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Thermal Expert System (TEXSYS) Final Report—Systems Autonomy Demonstration Project Volume 2 – Results

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THERMAL EXPERT SYSTEM (TEXSYS)
FINAL REPORT

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GLOSSARY

Acknowledge - Operator action which indicates reading of a message. No blockage of system activities will be induced.

Boeing Aerospace Thermal Bus System - The prototype thermal bus system as described in the Test Article Description (TAD).

Confirmation - Operator action which indicates reading of a message and permission granted to proceed with proposed action. System activities are blocked.

Control - Actions taken by the operator or expert system that changes or maintains the state of the system.

DACS - The Thermal Test Bed (TTB) DACS is a system of hardware and software that provides data collection and performs control functions for Space Station Thermal Management System thermal test articles. DACS can also allow for real-time trend monitoring, analysis, and fault detection, provide temporary data storage and retrieval during stand-alone operation, and allow growth as the test bed evolves.

Detection - The search and recognition process used to spot off-nominal behavior.

Faults - A single fault that could result in a directly related system fault.

Isolation

- in software - The pinpointing of a particular object or set of objects that are responsible for an off-nominal behavior.

- in hardware - The actions taken to partition a part of the thermal bus fluid loop from the rest of the bus.

Recovery - Actions taken to return to the same operational state or hardware configuration.

TTB - The TTB is an evolutionary program, providing the Space Station program with critical elements of thermal technology development and integrated system performance assessment. Primary goals of the TTB are: development of a ground-based system representative of the Space Station Thermal Management System (TMS) to verify readiness of two-phase thermal technology for use in the initial operational capability (IOC) Space Station; and to provide a mechanism by which advanced technology thermal control concepts are evaluated at the system level for Space Station applications.

Uncertainty - Uncertainty reasoning is a mechanism which is used to measure the degree of belief of a particular piece of knowledge. It enables evidence to be gathered to determine the degree to which a proposition is true.

Systems Autonomy Demonstration - The computer hardware and software that support TEXSYS, HITEX, TDAS and the BATBS.

Validation - Testing of a system by operation to prove that it produces the desired results. In this phase of testing the Expert System operates the BATBS in a continuum of fully manual to fully autonomous mode.

Verification - Testing of a system by analysis to prove its truth and accuracy. In this phase of testing Expert System rules, models and knowledge base will be evaluated against requirements and engineering knowledge for its ability to perform with the BATBS.

1.0 INTRODUCTION

As the National Aeronautics and Space Administration (NASA) progresses into the development phase of the Space Station, it recognizes the importance and potential payback of highly autonomous spacecraft subsystems.

The Crew and Thermal Systems Division (CTSD) has the overall responsibility for the development and integration of the Thermal Control System (TCS) for Space Station. An integral element of this responsibility is the establishment and maintenance of a TCS demonstration focal point for the agency. The Thermal Test Bed (TTB) provides this focus. During the definition stage of the TTB, it was recognized that Artificial Intelligence (AI) provided potential advantages and significant performance enhancements for the TCS control system within the Space Station. The inclusion of Expert System (E/S) controllers therefore, has been an important element of TTB planning in order to enable the proper evaluation of this capability in a realistic test environment.

In March of 1986, the Office of Aeronautics and Space Technology (OAST)-sponsored Systems Autonomy Demonstration Program (SADP) presented an opportunity to develop, integrate and evaluate an Expert System (E/S) controller. CTSD believed that the overall goals and schedules of the SADP and the Space Station Freedom (SSF) Thermal Test Bed (TTB) were compatible. A mutually beneficial working relationship with the Ames Research Center (ARC) and the Johnson Space Center's (JSC) CTSD and Systems Development and Simulation Division (SDSD) has been established to pursue these goals.

The resultant cooperative effort is known as the Thermal Expert System (TEXSYS) development project. TEXSYS attempted to enhance the conventional FORTRAN based control system presently in place in the TTB. In general, TEXSYS demonstrated the following features:

- Monitoring of the central thermal bus,
- Control of normal operations (startup, setpoint adjustment, and shutdown)
- Some incipient failure prevention through trend analysis,
- Fault recognition, warning, diagnosis, and correction advice for ten component faults

This document provides the Final Report for the TEXSYS test. The subject test was conducted in the Thermal Test Bed Test Enclosure (TTBTE) in Building 32 from July 12 through August 25, 1989 (Operational Testing) and from August 28 through September 1, 1989 (Demonstration Testing).

1 BACKGROUND

ARC engineers worked with JSC engineers experienced in operation of the Boeing Prototype Thermal Bus System (TBS) to understand the TBS operation. This knowledge was used by ARC to develop the knowledge base (model, tasks, and rules) for TEXSYS. The bulk of the knowledge engineering effort continued until February 23, 1989. A review of the expert system software was then conducted at Johnson Space Center (JSC). This review consisted of a paper check of the thermal rules, tasks, and model by EC to assure that the rules, tasks, and model contained correct information and were operationally correct. The delivery of TEXSYS on February 23, 1989 initiated six weeks of TEXSYS/TEXSYS Data Acquisition System (TDAS)/preliminary Human Interface for the Thermal Expert System (HITEX) integration and validation testing.

HITEX was delivered to JSC on April 16, 1989 and review of HITEX software began. Each stage of the software review was designed to insure the safest possible operation of the Boeing Aerospace (BA) TBS. The next stage of the review process was 14 weeks of playback taped data testing. Using taped data obtained from the Boeing Aerospace Corporation (BAC)/Data Acquisition and Control System (DACS) TBS testing of October 1988, TEXSYS Nominal Operating Procedure (NOP) and Fault Detection, Isolation and Recovery (FDIR) routines were tested and improved in a manner that did not require the BA TBS hardware, but gave the software developers ready access to bus data. Software validation testing continued until the first week of July when wet bus operational testing began. Operational testing continued for 33 days. Initial testing required TEXSYS to obtain confirmation from the human operator before doing tasks, until at the end of the operational testing, TEXSYS was allowed to perform all tasks on its own, except for venting non-condensible gas (NCG) and turning off the Rotary Fluid Management Device (RFMD). Operational testing allowed time to debug the developmental software to the point that it was ready to demonstrate to top management during the demonstration week of August 28 to September 1, 1989.

1.2 SUMMARY

All of the major objectives of the TEXSYS Operational and Demonstration testing were successfully completed. During the week of demonstration, TEXSYS performed nominal operating procedures of bus startup, setpoint decrease, setpoint increase, nominal shutdown, and emergency shutdown. TEXSYS also diagnosed required faults and took appropriate action. These faults were: Slow Leak, RFMD Motor Failure, Single Evaporator Blockage, High Coolant Sink Temperature, Back Pressure Regulating Valve (BPRV) Failure, BPRV Actuator Failure, NCG Buildup, Excessive Heat Load on a Single Evaporator, Accumulator Position Sensor Failure, and Pressure Transducer Failure. The test series summary describing these test series is included in Table 1.1.

1.3 APPLICABLE DOCUMENTS

The current versions of the following documents are applicable as references.

1. Project Plan for Systems Autonomy Demonstration of Thermal Control System for Space Station; NASA, December 1987.

2. Thermal Expert System (TEXSYS) Implementation Plan (TIP), STS-88-0318, CTSD-SS-266, August, 1988.

3. Boeing Aerospace (BA) Prototype Thermal Bus Test Article Description (TAD) Document, CTSD-SS-292, January 1989.

4. Nominal Operating Procedure (NOP), STS-88-0322, CTSD-SS-294, January, 1989.

5. Fault Detection, Isolation, and Recovery, STS-SS-0356, CTSD-SS-293, January, 1989.

6. Boeing Aerospace Corporation/Data Acquisition and Control System (BAC/DACS) Stand-Alone Quick Look Report, STS-88-0348, CTSD-88-294, November, 1988.

7. BAC/DACS Stand-Alone Test Final Report, STS-89-0095, CTSD-SS-310, February, 1989.

8. BAC/Thermal Expert System (TEXSYS) Test Requirements Document, STS-89-0342, CTSD-SS-276, March, 1989.

9. TEXSYS Test Plan Document, STS-89-0105, CTSD-SS-308, May, 1989.

10. TEXSYS Quick Look Report, STS-89-0127, CTSD-SS-335, September, 1989.

11. TEXSYS Software Test and Integration Plan (STIP), NASA/SDSD, February, 1989.

12. "As Run" Space Station (SS)/BA/TEXSYS Demonstration Test Procedure, CTSD-SS-273, July 1989.

Table 1.1 TEXSYS Test Series Summary

SERIES NUMBER	SETPOINT TEMP. (°F)	No. TEST POINTS	TEST NAME DESCRIPTION	OBJECTIVES	OBJECTIVE SATISFIED
1	70	7	COLD SYSTEM STARTUP	Demonstrate/ evaluate system startup procedures.	PARTIALLY
2	70 35	3	SET POINT RECONFIGURATION (70 °F TO 35 °F)	Demonstrate procedures to reconfigure a system loop from 70°F to 35°F setpoint.	YES
3	35 70	2	SET POINT RECONFIGURATION (35 °F TO 70 °F)	Demonstrate procedures to reconfigure a system loop from 35°F to 70°F setpoint.	YES
4	35	2	NCG VENTING	Demonstrate system ability to vent NCG.	YES
5	70 35	2 2	VARIABLE HEAT LOADS	Determine system transient characteristics due to load step functions.	YES
6	70	1	ACCUMULATOR POSITION SENSOR FAILURE	Inject accumulator position sensor failure fault to demonstrate erroneous instrumentation FDIR procedures.	YES
7	70	3	PRESSURE TRANSDUCER FAILURE	Inject pressure transducer failure fault to demonstrate erroneous instrumentation FDIR procedures.	YES
8	70	3	SINGLE EVAPORATOR BLOCKAGE	Inject single evaporator blockage fault to demonstrate evaporator loop flow out of tolerance FDIR procedures	YES
9	70	1	EXCESSIVE HEAT LOAD ON SINGLE EVAPORATOR	Introduce excessive heat load on 1 ø H_2O heat exchanger to demonstrate evaporator temperature not stable/tracking FDIR procedures	YES
10	70	1	RFMD MOTOR FAILURE	Inject RFMD motor failure fault to demonstrate RFMD power draw out of tolerance FDIR procedures	YES
11	70	1	BPRV FAILURE	Inject BPRV failure fault to demonstrate setpoint not stable/tracking FDIR procedures	YES
12	70	2	BPRV ACTUATOR FAILURE	Inject BPRV actuator failure fault to demonstrate setpoint not stable/tracking FDIR procedures	YES
13	70	2	HIGH COOLANT/SINK TEMPERATURES	Introducing high coolant/sink temperature fault to demonstrate inadequate subcooling FDIR procedures	YES
14	35	1	NON-CONDENSIBLE GAS BUILDUP	Determine non-condensible gas effects on system performance and demonstrate system ability to vent NCG.	YES
15	70	1	SLOW LEAK	Inject slow leak fault to demonstrate fluid inventory out of tolerance FDIR procedures	YES
16	70	4	SYSTEM SHUTDOWN	Demonstrate/evaluate system shutdown procedure	YES

2.0 TEST SYSTEM DESCRIPTION

The TEXSYS test system includes the following elements:

- o TEXSYS and Human Interface for TEXSYS (HITEX), developed by ARC.
- o TEXSYS Data Acquisition System (TDAS) developed by EF
- o TTB Data Acquisition and Control System (DACS) developed by CTSD
- o Data Acquisition and Recording System (DARS) developed by CTSD
- o BATBS test article, developed by CTSD

The TEXSYS demonstration hardware functional overview is presented in Figure 2.0.1. The TEXSYS demonstration hardware configuration is shown in Figure 2.0.2. The major software components, TEXSYS, HITEX, TDAS, and TTB DACS Flexible Control (FLEXCON), and their functions are included in Figure 2.0.3.

The BATBS, shown in Figure 2.0.4, is a representative two-phase central thermal management system for the SSF. The BATBS has five heat acquisition components including a total of three evaporators electrically heated and two fluid heated evaporators. Heat rejection from the BATBS was accomplished primarily through the Gregorig-Grooved Twin Condenser (GGC) and the Shear Flow Control Condenser (SCC). The GGC and SCC were cooled utilizing a facility coolant cart which provided a heat sink simulating space radiators. The BATBS Test Article layout in the TTBTE and location of facility support carts and control panels for this ambient test are shown in Figure 2.0.5.

Control of testing was executed from the Data Analysis Engineer (DAE) Room shown in Figure 2.0.6. The BATBS was operated through the DACS controllers located outside the TTBTE linked through DECNET to the system level DACS MicroVAX 3600 computer and the TEXSYS and HITEX Symbolics computers.

2.1 SOFTWARE AND COMPUTER HARDWARE DESCRIPTION

The software modules comprising the TEXSYS Demonstration Project software and required computer hardware are described in the following sections.

2.1.1 Software Functions

2.1.1.1 TEXSYS

TEXSYS functions as the thermal reasoning software with the

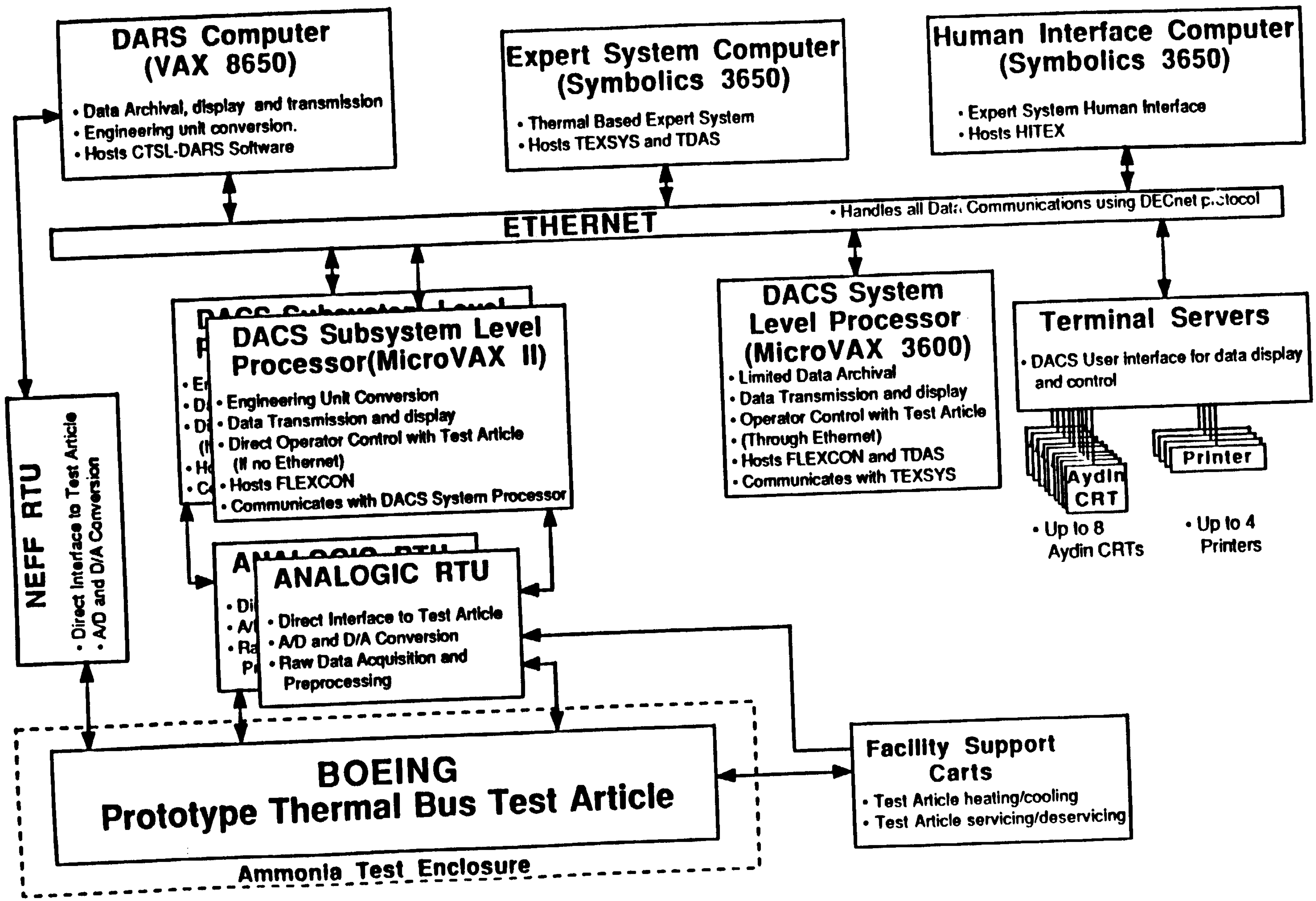

Figure 2.0.1. TEXSYS Demonstration Hardware Functional Overview

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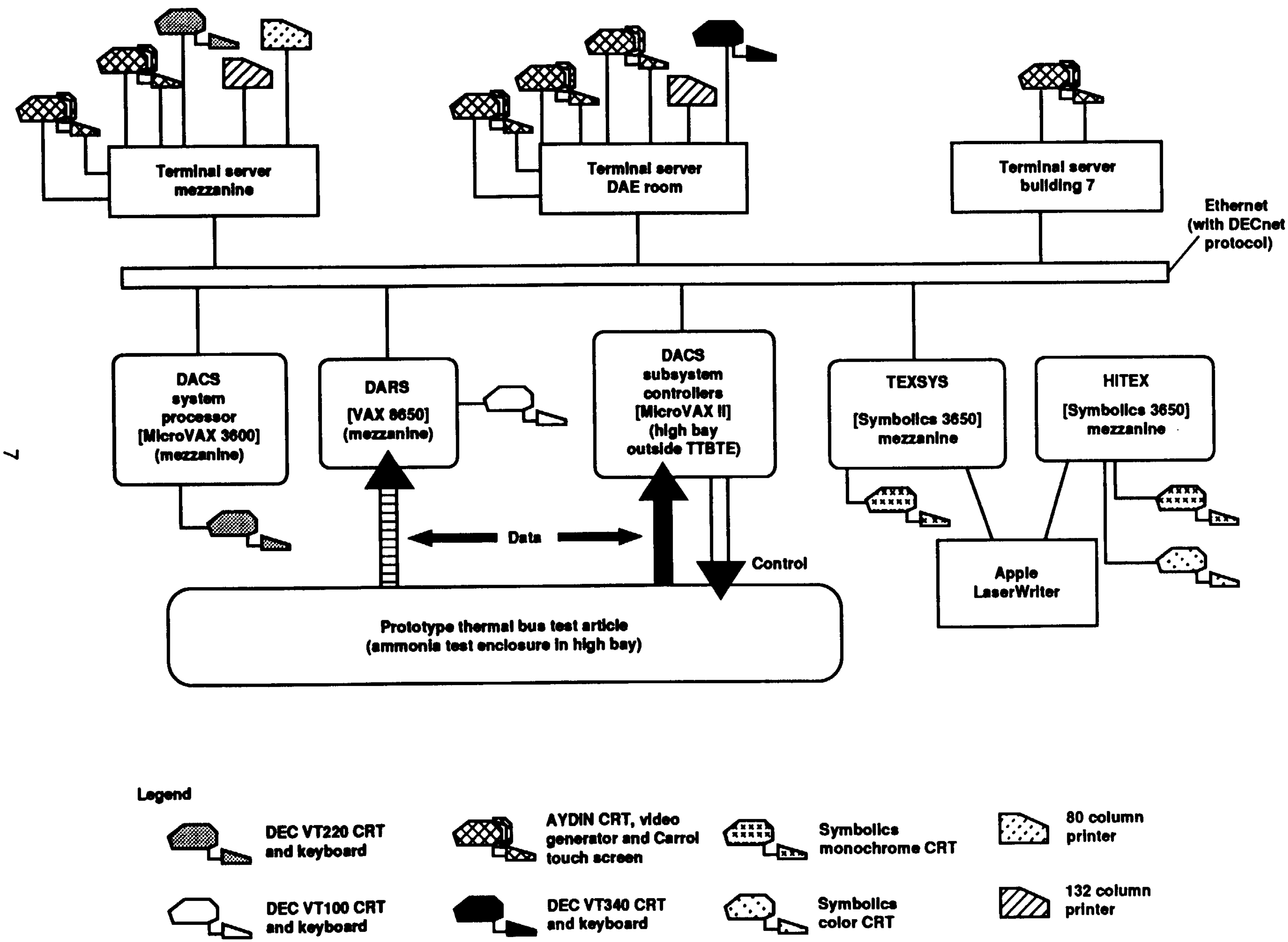

Figure 2.0.2. TEXSYS Demonstration Hardware Configuration

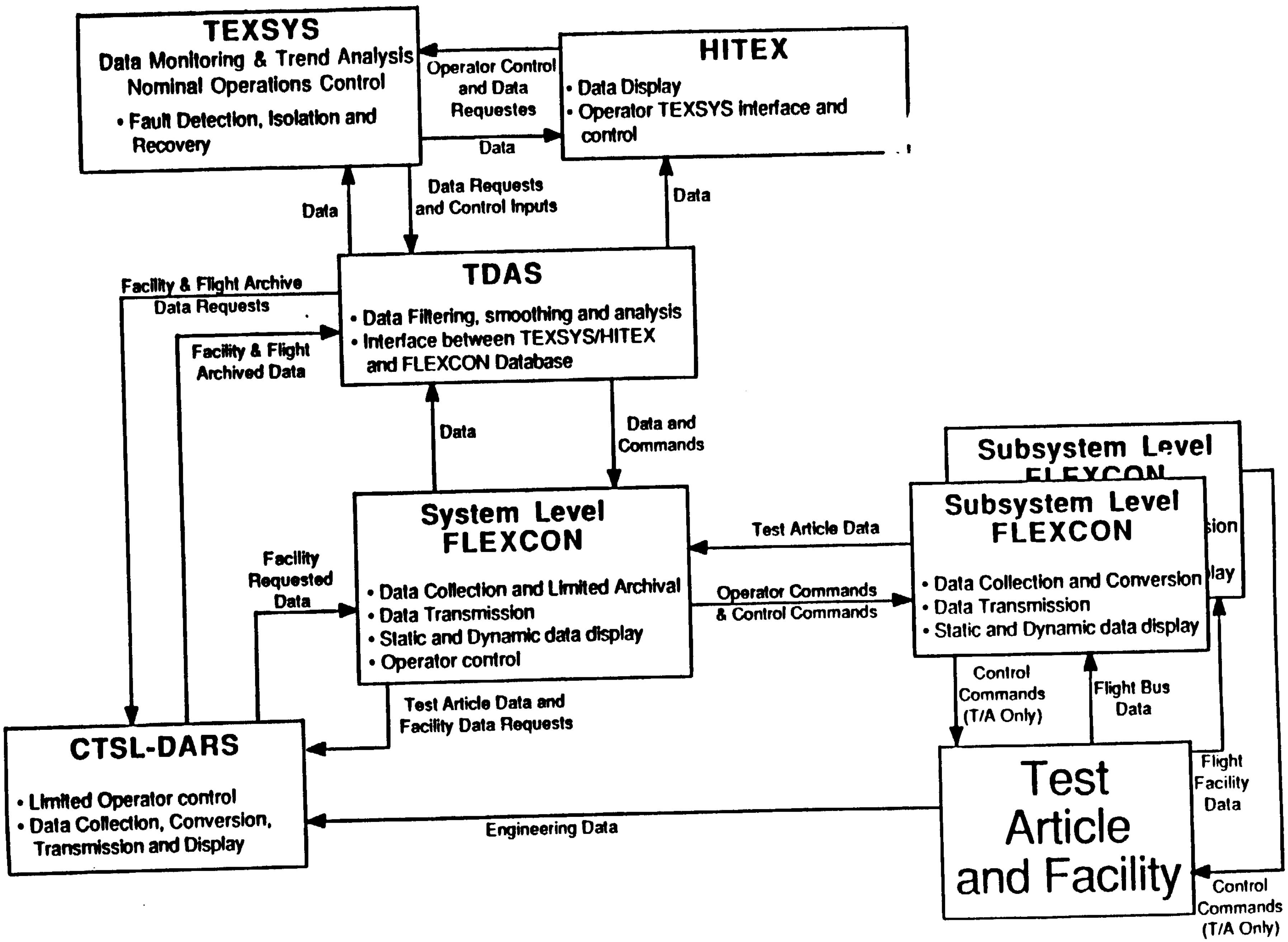

Figure 2.0.3. TEXSYS Project Software Functional and Communications Overview

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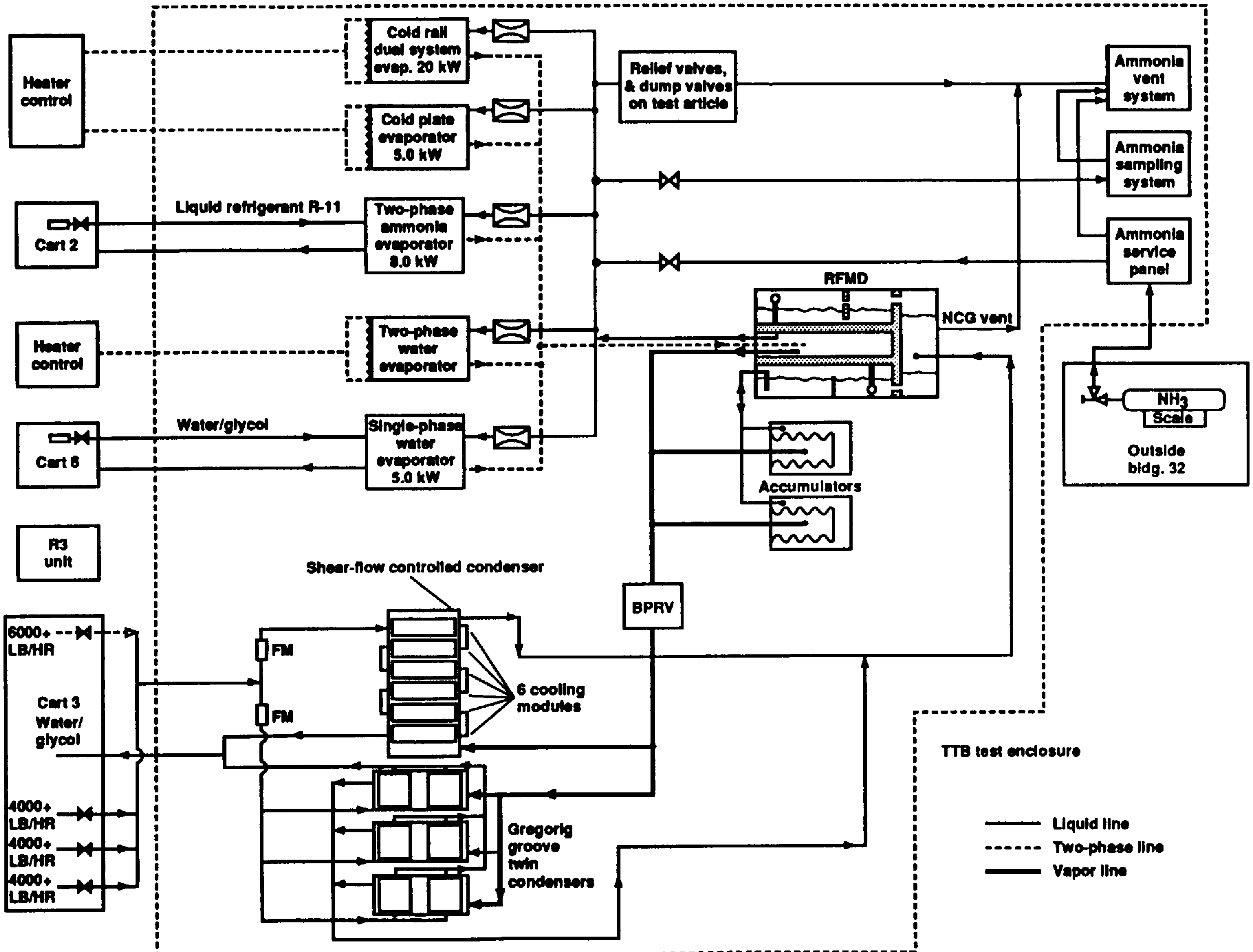

