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TR-1738-3

PRELIMINARY DESIGN PROGRAM FINAL REPORT

Vapor Compression Distillation Flight Experiment Program

Prepared Under

Program No. 1669

for

Contract No. NAS8-38250-11

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LIST OF ACRONYMS

C/M I	Control/Monitor Instrumentation
CDR	Critical Design Review
CIL	Critical Items List
CFA	Cooling Fan Assembly
ECLSS	Environmental Contrl and Life Support System
EFE	ECLSS Flight Experiment
FMEA	Failure Modes and Effects Analysis
FSA	Flight Support Accessories
ICD	Interface Control Document
ISSA	International Space Station Alpha
KSC	Kennedy Space Center
L/GMA	Liquid/Gas Mixing Assembly
MS-DOS	Microsoft Disk Operating System
MSFC	George C. Marshall Space Flight Center
ORU	Orbital Replacement Unit
PDR	Preliminary Design Review
PL/M	Programming Language for Microprocessors
SHA	Safety Hazard Analysis
SR&QA	Safety, Reliability and Quality Assurance
SSF	Space Station Freedom
TIMES	Thermoelectric Integrated Membrane Evaporation System
TRD	Technical Requirements Document
TSIP	Touch Screen Interface Panel
UPA	Urine Processor Assembly
VCD	Vapor Compression Distillation
WRT	Water Recovery Test
WSA	Wastewater Storage Assembly
WWP	Wastewater Processor

INTRODUCTION

This document fulfills the requirement of the Program Plan for Contract NAS8-38250-11 to document program work in a Final Report to be identified as TR-1738-3.

Purpose

The purpose of this report is to document the Preliminary Design of the Vapor Compression Distillation (VCD) Wastewater Processor (WWP) Flight Experiment including the test protocol, VCD WWP test hardware and the Flight Support Accessories (FSA) necessary to operate the VCD WWP as a Flight Experiment.

Scope

This report begins with a description of how the opportunity for this experiment developed and concludes with documentation of the design produced by the program that will be implemented in the Phase C/D portion of the overall VCD WWP Flight Experiment Program. Also, included is a basic description of the VCD WWP process.

Vapor Compression Distillation WWP Flight Experiment Background

The VCD technology development has been funded by NASA and Life Systems since 1977. The technology has progressed through preprototype integrated subsystems that have been tested at NASA facilities.

The VCD WWP technology was selected for use as the Urine Processor Assembly (UPA) for the Space Station Freedom as a result of performance demonstrated during the Comparative Test conducted at the Marshall Space Flight Center in 1989 and 1990. Figure 1 presents an illustration of the tested unit. Following selection, the design process continued through a Critical Design Review (CDR) which was held at Life Systems in August of 1994. Figure 2 presents an illustration of the high fidelity mockup of the UPA prepared for the CDR.

Following completion of the CDR, the UPA was placed on hold as a result of the restructure of the Space Station program from Space Station Freedom to International Space Station Alpha (ISSA). The new schedule for the restructured program called for a delay in the completion of the UPA with work not restarting until October of 1997. As a result of this delay an opportunity was created to conduct a flight experiment that would provide a means by which operation of the technology in zero gravity could be demonstrated and the risks of its future use on the ISSA greatly reduced.

The VCD WWP Flight Experiment is being developed in a two step process. The first step was a Preliminary Design program for which this document is the Final Report. The second step will be the completion of the final design through the flight and flight data interpretation.

The Preliminary Design study was to produce a design that could be implemented in either the SPACEHAB, Spacelab or Russian MIR flight vehicles. As work progressed the flight vehicle was identified to be the SPACEHAB. Therefore, the design documentation focused on the experiment being performed on the SPACEHAB flight vehicle.

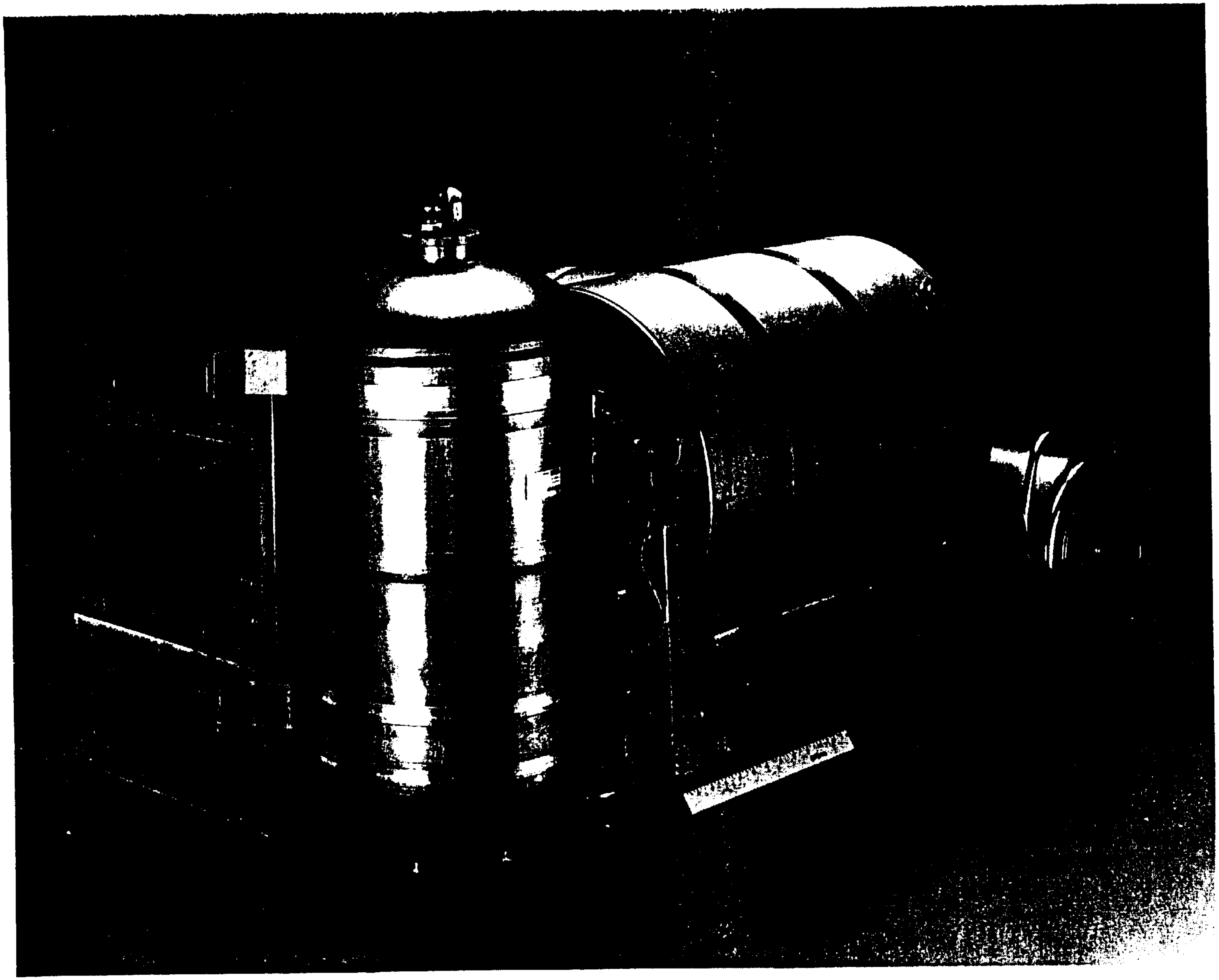


FIGURE 1 PREPROTOTYPE VAPOR COMPRESSION DISTILLATION ASSEMBLY WASTEWATER PROCESSOR

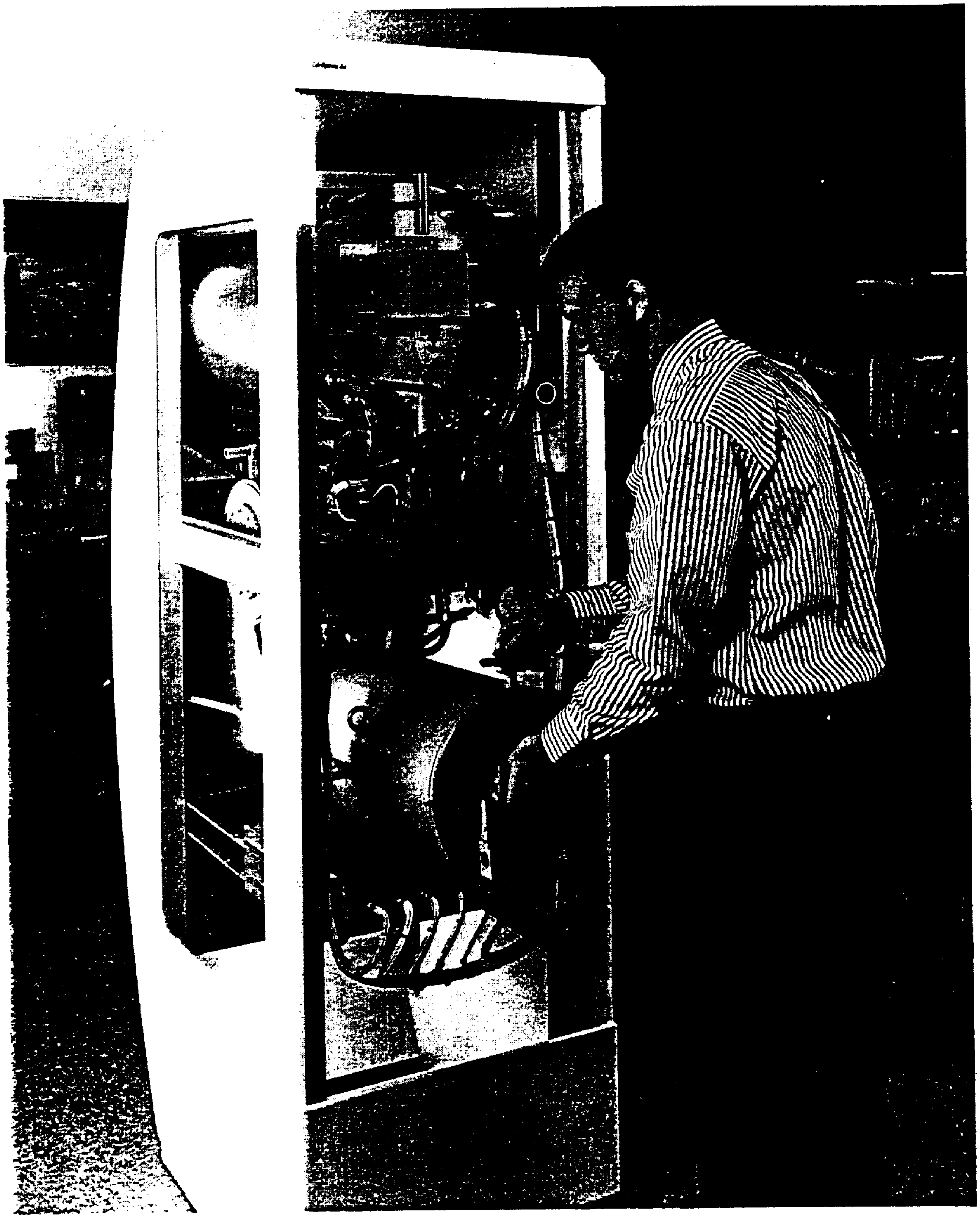


FIGURE 2 INTERNATIONAL SPACE STATION ALPHA
URINE PROCESSOR ASSEMBLY MOCKUP

UPA Mockup

Vapor Compression Distillation Technology Background

The VCD concept is illustrated in Figure 3. The concept utilizes a phase change process to efficiently recover product water from wastewater feed. A key characteristic of the process is the recovery of the latent heat of condensation from the product water. This recovery is accomplished by compressing water vapor to raise its saturation temperature and then condensing it on a surface which is in thermal contact with the evaporator. This results in heat transfer from the condenser to the evaporator. To achieve phase separation in microgravity, the evaporator/condenser and product water collector are rotated. This imparts sufficient centrifugal force on the fluids to achieve phase separation.

The primary focus of the VCD Flight Experiment is subsystem performance. NASA has recognized the need for water recovery from wastewater and has been developing VCD technology for space applications since the early 1960s. A summary of the hardware development, history and status is presented in Table 1. Key aspects of VCD technology have been verified with over tens of thousands of hours of testing. Significant improvements have been made in water production rates, water quality, specific energy, pump designs, packaging, maintainability and Control/Monitor Instrumentation (C/M I) throughout the development history. However, an important element lacking from previous subsystem development efforts is actual flight testing. Consequently, important goals of the VCD Flight Experiment are the demonstration and validation of the VCD technology, as well as the investigation of system performance, in microgravity.

Comparative Test Program

A VCD-based WWP was chosen for use onboard Space Station Freedom following a comparative selection program conducted by Boeing Defense and Space Group for the NASA George C. Marshall Space Flight Center (MSFC). This selection process began in the mid-1980s with the identification of candidate technologies for water reclamation from urine. After primary trade studies eliminated those technologies not mature enough to meet schedule requirements for the Space Station development, additional trade studies were performed to evaluate the remaining technologies with respect to performance, safety, reliability, maintenance, complexity and resource requirements. This resulted in the selection of the Thermoelectric Integrated Membrane Evaporation System (TIMES) as the baseline subsystem for water reclamation from urine. Parallel development of the VCD as the alternative technology was continued to minimize technical risk.[a]

The Comparative Test Program (initially the Technology Demonstration Program) began in late 1986 to provide "head-to-head" testing of baseline and alternative technology systems. Detailed testing was conducted to verify the operation and assess the performance of the competing systems to allow selection and continued development of a flight baseline. The performance parameters which were quantitatively compared included:

1. Production rate/water recovery;
2. Power requirements;
3. Product water quality; and
4. Expected flight resupply needs.

(a) Carrasquillo, R. L., Carter, D. L., Holder, D. W., Jr., McGriff, C. F and Ogle, K. Y., "Space Station Freedom Environmental Control and Life Support Systems Regenerative Subsystem Selection," NASA Technical Memorandum 4340, February, 1992.

