B,C,D,E,G,J,Q,M,R]	21.00
[A,B,C,F,G,J,K,M,R]	14.00
[A,B,C,F,G,J,L,M,R]	12.25
[A,B,C,F,G,J,M,R]	15.75
[A,B,C,F,G,J,N,M,R]	14.00
[A,B,C,F,G,J,O,M,R]	12.25
[A,B,C,F,G,J,P,M,R]	15.75
[A,B,C,F,G,J,Q,M,R]	15.75
[A,B,C,G,J,K,M,R]	17.50
[A,B,C,G,J,L,M,R]	15.75
[A,B,C,G,J,M,R]	19.25
[A,B,C,G,J,N,M,R]	17.50
[A,B,C,G,J,O,M,R]	15.75
[A,B,C,G,J,P,M,R]	19.25
[A,B,C,G,J,Q,M,R]	19.25
[A,B,C,H,G,J,K,M,R]	19.25
[A,B,C,H,G,J,L,M,R]	17.50
[A,B,C,H,G,J,M,R]	21.00
[A,B,C,H,G,J,N,M,R]	19.25
[A,B,C,H,G,J,O,M,R]	17.50
[A,B,C,H,G,J,P,M,R]	21.00
[A,B,C,H,G,J,Q,M,R]	21.00
[A,B,C,I,G,J,K,M,R]	19.25
[A,B,C,I,G,J,L,M,R]	17.50
[A,B,C,I,G,J,M,R]	21.00
[A,B,C,I,G,J,N,M,R]	19.25
[A,B,C,I,G,J,O,M,R]	17.50
[A,B,C,I,G,J,P,M,R]	21.00
[A,B,C,I,G,J,Q,M,R]	21.00
[A,C,D,E,G,J,K,M,R]	21.00
[A,C,D,E,G,J,L,M,R]	19.25
[A,C,D,E,G,J,M,R]	*22.75
[A,C,D,E,G,J,N,M,R]	21.00
[A,C,D,E,G,J,O,M,R]	19.25
[A,C,D,E,G,J,P,M,R]	*22.75
[A,C,D,E,G,J,Q,M,R]	*22.75
[A,C,F,G,J,K,M,R]	15.75
[A,C,F,G,J,L,M,R]	14.00
[A,C,F,G,J,M,R]	17.50
[A,C,F,G,J,N,M,R]	15.75
[A,C,F,G,J,O,M,R]	14.00
[A,C,F,G,J,P,M,R]	17.50
[A,C,F,G,J,Q,M,R]	17.50
[A,C,G,J,K,M,R]	19.25
[A,C,G,J,L,M,R]	17.50
[A,C,G,J,M,R]	21.00

* - **Critical Path** Route

SUBTASK 2.3 (CONT)

PATH	te
[A,C,G,J,N,M,R]	19.25
[A,C,G,J,O,M,R]	17.50
[A,C,G,J,P,M,R]	21.00
[A,C,G,J,Q,M,R]	21.00
[A,C,H,G,J,K,M,R]	21.00
[A,C,H,G,J,L,M,R]	19.25
[A,C,H,G,J,M,R]	*22.75
[A,C,H,G,J,N,M,R]	21.00
[A,C,H,G,J,O,M,R]	19.25
[A,C,H,G,J,P,M,R]	*22.75
[A,C,H,G,J,Q,M,R]	*22.75
[A,C,I,G,J,K,M,R]	21.00
[A,C,I,G,J,L,M,R]	19.25
[A,C,I,G,J,M,R]	*22.75
[A,C,I,G,J,N,M,R]	21.00
[A,C,I,G,J,O,M,R]	19.25
[A,C,I,G,J,P,M,R]	*22.75
[A,C,I,G,J,Q,M,R]	*22.75

To reach Subtask 3.3, all paths above are available minus 1.75 days. The longest path, **te**, is 21.00 days long and occurs nine times. None are critical path routes.

[A,B,C] to Subtask 3.1	5.25
[A,C] to Subtask 3.1	7.00

INTER-SUBTASK PATHS BETWEEN 2.2 & 2.3

PATH	te
[A,B,C, A ,J,Q,M,R]	15.75
[A,F,G,B,C, A ,J,Q,M,R]	19.25
[A,B,C, A ,J,Q]	14.00
[A,F,G,B,C, A ,J,Q]	17.50

* - **Critical Path** Route

SUBTASK 3.1

SPIF PREPARATIONS

PATH	te
[A,E,F,G,I,J]	8.313
[A,E,F,G,H,I,J]	7.875
[A,B,C,D,J]	11.375
[A,B,M,N,J]	7.438
[A,B,O,N,J]	6.563
[A,K,L,B,C,D,J]	9.625
[A,K,L,B,M,N,J]	5.688
[A,K,L,B,C,N,J]	9.625

SUBTASK 3.2

CENTAUR CISS ASSEMBLY CHECKOUT

PATH	te
[A,B,C,D,E,F,G,K,P]	6.563
[A,B,C,D,E,F,G,H,I,J,M,N,O,P]	13.125
[A,B,C,D,E,F,G,H,I,J,M,P]	12.25
[A,B,C,D,E,F,G,H,I,M,N,O,P]	13.563
[A,B,C,D,E,F,G,H,I,M,P]	12.688
[A,B,C,D,E,F,G,L,M,N,O,P]	13.125
[A,B,C,D,E,F,G,L,M,P]	12.25

SUBTASK 3.3

MOVE SPACECRAFT TO SPIF

PATH	te
[A,B,C,D,E,F,G,H,R]	*15.75
[A,B,C,D,E,I,J,K,R]	10.50
[A,B,C,D,E,I,J,L,M,N,O,Q,R]	14.00
[A,B,C,D,E,I,J,L,M,N,O,R]	14.875
[A,B,C,D,E,I,J,L,M,N,P,O,R]	14.875
[A,B,C,E,F,G,H,R]	*15.75
[A,B,C,E,I,J,K,R]	10.50
[A,B,C,E,I,J,L,M,N,O,Q,R]	14.00
[A,B,C,E,I,J,L,M,N,O,R]	14.875
[A,B,C,E,I,J,L,M,N,P,O,R]	14.875

* - **Critical Path** Route

SUBTASK 3.4

CENTAUR CARGO ELEMENT MATE & CHECKOUT

PATH	te
[A,B,C,D,E,F,H,I,J,K,L,M,N,O]	18.972
[A,B,C,D,E,F,H,I,J,K,L,M,O]	19.847
[A,B,C,D,F,H,I,J,K,L,M,N,O]	20.11
[A,B,C,D,F,H,I,J,K,L,M,O]	*20.985
[A,B,C,D,G,F,H,I,J,K,L,M,N,O]	18.36
[A,B,C,D,G,F,H,I,J,K,L,M,O]	19.235
[A,B,C,D,E,F,H,I,J,K,L,M] to Subtask 5.1	18.127
[A,B,C,D,F,H,I,J,K,L,M] to Subtask 5.1	19.235
[A,B,C,D,G,F,H,I,J,K,L,M] to Subtask 5.1	17.485

SUBTASK 3.5

CENTAUR CARGO ELEMENT MAJOR SYSTEMS TEST

PATH	te
[A,B,C,D,E,F,G,H,I,J,K,L,M]	*14.002
[A,B,C,D,E,F] to Subtask 3.6A	6.125
[A,B,C,D,E,F,G,H,I,J,K] to Subtask 5.1	12.251

SUBTASK 3.6

FINAL CENTAUR CARGO ELEMENT PREPARATIONS

PATH	te
From Subtask 3.4:	
[A,B,C,P,Q,R,S,T,U]	8.75
[A,B,C,D,E,R,S,T,U]	14.00
[A,B,C,D,E,F,G,H,I,J,K,L,M,N,O,P,Q,R,S,T,U]	33.25
[A,B,C,D,E,F] to Subtask 4.1	12.25
From Subtask 3.5A:	
[C,D,E,F] to Subtask 4.1	8.75
[C,D,E,F,G,H,I,J,K,L,M,N,O,P,Q,R,S,T,U]	29.75
[C,D,E,R,S,T,U]	10.50
From Subtask 3.5B:	
[E,F] to Subtask 4.1	1.75
[E,F,G,H,I,J,K,L,M,N,O,P,Q,R,S,T,U]	*22.75

* - **Critical Path** Route

SUBTASK 4.1

LAUNCH COMPLEX 39 PREPARATIONS

PATH	te
[A,B,C,F,H]	9.00
[A,B,C,E,F,G H]	9.50
[A,B,C,F,G H]	10.00

SUBTASK 4.2

CENTAUR CARGO ELEMENT CHECKOUT

PATH	te
[A,B,C,D,E,F,G,H,I,J,K,L,M,N,O]	5.603
[A,B,C,D,E,F,G,H,J,K,L,M,N,O]	5.691
[A,B,C,D,E,F,G,H,L,M,N,O]	*7.003
[A,B,C,D,E,G,H,I,J,K,L,M,N,O]	5.603
[A,B,C,D,E,G,H,J,K,L,M,N,O]	5.691
[A,B,C,D,E,G,H,L,M,N,O]	*7.003
[A,B,C,D,E,F,G,H,I,J,K,L] to Subtask 5.1	3.852
[A,B,C,D,E,F,G,H,J,K,L] to Subtask 5.1	3.94
[A,B,C,D,E,F,G,H,L] to Subtask 5.1	4.953
[A,B,C,D,E,G,H,I,J,K,L] to Subtask 5.1	3.852
[A,B,C,D,E,G,H,J,K,L] to Subtask 5.1	3.94
[A,B,C,D,E,G,H,L] to Subtask 5.1	4.953

SUBTASK 4.3

INSTALLATION IN ORBITER & CHECKOUT

PATH	te
[A,B,C,D,E,F,G,H,I,J,K,L]	4.40
[A,B,C,D,E,F,G,H,I,K,L]	4.40
[A,B,C,E,F,G,H,I,J,K,L]	*4.48
[A,B,C,E,F,G,H,I,K,L]	*4.48
[A,B,C,D,E,F,G,H,I] to Subtask 5.1	3.07
[A,B,C,E,F,G,H,I] to Subtask 5.1	3.15

* - **Critical Path** Route

SUBTASK 4.4

CENTAUR CARGO ELEMENT PRELAUNCH CLOSEOUT

PATH	te
[A,B,C,D,E,F,G,H,I,J,M,N,O,R]	*9.295
[A,B,C,D,E,F,G,H,I,J,M,N,P,R]	9.155
[A,B,C,D,E,F,G,H,I,J,M,N,Q,R]	*9.295
[A,B,C,D,E,F,G,H,I,J,M,N,R]	*9.295
[A,B,C,D,E,F,G,H,I,L,M,N,O,R]	8.578
[A,B,C,D,E,F,G,H,I,L,M,N,P,R]	8.438
[A,B,C,D,E,F,G,H,I,L,M,N,Q,R]	8.578
[A,B,C,D,E,F,G,H,I,L,M,N,R]	8.578
[A,B,C,D,E,F,G,H,I,M,N,O,R]	*9.295
[A,B,C,D,E,F,G,H,I,M,N,P,R]	9.155
[A,B,C,D,E,F,G,H,I,M,N,Q,R]	*9.295
[A,B,C,D,E,F,G,H,I,M,N,R]	*9.295
[A,B,C,K,D,E,F,G,H,I,J,M,N,O,R]	8.262
[A,B,C,K,D,E,F,G,H,I,J,M,N,P,R]	8.122
[A,B,C,K,D,E,F,G,H,I,J,M,N,Q,R]	8.262
[A,B,C,K,D,E,F,G,H,I,J,M,N,R]	8.262
[A,B,C,K,D,E,F,G,H,I,L,M,N,O,R]	7.545
[A,B,C,K,D,E,F,G,H,I,L,M,N,P,R]	7.405
[A,B,C,K,D,E,F,G,H,I,L,M,N,Q,R]	7.545
[A,B,C,K,D,E,F,G,H,I,L,M,N,R]	7.545
[A,B,C,K,D,E,F,G,H,I,M,N,O,R]	8.262
[A,B,C,K,D,E,F,G,H,I,M,N,P,R]	8.122
[A,B,C,K,D,E,F,G,H,I,M,N,Q,R]	8.262
[A,B,C,K,D,E,F,G,H,I,M,N,R]	8.262
[A,B,C,D,E,F,G,H] to Subtask 5.1	5.829
[A,B,C,K,D,E,F,G,H] to Subtask 5.1	4.796

* - **Critical Path** Route

SUBTASK 4.5

LAUNCH COUNTDOWN

PATH	te
From Subtask 4.4:	
[A,B,D,E,F,G,H,I,P]	3.982
[A,B,D,E,F,G,J,K,L,M,O,P]	2.989
[A,B,D,E,F,G,J,K,L,N,O,P]	2.907
[A,B,D,E,F,G,J,K,L,N,P]	2.907
[A,C,D,E,F,G,H,I,P]	*4.052
[A,C,D,E,F,G,J,K,L,M,O,P]	3.059
[A,C,D,E,F,G,J,K,L,N,O,P]	2.977
[A,C,D,E,F,G,J,K,L,N,P]	2.977
From Subtask 5.1:	
[G,H,I,P]	2.152
[G,J,K,L,M,O,P]	1.159
[G,J,K,L,N,O,P]	1.077
[G,J,K,L,N,P]	1.077

SUBTASK 5.1

EXERCISES & SIMULATIONS

PATH	te
[A,B]	28.333
[B,C]	59.833
[C,D]	86.083
[D,E]	113.083
[E,F]	135.833
[F,G]	169.418
[G,H]	184.419
[H,I]	207.918
[I,J]	213.871
[J,K]	217.772
[K,L]	224.931

NOTE: The paths in this Subtask have the lead-in times from other Subtasks included in their **te** times. For example, the longest lead-in path to path [F,G] is 168.335 days long and the [F,G] path itself is 1.083 days long. Therefore, this path is a total of 169.418 days long.