Figure 2.0.4. Simplified Integrated System Schematic

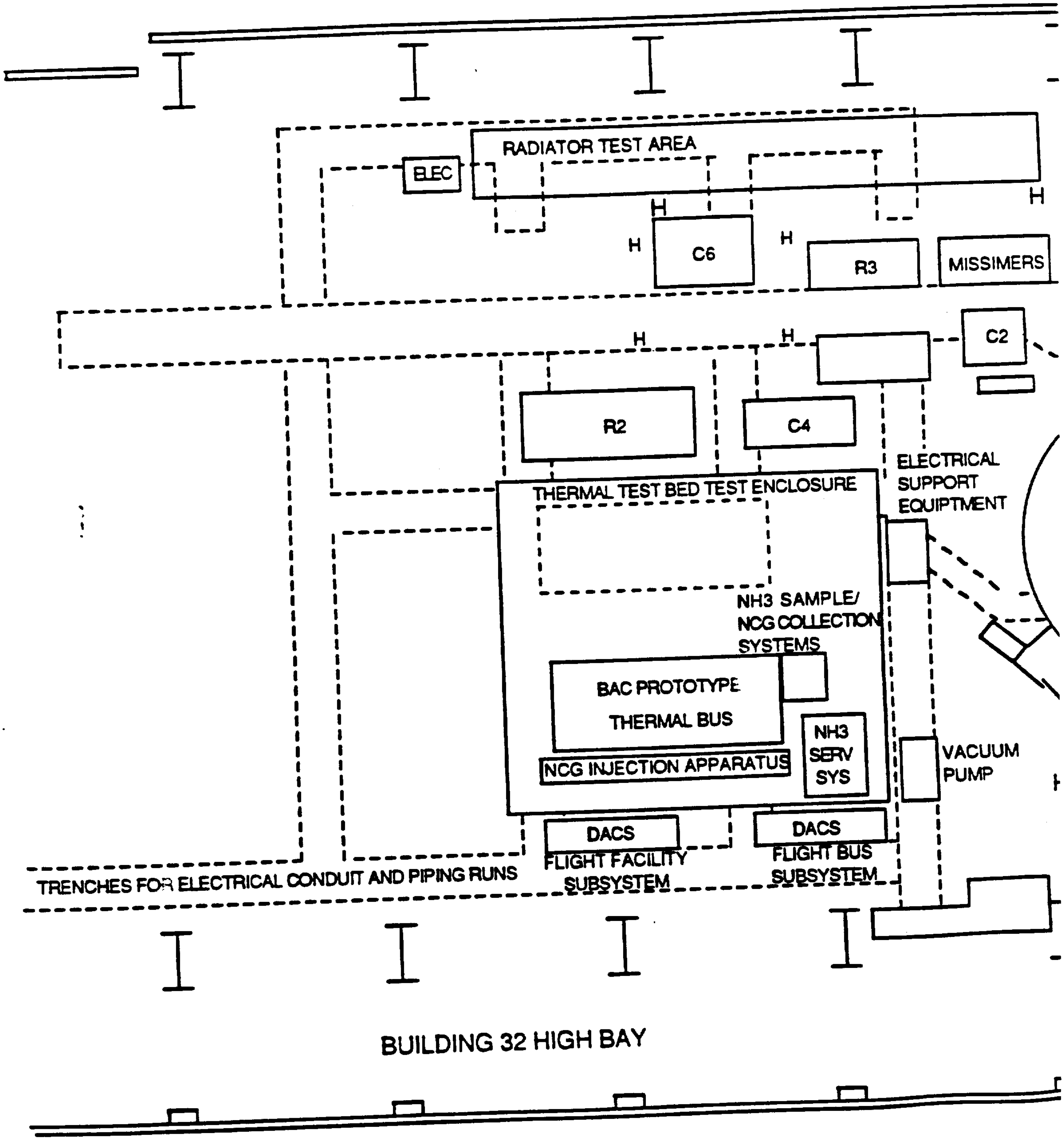

FIGURE 2.0.5 BAC PROTOTYPE THERMAL BUS TEST ARTICLE LAYOUT

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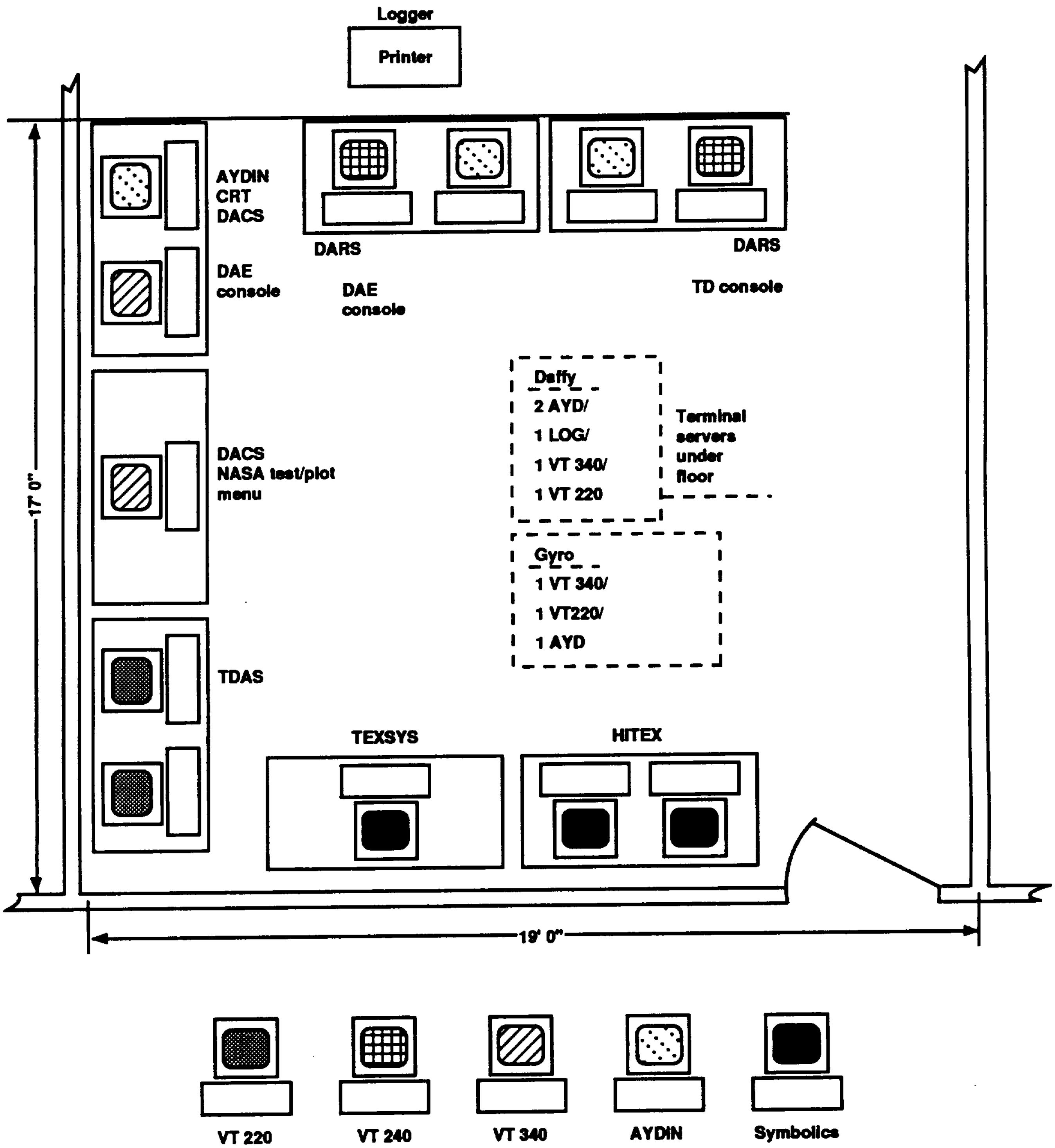

Figure 2.0.6. DAE Room

capability for real-time nominal and off-nominal control of the thermal system. It performs data monitoring for FDIR with respect to the current system operational mode and for fault prediction via trend detection and analysis. TEXSYS detects system level or component level faults, suggests possible causes of the fault, suggests isolation procedures which prevent the test article from reaching an unsafe or hazardous state, and recommends a plan for fault-recovery. At each step of the FDIR sequence, TEXSYS provides a mechanism by which HITEX can explain any suggestions and actions. It also monitors the startup and shutdown of the test article, identifying substandard behavior during all phases of testing. TEXSYS functions in an autonomous mode or in an "advisory" mode, which allows the operator to confirm or veto proposed actions. Each task performed by TEXSYS may be individually set by the operator to require operator confirmation or to allow autonomous action.

TEXSYS software can be thought of as a series of layers (see Figure 2.1.1.1). At the base is the Symbolics hardware, the Symbolics Common Lisp Environment (Genera 7.2), and IntelliCorp Knowledge Engineering Environment (KEE 3.1). Two generic software tools developed by SADP comprise the next layer: Executive Tool Kit (XTK) which provides overall control of goals and tasks via high-level procedural specification language with extensive multi-tasking, and message passing capabilities, and Model Tool Kit (MTK), which allows the development of complex models of physical systems through symbolic model based representation and dynamic causal modeling of physical components and systems, and integration of qualitative and quantitative data. The "top" layer consists of the TEXSYS System Tasks (which implement the event cycle, described below, and exercise procedural control over all other aspects of TEXSYS), the model, component library, component behavior and FDIR rules, bus related procedural tasks, and interface software routines. Graphic representation of model components and printouts of rules and tasks are included in Appendix C.

During operation, the TEXSYS system tasks implement a cycle of events, which are repeated continually. These events are 1) obtain sensor data from the thermal system 2) place this data into the model and propagate the values within the model, 3) determine if there are any anomalies within the data or conflicts with expected behavior which could point to system failures, 4) and inform the system operator of any anomalies or conflicts found and actions taken. In addition to the basics of this main loop, there are additional asynchronous actions which provide control of thermal system which may be invoked. These actions are primarily operator drive but may also be triggered during fault recovery. The main TEXSYS cycle is illustrated in Figure 2.1.1.1.2.

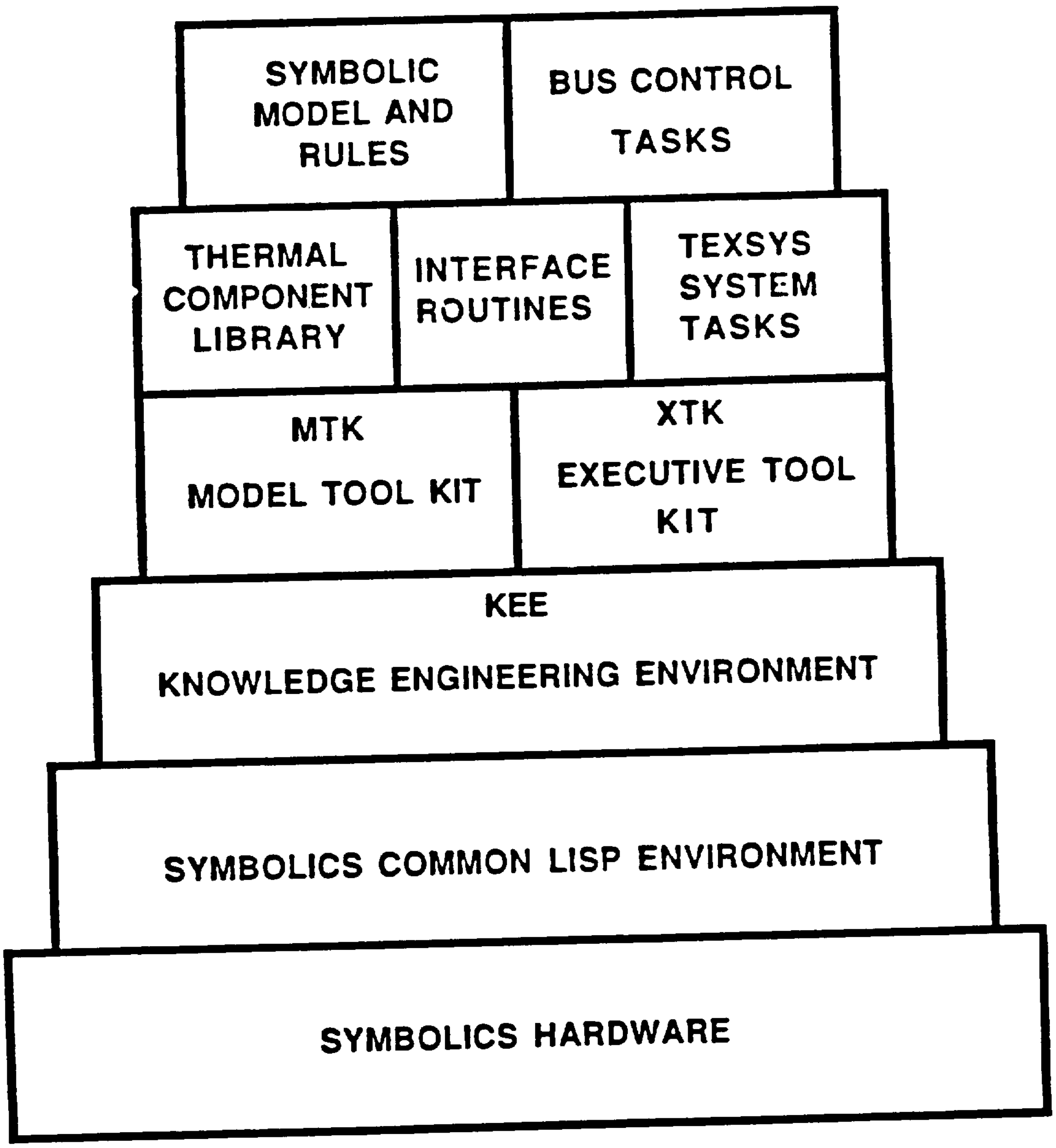

FIGURE 2..1.1.1.1. TEXSYS SOFTWARE LAYERS

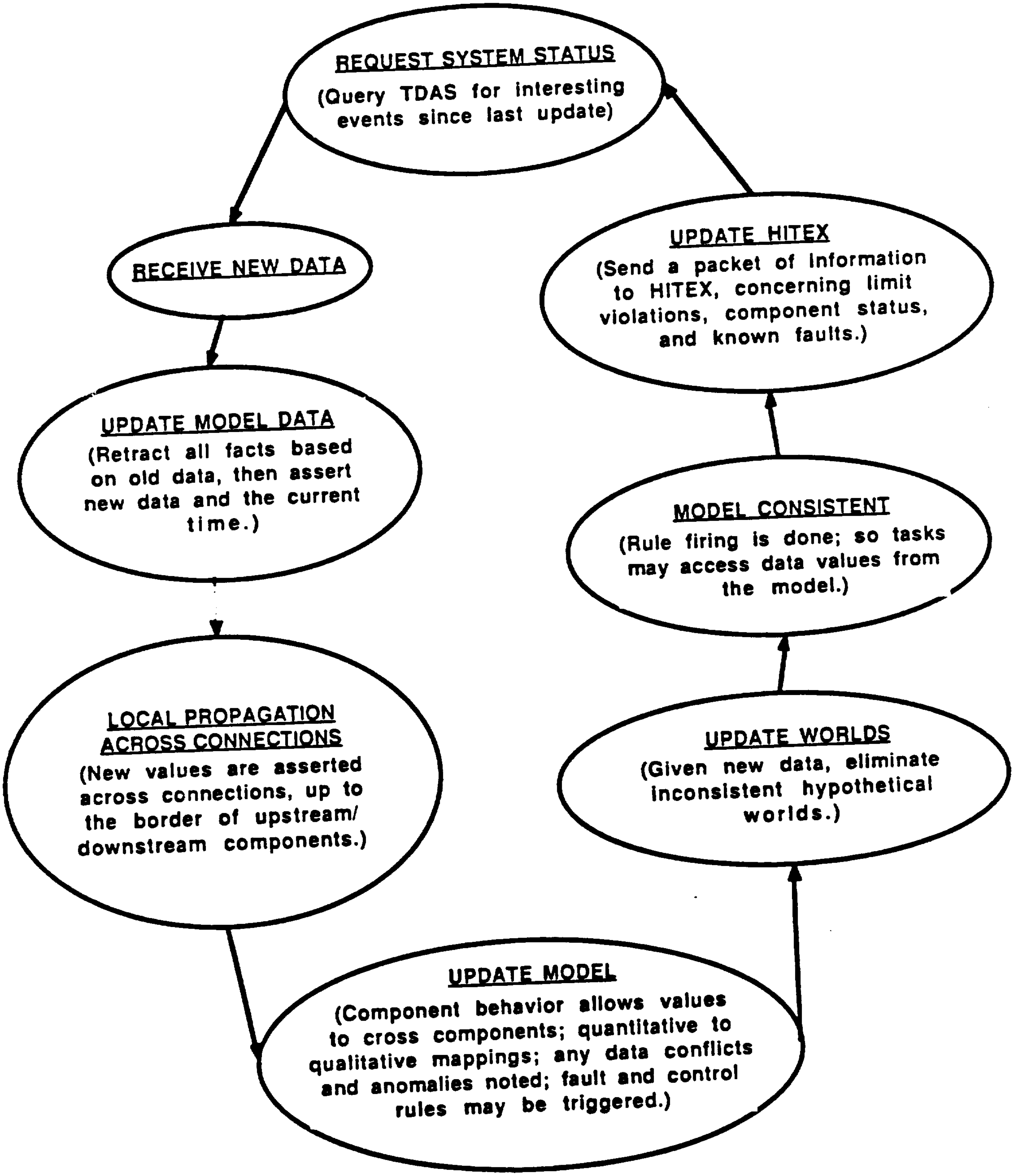

FIG. 2.1.1.1.2 TEXSYS SYSTEM CONTROL CYCLE

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2.1.1.2 Human Interface for Thermal Expert System (HITEX)

The HITEX runs on a dedicated computer, separate from the E/S and data acquisition system. It has the capability to display graphically and numerically any data collected by DACS, as well as historical data collected and archived by the DARS. It also makes available to the user schematic representations of the test article and its components at various levels of detail. HITEX offers a facility by which the user issues direct control commands. These capabilities are implemented through HITEX to TEXSYS to TDAS to DACS software. The operator has two screens to control and monitor the E/S and the BATBS. The graphics screen is a color screen primarily for monitoring the state of the TBS. The E/S screen is a black and white screen used to control and monitor the E/S. Appendix A contains printouts of graphics and expert system screen displays in several different configurations.

The Graphics System Screen (GSS) displays thermal data in schematics, plots, and tables in an operator configurable window format. The displays that are available are:

Main Boeing Schematic
Two-Phase Water Heat Exchanger (HX) Diagram
Single-Phase Water HX Diagram
Two-Phase Ammonia HX Diagram
Cold Plate HX Diagram
Cold Rail HX Diagram
Twin Condenser Diagram
Shear Flow Condenser Diagram
Sensor Table
Plot
Status-at-a-Glance Diagram
Global System Parameters

In addition, the operator can open and close isolation valves from the graphics screen by clicking on the valve on the main schematic and selecting "Toggle Valve State" from the menu.

The Expert System Screen (ESS) displays expert system information - warnings, diagnoses, diagnostic justifications (complex rule traces) of fault processing, graphical task-tree display of E/S processing, and log entries in a operator configurable window format. Provisions have been made for a procedure explanation capability. The ESS provides the operator a command interface mechanism to select and execute procedures, component commands, and a procedure confirmation (to allow varying levels of E/S autonomous operation). The operator initiated procedures are:

Setup NCG Venting Parameters
Initiate Setpoint Change

Close Valves
Open Valves
Turn On RFMD
Turn Off RFMD
Off Nominal Shutdown
Check RFMD Voltage and Frequency
Turn Off a Sensor
Activate Sensor
Nominal Shutdown
Nominal Startup
Vent NCGs from RFMD Once

The underlying HITEX software may be thought of as a series of layers, as shown in Figure 2.1.1.2.1. At the base is the Symbolics Common Lisp Language (Genera 7.2), and IntelliCorp KEE (3.1). A generic software tool developed by SADP, Schematic Tool Kit (STK) allows the development of complex schematics with dynamic data display. Remaining software modules are: XTK, HITEX Tasks, ESS software, the Graphics Library, Schematic, and Runtime HITEX using color KEE pictures and dynamic windows.

2.1.1.3 TEXSYS Data Acquisition System (TDAS)

TDAS functions as the software interface between TEXSYS, HITEX, and DACS. TDAS is responsible for extracting both real-time and archived data from the DACS, filtering it as necessary, and structuring it into a format that can be used by TEXSYS and HITEX. It also translates any control related requests for commands issued by TEXSYS and HITEX into FLEXCON compatible formats, and places this data into the appropriate FLEXCON queue or database location. TDAS software resides on 3 different computers. These machines are a MicroVAX, where the DACS for TTB also resides, and two Symbolics computers, where TEXSYS and HITEX reside. An ETHERNET with DECNET protocol is used for data communication between the MicroVAX and the Symbolics machines. An overview of the TDAS software is shown in Figure 2.1.1.3.1.

2.1.1.4 DACS/FLEXCON

DACS FLEXCON software functions as the primary data acquisition and control software for the TEXSYS test article. It provides the means by which data is collected from a test article and displayed for use by test personnel. Data is stored in the FLEXCON database and can be displayed either in tabular form or on graphical schematics representative of the test article. FLEXCON has an event/alarm logger that records and time codes any operator initiated changes and any alarms. FLEXCON provides several features that are convenient in a test environment.

Figure 2.1.1.4.1 presents a functional schematic of FLEXCON.

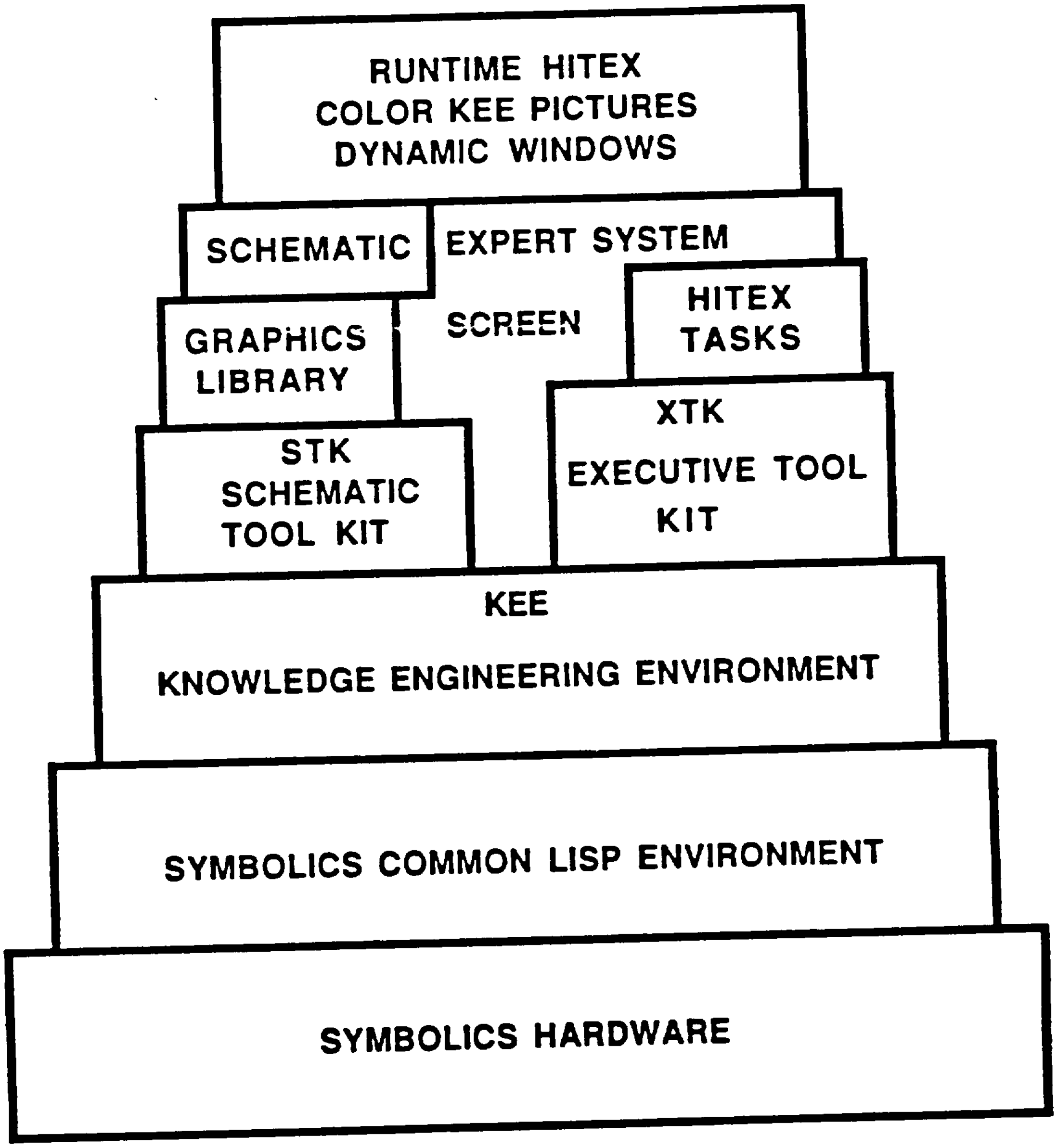

FIGURE 2..1.1.2.1. HITEX SOFTWARE LAYERS

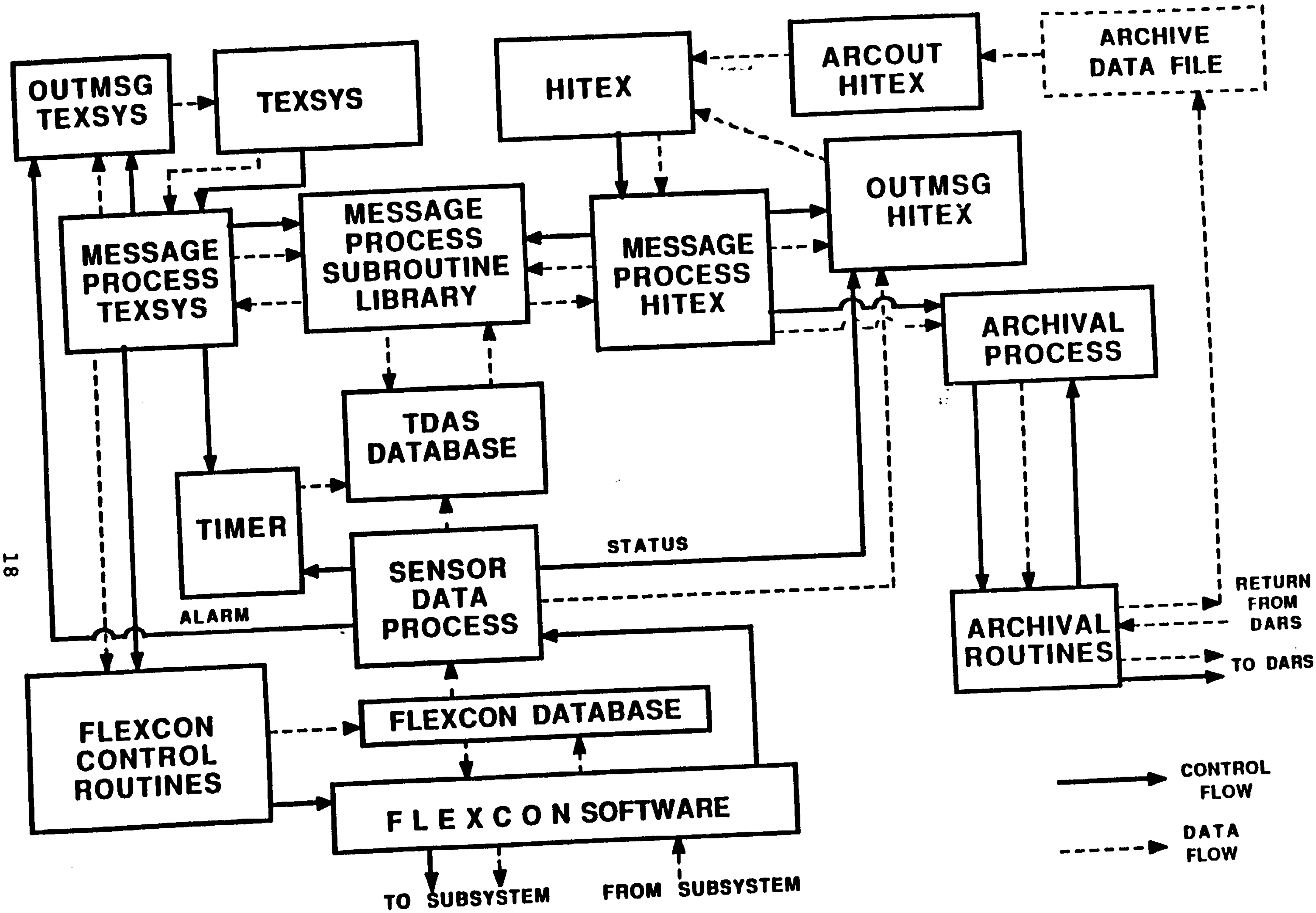

FIGURE 2.1.1.3.1 TDAS SOFTWARE FUNCTIONAL OVERVIEW

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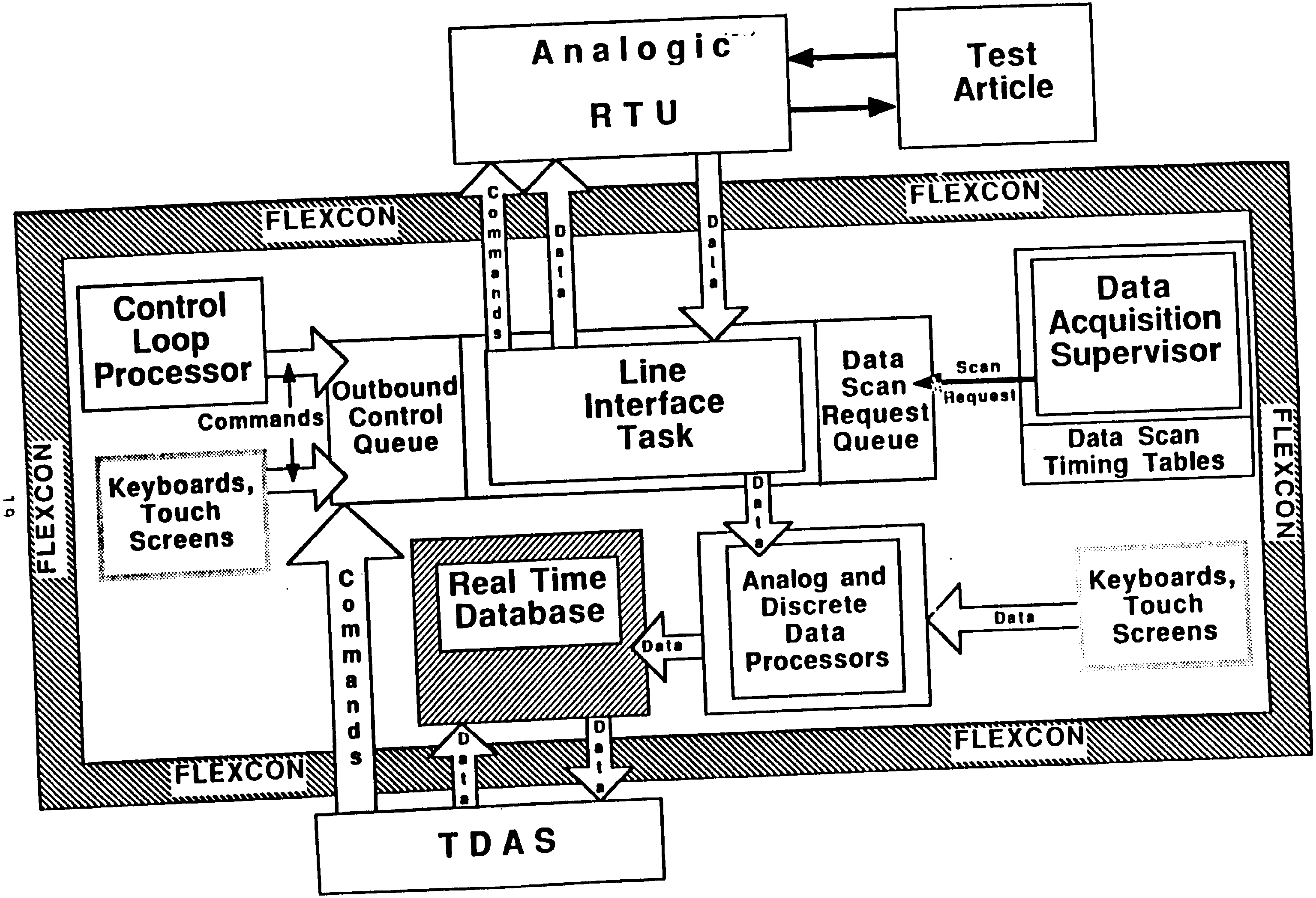

FIGURE 2.1.1.4.1 FLEXCON SOFTWARE FUNCTIONAL OVERVIEW

FLEXCON also allows for control of the test article, through both direct controls issued via a touch sensitive screen or through the Aydin keyboard and preprogrammed control loops initiated by an operator.

Automated control is achieved through the use of FLEXCON MACROs. A MACRO is a series of control statements initiated by an operator and executed sequentially which have the ability to change values stored and sent by FLEXCON. The control statements function via FLEXCON control blocks are described by screen text at each operation or decision point.

2.1.1.5 Data Acquisition and Recording System (DARS)

The main CTSL-DARS software functions include the data acquisition and display of engineering data, and the data archival of engineering and DACS flight data. CTSL-DARS provides mass data dumps of available instrumentation to TEXSYS/DACS. CTSL-DARS software can produce real-time tabular data of the stored information.

The DACS Data Services Facility (DDSF) functions as the software interface between the FLEXCON database and CTSL-DARS. The software gathers data from the FLEXCON database at a real-time selected rate. Permissible recording rates are 1, 2, 3, 4, 5, 6, 10, 15, 20, 30, 60 seconds. Data is transmitted to CTSL-DARS every minute.

DDSF also provides the capability to obtain a "snap-shot" of all parameters on demand and automatically at user selected intervals from DACS. A separate program provides the capability for real-time plots by sending selected data to the CTSL-DARS computer. Plot software on the CTSL-DARS computer is used to display the data on VT240 and VT340 type terminals. Hard copy output can be obtained on CTSD's Scriptprinter, Color Printer, and LN03 printers. After data has been archieved on CTSL-DARS, DDSF provides software to retrieve data for 1-15 parameters for user selected time intervals. This software includes an interface to TDAS for gathering data for HITEX archived data plots.

2.1.2 <u>Computer Hardware</u>

This section presents a functional description of the computer hardware elements utilized in the TEXSYS Demonstration.