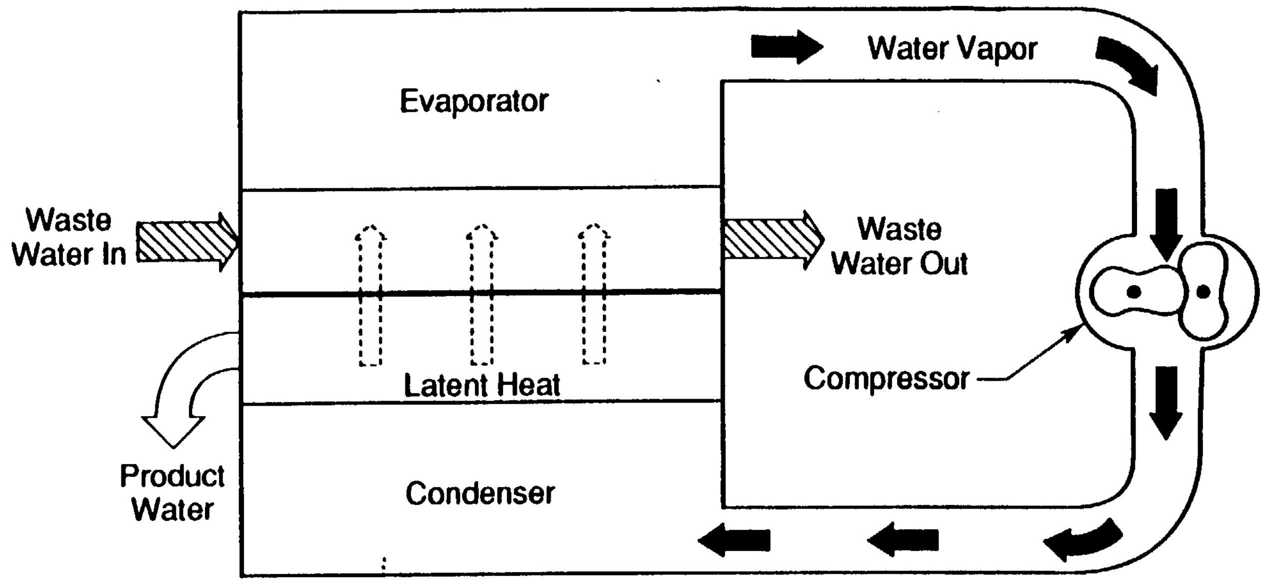


FIGURE 3 VAPOR COMPRESSION DISTILLATION CONCEPT

TABLE 1 VCD WWP HARDWARE DEVELOPMENT HISTORY

Unit	Time Frame, Year	Code	Hardware Type	Supplier	Sponsoring Organization
1	1962	MR 08-082	Engineering Prototype	Marquardt	Life Systems
2	1965	Model 1271	Engineering Prototype	GATX	MSFC
3	1968	--	Engineering Prototype	Chemtric	JSC
4	1971	SSP	SSP Ft Qualifiable Prototype	Chemtric	JSC
5	1976	VCD-1	Preprototype	Lockheed	JSC
6	1977	VCD-2	Preprototype	Life Systems	JSC
-	1981	VCD-2A	Modified VCD-2 (Lab. Preprototype)	Life Systems	JSC
-	1983	VCD-2B	Modified VCD-2A (Lab. Preprototype)	Life Systems	JSC
7	1985	VCD-III	VCD-2B (w/new Controller) (Lab. Preprototype)	Life Systems	Boeing/MSFC
8	1989	VCD-IV	Advanced Prototype	Life Systems	Boeing/MSFC
9	1989	VCD-IVA	Advanced Prototype	Life Systems	Life Systems
10	1990	VCD-IVB	Advanced Prototype	Life Systems	Life Systems
-	1991	VCD-V	Modified VCD-IVB for POST	Life Systems	Boeing/MSFC
11	1991	VCD-VA	Engineering Development Unit	Life Systems	Life Systems
12	1993	VCD-VI	Engineering Development Unit	Life Systems	Boeing/MSFC

Criteria for qualitative evaluation were:

1. Safety;
2. Technical maturity;
3. Maintenance;
4. Maintainability;
5. Reliability;
6. Integration;
7. Complexity;
8. Noise;
9. Microgravity sensitivity;
10. Technology issues;
11. Contamination potential;
12. Performance; and
13. Commonality.

Following intensive hardware testing over a 31-day period and a qualitative assessment of performance characteristics based on subsystem histories, the VCD WWP was selected as the Space Station flight baseline because of its superior water production rate, lower power requirements and mature design concept. The VCD also offered lower design concerns, though reliability of the fluids pump was cited as a major weakness. Water loss through the purge and possible sensitivity to microgravity were cited as minor weaknesses. Specific test results and evaluation summaries are contained in the reference footnoted below.[a]

Integrated Water Recovery Testing

As the Comparative Test Program was being concluded in 1990, NASA-MSFC initiated the integrated Water Recovery Test (WRT) to evaluate the performance of Space Station predevelopment water recovery systems and to achieve incremental water loop closure. Donor (open-loop) mode testing was done with a dual-loop, i.e., hygiene (including urine reclamation) water recovery loop and potable water recovery loop. This testing was referred to as Stage A (1A, 2A and 3A) and was completed in 1990. It utilized the then-baseline TIMES WWP. Stages B and C followed and concentrated on test investigations and trouble shooting activities of problems encountered in Stage A.

The TIMES subsystem was replaced by the VCD WWP as the new flight baseline for Stage C of the test.[b] Recipient (closed-loop) mode testing with a dual loop configuration (known as Stages 4 and 5) was completed in 1991. A total of 346 pounds of pre-treated urine/flushwater were processed by the VCD during 85.5 hours of operation yielding 89% water recovery. A major finding of the test was a gear failure which caused a downstream pump failure and resulted in a subsystem redesign to preclude similar propagated failures in the future. Although anomalies were encountered, the water production rate was significantly enhanced by addition of the VCD and reclaimed hygiene water

(a) Carrasquillo, R. L., Carter, D. L., Holder, D. W., Jr., McGriff, C. F and Ogle, K. Y., "Space Station Freedom Environmental Control and Life Support Systems Regenerative Subsystem Selection," NASA Technical Memorandum 4340, February, 1992.

(b) Bagdigian, R. M., Griffin, M. R., Griffith, G. K. and Traweek, M. S., "Phase III Integrated Water Recovery Testing at MSFC: Partially Closed Hygiene Loop and Open Potable Loop Results and Lessons Learned," SAE Technical Paper No. 911375, July, 1991.

routinely met Space Station Freedom (SSF) water quality specification.(a) Reverse closed-loop testing in a single (combined) loop configuration, referred to as Stages 7 and 8, was completed in 1992. A total of 1,331 pounds of pre-treated urine/flushwater was processed by the VCD during 319 hours of operation yielding a water recovery rate of almost 94%. The VCD water loss associated with the gas purge averaged only 2 to 3% of the wastewater processed. Planned recovery of this water in flight units would increase total water recovery from urine to 97%. Water quality requirements were regularly met with only one noteworthy anomaly which was repaired without recurrence.(b) The Water Recovery Test Program validated the decision resulting from the Comparative Test Program to utilize the VCD WWP as the Space Station flight baseline.

PROGRAM OBJECTIVES AND SCOPE

The overall objective of the VCD WWP Flight Experiment Program is to demonstrate the readiness of the technology for use in long-duration space missions as a WWP and reduce the risk of its use onboard ISSA. This section describes specific objectives and the overall programmatic effort to achieve them.

Flight Experiment Objectives

To achieve the goal of abating or avoiding problems associated with integrating VCD hardware onboard International Space Station Alpha, a flight experiment utilizing a full-sized VCD Wastewater Recovery System must be conducted. The VCD WWP and associated experiment support equipment should reflect, to the maximum extent possible, the design of VCD hardware currently developed and intended for use aboard the Space Station. The following are the general objectives of the VCD WWP FE.

1. Verify the readiness of VCD technology for utilization in space, including validation of:

    a. The VCD wastewater processing concept;
    b. The interaction of components and parts;
    c. The quality and quantity of product water; and
    d. The efficiency of the VCD process.

2. Verify ground-based analyses of VCD WWP components and process, including validation of:

    a. The sensitivity of VCD WWP components to the launch environment; and
    b. The sensitivity of VCD WWP components and processes to the microgravity environment on an integrated basis.

Specific flight experiment objectives which support these general objectives are listed below.

1. Verify integrated hardware operations:

(a) Bagdigian, R. M. and Holder, D. W., Jr., "Phase III Integrated Water Recovery Testing at MSFC: Closed Hygiene and Potable Loop Test Results and Lessons Learned," SAE Technical Paper No. 921117, July, 1992.

(b) Bagdigian, R. M. and Carter, D. L., "Phase III Integrated Water Recovery Testing at MSFC: Single Loop Test Results and Lessons Learned," SAE Technical Paper No. 932048, July, 1993.

a. Evaluate water production rate;
b. Evaluate water quality;
c. Evaluate power consumption;
d. Evaluate dynamic loads;
e. Evaluate all possible mode changes;
f. Evaluate free/entrained gas addition at various rates; and
g. Evaluate dry system start-up with evacuated Recycle Filter Tank.

2. Characterize wastewater droplet/film behavior:

   a. During normal start-up and shutdown;
   b. During normal operation;
   c. During emergency (e.g., power loss) shutdown and restart; and
   d. During shutdown following emergency shutdown.

3. Examine the effects of precipitates in Recycle Filter Tank.

4. Confirm gas/liquid separator performance.

Concentration on these specific objectives will identify operational risks, problems or anomalies which may impact actual implementation of the VCD WWP in space operations.

The objectives of the Preliminary Design Program are to:

1. Define an experiment test plan that, if successfully performed, accomplishes the program objectives stated above, and,

2. To develop and document a design through a Preliminary Design Review (PDR) that can be efficiently implemented into hardware and qualified for flight that can implement the specified experiment test plan.[a]

Justification for Conducting the VCD WWP Flight Experiment

The VCD-based technology has been selected for use onboard International Space Station Alpha following competitive trade studies and comparative hardware testing. Flight hardware development has progressed to the final stages of design[b], paralleled by performance and life testing of advanced prototypes and engineering development units[c]. Validation of the VCD processing concept and performance in microgravity is highly desirable to verify the readiness of this technology for utilization in space.

The effect of microgravity on VCD WWP performance is difficult to predict on the basis of ground tests alone. It is expected that some aspects of performance may actually be enhanced by microgravity, such as those which may result from a more uniform film thickness, lower bearing

(a) During the program effort the target flight vehicle was identified as the SPACEHAB to be flown on STS 90 scheduled for 10/02/97.
(b) Interim Critical Design Review was held 07/94.
(c) VCD-IVA, VCD-IVB, VCD-V, VCD-VA and VCD-VI.

loads, etc. However, there exists concern that other aspects may be hindered. The recent Environmental Control and Life Support System (ECLSS) Flight Experiment (EFE) examined two aspects related to VCD WWP operation in microgravity. The first was to evaluate two-phase liquid and gas mixture behavior in a metal bellows tank; the second was to study the separation of liquids from gases in a static phase separator. There is no current work in progress to determine the overall performance of VCD WWP hardware components or processing in microgravity.

A VCD-based WWP Flight Experiment is needed to ensure all microgravity sensitivities of the technology have been identified and controlled. On-orbit testing is essential to successfully conducting the experiment because drop tower and aircraft low-gravity testing in atmosphere does not provide adequate time to properly characterize VCD processing concepts, component interactions and performance. An on-orbit experiment of limited duration[a] would provide test data to quantify overall VCD water recovery performance and define which components, if any, require design modification to survive transport to orbit or to operate effectively in a microgravity environment. Risks which otherwise would be associated with implementing the VCD WWP onboard International Space Station Alpha without prior flight testing would be significantly reduced or eliminated. Confidence in the readiness of VCD technology to recover and reuse water from Space Station liquid wastes and support on-orbit water loop closure would be solidly established. More importantly, critical hardware which will enable much decreased Space Station logistical support for water replacement[b] and planned long-term life cycle cost savings would be validated.

Flight Experiment Scope

The scope of the complete VCD WWP Flight Experiment program begins with definition of the experiment and is completed with analysis of the test data generated by the in-space testing of the fabricated experiment in the SPACEHAB vehicle.

The program is structured into two distinct phases. The first is a Preliminary Design study that begins with definition of the experiment and ends with completion of a Preliminary Design Review. The second phase completes the experiment. It begins with the Preliminary Design being converted into a detail design for fabrication and ends with an analysis of the data generated by the operation of the experiment in space.

This report documents the results of the Preliminary Design program.

Flight Experiment Success Criteria

The VCD WWP Flight Experiment will be successful if it verifies the current design of the VCD or identifies modifications necessary to achieve reliable operation in space. The VCD WWP Flight Experiment will be fully successful if it operates through the baseline four-day test program and its performance meets or exceeds earth testing performance parameters. If the extra two days of

(a) Four-to-six days.
(b) The average daily water requirement for a crew of four onboard International Space Station Alpha is approximately 243.3 lb/day if laundry water is processed and about half that if the laundry is eliminated from the Space Station. Therefore, nominal station operation would require that approximately 88,800 lbs of water plus associated tankage, support structure and cargo carrier be transported to orbit annually. The use of the VCD Wastewater Processor to recover reuse water from onboard generated wastes would greatly reduce, if not eliminate, this logistics requirement.

operation are also achieved it will be a bonus. The minimum acceptable level of performance would be establishment of stead state operation in normal mode. If steady state operation is achieved, even if performance is below expectations or operational problems occur, there will be sufficient data generated to diagnose problems and/or uncover any inherent weakness in the VCD WWP design. This will enable the hardware to be upgraded prior to future use. The means by which data is to be utilized to analyze the performance of the VCD WWP Flight Experiment is shown by Table 2. Table 3 defines how specific performance evaluations are to be achieved.

Benefits

There are two major benefits that can be derived from the success of this project. The first is that the knowledge gained will significantly reduce the development risk that would exist if extended micro-gravity testing is not achieved before the VCD WWP technology is used on the ISSA. The second benefit is that flight tested hardware will be available that could be used either directly on the ISSA or as part of a ground test bed to support ISSA. This hardware would be available at an early date for use as best needed.

VAPOR COMPRESSION DISTILLATION WWP FLIGHT EXPERIMENT DESIGN DESCRIPTION

Test operation of a VCD in either an earth-based or flight experiment microgravity laboratory requires both the VCD test article and the hardware to simulate the interfaces necessary for the operation of an VCD that would be available with operation in an integrated system. Therefore, the VCD Flight Experiment design is separated into two groups of hardware and software. The first group is that hardware and software that represents the fully integrated VCD subsystem. This is the hardware and software that represents the VCD subsystem that wold fly onboard the Space Station. The second group of hardware and software is that hardware and software that simulates the interfaces that a VCD would see in operation onboard the Space Station. This group of hardware and software has been given the designation of FSA. Together both groups make up the Flight Experiment. Each group and their function is described in the following sections.