* - **Critical Path** Route

SUBTASK 5.2

ASCENT

PATH	te
[A,B]	* .07

SUBTASK 5.3

CENTAUR CARGO ELEMENT CHECKOUT & DEPLOYMENT

PATH	te
[A,B,C,E]	* .26
[A,B,D,C,E]	* .26

SUBTASK 5.4

CENTAUR FLIGHT

PATH	te
[A,B,C,D,E,F,G]	*.2821

SUBTASK 6.1

MONITOR CISS

PATH	te
[A,B,C,D,E]	*6.715

* - **Critical Path** Route

SUBTASK 6.2

REMOVE CISS

PATH	te
[A,B,C,D,E,G,H,I,J]	4.925
[A,B,C,D,F,G,H,I,J]	*6.675
[A,B,C,D,G,H,I,J]	4.925

SUBTASK 6.3

CISS REFURBISHMENT

PATH	te
[A,B,C,D,I,J,K,L,M,N,O]	*47.292
[A,B,C,D,G,H,J,K,L,M,N,O]	45.542
[A,B,C,E,D,I,J,K,L,M,N,O]	*47.292
[A,B,C,E,D,G,H,J,K,L,M,N,O]	45.542
[A,B,C,F,D,I,J,K,L,M,N,O]	43.792
[A,B,C,F,D,G,H,J,K,L,M,N,O]	42.042

* - **Critical Path** Route

APPENDIX E:

SLAM COMPUTER CODE

```
GEN,BROCK,CENTAUR GND PROC SYS,11/23/1985,,,,,,,72;
LIM,15,3,100;
TIMST,XX(8),CISS FLAG COUNT;
TIMST,XX(9),CISS COUNT;
RECORD,TNOW,# OF DAYS,,P,50;
VAR,XX(7),C,# OF VEHICLES;
NETWORK;
;
;     --------------------- RESOURCE GENERATION ---------------------
;
      RESOURCE/CCLS(2),1,2,3,4,5,6,7;      TWO CCLS COMPUTERS AT CPOCC
      RESOURCE/CX36(1),8;                  CENTAUR COMPLEX 36A
      RESOURCE/SPIF CELL(2),9;             TWO INTEGRATION CELLS @ SPIF
      RESOURCE/MMSE(2),10;                 TWO STS PAYLOAD CANISTERS
      RESOURCE/LC 39(2),11;                STS LAUNCH COMPLEX 39
      RESOURCE/TTF(1),12,13;               CENTAUR TRANSPORT FIXTURE
;
;     ------------------------- MAIN PROGRAM ------------------------
;
      CREATE,90,,1;                        GENERATE CENTAUR & CISS
      ASSIGN,XX(7)=XX(7)+1;
      ASSIGN,ATRIB(2)=XX(7);                  FLIGHT NUMBER
      GOON,2;
      ACT,,,N12A;
      ACT,,XX(7).LE.2,N11A;                CISS DELV WITH 1ST 2 CENTAUR
      ACT,,XX(8).NE.0,N11A;                DELV NEW CISS IF OLD-6 FLTS
      ACT;
      TERM;
;
;     ------ SUBTASK 1.1 ------- CISS @ HANGAR J --------------------
;
N11A  ASSIGN,XX(8)=0;                         RESET NEW CISS FLAG
      ACT,RLOGN(1.610,0.7782)*1;           UNLOAD CISS FM A/C
      GOON,5;
      ACT,RLOGN(1.610,0.7782)*6,,N11F;     MECHANICAL RCV/INSP
      ACT,RLOGN(1.610,0.7782)*6,,N11F;     ELECTRICAL RCV/INSP
      ACT,RLOGN(1.610,0.7782)*6,,N11F;     INST RCV/INSP
      ACT,RLOGN(1.610,0.7782)*2,,N11H;     XDUCER RINGOUT (PWR OFF)
      ACT,RLOGN(1.610,0.7782)*3;           PREP FOR STANDARD TURN ON
      AWAIT(7),CCLS;                          WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*1;           STANDARD TURN ON
      FREE,CCLS;                              RELEASE CCLS
      ACT,,,N11F;
N11H  GOON;
      ACT,RLOGN(1.610,0.7782)*3;           XDUCER RINGOUT (PWR ON)
N11F  ACCUM,5,5;
      AWAIT(12),TTF;                          WAIT FOR TTF
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```
      ACT,RLOGN(1.610,0.7782)*1;            TRANSPORT CISS TO CX 36A
N11J  COLCT,TNOW-ATRIB(1),SUBTASK 1.1,;
      AWAIT(8),CX36;                          AWAIT COMPLEX 36A FREE
      ACT,,,N21A;
;
;     ------  SUBTASK 1.2  -------  CENTAUR @ HANGAR J  ---------------
;
N12A  GOON;
      ACT,RLOGN(1.610,0.7782)*1;            UNLOAD CENTAUR FM A/C
      GOON,4;
      ACT,RLOGN(1.610,0.7782)*11,,N12C;     ELECTRICAL RCV/INSP
      ACT,RLOGN(1.610,0.7782)*4,,N12H;      MECHANICAL RCV/INSP
      ACT,RLOGN(1.610,0.7782)*11,,N12M;     HDYRAULIC SYS LOOP PRESS CK
      ACT,RLOGN(1.610,0.7782)*4;            PNEUMATIC RCV
      GOON;
      ACT,RLOGN(1.610,0.7782)*4;            PROP TANK PURGE
      GOON,2;
      ACT,,,N12K;
      ACT,,,N12H;
N12H  ACCUM,2,2;
      ACT,RLOGN(1.610,0.7782)*3;            CYRO BOLT FLANGE CK

      ACT,,,N51A;
      ACT,RLOGN(1.610,0.7782)*3;            PROP/HYD RCV
      GOON,2;
      ACT,RLOGN(1.610,0.7782)*6,,N12M;      PROP/HYD PREPS
      ACT,RLOGN(1.610,0.7782)*2;            FILL & DRAIN CK
N12K  ACCUM,2,2,,2;
      ACT,RLOGN(1.610,0.7782)*2,,N12M;      VENT FUNCT CK
      ACT,RLOGN(1.610,0.7782)*2;            PREPS FOR TRANSPORT
      GOON;
      ACT,RLOGN(1.610,0.7782)*1,,N12M;      TRANSPORT TO CX 36A
N12C  GOON;
      ACT,RLOGN(1.610,0.7782)*2;            PROP PROBE/CABLE CHECKS
N12M  ACCUM,5,5;
      COLCT,TNOW-ATRIB(1),SUBTASK 1.2,;
CENT  QUEUE(14),,,,MATE;                       CENTAUR READY FOR MATE
;
;     ------  SUBTASK 2.1  -------  CISS @ COMPLEX 36A  ---------------
;
N21A  ASSIGN,XX(1)=TNOW,6;                    TIME ENTERED COMPLEX 36A
      ACT,RLOGN(1.610,0.7782)*4,,N21B;      REMOVE COVERS
      ACT,RLOGN(1.610,0.7782)*1,,N21Q;      CK CX 36 BRDG CRANE
      ACT,RLOGN(1.610,0.7782)*1,,N21P;      FILL LH2 STOR TANK
      ACT,RLOGN(1.610,0.7782)*3,,N21O;      FILL LO2 STOR TANK
      ACT,RLOGN(1.610,0.7782)*2,,N21G;      INSTL FLUID INTERFACES
      ACT,RLOGN(1.610,0.7782)*2,,N21I;      PREP FOR STD TURN ON
N21B  GOON;
      ACT,RLOGN(1.610,0.7782)*3,,N21Q;      PREP CISS FOR MATE
N21G  GOON;
      ACT,RLOGN(1.610,0.7782)*4,,N21L;      INSTL FLUID INSUL
N21I  AWAIT(6),CCLS;                           WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*1;            STD TURN ON
```