2.1.2.1 TEXSYS Hardware

TEXSYS hardware consists of a Symbolics 3650 computer with 24 MB of memory and a 368 MB fixed disk, an external cartridge tape drive, an Apple laser printer, and a monochrome console.

2.1.2.2 HITEX Hardware

HITEX hardware consists of a Symbolics 3650 with 24 MB of memory an 8-bit CAD buffer, a 368 MB fixed disk, an external cartridge tape drive, a monochrome console, and a 19 inch high resolution color console, LGP-2 laser printer, DECNET support.

2.1.2.3 Data Acquisition and Control System (DACS) Hardware Functional Description

The DACS consists of a system level (DEC MicroVAX 3600 with 16 MB of memory) and two subsystem level processors (DEC MicroVAX II's Flight Bus CPU with 16 MB of memory and Flight Facility CPU with 4 MB of memory). Flight bus data is the data necessary for control of the test article. Flight facility data is informational data from the facility that is needed in a test.

The DACS system level processor supports up to eight Aydin color/graphics CRTs and up to four printers. The Aydin CRTs display both static (graphics) and dynamic data concurrently and allow operators to issue commands to the test article using the video generator/keyboard or the Carroll Technologies touch screen built on to all of the Aydin CRTs. The system processor drives up to six Aydin CRT's, the subsystem processor drives an Aydin CRT, one Remote Terminal Unit (RTU) and can drive one event logger (printer) as required. The current configuration does not have subsystem printers, as the system printer records events for both processors.

The DACS RTU which interfaces with the test article is produced by Analogic and consists of two chassis. One chassis has 16 type T thermocouple cards, with 64 thermocouple input channels. The other chassis has a total of 15 cards containing 8 RTD channels, 32 -10 V to 10 V differential input channels, 16 -20 to 20 V differential input channels, 32 0-5 V Transistor to Transistor Logic (TTL) input channels, 64 TTL output channels, 16 0-5 V analog output channels and 12 0-10 V analog output channels.

2.1.2.4 Data Acquisition and Recording System (DARS) Hardware and Software Functional Description

The DARS is hosted on a Digital Equipment Corporation (DEC) VAX 8650 computer. There is one DARS line printer for hardcopies of tabular data during test. Data acquisition for the DARS is accomplished using the NEFF 600 RTU supporting 512 channels of input data. The DARS records engineering data and can transfer 15 channels of DACS data to FLEXCON. The DARS system software is known as CTSL-DARS.

The main CTSL-DARS software functions include the data acquisition and display of the engineering data, the archival of the flight and engineering data, and real-time printouts of tabular data of the engineering information.

The data archived by the CTSL-DARS data can be used to create post-test data plots and tables from both the facility instrumentation and DACS data.

2.1.2.5 Communication Hardware

The communications hardware for the DACS/DARS network consists of a 500 meter ethernet backbone cable, tapped by DEC H4000 transceivers. The backbone cable runs partially around Building 32 Chambers A and B, through various areas of the high bay and along the mezzanine area of Building 32 and into Building 33. Outside users can access the Building 32-33 Local Area Network through the CTSD 2 (Building 7 VAX) gateway. The data communications are accomplished using the DECNET ethernet protocol.

2.2 THERMAL SYSTEM DESCRIPTION

The BATBS was built in support of SSF development under NASA/JSC contract NAS9-17478 and has been described in detail in the following documents: Boeing Prototype Ambient Test Requirements Document (TRD) (reference document CTSD-SS-200); Boeing Prototype Thermal Bus Test Article Description (TAD) (reference document CTSD-SS-292); Nominal Operating Procedure (NOP) for the Boeing Aerospace Corporation (BAC) Space Station Prototype Two-Phase Thermal Bus System (TBS) (reference document CTSD-SS-294); and Boeing Aerospace Corporation (BAC) Space Station Prototype Two-Phase Thermal Bus Fault Detection, Isolation and Recovery (FDIR) (reference document CTSD-SS-293). The following sections provide a description of the overall system functions and the modifications to allow testing with the TTB, DACS, DARS, and TEXSYS performing selected control and data acquisition and storage functions.

2.2.1 <u>Integrated System Description</u>

The TBS is mounted on Two JSC provided pallets and has an overall envelope of approximately 7 feet wide by 20 feet long by 6 feet high. A simplified integrated system schematic is shown in Figure 2.0.4. A detailed schematic including the TBS and facility support equipment with instrumentation is depicted in Figure 2.2.1.1.

The system thermal management approach consists of four primary fluid control elements: (1) the Rotary Fluid Management Device (RFMD), (2) Back Pressure Regulating Valve (BPRV), (3) the accumulator, and (4) the cavitating venturi. The functions and features of these components are summarized in Table 2-1.

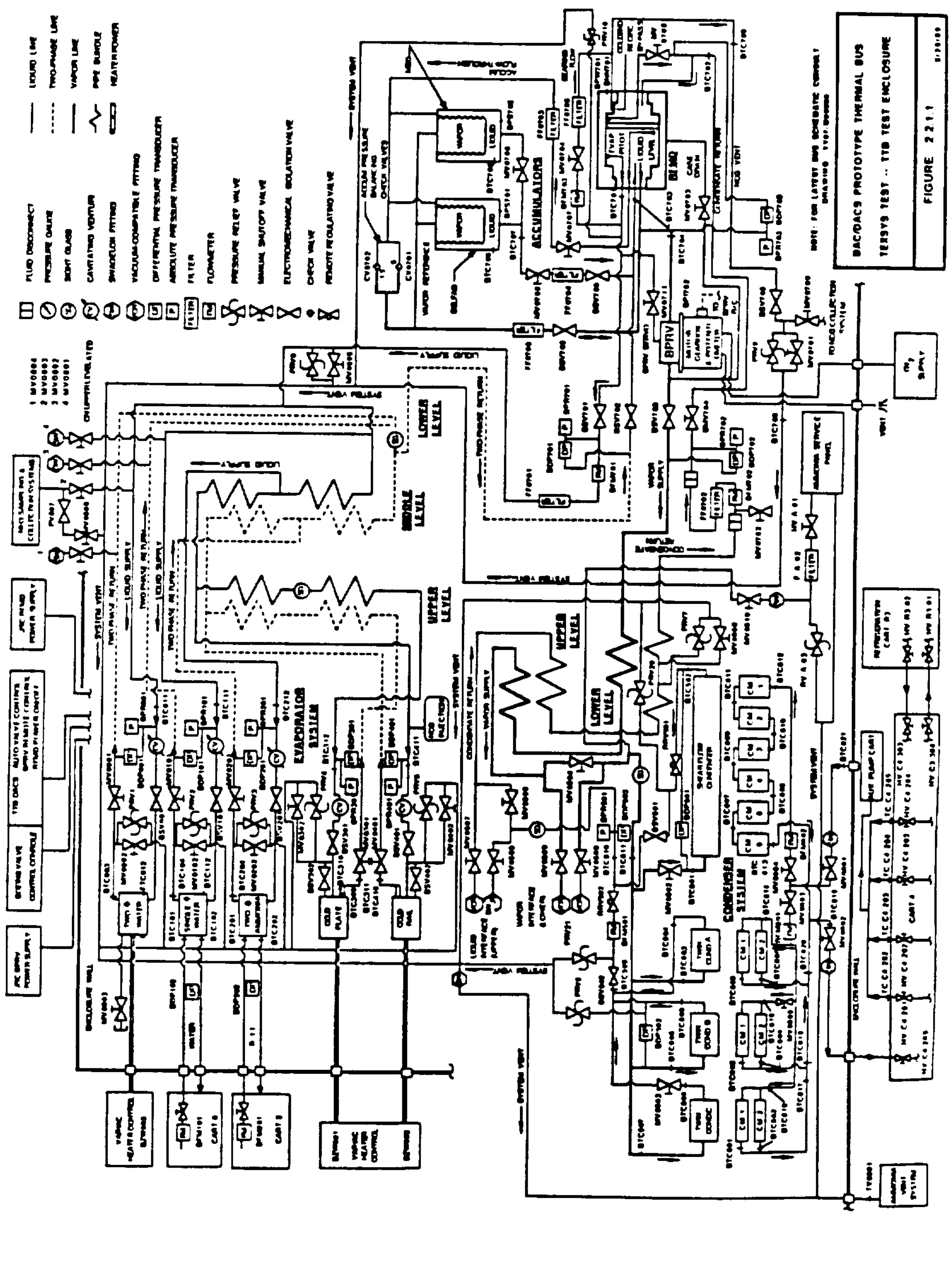

Figure 2.2.1.1. BAC/DACS Prototype Thermal Bus

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Table 2.1 Functions and Features of Primary Pumping and Control Elements

	RFMD	BPRV	Accumulator	Cavitating venturi
Functions	• Liquid/vapor separator • Evaporator feed pump • Regenerator • Non-condensible gas trap and vent	• To maintain a constant pressure and therefore a constant saturation temperature at the liquid/vapor interface within the RFMD	• To accomodate liquid inventory changes in the condenser and evaporator legs	• To provide controlled liquid flow rate to evaporators
Features	• Pitot pumps (non-cavitating) • Hydrodynamic (long-life) bearings • Non-contracting low pressure dynamic seals • Integral motor, self-cooling canned motor and rotor	• Pressure actuated servo • Redundant actuation bellows • No sliding seals • Adjustable set-point temperature	• Positive stops for bellows travel • Integral liquid quantity sensor	• Passive flow control • Flow stability with downstream pressure variations

System operation of this two-phase thermal bus or TBS system will be described by following a control mass through a complete circuit as shown in the simplified system schematic of Figure 2.0.4. Beginning at the RFMD, liquid is pumped to each heat acquisition device through the liquid supply (line 1) and passes through a cavitating venturi at each heat acquisition device. Flow rate control is provided by the cavitating venturis, which are functionally analogous to a choked orifice in a pneumatic system.

Continuing through the circuit, the heat collected from the heat acquisition devices (representing interfacing payloads or experiments) vaporizes a fraction of the fluid in the evaporator. The two-phase flow exiting the heat acquisition devices collects in the two-phase return (line 2) and returns to the RFMD. The two-phase flow enters the main chamber of the RFMD and is separated into liquid and vapor. The liquid is pumped back to the evaporator section. Vapor passes out of the RFMD through the BPRV to the condensers (line 3), where it is condensed by rejecting heat to the Cart 4 cooling modules attached to the condenser which in turn reject the heat to the mechanical refrigeration units of the TTB TE. Condensate from the condenser returns to the RFMD (line 4) into a chamber separated from the main chamber by a thermal barrier. The subcooled liquid passes through peripheral holes in the thermal barrier and mixes in an intermediate chamber with liquid from the main chamber. This relatively cold liquid mixture is pumped by a pitot through atomizers into the main chamber vapor space, where it encounters the incoming evaporator two-phase flow. The atomized subcooled liquid is immediately saturated by condensing some of the vapor, which rejoins the annular rotating liquid. Thus, the RFMD acts as a regenerator as well as the pump and phase separator.

The details of the individual system modules are as follows.

2.2.1.1 Pump Module Description

The pump module assembly, consisting of the RFMD, BPRV, dual accumulators, filters, and system/pump health monitoring instrumentation, is integrated as a package and mounted at the TBS pallet boundary. The pump module and instrument package is shown in Figure 2.2.1.1.1.

2.2.1.2 Evaporator Description

The five evaporators included in this system design are summarized with their actual heat sources in Table 2-2. These represent five potential thermal interfaces for use on the Space Station. Three evaporators were designed as fluid to fluid interface HXs (although one is heated electrically for the

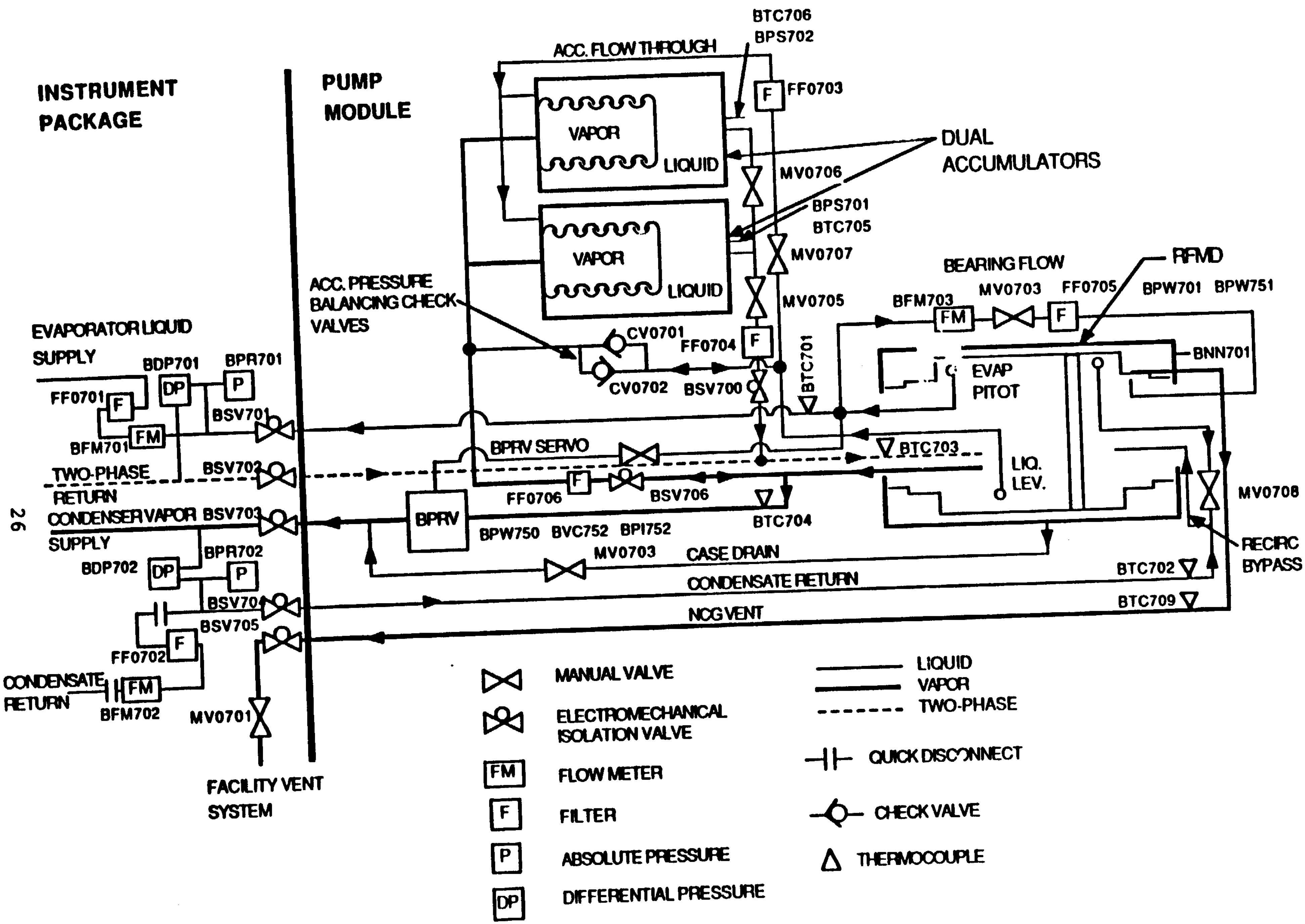

Figure 2.2.1.1.1 Pump Module and Pump Module Instrument Package

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TABLE 2-2. SUMMARY OF HEAT ACQUISITION DEVICE MAXIMUM HEAT LOAD CAPABILITY

Heat Acquisition Device	Heating	Maximum Design Heat Load
Single-Phase Water HX	Pumped single-phase water loop	5 kW
Two-Phase Water HX	Electric strip heaters	3 kW
Two-Phase Ammonia HX	Pumped single-phase refrigerant R-11	8 kW
Cold Plate (Swirl Flow)	220 v. electric strip heater	5 kW
Cold Rail Evaporator	220 v. electric strip heaters	2 kW

current test) and two evaporators were electrically-heated representing mechanical contact HXs. Each HX has an instrument package adjacent to it which contains pressure transducers, a cavitating venturi, isolation valves, a drain valve, and a pressure relief valve. The instrumentation packages permit data for real-time monitoring of HX performance and for post test performance correlation of these system components. Closing the isolation valve, located on the liquid supply line of the HX, also permits simulation of an out-of-service interface and how it effects the performance of the TBS. The same basic instrumentation package is used for all three fluid heat exchangers.

Both the cold plate and cold rail evaporators used the same instrumentation package. The isolation valve located downstream of the cavitating venturi is closed directing the same total flow through the remaining coil thereby forcing the remaining coil to absorb the entire heat load. The cold plate and cold rail HXs are electrically heated with 220 VAC strip heaters. The heaters are controlled by the heater control console and are equipped with thermostats and alarms set at 160°F to protect the HX from overheating.

2.2.1.3 Condenser Description

Heat rejection is provided by two types of condensers; a shear flow controlled condenser, designed to interface with the LTV Aerospace Corporation radiator module, and three Gregorig grooved twin condensers, designed to interface with Grumman Aerospace Company (GAC) radiators. The shear flow controlled condenser and the set of three twin condensers are each designed to dissipate 12.5 kW at 70°F (a total of 25.0 kW).

2.2.2 <u>Thermal Test Article Layout</u>

Figure 2.2.2.1 shows the planned test layout including the test article (BAC TBS and DACS), support carts, and other support equipment. The test article pallets are located inside the test enclosure and all other support equipment is located outside in the high bay area as shown on this figure.

The TEXSYS and HITEX Symbolics system processors along with the DACS system processor and the DARS processor both reside in the Building 32 mezzanine area. All processors have associated CRTs that are located in the DAE room (Figure 2.2.2.2).

The DACS subsystem processors are located on the high bay floor along with associated CRTs (one Aydin and one VT 220) (per Figure 2.0.6).

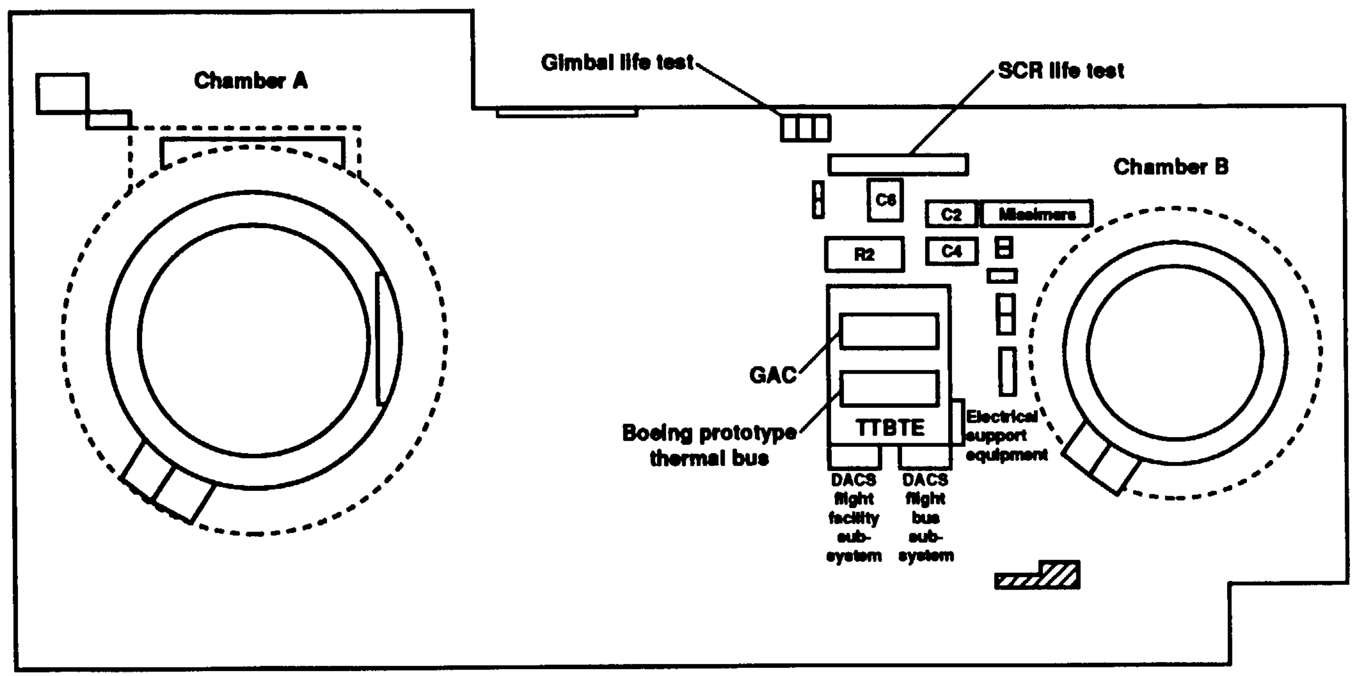

Figure 2.2.2.1. Layout Schematic of High Bay Area of JSC Building 32

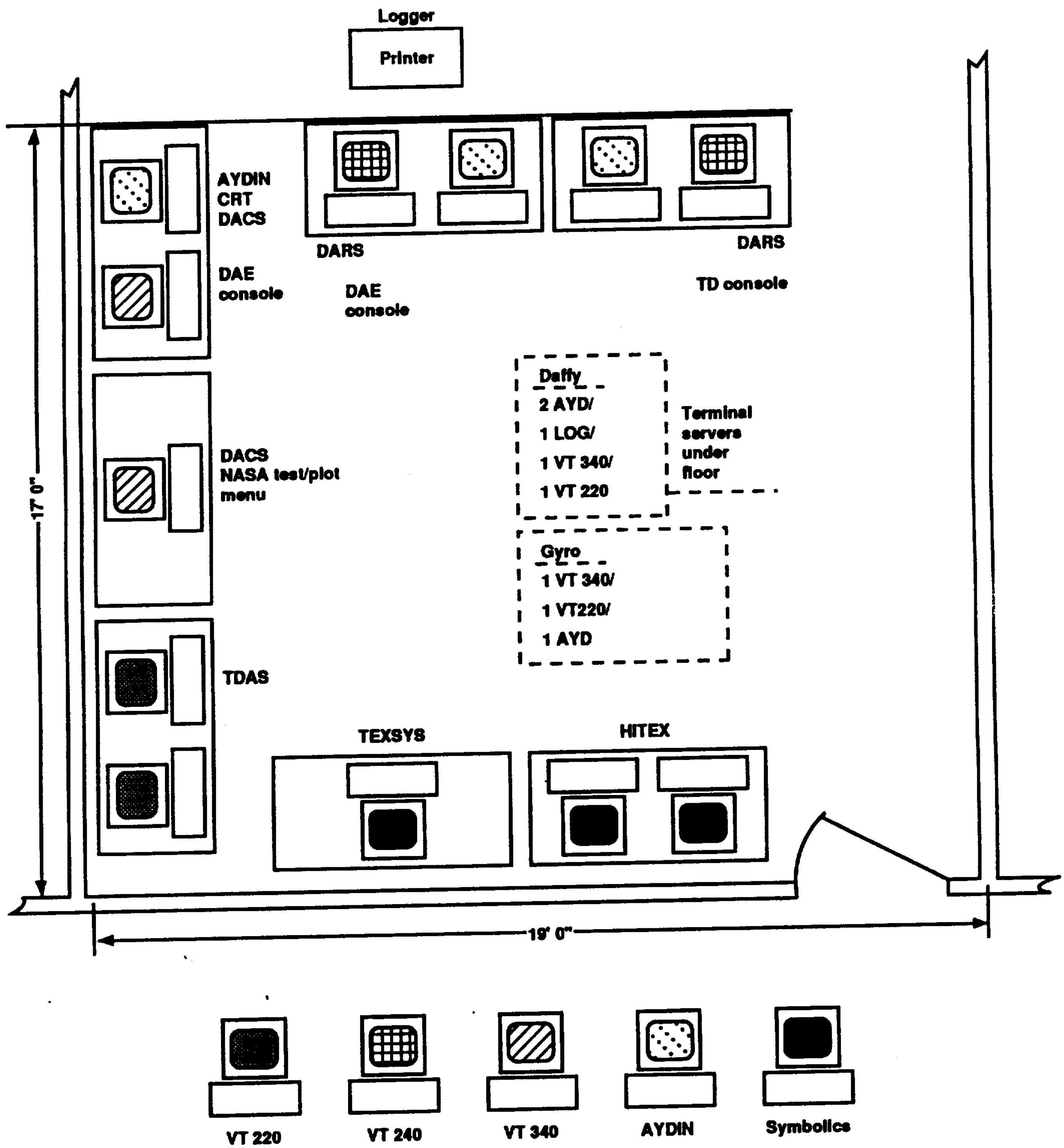

Figure 2.2.2.2. DAE Room

2.2.3 Facility Support Hardware

As shown in Figure 2.2.2.1, there are several pieces of facility support equipment and components required to support the TBS. The major units are as follows.

2.2.3.1 Electrical Heater Description

The cold plate and cold rail evaporators and two-phase water HX were heated electrically by Minco heaters applied to the surface of each evaporator or HX. The Variac heater control supplied a maximum of 2.1 kW to the cold plate, 2.0 kW to the cold rail and 3.3 kW to the two-phase water heat exchanger.

2.2.3.2 Cart 6/Cart 2 Description

Facility heating cart C6 provided thermal load for the single-phase water HX. A maximum of 12.0 kW of heating was supplied by the aqueous ethylene glycol (80% water/20% by volume) circulating fluid. Facility cart C2 provided thermal load for the two-phase ammonia HX. The refrigerant R-11 circulating medium supplied a maximum of 8.0 kW of heating.

Both facility carts were provided by JSC. Carts were controlled manually to change the thermal loads on the HXs. Flow, temperature and pressure requirements are described in Table 2-4.

2.2.3.3 Cart 4 Description

Heat rejection during the TEXSYS test was provided by a radiator simulator cart (Cart 4) utilizing a 50% water/50% ethylene glycol by volume solution. Typically Cart 4 provided a flowrate of approximately 10,000 lbs/hr at $11^{\circ}F$. The nominal heat rejection capacity of the cooling cart was rated at 25.0 kW at a thermal bus setpoint of $70^{\circ}F$. Refrigeration cart R2 provided the heat sink for Cart 4.

Figure 2.4 Summary of Test Article Support Heating and Cooling Requirements

Thermal simulation cart	Required total flowrate	Temperature range	Maximum total heat load	Component serviced	Component nominal flowrate	Cart function	Facility-side component ΔP	Facility-side maximum ΔT	Component fitting size and type	Working fluid
Cart 4/ R2 or R3	18,000 lb/hr	0°F to 60°F	25 kW	Gregorig groove condenser	12,000 lb/hr	Cooling	4 psi through each of 3 legs	5°F at 12.5 kW	3/4" stubs	Water glycol 50% H_2O by volume
				Shear flow condenser	6,000 lb/hr	Cooling	15 psi	10°F at 12.5 kW	3/4" stubs	Water glycol 50% H_2O by volume
Cart 6 1 ø H_2O cart	3,400 lb/hr	35°F to 110°F	5.0 kW	One-phase water HX	3,400 lb/hr	Heating	2 psi	5°F	1" inlet 1" outlet	Water glycol 80% H_2O by volume
Cart 2	5,000 lb/hr	35°F to 110°F	5.0 kW	Two-phase ammonia HX	5,000 lb/hr	Heating	3 psi	15°F assumed	3/4" outlet 1/2" tube inlet	Refrigerant 11

3.0 TEST OBJECTIVES

The primary goal of this test was to provide a comprehensive performance demonstration of each of the hardware/software elements being utilized in TEXSYS, including the BA thermal bus, TEXSYS, HITEX, DACS, TDAS, and the facility DARS. Ambient test series performed during the BAC/DACS stand-alone ambient test were repeated to demonstrate manual NOP. FDIR procedures were demonstrated for each system level functional fault. Upon satisfactory (as defined by EC2) completion of manual testing, the E/S then was tested in automatic NOP and FDIR procedures. Specific test results are discussed in detail in Section 6.0. Specific test objectives are as follows.

This test demonstrated prototype thermal bus operation utilizing knowledge-based systems and symbolic control techniques. The primary objectives for the TEXSYS/Thermal Bus Test included operation of:

- The TEXSYS/Thermal Bus physical interface via CTSD/DACS
- HITEX data acquisition and display functions for the thermal bus
- TEXSYS/HITEX communications protocol
- TEXSYS/HITEX monitoring, control, FDIR, and advisory functions

Thermal bus operator low level control functions available through TEXSYS/HITEX demonstrated in this test are:

1) Pump on/off control

2) Valve Operation - isolation and control valves

3) Activate/deactivate sensors

Higher level control tasks utilizing the above basic functions were also available. These include:

1) Startup

2) Shutdown

3) Setpoint change 70° - 35°F, 35° - 70°F

4) Nominal operations, 70° and 35°F

FDIR capabilities tested included the following which are derived from the FDIR document and numbers which refer to the particular FDIR paragraph.

SYSTEM LEVEL FAULT	COMPONENT LEVEL FAULT
1. Erroneous instrumentation	3.33 Accumulator position sensor failure
	3.35 Pressure transducer failure
2. RFMD power usage out of tolerance	3.4 RFMD motor failed
3. Evaporator loop flow out of tolerance	3.22 Single Evaporator blockage
4. Inadequate subcooling	3.27 High coolant/sink temperature
	3.11 BPRV failure
5. Setpoint not stable/ tracking	3.10 Non-condensible gas (NCG) buildup
	3.11 BPRV failure
	3.12 BPRV actuator failure
6. Evaporator(s) temperature	3.20 Excessive heat load on single evaporator
7. Fluid inventory out of tolerance	3.30 Slow leak

A subset of these fault scenarios was chosen for the demonstration test, based upon E/S performance during playback software testing with the ammonia charged BATBS.

4.0 APPROACH

This demonstration project was a joint cooperative effort between research and operational NASA Centers: ARC and JSC. The required AI technologies were developed and implemented by knowledge engineers and AI and human factors researchers at ARC; while relying upon the Thermal Control System (TCS) domain experts and knowledge and integration engineers residing at JSC. The demonstration was conducted at JSC with the TCS hardware test bed. The project approach involved a multidisciplinary integration of knowledge engineering, man/machine interfaces, and systems architecture to enhance automation of a prototypic Space Station TCS (Figure 4.0.1).

Prior to beginning any of the testing, the TBS/hardware/software loop was checked out to determine that all systems were operating and to ensure the integrity of the test rig. Section 4.0 of the Test Plan Document (TPD) contains pretest functional checkout guidelines and procedures.

Each test point series was designed to meet specific test objectives. The nominal case test points were designed to provide information on the performance of the TEXSYS E/S. The manually injected fault simulation provided performance data and operational expertise for the automated FDIR procedures of TEXSYS.

The BA prototype thermal bus system variable parameters are: (1) total evaporator heat load and load distribution, (2) the TBS setpoint temperature, and (3) the condenser sink temperature.

The single phase water HX was heated using facility Cart 6. R-11 transferred heat to the two-phase ammonia evaporator supplied by facility Cart 2. The heat applied electrically to the cold plate, cold rail, and two-phase water evaporators was supplied and controlled by the Variac Heater Control. The condenser section cooling was provided by radiator simulator Cart 4 using water/ethylene glycol as a coolant, providing 25.0 kW of cooling capacity. TBS loop setpoint temperature was changed by adjusting the back pressure regulating valve. The TBS setpoint temperature is the saturation temperature a the loop operating pressure. Figure 4.0.2 shows the vapor pressure curve for ammonia.

The wet bus testing phase of the TEXSYS Project was divided into operational testing and demonstration testing. The approach was for operational testing to be a time of debugging and proving TEXSYS. Demonstration testing was then a time to show TEXSYS capabilities.