Design Configuration

The following sections define physical characteristics of the experiment hardware, including description of the individual components that make up the Flight Experiment design.

Mechanical Schematic with Sensors

The mechanical schematic with sensors of the VCD WWP Flight Experiment is shown by Figure 4. As described, the experiment consists of the VCD shown on the left of the schematic, and FSA, shown on the right side of the schematic.

The VCD processes synthetic wastewater generated by the FSA. Synthetic wastewater generated by the FSA flows into the Wastewater Storage Assembly (WSA). When the level in the WSA reaches its high control point the VCD is transitioned into Normal mode and the full WSA is processed until it reaches the low control point, at which the VCD returns to Standby. Product water from the VCD is collected in the FSA Product Water Tank. Purge gas is discharged through the evaporator into the avionics cooling air generated by the Cooling Fan Assembly (CFA).

TABLE 2 PERFORMANCE VERIFICATION DATA

	Type of Data[a]																													
	Flow Rate			Pressure			Quantity	Speed							Temperature						Two-Phase Flow		Product Water Quality				Other			
Purpose of Data	Product Water(EF3)	Condensate(EF1)	Recycle(EF2)	Evaporator(EP1)	Condenser(P11, P12)	Gas/Liquid Separator(P2)	Wastewater Storage Tank(Q1)	Compressor(S1)	Fluids Pump(S2)	Purge Pump(S3)	Still(S4)	Feed Water Pump(ES2)	Concentrate Pump(ES1)	Feed Air Pump(ES3)	Evaporator(ET2)	Compressor Outlet(T1)	Condensor(ET1)	Coolant Supply(ET4)	Purge Pump(ET3)	Coolant Out(T2)	Air-in-Water(EL1)	Water-in-Air(L2)	Conductivity[b] (K1)	Ion Concentrations[c](C)	pH[c](C)	TOC[c,d](C)	Current(I1)	Liquid Level(L1)	Recycle Filter Tank ΔP(P33,P32)	Vibration Spectrum(EN1, EN2)
1. Verify Integrated Operation:																														
a. Water Production Rate	P	X	X				X					X	X	X	X		X													
b. Power Consumption								X	X	X	X	X	X	X		X			X	X							P			
c. Water Quality															X		X						X	P	X	X				
d. Modes/Transitions[e]				X	X			X			X				X	X	X	X	X	X			X	X	X	X	X	X		X
e. Free/Entrained Gas Addition	X			X	X	X	X							X		X	X		X		X	X					P			
f. Dry Start-Up	X			X	X										X	X	X										P			
2. Characterize Wastewater Droplet/Film Behavior:																														
a. Normal Startup/Shutdown	X			X	X			X	X		X				X	X	X		X				P	X	X	X		X		X
b. Normal Operation	X			X	X			X	X		X				X		X		X				P	X	X	X		X		X
c. Emergency Shutdown and Restart	X			X	X			X	X		X				X		X						P	X	X	X		X		X
d. Shutdown Following Emergency Shutdown				X	X										X		X						P	X	X	X		X		X
3. Characterize Effect of Precipitates In Recycle Filter Tank																													P	
4. Confirm Performance of Gas/Liquid Separator:																														
a. Separation of Air from Water						X				X								X	X		P									
b. Prevention of Water Entering Gas Vent						X				X								X	X			P								

(a) P = Primary data required; X = Supporting data required.
(b) Measured using Conductivity Sensor in VCD Wastewater Processor and using laboratory instruments on ground with samples collected in microgravity.
(c) Measured using laboratory instruments on ground with samples collected in microgravity.
(d) TOC = Total Organic Carbon.
(e) Verify normal operation of firmware and hardware.

TABLE 3 DATA ANALYSIS - PURPOSE AND APPROACH

Purpose of Data	Analysis Approach
1. Verify Integrated Operation:	
• Water Production Rate	• Compare microgravity and 1-g production rates
• Power Consumption	• Compare microgarvity and 1-g consumption rates
• Water Quality	• Collect Water Samples in microgravity for analysis on ground; Compare water quality in microgravity to that obtained in 1-g
• Dynamic Response	• Compare microgravity and 1-g vibration of rotating components
• Modes/Transitions	• Verify normal operation of firmware and hardware
• Free Gas Addition	• Compare current, compressor outlet temperature and other operating parameters in microgravity to those obtained in 1-g
• Dry Start-Up	• Compare liquid flow rate values and power consumption with 1-g test data
2. Characterize Wastewater Droplet/Film Behavior During:	
• Normal Startup/Shutdown	• Compare liquid flow rate values with 1-g test data
• Normal Operation	• Compare liquid flow rate values with 1-g test data
• Emergency Shutdown and Restart	• Compare liquid flow rate values with 1-g test data
• Shutdown following Emergency Shutdown	• Compare liquid flow rate values with 1-g test data
3. Characterize Effect of Precipitates in Recycle Filter Tank	• Measure pressure drop across filter versus time and solids concentration. Repeat measurements with each new recycle filter tank; Compare data from microgravity to that obtained in 1-g
4. Confirm Performance of Gas/Liquid Separator:	
• Separation of Air from Water	• Compare levels of purge gas in condensate in microgravity to levels obtained in 1-g
• Prevention of Water Entering Gas Vent	• Compare amount of liquid water, if any, in Purge Gas Vent in microgravity to amount obtained in 1-g

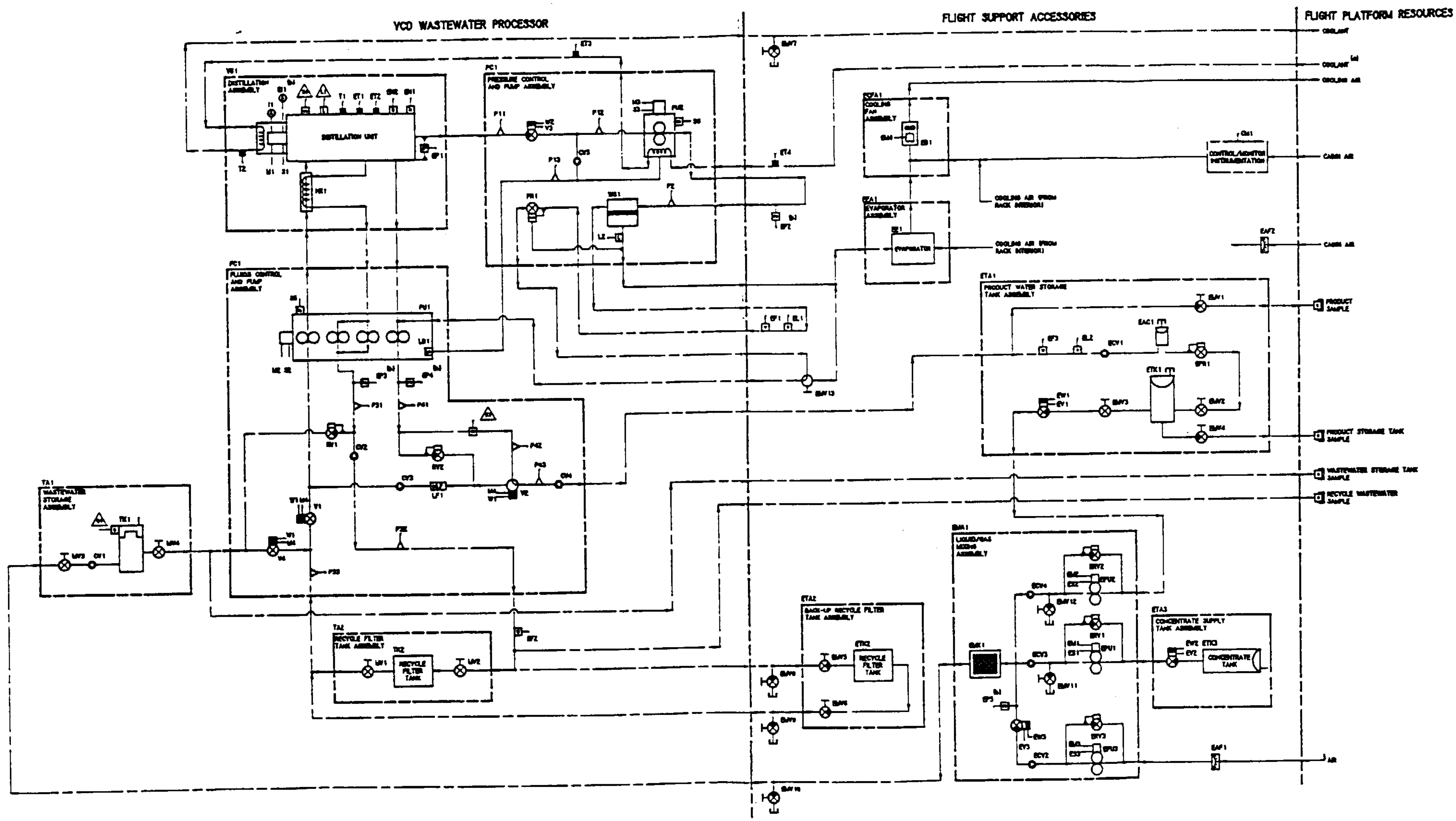


FIGURE 4 VCD WWP FLIGHT EXPERIMENT MECHANICAL SCHEMATIC WITH SENSORS

LEGEND

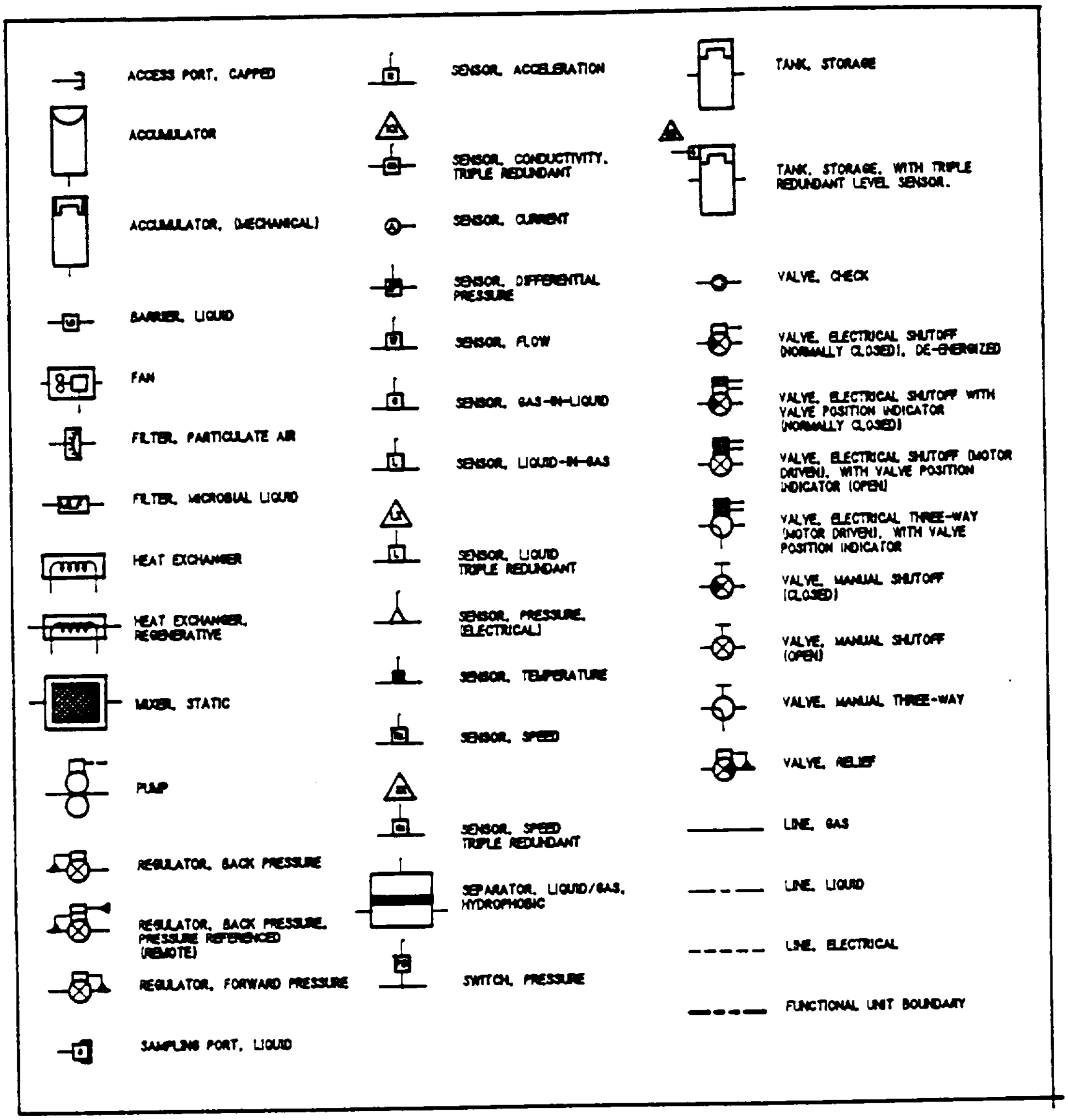


Figure 4 - continued

To initiate the next operating cycle, fresh wastewater is again generated by the FSA. This is done by combining product water with wastewater concentrate and free air in the Liquid/Gas Mixing Assembly (L/GMA).

Vapor Compression Distillation WWP Component Descriptions. The configuration of the VCD for flight testing was defined by Trade Study No. 3 documented in Life Systems' report TR-1738-22, Trade Studies and Rationale for Flight Experiment Configuration. This study determined a full size VCD subsystem operating at full rate, like that designed for the UPA for ISSA, could be accommodated within the flight vehicle resources and would therefore be the most effective experiment configuration. On this basis, all of the Orbital Replacement Unit (ORU) designs will be derived directly from the information presented at the UPA Critical Design Review. Further, the Flight Experiment hardware could be converted for full capacity use in the ISSA program.

The VCD WWP subassembly consists of the following five (5) major components. Each component is described below.

Distillation Assembly: Evaporates water from a flowing wastewater stream and subsequently condenses the water vapor to form product water. This operation is performed with a rotating centrifuge drum to provide liquid/vapor separation in microgravity. A functional schematic of a Distillation Assembly is shown in Figure 5.

Fluids Control and Pump Assembly: Manages and directs the flows of wastewater feed, wastewater recycle and product water within the VCD subsystem.

Pressure Control and Pump Assembly: Provides for the pumping and removal of noncondensable gases and water vapor.

Wastewater Storage Assembly: Stores wastewater prior to processing.