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        FREE,CCLS,5;
        ACT,RLOGN(1.610,0.7782)*1,,N21Q;     PRESSURE CHGOVR
        ACT,RLOGN(1.610,0.7782)*10,,N21U;    AIRBRN INSTR CK OUT
        ACT,RLOGN(1.610,0.7782)*2,,N21R;     HE STG PRESS CK
        ACT,RLOGN(1.610,0.7782)*4,,N21R;     PAVCS FUNCT CK OUT
        ACT;
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*3,,N21K;     AVIONICS FUNCT CK
N21U    GOON,2;
        ACT,
        ACT,,,N22B;
N21R    ACCUM,2,2;
        ACT,RLOGN(1.610,0.7782)*2,,N21N;     PURGE SYS CK
N21K    FREE,CCLS;                              RELEASE CCLS
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*2;           ROTATION TEST
        FREE,CCLS;                              RELEASE CCLS
N21L    ACCUM,2,2,,2;
        ACT,,,N51A;
        ACT;
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*5;           PRESS SYS FUNCT TEST
        FREE,CCLS;                              RELEASE CCLS
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*4;           CISS VENT SYS CK OUT
        FREE,CCLS;                              RELEASE CCLS
N21N    ACCUM,2,2;
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*2;           HE STOR PRESS CK
        FREE,CCLS;                              RELEASE CCLS
N21O    ACCUM,2,2;
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*2;           LO2 SYS VALID
        FREE,CCLS;                              RELEASE CCLS
N21P    ACCUM,2,2;
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*2;           LH2 SYS VALID
        FREE,CCLS;                              RELEASE CCLS
N21Q    ACCUM,5,5;
CISS    QUEUE(15),,,,MATE;                      CISS READY FOR MATE
MATE    SELECT,ASM,,,CISS,CENT;                 BRING CENT-CISS TOGETHER
        ACT,RLOGN(1.610,0.7782)*1;           MATE CENTAUR
N21W    COLCT,TNOW-ATRIB(1),SUBTASK 2.1,;
        ACT;
;
;       ------  SUBTASK 2.2  -------  CENTAUR/CISS @ CX 36A (PART I)  ----
;
N22A    GOON,12;
        ACT,RLOGN(1.610,0.7782)*2,,N22C;     PROBE CHECKOUT
        ACT,RLOGN(1.610,0.7782)*2,,N22F;     ENG ELECT READINESS
        ACT,RLOGN(1.610,0.7782)*2,,N22I;     SERVO HARNESS CHECKS
        ACT,RLOGN(1.610,0.7782)*2,,N22I;     INSTL FLUID INTERFACES
        ACT,RLOGN(1.610,0.7782)*2,,N22L;     CLEAN TANK WALLS
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        ACT,RLOGN(1.610,0.7782)*2,,N22P;     ELECT INTERFACE TEST
        ACT,RLOGN(1.610,0.7782)*2,,N22Y;     PREPS FOR STD TURN ON
        ACT,RLOGN(1.610,0.7782)*2,,N22U;     CONNECT FLUID LINES
        ACT,RLOGN(1.610,0.7782)*3,,N22V;     CRYO BOLT FLANGE CKS
        ACT,RLOGN(1.610,0.7782)*1,,N22V;     REMOVE ENGINE SUPPORTS
        ACT,RLOGN(1.610,0.7782)*2,,N22S;     RF RECV/INSPECT
        ACT,RLOGN(1.610,0.7782)*2,,N22Q;     XDUCER RNG OUT (PWR OFF)
N22C    ACCUM,2,2,,3;
        ACT,RLOGN(1.610,0.7782)*3,,N22G;     CX 36A ELECT READINESS
        ACT,RLOGN(1.610,0.7782)*1,,N22E;     BLAST DOOR CHECKOUT
        ACT,RLOGN(1.610,0.7782)*2;           FACILITY ELECT READINESS
N22E    ACCUM,2,2;
        ACT,,,N22R;
N22G    GOON,2;
        ACT,,,N22R;
        ACT,,,N23Q;
N22F    GOON;
        ACT,RLOGN(1.610,0.7782)*2,,N22C;     N2H4 SYS ELECT CHECKS
N22I    ACCUM,2,2,,2;
        ACT,RLOGN(1.610,0.7782)*5,,N22K;     INTERMED BULKHEAD CK OUT
        ACT,,,N22M;
N22L    GOON;
        ACT,RLOGN(1.610,0.7782)*2;           INSTALL LO2 INSULATION
N22M    ACCUM,2,2;
        ACT,RLOGN(1.610,0.7782)*5;           INSTALL LH2 INSULATION
        GOON;
        ACT,RLOGN(1.610,0.7782)*2,,N22O;     ALIGN & INSTL TRUNNION
N22P    GOON;
        ACT,RLOGN(1.610,0.7782)*1;           CK CX 36A BRDG CRANE
N22O    ACCUM,2,2;
        ACT,RLOGN(1.610,0.7782)*1;           ERECT TTF
        GOON,3;
        ACT,RLOGN(1.610,0.7782)*3,,N22R;     ECS SYS CONNECTION
        ACT,RLOGN(1.610,0.7782)*1,,N22T;     VENT DOOR CHECKOUT
        ACT,RLOGN(1.610,0.7782)*3;           INSTL TTF INSUL PANELS
        GOON;
        ACT,RLOGN(1.610,0.7782)*5;           VERIFY STRUCTURES
N22W    ACCUM,2,2;
        ACT,RLOGN(1.610,0.7782)*4,,N22R;     STRUCTURAL PREPS FOR TCD
N22T    GOON;
        ACT,RLOGN(1.610,0.7782)*2,,N22W;     INSTALL SEPARATION SPRINGS
N22Y    AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*1;           STANDARD TURN ON
        FREE,CCLS;                              RELEASE CCLS
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*8;           AVIONICS SUBSYS FUNCT CK OUT
        FREE,CCLS;                              RELEASE CCLS
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*3;           PAVCS SUBSYSTEM CHECKOUT
        FREE,CCLS;                              RELEASE CCLS
        AWAIT(6),CCLS;                          WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*3;           VENT SYS FUNCT CK
        FREE,CCLS,4;                            RELEASE CCLS
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       ACT,,,N51C;
       ACT,RLOGN(1.610,0.7782)*3,,N22K;      INSTL FORWORD BULKHEAD INSUL
       ACT,RLOGN(1.610,0.7782)*4,,N22D;      FOAM .ENT SYS FLANGES
       ACT;
       AWAIT(6),CCLS;                           WAIT FOR CCLS
       ACT,RLOGN(1.610,0.7782)*3;            PRESSURE SYS FUNCT CK
       FREE,CCLS,2;                             RELEASE CCLS
       ACT,RLOGN(1.610,0.7782)*3,,N22N;      HELIUM STORAGE PRESSURE
       ACT,RLOGN(1.610,0.7782)*1;            PRESSURE CHANGEOVER
N22N   ACCUM,2,2;
       ACT,RLOGN(1.610,0.7782)*4;            CCVAPS/APCS FUNCT CK
       GOON,2;
       ACT,RLOGN(1.610,0.7782)*3,,N22R;      PNEUMATIC READINESS
       ACT,RLOGN(1.610,0.7782)*1,,N22R;      PRESSURE CHANGEOVER
N22K   ACCUM,2,2;
       ACT,RLOGN(1.610,0.7782)*4;            PURGE SYSTEM CHECKOUT
       GOON;
       ACT,RLOGN(1.610,0.7782)*2,,N22R;      HAZARD GAS DETECT SYS CK
N22D   GOON,2;
       ACT,RLOGN(1.610,0.7782)*4,,N22R;      FLUID SAMPLING
       ACT,RLOGN(1.610,0.7782)*1;            FILL LH2 STORAGE TANK
       GOON;
       ACT,RLOGN(1.610,0.7782)*3,,N22R;      FILL LO2 STORAGE TANK
N22U   GOON,2;
       ACT,,,N51B;
       ACT,RLOGN(1.610,0.7782)*2;            N2H4 SYS THRUSTER LOOP PRESS
       GOON,2;
       ACT,,,N22X;
       ACT,RLOGN(1.610,0.7782)*3;            N2H4 LEAK & FUNCT TEST
       GOON;
       ACT,RLOGN(1.610,0.7782)*2;            BATTERY ACTIVITY
       GOON;
       ACT,RLOGN(1.610,0.7782)*1;            INSTALL BATTERIES
       AWAIT(6),CCLS;                           WAIT FOR CCLS
       ACT,RLOGN(1.610,0.7782)*3;            AVIONICS SUBSYS VERFICATION
       FREE,CCLS;                               RELEASE CCLS
       ACT,,,N22R;
N22V   ACCUM,2,2,,2;
       ACT,,,N22X;
       ACT,RLOGN(1.610,0.7782)*4;            MAIN ENGINE LEAK CK
       GOON,2;
       ACT,RLOGN(1.610,0.7782)*1,,N22R;      INSTALL ENGINE SUPPORTS
       ACT,RLOGN(1.610,0.7782)*3;            HYDRAULIC LEAK & FUNCT TEST
       GOON;
       ACT,RLOGN(1.610,0.7782)*3,,N22Z;      HYDRAULIC END-TO-END TEST
N22X   ACCUM,2,2;
       ACT,RLOGN(1.610,0.7782)*4;            INSTL PROP DUCT HEAT SHIELD
       GOON;
       ACT,RLOGN(1.610,0.7782)*5;            FOAM PROP SYS TRANSDUCERS
       GOON;
       ACT,RLOGN(1.610,0.7782)*5;            INSTALL PROP HEAT SHIELD
N22Z   ACCUM,2,2;
       ACT,RLOGN(1.610,0.7782)*2,,N22R;      PROP/HYDRAULIC TCD READINESS
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N22S  GOON;
      ACT,RLOGN(1.610,0.7782)*2;              PUMP SPEED CHECKOUT
      GOON;
      ACT,RLOGN(1.610,0.7782)*2;              RF SUBSYSTEM CHECKOUT
      GOON;
      ACT,RLOGN(1.610,0.7782)*1,,N22R;        HELIUM STORAGE PRESSURE
N22Q  GOON;
      ACT,RLOGN(1.610,0.7782)*3;              TRANSDUCER RING OUT (PWR ON)
N22B  ACCUM,2,2;
      ACT,RLOGN(1.610,0.7782)*10;             AIRBRN INSTRM MEASUREMENTS
      GOON;
      ACT,RLOGN(1.610,0.7782)*3;              INSTALL TANK TV CAMERA
N22R  ACCUM,14,14;
      AWAIT(4),CCLS/2;                           WAIT FOR TWO CCLS'S
      ACT,RLOGN(1.610,0.7782)*1;              TERMINAL COUNTDOWN DEMO
      FREE,CCLS/2;                               TWO CCLS'S
      COLCT,TNOW-ATRIB(1),SUBTASK 2.2,;
      ACT;
;
;     ------  SUBTASK 2.3  -------  CENTAUR/CISS @ CX 36A (PART II)  ---
;
N23A  GOON,3;
      ACT,,,N51D;
      ACT,RLOGN(1.610,0.7782)*3,,N23C;        POST-TCD CHECKS
      ACT,RLOGN(1.610,0.7782)*4;              TCD DATA REVIEW
N23C  ACCUM,2,2,,6;
      ACT,,,N31A;
      ACT,,,N23F;
      ACT,RLOGN(1.610,0.7782)*3,,N23G;        MSN SEQ SIM PREPS
      ACT,RLOGN(1.610,0.7782)*4,,N23G;        PROP FLT READ OPS
      ACT,RLOGN(1.610,0.7782)*4,,N23G;        FINAL CLEANING
      ACT,RLOGN(1.610,0.7782)*3;              ACTIVATE BATTERIES
      GOON;
      ACT,RLOGN(1.610,0.7782)*1;              INSTALL BATTERIES
N23G  ACCUM,5,5;
      AWAIT(5),CCLS;                             WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*1;              MISSION SEQUENCE SIM TEST
      FREE,CCLS;                                 RELEASE CCLS
N23J  GOON,7;
      ACT,RLOGN(1.610,0.7782)*2,,N23M;        REMOVE BATTERIES
      ACT,RLOGN(1.610,0.7782)*1,,N23M;        CK CX 36A BRDG CRANE
      ACT,RLOGN(1.610,0.7782)*3,,N23M;        PREPS FOR DE-ERECTION
      ACT,RLOGN(1.610,0.7782)*2,,N23M;        PROP/HYDRAULIC SYS OPS
      ACT,RLOGN(1.610,0.7782)*1,,N23M;        PRESSURE CHANGEOVER
      ACT,RLOGN(1.610,0.7782)*3,,N23M;        MSN SEQ SIM DATA REVIEW
      ACT;
N23Q  ACCUM,2,2;
      ACT,RLOGN(1.610,0.7782)*3;              INSTALL ORDINANCE
N23M  ACCUM,7,7;
      FREE,CX36;                                 RELEASE COMPLEX 36A
      COLCT,TNOW-XX(1),TIME @ CX 36A,,,,2;
      ACT,,,N33A;