Operational testing provided a series of tests with increasing E/S autonomy, to perform integrated checkout and evaluation of

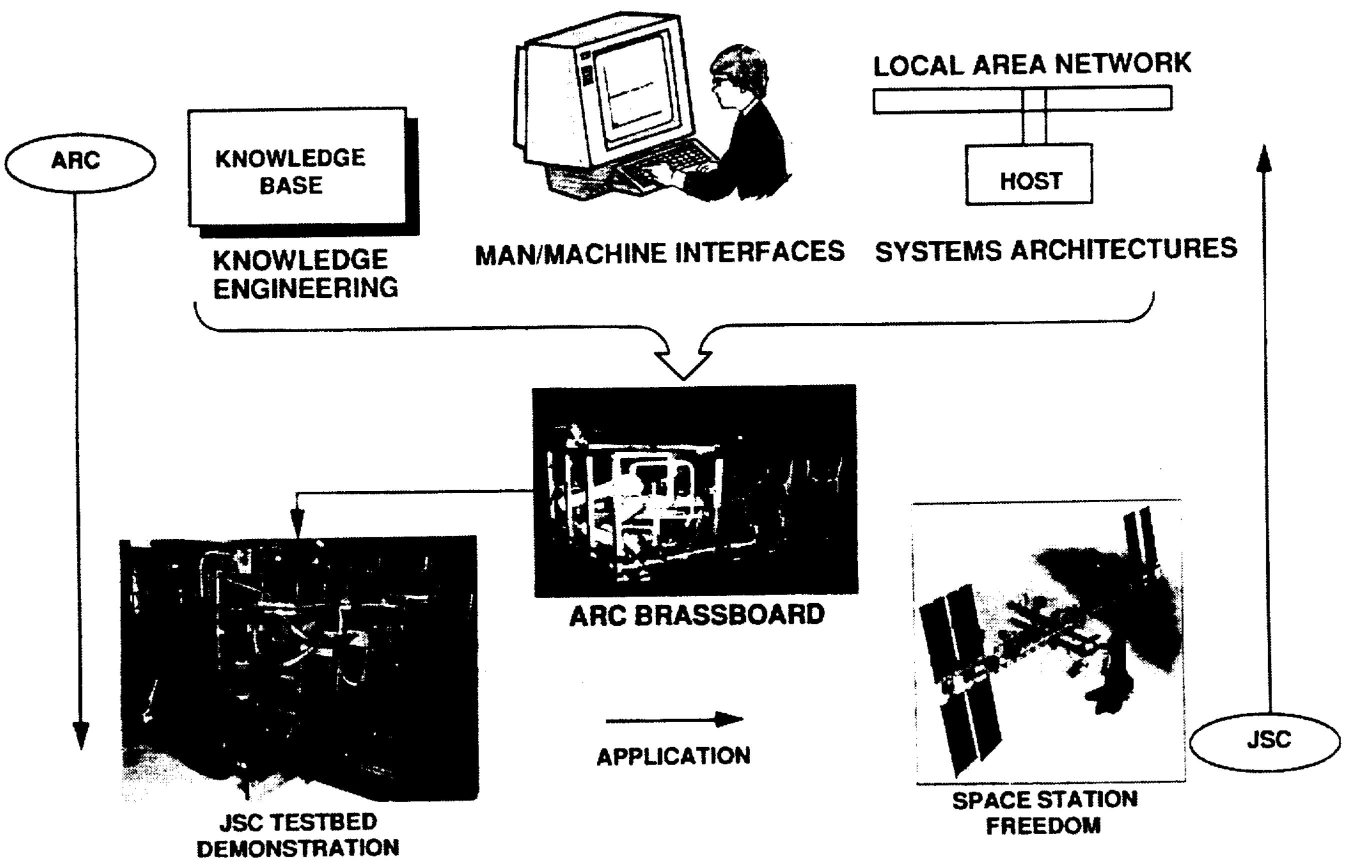

Figure 4.0.1. A Joint ARC/JSC Automation Technology Demonstration

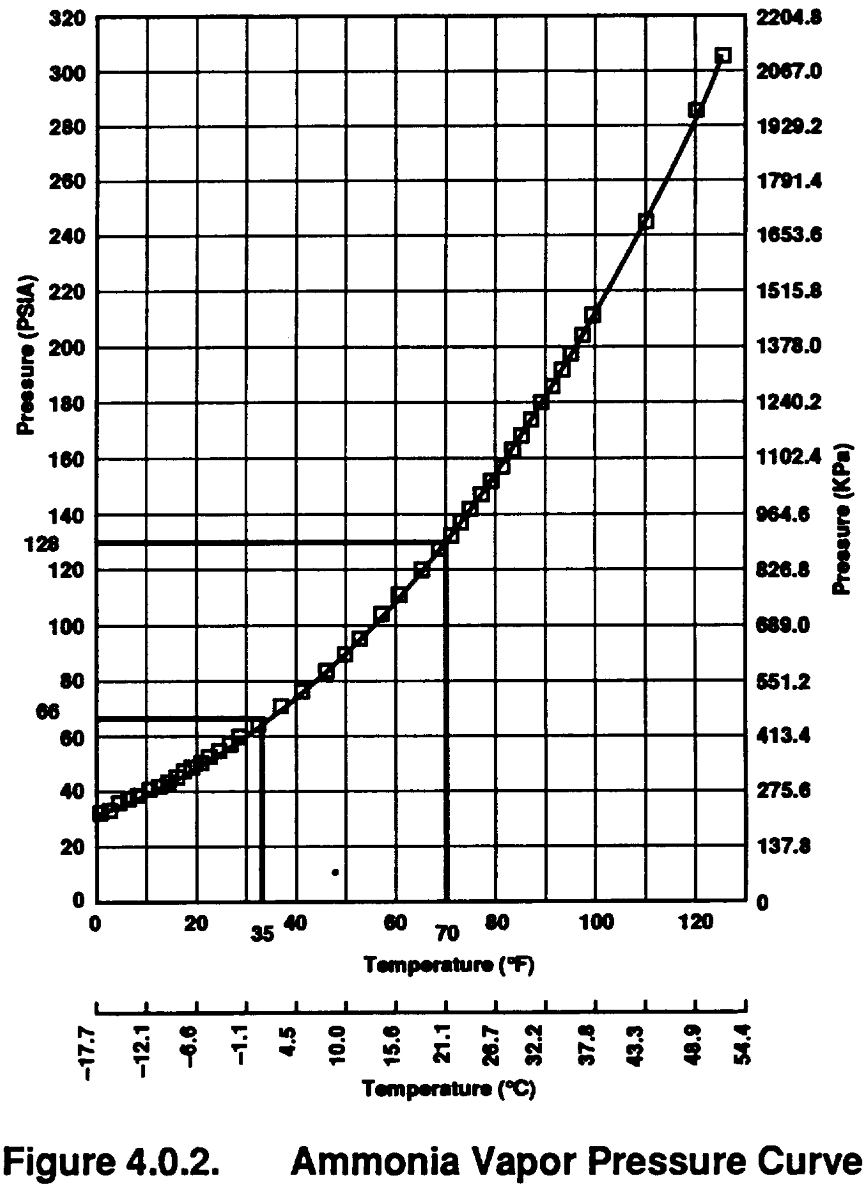

Figure 4.0.2. Ammonia Vapor Pressure Curve

all aspects of the TEXSYS demonstration project including:

- Data acquisition, management, and transmissions
- Thermal bus nominal control techniques
- Fault Detection, Isolation, and Recovery

Operational testing provided the first integrated checkout of all components. Operational testing progressed to concentrate primarily on fault detection scenarios and operations. Finally, operational testing progressed to serve as a full dress rehearsal for the formal demonstration to follow. If any changes were made to the E/S before, during or after any of the operational tests, the next operational test, in sequence, was required to check out the software changes.

4.1 DEMONSTRATION TEST

The formal TEXSYS Demonstration displayed the E/S monitoring, control and advisory functions. As with the operational tests, all standard TTB test procedures were followed. Only test points formally conducted during the operational tests were considered for the Demonstration Test. All NOP and FDIR operations were performed during the Demonstration Test week. A subset of these faults were selected for demonstration to management (based mainly on time constraints).

These specific faults selected were:

SYSTEM LEVEL FAULT	COMPONENT LEVEL FAULT
1. Erroneous instrumentation	3.35 Pressure transducer failure
2. RFMD power usage out of tolerance	3.4 RFMD motor failed
3. Evaporator loop flow out of tolerance	3.22 Single evaporator blockage

5.0 TEST OPERATIONS

All TEXSYS test operations were conducted according to the Space Station Boeing/TEXSYS Thermal Bus Demonstration Test Procedure (CTSD-SS-273).

5.1 OPERATIONAL TESTING

Following completion of leak checking of the TBS and dry functional checkout of the manual valve panel and the DACS control routines, ammonia servicing was initiated on July 12, 1989. Two small leaks were repaired and ammonia servicing was completed the following day. The initial ammonia charge was approximately 89 lbs. HITEX/TDAS was used to monitor bus conditions during the servicing. The initial startup and wet functional testing were performed using DACS control routines. Initially the panel mounted accumulator position sensor and the DACS accumulator position sensor were not in agreement and the DACS accumulator read full, indicating either a faulty sensor or an excessive ammonia charge. TEXSYS was used to monitor the DACS wet functional operations. It indicated "accumulator sensor failure" faults on BPS701 (low) and BPS702 (high), "excessive fluid inventory" (which was later to be determined as the cause of the high accumulator reading), unstable setpoint temperature (due to real drift from the previous BAC/DACS test calibration), and "evaporator loop flow out of tolerance fault" (due to unrealistic setting of transition points in the rules).

TEXSYS wet functional testing was initiated on July 14, 1989. All valves were opened and closed from the HITEX Expert System Screen (ESS). Evaporator loop flow checks were performed for the Single Phase Water and the Two Phase Water Heat Exchangers to set the transition point values for the "Evaporator Loop Flow Out of Tolerance" and "Single Evaporator Blockage" Faults. Shutdown was performed using TEXSYS (confirmation required from the operator to initiate tasks) with no observed problems. The following is a chronological summary of TEXSYS operational testing.

<u>July 19, 1989</u>: The TBS startup was performed by using TEXSYS. Some valve open/close operations were checked out from the HITEX graphics screen. The pressure transducer failure Test Series 7 was performed. This series was repeated as TEXSYS was offline (due to a flag setting problem) and was not receiving data from TDAS. The "excessive heat load on single evaporator" (Test Series 9) was performed. DARS computer (CTSD5) was down all afternoon, so no data recording was possible. The "accumulator position sensor failure" was recognized for high and low values for sensor BPS701 (Test Series 6). The "single evaporator blockage" (8B-closing BSV001) was diagnosed only after manual insertion of heat load data and a false assertion that the solenoid valve was open into the TEXSYS model. This fault was

later repeated closing MV0001 (Test Series 8A). The "RFMD motor failure" was not performed as planned because TEXSYS developed an inconsistent baseline world during setup for the fault. The shutdown was performed manually at the manual value panel.

July 20, 1989: The startup was performed using TEXSYS at noon. Problems with DARS precluded an earlier startup. "Single evaporator blockage" was performed by closing MV0001 (8A). TEXSYS diagnosed the system level fault but had a bug in the component level fault diagnosis procedure. There were DARS problems (with the Database) and data recording was lost. The "BPRV actuator failure" was performed successfully (no data recording). Testing was held until 6:45 pm waiting on DARS. A shutdown was accomplished using the "RFMD motor failure" and was diagnosed successfully by TEXSYS. It "closed BSV706 and shut off RFMD" approximately 2 minutes after these operations were performed manually.

July 21, 1989: The startup with TEXSYS required two attempts. The "BPRV failure" fault was performed. TEXSYS recognized a "suspected BPRV failure" but was unable to confirm the fault due to problems in this task. The two phase water heat exchanger was mapped to determine "delta temperature to heat load ratios (DT/W)" to fix the "single evaporator blockage" fault rules. The "high sink/coolant temperature" fault was performed at 13.5 kW (13B) and was diagnosed by TEXSYS at 55°F. An "inadequate subcooling" fault was also indicated. The "slow leak fault" (16A and B) was attempted, venting a total of 12.5 lbs of ammonia with an accumulator position sensor decrease from 37.32% to 11.33%. The fault was not diagnosed by TEXSYS. The historical delta function was not working properly. A nominal shutdown was performed using TEXSYS and the systems was deserviced for the Apollo public tour over the weekend.

July 24, 1989: The work required to replace BTC402 and BDP702 was accomplished. During this time the DARS tape drive was also replaced. Leak checking was performed that continued through the evening shift. Pumpdown began and the preliminary pressure decay check was passed with a rate of rise of 550 Microns.

July 25, 1989: The TBS pumpdown continued until a satisfactory final pressure decay check was passed with a 270 micron rate of rise. The TBS was serviced. A TEXSYS startup was successful but TDAS bugs precluded operational testing and a shutdown was accomplished. After TDAS software fixes were completed, a second TEXSYS TBS startup was accomplished. The startup was smooth but system stability could not be achieved. The setpoint drifted up. It was noted the condensate return flow was zero and temperature was 90°F. The bus was shutdown and a check of the bus was performed. It was found that condensate return line manual isolation valve BMV704 was inadvertently left closed after servicing.

July 26, 1989: The system was started using TEXSYS and four attempts were required. During 70°F operations, the "single evaporator blockage" fault was triggered several times and TEXSYS cycled BSV701 (the wrong valve) open and closed. In the first instance, the valve power supply was at 12 volts so the valve was closed but TEXSYS was unable to reopen the valve. The DACS screen showed the valve as green (open) during this period but the printout on the logger indicated when the valve was opened and closed. Apparently at 12 volts, when a valve changes to closed, this will not be indicated by the DACS screen. The valve was closed approximately ten minutes.

Heat loads were removed to allow overheated evaporators to cool and the valve power supply was set at 24 volts. TEXSYS retriggered the "single evaporator blockage" fault and closed the valve even though the confirmation level was set. A "prompt/acknowledge" was inserted into this task in the model. The transition points for the evaporator flow and the two phase water heat exchanger delta temperature/heat load ratio still needed to be adjusted upward. TEXSYS performed a 70° to 35°F setpoint reconfiguration. It again skipped the "heat load turndown" and the "let accumulators settle" tasks which are supposed to be performed before the BPRV moves. This problem was supposedly fixed the week of July 17, 1989. TEXSYS was taken down and the set point reconfiguration completed using DACS. The system was shutdown manually using DACS. It appeared that the "system build" (software save) done over the weekend did not include all of last week's (week of July 17, 1989) patches to TEXSYS and that the model was left in an inconsistent state.

July 27, 1989: TEXSYS started up the system on the second attempt. Setpoint changes from 70° to 60°F and 60° to 70°F were performed to checkout the fixes made to the set point increase task (making sure TEXSYS has evaporator loads shut off and that the accumulators settle out before adjusting the BPRV). It seemed to work. The two phase water heat exchanger was mapped at three heat loads to obtain steady state and transient DT/W ratio information. This information was for the rules for "single evaporator blockage". The "evaporator flow loop out of tolerance" transition points were adjusted and TEXSYS ran for about an hour under steady state conditions with no faults triggered. TEXSYS performed shutdown. The GSS was down (TDAS link to HITEX down), but the ESS still received information and performed functions adequately.

July 28, 1989: A TBS startup was performed smoothly using TEXSYS. Errors occurred after startup: a second setpoint change (unstable setpoint fault???) and request to close BSV701 ("single evaporator blockage" fault) were vetoed. A warning occurred that the RFMD monitor task was vetoed (operator says it was not). This appeared to be a network (DNA) problem (TDAS was running out of buffer space for network processing). Variable heat loads were performed at 70°F at 5, 10, and 15 kW. Set point decreased from 70° to 35°F using TEXSYS. The set point hung about 38.6°F with accumulators full at 5.0 kW heat load. The "vent NCGS from RFMD once" routine was performed four times(via HITEX) to try to decrease accumulator volume. It went from 99+ to 98%. Heat loads on Cart 6 were increased too rapidly for a 35°F setpoint. This Cart should be brought on-line at 65°F and minimum flow when at 35°F setpoint temperature. Variable heat loads at 13.0 kW (5F) and 5.3 kW (5D) were performed. Excessive heat load or evaporator blockage faults did not trigger because the transition points on trends were not currently defined in the TEXSYS model. The set point was returned to 70°F by TEXSYS. It required two attempts (confirmation levels were not set so the task was aborted by operator) on the first attempt. The system had lined out at 70°F but TEXSYS had not "succeeded" (concluded) the set point change task so the task was forced to succeed by the operator. An "accumulator position sensor failure" fault was performed at 5.0 kW per deviation sheet. "Low extreme sensor failure" and "fluid inventory out of tolerance" (low and high due to voltage spikes) faults were triggered. A "pressure sensor failure" fault was induced, but as it was indicated on the TEXSYS monitor HITEX and TDAS links died. The system was shutdown manually.

<u>July 31, 1989</u>: A TBS startup was performed using TEXSYS. A restart of FLEXCON was required. The "BPRV failure" fault was performed twice. During first attempt TEXSYS thought the system was in setpoint change mode. This was corrected and the fault retried. The "suspected BPRV failure" was indicated but the BPRV failure confirmation task did not conclude until it was forced by the TEXSYS operator. A problem in the "confirmation" or "succeeding" of tasks existed. The TEXSYS status in the ESS.TEMP.KB was changed from "waiting" to "running" on HITEX. The "excessive evaporator heat load" was performed. The component level fault was recognized but the fault was terminated before the system level fault was triggered. The heat exchanger was loaded to 10.0 kW giving an outlet temperature of 76°F (the rated design of the heat exchanger is 5.0 kW) As currently implemented the system level fault would need an outlet temperature of 81°F to fire. This rule needed to be adjusted. This fault scenario was interrupted by a HITEX DNA network problem. A "BPRV actuator failure" fault was performed. A "pressure transducer failure" fault was performed and interrupted by four computer link down problems of various kinds. The off-nominal shutdown procedure was used to shutdown the system and required approximately 10 minutes as opposed to the nominal shutdown which required 30-45 minutes.

August 2, 1989: The startup using TEXSYS required 3 attempts (a manual RFMD panel switch was incorrectly set on first attempt; computer relays (network tasks) died during second attempt). "Pressure transducer failure" was performed, during which computer links died. TEXSYS ATMS was flushed and the fault retried. The "evaporator blockage" fault was attempted twice. TEXSYS announced the "evaporator loop flow out of tolerance" system level fault on the first attempt. TEXSYS did not come up with the component level fault at all. TEXSYS calculates delta temperature on evaporator surface minus inlet temperature and as the surface temperature rose, the inlet also rose. DT/W ratios were not quite high enough to trigger this fault. Last week (week of July 24, 1989) this fault was triggering frequently and DT/W ratio was too low. The fault logic needs another iteration. In trying to change a valve state from the ESS, the value change task hung in a loop during the confirmation process. A set point decrease to get down to 35°F was attempted. TEXSYS concluded the set point change task too soon and changed the system mode to steady state. This caused faults to be falsely triggered and the operator could not veto several fault tasks that were connected to Model Monitor (a core level TEXSYS process). The TEXSYS operator reset mode to set point decrease. The TBS only reached 44°F and then it rose to 50°F. Venting (0.5 lb of ammonia) and increasing heat load failed to decrease the setpoint temperature.

A check downstairs found the insulation completely off of the side of the pump module. The ammonia tech closed up pump module and taped down seams. Set point change increase to 70°F with TEXSYS did not check heat loads and "settle accumulators". TEXSYS died while trying to change set point. Setpoint was increased to 60°F and 70°F using DACS as TEXSYS died again. Shutdown used the TEXSYS off-nominal procedure.

August 3, 1989: The startup was successful on TEXSYS on fifth attempt. Problems were (one confirmation level problem, two DNA link problems, and one operator shutdown because slow TEXSYS cycles gave low speed and bearing flow information even though the system was recovering). A setpoint change to 70°F was initiated separately during startup and reset system mode back to startup. Setpoint change to 35°F using TEXSYS was performed. It required about 1 hour 45 minutes to get to 35°F. NCG was vented twice. "Excessive heat load on single phase water heat exchanger" was picked up by TEXSYS. Heat load peaked at 10kW. Setpoint was changed to 70°F. TEXSYS asked heat loads to be removed and did "let accumulators settle" task as it should have. Shut down was performed using off-nominal shutdown procedure on TEXSYS.

August 4, 1989: A smooth startup was performed using TEXSYS. Two changes to the text of the startup task were incorporated (to turn on the RFMD panel switch before activating the RFMD from the computer, and deleting closing manual valve switches). The "BPRV failure" fault was induced. TEXSYS gave "unstable setpoint" fault and "BPRV failure" indications. TEXSYS did a setpoint change to 35°F. NCG injection fault was performed and three injections of helium were required for end-to-end delta pressure (BDP703) to drop from 6.7 psid to 0.3 psid. TEXSYS diagnosed "excessive NCG" at approximately 2.7 psid. The operator allowed venting 24 - 2 second bursts with no effect (2 DACS, 22 TEXSYS). The valve open time was reset to 10 seconds and nine vents on DACS and 3 vents on TEXSYS (TEXSYS had gone down during this fault) were tried without any effect. The Ammonia Technician vented 0.4 lbs. of ammonia from NCG tank. The Test Manager decided to raise setpoint without recovering end to end delta pressure. There probably was still some NCG in the system. Cart 6 was brought on-line to set up for "single evaporator blockage." Several excessive heat load faults on single phase water heat exchanger triggered (at 7.0 - 8.0 kW). Blockage fault (8B) was tried by closing BSV001 with DACS deactivated so TEXSYS would not get updates of that parameter. TEXSYS did not recognize the fault as the flow on BFM701 dropped from 1.4 to 1.1 gpm (0.9 gpm was required to trigger fault). "Pressure transducer" fault again had a HITEX/TEXSYS relay die. The system was reset and component and system (erroneous instrumentation) faults triggered. A system level "evaporator temperatures not stable/tracking" did not trigger with Cart 6 at 97 degree outlet and 12.6 kW on the heat exchanger. Nominal shutdown used TEXSYS.

August 7, 1989: Discrepancy Report (DR) work on RFMD speed sensor and valve indication problems delayed startup. Jumpers were installed and analogic digital card replaced. TEXSYS was used to perform startup. Valve close task was set to confirmable during startup to prevent TEXSYS from closing valves in response to bearing flow dips. These have been done from DACS before TEXSYS ever sees dip in bearing flow. The lag between the manual panel gages and the messages to the HITEX operator (panel-DACS subsystem-DACS system TDAS-TEXSYS-HITEX) has been too long for TEXSYS to respond in a timely manner. HITEX printer went down. Accumulator position sensor fault was performed and triggered component fault and low and excess fluid inventory faults (due to data spikes). "Excessive heat load on evaporator" fault was performed and the component fault diagnosed. System level (evaporator not stable/tracking) was not triggered with single phase water HX at 13.0 kW (with 71°F in and 77°F out). Nominal shutdown was performed via TEXSYS.

August 8, 1989: DARS recording problem occurred during first startup attempt. Startup was performed using TEXSYS. BSV700 was adjusted via DACS when TEXSYS slowed because of checking model state. "Pressure transducer failure" fault was performed. HITEX link down occurred during this fault. "BPRV failure" fault was performed. TEXSYS diagnosed BPRV failure but was unable to identify the type of failure. For some reason, two diagnosis tasks were spawned and ran simultaneously. "High coolant sink" fault was induced and "high sink temperature" diagnosed at 57°F. Subcooling was 10°F and it was decided to recover from fault then rather than wait until "insufficient subcooling" fault was also triggered (at 8°F subcooling). "BPRV actuator failure" fault was induced at 5.2 kW load and 30°F sink temperature and successfully diagnosed. "RFMD failure" fault was induced. TEXSYS required 1 minute 45 seconds from RFMD shutoff to close BSV706. Shutdown was completed manually.

August 9, 1989: Startup was performed smoothly using TEXSYS without confirmations on valve tasks. "Pressure transducer" fault and "RFMD failure" fault were performed. About 2 minutes from RFMD shutdown was required to close BSV706 (manually). The bus was restarted manually from HITEX. During attempted BPRV failure, the bus dropped only to 66°F and stabilized with cooling at 18°F. TEXSYS registered "setpoint not stable/tracking" fault. TDAS died and took TEXSYS off-line with inconsistent baseline worlds. The TEXSYS operator adjusted transition point in "Evaporator not stable/tracking" rules and brought TEXSYS down while setting up for faults. It had both startup and steady-state as system modes. Single phase water HX was heated up to 12.0 kW and neither of the above faults triggered. Rules needed to be adjusted on these faults. RFMD motor failure fault with confirmables off - required two minutes from "RFMD off" until BSV706 closed. During off - nominal shutdown TEXSYS had long cycles (1 1/2 to 2 minutes) between messages to operator to turn off various heaters.

August 10, 1989: Startup was performed using TEXSYS. BSV706 closed late and caused bearing flow to dip. It took two minutes to send a message between TEXSYS and HITEX at the point in the procedure where it tells operator to put heat load on system. BPRV failure fault was attempted twice. TEXSYS indicated "suspected BPRV failure" but did not confirm failure. TEXSYS cycle times were so long that it was unable to see the potentiometer move when it commanded a setpoint change during the diagnosis process. On the second attempt it diagnosed a BPRV actuator failure. During setup for the demonstration, a power outage caused the bus, DARS NEFF, and bus subsystem computer to go down. The wrong breaker was thrown when maintenance personnel were shutting down some fans. The breaker was tagged "do not operate". The system was restarted with TEXSYS, but had to open and close BSV701 a couple of times with DACS. Single evaporator blockage fault was attempted by closing BSV001. TEXSYS did not pick up fault. The new transition points entered (August 9, 1989) did not get saved out. BPR001 pressure readings vs applied voltage were taken to see when TEXSYS recognized pres‿ure transducer failure (at 1.25v and 63.5 psia). TEXSYS shutdown the bus using off-nominal shutdown.

August 11, 1989: TEXSYS startup experienced one inappropriate closing of BSV701 (TEXSYS bogged down thinking). BPRV failure fault was in progress when a freon leak on R2 caused freon/NH3 alarms to go off. The valve panel was killed and shutdown the bus. This problem was believed to be the power supply amps limit not being reset to 3 amps after August 10 power outage. The bus was restarted using DACS while TEXSYS was being reset. BPRV failure was attempted twice without success. It is thought that not doing startup with TEXSYS caused BPRV "slip" to be undefined with updates on BPRV position. No BPRV failure fault can be seen. This was recoded. TEXSYS performed 70 to 35°F setpoint change and reached 35°F in approximately 45 minutes. Several "NCG buildup" faults indicated due to flat spots in downward trend of setpoint temperature. "Emergency two phase water HX blockage" faults indicated. Surface temperatures were high on heat exchanger but it was not blocked off. At 35°F, the end-to-end delta pressure fell off, but was restored by two 2 second vents (via TEXSYS "vent NCGS from RFMD once" routine). Setpoint was reconfigured from 35 to 70°F using TEXSYS routine which worked properly and required one hour. The TEXSYS operator took TEXSYS off line due to long cycle times (346 seconds). DACS manual shutdown was performed.

August 14, 1989: TEXSYS startup of the bus was slow and sluggish. "Excessive heat load" component fault triggered after 70°F set point reached. TEXSYS garbage collection was performed. During an attempted BPRV failure fault, the bus shutdown by automatic low bearing flow relay shutdown. Right after MV0711 was closed the BPRV "failed" open and the accumulator filled completely up as during a setpoint change. The shutdown diagnosis was that as the setpoint was dropping, there was a huge heat slug on Cart 6 from 10.0 kW up to 19.0 kW and down to 4.0 kW. Approximately 5 minutes later, end to end delta pressure spiked and then bearing flow dropped and the system shutdown. During the original DACS test the heat load was kept constant at 5.0 kW during this fault (only electrical heat loads on systems). We should duplicate those conditions when performing the BPRV failure fault. The system was restarted using TEXSYS, raggedly with opening and closing BSV700 and BSV701 (DACS and TEXSYS both) and Pacific Power Supply HZ dropped to 340 HZ to provide more power to the RFMD. BPRV failure was repeated twice again. The first repetition had "suspected BPRV failure" indicated but after TEXSYS adjusted setpoint TDAS died and the fault was not confirmed. On the second attempt the "suspected BPRV failure" indicated but the TEXSYS-HITEX relay died as TEXSYS was about to change the setpoint to check for BPRV failure. "Single evaporator blockage" was performed by closing BSV001. Evaporator loop flow BFM701 dropped to 1.1 GPM (the amount required to trigger a low flow alarm) as the evaporator surface temperature BTC005 reached 140°F (high limit for fault), TEXSYS diagnosed a "single evaporator blockage emergency". The bus was shutdown using the nominal TEXSYS shutdown procedure.

August 15, 1989: Two aborted startups were experienced. During the first startup, the DACS bus subsystem computer died from a software glitch. The second was from "initloop" being run while the bus was running (it shuts off RFMD). The BPRV failure was attempted twice. TEXSYS "suspected BPRV failure". During processing "confirm BPRV failure" task, TEXSYS correctly attempted to adjust setpoint and asked operator to vary coolant sink temperature. It may have missed the setpoint tracking the coolant temperature because of a 10 minute wait in the task. TEXSYS operator terminated the task. On the second attempt at BPRV failure, TEXSYS "suspected the BPRV failure" and adjusted the setpoint. The TEXSYS operator terminated the confirm BPRV failure as TEXSYS cycle times were 5-6 minutes long. Single evaporator blockage fault was attempted. TEXSYS indicated "evaporator loop flow out of tolerance" (system level) and "single evaporator blockage warning". The fault terminated manually when evaporator surface temperature BTC005 reached 140^{o}F high limit. Pressure transducer fault was performed. TEXSYS indicated a pressure transducer fault and "erroneous instrumentation" (system) fault within 2 minutes. The RFMD motor failure was used as shutdown with the time between "RFMD off" and closing BSV706 only 45 seconds.

August 16, 1989: During startup TEXSYS did not open BSV700, BSV701, and BSV706 (these operations were performed through DACS). TDAS and TEXSYS parameters were adjusted manually during setpoint change to 70^{o}F. TEXSYS falsely indicated "BPRV actuator failure". A high coolant/sink temperature "fault" was performed. TEXSYS recognized the fault at 55^{o}F. TEXSYS garbage collection was performed. BPRV failure was attempted twice. During both attempts, TEXSYS did "suspected BPRV failure" task and initiated the "confirm BPRV failure" task. It adjusted the setpoint to 80^{o}F and requested that the coolant temperature be raised 10^{o}F. In the first instance, the TEXSYS model locked. The second attempt was terminated due to NH_3 technicians going off shift. Demonstration practice - pressure transducer failure (7 minutes), BPRV actuator failure (6 minutes), and RFMD motor failure (2 minutes from RFMD off to closing BSV706) - were all successful. (Times do not include transition times between faults). Sequencing through heater shutdown took too long for observers to want to watch (8 additional minutes).