Recycle Filter Tank Assembly: Filters and accumulates solid precipitates that crystalize out of solution within the wastewater stream as the recycling wastewater concentrates beyond its saturation level. (Note: A second Recycle Filter Tank Assembly is provided to allow for two additional days of optional testing. This second tank is grouped with the experiment's support hardware discussed below.)

Vapor Compression Distillation WWP Flight Support Accessories. The VCD WWP Flight Support Accessories consist of the following five (5) major components:

Product Water Storage Assembly: Stores product water after processing for sampling or recycling for continued testing.

Concentrate Storage Assembly: Stores concentrated wastewater to be combined with recycled product water to provide additional batches of wastewater for continued cyclic testing.

Gas/Liquid Mixing Assembly: Mixes concentrated wastewater, product water and free gas for storage in Wastewater Storage Assembly.

Back-up Recycle Filter Tank: Provides redundancy for Recycle Filter Tank and added test capacity.

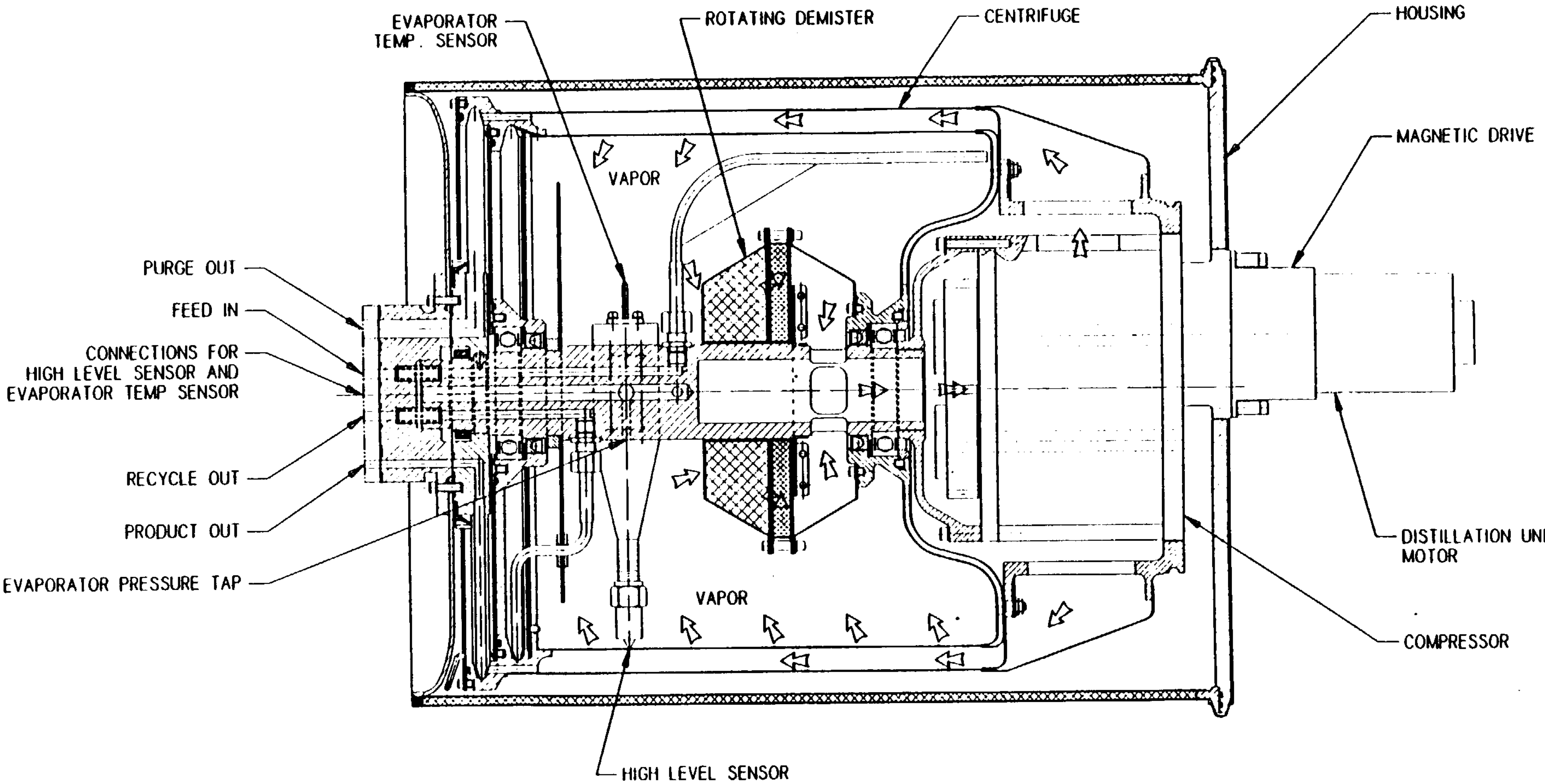


FIGURE 5 DISTILLATION ASSEMBLY FUNCTIONAL SCHEMATIC

Evaporator Assembly: Provides a means by which any condensate that may form in the purge line is vaporized into the avionics air flow generated by the Cooling Fan Assembly. The evaporator is sized so that all condensate generated by cooling of the purge gas can be processed in this manner if the phase separator fails.

Control/Monitor Instrumentation

Operation of the Flight Experiment is to be fully automated through C/M I. Two separate C/M Is are to be utilized in the experiment. The first is that which controls the VCD WWP which is designated the Model 540 C/M I. The Model 540 C/M I represents the C/M I that would control the VCD WWP when implemented on the Space Station. The second is that which controls the overall experiment and the FSA which is designated the Model 684 C/M I. This C/M I monitors the FSA instrumentation, controls the FSA actuators and provides command signals to the Model 540. It also provides the crew interface and the mass storage of experiment operating data. Figure 6 illustrates the relationship of the C/M Is by showing the electrical block diagram of the flight experiment. Both C/M I's are packaged within a single enclosure. Each C/M I component is described below.

- Model 540 Control/Monitor Instrumentation (Model 540 Controller)

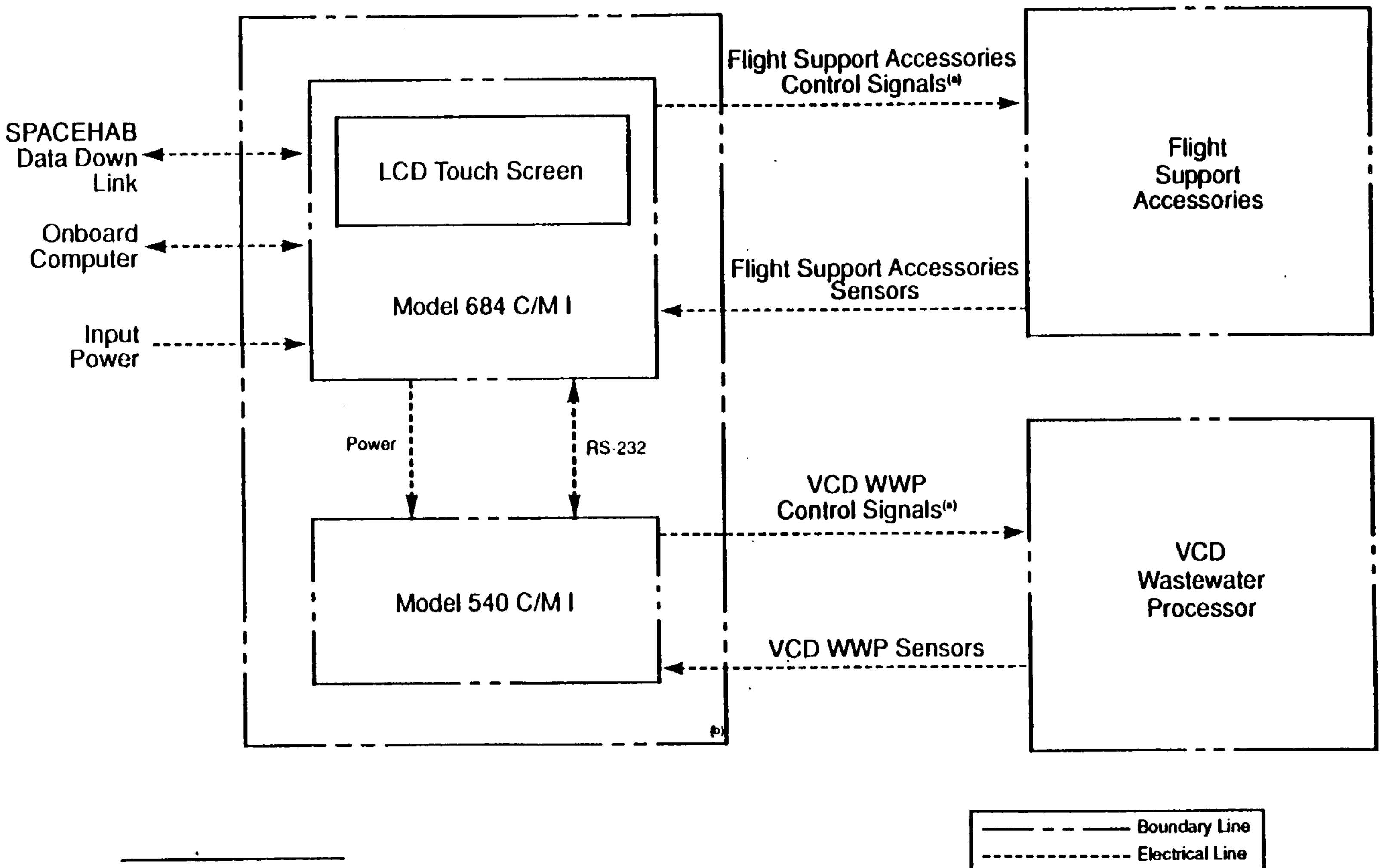
  The Model 540 Controller provides monitoring and control of the VCD. The controller includes the computer processing, generic sensor, special sensor and actuator signal conditioning as well as power protection and conversion functions required to automatically control the VCD subsystem. The signal conditioning includes both controlling power to the actuators and processing sensor signals from the mechanical subsystem. The Signal Conditioner provides for special sensor signal conditioning and actuator drive electronics. The VCD control software resides in the Model 540 Controller. The major functions of the software are to implement modes of operation, perform process control and provide for fault detection.

- Model 684 Control/Monitor Instrumentation (Model 684 Controller)

  The Model 684 Controller provides experimental test sequencing, data logging/storage, power distribution, flight experiment/flight vehicle communications and crew interface. The controller includes computer processing, sensor and actuator signal conditioning, special power drivers, power conversion and touch screen display and keyboard interface functions required to control the flight experiment. A standard RS-232 communication bus to the Model 540 Controller provides intra-experiment control and data transfer. Additional capabilities include a communication link to the SPACEHAB for downlinking of data, a communication link to the onboard lap top computer and provisions for single sensor shutdown of the experiment for safety.

Experiment Packaging

The VCD Flight Experiment is designed to be packaged in a SPACEHAB or a Spacelab double rack (SPACEHAB now chosen). The packaging configuration is illustrated by Figure 7. The Flight Experiment Assembly is packaged and mounted in a subframe structure. The assembly will be tested in this structure and shipped in this structure. Upon receipt at the Kennedy Space Center (KSC), this structure will then be mounted within the SPACEHAB rack.



(a) Includes power for sensors/actuators.
(b) Housed in single enclosure.

FIGURE 6 VCD WWP ELECTRICAL BLOCK DIAGRAM

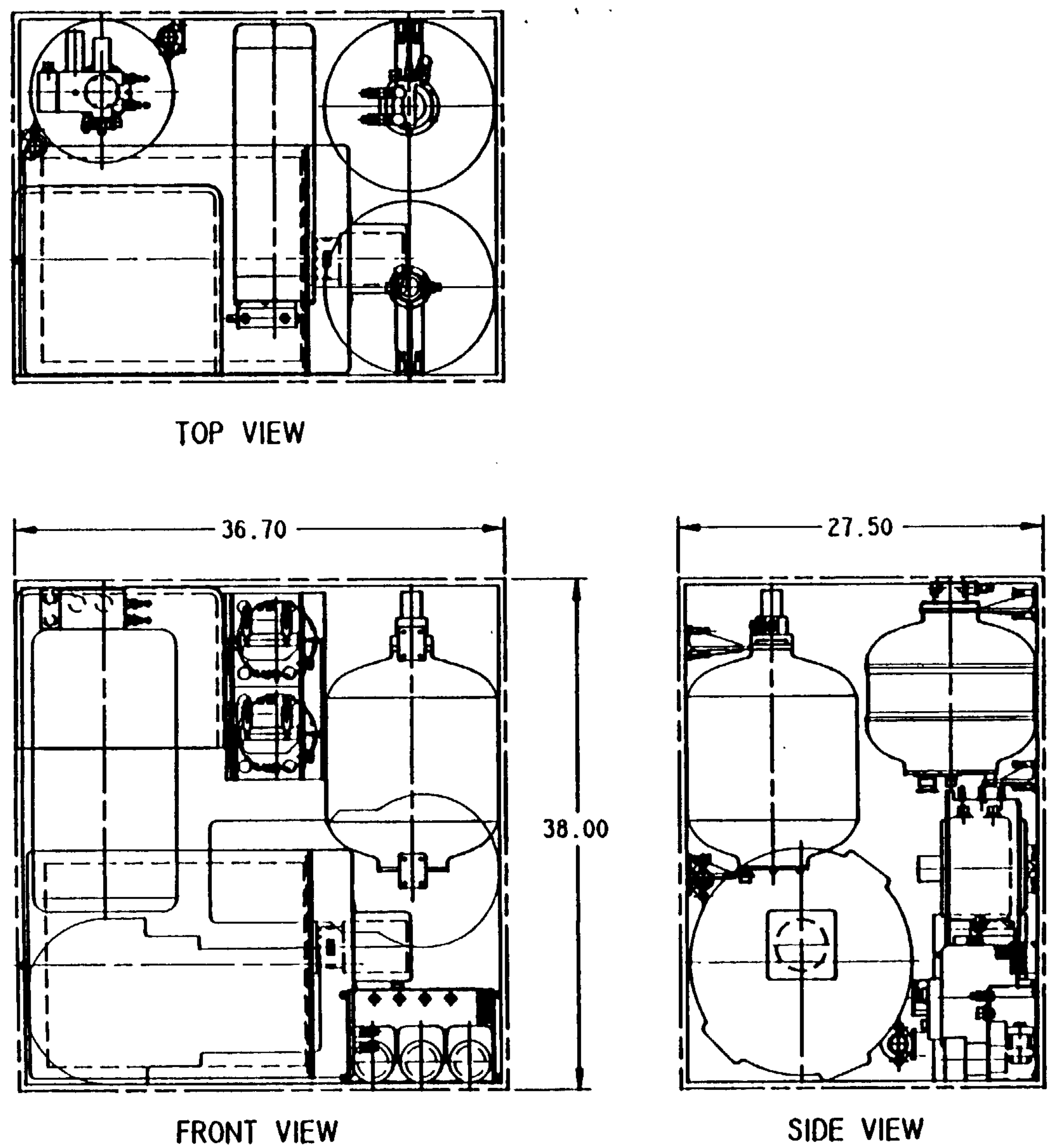


FIGURE 7 VCD WWP RACK PACKAGING

Experiment Interfaces

The overall experiment described in the sections above is illustrated by Figure 8. This figure shows the relationship between the components within the experiment and also the interfaces of the experiment with the SPACEHAB. Characteristics of the individual components are shown by Table 4.