      ACT,RLOGN(1.610,0.7782)*1;              MOVE TO SPIF
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N23R  COLCT,TNOW-ATRIB(1),SUBTASK 2.3,,,,2;
      ACT,,,N51E;
      ACT,,,N32A;
N23F  AWAIT(6),CCLS;                           WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*1;            CALIBRATE IMG
      FREE,CCLS;                               RELEASE CCLS
      ACT,,,N23G;
;
;     ------ SUBTASK 3.1 ------- SPIF PREPARATIONS ----------------
;
N31A  AWAIT(9),SPIF CELL,,3;                   WAIT FOR SPIF CELL
      ACT,RLOGN(1.610,0.7782)*.5,,N31E;     PREP SPIF CABLE TRAY
      ACT,RLOGN(1.610,0.7782)*3,,N31B;      INSTL & CONNECT SMCH CABLE
      ACT,RLOGN(1.610,0.7782)*.5;           INSTL STD SWTC PANEL/CONSOLE
      GOON;
      ACT,RLOGN(1.610,0.7782)*1.5;          INSTL & CONNECT OAS CABLES
N31B  ACCUM,2,2,,3;
      ACT,RLOGN(1.610,0.7782)*.75,,N31N;    INSTL BATT PACK SIM
      ACT,RLOGN(1.610,0.7782)*.75,,N31M;    INSTL CENTAUR GSE IN CELL
      ACT,RLOGN(1.610,0.7782)*3;            VALID/VERIFY OAS/SMCH
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5,,N31J;     VERIFY COMM/TLM INTERFACES
N31M  GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           PERFORM PAYLOAD INTEG TEST
N31N  ACCUM,2,2;
      ACT,,,N31J;
N31E  GOON;
      ACT,RLOGN(1.610,0.7782)*1.5;          INSTL P/L RETENTION FITTINGS
      GOON;
      ACT,RLOGN(1.610,0.7782)*1;            ALIGN P/L RETENTION FITTINGS
      GOON,2;
      ACT,RLOGN(1.610,0.7782)*.5,,N31I;     INSTL SPIF PLATFORMS/BARRIER
      ACT,RLOGN(1.610,0.7782)*.75;          CONFIG FOR GN2/GHE SUPPORT
N31I  ACCUM,2,2;
      ACT,RLOGN(1.610,0.7782)*1;            CLEAN FACILITY
N31J  ACCUM,3,3;
      COLCT,TNOW-ATRIB(1),SUBTASK 3.1,;
;
;     ------ SUBTASK 3.2 ------- CENTAUR CISS ASSEMBLY CHECKOUT ----
;
N32A  ACCUM,2,2;
      ASSIGN,XX(2)=TNOW;                       TIME ENTERED SPIF
      ACT,RLOGN(1.610,0.7782)*.5;           CLEAN TTF & MOVE INTO SPIF
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           TTF INTO TRANS AISLE
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           REMV CENTAUR FROM TTF
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           INSTL CENTAUR IN INT CELL
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           POSITION CELL PLATFORMS
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           ESTAB CLEAN ENV IN CELL
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      GOON,3;
      ACT,,,N32K;
      ACT,RLOGN(1.610,0.7782)*2,,N32M;      INSTL MSN UNIQUE H/W
      ACT,RLOGN(1.610,0.7782)*1;            CLEAN & INSPECT CENTAUR
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           CONNECT CENTAUR TO SMCH/RF
      GOON,2;
      ACT,RLOGN(1.610,0.7782)*.5,,N32M;     ESTAB CENTAUR COOLING
      ACT,RLOGN(1.610,0.7782)*.75;          CONNECT SPACECRAFT IVE
N32M  ACCUM,3,3,,2;
      ACT,RLOGN(1.610,0.7782)*2,,N32P;      REVIEW TEST DATA
      ACT;
      AWAIT(5),CCLS;                           WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*2;            AVONICS FUNCT VERIF
      FREE,CCLS;                               RELEASE CCLS
      ACT,RLOGN(1.610,0.7782)*.5;           CENTAUR-S/C SEP INTEFACE
N32P  ACCUM,3,3;
      COLCT,TNOW-ATRIB(1),SUBTASK 3.2,;
      ACT,,,N34A;
N32K  GOON;
      ACT,RLOGN(1.610,0.7782)*.75;          REMV TTF FROM SPI
      FREE,TTF;                                RELEASE TTF
      ACT,,,N32P;
;
;     ------  SUBTASK 3.3  -------  MOVE SPACECRAFT TO SPIF  -----------
;
N33A  GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           OFF LOAD SPACECRAFT EAGE
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           XPORT EAGE TO SPIF & CLEAN
      GOON,2;
      ACT,RLOGN(1.610,0.7782)*3.5,,N33E;    INSTL EAGE IN INTEG CELL
      ACT,RLOGN(1.610,0.7782)*3.5;          INSTL EAGE CABLING IN CELL
N33E  ACCUM,2,2,,2;
      ACT,RLOGN(1.610,0.7782)*.5,,N33F;     VERIFY EAGE
      ACT,RLOGN(1.610,0.7782)*.5;           MOVE MAGE TO SPIF
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           CLEAN MAGE
      GOON,2;
      ACT,RLOGN(1.610,0.7782)*.5,,N33R;     MOVE MAGE INTO XFER AISLE
      ACT,RLOGN(1.610,0.7782)*.5;           XPORT SPACECRAFT TO SPIF
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           CLEAN S/C & MOVE INTO SPIF
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;           MOVE S/C INTO XFER AISLE
      GOON,2;
      ACT,RLOGN(1.610,0.7782)*.5,,N33O;     REVIEW DATA
      ACT,RLOGN(1.610,0.7782)*.5;           REMOVE S/C FROM TRANSPORTER
      GOON,2;
      ACT,,,N33O;
      ACT,RLOGN(1.610,0.7782)*.5,,N33R;     REMOVE S/C TRANSPORT FM SPIF
N33F  GOON;
      ACT,RLOGN(1.610,0.7782)*2;            EAGE CLOSED LOOP TEST
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     GOON;
     ACT,RLOGN(1.610,0.7782)*2,,N33R;
N33D ACCUM,2,2;
     ACT,RLOGN(1.610,0.7782)*1;           INSPECT SPACECRAFT
N33R ACCUM,4,4;
     COLCT,TNOW-ATRIB(1),SUBTASK 3.3,;
     ACT,,,N34A;
;
;    ------ SUBTASK 3.4 ------- CENTAUR CARGO MATE & CHECKOUT -----
;
N34A ACCUM,2,2;
     ACT,RLOGN(1.610,0.7782)*.6;          PREP INTEG CELL FOR S/C
     GOON;
     ACT,RLOGN(1.610,0.7782)*.4;          CLEAN S/C-CENTAUR INTERFACE
     GOON;
     ACT,RLOGN(1.610,0.7782)*1;           INSTL S/C ONTO CENTAUR
     GOON,3;
     ACT,RLOGN(1.610,0.7782)*.6,,N34F;    REMV S/C HANDLING EQUIP
     ACT,RLOGN(1.610,0.7782)*1.25,,N34F;  INSTL & ADJUST CELL PLATORMS
     ACT,RLOGN(1.610,0.7782)*.25;         CONNECT BATTERY CHARGE
N34F ACCUM,3,3;
     ACT,RLOGN(1.610,0.7782)*.75;         SECURE CELL/ESTAB ENVIRON
     GOON;
     ACT,RLOGN(1.610,0.7782)*1;           REMOVE SPACECRAFT COVERS
     GOON;
     ACT,RLOGN(1.610,0.7782)*.25;         CONNECT SPACECRAFT COOLING
     GOON;
     ACT,RLOGN(1.610,0.7782)*.75;         CONNECT SPACECRAFT TO EAGE
     GOON;
     ACT,RLOGN(1.610,0.7782)*.66;         VERIFY S/C-EAGE INTERFACES
     AWAIT(5),CCLS;                          WAIT FOR CCLS
     ACT,RLOGN(1.610,0.7782)*4.33;        PERFORM SPACECRAFT TESTING
     FREE,CCLS,3;                            RELEASE CCLS
     ACT,,,N51F;
     ACT,RLOGN(1.610,0.7782)*.5,,N34D;    POWER DOWN/SECURE SPACECRAFT
     ACT,RLOGN(1.610,0.7782)*1;           REVIEW SPACECRAFT TEST DATA
N34D ACCUM,2,2;
     COLCT,TNOW-ATRIB(1),SUBTASK 3.4,,,,2;
     ACT,,,N35A;
     ACT,,,N36A;
;
;    ------ SUBTASK 3.5 ------- CENTAUR CARGO MAJOR SYSTEM TEST ---
;
N35A AWAIT(4),CCLS;                          WAIT FOR CCLS
     ACT,RLOGN(1.610,0.7782)*.4;          PREPS FOR CENT/STS INTERFACE
     GOON;
     ACT,RLOGN(1.610,0.7782)*.6;          CENTAUR/STS INTERFACE TEST
     FREE,CCLS;                              RELEASE CCLS
     ACT,RLOGN(1.610,0.7782)*1;           REVIEW CENTAUR/STS TEST DATA
     AWAIT(4),CCLS;                          WAIT FOR CCLS
     ACT,RLOGN(1.610,0.7782)*1;           PREPS FOR CENT-S/C INTERFACE
     GOON;
     ACT,RLOGN(1.610,0.7782)*.5;          CENTAUR-S/C INTERFACE TEST
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        FREE,CCLS,2;                              RELEASE CCLS
        ACT,,,N36C;
        ACT,RLOGN(1.610,0.7782)*.5;           SUVIEW CENTAUR-S/C TEST DATA
        AWAIT(4),CCLS;                            WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*1;            PERFORM MISSION SIMULATION
        FREE,CCLS;                                RELEASE CCLS
        ACT,RLOGN(1.610,0.7782)*1;            REVIEW MISSION SIM DATA
        AWAIT(3),CCLS;                            WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*.25;          PREPS FOR END-TO-END TEST
        GOON;
        ACT,RLOGN(1.610,0.7782)*.75;          END-TO-END SYSTEMS TEST
        FREE,CCLS,2;                              RELEASE CCLS
        ACT,,,N51G;
        ACT,RLOGN(1.610,0.7782)*.75;          REVIEW END-TO-END TEST DATA
        GOON;
        ACT,RLOGN(1.610,0.7782)*.25;          SECURE SPACECRAFT/CENTAUR
        COLCT,TNOW-ATRIB(1),SUBTASK 3.5,;
        ACT,,,N36E;
;
;       ------  SUBTASK 3.6  -------  FINAL CENTAUR CARGO ELEMENT PREPS  -
;
N36A    GOON;
        ACT,TRIAG(0.54,0.6,0.66);             PREP P/L HANDLING FIXTURE
        GOON;
        ACT,TRIAG(1.26,1.4,1.54);             INSTL/CHECKOUT PHF J-HOOKS
N36C    ACCUM,2,2;
        AWAIT(10),MMSE                            WAIT FOR MMSE CANISTER
        ACT,TRIAG(2.7,3,3.3);                 PREPARE MMSE CANISTER
        GOON;
        ACT,TRIAG(.9,1.0,1.1);                MOVE MMSE CANISTER TO SPIF
N36E    ACCUM,2,2;
        ACT,RLOGN(1.610,0.7782)*1;            SERVICE RCS PROPELLANT SYS
        GOON,2;
        ACT,,,N41A;
        ACT,RLOGN(1.610,0.7782)*3;            SERVICE SPACECRAFT PROP SYS
        GOON;
        ACT,RLOGN(1.610,0.7782)*1;            PERFORM STRAY VOLTAGE CHECKS
        GOON;
        ACT,RLOGN(1.610,0.7782)*.6;           INSTALL SMALL ORDINANCE
        AWAIT(3),CCLS;                            WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*.4;           VERIFY ORDINANCE CONTINUITY
        FREE,CCLS;                                RELEASE CCLS
        AWAIT(3),CCLS;                            WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*.6;           INSTALL & VERIFY BATTERIES
        FREE,CCLS;                                RELEASE CCLS
        ACT,RLOGN(1.610,0.7782)*.4;           DISCONNECT SPIF INTERFACES
        GOON;
        ACT,RLOGN(1.610,0.7782)*.5;           CLEAN & INSPECT CENTAUR-S/C
        GOON;
        ACT,RLOGN(1.610,0.7782)*.5;           COMPLETE MOVE PREPS
        GOON;
        ACT,RLOGN(1.610,0.7782)*1;            CENTAUR CARGO DATA REVIEW
        GOON;
```