August 17, 1989: TEXSYS startup was sluggish. It commanded BSV706 and BSV701 to open twice. There was a delay in opening BSV700. TEXSYS was slow in requesting heat loads as well as in processing setpoint change to 70^{o}F. "Excessive heat load" fault was done on single phase H2O HX. Demonstration faults were practiced: Pressure transducer fault, BPRV actuator failure fault, and RFMD motor failure fault. Restart with TEXSYS was smoother than the first startup. "Single evaporator blockage" fault was attempted twice. System level fault - "evaporator temperatures not stable/tracking" was diagnosed. The component level fault was not diagnosed on either attempt. Attempted BPRV failure fault was unsuccessful. Faults that showed up were: "Setpoint not stable/tracking" (system level fault), "evaporator loop flow out of tolerance", "evaporator temperatures not stable/tracing", and "loss of subcooling" faults. There was no BPRV failure announcement. Accumulator position sensor failure fault was induced. TEXSYS diagnosed "accumulator position sensor low extreme" (component) and "erroneous instrumentation" (system) faults. TEXSYS performed setpoint change down to 60^{o}F and back up to 70^{o}F using "quick" setpoint change task. This took about 20 minutes and could be an additional demonstration item. During setpoint change TEXSYS indicated "BPRV actuator failure" messages both up and down (spurious). TEXSYS confirmed actuator movement and concluded tasks were successful. Demonstration practice was repeated again with plots on HITEX set up ahead of time. Pressure transducer fault required three minutes and BPRV actuator failure required six minutes. RFMD motor failure was too slow with confirmations left on. DACS was used to close BSV706 four minutes after RFMD shut off. Time from RFMD off to TEXSYS deciding to shut valve was 4.5 minutes, then operator shut off heat loads and completed shutdown.

<u>August 18, 1989</u>: System rebuild the previous evening did not work properly, scrambling the TEXSYS model. Initial system startup was with an old version of TEXSYS but it was decided to shutdown for system rebuild. The second TEXSYS startup was very smooth. Burying task tree graphics on ESS sped up operations and made data transfer faster. Accumulator position BPS702 was at 2% (very low) and increased up to 50%. BPRV failure was attempted twice. On the first attempt coolant was at 40^{o}F and increased to 50^{o}F and with the system becoming unstable so the series was terminated. A quick setpoint change from 70^{o}F to 60^{o}F and back was used to check out some TDAS/HITEX update problems. Second attempt at BPRV failure fault was unsuccessful due fault being repeated within time out period of BPRV failure task. (The task will only "fire" every 70 minutes). TEXSYS was taken down, reinitialized model and re-established links. "Single evaporator blockage" performed successfully (1st time) with BSV001 (8B). Evaporator blockage (component level) fault was recognized. TEXSYS toggled BSV001, saw the temperature decrease, and concluded the fault was due to a sticking valve. Demonstration faults: pressure transducer failure, BPRV actuator failure, and RFMD motor failure were performed in 16 minutes total time.

<u>August 21, 1989</u>: Startup with TEXSYS was ragged. Valves opened and closed manually and by TEXSYS to achieve stability. Accumulator positions were low (1.9%) to start (wanted to add some ammonia). The team practiced pressure transducer failure,

BPRV actuator failure, and RFMD failure and repeated pressure transducer failure and RFMD failure for W. Guy. Restarts using TEXSYS were smooth. "BPRV failure" fault was unsuccessful. "Single evaporator blockage" fault (closing BSV001) recovery performed successfully by TEXSYS. Shutdown using RFMD motor failure fault.

<u>August 22, 1989</u>: TEXSYS performed startup. "Single evaporator blockage" fault by closing BSV001 was attempted twice. TEXSYS successfully recovered from fault on second attempt. When attempting BPRV failure, TEXSYS did not conclude "confirm BPRV failure" task. Successfully repeated was single evaporator blockage. Demonstration faults: pressure transducer failure, single evaporator blockage, and RFMD failure faults were practiced. System was restarted using TEXSYS but had to close BSV701 twice through DACS. Pressure transducer failure, single evaporator blockage (three times), and RFMD failure were practiced.

<u>August 23, 1989</u>: Two demonstration practice sessions were performed: pressure transducer failure, single evaporator blockage, and RFMD failure faults. The bus would not start for demonstration after several attempts because of low bearing flow and insufficient ammonia inventory. It was charged with 15 lbs ammonia. The RFMD was started manually. It was very sluggish, with a high power draw. TBS was brought up very slowly, increasing frequency on Pacific power supply. The "excessive heat load" fault was performed. The component fault triggered early on. The system fault triggered only by requesting TDAS update (deadbands too wide) at 24.0 kW on bus and single phase water and two phase ammonia heat exchanger outlet temperature of 77^{o}F. A nominal shutdown was performed with TEXSYS.

<u>August 24, 1989</u>: The TEXSYS startup was smooth. The "BPRV failure" had five unsuccessful attempts. The sixth attempt was successful. TEXSYS confirmed that the BPRV had failed open. The "excessive heat load" fault resulted in component and system level faults successful with heat load at 23.5 kW, single phase water outlet temperature at 77.2^{o}F and heat load at 13.1 kW and two phase ammonia outlet temperature at 76.3 and heat load at 5.0 kW. The BPRV failure was repeated twice unsuccessfully. TDAS link went down so the TBS was shutdown manually. An added 8.2 lbs ammonia to the bus for slow leak fault. The slow leak was to be no more than 18 lbs. The bus should not be restarted without replacing ammonia vented during slow leak fault.

<u>August 25, 1989</u>: The TEXSYS startup was sluggish. The slow leak was performed (vented 17 lbs) but was not diagnosed by TEXSYS. The bus was serviced with 20.3 lbs ammonia. "Slow leak" was performed again, venting 12.8 lbs. "Slow leak" (component) and "fluid inventory out of tolerance" (system) faults were

successfully diagnosed by TEXSYS. The "BPRV failure" was attempted. The "suspected BPRV failure", "confirm BPRV failure" and "diagnose BPRV failure" tasks fired. TEXSYS was not able to determine specific type of BPRV failure. Manual shutdown was performed.

5.2 DEMONSTRATION TESTING

August 28, 1989: Demonstration test activities began with a TEXSYS startup (Test Series 1) but low bearing flow caused an automatic shutdown. The bus was restarted manually using the Pacific Power Supply to bring up RFMD speed. TEXSYS was off-line for debugging transition point active-value updating problems.

The "high coolant/sink temperature" fault simulation (Test Series 13) was performed and the component level fault was diagnosed by TEXSYS. While attempting to induce the system level "loss of subcooling" fault setpoint control of the bus was lost. During this time TEXSYS indicated a number of faults: "slow leak" due to inventory decline because of rising setpoint temperature, a "suspected BPRV failure" due to setpoint drift with nominal subcooling, an "evaporator blockage" fault due to high temperatures when heat load was reduced, and "unstable evaporator temperatures". When the setpoint exceeded 85°F, TEXSYS requested an emergency shutdown, which was vetoed by the operator. High RFMD power draw triggered a "high RFMD power draw" fault on TEXSYS. A manual emergency shutdown was performed, for which TEXSYS generated "low power draw emergency, RFMD motor failure" and "low bearing flow emergency" fault messages. The bus was allowed to cool down and TEXSYS was taken off line for dynamic garbage collection.

RFMD speed sensor (BNN701) was noisy and spiked high and low when the RFMD was off-line. A capacitor was put in the circuit and the signal damped down. BNN701 continued to show intermittent high spikes throughout the day. TEXSYS marked the sensor as abnormal in the model upon observing spike, which required the TEXSYS operator to periodically reset the sensor status to nominal.

The system was restarted using TEXSYS. The setpoint temperature was still very high (85°F). Shortly after TEXSYS reset the BPRV to request a lower temperature, the low flow relay triggered an automatic shutdown. Heat loads were removed. Resetting the panel turned back on the RFMD so startup was continued. The Pacific Power Supply was used to bring the pump up to speed. Valves (BSV701, BSV700, BSV706) were opened and closed repeatedly to establish flow. A ten second vent (BSV705 opened) was used to regain temperature control and establish end-to-end delta pressure. System heat load was increased to 5.0 kW and the system allowed to stabilize.

"Pressure transducer failure" (Test Series 7) and "accumulator position sensor failure" (Test Series 6) faults were induced at 70°F setpoint temperature and 5.0 kW system heat load. The component level and "erroneous instrumentation" system level faults were correctly indicated by TEXSYS. Variable heat loads at 70°F at 5.0 kW (Test Point 5A) and 10.0 kW (Test Point 5B) were recorded. "Single evaporator blockage" fault was induced twice at the two-phase water heat exchanger by closing BSV001 (Test Series 8B). The first instance gave all expected fault messages ("evaporator loop flow out of tolerance" and "single evaporator blockage" fault) but did not toggle valve BSV001. The second repetition of the fault triggered the "evaporator loop flow out of tolerance" and "single evaporator blockage emergency" (a more severe level of the fault which directs the operator to remove heat loads but bypasses toggling the valve BSV001) faults. An "off-nominal" shutdown (Test Series 16) was used to terminate testing for the day.

August 29, 1989: The initial system startup using TEXSYS was terminated when all valves closed because Twin Condenser isolation valve (BSV502) had an excessive current draw. The solenoid valve power supply was disconnected, leaving BSV502 failed in the closed position. Condenser capacity was then limited to approximately 12.0 kW with all heat load removal shifted to the Shear Flow Condenser.

The bus was started up using TEXSYS. The system setpoint (BTC704) was decreased from 77°F to 70°F using "quick" setpoint change routine. A "single evaporator blockage" fault was induced by closing BSV001. TEXSYS indicated the system level "evaporator loop flow out of tolerance" fault and the component level "single evaporator blockage" fault. TEXSYS toggled open BSV001, recovering from the fault successfully. A "slow leak" fault was incorrectly triggered during the "single evaporator blockage" simulation. Accumulator bellows casing temperature decrease lags setpoint temperature decrease and can falsely trigger a "slow leak" when the accumulator moves to its steady-state position as vapor bubbles in the accumulator collapse.

"BPRV actuator failure" fault was performed and diagnosed by TEXSYS. TEXSYS was put into standby to continue repairs to active value propagation software (begun August 28, 1989). A 70°F to 35°F setpoint reconfiguration was initiated using the TEXSYS nominal procedure. During the setpoint change, TEXSYS indicated "power draw out of tolerance", "excessive NCG buildup", and "high sink temperature" faults. "Evaporator temperatures not stable/tracking", "excessive NCG buildup", "high sink temperatures", "suspected BPRV failure" and "single evaporator blockage on the coldplate" faults were issued after 35°F setpoint temperature was reached. Stability was not maintainable at 35°F

- end-to-end delta pressure remained low and the setpoint temperature drifted upwards. Coolant was still flowing to the twin condensers and Cart 4 was decreased to -10°F.

Setpoint reconfiguration from 35°F to 70°F was initiated. During the setpoint change, an ammonia leak (dripping on the floor) developed at the liquid sight glass. An emergency manual shutdown was performed and the bus was vented down to 10 psig pressure. The sight glass gland nut was tightened, and the bus was reserviced with 90 lbs. of ammonia.

<u>August 30, 1989:</u> Initial system startup was delayed by DACS/DARS communication problems. The bus was started using the TEXSYS. A manual shutdown was performed due to low bearing flow and apparent lack of inventory. Accumulator position sensor BPS702 read 2% - ammonia filled condensers and vapor side of accumulators. The RFMD was restarted through DACS and run at reduced frequency to provide more power. Approximately 18 lbs. of ammonia were vented. Startup required two and one-half hours to complete. An early declaration of steady-state on TEXSYS during startup resulted in the triggering of several "faults" (conditions due to the startup rather than true faults). These included: "power draw out of tolerance", and "evaporator loop flow out of tolerance". A "high sink/coolant temperature" fault was declared for the twin condensers (off-line due to failed valve BSV502).

The setpoint was adjusted downward to 70°F using the TEXSYS "quick" setpoint change routine. An "NCG buildup" fault was indicated, the venting routine performed, and end-to-end delta pressure was restored. A "slow leak" fault was indicated based on accumulator position sensor BPS702 due to signal spikes. The sensor settled to a steady-state position from a high level following setpoint decrease to 70°F.

"Excessive heat load on single evaporator" was induced on the single phase water heat exchanger by raising the Cart 6 temperature to 92°F. This component level fault and the system fault "evaporator temperatures not stable/tracking" were recognized by TEXSYS. Cart 6 was then taken off-line and the system set up for the "BPRV failure" fault. A "BPRV failure" fault was initiated. TEXSYS indicated "NCG buildup" due to the initial low end-to-end delta pressure, and "evaporator temperatures not stable/tracking" due to thermal lag as the setpoint temperature (BTC704) dropped. "Suspected BPRV failure" and "diagnose BPRV failure" tasks were initiated by TEXSYS. It attempted to adjust the setpoint temperature upwards and requested that the operator raise the coolant temperatures to control setpoint but was unable to complete the diagnose as the task exceeded its allowable time limit. An incorrect "BPRV actuator failure" fault was indicated. TEXSYS was taken off-line for a garbage collection. The "BPRV failure" fault was then successfully repeated. TEXSYS correctly diagnosed a "failed open" BPRV and an "setpoint not stable/tracking" system level fault.

A 70°F to 35°F nominal setpoint reconfiguration was initiated. "Excessive NCG buildup" was diagnosed and a total of 4.9 lbs. of ammonia was vented. The setpoint temperature decreased only to 40°F. A false "single evaporator blockage" fault was indicated as the heat load was decreased on the two-phase water heat exchanger while the surface delta temperature increased due to the drop in setpoint temperature.

The setpoint was reconfigured to 70°F. The operator requested a nominal setpoint change but the setpoint change task did not request heat load removal or wait for the accumulator to settle out before adjusting the BPRV position. TEXSYS operator had left system mode defined as "setpoint decrease" when a BPRV failure confirmation task (generated when the setpoint decrease task timed out above 35°F so TEXSYS suspected a BPRV failure) was aborted. A "slow leak" fault message was generated by spikes in accumulator position sensor reading (BPS702). Several false "power draw out of tolerance" messages were also triggered by spikes in the RFMD power reading (BPW701). When the system reached 70°F, the bus was shutdown using the TEXSYS nominal shutdown routine.

<u>August 31, 1989:</u> System startup was performed smoothly using TEXSYS. The setpoint was decreased from 77°F to 70°F using the TEXSYS "quick" setpoint change routine. An "NCG buildup" fault message was generated when the end-to-end delta pressure dropped due to the setpoint decrease. The fault task self terminated when the delta pressure was restored. A "slow leak" fault was induced and 8.4 lbs. of ammonia vented causing an accumulator position sensor decrease from 87% to 73%. TEXSYS successfully diagnosed the "slow leak" component fault and the "losing fluid inventory" system level fault.

A setpoint change was induced using the TEXSYS nominal setpoint change routine. A setpoint of 35°F was requested; the system reached 40°F. Requesting a setpoint of 30°F and venting failed to reduce setpoint further. During this time HITEX was reset after a plotting bug occurred. The setpoint was returned to 70°F. TEXSYS was taken off-line for a "garbage collection" and an additional 7.2 lbs. of ammonia was vented.

A TEXSYS nominal setpoint reconfiguration from 70°F to 35°F was performed. Variable heat loads at 35°F were initiated at 5.1 kW (Test Series 5D) and ended at 6.3 kW (Test Series 5E) when the system became unstable (setpoint temperature began drifting up and end-to-end delta pressure dropped off). TEXSYS indicated an

"NCG buildup" and venting was performed to restore end-to-end delta pressure. The setpoint temperature was then reconfigured to 70^{o}F using the TEXSYS nominal setpoint change routine. TEXSYS was taken off-line to purge excess data from the model.

"Single evaporator blockage fault" was attempted twice by closing MV0001. System level faults "evaporator loop flow out of tolerance" and "evaporator temperatures not stable/tracking" were recognized by TEXSYS. In the first instance, calculations required for the component level fault were not being performed so TEXSYS was taken off-line again to "flush" the model. In the second instance, TEXSYS diagnosed the "single evaporator blockage" fault so slowly that manual recovery procedures had already been performed. "Pressure transducer failure" fault was induced. The "pressure sensor failure" component fault and the "erroneous instrumentation system level fault" were diagnosed by TEXSYS. An "single evaporator blockage" fault was induced by closing BSV001. TEXSYS diagnosed "evaporator loop flow out of tolerance" and "evaporator temperatures not stable/tracking" system level faults. It was unable to diagnose the component level "single evaporator blockage" fault because valve (BSV001) status was not reset from abnormal to normal after the previous attempt at this test series. A "RFMD motor failure" fault was used to terminate the days activities. Emergency shutdown procedures had been left in a state which required operator confirmation, so the time to "safe" the system was excessive (8 minutes).

<u>September 1, 1989:</u> System startup was performed smoothly using the TEXSYS procedures. A demonstration including: "pressure transducer failure", "single evaporator blockage", and "RFMD motor failure" faults was successfully performed for SSF personnel. The bus was restarted but TEXSYS shut down the bus as the system had almost reached stability. TEXSYS turned off the RFMD because the Symbolics Operating System started a garbage collection at the time TEXSYS turned the RFMD on and the TEXSYS model had not received the information that the RFMD was running. An "erroneous instrumentation" fault was attempted by entering false data values into channel BDP001. An "evaporator loop flow out of tolerance" alarm was generated by entering false values onto data channel BFM701.

"High coolant/sink temperature" fault was induced and correctly diagnosed by TEXSYS. The test series was terminated prior to inducing the "loss of subcooling" system level fault due to time constraints. The system was shutdown using the TEXSYS off-nominal procedure and test activities were terminated. The bus was deserviced and secured with a 10 psig ammonia pad pressure on September 5, 1989.

6.0 DEMONSTRATION TEST RESULTS

This section presents the TEXSYS test results relating to specific test objectives. The system was operated over a heat load range from 1.0 kW to 25.0 kW and system setpoint temperatures of 35°F to 70°F during operational and demonstration testing. All test points were successfully accomplished over this seven week period. Table 6.1 presents a data summary for all successful test points obtained during the demonstration test week (except where noted). Parameters included in the data table are: time, test point identification, bus setpoint temperature, system heat load, facility-side sink temperature, system and component level faults if applicable, and comments. Hard copy output for the HITEX ESS containing information about TEXSYS nominal control activities or FDIR activities and the HITEX GSS containing data tables, data plots, schematics and system status information are included in Appendix A.

6.1 NOMINAL OPERATIONS

TEXSYS oversaw and executed the following preprogrammed normal thermal bus operating procedures: System Startup, Setpoint Reconfiguration, Variable Heat Loads, and System Shutdown. These operations represent normal operations that the thermal management system will perform for SSF. TEXSYS performed these operations in an acceptable manner for a development system. To be considered a real-time operational system, analysis and decision times (TEXSYS cycle times) must be decreased. Timing of events is critical during system startup and shutdown. If operations are not performed in a timely manner, operational anomalies result.

The details of the Nominal Operations performance are described in Sections 6.1.1 through 6.1.5.

6.1.1 Startup - Test Series 1

System startup is performed according to the procedures described in Table 6.1.1.1. Startup of the TBS requires minimal TEXSYS cycle times. Once the RFMD is turned on, valves must be opened at critical rpm levels as the RFMD comes up to speed. The time to come up to speed is approximately 45 seconds. If valves are not opened at the correct times, startup stability can be delayed or possible aborted.

During the demonstration week, ten system startups were attempted (see Table 6.1.1.2). Three of the startups were performed smoothly and were satisfactory (see table numbers 4, 7, and 8). The RFMD speed rose in a manner in which TEXSYS could open the valves in a time that would allow RFMD bearing flow to reach its proper level. RFMD motor power draw reduced to a running level,

TABLE 6.0.1 SUMMARY OF COMPLETED TEST POINTS

START TIME	END TIME	TEST SERIES NO.	SET POINT TEMP. (°F) BTC704	TOTAL HEAT LOAD (KW) BZQ011	SINK TEMP. (°F) BTC621	TEST SERIES NAME (NOP OR COMPONENT LEVEL FAULT)	NOMINAL OPS	FDIR OPS	COMMENTS
240:12:24	240:13:12	1	80	4.7	40	STARTUP	X		
240:15:51	240:17:21	13	70	4.6	67 MAX	HIGH COOLANT / SINK TEMPERATURE		X	LOSS OF SUBCOOLING SYSTEM LEVEL FAULT NOT ACHIEVED - LOST CONTROL OF BUS & SHUTDOWN
240:20:59	240:21:14	1	78	2.6	0	STARTUP	X		
240:22:15	240:22:22	7	70	5.1	0	PRESSURE TRANSDUCER FAILURE		X	ERRONEOUS INSTRUMENTATION SYSTEM LEVEL FAULT
240:22:40	240:22:48	6	70	5.1	0	ACCUMULATOR POSITION SENSOR FAILURE		X	ERRONEOUS INSTRUMENTATION SYSTEM LEVEL FAULT
240:23:17	240:23:25	12	70	5.1	0	BPRV ACTUATOR FAILURE		X	SETPOINT NOT STABLE/TRACKING SYSTEM LEVEL FAULT
240:23:26	240:23:35	5A	70	5.1	0	VARIABLE HEAT LOADS	X		
240:23:37	240:00:05	5B	70	10	0	VARIABLE HEAT LOADS	X		
241:01:14	241:01:22	8	70	10	0	SINGLE EVAPORATOR BLOCKAGE		X	EVAPORATOR LOOP FLOW OUT OF TOLERANCE - SYSTEM LEVEL FAULT
241:01:30	241:01:38	16	70	0	0	OFF-NOMINAL SHUTDOWN	X		
241:15:14	241:16:03	1	77	4.6	0	STARTUP	X		
241:16:07	241:16:20	8	70	4.1	0	SINGLE EVAPORATOR BLOCKAGE		X	EVAPORATOR LOOP FLOW OUT OF TOLERANCE - SYSTEM LEVEL FAULT
241:16:36	241:16:43	12	70	4.1	0	BPRV ACTUATOR FAILURE		X	SETPOINT NOT STABLE/TRACKING SYSTEM LEVEL FAULT
241:17:29	241:18:15	2	70 / 35	3.4	-6	SETPOINT RECONFIGURATION 70 °F TO 35 °F	X		35/70 SET POINT CHANGE ABORTED DUE TO SIGHT GLASS LEAK. EMERGENCY SHUTDOWN PERFORMED

TABLE 6.0.1 SUMMARY OF COMPLETED TEST POINTS

START TIME	END TIME	TEST SERIES NO.	SET POINT TEMP. (°F) BTC704	TOTAL HEAT LOAD (KW) BZQ011	SINK TEMP. (°F) BTC621	TEST SERIES NAME (NOP OR COMPONENT LEVEL FAULT)	NOMINAL OPS	FDIR OPS	COMMENTS
242:14:11	242:16:20	1	77	5.4	0	STARTUP	X		
242:14:39	242:15:58	4	77	3.4	0	NCG VENTING		X	
242:17:05	242:17:44	9	70	12	0	EXCESSIVE HEAT LOAD ON SINGLE EVAPORATOR		X	EVAPORATOR TEMPERATURES NOT STABLE/TRACKING SYTEM LEVEL FAULT
242:21:21	242:21:47	11	70	4.6	15	BPRV FAILURE		X	SETPOINT TEMPERATURE NOT STABLE/ TRACKING - SYSTEM LEVEL FAULT
242:22:10	243:00:53	2	70 / 40	3	0	SETPOINT RECONFIGURATION 70 °F TO 35 °F	X		ONLY REACHED 40 °F
242:23:53	243:00:44	4	70 /40	3	0	NCG VENTING		X	
243:00:53	243:01:21	3	40 / 70	3.5	0	SETPOINT RECONFIGURATION 40 °F TO 70 °F	X		
243:01:32	243:01:52	16	70	0	0	NOMINAL SHUTDOWN	X		
243:12:18	243:12:47	1	77	5.4	-5	STARTUP	X		
243:13:52	243:14:04	15	70	5.4	-5	SLOW LEAK		X	FLUID INVENTORY OUT OF TOLERANCE SYSTM LEVEL FAULT VENTED 8.4 LBS AMMONIA
243:14:10	243:15:46	2	70 / 40	5.4	-5	SETPOINT RECONFIGURATION 70 °F TO 35 °F	X		ONLY REACHED 40 °F
243:15:58	2 3:16:44	3	45 / 70	5.4	-5	SETPOINT RECONFIGURATION 45 °F TO 70 °F	X		
243:18:34	243:19:45	2	70 / 35	5	-5	SETPOINT RECONFIGURATION 70 °F TO 35 °F	X		
243:20:15	243:20:15	5D	35	5	-5	VARIABLE HEAT LOADS	X		
243:20:15	243:20:28	5E	35	6.3	-5	VARIABLE HEAT LOADS	X		MAXIMUM WITH SHEAR CONDENSER

TABLE 6.0.1 SUMMARY OF COMPLETED TEST POINTS

START TIME	END TIME	TEST SERIES NO.	SET POINT TEMP. (°F) BTC704	TOTAL HEAT LOAD (KW) BZQ011	SINK TEMP. (°F) BTC621	TEST SERIES NAME (NOP OR COMPONENT LEVEL FAULT)	NOMINAL OPS	FDIR OPS	COMMENTS
243:21:30	243:22:10	3	35 / 70	5.2	-5	SETPOINT RECONFIGURATION 35 °F TO 70 °F	X		
244:01:04	244:01:06	7	70	4.9	-5	PRESSURE TRANSDUCER FAILURE		X	ERRONEOUS INSTRUMENTATION SYSTEM LEVEL FAULT
244:01:31	244:01:50	16	70	0	-5	OFF-NOMINAL SHUTDOWN		X	END OF TOO SLOW RFMD FAILURE (CONFIRMATIONS LEFT ON)
244:13:27	244:13:56	1	70	4.9	0	STARTUP	X		
244:15:59	244:16:03	7	70	4.9	0	PRESSURE TRANSDUCER FAILURE		X	ERRONEOUS INSTRUMENTATION SYSTEM LEVEL FAULT
244:16:04	244:16:10	8	70	4.6	0	SINGLE EVAPORATOR BLOCKAGE		X	EVAPORATOR LOOP FLOW OUT OF TOLERANCE - SYSTEM LEVEL FAULT
244:16:12	244:16:17	10	70	0	0	RFMD FAILURE		X	RFMD POWER DRAW OUT OF TOLERANCE SYSTEM LEVEL FAULT
244:16:55	244:17:17	1	70	5	40	STARTUP	X		
244:19:07	244:20:41	13	70	5	70	HIGH SINK/COOLANT TEMPERATURE		X	TERMINATED DUE TO LACK OF TIME
244:20:41	244:20:44	16	70	0	70	OFF-NOMINAL SHUTDOWN	X		

TABLE 6.1.1.1 STARTUP PROCEDURES - TEST SERIES 1

1.0 BUS PREPARATIONS:

Verify manual valves are in the NORMAL valve configuration, except as follows:

HV-N-05 - CLOSED
HV-N-06 - CLOSED
HV-N-07 - OPEN

2.0 CURRENT STATUS AND SHUTDOWN PANEL:

Verify that CURRENT STATUS and SHUTDOWN PANEL is "ON" and switches are as follows:

Isolation valve controller auto/manual switch to "MANUAL".

Isolation valve switches for BSV705 and BSV706 are "CLOSED" (switches down and lights off), and all other isolation valve switches are "OPEN" (switches up and lights on).

BPRV control auto/manual switch to "MANUAL".

BPRV control on/off switch "ON".

RFMD power relay on/off switch to "OFF".

BPRV motor power (power switch 1) on/off switch to "ON".

3.0 SOFTWARE PREPARATIONS:

Perform/verify DACS and FLEXCON startup according to DACS checklist NN-1018. Delete .SHR files.

Start/verify DARS recording. After DARS is running, start DACS to DARS recording process from NASATEST menu.

From NASATEST menu, start DATA REQUEST processes.

From NASATEST menu, start AUTOSNAP, with 10 minute interval.

Perform/verify TDAS startup if required for test.

Perform/verify TEXSYS startup if required for test.

Perform/verify HITEX startup if required for test.

Perform/verify software links if required for test.

TABLE 6.1.1.1 STARTUP PROCEDURES - TEST SERIES 1 (Continued)

4.0 SOFTWARE UTILIZATIONS:

Run INITLOOP and run SYSCALC.

Set potentiometer value for 35 deg. F setpoint to 4.275 Volts as shown on the DACS BPRV control and parameter screen.

Set pontentiometer value for 75 deg. F setpoint to 5.890 volts as shown on the DACS BPRV control and parameter screen.

Execute FACILITY.COM from [BASELINE.DATABASE] on flight facility subsystem.

Execute BUSCALC.COM from [BASELINE.DATABASE] on flight bus subsystem.

5.0 CONTROL PREPARATIONS:

Verify RFMD and BPRV (both sides) are "OFF" as shown on the BPRV and RFMD manual DACS control screen.

Configure the valves on DACS to match the BAC manual panel valve positions (lights). All valves should be "OPEN" except for BSV705 and BSV706 which are "CLOSED".

6.0 CURRENT STATUS AND SHUTDOWN PANEL:

Change the valve power supply from 12 Vdc to 24 Vdc.

Put the Isolation valve panel Auto/Manual switch to the "AUTO" position.

Put BPRV control Auto/Manual switch to the "AUTO" position.

Put RFMD power relay On/Off switch to the "OFF" position.

7.0 CONTROL AND MONITORING PREPARATIONS:

Set the CRT privileges to both subsystem Aydin CRTS to "OFF" using CRTPRIVSWITCH.

Set the System Aydin CRT privileges to "OFF" from the NASATEST menu (option 3).

From the System Parameter Page, activate system CRTs number 2, 3, 4, 5, and 6.

TABLE 6.1.1.1 STARTUP PROCEDURES - TEST SERIES 1 (Continued)

Verify sufficient paper for printers.

Verify HITEX configured as desired if required for test.

THERMAL CONDITIONING

8.0 Verify facility cooling Cart C4 is set to 0 deg F (or other temperature per DAE call) for 70 deg F setpoint.

9.0 Have DAE verify when the thermal stability of the Bus is achieved.

GMT_____:_____:_____:_____

10.0 PER DAE CALL: Configure Cart 6 to bypass Bus and precondition working fluid to 80 deg F.

11.0 ET verify/set all Variacs (6 circuits) controlling heat to the Bus are set to "ZERO".

12.0 On the CURRENT STATUS AND SHUTDOWN PANEL verify the outputs of the HP-6624A power supply are at the following levels.

DEVICE	CHANNEL #	VOLTAGE
RFMD Speed Sensor	1	15 Vdc
Kill Circuit	3	24 Vdc
Absolute Press Transducer	4	28 Vdc

13.0 ET verify or switch ALL VARIAC breakers to "ON".

14.0 DACS/TEXSYS/HITEX verify/set following valves to "CLOSE":

BSV700, BSV701, BSV705, BSV706

DACS/TEXSYS/HITEX verify/set following valves to "OPEN":

BSV001, BSV101, BSV201, BSV301, BSV302, BSV401, BSV402, BSV501, BSV502, BSV702, BSV703

15.0 DAE verify valve setting as described above on the manual panel.

16.0 Verify/set BPRV position for 75 deg F setpoint.

17.0 Verify RFMD power switch on the CURRENT STATUS PANEL is in the "OFF" position and that the RFMD power status (BPW750) on the DACS is "OFF".

TABLE 6.1.1.1 STARTUP PROCEDURES -
TEST SERIES 1 (Continued)

18.0 On the Pacific Power supply, set the RFMD power supply voltage to 115 volts and the RFMD frequency to 400 Hz and push power "on" button.

19.0 On the CURRENT STATUS AND SHUTDOWN PANEL verify the bearing low-flow switch is in the "OVERRIDDEN" position.

20.0 NOTE: At DAE call TD concurrence, an additional CRT may have control functions activated to facilitate startup operations.

On the CURRENT STATUS AND SHUTDOWN PANEL, turn the RFMD power relay on/off switch to "ON" position. From DACS/TEXSYS/HITEX turn RFMD power to "ON".