Crew Interface

The Flight Experiment is initiated by crew action through the front panel of the Model 684 C/M I. The first action is to turn on power through a single switch. The next action is to initiate the experiment through the Touch Screen Interface Panel (TSIP). A single key pad is utilized. Each input requires two finger actuation to avoid accidental input of instructions. Foot restraints within the SPACEHAB allow for two-handed inputs through the TSIP.

Once initiated the experiment is totally automated. Operating data is displayed for crew monitoring on the TSIP. Operating data is also downlinked to earth for real time monitoring by flight support personnel. Manual mode selections are possible through the TSIP. If changes in internal operating parameters are required, they can be made through the Onboard Computer Interface.

Crew interaction is only required for taking of liquid samples, implementation of the Backup Recycle Filter Tank, diversion of the Purge Pump discharge to the Evaporator Assembly, if required, and removal of power from the experiment when testing is complete.

Data collection for experiment evaluation is performed by the Model 684 C/M I. Data is stored in Electrically Erasable and Programmable Memory (Flash) and on a hard disk drive.

Mission Test Plan

The objectives of the overall program require that the test plan generate a wide spectrum of microgravity test data for comparison against earth-based testing. The comparison of this data is to be the basis of evaluating the readiness of VCD technology for space missions and/or identifying modifications to achieve this readiness.

For a test program to meet the required objectives, it must demonstrate two things. They are:

1. Efficient function in microgravity and
2. Tolerance to shutdown both planned and unplanned.

If failures occur, it must also provide sufficient data to allow future resolution of the failure.

The objectives of the Flight Experiment are to be achieved by a four-day test with the possibility of an extra two days if flight circumstances allow. During the base case four (4) day test, four (4) types of tests are to be performed. They are:

- Operation for one (1) day at nominal design conditions.

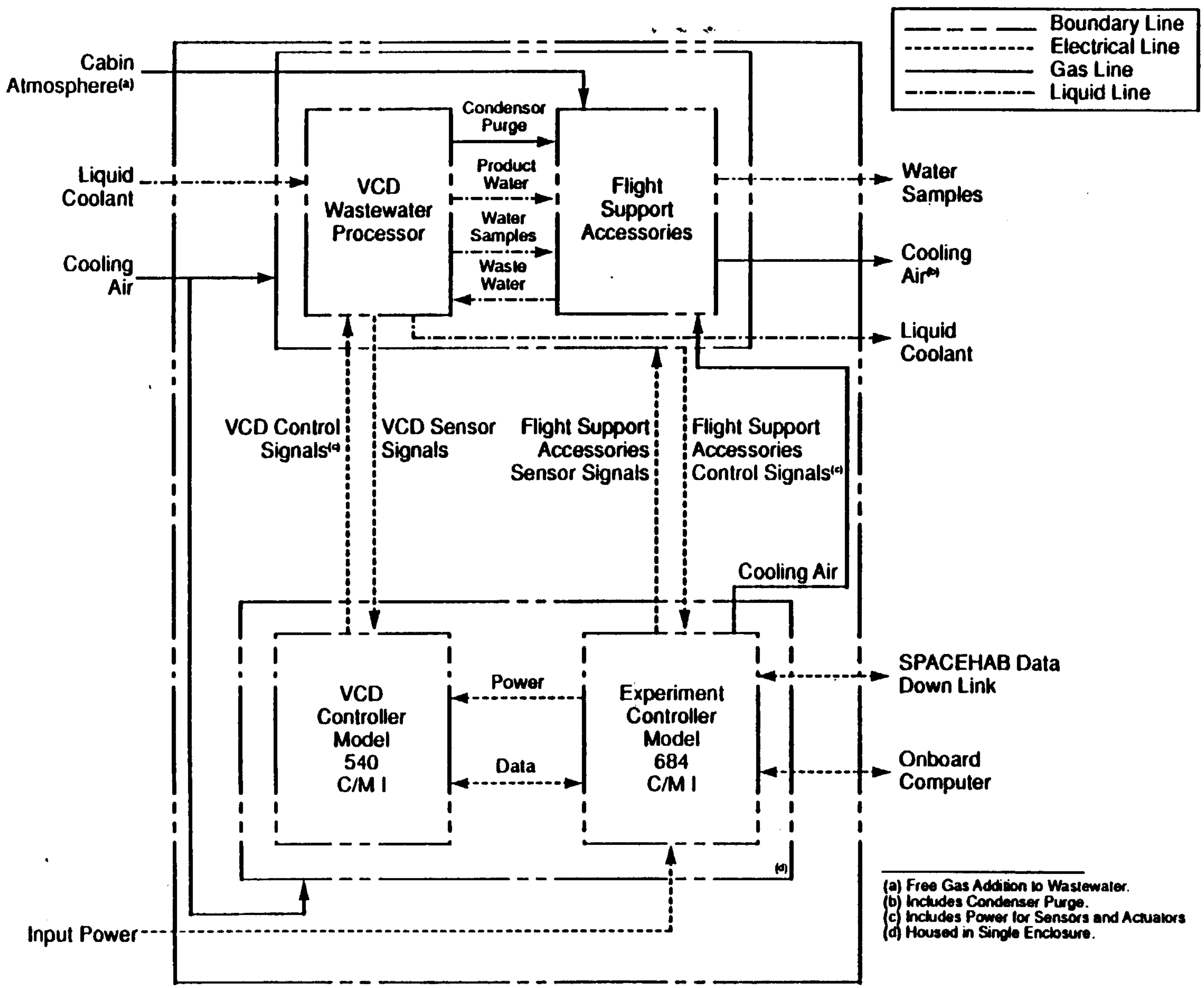


FIGURE 8 VCD WWP FLIGHT EXPERIMENT INTERFACE BLOCK DIAGRAM

TABLE 4 COMPONENT CHARACTERISTICS AND PERFORMANCE SUMMARY

Component Name	Wet Weight, lb[(b)]	Power, W[(a)]		Heat Load, W[(a)]		Envelope, in.
		Normal	Standby	Normal	Standby	
VCD Wastewater Processor						
Distillation Assembly	98.5	154	0	154	0	18.1 Dia x 28.2
Fluids Control and Pump Assembly	56.2	19	0	19	0	8.0 x 15 x 23
Pressure Control and Pump Assembly	64.0	23	0	23	0	8.5 x 15 x 23
Wastewater Storage Assembly	13.5	0	0	0	0	12.75 Dia x 10.1
Recycle Filter Tank Assembly	3.9	0	0	0	0	6.0 Dia x 21.0
Model 540 C/M I	22.6	104	28	104	28	(c)
Cable Assemblies	6.0	0	0	0	0	--
Total:	264.7	300	28	300	28	
Flight Support Accessories						
Product Water Storage Tank Assembly	46.9	0	0	0	0	10.7 Dia x 21.0
Concentrate Supply Tank Assembly	75.3	0	0	0	0	11.0 Dia x 18.0
Liquid/Gas Mixing Assembly	7.0	0	84[(d)]	0	84[(d)]	12 x 6.0 x 6.0
Cooling Fan Assembly	3.0	100	100	100	100	5.0 x 6.0 x 6.0
Backup Recycle Filter Tank Assembly	25.5	0	0	0	0	6.0 Dia x 21.0
Model 684 C/M I	21.1	28	108	28	108	(c)
Cable Assemblies	6.0	0	0	0	0	--
Frame and Brackets	58.8	0	0	0	0	--
Sample Bottles[(e)]	3.0	0	0	0	0	--
Evaporator Assembly	0.5	0	0	0	0	3.0 x 3.0 x 1.0
Total:	247.1	128	292	128	292	
Total Experiment:	511.8	428	320	428	320	38.0 x 36.7 x 27.5

(a) Producing water from wastewater at a nominal rate of 4.5 lb/hr for three 4-hour periods per 24-hour day
(b) Initial launch configuration, including liquid inventories.
(c) Model 540 C/M I and Model 684 C/M I in a single enclosure 12.1 x 15.63 x 14.1 (H x W x D) in.
(d) Power applied to peristaltic pump. Independent of fluid rate and not continuous.
(e) Not part of Flight Experiment Envelope (eighteen 150 cc bottles).

- Operation for one (1) day at nominal design conditions with the exception that the quantity of free gas addition will be varied.
- Operation for one (1) day demonstrating system failure recovery operation.
- Operation for one (1) day in cyclic operation on the basis of the light/dark orbit cycle (i.e., 57 minutes on and 33 minutes off).

Data is to be collected in mass storage for detailed post-flight evaluation. It will also be downlinked to earth for real time monitoring during the flight. In addition to collection of experiment sensor data, liquid samples will be collected by the crew for evaluation after return to earth. The experiment test program is illustrated by Figure 9. The recommended water sampling protocol is shown in Table 5. A detailed profile of the third day recovery test is shown by Figure 10. A description of the six-day test is given by Table 6. A description of the day 3 failure testing is given by Table 7.

Software

Software for the VCD Flight Experiment is separated into two packages. The first is for the Model 540 C/M I which controls the VCD portion of the experiment. The second is for the Model 684 C/M I which controls the FSA portion of the experiment and provides overall experiment sequencing and interface communication. The total software package provides for operation of the VCD in the modes shown (along with mode transitions) by Figure 11. The operating modes are described by Table 8. Figure 12 provides a Software Block Diagram describing the software configuration. The design of each software package is described below.

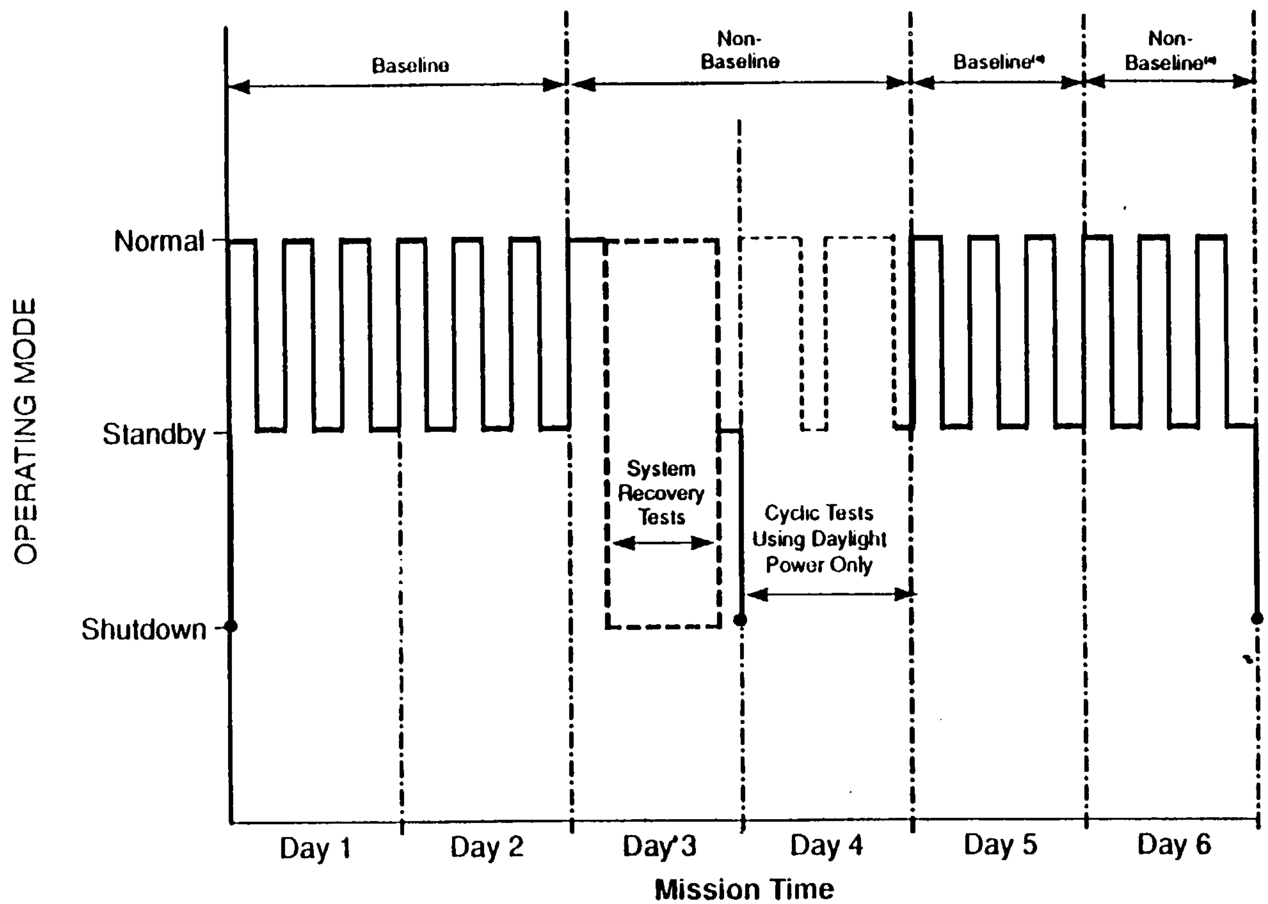
Model 540 C/M I Software

The VCD WWP Flight Experiment Software for the Model 540 C/M I controller consists of an Operating System and an Application Specific Code. All software is developed using Programming Language for Microprocessors (PL/M). However, some assembly language coding is also done.

Model 540 C/M I Operating System Software. The Operating System software is to be utilized in the Model 540 C/M I's Life Systems' proven Series 400 Operating System. This operating system has been used extensively in Life Systems' Space Station hardware development work. The Series 400 Operating System demonstrated experience includes use in the Environmental Control and Life Support System Flight Experiment (EFE). It will also be utilized in the In-Space Technology Experiment Program (IN-STEP) Electrolysis Performance Improvement Concept Study (EPICS) Flight Experiment. Figure 13 illustrates the Series 400 Operating System.