```
      ACT,RLOGN(1.610,0.7782)*1;             OPEN INTEGRATION CELL
      GOON;
      ACT,RLOGN(1.610,0.7782)*.3;            POSITION PHF/XFER PRESS SYS
      GOON;
      ACT,RLOGN(1.610,0.7782)*.7;            TRANSFER CCE TO PHF
      GOON;
      ACT,RLOGN(1.610,0.7782)*1;             XFER CCE TO MMSE CANISTER
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;            MOVE MMSE CANISTER OUT SPIF
      COLCT,TNOW-XX(2),TIME @ SPIF;
      ACT,TRIAG(0.45,0.5,0.55);              MOVE MMSE CANISTER TO LC 39
      COLCT,TNOW-ATRIB(1),SUBTASK 3.6,,,,2;
      ACT,,,N51H;
      ACT,,,N42A;
;
;     ------  SUBTASK 4.1  -------  LAUNCH COMPLEX 39 PERPARATIONS  ----
;
N41A  AWAIT(11),LC 39;                          WAIT FOR LC 39
      ACT,TRIAG(6.75,7.5,8.25);              CLEAN PAYLOAD CHANGEOUT ROOM
      GOON;
      ACT,TRIAG(0.18,0.2,0.22);              SECURE P/L CHANGEOUT ROOM
      GOON,3;
      ACT,RLOGN(1.610,0.7782)*1.25,,N41H;    CONFIGURE PGHM FOR CENTAUR
      ACT,RLOGN(1.610,0.7782)*.75,,N41F;     INSTALL CENTAUR GSE IN PCR
      ACT,RLOGN(1.610,0.7782)*1.25;          INSTALL S/C GSE IN PCR
N41F  ACCUM,2,2;
      ACT,TRIAG(0.225,0.25,0.275);           POSITION PCF PLATFORMS
      GOON;
      ACT,TRIAG(0.675,0.75,0.825);           VERIFY PCR INTERFACE CABLES
N41H  ACCUM,2,2;
      COLCT,TNOW-ATRIB(1),SUBTASK 4.1,;
      ACT,,,N42A;
;
;     ------  SUBTASK 4.2  -------  CENTAUR CARGO ELEMENT CHECKOUT  ----
;
N42A  ACCUM,2,2;
      ASSIGN,XX(3)=TNOW;                        TIME ENTERED COMPLEX 39
      ACT,TRIAG(0.135,0.15,0.165);           RAISE MMSE CANISTER TO RSS
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;            XFER CENTAUR-S/C TO PGHM
      GOON;
      ACT,TRIAG(0.18,0.2,0.22);              SECURE RSS & CARGO ELEMENT
      GOON;
      ACT,TRIAG(0.135,0.15,0.165);           LOWER & REMOVE MMSE CANISTER
      FREE,MMSE,2;                              RELEASE MMSE CANISTER
      ACT,TRIAG(0.225,0.25,0.275),,N42G;     CONNECT CENT INTERFACE IN RSS
      ACT,TRIAG(0.225,0.25,0.275);           CONNECT S/C INTERFACES IN RSS
N42G  ACCUM,2,2;
      AWAIT(3),CCLS;                            WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*.25;           CONDUCT SPACECRAFT TESTS
      FREE,CCLS,3;                              RELEASE CCLS
      ACT,TRIAG(1.35,1.5,1.65),,N42L;        LAUNCH PAD VALIDATION
      ACT,TRIAG(0.18,0.2,0.22),,N42J;        SECURE CENTAUR CARGO ELEMENT
```