GMT_____:_____:_____:_____

Monitor the RFMD speed (BNN701 on DACS/TEXSYS/HITEX and meter on panel) and bearing flow rate (BFM703 on DACS/TEXSYS/HITEX and meter on panel).

21.0 When RFMD speed reaches 2000 RPM on BNN701 (and/or on panel) and bearing flow BFM703 is > 0.3 GPM, on the CURRENT STATUS AND SHUTDOWN PANEL (manual) or on DACS switch:

- BSV706 (accumulator vapor on/off isolation valve) to "OPEN".

- BSV701 (evaporator supply isolation valve) to "OPEN".

NOTE: If bearing flow BFM703 drops below 0.3 GPM after BSV706 and BSV701 are opened, close BSV701. If bearing flow does not recover to > 0.3 GPM, close BSV706 and shutdown RFMD.

22.0 When the RFMD speed reaches 2800 RPM on BNN701 (and/or on panel): on the CURRENT STATUS AND SHUTDOWN PANEL (manual) or on DACS/TEXSYS/HITEX, switch - BSV700 (accumulator flow through valve) to "OPEN".

NOTE: Once RFMD speed sensor has reached a steady speed > 2800 RPM, the low speed alarm on DACS needs to be adjusted upwards (it is reset to default value when the system is brought on line at the start of the day); therefore, DACS/TEXSYS/HITEX operator must raise BNN701 EU low alarm limit from 120.0 to 2800.0 RPM.

23.0 Set the RFMD power supply voltage to 115 or to 75 Volts per

DAE request and RFMD frequency to 400 Hz. Record event time and voltage reading.

RFMD Voltage ___________

24.0 Adjust Cart 6 flow and temperature to apply 3.0 KW (per DAE call) to single phase water heat exchanger as indicated on BZQ010, OR apply heat load to two phase water heat exchanger heater per DAE call.

25.0 When the bearing flow is clearly above the minimum flow rate (0.24 GPM on BFM703), on the CURRENT STATUS AND SHUTDOWN PANEL, push the low-flow relay switch to the "ARMED" position.

26.0 Verify/adjust the BPRV position (Bus set point) for 70 deg F (as indicated on BPI752) manually or through DACS/TEXSYS/HITEX.

NOTE: Once BPRV position is verified for 70 deg F, exit STARTUP macro before it adjusts setpoint.

27.0 Proceed with desired bus operation.

GMT_____:_____:_____:_____

TABLE 6.1.1.2. SYSTEM STARTUP ATTEMPTS

DAY	TIME START	TIME COMPLETE	SETPOINT	PERFORMANCE
1) Monday	240:12:24	240:13:12	80°F	Unsatisfactory due to TEXSYS "model-monitor" task problems.
2) Monday	240:20:59	240:21:14	78°F	Unsatisfactory due to hot bus conditions, long cycle times and slow HITEX updates.
3) Tuesday	241:12:41	-	77°F	Aborted because of isolation valve BSV502 failure.
4) Tuesday	2[illegible]1:15:14	241:16:03	77°F	Satisfactory
5) Wednesday	242:13:23	242:13:50	77°F	Aborted due to low bearing flow.
6) Wednesday	242:14:11	242:16:20	77°F	Unsatisfactory due to excess bus inventory and early TEXSYS declaration of "steady-state" gave several "faults.
7) Thursday	243:12:18	243:12:47	77°F	Satisfactory
8) Friday	244:13:27	244:13:56	70°F	Satisfactory
9) Friday	244:16:26	-	70°F	Aborted when garbage collection interrupted startup and TEXSYS turned off RFMD.
10) Friday	144:16:55	244:17:17	70°F	Satisfactory except for valve opening and closing timing.

and the system stabilized. Three times the startup was aborted.

Time lags between DACS operator and TEXSYS perception of RFMD speed and bearing flow data caused conflict between the human operator and the TEXSYS "RFMD startup monitor" task in the opening and closing of valves. For example, an operator might close a valve in response to low bearing flow, TEXSYS would then open the valve or TEXSYS might see low bearing flow when the system had already recovered and close a valve unnecessarily. This issue should be addressed in any future software modifications.

During Demonstration Testing, the initial system startup (Table 6.1.1.2, item 1) was begun with TEXSYS but completed manually due to problems in the TEXSYS "model-monitor" task. Following bus shutdown during "high coolant/sink" fault, the system was restarted using TEXSYS (Table 6.1.1.2, item 2). Shortly after TEXSYS reset the BPRV to request a lower temperature, the low flow relay triggered an automatic shutdown. Heat loads were removed. Resetting the panel turned back on the RFMD so startup was continued. The Pacific Power Supply was used to bring the pump up to speed. Valves (BSV701, BSV700, BSV706) were opened and closed repeatedly to establish flow. A ten second vent (BSV705 opened) was used to regain temperature control and establish end-to-end delta pressure. System heat loads were increased to 5.0 kW and the system allowed to stabilize.

The third startup attempt listed in Table 6.1.1.2 was aborted due to isolation valve BSV502 failure. The startup following the valve work around (table item 4) was satisfactory. The fifth startup attempt was terminated due to low bearing flow. The RFMD was restarted (table item 6) through DACS and run at reduced frequency to provide more power. Approximately 18 lbs. of ammonia were vented. Startup (table item 6) required two and one-half hours to complete. An early declaration of steady-state on TEXSYS during startup resulted in the triggering of several "faults" (conditions due to the startup rather than true faults). These included: "power draw out of tolerance" and "evaporator loop flow out of tolerance". A "high sink/coolant temperature" fault was declared for the twin condensers (off-line due to failed valve BSV502).

Startups on the last two days of testing (table items 7 and 8) were smooth and satisfactory. System restart following the September 1, 1989 demonstration required two attempts. Startup (see table item 9) was terminated after the system had almost reached stability. TEXSYS turned off the RFMD because the Symbolics Operating System started a garbage collection at the time TEXSYS turned the RFMD on and the TEXSYS model had not received the information that the RFMD was running. The second attempt (table item 10) was successful. Sample successful and ragged startup GSS screen print is contained in Appendix A, page A-2, 3.

6.1.2 Setpoint Decrease - Test Series 2

TEXSYS provides two methods to decrease setpoint temperature: "nominal" and "quick" setpoint change routines. In the "nominal" setpoint change, TEXSYS decreases the system setpoint by waiting for the system to stabilize, reducing heat loads, and setting the BPRV to the desired temperatures via DACS control routines. The procedures in Table 6.1.2.1 are followed. The "quick" setpoint change routine resets the BPRV without checking for system stability or decreasing heat loads. TEXSYS successfully decreased the setpoint eight times (four times by the quick routine and four times by the nominal routine). The quick routine was typically used for small temperature changes such as when decreasing from the startup setpoint to 70°F setpoint for nominal operations. The Nominal Setpoint change routine was used when closer attention to system conditions was desired such as when decreasing to 35°F.

On August 29, 1989 a 70°F to 35°F setpoint reconfiguration was initiated using the TEXSYS nominal procedure. During the setpoint change, TEXSYS indicated "power draw out of tolerance" (power sensor readings occasionally spike low), "excessive NCG buildup", and "high sink temperature" (a bad temperature sensor BTC615 had not been "turned off" in TEXSYS by the operator). The NCG task was "succeeded" by the operator without actual venting being performed.

A 70°F to 35°F nominal setpoint reconfiguration was initiated on August 30, 1989. "Excessive NCG buildup" was diagnosed and a total of 4.9 lbs. of ammonia was vented. A false "single evaporator blockage" fault was indicated when the heat load was decreased on the two-phase water heat exchanger while the surface delta temperature increased due to the drop in setpoint temperature. The setpoint temperature plateaued at 40°F. Two 70°F to 35°F setpoint reconfigurations using the nominal TEXSYS procedure were attempted on August 31, 1989. During the first attempt, the setpoint temperature reached only 40°F. After venting 7.2 lbs. of ammonia, a second successful setpoint change was performed.

TEXSYS monitored the reduction in setpoint in a consistent, reliable manner. Because the bus is in a relatively unstable condition during setpoint change (end-to-end delta pressure is low and fluid flows are not balanced), TEXSYS would at times announce faults and request action more frequently than was deemed necessary by the HITEX operator. The two reoccurring nuisance faults (faults that were not real but characteristic of a TBS in transition) were buildup of NCGs and evaporator loop

TABLE 6.1.2.1 SETPOINT RECONFIGURATION ($70^{\circ}F$ TO $35^{\circ}F$) - TEST SERIES 2

NOTE: Operating condition should be stable prior to setpoint change.

OBJECTIVE: Demonstrate operations to reconfigure the bus setpoint temperature from $70^{\circ}F$ to $35^{\circ}F$.

1. Verify isolation valves are in nominal valve configuration.

2. Shutdown facility heater cart C6 to remove heat load from one phase H2O HX. Monitor flow (BFM101) and heat load (BZQ010) and verify these readings go to "zero".

3. Shutdown facility heater cart C2 to remove heat load from two phase NH3 HX. Monitor flow (BFM201) and heat load (BZQ013) and verify these readings go to "zero".

4. Decrease heat load for cold plate, cold rail, and two phase H2O HX heaters to 1.0 kW each (heat load on each heater circuit is 0.5 kW) on the Variac Heater Control. Verify each HX heat load is 1.0 kW on BZW001, BZW002, and BZW003.

5. Adjust BPRV to $35^{\circ}F$ temperature (and 66 psia pressure).

6. If NCG buildup is indicated following setpoint reconfiguration:

   a. The setpoint temperature stabilizes at a temperature above $35^{\circ}F$, and....

   b. Condenser loop end-to-end delta pressure (BDP703) drops below 3 psid (as long as subcooling $8^{\circ}F$), vent NCG from the RFMD.

7. Record current weight of the NCG/NH_3 collection system tank.

8. Vent NCG (manually or using automatic procedures).

9. Monitor system temperature BTC704 and system pressure BPR703, until system achieves stability at $35^{\circ}F$ setpoint.

10. Proceed to next operation.

flow out of tolerance.

HITEX ESS (showing a Task Tree graph and status messages) and GSS printouts are included in Appendix A, Pages A-4 and A-5, for a typical 70°F to 35°F setpoint decrease (August 29, 1989).

6.1.3 Setpoint Increase - Test Series 3

The TEXSYS "nominal" or "quick" setpoint change procedures can be used to increase setpoint temperature. The "nominal" procedure (described in Table 6.1.3.1) increases the system setpoint by calling for heat loads to be removed, waiting for system stability, and setting the BPRV to the desired temperature via the DACS control routine. Setpoint increases can also be made in a "quick" manner by simply resetting the BPRV.

The "nominal" setpoint change routine was used in three instances. On August 30, 1989, the setpoint was reconfigured from 40°F to 70°F. The operator requested a nominal setpoint change but the setpoint change task did not request heat load removal or wait for the accumulator to settle out before adjusting the BPRV position. TEXSYS operator had left system mode defined as "setpoint decrease" when a BPRV failure confirmation task (generated when the earlier setpoint decrease task timed out above 35°F so TEXSYS suspected a BPRV failure) was aborted.

On August 31, 1989, the setpoint was successfully reconfigured twice using the "nominal" routine from 45°F to 70°F (243:15:58 to 243:16:44 GMT) and from 35°F to 70°F (243:21:30 to 243:22:10 GMT). TEXSYS also performed four quick setpoint change requests in conjunction with BPRV failure diagnosis on Wednesday (August 30, 1989).

A typical HITEX ESS printout for a 35°F to 70°F setpoint change (243:21:30 to 243:22:10 GMT) showing task tree graph and messages and a GSS printout for the latter portion of the setpoint changes are included in Appendix A (pages A-6 and A-7).

6.1.4 Variable Heat Loads - Test Series 5

During demonstration testing heat loads were varied at 5.0 kW and 10.0 kW at 70°F setpoint and at 5.0 kW and 6.3 kW at 35°F setpoint. This data is presented in Table 6.1.4.1. Heat loads were limited to relatively low levels due to the failure of the twin condenser isolation valve (BSV502). In each case, TEXSYS successfully accepted the varying heat loads with no fault announcement.

TABLE 6.1.3.1 SETPOINT RECONFIGURATION (35°F TO 70°F)
TEXSYS TEST SERIES 3

NOTE: Operating condition should be stable prior to setpoint change.

OBJECTIVE: Demonstrate operations to reconfigure the bus setpoint temperature from 35°F to 70°F.

1. Verify isolation valves are in the nominal valve configuration.
2. Turn off evaporator heat loads (0.0 total system load).
3. Wait until accumulators stop stroking (approximately 5 minutes). BPS701 and BPS702 position sensors should be stable (+/-2%) for at least one (1) minute.
4. Adjust setpoint to 70°F.
5. Increase heat loads to desired levels.
6. Monitor BTC701 and BTC704 temperatures and BDP703 delta pressure as system moves toward 70°F temperature and 130 psia pressure until system achieves stability at new setpoint.
7. Proceed to next operation.

TABLE 6.1.4.1 VARIABLE HEAT LOADS - TEST SERIES 5

OBJECTIVE: Determine system transient characteristics due to stepping up loads on evaporators and heat exchangers

Heat load variations performed during Demonstration Test:

START TIME	END TIME	TEST SERIES NO.	SETPOINT TEMP. (°F) BTC704	TOTAL HEAT LOAD (kW) BZ0011	SINK TEMP. (°F) BTC621	TEST SERIES NAME (NOP OR COMPONENT LEVEL FAULT)	NOMINAL OPS
240:23:26	240:23:35	5A	70	5.1	0	VARIABLE HEAT LOADS	X
240:23:37	240:00:05	5B	70	10	0	VARIABLE HEAT LOADS	X
243:20:15	243:20:15	5D	35	[illegible]	-5	VARIABLE HEAT LOADS	X
243:20:15	243:20:28	5E	35	6.3	-5	VARIABLE HEAT LOADS	X

6.1.5 System Shutdown - Test Series 16

Daily system shutdowns during the TEXSYS test were performed using the procedures in Table 6.1.5.1. TEXSYS provided two routines for system shutdown. The nominal shutdown calls for heat loads to be removed, waiting for the heat to dissipate, closes the accumulator isolation valve, and then turns off the RFMD. The emergency shutdown closes the accumulator isolation valve, turns off the RFMD, and then calls for heat loads to be removed.

The first day of Demonstration Testing (August 28, 1989) was successfully terminated using the operator initiated TEXSYS "off-nominal" shutdown procedure. Testing was terminated on the second day (August 29, 1989) by an emergency manual shutdown because of the leak at the liquid sight glass. The third day of testing (August 30, 1989) was successfully terminated using the operator initiated TEXSYS "nominal" shutdown routine. "RFMD" motor failure" fault was used to terminate the fourth day (August 31, 1989) of testing. TEXSYS initiated the "off-nominal" shutdown procedures but required an excessive amount of time to "safe" the system (8 minutes) because the procedures had been inadvertently set to require operator confirmation. When the accumulator isolation valve stays open too long (as in this instance), ammonia enters the vapor side of the accumulator, increasing the difficulty of the next RFMD startup. The final day (September 1, 1989) of testing was terminated using the operator initiated "off-nominal" TEXSYS shutdown routine.

See Appendix A, pages A-8, A-9, for ESS and GSS prints of a "nominal" shutdown (August 30, 1989) and page A-10 for an ESS print of an "off-nominal" shutdown.

6.2 FAULT DETECTION, ISOLATION, AND RECOVERY OPERATIONS (FDIR)

Fault detection, isolation, and recovery (FDIR) techniques were selected for inclusion in the TEXSYS knowledge-base. Ten component level faults (out of a possible thirty-eight) were used to demonstrate the seven system level faults. TEXSYS displayed and analyzed system status information and acted, both autonomously and in cooperation with the human operator, to attempt recovery of nominal system performance or safe system shutdown provided and explanations of these recovery actions to the operator. The faults included:

System Faults	Component Faults
Erroneous Instrumentation	Accumulator Position Sensor Failure Pressure Transducer Failure

TABLE 6.1.5.1 SYSTEM SHUTDOWN PROCEDURE - TEST SERIES 16

OBJECTIVE: Demonstrate/evaluate system shutdown procedures.

1. Verify/adjust setpoint temperature to 70°F, as indicated on BP1752 (6120 mV).

2. Shutdown facility heater cart C6 to remove heat load from single phase water heat exchanger. Monitor flow on BFM101 and heat load on BZQ010 and verify these readings go to "zero".

3. Shutdown facility heater cart C2 to remove heat load from two phase ammonia heat exchanger. Monitor flow on BFM201 and heat load on BZQ013 and verify these readings go to "zero".

4. Shutdown cold plate, cold rail, and two phase water heat exchanger heater from the Variac Heater Control. Verify the power reading is zero on BZW001, BZW002, and BZW003. Set all power switches to "off".

5. Continue to circulate TBS fluid until the evaporator temperatures (BTC003, BTC204, BTC311, and BTC410) drop below 75°F.

6. Disarm the RFMD low bearing-flow auto kill relay switch on the Current Status and Shutdown Panel.

7. Close the accumulator vapor line isolation valve BSV706.

8. Turn off the RFMD power (BPW750).

9. Allow all TC's to come to equilibrium at ambient (75°F +/- 10°F) conditions (BTC003, BTC104, BTC702, BTC707, BTC705, BTC706, BTC998, or BTC999 on DACS). Switch isolation valve controller on CSSP from "auto" to "manual". Verify valves open manually except BSV705 and BSV706 (these should be closed).

10. On the Current Status and Shutdown Panel, set the voltage output of the HP6032A Power Supply to 12 VDC. Switch RFMD power suppl to "off". Turn BPRV to manual.

11. Shut off power to the Variac Heater Control Rack.

12. Verify data has been stored, back up systems if required, and secure DARS, DACS, TEXSYS, and HITEX computer systems.

Fluid Inventory Out of Tolerance	Slow Leak
RFMD Power Draw Out of Tolerance	RFMD Motor Failure
Evaporator Loop Flow Out of Tolerance	Single Evaporator Blockage
Inadequate Subcooling	High Coolant Sink Temperature
Setpoint Not Stable	BPRV Failure NCG Buildup BPRV Actuator Failure
Evaporator Temperature Not Stable	Excessive Heat Load on Single Evaporator

6.2.1 Non-Condensible Gas (NCG) Venting - Test Series 4

NCG venting was performed numerous times during the TEXSYS operational and demonstration testing using procedures described in Table 6.2.1.1. An operator initiated task, VENT NCG FROM RFMD ONCE, allowed the operator to vent NCG at will. A typical HITEX GSS screen dump showing NCG venting is included in Appendix A (page A-11). The spikes in the plot of NCG vent valve (BSV705) indicate valve opening.

A TEXSYS task, Excessive NCG Recovery, was initiated by TEXSYS when it detected the presence of NCG. This task contained parameters, set by the operator, which allowed a variable sequence of vents designed to restore system end-to-end delta pressure.

During 70^{o}F to 35^{o}F setpoint change, TEXSYS would at times request to vent NCG more frequently than deemed necessary by the HITEX operator. At these times the task would be vetoed or succeeded (artificially concluded) by the HITEX operator.

6.2.2 Accumulator Position Sensor Failure - Test Series 6

"Accumulator Position Sensor Failure" was induced once successfully on August 29, 1989 using procedures in Table 6.2.2.1. with the bus operating at a 70^{o}F setpoint temperature and a 5.1 kW total heat load. During the "accumulator position sensor failure" test series, a voltage signal was induced on the accumulator position sensor (BPS701) data channel so that the readout approximated the value on the second accumulator. Spikes in the induced voltage signal caused the BPS701 readings to dip momentarily to zero. TEXSYS diagnosed an "extremely low accumulator position sensor fault" (component level) and an "erroneous instrumentation fault" (system level). The HITEX operator turned off BPS701 sensor in response to a request from TEXSYS. The

TABLE 6.2.1.1 NON-CONDENSIBLE GAS VENTING PROCEDURES
TEST SERIES 4

OBJECTIVE: Determine if NCG is present in bus following setpoint change. Demonstrate effective procedures to vent NCG if present.

1. If NCG buildup is indicated following setpoint reconfiguration...
   a. The setpoint temperature stabilizes at a temperature above 35°F, and...
   b. Condenser loop end-to-end delta pressure (BDP703) drops below 3 psid (as long as subcooling BTC704-BTC702>8°F, vent NCG from the RFMD.

2. Record current weight of the NCG/NH_3 collection system tank.

   NOTE: HV-N-07 is open and HV-N-06 is closed at this point

3. Vent NCG (manually or using DACS automatic procedure) as follows:
   a. Open the NCG bleed valve (BSV705) for TBD seconds (DAE call) (DACS default value).
   b. Wait TBD minutes (DAE call) (DACS default value) and monitor BDP703.
   c. If the end-to-end delta pressure (BDP703) is not restored above 3 psid (DACS default value), repeat steps up to TBD times (DAE call) (DACS default value).
      NOTE: Total BSV705 elapsed open time should not exceed 2.5 minutes (DACS default value) during test.
   d. When end-to-end delta pressure (BDP703) is restored, record final weight of NCG/NH_3 collection system tank.
   e. Close HV-N-07 and open HV-N-06 to vent tank. When venting is complete, close HV-N-06 and open HV-N-07 (as required).

4. Monitor system temperature BTC704 and system pressure BPR703, until system achieves stability at 35°F setpoint.

5. Proceed to next operation.

TABLE 6.2.2.1 ACCUMULATOR POSITION SENSOR FAULT INJECTION PROCEDURES - TEST SERIES 6

Objective: Inject accumulator position sensor fault to demonstrate Erroneous Instrumentation FDIR procedures.

1. Verify accumulator position sensor BPS701 is "turned off" on TEXSYS.

2. Record current reading for accumulator position sensor BPS701 and BPS702 from the DACS screens.

3. Using the injection voltage source, adjust the voltage induction signal so the DACS BPS701 reading approximately matches DACS BPS702 readings. Record voltage and BPS701 and BPS702 readings.

4. "Rehabilitate" (turn on) sensor BPS701 in TEXSYS.

5. Drop the induced voltage slowly (and as smoothly as possible) to 5%.

6. Record TEXSYS response (a low accumulator position sensor failure is expected).

7. "Turn off" sensor BPS701 in TEXSYS.

8. Remove the injected voltage (return voltage to zero) at the fault injection panel. When DACS reading is out of alarm condition and TEXSYS fault mode no longer exists, proceed to the next test series.

NOTE: System should be in stable operating condition before performing FDIR procedures.

induced voltage was then removed from the data channel.

A simplified version of the "accumulator position sensor failure" fault processing within TEXSYS is depicted in Figure 6.2.2.1. This figure illustrates only one possible path for fault processing as there are eight accumulator position component fault rules which may trigger due to various types of accumulator anomalies. Fault processing occurs during the expert system control cycle as described in Figure 2.1.1.1.2.

Hardcopy printouts of the HITEX screens are included in Appendix A. The ESS printout (page A-12) contains fault messages, a task graph of operator and TEXSYS actions, and the notification from TEXSYS requesting that the operator turn off the faulty sensor. The GSS printout (page A-13) includes a schematic of the accumulator area, system status information, and plots of accumulator positions (BPS701 and BPS702) and system heat loads.

6.2.3 Pressure Transducer Failure - Test Series 7

"Pressure transducer failure" was induced three times (times listed in Table 6.0.1) during the demonstration testing week using the procedures in Table 6.2.3.1. "Pressure transducer failure" was simulated in the following manner: With the bus operating at a 70.5^{o}F setpoint temperature and a total system heat load of 5.1 kW, a 1.0 volt signal was injected to induce an erroneous pressure reading on data channel BPR001 (two-phase water heat exchanger ammonia inlet pressure). This signal produced a reading of 50 psia compared to the nominal reading of 144 psia. TEXSYS successfully diagnosed "erroneous pressure sensor" (component level) and "erroneous instrumentation" (system level) faults in all three instances and sent a message to the HITEX operator requesting that BPR001 be turned off. The induced voltage was then removed from the data channel.

A simplified version of the pressure sensor fault processing (test series performed August 28, 1989) within TEXSYS is depicted in Figure 6.2.3.1. Fault processing occurs during the expert system control cycle as described in Figure 2.1.1.1.2. Hardcopy printouts of one sample (August 28, 1989) set of HITEX screens are included in Appendix A. The ESS printout (page A-14) contains fault messages, a task graph of TEXSYS actions and the notification from TEXSYS requesting that the operator turn off the faulty sensor. The GSS printout (page A-15) includes a diagram of the two-phase water heat exchanger, system status information, and plots of pressure (BPR001, BPR701, BPR201, BPR301, BPR401) and delta pressure (BDP701, BDP001) data.

6.2.4 Single Evaporator Blockage - Test Series 8

Evaporator blockage was simulated using two different methods according to procedures contained in Table 6.2.4.1. A "single evaporator blockage fault" was induced at the two-phase water heat

Accumulator position sensor BPS701 is "turned on" in TEXSYS. A "nominal" value is inserted in the TEXSYS model.

Accumulator position sensor "failure" is induced. Spikes in the induced voltage signal cause the BPS701 reading to dip to the low sensor limit (zero or below).

New value for BPS701 is inserted into the TEXSYS model.

The new value is propagated through the model and the model is updated.

The low BPS701 value causes "Accumulator.Position.Sensor. Low.Extreme.Fault.Rule" to fire. This rule declares that system fault mode "Erroneous.Instrumentation.Fault" and component fault mode "Accumulator.Position.Sensor.Low.Extreme.Fault" exist.

Fault modes trigger recovery tasks:

"Erroneous.Instrumentation.Recovery" which generates a message to the operator that there is an erroneous sensor reading, and

"Accumulator.Position.Sensor.Low.Extreme.Fault.Recovery" which generates a message to the operator that the sensor is faulty, asks if the operator wishes to turn off the sensor, and indicates that the fault may reoccur if the sensor is not turned off.

TEXSYS sends these messages to HITEX during the next HITEX update.

Figure 6.2.2.1. Simplified Accumulator Position Sensor Failure Fault Processing

TABLE 6.2.3.1 PRESSURE TRANSDUCER FAILURE FAULT INJECTION PROCEDURES - TEST SERIES 7

Objective: Inject pressure transducer failure fault to demonstrate Erroneous Instrumentation FDIR procedures.

1. Record current pressure and voltage readings for pressure sensors: BPR001, BPR101, BPR201, BPR301, BPR401, and BPR701 from the DACS analog summary and HITEX screens.

2. Apply a 1.0 volt signal to BPR001 using the fault injection voltage source. Record the voltage is applied, observe and record the resulting DACS and HITEX readings for BPR001.

3. Perform the following validity checks for BPR001 (record all values):
   a. Compare BPR001 and backup channel BPR701. A difference greater than 5 PSI indicates a fault in one of the channels.
   b. Check that BPR001 is in the range 0 < BPR001 < 230 psia.
   c. Compare pressures BPR001, BPR101, BPR201, BPR301, and BPR401. All readings should be within 15 psi (odd pressure is erroneous).

4. Recovery procedure:
   a. Primary channel faulty-disregard data, use backup channel; do not use in backup channel validation comparisons.

5. Remove fault injection voltage source at the fault injection panel. When DACS reading recovers from alarm condition and TEXSYS fault mode no longer exists, proceed to the next series.

NOTE: System should be in stable operation condition before performing FDIR procedures.

Pressure sensor "failure" fault is induced.

↓

New data (50 psia) for BPR001 is inserted onto the TEXSYS model.

↓

The new value is propagated throughout the model and compared to other local pressure readings (approximately 144 psia).

↓

Inconsistent pressure values cause TEXSYS to introduce multiple "hypothetical worlds" where each candidate cause of the "bad" value are examined.

↓

The "bad" sensor hypothesis is selected since other pressure readings agree and the sensor is marked as "abnormal" in the model.

↓

Tagging the sensor as "abnormal" causes "Pressure.Sensor.Fault.Rule" to fire. This rule declares that system fault mode "Erroneous.Instrumentation.Fault" and component fault mode "Pressure.Sensor.Erroneous.Fault" exists.

↓

Fault modes trigger recovery tasks:

"Erroneous. Instrumentation.Recovery" which generates a message to the operator that there is an erroneous sensor reading, and

"Pressure.Sensor.Erroneous.Fault.Recovery" which generates a message to the operator that the sensor is faulty, asks if the operator wishes to turn off the sensor, and indicates that the fault may reoccur if the sensor is not turned off.

TEXSYS sends these messages to HITEX during the next HITEX update.

Figure 6.2.3.1. Simplified Pressure Sensor Failure Fault Processing

TABLE 6.2.4.1 SINGLE EVAPORATOR BLOCKAGE FAULT INJECTION PROCEDURES - TEST SERIES 8

OBJECTIVE: Inject single evaporator blockage fault to demonstrate evaporator flow loop out of tolerance FDIR procedures.

TEST POINT A

1. Record current two phase H2O HX heat load (BZW003) and evaporator liquid supply flow rate (BFM701). Calculate and record two phase H2O delta temperature (BZT011=[BTC005-BTC011]).

2. Close MV0001.

3. Monitor BFM701. Record if flow rate crosses a high or low warning or alarm limit:
   1.09 gpm high alarm
   0.95 gpm high warning
   0.55 gpm low alarm
   0.65 pgm low warning

4. Monitor evaporator delta temperature. Record if delta temperature exceeds high alarm limit ($5^{o}F$ at 3.0 kW heat load). BTC005 should not exceed $130^{o}F$ maximum.

5. Open and close BSV001 a maximum of 5 times (DAE call) to simulate clearing a sticking control valve (leave valve in open position at end of cycling sequence). Monitor evaporator temperatures to determine if overheating is relieved. Fault relief indicates that a "stuck" valve was at fault.

6. Record BZW003, BFM701, and [BTC005-BTC011] readings.

7. Proceed to next test series.

TEST POINT B

1. Record current two phase H2O HX heat load (BZW003) and evaporator liquid supply flow rate (BFM701). Calculate and record a two phase H2O delta temperature (BZT011 = [BTC005 - BTC011])

2. Close BSV001.

3. Monitor BFM701. Record if flow rate crosses a high or low warning or alarm limit:
   1.09 gpm high alarm
   0.95 gpm high warning
   0.55 gpm low alarm
   0.65 gpm low warning

4. Monitor evaporator delta temperature. Record if delta temperature exceeds high alarm limit ($5^{o}F$ at 3.0 kW heat load). BTC005 should not exceed $130^{o}F$ maximum.

5. Open and close BSV001 a maximum of 5 times (DAE call) to simulate clearing a sticking control valve (leave in open position at end of cycling sequence). Monitor evaporator temperatures to determine if overheating is relieved. Fault relief indicates that a "stuck" valve was at fault.

6. Record BZW003, BFM701, and [BTC005-BTC011] readings.

7. Proceed to next test series.

... condition before performing FDIR procedures.

exchanger by closing the ammonia outlet manual valve MV0001 (performed twice) or by closing the ammonia inlet servo valve BSV001 with DACS valve position updating deactivated (performed five times). In each case, the system level fault "evaporator loop flow out of tolerance", was successfully diagnosed by TEXSYS. The total evaporator flow (BFM701) dipped from 1.4 gpm to 0.9 gpm when MV0001 was closed and to 1.1 - 1.2 gpm when BSV001 was closed.

When the blockage was induced by closing MV0001 (Test Series 8A) (August 31, 1989) TEXSYS successfully diagnosed a second system level fault, "evaporator temperatures not stable/tracking". The evaporator outlet temperature was approximately 6^{o}F above the setpoint temperature. In the first attempt, the component level fault was not being propagated properly through the model. In the second attempt, the component level fault "single evaporator blockage" was diagnosed, but so slowly that DACS alarm limits were exceeded and manual recovery procedures initiated.