The Operating System will perform the following functions:

1. Perform Intra-experiment Communication: The Model 540 C/M I will communicate with the Model 684 C/M I sending data and receiving commands (OS10.0).
2. Perform Transitions: This involves executing a sequence of steps to change the operating mode of the system, monitoring the transition progress and updating the system status to reflect the transition mode (OS5.0).



(a) Optional, depending on mission.

FIGURE 9 VCD FLIGHT EXPERIMENT MISSION PROFILE/TIMELINE

TABLE 5 SAMPLING PROTOCOL OUTLINE FOR VCD WWP FLIGHT EXPERIMENT

Day[(a)]	Test[(a)]	Cycle	Sample Collection Time[(b)]	Sample Collection Ports[(c)]	On Ground Tests[(d)]	Sample Size, mL
1	Baseline	1	I	W,R	A,R	125, 25
		1	M	S	A	125
		1	F	R	R	25
		2	F	R	R	25
		3	M	P	A	125
		3	F	R	R	25
2	Parametric	1	M	S	A	125
		1	F	R	R	25
		2	F	R	R	25
		3	M	P	A	125
		3	F	R	R	25
3	Nonbaseline	1	T	S	A	125
		1	F	R	R	25
		2	T	S,P	A	125, 125
		2	T	R	R	25
4	Nonbaseline	1	F	S,R	A,R	125, 25
		6	F	S,R	A,R	125, 25
		10	F	S,R	A,R	125, 25
		12	F	R	R	25
5[(e)]	Nonbaseline	1	I	W,R	A,R	125, 25
		1	M	S,P	R	125, 125
6[(e)]	Nonbaseline	1	M	S	A	125
		1	F	R	R	25
		2	M	S	A	125
		2	F	R	R	25
		3	M	S	A	125
		3	F	R	R	25
Totals				34		2,550[(f)]

(a) Per Vapor Compression Distillation Wastewater Process Interim Design Review, November 30, 1994.
(b) I = 30 min into Normal mode; M = 120 min into Normal mode; F = 210 min into Normal mode; T = To Be Determined.
(c) A = All; S = Product Sample; P = Product Storage Tank Sample; R = Recycle Wastewater Sample; W = Wastewater Storage Tank Sample.
(d) A = All (includes conductivity, ion concentrations, pH and Total Organic Carbon); R = Refractive Index.
(e) Optional, depending on mission.
(f) 2,550 mL = 2,550 g (assuming density of water is 1.00 g/mL) = 5.622 lb water.

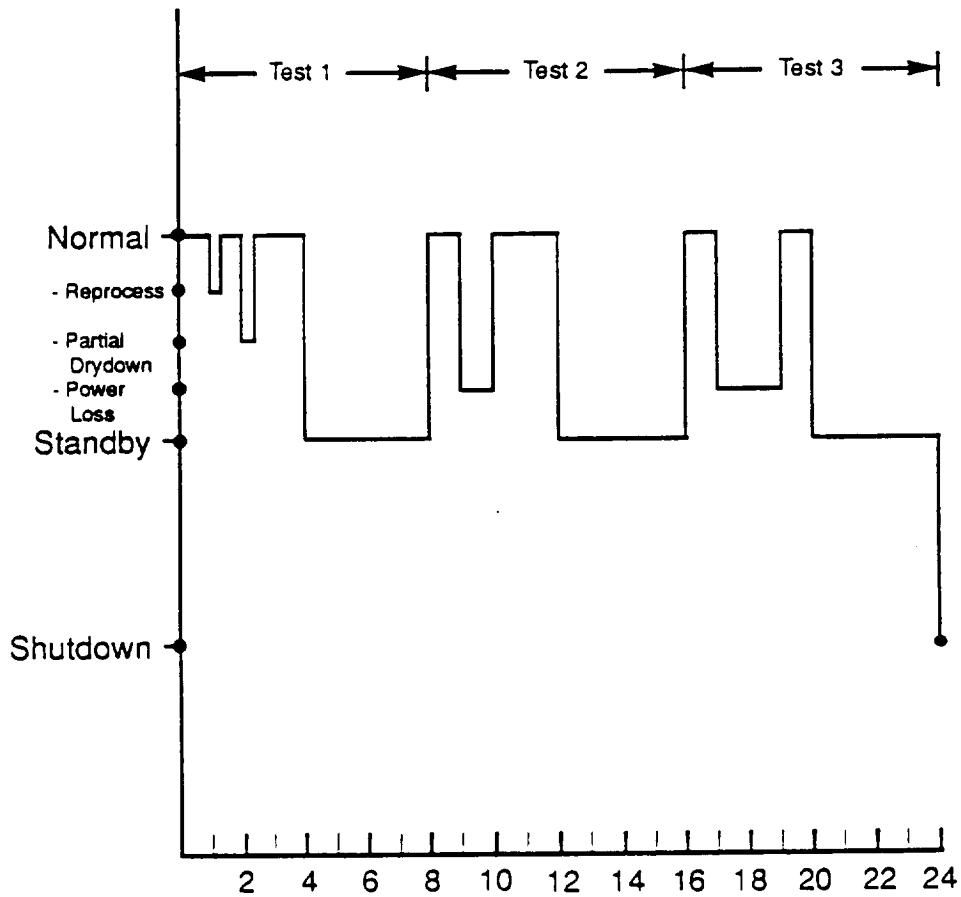


FIGURE 10 VCD WWP DAY 3 SIMULATED FAILURE TESTING

TABLE 6 VCD WWP FLIGHT EXPERIMENT TEST PLAN

Day	Test Element	Test Description
1	Baseline	• Cyclic Testing (three 8-hr cycles, each 4 hr in Normal Mode, processing 18 lb[(a)] of wastewater and 4 hr in Standby Mode redistributing liquid inventories for next Normal Mode) • All operating parameters at nominal values
2	Parametric	• Cyclic Testing (same as Day 1) • All operation parameters nominal <u>except</u> variable free gas addition (first 8-hr cycle, 5%; second 8-hr cycle, 10%; third 8-hr cycle, 15% free gas)
3	Nonbaseline	• System Recovery Tests: - Reprocessing of product water for simulated high conductivity - Partial dry-down for simulated high liquid level - First system restart following simulated power failure - Second system restart following simulated power failure • All noneffected parameters at nominal values
4	Nonbaseline	• Cyclic Testing using "low cost" daylight power (six consecutive 90 min cycles[(b)] followed by 3-hr Standby; two series per day) • All operating parameters at nominal values
5[(c)]	Baseline	• Cyclic Testing (same as Day 1) • All operating parameters nominal but using back-up recycle filter tank since primary tank at 25% solids concentration
6[(c)]	Nonbaseline	• Cyclic Testing (same as Day 1) • All operating parameters nominal except operation beyond 25% solids by returning to primary filter tank

(a) Based on a nominal 4.5 lb/hr production rate.
(b) Based on a standard low-earth orbit day/night cycle, i.e., 53 min Normal Mode (daylight), 37 min Standby Mode (darkness)
(c) Optional, depending on mission.

TABLE 7 VCD WWP SYSTEM RECOVERY TEST PLAN

Hr	Test Action	Description
0	Start Failure Recovery Test	• Initiate operation in Normal mode. All parameters Normal.
1	High Conductivity	• Simulate a high product water conductivity by automatic override of K1 value by Model 684 C/M I. Verify VCD operation in reprocess configuration of the Normal mode
2	High Liquid Level	• Simulate a high liquid level inside Distillation Assembly by automatic override of L1 by Model 684 C/M I. Verify operation in partial drydown configuration of the Normal mode.
4	Standby	• Transition to Standby at end of batch. All parameters Normal. At end of period fill Wastewater Storage Tank Assembly.
8	Normal	• When Wastewater Storage Tank Assembly reaches high level setpoint transition to Normal Mode. All parameters Normat.
9	Actuator Power Loss	• Simulate power failure by automatic removal of power from actuators by Model 684 C/M I.
10	Restart	• Automatically return power to actuators through Model 684 C/M I. Manually verify successful restart, if necessary, manually initiate partial drydown to recover.
12	Standby	• Transition to Standby at end of batch. All parameters Normal. At end of period fill Wastewater Storage Tank Assembly.
16	Normal	• When Wastewater Storage Tank Assembly reaches high level setpoint transition to Normal mode. All parameters Normal.
17	Actuator Power Loss	• Simulate power failure by automatic removal of power from actuators by Model 684 C/M I.
19	Restart	• Automatically return power to actuators through Model 684 C/M I. Manually verify successful restart, if necessary, manually initiate partial drydown to recover.
20	Standby	• Transition to Standby at end of batch. All parameters Normal. At end of period fill Wastewater Storage Tank-Assembly.

3. Perform Control Loops: This function is responsible for monitoring the states of the VCD components and performing actuator operations as required. The monitoring of the component involve reading sensor values and comparing them to high and low setpoint values and performing appropriate actions. The control algorithms are defined in the Application Specific portion of the software.

4. Diagnose Faults: Fault diagnosis is accomplished by two major functions, namely, Fault Detection and Fault Isolation. Fault Detection is accomplished by comparison of sensor signal values with predetermined setpoint values for normal, warning and alarm conditions. Fault Isolation identifies the cause of the failure of the system. Data will be collected to allow manual fault isolation. Automatic fault isolation will not be incorporated (OS4.0, OS9.0).

5. Input Sensors: This function brings the analog and digital signals from the subsystem hardware through the generic signal conditioning to the C/M I and converts them into a form readable by the computer (OS3.0).

6. Output Actuators: Based on the states of the various ORUs, output signals are sent to the subsystem mechanical assembly from the C/M I through the signal conditioning (OS7.0).

7. System Service Handling: This function will provide special system services like hardware and software initialization, internal timer updates, power failure handling and arithmetic routines (OS1.0, OS2.0, OS6.0, OS8.0).

8. Data Accessing: This function is responsible for providing read/write access to System Data Tables, Sensor Data Stores and Actuator Data Stores (OS18.0).

Model 540 Application Software. Figure 14 illustrates the Model 540 Application Software. The Application Specific Code consists of:

1. Tables used by the Mode Transition Function in the Operating System (AS4.0).

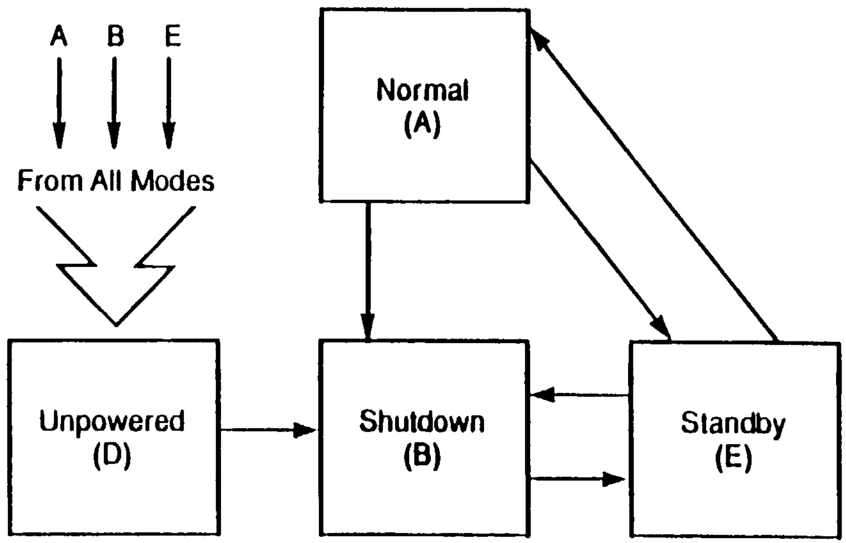
2. Setpoint tables for the different operation modes for the purpose of fault detection and control of the system (AS4.0).

3. Definitions for the different control algorithms used in the system (AS2.0).

4. Definitions that provide control for devices in the system like pumps, valves and motors (AS1.0).

5. Routines for calculating parameters not directly measured by the mechanical subsystem that are required as sensor values for the real time control of the system (AS3.0).

6. Application Initialization: This function is responsible for setting the control loops and device drivers to a predetermined initial stable state so as to provide a valid starting point for the process (AS5.0).



- 4 Modes
- 3 Operating Modes
- 9 Mode Transitions
- 6 Programmable, Allowed Mode Transitions

FIGURE 11 MODES AND TRANSITIONS

TABLE 8 MODE DEFINITIONS

Mode (Code)	Definitions
Normal (A)	VCD Wastewater Processor: The VCD is processing wastewater from the Wastewater Storage Assembly (TA1). If product water does not meet the quality specifications as determined by the Conductivity Sensor (K1), it is diverted from the product water interface back into the waste recycle loop for reprocessing by Valve V2. If a high liquid level is detected in the evaporator, the VCD will automatically shut off feed sending the system into partial drydown until the level is brought back to normal and the feed can be renewed automatically. Experiment Support Hardware: Product water from the VCD Wastewater Processor is being collected in the Product Water Storage Tank Assembly. The Cooling Fan Assembly is evaporating possible liquid condensate droplets that may have been collected in the evaporator wick and providing cooling air flow. The SPACEHAB Coolant Package is providing liquid coolant to the VCD. Mode Initiation: • Automatic mode transition from Standby when the Wastewater Quantity (Q1) in Tank TA1 is above the high control setpoint; or • Crew initiated mode transition via experiment controller from Standby <u>unless</u> there is less than a minimum quanitity (Q1) of waste fluid in the Wastewater Storage Assembly.

continued-

Table 8 - continued

Mode (Code)	Definitions
Standby (E)	VCD Wastewater Processor: Wastewater is not being processed but the VCD is ready to receive wastewater from the experiment support hardware. Experiment Support Hardware: Upon inititiation by the experiment controller, the collected product water and waste concentrate are pumped to the Wastewater Storage Assembly (TA1). Depending on the test protocol, appropriate amounts of air are added to generate the desired wastewater formulation. The Cooling Fan Assembly is evaporating possible liquid condensate droplets that may have been collected in the evaporator wick and providing cooling air flow. The SPACEHAB Coolant Package is providing liquid coolant to the VCD. Mode Initiation: • Automatic mode transition from Normal mode due to Q1 below low control setpoint; • Crew initiated mode transition from Normal via experiment controller; or • Crew initiated mode transition from Shutdown via experiment controller.

continued-

Table 8 - continued

Mode (Code)	Definitions
Shutdown (B)	VCD Wastewater Processor: The VCD is not processing wastewater. All rotating components are shut off. The Model 540 C/M I is active. Experiment Support Hardware: The experiment support hardware is not collecting product water. It is not generating wastewater. Only the Cooling Fan Assembly is operating. All other rotating components are shut off. The Model 684 C/M I is active. Liquid coolant is not required. Mode Initiation: • Crew initiated mode transition from Normal via experiment controller; • Crew initiated mode transition from Standby via experiment controller; • Power-On-Reset (POR) from Unpowered mode; • Automatically initiated mode transition from Normal or Standby for any warning condition generated by an out-of-range sensor value; • Automatically initiated mode transition from Normal if not able to correct a high liquid level condition; or • Automatically initiated mode transition from Normal if not able to return the product water to the required quality specification.

continued-

Table 8 - continued

Mode (Code)	Definitions
Unpowered (D)	VCD Wastewater Processor: No electrical power is applied to the VCD. Actuator positions cannot be verified. No wastewater is processed. Experiment Support Hardware: No electrical power is applied to the experiment support hardware. Actuator positions cannot be verified. No wastewater is generated. No liquid coolant is required from the SPACEHAB Coolant Package. Mode Initiation: • Manually removing input power; or • Electrical power failure.