```
        ACT,RLOGN(1.610,0.7782)*.25;           REVIEW SPACECRAFT TEST DATA
N42J    ACCUM,2,2;
        ACT,TRIAG(0.45,0.5,0.55);              SHUTTLE ROLLOUT TO LC 39
N42L    ACCUM,2,2,,2;
        ACT,,,N51I;
        ACT;
        AWAIT(3),CCLS;                            WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*.5;            PREPS FOR TCDT
        GOON;
        ACT,TRIAG(0.25,0.25,0.275);            TERM COUNTDOWN DEMO TEST
        FREE,CCLS;                                RELEASE CCLS
        ACT,RLOGN(1.610,0.7782)*.25;           SECURE FROM TCDT
        COLCT,TNOW-ATRIB(1),SUBTASK 4.2,;
;
;       ------  SUBTASK 4.3  -------  ORBITER INSTALLATION & CHECKOUT  ---
;
        ACT,TRIAG(0.45,0.5,0.55);              OPEN STS PAYLOAD BAY DOORS
        GOON;
        ACT,RLOGN(1.610,0.7782)*.66;           INSTALL CCE IN STS P/L BAY
        GOON,2;
        ACT,TRIAG(0.225,0.25,0.275),,N43E;     INSTALL STS ACCESS PLATFORMS
        ACT,RLOGN(1.610,0.7782)*.33;           INSTALL CISS/SMCH INTERFACES
N43E    ACCUM,2,2;
        ACT,RLOGN(1.610,0.7782)*.33;           INSTALL PROP DUMP LINES
        GOON;
        ACT,RLOGN(1.610,0.7782)*.33;           INSTALL LH2 PROPELLANT LINES
        AWAIT(3),CCLS;                            WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*.33;           INTERFACE VERIF TEST, PART 1
        FREE,CCLS;                                RELEASE CCLS
        ACT,RLOGN(1.610,0.7782)*.66;           LEAK CHECK PROPELLANT LINES
        GOON,3;
        ACT,,,N51J;
        ACT,RLOGN(1.610,0.7782)*.66,,N43K;     INSULATION FOAM & CLOSEOUT
        ACT;
        AWAIT(3),CCLS;                            WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*.66;           INTERFACE VERIF TEST, PART 2
        FREE,CCLS;                                RELEASE CCLS
N43K    ACCUM,2,2;
        AWAIT(3),CCLS;                            WAIT FOR CCLS
        ACT,RLOGN(1.610,0.7782)*.66;           CENTAUR END-TO-END VERIF
        FREE,CCLS;                                RELEASE CCLS
        COLCT,TNOW-ATRIB(1),SUBTASK 4.3,;
;
;       ------  SUBTASK 4.4  -------  CCE PRELAUNCH CLOSEOUT  ------------
;
        ACT,RLOGN(1.610,0.7782)*.33;           SECURE CENTAUR CARGO ELEMENT
        GOON;
        ACT,TRIAG(0.45,0.5,0.55);              SECURE ORBITER
        GOON,2;
        ACT,TRIAG(1.125,1.25,1.375),,N44D;     LOAD OMS PROPELLANT
        ACT,TRIAG(0.594,0.66,0.726);           LOAD APU PROPELLANT
N44D    ACCUM,2,2;
        AWAIT(2),CCLS;                            WAIT FOR CCLS
```

```
         ACT,RLOGN(1.610,0.7782)*.25;          ACTIVATE CCE/STS ELECTRICS
         GOON;
         ACT,TRIAG(0.18,0.2,0.22);             CLEAR LC 39/INSTL ORDINANCE
         GOON;
         ACT,TRIAG(0.18,0.2,0.22);             STS ORDINANCE RESISTANCE CKS
         FREE,CCLS;                               RELEASE CCLS
         ACT,TRIAG(0.54,0.6,0.66);             STS ORDINANCE CLOSEOUT
         GOON,2;
         ACT,,,N51K;
         ACT,RLOGN(1.610,0.7782)*.33;          FINAL SPACECRAFT CHECKS
         GOON,3;
         ACT,TRIAG(0.594,0.66,0.726),,N44M;    LOAD ORBITER MASS MEMORY
         ACT,RLOGN(1.610,0.7782)*.25,,N44M;    REVIEW SPACECRAFT DATA
         ACT,TRIAG(0.594,0.66,0.726);          ORBITER FUEL CELL CLOSEOUT
N44M     ACCUM,3,3;
         ACT,TRIAG(0.594,0.66,0.726);          ORBITER CREW CABIN CLOSEOUT
         GOON,4;
         ACT,RLOGN(1.610,0.7782)*.25,,N44R;    REMOVE NON-FLIGHT ITEMS
         ACT,RLOGN(1.610,0.7782)*.33,,N44R;    REVIEW CENTAUR DATA
         ACT,RLOGN(1.610,0.7782)*.33,,N44R;    FINAL CENTAUR CARGO INSPECT
         ACT;
         AWAIT(2),CCLS;                           WAIT FOR CCLS
         ACT,RLOGN(1.610,0.7782)*.33;          INSTALL CISS FLIGHT BATTERY
         FREE,CCLS;                               RELEASE CCLS
N44R     ACCUM,4,4;
         COLCT,TNOW-ATRIB(1),SUBTASK 4.4,,,,2;
;
;        ------ SUBTASK 4.5 ------- LAUNCH COUNTDOWN -----------------
;
         ACT,TRIAG(0.297,0.33,0.363),,N45D;    CONNECT ORDINANCE
         ACT;
         AWAIT(2),CCLS;                           WAIT FOR CCLS
         ACT,RLOGN(1.610,0.7782)*.25;          CENTAUR-S/C STRAY VOLT CHKS
         FREE,CCLS;                               RELEASE CCLS
         ACT,RLOGN(1.610,0.7782)*.15;          CHECK CENTAUR-S/C ORDINANCE
N45D     ACCUM,2,2;
         ACT,TRIAG(0.36,0.4,0.44);             PROPELLANT LOAD PREPARATIONS
         GOON;
         ACT,TRIAG(0.81,0.9,0.99);             PAYLOAD BAY CLOSEOUT
         AWAIT(1),CCLS/2;                         WAIT FOR CCLS
         ACT,RLOGN(1.610,0.7782)*.2;           POWER UP CENT/VERIFY STATUS
N45G     ACCUM,2,2,,2;
         ACT,TRIAG(0.297,0.33,0.363),,N45J;    DISCONN CCE/CLOSE P/L DOORS
         ACT,TRIAG(1.75,1.75,2.031);           CISS/CENTAUR GHE TO 2000 PSI
         GOON;
         ACT,TRIAG(.35,.35,.403),,N45P;        CISS/CENTAUR GHE TO 4000 PSI
N45J     GOON;
         ACT,TRIAG(.15,.15,.173);              PREPARE LH2/LO2 TANKNG SKIDS
         GOON;
         ACT,TRIAG(.33,.33,.38);               LH2 & LO2 CRYO PROP LOADING
         GOON,3;
         ACT,TRIAG(.33,.33,.38),,N45P;         IMG CALIBRATION
         ACT,TRIAG(.25,.25,.288),,N45P;        IMG ALIGNMENT
```

```
        ACT,TRIAG(.25,.25,.288);              LO2/LH2 TOPOFF & REPLENISH
N45P    ACCUM,4,4;
        COLCT,TNOW-ATRIB(1),SUBTASK 4.5,;
        COLCT,TNOW-XX(3),TIME @ LC 39;
        FREE,LC 39;                              RELEASE LAUNCH COMPLEX 39
        ACT,,,N52A;
;
;       ------  SUBTASK 5.1  -------  EXERCISES & SIMULATIONS  -----------
;
N51A    ACCUM,2,2;
        ACT,TRIAG(.25,.25,.75);               CPOCC IN-HOUSE EXERCISE #1
N51B    ACCUM,2,2;
        ACT,TRIAG(.25,.25,.75);               CPOCC IN-HOUSE EXERCISE #2
N51C    ACCUM,2,2;
        ACT,TRIAG(.25,.25,.75);               CPOCC IN-HOUSE EXERCISE #3
N51D    ACCUM,2,2;
        ACT,TRIAG(1,1,1.5);                   CPOCC-S/C POCC EXERCISE #1
N51E    ACCUM,2,2;
        ACT,TRIAG(1,1,1.5);                   CPOCC-S/C POCC EXERCISE #2
N51F    ACCUM,2,2;
        ACT,TRIAG(1,1,1.5);                   JOINT INTEGRATED SIM #1
N51G    ACCUM,2,2;
        ACT,TRIAG(2,2,2.5);                   JOINT INTEGRATED SIM #2
N51H    ACCUM,2,2;
        ACT,TRIAG(1,1,1.5);                   LAUNCH READINESS DEMO #1
N51I    ACCUM,2,2;
        ACT,TRIAG(2,2,2.5);                   JOINT INTEGRATED SIM #3
N51J    ACCUM,2,2;
        ACT,TRIAG(1,1,1.5);                   LAUNCH READINESS DEMO #2
N51K    ACCUM,2,2;
        ACT,TRIAG(1,1,1.5);                   JOINT INTEGRATED SIM #4
        COLCT,TNOW-ATRIB(1),SUBTASK 5.1,;
        ACT,,,N45G;
;
;       ------  SUBTASK 5.2  -------  ASCENT  ----------------------------
;
N52A    ASSIGN,XX(4)=TNOW;                    LAUNCH TIME
        ACT,.07;                              ORBITER ASCENT
        GOON;
;
;       ------  SUBTASK 5.3  -------  CENTAUR CARGO CHECKOUT/DEPLOY  -----
;
        ACT,.04;                              MONITOR CENTAUR/CISS SYSTEMS
        GOON,2;
        ACT,.2,,N53C;                         CENTAUR/CISS CHECKOUT
        ACT,.2;                               SPACECRAFT SYSTEMS CHECKOUT
N53C    ACCUM,2,2;
        ACT,.02;                              DEPLOY CENTAUR/SPACECRAFT
        FREE,SPIF CELL;                          RELEASE INTEGRATION CELL
        GOON,2;
        ACT,,,N61A;
```

```
;
;     ------  SUBTASK 5.4  -------  CENTAUR FLIGHT  -------------------
;
      ACT,.032;                              MANEL.ER STS AWAY FM CENTAUR
      GOON;
      ACT,.0055;                             CENTAUR MAIN ENGINE START #1
      GOON;
      ACT,.2167;                             HOLMANN TRANSFER ORBIT
      GOON;
      ACT,.0014;                             CENTAUR MAIN ENGINE START #2
      GOON;
      ACT,.0055;                             SEPARATE S/C FROM CENTAUR
      GOON;
      ACT,.021;                              CENT ORBIT DEFLECT/BLOWDOWN
      FREE,CCLS/2;                              RELEASE TWO CCLS'S
      COLCT,TNOW-ATRIB(1),SUBTASK 5.4,;
      TERM;
;
;     ------  SUBTASK 6.1  -------  MONITOR CISS  ---------------------
;
N61A  GOON;
      ACT,.1;                                PUT CISS INTO SAFE CONDITION
      GOON;
      ACT,6.0;                               MONITOR CISS SYSTEMS
      GOON;
      ACT,0.5;                               PREPARE CISS FOR RE-ENTRY
      GOON;
      ACT,0.04;                              MONITOR CISS DURING RE-ENTRY
      COLCT,TNOW-XX(4),LENGHT OF FLIGHT;
      ASSIGN,ATRIB(3)=ATRIB(3)+1;               COUNT # OF CISS FLIGHTS
;
;     ------  SUBTASK 6.2  -------  REMOVE CISS  ----------------------
;
      ASSIGN,XX(5)=TNOW;                        END OF FLIGHT TIME
      ACT,TRIAG(.315,.35,.385);              ORBITER POST-LANDING CHECKS
      GOON;
      ACT,TRIAG(.18,.2,.22);                 MOVE ORBITER TO OPF
      GOON;
      ACT,TRIAG(.9,1.0,1.1);                 OPEN PAYLOAD BAY DOORS
      GOON,3;
      ACT,RLOGN(1.610,0.7782)*1,,N62G;       DISCONNECT CISS ELECTRICS
      ACT,RLOGN(1.610,0.7782)*2,,N62G;       DISCONNECT CISS FLUIDS
      ACT,RLOGN(1.610,0.7782)*1;             DISCONNECT CISS STRUCTURE
N62G  ACCUM,3,3;
      ACT,RLOGN(1.610,0.7782)*.5;            ATTACH CISS LIFTING SLINGS
      GOON;
      ACT,TRIAG(.45,.5,.55);                 LIFT CISS FROM ORBITER
      AWAIT(13),TTF;                            WAIT FOR TTF
      ACT,TRIAG(.225,.25,.275);              PLACE CISS ON TTF
      COLCT,TNOW-ATRIB(1),SUBTASK 6.2,;
      COLCT,TNOW-XX(5),TIME TO REMVE CISS;
```