In the first (August 28, 1989) attempt to demonstrate the "single evaporator blockage fault" by closing BSV001 (8B) TEXSYS issued all the expected diagnosis and recovery messages but failed to toggle BSV001 open. The fault was repeated and successfully diagnosed as an "emergency" level fault, a more severe condition in which TEXSYS directs the operator to remove heat loads and does not attempt to toggle BSV001. In the third repetition (August 29, 1989), the fault was successfully diagnosed and TEXSYS recovered by toggling open the "sticking" valve. The component level fault was not diagnosed in the fourth repetition of this test series (8B) (August 31, 1989) because the status of BSV001 had not been reset in the model from the last repetition of 8A (operator error). The latest repetition (September 1, 1989) of the single evaporator blockage fault was performed as a part of the demonstration for Space Station personnel. TEXSYS successfully diagnosed an emergency level component fault.

A simplified version of the "single evaporator blockage" analysis process performed August 29, 1989 is depicted in Figure 6.2.4.1. Fault processing occurs during the expert system control cycle as described in Figure 2.1.1.1.2. HITEX hardcopy outputs for "single evaporator blockage fault" alarm (TEXSYS toggles valve BSV001) and "single evaporator blockage emergency" are included in Appendix A. The ESS printouts (pages A-16, A-18) show alarm messages and task tree graph depicting TEXSYS activities. The pertinent GSS printout (pages A-17, A-19) data are the plots including two-phase water heat exchanger outlet, surface, and inlet temperatures (BTC003, BTC005, BTC011), heat load (BZW003), and total evaporator supply flowrate (BFM701).

6.2.5 Excessive Heat Load On Single Evaporator - Test Series 9

The "excessive heat load on a single evaporator fault" was induced once successfully on the single phase water heat exchanger using the

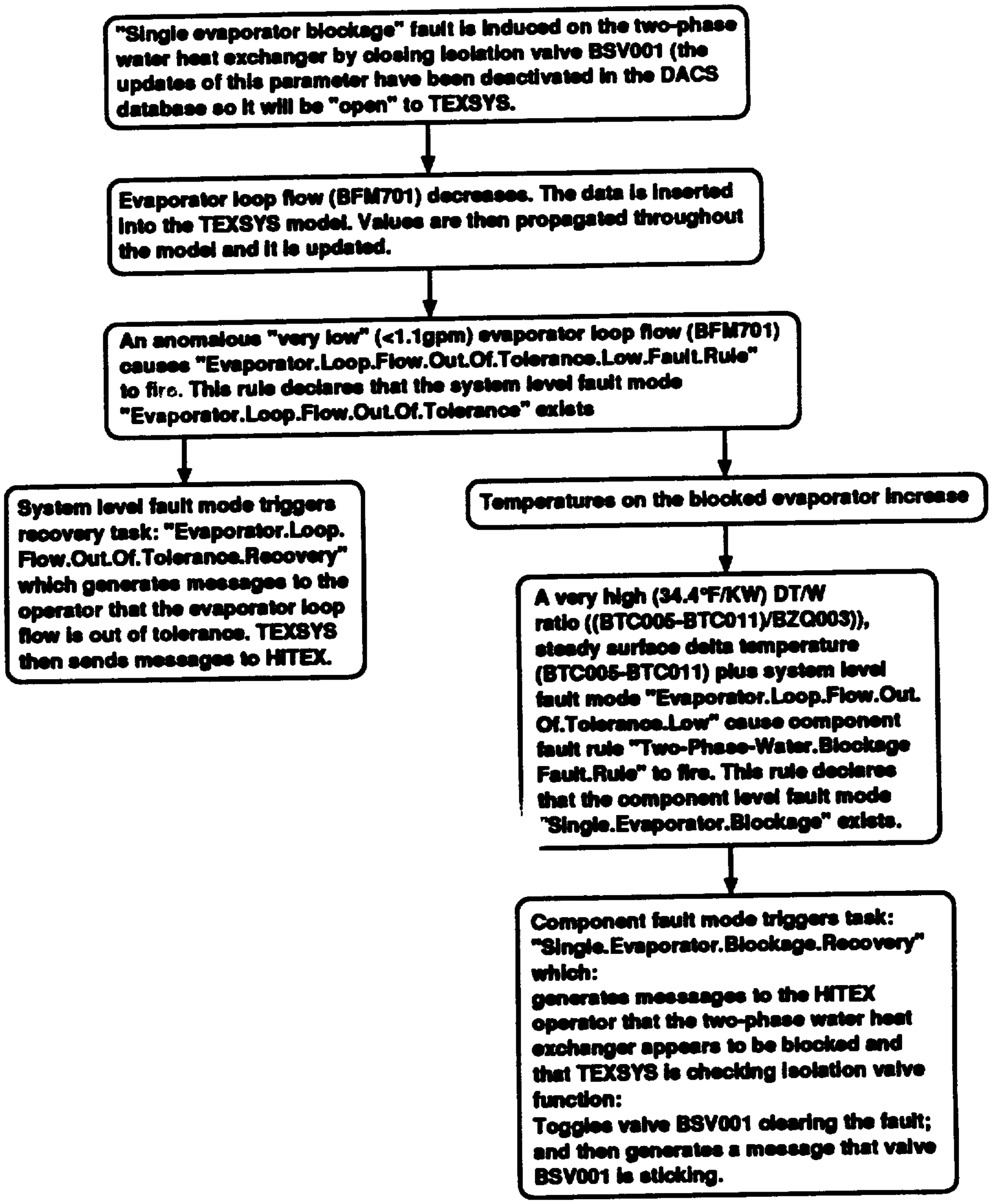

Figure 6.2.4.1. Simplified Single Evaporator Blockage Fault Processing

procedures described in Table 6.2.5.1. The TBS was operating at a 70°F setpoint temperature and an initial total heat load of 5.0 kW. The Cart 6 water supply temperature was raised from 80°F to 92°F providing increasing heat loads (BZQ010) from 5.0 kW (design heat load) to 10.0 kW. TEXSYS successfully diagnosed the "excessive heat load on a single evaporator" component level fault based on a heat load of 5.2 kW, an increasing long term trend of the ammonia outlet temperature (BTC104), and an increasing short term trend of the average surface temperature. The operator was directed to remove heat loads from the heat exchanger. The "evaporators not stable/tracking" system level fault was successfully diagnosed by TEXSYS based on a 6°F difference between the ammonia outlet temperature (BTC104) and the bus system setpoint temperature (BTC704). The operator was directed to shut down the fluid heat exchangers and reduce heat loads on the electrically heated evaporators to less than 2.0 kW each.

A simplified version of the "excessive heat load on a single evaporator" fault processing is described in Figure 6.2.5.1. This figure illustrates only one possible path for fault processing as there are three component fault rules which may trigger the "excessive heat load on single evaporator" fault and four system fault rules which trigger the "evaporators temperatures not stable/tracking" fault. Fault processing occurs within the overall expert system control cycle as depicted in Figure 2.1.1.1.2.

HITEX screen printouts are included in Appendix A for reference. The ESS printout (page A-20) shows alarm messages and a task tree graph for the system and component level faults. The GSS printouts (page A-21 and 22) depict pertinent plot data and various system status data. The plots labeled STARTUP1 contains system setpoint temperature (BTC704). The plots labeled XEVAHL depicts single phase water heat exchanger data: surface (BTC106), outlet (BTC104), and inlet (BTC111) ammonia temperatures, and heat load (BZQ010).

6.2.6 RFMD Motor Failure - Test Series 10

The "RFMD motor failure" was performed according to the procedures in Table 6.2.6.1. The "RFMD motor failure" fault was simulated by shutting down the RFMD at the manual switch panel. RFMD speed, power, and flows fall to "zero" but the computer databases still indicate the RFMD motor commanded "on". TEXSYS successfully diagnosed the "RFMD motor failure" component level fault and the "RFMD power draw out of tolerance - low" system level fault during both attempts during demonstration week. TEXSYS then "safed" the system by commanding the RFMD "off", shutting the accumulator vapor line isolation valve (BSV705) and directing the operator to remove heat loads. The recovery procedure was delayed by eight minutes on the first attempt (August 31, 1989) due to improper operator confirmation levels, but was repeated successfully on the second attempt (September 1, 1989).

A simplified version of the "RFMD motor failure" fault processing

TABLE 6.2.5.1 EXCESSIVE HEAT LOAD ON SINGLE EVAPORATOR FAULT INJECTION PROCEDURES - TEST SERIES 9

OBJECTIVE: Introduce excessive heat load on single phase water heat exchanger to demonstrate evaporator temperatures not stable/tracking FDIR procedures.

1. Record current one phase H2O heat load (BZQ010). Calculate and record one phase H2O HX delta temperature (BTZ101=BTC106-BTC111). Record current flowrate (BFM101) and maintain constant water flow during test series.

2. Increase heat load on one phase H2O HX to 6.0 kW. Record time for BZQ010 to reach 6.0 kW. Monitor delta temperature for approximately 15 minutes. Record if delta temperature exceeds high alarm limit (14.5°F at 6.0 kW; shut off heat supply immediately if delta temperature exceeds 25°F at 6.0 kW). Record heat load BZQ010 and delta temperature (BTC106-BTC111).

3. Increase heat load on one phase H2O HX to 7.0 kW and record time for heat load to reach 7.0 kW. Monitor delta temperature for approximately 15 minutes. Record if delta temperature exceeds high alarm limit (17°F at 7.0 kW). Shut off heat immediately if delta temperature exceeds 30°F at 7.0 kW. Record heat load BZQ010 and delta temperature (BTC106-BTC111).

4. Increase heat load on one phase H2O HX to 8.0 kW and record time for heat load to reach 8.0 kW. Monitor delta temperature for approximately 15 minutes. Record if delta temperature exceeds high alarm limit (19°F at 8.0 kW). Shut off heat immediately if delta temperature exceeds 33°F at 8.0 kW. Record heat load BZQ010 and delta temperature (BTC106-BTC111). Continue increasing heat loads to trigger system level fault "evaporators not stable/ tracking".

5. Reduce one phase H2O HX heat load to 5.0 kW or less.

6. Proceed to next test series.

NOTE: System should be in stable operating condition before operating FDIR procedures.

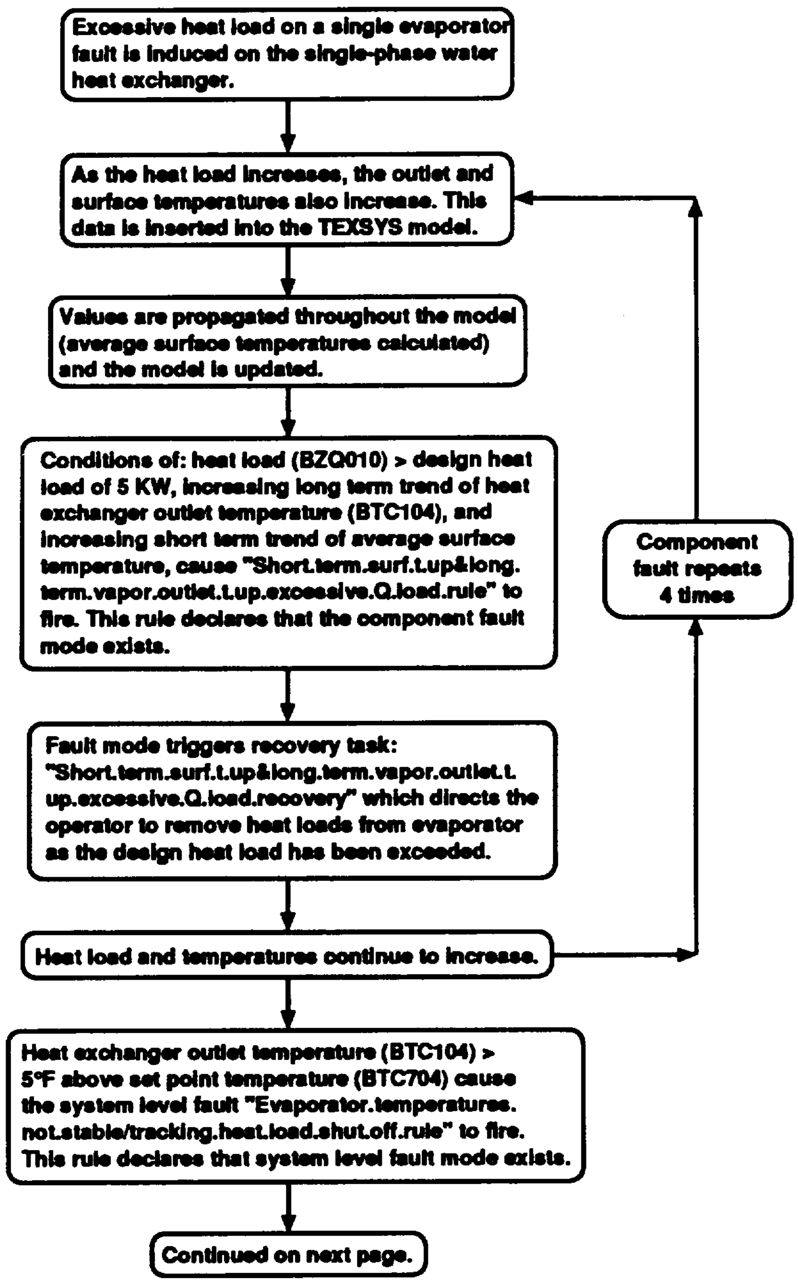

Figure 6.2.5.1. Simplified Excessive Heat Load on a Single Evaporator Fault Processing

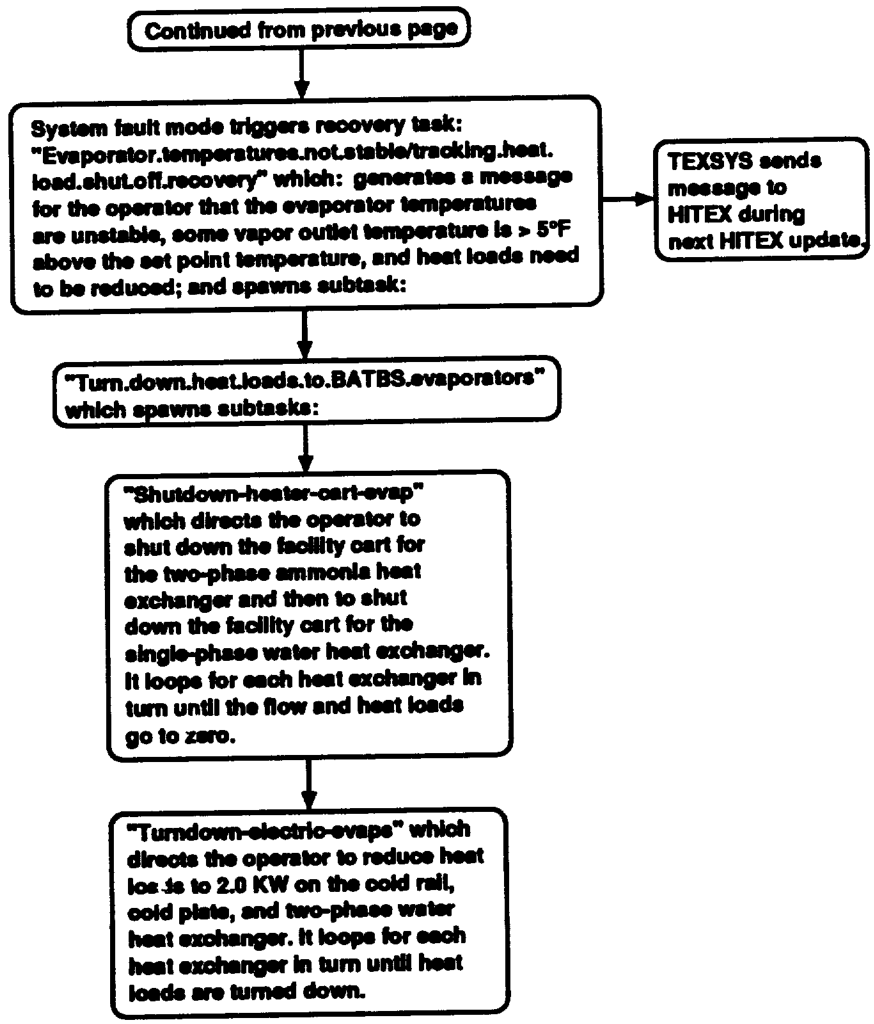

Figure 6.2.5.1. Concluded

TABLE 6.2.6.1 RFMD MOTOR FAILURE FAULT PROCEDURES - TEST SERIES 10

OBJECTIVE: Inject RFMD motor failure fault to demonstrate RFMD power out tolerance FDIR procedures.

1. Record RFMD power (BPW701) and RFMD speed (BNN701).

2. Disarm the RFMD low bearing flow relay on the current status and shutdown panel.

3. Manual shut off RFMD power to simulate an RFMD motor failure.

4. Close accumulator vapor valve (BSV706). Shutdown heaters if restart is not to be performed immediately (within 2-3 minutes)

5. Perform fault diagnosis procedures:

   a. Verify 115 volts, 400 Hz, power is supplied to the RFMD motor circuit.

   b. If RFMD motor speed (BNN701) is less than 100 RPM and RFMD power (BPW701) is "zero", the fault is confirmed.

   c. If RFMD speed is greater than 100 RPM but the trend shows a speed of zero will be reached in less than 60 seconds and the power is zero, the fault is confirmed.

6. Record RFMD power (BPW701) and RFMD speed (BNN701).

7. Perform hot restart procedures:

   a. Close evaporator liquid supply (BSV701) and accumulator flow-through (BSV700) valves.

   b. Wait one minute after RFMD speed (BNN701) reaches zero and then restart RFMD (115 volts, 400 Hz). At 2000 RPM, open accumulator vapor (BSV706) and flow-through (BSV700) valves and evaporator liquid valve (BSV701).

   c. Rearm the RFMD low bearing flow relay on the CURRENT STATUS AND SHUTDOWN PANEL.

8. Apply heat loads per Test Point A above and proceed to next test series.

NOTE: System should be in stable operating condition before performing FDIR procedures.

within TEXSYS is depicted in Figure 6.2.6.1. Fault processing occurs during the expert system control cycle as described in Figure 2.1.1.2.

HITEX screen hardcopy data from operational testing (August 22, 1989) prior to the demonstration week, illustrating sample ESS (page A-23) and GSS (page A-24) output are included in Appendix A. Screen hard copies were not obtained during demonstrations due to time constraints.

The ESS printout (page A-23) includes alarm messages and a task graph depicting TEXSYS activities. The GSS printout (page A-24) shows system status information and plots of RFMD parameters: speed (BNN701), power draw (BPW703), end-to-end delta pressure (BPD703), and evaporator supply delta pressure (BDP701).

6.2.7 BPRV Failure - Test Series 11

The "BPRV failure" was induced according to the procedures in Table 6.2.7.1. "BPRV failure" was simulated by closing MV0711 in the BPRV servo line, cutting off servo pressure, and causing the BPRV to "fail" open. System setpoint temperature (BTC704) decreased until equilibrium with the coolant sink temperature was reached. This test series was performed twice (August 31, 1989) during the demonstration week. In the first instance TEXSYS diagnosed a "suspected BPRV failure", initiated the diagnosis task, but was unable to identify the specific type of "BPRV failure" due to task timing problems. A "BPRV actuator failure" was incorrectly diagnosed during this failed test series. In the second attempt, TEXSYS diagnosed a "suspected BPRV failure" and initiated the diagnosis task which attempted to change the setpoint upwards and control the setpoint temperature by raising the coolant sink temperature. TEXSYS then successfully concluded that the BPRV had failed open. The system level fault "setpoint temperature not stable/tracking" was also initiated. Physical conditions during the BPRV failure fault also triggered requests for NCG venting (a nuisance ignored by the operator) and "evaporator temperatures not stable/tracking fault" messages due to thermal lag as system temperatures dropped.

A simplified version of the "BPRV failure" fault processing within TEXSYS is depicted in Figure 6.2.7.1. Fault processing occurs within the expert system control cycle as described in Figure 2.1.1.1.2.

HITEX screen dumps showing pertinent data are included in Appendix A. The ESS printout (page A-25) shows alarm messages and a task graph of TEXSYS activities. The GSS printout (page A-26) includes system status information and plots of BPRV parameters, such as setpoint temperature (BTC704), BPRV position indicator readout (BP1752), desired setpoint (DESIRE), condensate return temperature (BTC702), and coolant sink temperature (BTC621).

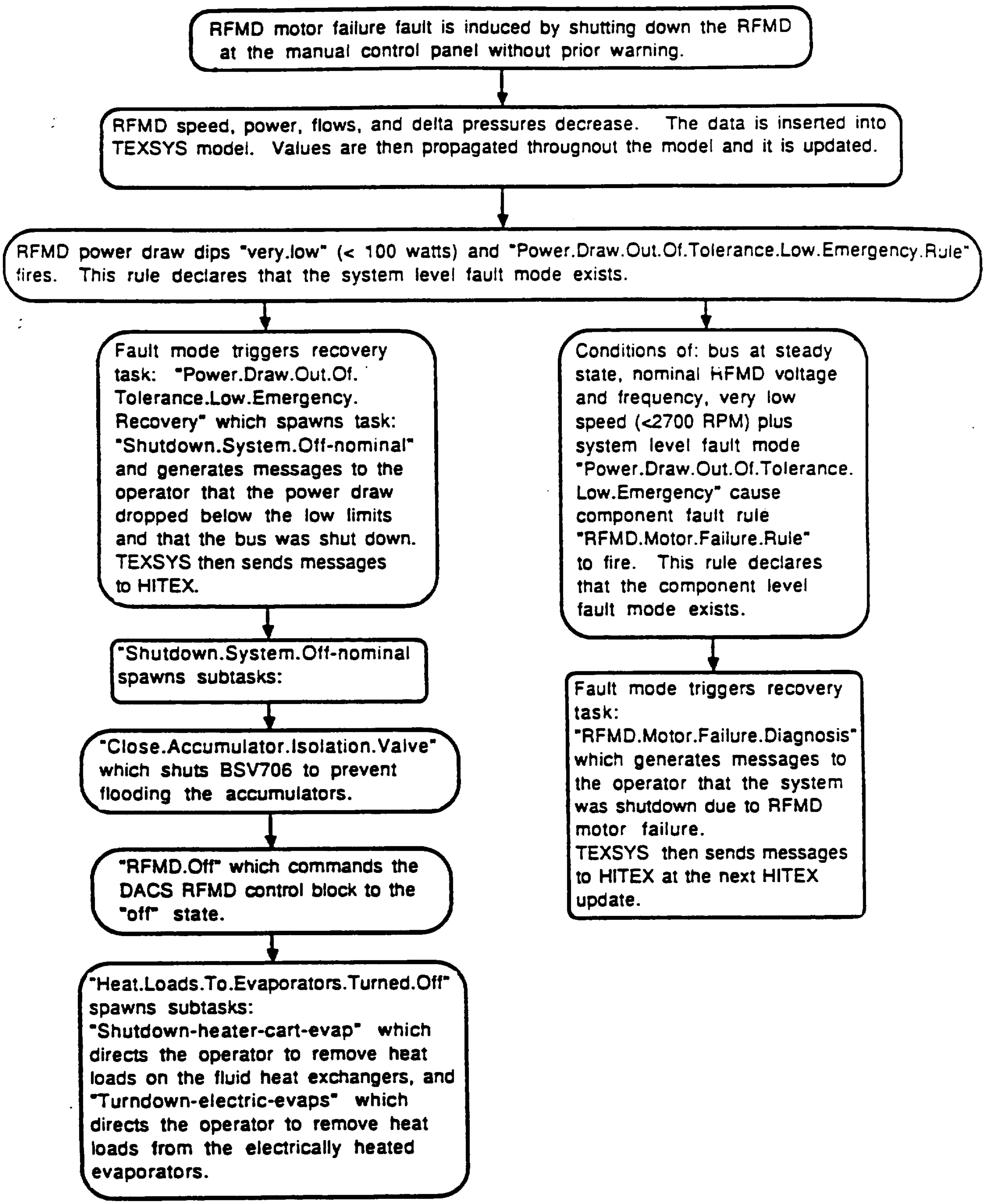

FIGURE 6.2.6.1 SIMPLIFIED RFMD MOTOR FAILURE FAULT PROCESSING

TABLE 6.2.7.1 BPRV FAILURE FAULT INJECTION PROCEDURES - TEST SERIES 11

OBJECTIVE: Inject BPRV failure to demonstrate setpoint not stable/tracking FDIR procedures.

1. Record temperature BTC704 and BPRV position BP1752.

2. If setpoint temperature (BTC704) teaches $85^{O}F$ at any time, kill evaporator heat loads.

3. Close MV0711, BPRV servo line valve

4. Perform BPRV failure fault diagnosis:

   a. If initially at a steady setpoint condition and the setpoint deviates in one direction more than $3^{O}F$ for more than five minutes, and adequate subcooling exists to support the operation at the commanded setpoint (at least $6^{O}F$ delta below the commanded setpoint), a BPRV failure is indicated. To confirm the BPRV failure, command the setpoint to change in the direction opposite the deviation. If no setpoint response occurs in the direction commanded, a BPRV failure is confirmed.

   b. If all system health parameters are within normal bounds and system setpoint fluctuates by more than +/- $3^{O}F$ at constant system heat load and coolant temperature, a sticking poppet BPRV failure exists. If the setpoint can be controlled (raised or lowered) by raising or lowering the coolant temperature at constant heat load, a stuck partially or fully open BPRV failure is indicated. If the setpoint trend shows a continuing rise with zero flow (BFM702) in the condenser loop, and NCG venting sequence has been completed with the previous 5 minutes, a stuck closed or near-closed BPRV failure is possible.

5. When FDIR procedures are complete, reduce heat load to 0.0 kW total (on coldpate, others zero). When BTC704 temperature begins to drop, command setpoint to $70^{O}F$. Re-open MV0711 very slowly so as not to "shock" the system. Return heat load to 5.0 kW.

6. When system has restabilized, proceed to the next test series.

NOTE: System should be in stable operating condition before performing FDIR procedures.

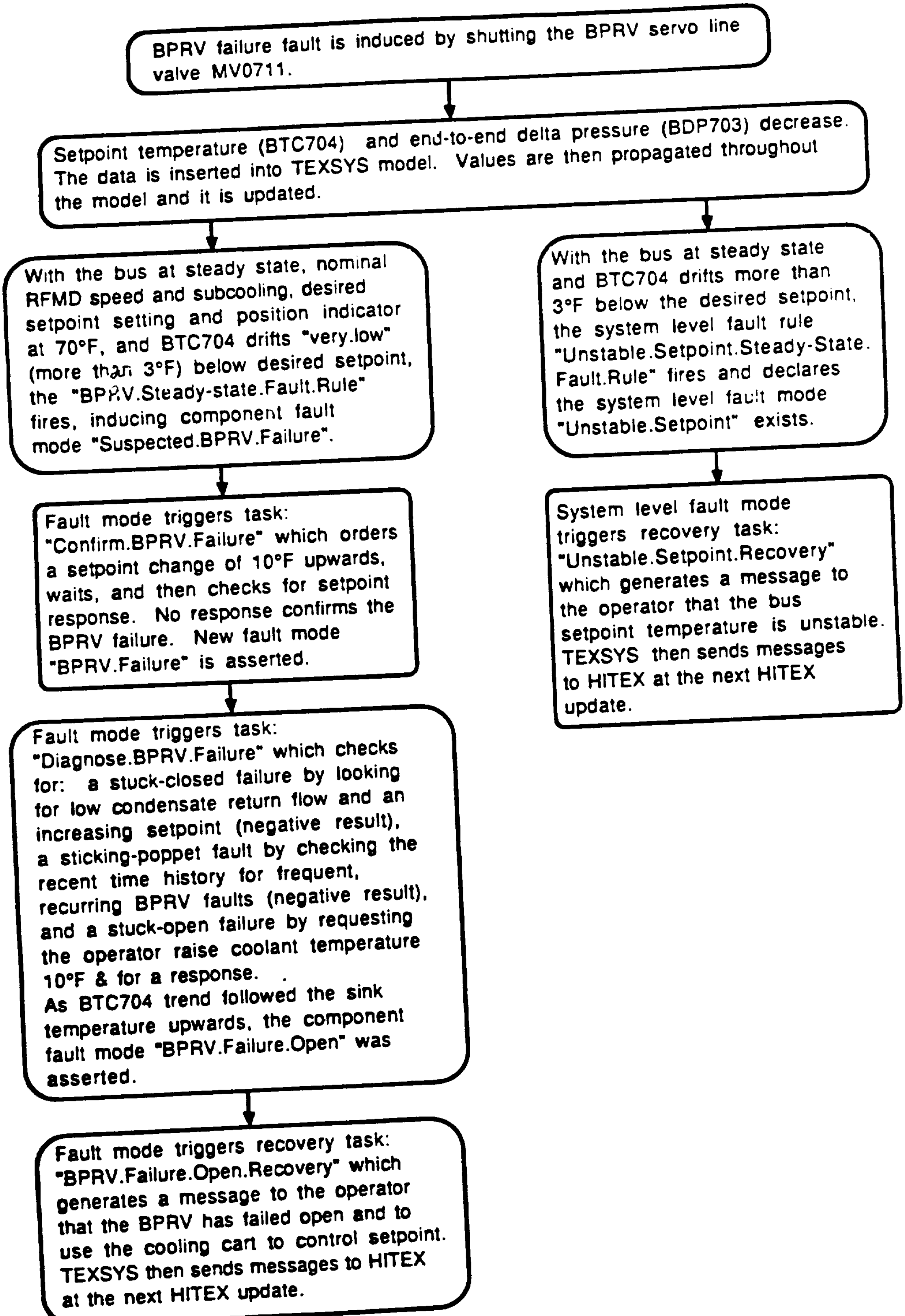

FIGURE 6.2.7.1 SIMPLIFIED BPRV FAILURE FAULT PROCESSING 10/16/89

6.2.8 BPRV Actuator Failure - Test Series 12

The "BPRV actuator failure " was induced according to the procedures described in Table 6.2.8.1. "BPRV actuator failure" was simulated twice during the demonstration week by putting the BPRV control into manual mode at the manual switch panel. A setpoint change from 70°F to 35°F command was issued through HITEX and the bus failed to respond, indicating a BPRV actuator failure. TEXSYS issued warning to the operator that the BPRV actuator did not appear to have moved, that setpoint change was unsuccessful, and TEXSYS reset the setpoint to 70°F (August 28, 1989). In the second repetition (August 29, 1989), the recovery task also correctly fired, issued a message to the operator that the BPRV actuator drive or position sensor had failed and directed the operator to monitor system for stability. The BPRV control was then returned to the automatic mode following completion of the fault simulation procedures. A simplified version of the "BPRV actuator failure" fault processing within TEXSYS is depicted in Figure 6.2.8.1. Fault processing occurs during the expert system control cycle as described in Figure 2.1.1.2.

HITEX printouts are included in Appendix A. The ESS screen dump (page A-27) contains fault and status messages and a task graph showing TEXSYS activities. The GSS screen dump (page A-28) displays system status information and plots. Data of interest from the BPRV actuator failure fault are included in the plot labeled STARTUP1. These parameters are setpoint temperature (BTC704), BPRV position indication (BPI752), and desired setpoint temperature (DESIRE).