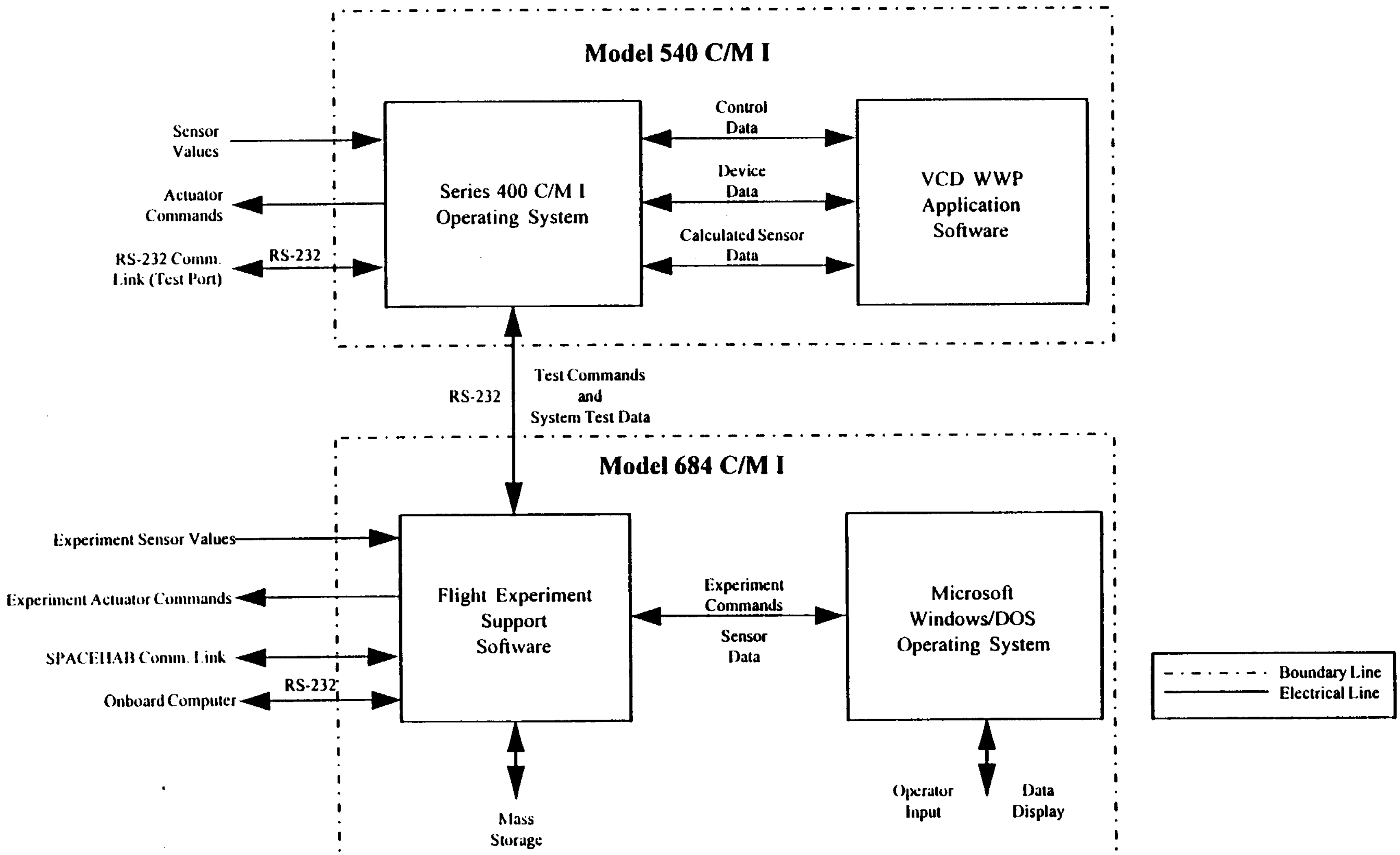
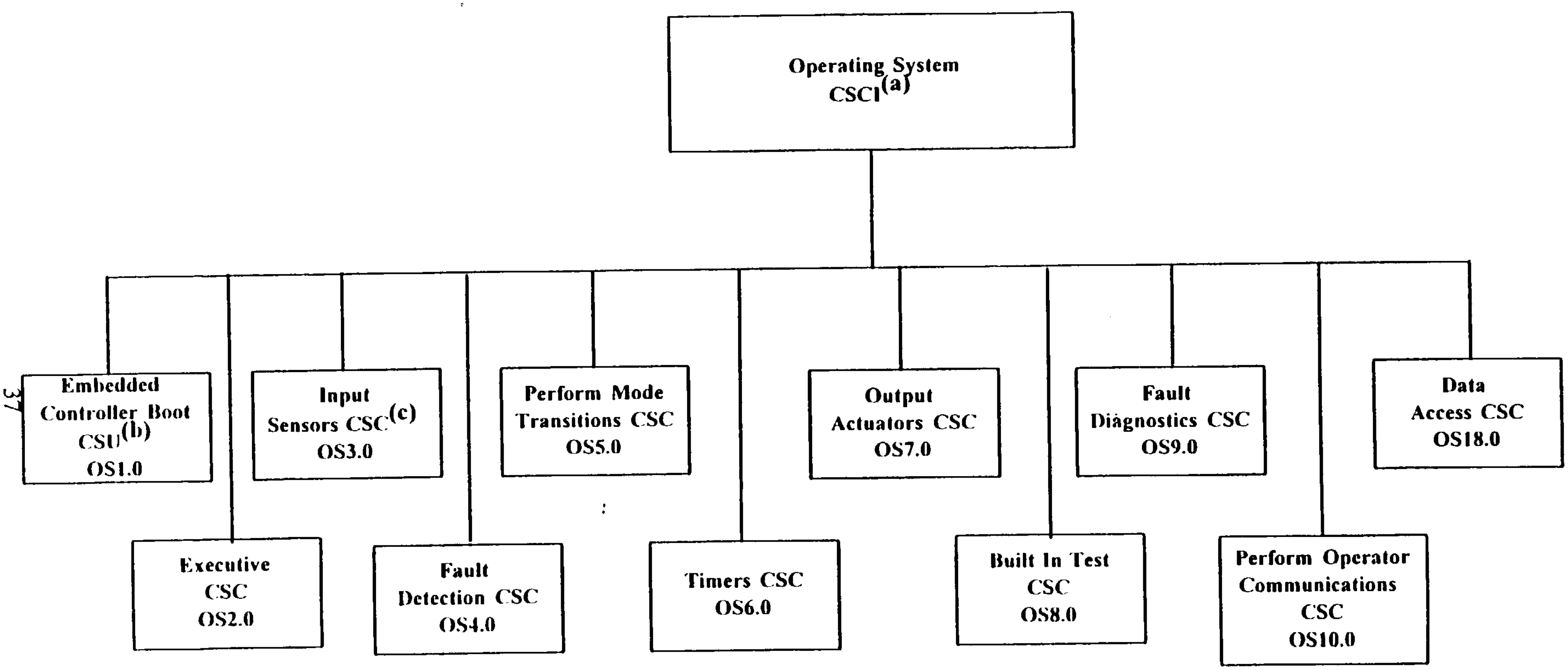
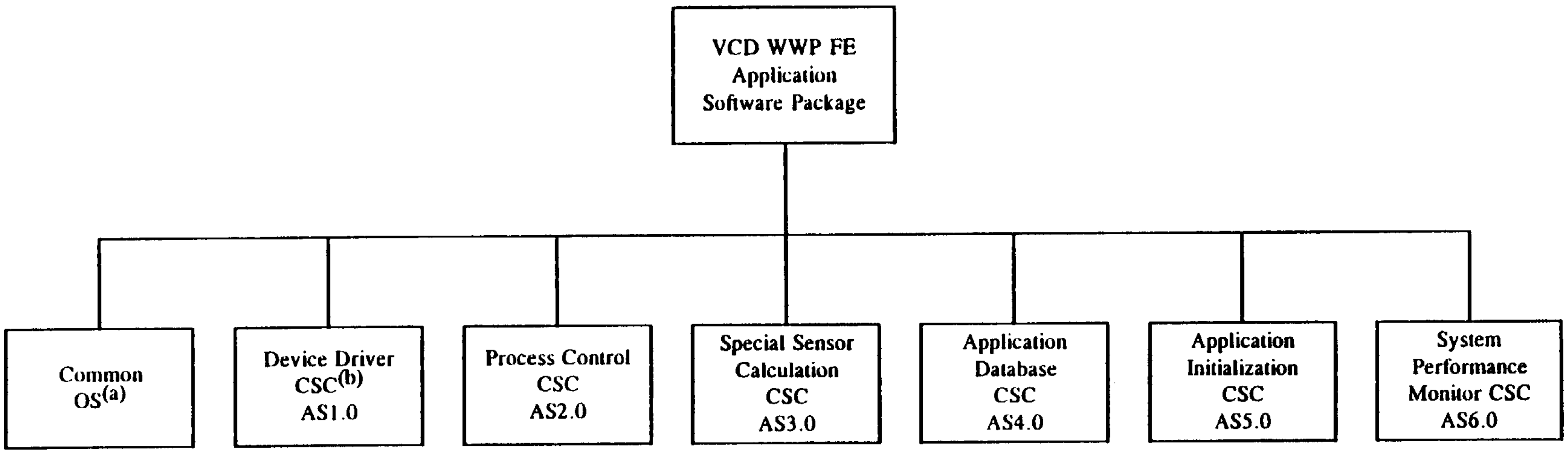


FIGURE 12 SOFTWARE BLOCK DIAGRAM



(a) Computer Software Configuration Item. Proven Life Systems Series 400 Operating System Software utilized.
(b) Computer Software Unit.
(c) Computer Software Component.

FIGURE 13 SERIES 400 OPERATING SYSTEM SOFTWARE



(a) Operating System.
(b) Computer Software Component.

FIGURE 14 MODEL 540 C/M I APPLICATION SOFTWARE

Model 684 C/M I Software

The VCD Flight Experiment support software for the Model 684 C/M I consists of an Operating System, general routines to instruct the Operating System to perform certain low level functions and Application Specific Code. The general routines and most of the Application Specific Code are developed in C. The Crew Interface is developed in Visual Basic running under Microsoft Windows.

Model 684 Operating System Software. The Operating System used is Microsoft Disk Operating System (MS-DOS). Figure 15 illustrates the Model 684 Operation System software. Its functions include:

1. Perform Intra-Experiment and External Communication: The Model 684 C/M I communicates with the Model 540 C/M I for the purpose of receiving data and issuing commands. There is also a provision for external communication to enable the operator to issue commands to the system and obtain a visual feedback of the state of the system. The Model 684 C/M I is also responsible for downlinking of data (OS7.0).

2. Read Sensors: This function reads the analog and digital signals from the FSA subsystem hardware through the generic sensor signal conditioning to be interpreted by higher level routines (OS3.0).

3. Output Actuators: Output signals based on decisions made at a higher level are sent to the FSA subsystem hardware through the signal conditioning (OS6.0).

4. System Service Handling: This involves handling of services like hardware and software initialization, internal timer updates and power failure handling (OS2.0, OS5.0).

5. Data Logging/Storage: This refers to the allocation of the appropriate space and functions to store data retrieved from the Flight Experiment and the FSA hardware (OS4.0).

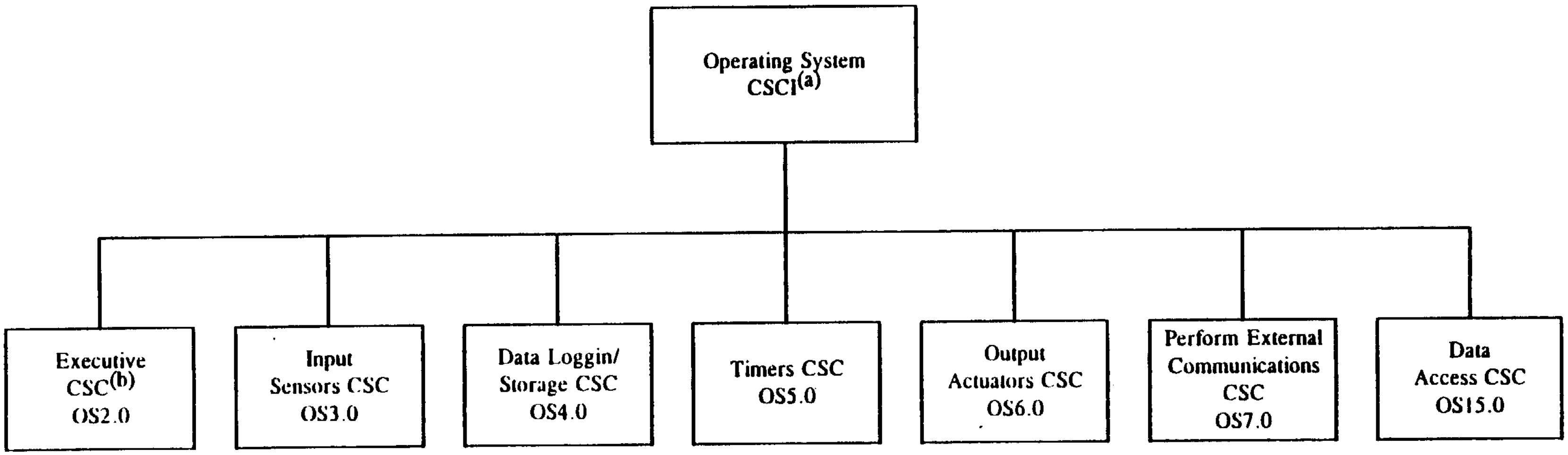
6. Data Access: This function provides read/write access to the Flight Support Sensor and Actuator Tables (OS15.0).