```
;
;     ------  SUBTASK 6.3  -------  CISS REFURBISHMENT  ---------------
;
N63A  ASSIGN,XX(6)=TNOW;                          TIME START REFURBISHMENT
      ACT,TRIAG(0.9,1,1.1);                     TRANSPORT CISS TO HANGAR J
      GOON;
      ACT,RLOGN(1.610,0.7782)*.5;               REMOVE CISS FROM TTF
      FREE,TTF;                                   RELEASE TTF
      ACT,,ATRIB(3).GE.6,N71A;                  DO NOT REFURB IF 6 FLIGHTS
      ACT;
      GOON,3;
      ACT,RLOGN(1.610,0.7782)*6,,N63D;          CISS MECHANICAL INSPECTION
      ACT,RLOGN(1.610,0.7782)*6,,N63D;          CISS ELECTRICAL INSPECTION
      ACT,RLOGN(1.610,0.7782)*4;                INSPECT FLUID LINE INSULATE
N63D  ACCUM,3,3,,2;
      ACT,RLOGN(1.610,0.7782)*3,,N63G;          PREPS FOR STANDARD TURN ON
      ACT,RLOGN(1.610,0.7782)*2;                TRANSDUCER RINGOUT (PWR OFF)
      GOON;
      ACT,RLOGN(1.610,0.7782)*3,,N63J;          TRANSDUCER RINGOUT (PWR ON)
N63G  AWAIT(7),CCLS;                              WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*1;                STANDARD TURN ON
      FREE,CCLS;                                  RELEASE CCLS
N63J  ACCUM,2,2;
      AWAIT(7),CCLS;                              WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*3;                AVONICS SUBSYSTEM FUNCT CK
      FREE,CCLS;                                  RELEASE CCLS
      AWAIT(7),CCLS;                              WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*4;                CISS VENT SYSTEM CHECKOUT
      FREE,CCLS;                                  RELEASE CCLS
      ACT,RLOGN(1.610,0.7782)*2;                HELIUM SYSTEM CHECK
      AWAIT(7),CCLS;                              WAIT FOR CCLS
      ACT,RLOGN(1.610,0.7782)*4;                PAVCS CHECKOUT
      FREE,CCLS;                                  RELEASE CCLS
      ACT,RLOGN(1.610,0.7782)*2;                PURGE SYSTEM CHECKOUT
      COLCT,TNOW-ATRIB(1),SUBTASK 6.3,;
      COLCT,TNOW-XX(6),TIME TO REFURBUSH;
      AWAIT(8),CX36;                              AWAIT COMPLEX 36A FREE
      AWAIT(12),TTF;                              WAIT FOR TTF
      ACT,,,N21A;                               MOVE CISS TO CX 36A
;
;     ----------------------  TERMINATE CISS  -------------------------
;
N71A  ASSIGN,XX(9)=XX(9)+1;                        COUNT FINISHED CISS
      ASSIGN,XX(8)=1;                              SET CISS FLAG - NEW CISS
      TERM;
;
;     ----------------------  END MAIN PROGRAM  -----------------------
;
      ENDNETWORK;
INIT,0,1825;
SIMULATE;
FIN;
```

APPENDIX F:

S/CGPS MODEL OUTPUT

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************************************************************************
*                                                                      *
*                                                                      *
*                                                                      *
*                                                                      *
*                     * * * * * * * * * * * * * * *                    *
*                     *                           *                    *
*                     *    SLAM II VERSION 2.3    *                    *
*                     *                           *                    *
*                     * * * * * * * * * * * * * * *                    *
*                                                                      *
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*                                                                      *
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*                                                                      *
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S L A M   E C H O   R E P O R T

SIMULATION PROJECT CENTAUR GND PROC SYS   BY BROCK

DATE 11/23/1985   RUN NUMBER 1 OF 1

SLAM VERSION JUN 84

GENERAL OPTIONS

PRINT INPUT STATEMENTS (ILIST):	YES
PRINT ECHO REPORT (IECHO):	YES
EXECUTE SIMULATIONS (IXQT):	YES
WARN OF DESTROYED ENTITIES:	NO
PRINT INTERMEDIATE RESULTS HEADING (IPIRH):	YES
PRINT SUMMARY REPORT (ISMRY):	YES

LIMITS ON FILES

MAXIMUM NUMBER OF USER FILES (MFILS):	15
MAXIMUM NUMBER OF USER ATTRIBUTES (MATR):	3
MAXIMUM NUMBER OF CONCURRENT ENTRIES (MNTRY):	100

FILE SUMMARY

FILE NUMBER	INITIAL ENTRIES	RANKING CRITERION
1	0	FIFO
2	0	FIFO
3	0	FIFO
4	0	FIFO
5	0	FIFO
6	0	FIFO
7	0	FIFO
8	0	FIFO
9	0	FIFO
10	0	FIFO
11	0	FIFO
12	0	FIFO
13	0	FIFO
14	0	FIFO
15	0	FIFO

STATISTICS BASED ON OBSERVATIONS

COLCT NUMBER	COLLECTION MODE	IDENTIFIER	HISTOGRAM SPECIFICATIONS NCEL	HLOW	HWID
1	NETWORK	SUBTASK 1.1			
2	NETWORK	SUBTASK 1.2			
3	NETWORK	SUBTASK 2.1			
4	NETWORK	SUBTASK 2.2			
5	NETWORK	TIME @ CX 36A			
6	NETWORK	SUBTASK 2.3			
7	NETWORK	SUBTASK 3.1			
8	NETWORK	SUBTASK 3.2			
9	NETWORK	SUBTASK 3.3			
10	NETWORK	SUBTASK 3.4			
11	NETWORK	SUBTASK 3.5			
12	NETWORK	TIME @ SPIF			
13	NETWORK	SUBTASK 3.6			
14	NETWORK	SUBTASK 4.1			
15	NETWORK	SUBTASK 4.2			
16	NETWORK	SUBTASK 4.3			
17	NETWORK	SUBTASK 4.4			
18	NETWORK	SUBTASK 4.5			
19	NETWORK	TIME @ LC 39			
20	NETWORK	SUBTASK 5.1			
21	NETWORK	SUBTASK 5.4			
22	NETWORK	LENGHT OF FLIGHT			
23	NETWORK	SUBTASK 6.2			
24	NETWORK	TIME TO REMVE CI			
25	NETWORK	SUBTASK 6.3			
26	NETWORK	TIME TO REFURBUS			

STATISTICS FOR TIME PERSISTENT VARIABLES

TIMST NUMBER	VARIABLE	IDENTIFIER	INITIAL VALUE	HISTOGRAM SPECIFICATIONS NCEL	HLOW	HWID
1	XX(8)	CISS FLAG COUNT	0.000E+00			
2	XX(9)	CISS COUNT	0.000E+00			

CONTINUOUS VARIABLES

NUMBER OF DD EQUATIONS (NNEQD):	0
NUMBER OF SS EQUATIONS (NNEQS):	0
MINIMUM STEP SIZE (DTMIN):	0.1000E+19
MAXIMUM STEP SIZE (DTMAX):	0.1000E+21
TIME BETWEEN SAVE POINTS (DTSAV):	0.5000E+02
ACCURACY ERROR SPECIFICATION (LLERR):	WARNING
ABSOLUTE ERROR LIMIT (AAERR):	0.1000E-04
RELATIVE ERROR LIMIT (RRERR):	0.1000E-04

RECORDING OF PLOTS/TABLES

PLOT/TABLE NUMBER 1

INDEPENDENT VARIABLE:	NOW
IDENTIFIER:	# OF DAYS
DATA STORAGE UNIT:	NSET/QSET
DATA OUTPUT FORMAT:	PLOT
TIME BETWEEN PLOT POINTS (DTPLT):	0.5000E+02
STARTING TIME OF PLOT (TTSRT):	0.0000E+00
ENDING TIME OF PLOT (TTEND):	0.1825E+04
DATA POINTS AT EVENTS (KKEVT):	YES

DEPENDENT VARIABLES

VARIABLE	SYM	IDENTIFIER	LOW ORD VALUE	HIGH ORD VALUE
XX(7)	C	# OF VEHICLES	MIN NEAR 0.0E+00	MAX NEAR 0.0E+00

RANDOM NUMBER STREAMS

STREAM NUMBER	SEED VALUE	REINITIALIZATION OF STREAM
1	428956419	NO
2	1954324947	NO
3	1145661099	NO
4	1835732737	NO
5	794161987	NO
6	1329531353	NO
7	200496737	NO
8	633816299	NO
9	1410143363	NO
10	1282538739	NO

INITIALIZATION OPTIONS

BEGINNING TIME OF SIMULATION (TTBEG):	0.0000E+00
ENDING TIME OF SIMULATION (TTFIN):	0.1825E+04
STATISTICAL ARRAYS CLEARED (JJCLR):	YES
VARIABLES INITIALIZED (JJVAR):	YES
FILES INITIALIZED (JJFIL):	YES

NSET/QSET STORAGE ALLOCATION

DIMENSION OF NSET/QSET (NNSET):	10000
WORDS ALLOCATED TO FILING SYSTEM:	700
WORDS ALLOCATED TO INDEXED LIST TAGS:	102
WORDS ALLOCATED TO NETWORK:	8345
WORDS AVAILABLE FOR PLOTS/TABLES:	853

INPUT ERRORS DETECTED: 0

EXECUTION WILL BE ATTEMPTED

S L A M   S U M M A R Y   R E P O R T

SIMULATION PROJECT CENTAUR GND PROC SYS   BY BROCK

DATE 11/23/1985   RUN NUMBER   1 OF   1

CURRENT TIME   0.1825E+04
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
SUBTASK 1.1	0.405E+02	0.359E+02	0.885E+00	0.152E+02	0.659E+02	2
SUBTASK 1.2	0.368E+02	0.744E+01	0.202E+00	0.243E+02	0.519E+02	20
SUBTASK 2.1	0.885E+03	0.593E+03	0.670E+00	0.615E+02	0.180E+04	11
SUBTASK 2.2	0.847E+03	0.536E+03	0.632E+00	0.111E+03	0.160E+04	10
TIME @ CX 36A	0.126E+03	0.150E+02	0.119E+00	0.101E+03	0.158E+03	10
SUBTASK 2.3	0.877E+03	0.533E+03	0.608E+00	0.147E+03	0.162E+04	10
SUBTASK 3.1	0.864E+03	0.536E+03	0.620E+00	0.131E+03	0.161E+04	10
SUBTASK 3.2	0.892E+03	0.532E+03	0.597E+00	0.159E+03	0.164E+04	10
SUBTASK 3.3	0.892E+03	0.534E+03	0.599E+00	0.164E+03	0.164E+04	10
SUBTASK 3.4	0.912E+03	0.532E+03	0.583E+00	0.182E+03	0.166E+04	10
SUBTASK 3.5	0.924E+03	0.531E+03	0.574E+00	0.194E+03	0.167E+04	10
TIME @ SPIF	0.674E+02	0.867E+01	0.129E+00	0.555E+02	0.853E+02	10
SUBTASK 3.6	0.945E+03	0.532E+03	0.563E+00	0.211E+03	0.169E+04	10
SUBTASK 4.1	0.937E+03	0.531E+03	0.566E+00	0.207E+03	0.168E+04	10
SUBTASK 4.2	0.950E+03	0.531E+03	0.559E+00	0.220E+03	0.169E+04	10
SUBTASK 4.3	0.957E+03	0.532E+03	0.556E+00	0.226E+03	0.170E+04	10
SUBTASK 4.4	0.963E+03	0.532E+03	0.552E+00	0.232E+03	0.171E+04	10
SUBTASK 4.5	0.971E+03	0.531E+03	0.547E+00	0.237E+03	0.171E+04	10
TIME @ LC 39	0.256E+02	0.304E+01	0.119E+00	0.209E+02	0.316E+02	10
SUBTASK 5.1	0.962E+03	0.532E+03	0.553E+00	0.231E+03	0.170E+04	10
SUBTASK 5.4	0.971E+03	0.531E+03	0.547E+00	0.237E+03	0.171E+04	10
LENGHT OF FLIGHT	0.697E+01	0.206E-04	0.295E-05	0.697E+01	0.697E+01	10
SUBTASK 6.2	0.975E+03	0.495E+03	0.508E+00	0.275E+03	0.172E+04	9
TIME TO REMVE CI	0.795E+02	0.241E+02	0.303E+00	0.313E+02	0.116E+03	9
SUBTASK 6.3	0.102E+04	0.495E+03	0.485E+00	0.326E+03	0.176E+04	9
TIME TO REFURBUS	0.451E+02	0.536E+01	0.119E+00	0.387E+02	0.554E+02	9

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
CISS FLAG COUNT	0.000	0.000	0.00	0.00	1825.000	0.00
CISS COUNT	0.000	0.000	0.00	0.00	1825.000	0.00

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	AWAIT	0.018	0.132	1	0	3.242
2	AWAIT	0.000	0.000	1	0	0.000
3	AWAIT	0.002	0.049	1	0	0.055
4	AWAIT	0.000	0.000	1	0	0.000
5	AWAIT	0.000	0.000	1	0	0.000
6	AWAIT	0.012	0.107	1	0	0.131
7	AWAIT	0.000	0.000	1	0	0.000
8	AWAIT	0.000	0.000	1	0	0.000
9	AWAIT	0.000	0.000	1	0	0.000
10	AWAIT	0.000	0.000	1	0	0.000
11	AWAIT	0.000	0.000	1	0	0.000
12	AWAIT	0.027	0.164	1	0	4.561
13	AWAIT	0.364	0.481	1	1	66.495
14	QUEUE	4.798	2.895	10	9	437.800
15	QUEUE	0.000	0.000	1	0	0.000
16	CALENDAR	6.168	3.147	19	7	2.236

SERVICE ACTIVITY STATISTICS

ACT IND	START NODE LABEL/TYPE	SER CAP	AVERAGE UTIL	STD DEV	CUR UTIL	AVERAGE BLOCK	MAX IDL TME/SER	MAX BSY TME/SER	ENT CNT
0	MATE SELECT	1	0.009	0.10	0	0.00	198.46	2.70	

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	CCLS	2	0.71	0.691	2	1
2	CX36	1	0.72	0.448	1	1
3	SPIF CEL	2	0.64	0.480	1	0
4	MMSE	2	0.16	0.365	1	0
5	LC 39	2	0.24	0.429	1	0
6	TTF	1	0.78	0.414	1	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	CCLS	1	1.2917	0	2
2	CX36	0	0.2780	0	1
3	SPIF CEL	2	1.3586	1	2
4	MMSE	2	1.8413	1	2
5	LC 39	2	1.7566	1	2
6	TTF	0	0.2200	0	1

TABLE NUMBER 1
RUN NUMBER 1

\# OF DAYS   # OF VEHICLES

MINIMUM 0.0000E+00
MAXIMUM 0.2100E+02

PLOT NUMBER 1
RUN NUMBER 1