6.2.9. High Coolant/Sink Temperature - Test Series 13

The "high coolant/sink temperature" fault was attempted twice during the demonstration test week using procedures in Table 6.2.9.1. With the system setpoint at 70°F and system heat load at 4.5-5.0 kW the sink coolant temperature was increased up to 67°F in an attempt to induce the system level "loss of subcooling" fault. The first attempt (August 28, 1989) was terminated due to loss of bus control and emergency shutdown of the system. The second attempt (August 1, 1989) was terminated due to lack of time with the sink temperature at 60°F. In both instances, the component level "high coolant/sink temperature" (55-56°F) was diagnosed by TEXSYS. Loss of system stability was indicated by "NCG buildup fault" triggered by low end-to-end delta pressure, "fluid inventory out of tolerance faults", "evaporator and/or setpoint temperatures not stable/tracking faults". "High sink/coolant temperature" fault had been used to induce the "loss of subcooling" fault earlier during operational testing (July 21, 1989) and required a very slow careful process of raising sink temperature to avoid losing system control.

A simplified version of the "high coolant/sink temperature" fault processing (test series performed September 1, 1989) is depicted in Figure 6.2.9.1. This figure illustrates only one possible path for

TABLE 6.2.8.1 BPRV ACTUATOR FAILURE FAULT INDUCTION PROCEDURES - TEST SERIES 12

1. Record temperature BTC704 and BPRV position BP1752

2. Put BPRV auto/manual switch into manual position. Issue command to TEXSYS to change setpoint to $35^{o}F$.

3. If temperature (BTC704) reaches $85^{o}F$, kill evaporator heat loads.

4. Perform BPRV actuator failure fault diagnosis procedure. Failure of the BPRV calibrated position indicator to respond to a commanded setpoint change indicates a failure in the drive unit. If the failure occurs between the position indicator and the BPRV setpoint screw, the indicator will still read but the valve setting will not change.

5. When fault diagnosis procedures are complete, return setpoint temperature to $70^{o}F$. Put BPRV auto/manual switch into auto position. Verify power restored to BPRV drive.

6. Proceed to next test series.

NOTE: System should be in stable operating condition before performing FDIR procedures.

BPRV actuator failure fault is induced by putting the BPRV control into manual mode.

↓

The operator initiates a "Quick Setpoint Change" on HITEX and this command is passed to TEXSYS.

↓

TEXSYS initiates the "BATBS-Automatic-setpoint-control" task which through TDAS, initiates the DACS control routine to change the BPRV setting to 35°F. After 90 seconds the task checks the BPRV actuator position. As the BPRV position remains unchanged, the operator is notified that the position change was not accomplished (and that the setpoint change failed), and the commanded BPRV position is reset to its initial value (70°F).

↓

With nominal subcooling, end-to-end delta pressure, and temperature instrumentation (BTC702 and BTC704), the difference between the desired setpoint (35°F) and the constant position indicator and actual setpoint temperature (70°F) causes the component fault rule to fire and assert that the fault mode "BPRV.Actuator.Failure" exists.

↓

Fault mode triggers recovery task:

"BPRV.Actuator.Recovery" which notifies the operator that the actuator drive or position sensor has failed and to monitor the system for stability.

TEXSYS sends these messages to HITEX during the next HITEX update.

FIGURE 6.2.8.1 SIMPLIFIED BPRV ACTUATOR FAILURE FAULT PROCESSING

TABLE 6.2.9.1 HIGH COOLANT/SINK TEMPERATURE FAULT INJECTION PROCEDURE - TEST SERIES 13

OBJECTIVE: Introduce high coolant/sink temperature fault to demonstrate inadequate subcooling FDIR procedures.

1. Raise coolant temperature fault to determine minimum level of subcooling required.

2. Monitor condensate return subcooling (BTC704 - BTC702) and record any violation of the low warning (delta temperature < 8^{o}F) and low alarm (delta temperature < 6^{o}F) limits, indicating inadequate subcooling fault. Monitor condenser outlet to cooling module delta temperatures. If these (below) delta temperatures < 10^{o}F, a high coolant/sink temperature fault is indicated. Record delta temperatures if this occurs.

   BTC502 - BRC613
   BTC504 - BTC605
   BTC506 - BTC603
   BTC508 - BTC601

3. Monitor end-to-end delta pressure BDP703. Record any violation of low alarm (3 psid), confirming the inadequate subcooling fault.

4. Return coolant temperature to 0^{o}F and proceed to next test series.

NOTE: System should be in stable operating condition before performing FDIR procedures.

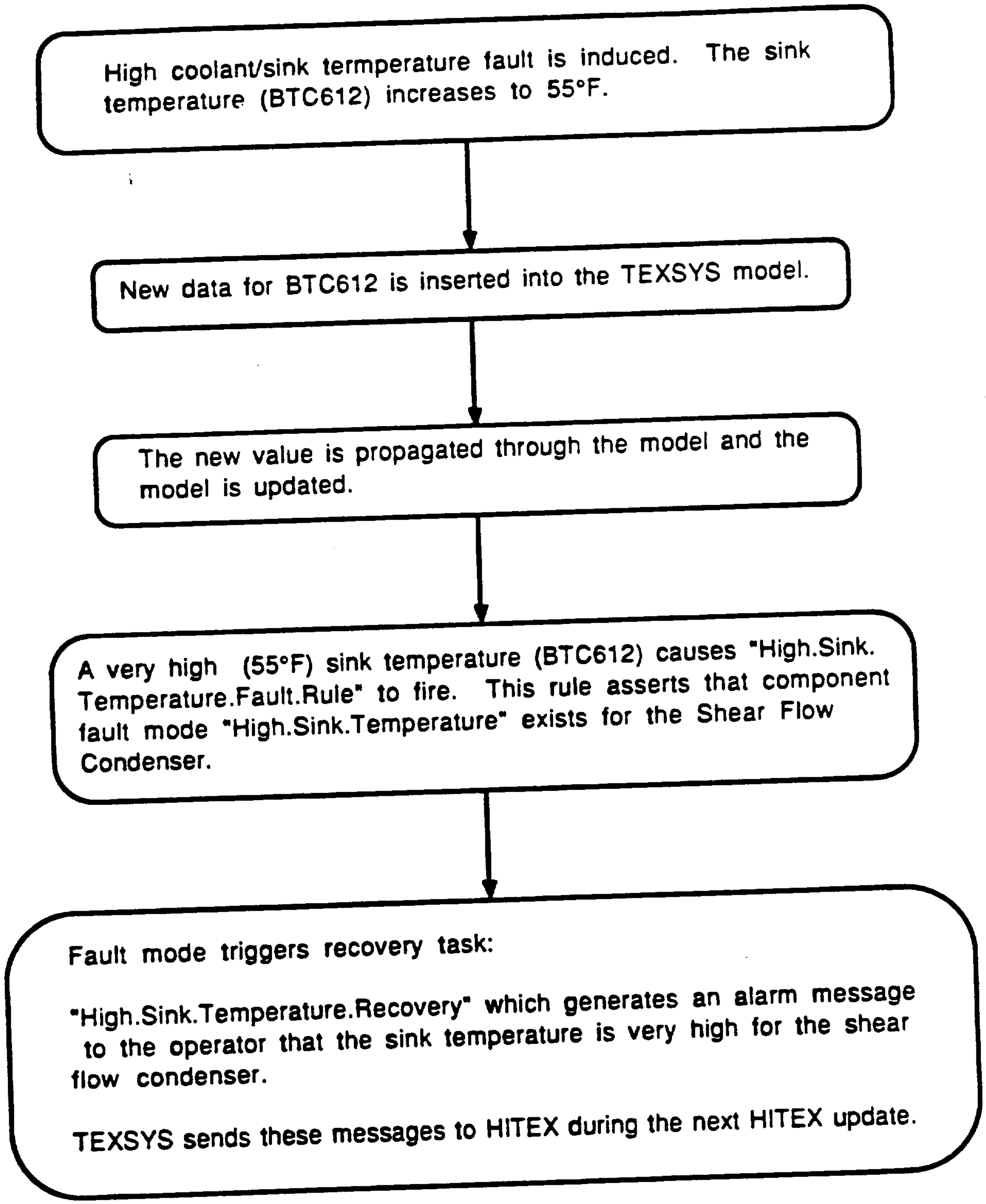

FIGURE 6.2.9.1 SIMPLIFIED HIGH COOLANT/SINK TEMPERATURE FAULT PROCESSING

fault processing. There are three generic component fault rules each of which may apply to any of the four condensers. There are also three system level "loss of subcooling" fault rules. Fault processing occurs within the expert system control cycle as depicted in Figure 2.1.1.1.2.

HITEX screen printouts for the component level fault are included in Appendix A. The ESS screen dump (page A-29) shows a TEXSYS task graph and alarm messages. The GSS screen dump (page A-30) includes system status information and coolant temperature data (BTC621, BTC612, BTC614) plots.

6.2.10 NCG Buildup - Test Series 14

NCG venting for the "NCG buildup" fault series was performed according to the procedures in Table 6.2.10.1. TEXSYS successfully diagnosed that NCG buildup was present in the thermal bus system following the reservicing required after the sight glass leak.

A simplified version of the "NCG buildup" fault processing is shown in Figure 6.2.10.1. Fault processing occurs during the expert system control cycle as described in Figure 2.1.1.1.2.

A HITEX ESS screen dump shows an excessive NCG recovery task graph and alarm messages (in Appendix A, page A-31). A HITEX GSS screen dump (in Appendix A, page A-32) includes plots with deterioration in end-to-end delta pressure (BDP703) and NCG venting (valve BSV705 opening), and other system status information.

NCG buildup was deliberately introduced during the operational testing at 35^{o}F by injecting helium gas (on August 4, 1989). TEXSYS diagnosed the "NCG buildup" fault and NCG venting was performed.

6.2.11 Slow Leak - Test Series 15

The "slow leak" fault simulation was conducted according to the procedure in Table 6.2.11.1. During the Demonstration Test week, the "slow leak" test series (16B) was performed at a 70^{o}F system setpoint temperature and a 5.4 kW total heat load. An accumulator position decrease of 88% to 75% resulted from manual venting of 8.4 lbs. of ammonia over a 12 minute period. TEXSYS successfully diagnosed a "slow leak" component level fault and a "losing fluid inventory" system level fault.

A simplified version of the "slow leak" fault processing within TEXSYS is depicted in Figure 6.2.11.1. This figure illustrates only one possible path for fault processing. There are two component fault rules which may trigger the "slow leak" fault and five system fault rules which may trigger the "fluid inventory out of tolerance" fault. Fault processing occurs within the overall expert system control cycle as depicted in Figure 2.11.1.2. HITEX ESS printout (page A-33)

TABLE 6.2.10.1 NCG BUILDUP FAULT INJECTION PROCEDURES - TEST SERIES 14

OBJECTIVE: Determine the effect of system non-condensible gas on system performance and demonstrate the ability of the system to effectively remove the NCG.

NCG INJECTION PROCEDURES (If required):

1. Inject (TBD) amount of gas at steady-state setpoint. Record amount of gas injected.

2. Record system transients following gas injection until steady state is achieved.

3. After completing gas injection at $70^{o}F$ for Test Point A, reconfigure system for $35^{o}F$ setpoint and perform setpoint change.

NON-CONDENSIBLE GAS VENTING PROCEDURES:

1. Record current weight of the NCG/NH_3 collection system tank.

   NOTE: HV-N-07 is open and HV-N-06 is closed at this point

2. Vent NCG (manually or using DACS automatic procedure) as follows:

   a. Open the NCG bleed valve (BSV705) for 2 seconds (DACS default value)

   b. Wait TBD minutes (1.5 minutes DACS default value) and monitor BDP703.

   c. If the end-to-end delta pressure (BDP703) is not restored above 3 psid (DACS default value), repeat steps up to 5 times (DACS default value).

   d. When end-to-end delta pressure (BDP703) is restored, record final weight of NCG/NH_3 collection system tank.

   e. Close HV-N-07 and open HV-N-06 to vent tank. When venting is complete, open HV-N-07 and close HV-N-06.

3. Monitor system temperature BTC704 and system pressure BPR703, until system achieves stability at setpoint.

4. Proceed to next operation.

   NOTE: Total BSV705 elapsed open time should not exceed 2.5 minutes (DACS default value) during test.

NOTE: Perform NCG venting procedures if required to maintain operational capability or accomplish setpoint change.

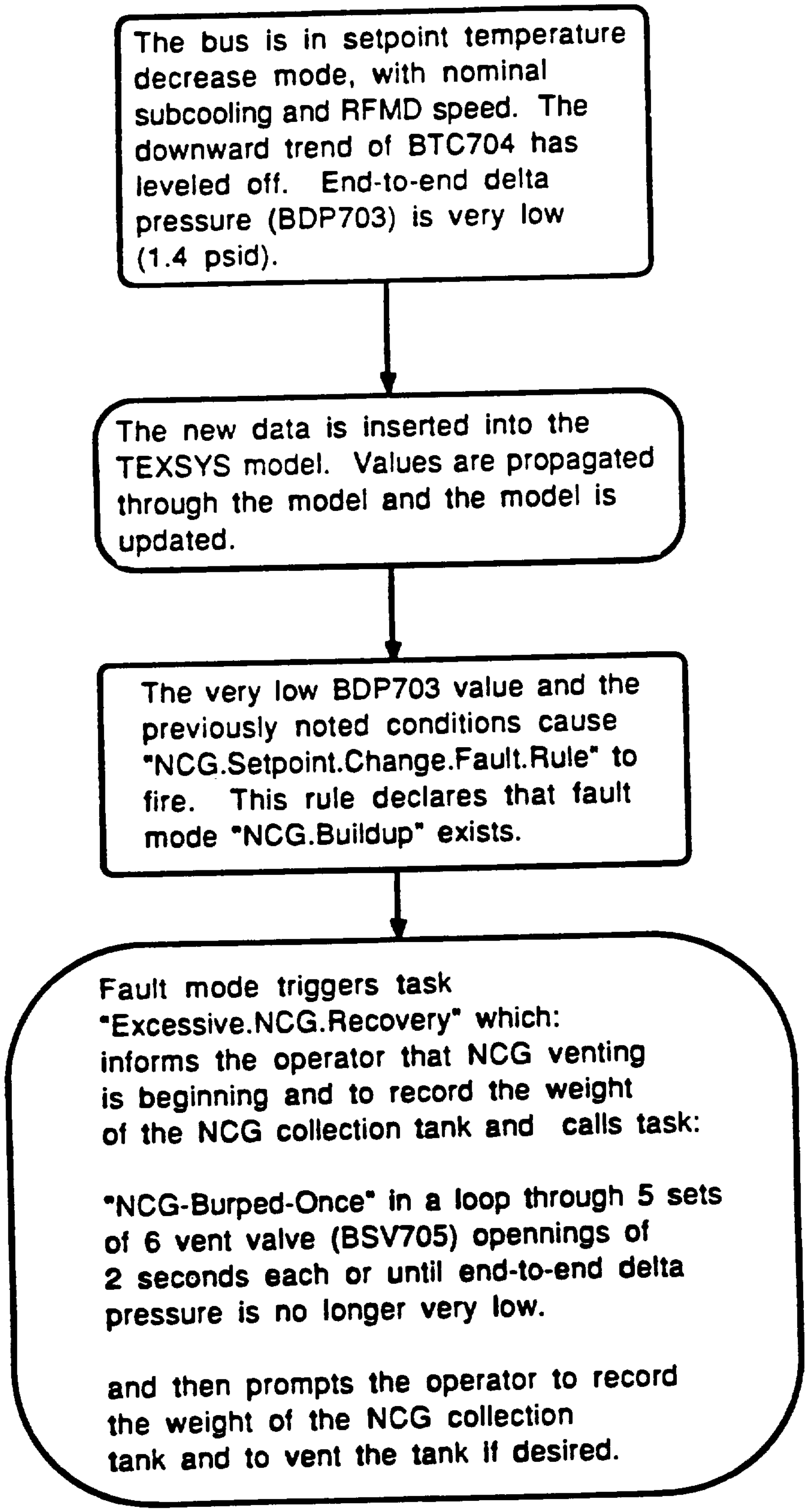

FIGURE 6.2.10.1 SIMPLIFIED NCG BUILDUP FAULT PROCESSING

TABLE 6.2.11.1 SLOW LEAK FAULT PROCEDURES - TEST SERIES 15

OBJECTIVE: Inject slow leak fault to demonstrate fluid inventory out of tolerance FDIR procedures.

TEST POINT A

1. Reconfigure system to $70^{\circ}F$ setpoint, then adjust parameters per Test Point 15A.

2. Record current values of the following parameters: weight of the NCG/NH_3 collection system tank, accumulator positions (BPS701 and BPS702), pressures BPR001 and BPR701.

3. Verify MV0807 is closed. Open valve MV0804. Verify HV46 closed. Verify HV45 open.

4. Open MV0807 partially as requested by DAE to simulate a slow leak.

5. Allow NCG/NH_3 collection tank to fill with HV-N-05 open and HV-N-06 closed.

6. Observe weight scale and close MV0804 as weight approaches 1.0 lb. charge.

7. Record weight of NCG/NH_3 collection system tank, accumulator positions BPS701 and BPS702, and pressures BPR001 and BPR701.

8. Vent NCG/NH_3 collection tank by closing HV-N-05 and opening HV-N-06; and the closing HV-N-06 when venting is complete.

TEST POINT B

1. Record current values of following parameters: weight of the NCG/NH_3 collection system tank, accumulator positions BPS701 and BPS702, and pressures BPR001 and BPR701.

2. Open MV0807. Allow NCG/NH_3 collection tank to fill with HV-N-05 open and HV-N-06 closed. Close MV0807 and record full tank weight. Vent NCG/NH_3 collection tank by closing HV-N-05 and opening HV-N-06, and then closing HV-N-06 when venting complete. Record empty tank weight.

3. Repeat above steps until accumulator reach low limits.

4. Observe flowmeters during slow leak test series to ensure flows to not "overspin" turbine flow meters. If required, decrease leak rate (turn down HV-N-05) to keep flows then than 1.0 pgm.

5. Observe two phase return temperature (BTC703), evaporator outlet temperatures (BTC003, BTC104, BTC204, BTC311, and BTC410), and evaporator liquid supply (BTC701). If these temperatures differ by more than $3^{\circ}F$, shut off heat supply to affected evaporator.

TABLE 6.2.11.1 (Continued)

6. When accumulators reach low limit, shut off evaporator heat supplies, close accumulator vapor line isolation valve (BSV706), disarm the RFMD low-bearing flow auto-kill relay switch on the CURRENT STATUS AND SHUTDOWN PANEL, and turn off RFMD power (BPW750).

7. Record current values of:

   a. Weight of NCG/NH_3 collection tank.

   b. Accumulator positions BPS701 and BPS702.

   c. Pressures BPR001 and BPR701.

8. Proceed to system shutdown.

NOTE: System should be in stable operating condition before performing FDIR procedures.

During a window of approximately 15 minutes after steady state or a new heat load is reached, the "Bellows.Postion.Historical.Delta.Reading.Taken.Rule" fires every 3-4 minutes while these conditions axist. This rule triggers the task "Historical.Snap.Shot" that records the changes in accumulator position (historical delta) used in slow leak fault detection.

↓

Slow leak fault is induced. Accumulator position decreases as ammonia is vented over time.

↓

New value for BPS702 is inserted into the TEXSYS model.

↓

The new value is propagated through the model and the model is updated.

↓

Conditions of steady heat load (for at least 3 minutes), decreasing long term trend (for at least 4 minutes) of accumulator position (BPS702), and a very low "historical delta" cause "Slow.Leak.From.Bellows. Position. Delta.Fault.Rule" to fire. This rule declares that system fault mode "Losing.Fluid.Inventory" and component fault mode "Slow.Leak.From.Bellows.Position.Delta.Fault" exist.

↓

Fault modes trigger recovery tasks:

"Losing.Fluid.Recovery" which issues a warning to the operator that "BATBS accumulator trends at steady state indicate a loss of fluid inventory".

"Slow.Leak.From Bellows.Position.Delta.Fault.Recovery" which issues an alarm to the operator that the bellows position decreased 7% or more at steady state and steady heat load so a slow leak was diagnosed.

TEXSYS sends these messages to HITEX during the next HITEX update.

FIGURE 6.2.11.1 SIMPLIFIED SLOW LEAK FAULT PROCESSING

showing alarm messages and a Task Tree graph and a GSS printout (page A-34) with accumulator position (BPS702) data plots are included in Appendix A.

7.0 SYSTEM PERFORMANCE EVALUATION

7.1 TEXSYS OPERATION

TEXSYS successfully completed all the nominal operations procedures except startup. Startup was deemed only partially successful because of problems with the valve monitor task caused by excessive total computer cycle times. The total computer cycle time included the DACS data acquisition and subsystem to system level processing, DACS to TDAS processing, TDAS internal processing, TDAS to TEXSYS network processing, TEXSYS internal data manipulation and "reasoning", TEXSYS to HITEX network processing and HITEX internal processing. A combination of DACS update rates, time lost in network processing, and TEXSYS cycle time contributed to the excessive total cycle times. TEXSYS successfully analyzed the TBS status and conditions within the system model to diagnose and recover from all ten component faults and from seven system level Fault Detection, Isolation and Recovery (FDIR) conditions.

TEXSYS in effect became the bus operator, and was supervised by the Test Manager (TM). TEXSYS performance, similar to that of a novice operator, requires more experience and efficiency in procedures. TEXSYS did however, function very well overall. Faulty instrumentation could be analyzed and quickly announced. Straight forward situations (inadequate subcooling or a blocked evaporator) could be determined with consistency. On most occasions problems such as "BPRV Failure" requiring much analysis could only be partially resolved by TEXSYS.

TEXSYS internal computer cycle time was a problem with TEXSYS performance. The cycle times would get longer as accumulated "garbage" (stored historical data) delayed response to changing bus conditions. The system had to be taken off line for approximately an hour for routine "garbage" collection (deletion of the excess data from files) to clear the problem.

Communication between computers was also a problem. The links between HITEX, TEXSYS, and TEXSYS Data Acquisition System (TDAS) often failed several times daily during Operational Testing, but was more reliable during Demonstration Testing.

7.2 HUMAN INTERFACE TO THE THERMAL EXPERT SYSTEM (HITEX) OPERATION

HITEX provides alphanumeric and graphical data concerning bus health and the operator command interface to the expert system via its Expert System Screen (ESS) and Graphics System Screen (GSS). The ESS displays expert system information - warnings, diagnoses, diagnostic justifications (complex rule traces) of fault processing, graphical task-tree display of expert system processing, and log entries in a operator configurable window format. Provisions have been made for a procedure explanation capability. The ESS provides the operator a command interface to select and execute procedures, component commands, and a procedure confirmation (to allow varying levels of expert system autonomous operation) mechanism. On the ESS, complete control of the bus is provided including startup, setpoint change, NCG venting, and shutdown.

The GSS displays thermal data in schematics, plots, and tables in an operator configurable window format. GSS valves may be toggled by selecting the valve and the appropriate command with the mouse.

The HITEX screens proved to be a reliable source of information. The schematics, plots, and tables provided on GSS gave a quick view of the bus health and the background required to make decisions. The ESS provided textual messages concerning the health of the bus and the steps TEXSYS was taking to maintain that health. The ESS had a useful graphical Task Tree that showed the sequence of activities that TEXSYS was following to achieve an operation.

HITEX has some deficiencies that should be resolved for an operational system. Data and commands coming to HITEX can be very slow, especially from TEXSYS. Elimination of the graphical Task Tree speeds up data communications, but deprives the operator of useful information. The ability to change screen configuration on both GSS and ESS needs to be accelerated. Use of the Mouse was sometimes slow and unreliable. The mouse commands were not always recognized by the computer and an "Initialize Mouse" command would have to be issued to restart the mouse process. Both the ESS explanation and diagnostic justification capabilities need to deliver useful, high-level information in a format the operator can understand.

7.3 TEXSYS DATA ACQUISITION SYSTEM (TDAS) OPERATION

TDAS provided an efficient and reliable translation between DACS/FLEXCON on the VAX system and TEXSYS/HITEX on the Symbolics System on most occasions. Some problems were encountered due to lost network links and active value updating. As expected, an iterative process was required during operational testing to arrive at workable TDAS significance limits (allowable variation in data parameter values). TDAS performed well during the demonstration.

7.4 DATA ACQUISITION AND CONTROL SYSTEM (DACS) OPERATION

The DACS monitoring function provided information for monitoring thermal bus performance. The DACS manual control routines provided reliable control of the bus operations. TEXSYS used DACS to perform valve opening and closure, BPRV setpoint change, Non-condensible Gas (NCG) venting, and RFMD power on/off. All were accomplished routinely during the test.

7.5 DATA ACQUISITION AND RECORDING SYSTEM (DARS) DATA ARCHIVAL

The DARS system was utilized during the test for data storage. The archived data was used for HITEX archived plots.

7.6 THERMAL BUS OPERATION

The BA developed prototype Thermal Bus System (TBS) provided a stable and reliable platform to test TEXSYS. During nominal operations, it provided reliable and consistent operation. Bus conditions could be consistently repeated. This allowed test profiles to be repeated for TEXSYS demonstrations. The TBS proved to be a robust system. Faults could be induced and held, in some cases, to bus instability. After fault removal the bus could be returned to nominal operating conditions.

Three bus anomalies developed that required special bus management techniques to continue operation. A quick disconnect fitting in the pump module section had developed a very slow leak (noticed during the initial system ammonia fill), but was deemed to be manageable. A larger leak (ammonia liquid dripping on the chamber floor) developed through the vapor sight glass on the afternoon of the second day of Demonstration Testing. The system was shutdown with no damage to equipment or harm to personnel and the ammonia charge vented. The sight glass gland nut was tightened, ammonia added to the bus, and testing continued. The twin condenser isolation valve (BSV502) failed closed on the morning of the second day of Demonstration Testing. This removed the twin condensers cooling capacity. Coolant flow was reduced to the twin condensers, diverting all bus heat load to the shear flow condenser at a reduced heat capacity of 12.0 kW.

7.7 LESSONS LEARNED

Several anomalies appeared during the TEXSYS Demonstration that resulted from three basic issues. The issues are excessive computer cycle time, "garbage" collection, and software robustness. As a developmental system, TEXSYS was successful. Continued growth to an operational system will require attention to these issues.

<u>Computer Cycle Time:</u> The total cycle time for TEXSYS to understand bus data and to be able to institute a procedure is dependent upon three variables. The time required to acquire data is dependent upon the DACS data acquisition cycle time. The

transmission of the data through the communication links to TEXSYS adds to the DACS acquisition time. Finally, TEXSYS has its own model cycle time. Thus the architecture and the model analysis time must all be evaluated to speed up TEXSYS. The long computer cycle times were most apparent during startup when many things happen in quick progression. The cycle time in the links, the time updating the model, and the sending of commands three or four times, made startup by TEXSYS too slow.

Software "Garbage" Collection (purging computer memory of excess data): During normal TEXSYS operations, large amounts of data accumulate and consume memory resources between "garbage" collections. TEXSYS does not normally purge data unless the operator initiates these procedures. The consequence of accumulating excess data is that cycle times for updating the TEXSYS model required longer and longer periods. During testing the computer had to be taken off-line for approximately one hour while "garbage" collection was performed (typically 1-2 times daily). The Symbolics also has an on-line ephemeral "garbage" collection that automatically takes the computer off-line for short periods. Ephemeral garbage collection caused TEXSYS to abort a startup when RFMD "on" status information was not received.

Robustness: The HITEX/TEXSYS/TDAS software will require improvement in on-line reliability and ease of software maintainability prior to use as a "real" operational system. Down time due to Symbolics system "garbage" collection and lost network links is excessive. Operation without presence of an experienced software expert should be possible.

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The TEXSYS test objectives to demonstrate AI real-time control and FDIR of a candidate Space Station Thermal Control System (TCS) prototype test article were successfully completed. The TEXSYS system was able to perform the required nominal operations: startup, setpoint change and shutdown, and FDIR activities for all ten component level faults. Although TEXSYS performance during certain speed critical startup activities was marginal, TEXSYS FDIR capabilities proved to be an enhancement to the real-time control provided by the conventional control system.

TEXSYS provided FDIR capabilities and fault prediction via trend monitoring and analysis unavailable through the conventional control system.

8.1.1 DACS/Thermal Bus Operations

The DACS monitoring, and control functions worked as expected. DACS operated successfully throughout the test reliably providing bus data to TEXSYS. When required, DACS controlled the bus and supported FDIR procedures. The Boeing prototype thermal bus proved to be a reliable, stable platform against which to test software. It could, however, only handle 12.0 kW heat load during the last week of testing due to a failed valve. During the test, the bus showed the ability to return to operation after fault injection and removal.

8.1.2 HITEX Operations

HITEX provided alphanumeric and graphical data for the operator that allowed knowledge of the bus status. Via the ESS, the operator was aware of the anomalies appearing in the bus and the operations that TEXSYS was undertaking. The operator could also initiate procedures to control the bus. Via the graphical screen, the engineering data pertaining to the bus could be viewed in tables or graphs. Schematics allowed the operator to view the data in perspective to its location on the bus.

8.1.3 TEXSYS Operations

TEXSYS successfully displayed and analyzed the thermal bus system health to successfully diagnose each FDIR fault induced and to institute a recovery. All the Nominal Operating Procedures (NOP) were successfully completed, except for startup (partially successful). Starting the bus up was a problem for TEXSYS because of excessive computer cycle time (see Lessons Learned).

8.2 RECOMMENDATIONS

Though the TEXSYS test objectives to demonstrate AI real-time control and FDIR were successfully completed, there are issues that will make TEXSYS/HITEX more efficient.

8.2.1 TEXSYS

The way TEXSYS gathers its data and updates it model must be evaluated to decrease TEXSYS cycle time. The items which impact model updating should be listed, analyzed and reprogrammed to speed up TEXSYS time for important events.

8.2.2 HITEX

HITEX functions should also be evaluated with respect to improving cycle times. TEXSYS communication with HITEX should be a first priority. "Mouse" routines should be examined for possible improvement in reliability and speed.

Better explanations are also required to make the system more user-friendly.

8.2.3 Thermal Bus

If the BATBS is to be used in the future, the burned out isolation valve BSV502 should be replaced.

8.3 SUMMARY

The Thermal Expert System (TEXSYS, HITEX, TDAS, DACS, DARS, and BATBS) successfully met all of its key requirements for monitor and control of normal operations and FDIR. Except for some time-critical startup activities, TEXSYS adequately handled bus operations under nominal conditions. TEXSYS recognized and initiated recovery procedures for ten component level faults. As a development tool, TEXSYS achieved its goals. Further improvement in computer cycle time reduction, "garbage" collection, and software reliability and maintainability is recommended to make TEXSYS an efficient operational tool.

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13. ABSTRACT *(Maximum 200 words)*

The Systems Autonomy Demonstration Project (SADP) produced a knowledge-based real-time control system for control and fault detection, isolation, and recovery (FDIR) of a prototype two-phase Space Station Freedom external active thermal control system (EATCS). The Thermal Expert System (TEXSYS) was demonstrated in recent tests to be capable of reliable fault anticipation and detection, as well as ordinary control of the thermal bus. Performance requirements were addressed by adopting a hierarchical symbolic control approach—layering model-based expert system software on a conventional, numerical data acquisition and control system. The model-based reasoning capabilities of TEXSYS were shown to be advantageous over typical rule-based expert systems, particularly for detection of unforeseen faults and sensor failures.

Volume 1 gives a project overview and testing highlights. Volume 2 provides detail on the EATCS testbed, test operations, and online test results. Appendix A is a test archive, while Appendix B is a compendium of design and user manuals for the TEXSYS software.

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