```
                                SCALES OF PLOT
C=# OF VEHICLE0.000E+00           0.105E+02             0.210E+02
              0   10   20   30   40   50   60   70   80   90  100 DUPS
# OF DAYS
  0.0000E+00  C                        +                        +
  0.5000E+02  + C                      +                        +
  0.1000E+03  +    C                   +                        +
  0.1500E+03  +    C                   +                        +
  0.2000E+03  +      C                 +                        +
  0.2500E+03  +      C                 +                        +
  0.3000E+03  +         C              +                        +
  0.3500E+03  +         C              +                        +
  0.4000E+03  +           C            +                        +
  0.4500E+03  +             C          +                        +
  0.5000E+03  +             C          +                        +
  0.5500E+03  +                C       +                        +
  0.6000E+03  +                        +                        +
  0.6500E+03  +                C       +                        +
  0.7000E+03  +                  C     +                        +
  0.7500E+03  +                    C   +                        +
  0.8000E+03  +                    C   +                        +
  0.8500E+03  +                       C+                        +
  0.9000E+03  +                       C+                        +
  0.9500E+03  +                        +C                       +
  0.1000E+04  +                        +C                       +
  0.1050E+04  +                        +   C                    +
  0.1100E+04  +                        +     C                  +
  0.1150E+04  +                        +     C                  +
  0.1200E+04  +                        +       C                +
  0.1250E+04  +                        +       C                +
  0.1300E+04  +                        +          C             +
  0.1350E+04  +                        +          C             +
  0.1400E+04  +                        +            C           +
  0.1450E+04  +                        +            C           +
  0.1500E+04  +                        +              C         +
  0.1550E+04  +                        +                 C      +
  0.1600E+04  +                        +                 C      +
  0.1650E+04  +                        +                   C    +
  0.1700E+04  +                        +                   C    +
  0.1750E+04  +                        +                      C +
  0.1800E+04  +                        +                      C +
  0.1850E+04  +                        +                        C
              0   10   20   30   40   50   60   70   80   90  100 DUPS
# OF DAYS
```

APPENDIX G:

PERFORMANCE DATA FOR THE S/CGPS SIMULATION MODELS

MODEL CONFIGURATION: STANDARD BASELINE MODEL

VARIABLE	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	4.28	0.61	4.107	4.453
#CENT	41.0	0.0	41.0	41.0
#FLTS	15.9	2.07	15.311	16.488
FLT TIME	236.0	14.6	231.850	240.150
#REFURB	14.0	2.07	13.412	14.588
REFURB TIME	365.0	22.3	358.661	371.339
AWAIT(1)	3.02	1.15	2.693	3.346
AWAIT(8)	86.5	16.3	81.866	91.133
# FOR CX	1.3	0.64	1.118	1.482
AWAIT(12)	71.3	22.6	64.875	77.724
# FOR TTF	1.88	0.33	1.786	1.973
AWAIT(13)	195.0	29.9	186.500	203.499
# FOR TTF	1.0	0.59	0.832	1.168
QUEUE(14)	907.0	50.50	892.645	921.355
# FOR CISS	25.7	2.26	25.058	26.342
CCLS USE	0.610	0.019	0.604	0.615
CX36 USE	0.813	0.052	0.798	0.828
TTF USE	0.850	0.053	0.834	0.865

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: THREE CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	4.22	0.41	4.103	4.337
#CENT	41.0	0.20	40.943	41.057
#FLTS	18.0	2.04	17.201	18.580
FLT TIME	274.0	6.67	272.104	275.896
#REFURB	16.0	2.09	15.406	16.594
REF TIME	421.0	39.0	409.914	432.086
AWAIT(1)	2.39	0.95	2.120	2.660
AWAIT(8)	107.0	2.18	106.380	107.620
# FOR CX	1.26	0.44	1.135	1.385
AWAIT(12)	66.5	2.07	65.912	67.088
# FOR TTF	1.98	0.14	1.940	2.019
AWAIT(13)	210.0	42.0	198.061	221.938
# FOR TTF	1.9	0.42		
QUEUE(14)	781.0	49.8	766.844	795.156
# FOR CISS	23.0	2.11	22.400	23.600
CCLS USE	0.62	0.01	0.617	0.623
CX36 USE	0.88	0.049	0.866	0.894
TTF USE	0.91	0.049	0.896	0.924

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: FOUR CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	5.04	0.40	4.926	5.154
#CENT	41.0	0.20	40.943	41.057
#FLTS	22.6	1.73	22.108	23.092
FLT TIME	326.0	7.33	323.916	328.084
#REFURB	20.6	1.74	20.105	21.095
REF TIME	521.0	30.4	512.359	529.641
AWAIT(1)	2.00	0.85	1.758	2.242
AWAIT(8)	35.5	1.42	35.096	35.904
# FOR CX	2.2	0.45	2.072	2.328
AWAIT(12)	35.5	1.42	35.096	35.904
# FOR TTF	1.88	0.33	1.786	1.974
AWAIT(13)	191.0	2.27	190.354	191.645
# FOR TTF	1.9	0.33	1.806	1.994
QUEUE(14)	667.0	2.97	666.155	667.844
# FOR CISS	17.7	2.03	17.123	18.277
CCLS USE	0.78	0.016	0.775	0.785
CX36 USE	0.89	0.020	0.884	0.896
TTF USE	0.92	0.020	0.914	0.926

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO CX 36 MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	5.74	0.48	5.613	5.886
#CENT	40.9	0.24	40.832	40.968
#FLTS	22.0	1.48	21.579	22.421
FLT TIME	274.0	9.95	271.172	276.828
#REFURB	19.6	1.21	19.256	19.944
REF TIME	425.0	23.5	418.319	431.680
AWAIT(1)	2.62	0.93	2.355	2.884
AWAIT(8)	25.8	7.32	23.719	27.881
# FOR CX	0.9	0.61	0.726	1.073
AWAIT(12)	62.8	14.2	58.763	66.836
# FOR TTF	2.92	0.27	2.843	2.996
AWAIT(13)	126.0	12.4	122.475	129.524
# FOR TTF	1.7	0.35	1.601	1.799
QUEUE(14)	804.0	29.8	795.529	812.470
# FOR CISS	18.1	1.76	17.599	18.600
CCLS USE	0.752	0.007	0.750	0.754
CX36 USE	1.03	0.017	1.025	1.034
TTF USE	0.83	0.011	0.827	0.833

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO TTF MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	7.82	0.87	7.573	8.067
#CENT	41.0	0.14	40.960	41.040
#FLTS	26.1	2.02	25.526	26.674
FLT TIME	342.0	22.6	335.575	348.424
#REFURB	23.7	2.45	23.004	24.396
REF TIME	445.0	41.0	433.345	456.654
AWAIT(1)	1.25	0.62	1.074	1.426
AWAIT(8)	154.0	21.1	148.002	160.000
# FOR CX	4.2	0.94	3.933	4.467
AWAIT(12)	5.39	13.5	1.553	9.227
# FOR TTF	1.06	0.24	0.992	1.128
AWAIT(13)	87.4	26.1	79.981	94.819
# FOR TTF	1.1	0.85	0.858	1.342
QUEUE(14)	602.0	44.6	589.322	614.678
# FOR CISS	14.1	2.24	13.463	14.737
CCLS USE	0.89	0.017	0.885	0.895
CX36 USE	0.93	0.015	0.926	0.934
TTF USE	1.37	0.023	1.363	1.376

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: THREE TTF MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	9.1	0.30	9.015	9.185
#CENT	40.9	0.30	40.815	40.985
#FLTS	26.9	0.52	26.752	27.048
FLT TIME	402.0	77.2	380.055	423.945
#REFURB	25.6	1.37	25.211	25.989
REF TIME	462.0	22.0	455.746	468.254
AWAIT(1)	1.21	0.57	1.048	1.372
AWAIT(8)	226.0	9.59	223.274	228.726
# FOR CX	5.9	0.27	5.823	5.977
AWAIT(12)	0.78	0.32	0.689	0.871
# FOR TTF	1.00	0.00	1.000	1.000
AWAIT(13)	2.31	11.0	0.000	5.437
# FOR TTF	0.4	0.78	0.178	0.622
QUEUE(14)	585.0	22.3	578.662	591.339
# FOR CISS	12.5	0.55	12.344	12.656
CCLS USE	0.93	0.002	0.929	0.931
CX36 USE	0.93	0.004	0.929	0.931
TTF USE	1.65	0.014	1.646	1.654

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO CX 36/THREE CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	5.52	0.62	5.344	5.696
#CENT	41.0	0.20	40.943	41.057
#FLTS	23.7	1.27	23.339	24.061
FLT TIME	301.0	12.4	297.475	304.525
#REFURB	2.16	0.16	2.115	2.205
REF TIME	455.0	35.2	434.994	455.006
AWAIT(1)	2.15	0.78	1.928	2.372
AWAIT(8)	22.9	1.32	22.525	23.275
# FOR CX	1.1	0.68	0.907	1.293
AWAIT(12)	84.0	18.8	78.656	89.344
# FOR TTF	2.92	0.27	2.843	2.997
AWAIT(13)	143.0	21.4	136.917	149.083
# FOR TTF	1.1	0.47	0.966	1.234
QUEUE(14)	681.0	27.5	673.182	688.817
# FOR CISS	15.6	1.62	15.140	16.060
CCLS USE	0.85	0.010	0.847	0.853
CX36 USE	1.25	0.016	1.245	1.255
TTF USE	0.89	0.012	0.887	0.893

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO CX 36/FOUR CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	5.28	0.67	5.090	5.470
#CENT	41.0	0.20	40.943	41.057
#FLTS	24.8	0.96	24.527	25.073
FLT TIME	332.0	6.42	330.175	333.825
#REFURB	22.2	1.42	21.796	22.604
REF TIME	522.0	31.5	543.046	560.954
AWAIT(1)	1.87	0.72	1.665	2.075
AWAIT(8)	36.2	1.25	35.845	36.555
# FOR CX	0.8	0.65	0.615	0.985
AWAIT(12)	91.3	13.4	87.910	95.109
# FOR TTF	2.72	0.45	2.592	2.848
AWAIT(13)	3.74	9.05	1.167	6.313
# FOR TTF	2.1	0.44		
QUEUE(14)	644.0	23.5	637.320	650.680
# FOR CISS	15.0	1.20	14.659	15.341
CCLS USE	0.86	0.005	0.859	0.861
CX36 USE	1.38	0.015	1.376	1.384
TTF USE	0.92	0.005	0.919	0.921

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO CX 36/TWO TTF MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	6.34	1.52	5.908	6.772
#CENT	41.00	0.15	40.957	41.043
#FLTS	27.2	6.57	25.332	29.068
FLT TIME	244.0	21.8	237.803	250.197
#REFURB	24.7	6.57	22.832	26.568
REF TIME	341.0	44.3	328.407	353.593
AWAIT(1)	3.64	1.23	3.29	3.99
AWAIT(8)	49.9	39.2	38.757	61.043
# FOR CX	1.9	1.23	1.55	2.25
AWAIT(12)	30.6	28.0	22.641	38.559
# FOR TTF	1.77	0.43	1.648	1.892
AWAIT(13)	102.0	64.2	83.751	120.249
# FOR TTF	2.2	1.25	1.845	2.555
QUEUE(14)	504.0	133.0	466.194	541.806
# FOR CISS	18.0	6.51	16.149	19.851
CCLS USE	0.76	0.07	0.74	0.78
CX36 USE	1.40	0.093	1.374	1.426
TTF USE	1.45	0.094	1.423	1.477

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO CX 36/THREE CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	8.0	2.55	7.275	8.725
#CENT	41.0	0.00	41.000	41.000
#FLTS	33.8	2.91	32.973	34.627
FLT TIME	282.0	38.7	270.999	293.001
#REFURB	32.3	2.45	31.604	32.996
REF TIME	362.0	24.5	355.036	368.964
AWAIT(1)	4.1	1.85	3.574	4.626
AWAIT(8)	69.8	49.8	55.644	83.956
# FOR CX	3.0	2.44	2.306	3.694
AWAIT(12)	1.96	3.26	1.033	2.887
# FOR TTF	4.22	2.44	3.526	4.914
AWAIT(13)	18.0	16.1	13.423	22.577
# FOR TTF	0.7	1.45	0.288	1.112
QUEUE(14)	365.0	65.6	346.353	383.647
# FOR CISS	4.6	1.09	4.29	4.91
CCLS USE	1.22	0.032	1.211	1.229
CX36 USE	1.43	0.043	1.418	1.442
TTF USE	1.63	0.061	1.613	1.647

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO TTF/THREE CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	7.86	0.50	7.718	8.002
#CENT	40.9	0.27	40.823	40.977
#FLTS	28.4	1.22	28.053	28.747
FLT TIME	349.0	14.5	344.878	353.122
#REFURB	25.6	1.75	25.103	26.097
REF TIME	449.0	29.1	440.728	457.272
AWAIT(1)	0.33	0.24	0.262	0.398
AWAIT(8)	151.0	16.8	146.224	155.776
# FOR CX	4.0	0.62	3.824	4.176
AWAIT(12)	3.22	7.00	1.23	5.21
# FOR TTF	1.04	0.20	0.983	1.097
AWAIT(13)	71.2	14.7	67.021	75.388
# FOR TTF	1.9	0.76	1.684	2.116
QUEUE(14)	467.0	28.4	458.927	475.073
# FOR CISS	11.2	1.33	10.822	11.578
CCLS USE	0.99	0.005	0.989	0.991
CX36 USE	1.00	0.004	0.999	1.001
TTF USE	1.41	0.013	1.406	1.414

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO TTF/FOUR CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	95% CONFIDENCE INTERVAL UPPER LIMIT
#CISS	7.18	0.44	7.054	7.305
#CENT	40.9	0.3	40.815	40.985
#FLTS	28.6	0.9	28.344	28.856
FLT TIME	405.0	9.27	402.365	407.635
#REFURB	26.0	1.5	25.574	26.426
REF TIME	486.0	18.9	480.628	491.372
AWAIT(1)	0.36	0.25	0.289	0.431
AWAIT(8)	194.0	14.8	189.793	198.207
# FOR CX	2.7	0.55	2.547	2.856
AWAIT(12)	2.09	4.23	0.888	3.292
# FOR TTF	1.04	1.98	0.477	1.603
AWAIT(13)	43.4	11.1	40.245	46.555
# FOR TTF	1.9	0.74	1.69	2.11
QUEUE(14)	461.0	30.2	452.415	469.585
# FOR CISS	10.6	1.02	10.31	10.89
CCLS USE	1.00	0.004	0.999	1.001
CX36 USE	1.00	0.004	0.999	1.001
TTF USE	1.35	0.011	1.347	1.353

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO CX 26/TWO TTF/THREE CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	7.46	1.27	7.099	7.821
#CENT	40.9	0.27	40.823	40.977
#FLTS	31.5	5.89	29.826	33.174
FLT TIME	259.0	21.7	252.832	265.168
#REFURB	28.9	5.75	27.266	30.534
REF TIME	371.0	43.9	358.521	383.479
AWAIT(1)	4.55	1.16	4.22	4.88
AWAIT(8)	65.5	28.8	57.313	73.687
# FOR CX	2.2	1.2	1.859	2.541
AWAIT(12)	29.0	17.2	24.111	33.889
# FOR TTF	1.92	0.27	1.843	1.997
AWAIT(13)	102.0	27.6	94.155	109.845
# FOR TTF	2.0	1.29	1.633	2.367
QUEUE(14)	186.0	125.0	150.468	221.532
# FOR CISS	5.2	6.36	3.392	7.008
CCLS USE	1.18	0.077	1.158	1.202
CX36 USE	1.54	0.097	1.512	1.568
TTF USE	1.61	0.099	1.582	1.638

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO CX 36/TWO TTF/FOUR CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	5.86	1.35	5.476	6.245
#CENT	41.0	0.00	41.000	41.000
#FLTS	23.9	6.84	21.956	25.844
FLT TIME	244.0	23.0	237.462	250.537
#REFURB	21.5	6.25	19.723	23.277
REF TIME	353.0	31.2	344.131	361.869
AWAIT(1)	4.2	1.7	3.717	4.683
AWAIT(8)	80.1	22.7	73.647	86.553
# FOR CX	1.8	1.06	1.499	2.101
AWAIT(12)	58.5	23.6	52.792	65.208
# FOR TTF	2.57	0.22	2.507	2.633
AWAIT(13)	165.0	48.1	151.327	178.673
# FOR TTF	1.6	1.08	1.293	1.907
QUEUE(14)	371.0	199.0	314.433	427.567
# FOR CISS	13.7	7.18	11.659	15.741
CCLS USE	0.91	0.105	0.88	0.94
CX36 USE	1.61	0.174	1.561	1.659
TTF USE	1.80	0.177	1.75	1.85

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: TWO CX 36/THREE TTF/ THREE CISS MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	9.59	1.5	9.164	10.016
#CENT	41.0	0.00	41.000	41.000
#FLTS	36.4	3.69	35.351	37.449
FLT TIME	311.0	25.8	303.666	318.334
#REFURB	33.4	4.27	32.186	34.614
REF TIME	388.0	34.3	378.25	397.75
AWAIT(1)	4.88	1.24	4.528	5.232
AWAIT(8)	110.0	3.37	109.042	110.958
# FOR CX	3.7	0.99	3.419	3.981
AWAIT(12)	55.3	3.71	54.245	56.355
# FOR TTF	1.18	0.39	1.069	1.291
AWAIT(13)	55.6	37.1	45.054	66.146
# FOR TTF	0.4	1.6	0.000	0.855
QUEUE(14)	67.3	56.4	51.268	83.332
# FOR CISS	2.0	3.52	0.999	3.001
CCLS USE	1.29	0.03	1.281	1.299
CX36 USE	1.64	0.047	1.627	1.653
TTF USE	2.01	0.065	1.992	2.028

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: 120 DAY INPUT MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	4.24	0.48	4.104	4.377
#CENT	30.9	0.24	30.832	30.968
#FLTS	15.7	1.54	15.262	16.138
FLT TIME	232.0	9.61	229.268	234.732
#REFURB	13.7	1.51	13.271	14.129
REF TIME	363.0	1.81	362.485	363.515
AWAIT(1)	3.00	1.31	2.628	3.372
AWAIT(8)	82.6	17.3	77.682	87.518
# FOR CX	1.4	0.5	1.258	1.542
AWAIT(12)	70.5	14.8	66.293	74.707
# FOR TTF	1.96	0.2	1.903	2.017
AWAIT(13)	201.0	26.6	193.439	208.562
# FOR TTF	1.9	0.48	1.764	2.036
QUEUE(14)	624.0	51.3	609.418	638.582
# FOR CISS	15.1	1.53	14.665	15.535
CCLS USE	0.53	0.006	0.528	0.532
CX36 USE	0.81	0.043	0.798	0.822
TTF USE	0.85	0.043	0.838	0.862

SIGNIFICANT STATISTICS FROM SIMULATION RUN

SIMULATION RUN CONFIGURATION: 180 DAY INPUT MODEL

	SAMPLE MEAN	STANDARD DEVIATION	95% CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
#CISS	3.96	0.28	3.880	4.040
#CENT	20.9	0.24	20.832	20.968
#FLTS	14.9	0.77	14.681	15.119
FLT TIME	234.0	3.83	232.911	235.089
#REFURB	12.9	0.55	12.744	13.056
REF TIME	371.0	9.00	368.442	373.558
AWAIT(1)	2.61	1.05	2.312	2.908
AWAIT(8)	68.3	9.98	65.463	71.137
# FOR CX	1.0	0.14	0.96	1.04
AWAIT(12)	72.9	9.51	70.197	75.603
# FOR TTF	1.94	0.24	1.872	2.008
AWAIT(13)	208.0	9.03	205.433	210.567
# FOR TTF	2.0	0.28	1.92	2.08
QUEUE(14)	151.0	44.6	138.322	163.678
# FOR CISS	6.0	0.84	5.761	6.239
CCLS USE	0.49	0.003	0.489	0.491
CX36 USE	0.79	0.046	0.777	0.803
TTF USE	0.84	0.046	0.827	0.853

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Vita

John Timothy Brock was born on 15 November 1949 in Rome, Georgia. He graduated from Adairsville High School in Adairsville, Georgia in 1967 and attended the University of Georgia in Athens, Georgia, from which he recieved the degree of Bachelor of Science in Mathematics in May 1972. Upon graduation he recieved a commission in the United States Air Force through the Reserve Officers' Training Program. He entered active duty in September 1972. His initial assignment was as the Training Officer at Detachment 8, 14th Missile Warning Squadron, Laredo AFB, Texas until January 1975. He was then assigned to the 16th Surveillance Squadron, Shemya AFB, Alaska, as a expert Space Surveillance Systems Officer. His following assignment was to the 4000 Aerospace Applications Group, Offutt AFB, Nebraska. His duties there included Satellite Systems Officer, Satellite Systems Director, Head of the Early Orbit Planning Team, and Assistant Chief of the Command & Control Branch. Most recently, he was assigned to the Office of the Secretary of the Air Force, Office of Special Projects, Los Angeles AFS, California, where he was a Launch Systems Integrations Officer. He entered the Air Force Institute of Technology in May of 1984.

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