7. System Performance Monitor: This software component (not active in the Flight Experiment) is responsible for carrying out an on-line evaluation of the performance of the VCD (AS6.0).

General routines will be developed to instruct the Operating System to carry out certain low level operations. The functions provided by these general routines are:

1. Perform Control Loops: This function monitors the states of the various subsystems in the FSA and instructs the Operating System to perform new actuator outputs that may be required.

2. Input Sensors: This function converts the signals read in by the Operating System and converts them to a form readable by the computer.



(a) Computer Software Configuration Item.
(b) Computer Software Component.

FIGURE 15 MODEL 684 C/M I OPERATING SYSTEM SOFTWARE

Model 684 Application Software. Figure 16 illustrates the Model 684 Application Software. The Application Specific Code consists of:

1. Setpoint tables for the sensors in the FSA for real time control of the FSA (AS4.0).

2. Definitions for the sequential execution of predetermined steps of the experiment and the control algorithms (if necessary) used in the FSA (AS2.0).

3. Definitions to provide control for devices in the FSA like pumps, valves and motors (AS1.0).

4. Routines for calculating parameters not directly measured by the FSA that are required as sensor values for control of the FSA subsystems (AS3.0).

5. Operator Interface: This enables the operator to issue commands to the Flight Experiment and Experiment Support hardware. The interface is developed in Visual Basic. Through this interface the operator can also obtain updated information about he sensor values, actuator values and the state of the system and its various components. Input to this interface is provided by means of touch through a touchscreen LCD display. To prevent any unwanted action due to accidental touching of the display, two-finger actuation is required to activate the ability to issue commands. Extensive menus are provided to enable the operator to obtain information about the system. It is also possible to start the test from an arbitrary but valid point in the sequence (AS7.0).

6. Application Initialization: This function is responsible for placing the FSA in an initial state (AS5.0).

7. System Performance Monitor: This software component (not active in the Flight Experiment) provides an online evaluation of the FSA performance (AS6.0).

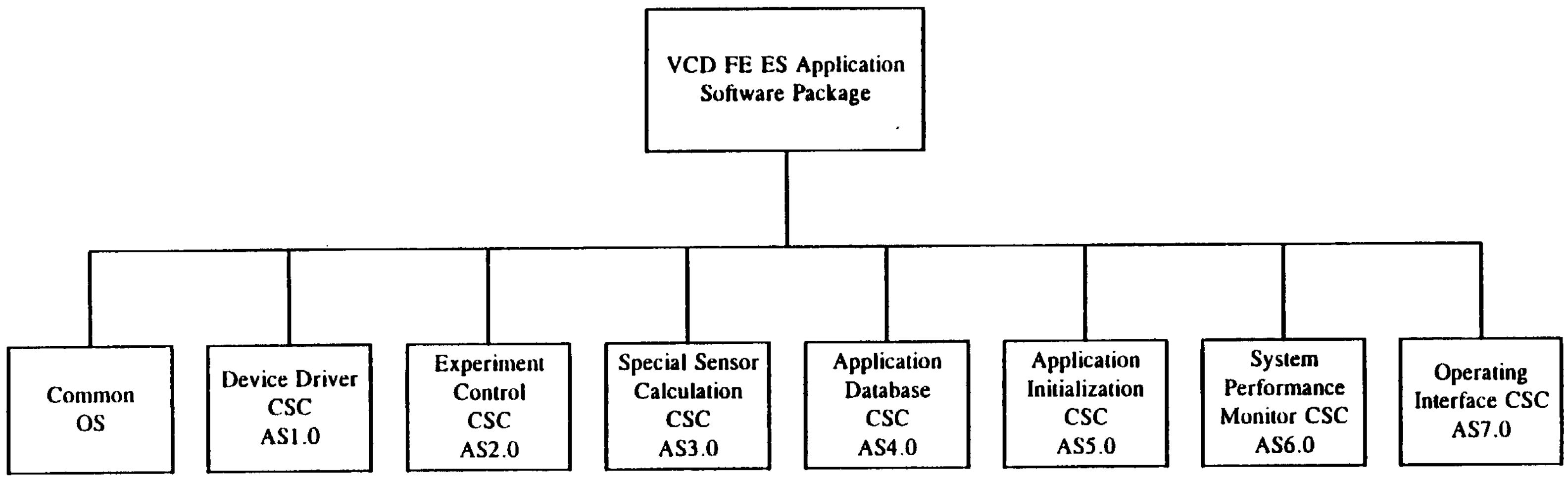
DESIGN DOCUMENTATION

The product of the Preliminary Design Phase of the program is an experiment design that will be the basis for the Phase C/D portion of the program. The design product is documented in three ways. They are design drawings, design documents and a high fidelity mockup. Each form of documentation is described below.

Design Drawings

For the PDR, Form, Fit and Function drawings were made for each Orbital Replacement Unit (ORU). From these drawings a rack packaging drawing was prepared. Design drawings produced are defined below:

Drawing No.	Title
VCD Flight Experiment Definition Drawings	
D-16001	VCD WWP Flight Experiment Mechanical Schematic with Sensors



(a) Operating System.
(b) Computer Software Component.

FIGURE 16 MODEL 684 C/M I APPLICATION SOFTWARE

Drawing No.	Title
D-16008	VCD WWP Flight Experiment Mechanical Subassemblies

VCD ORU Definition Drawings

D-16014	Distillation Assembly
D-16020	Wastewater Storage Assembly
D-16021	Recycle Filter Tank Assembly
D-16026	Fluids Control and Pump Assembly
D-16027	Pressure Control and Pump Assembly

FSA ORU Definition Drawings

D-16031	Backup Recycle Filter Tank Assembly
D-16032	Product Water Storage Assembly
D-16033	Liquid/Gas Mixing Assembly
D-16034	Concentrate Supply Tank Assembly
D-16035	Model 684 C/M I
D-16038	VCD WWP Subrack Assembly
D-16041	Evaporator Assembly
D-16042	Cooling Fan Assembly

A complete set of the above drawings can be found in the PDR Data Package (TR-1738-25-2).

Design Documentation

The final approval of the VCD WWP for flight will require documentation of the analyses performed to ensure its readiness. In all cases these documents will be finalized during the Phase C/D portion of the program. However, many of these have been initiated during this phase of the program and are completed to the extent possible. Design documents prepared during the Preliminary Design are defined below.

Technical Requirements Document

The Technical Requirements Document (TRD), TR-1738-5, defines the experiment on the basis of its need, objectives and means by which the experiment objectives are to be achieved.

Safety Hazard Analysis

The Safety Hazard Analysis (SHA), TR-1738-8, presents an analysis of the hazards identified that are associated with operation of the VCD WWP Flight Experiment. Data contained in this document will support the future program safety reviews.

Failure Modes and Effects Analysis

The Failure Modes and Effects Analysis (FMEA), TR-1738-9, defines how the experiment will react to failures and defines why it meets the requirements of the contract.

Critical Items List

The Critical Items List (CIL), TR-1738-10, takes the results of the FMEA and defines those items which require special consideration due to their criticality for safe and reliable operation.

Nonmetallic Materials List

The Nonmetallic Materials List, TR-1738-11, defines the document which will be used to define the nonmetallic materials to be utilized in the experiment. It will be completed during Phase C/D.

End Item Specification

The End Item Specification, SS-0042, is a B1 Prime Item Development Specification prepared per the requirements of MIL-STD-490A. The specification defines the basis of how the Phase C/D program detailed design and end item verification will be achieved.

Interface Control Document

The Interface Control Document (ICD), TR-1738-21, defines the interfaces (fluid, structural, crew, electrical, data) of the experiment as they are currently known. This document will provide the means of transmitting interface data to McDonnell Douglas for preparation of their ICD for flight.

Trade Studies and Rationale for Flight Experiment Configuration

Trade studies performed to define the experiment are documented in the Trade Studies and Rational for Flight Experiment Configuration Report, TR-1738-22.

Retrofit Kit Definition Document

The Retrofit Kit Definition Document, TR-1738-23, defines the means by which the experiment could be incorporated in the SPACEHAB, Spacelab or MIR flight vehicles.

Safety, Reliability and Quality Assurance Plan

The Safety, Reliability and Quality Assurance Plan (SR&QA Plan), TR-1738-24, defines Life Systems plan for ensuring that the end item experiment meets contract requirements.

Preliminary Thermal Analysis Report

The Preliminary Thermal Analysis Report, TR-1738-37, presents an analysis of each component for its contribution to waste heat and the possibility of overheating to identify potential areas of concern that would require more rigorous analysis.

Preliminary Loads Analysis Report

The Preliminary Loads Analysis Report, TR-1728-35, presents an analysis of the force loads that the experiment will be subjected to in the SPACEHAB vehicle.

Preliminary Stress Analysis Report

The Preliminary Stress Analysis Report, TR-1738-38, documents the analyses to be performed for each component during the Phase C/D program.

Synthetic Wastewater Formulation

The formulation and characterization of the synthetic wastewater is documented in TR-1738-31.

A complete set of the above program documents can be found in the PDR Data Package (TR-1738-25-2).

High Fidelity Mockup

A key product of the Preliminary Design of the VCD WWP Flight Experiment is the high fidelity mockup pictured in Figure 17. This mockup was fabricated based on the drawings listed in the Design Drawings section of this report. It illustrates the packaging plan and defines the envelope required.

PRELIMINARY DESIGN REVIEW

The PDR took place in two phases. The first phase was a review by representatives of NASA and Boeing of design data submitted by Life Systems prior to the PDR meeting. The second phase was review of the design as presented by Life Systems at the PDR. As a result of this process, Review Item Discrepancies (RIDs) were prepared. The two phases of the review and the resulting RIDs are discussed separately below.

Data Package Review

The preliminary design prepared by Life Systems was documented by the materials described in the Design Documentation section of this report. A complete compilation of this information was collected in the VCD WWP Flight Experiment Preliminary Design Review Data Package, TR-1738-25-2. Materials contained in this data package that were defined to be "RIDable" by Marshall are defined by Table 9.

Preliminary Design Review Meeting

The PDR meeting was held at the Marshall Space Flight Center on March 14 and 15, 1995. The basis of this review was the Preliminary Design Review Presentation Package (TR-1738-25-3) which provided a means, by use of viewgraphs, to present and explain the VCD WWP Flight Experiment design. The events of the meeting are summarized by the Meeting Minutes, TR-1738-25-4, dated March 29, 1995.

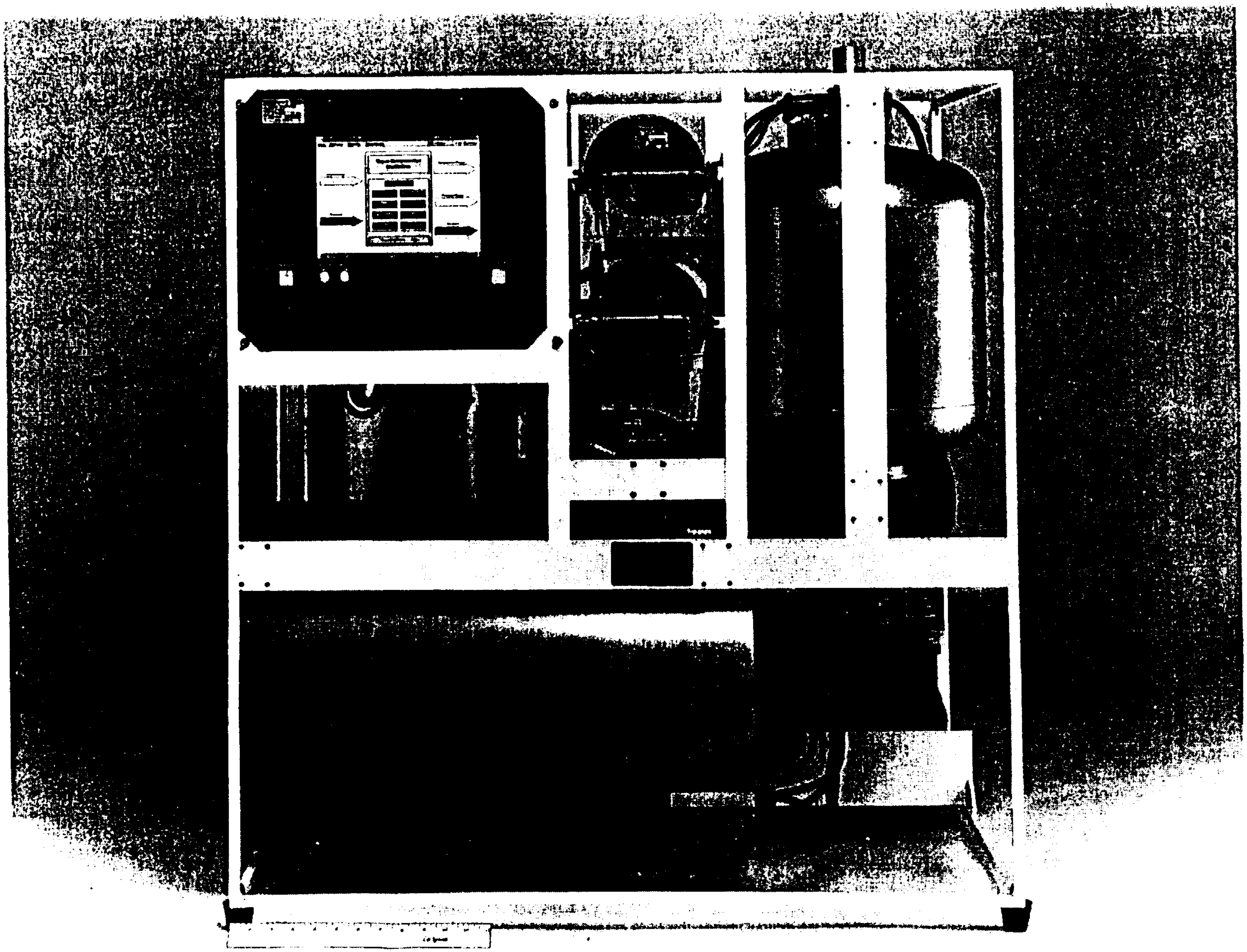


FIGURE 17 VCD FLIGHT EXPERIMENT MOCKUP

TABLE 9 VCD WWP FLIGHT EXPERIMENT PRELIMINARY DESIGN REVIEW "RIDABLE" DOCUMENTS

- Preliminary Technical Document (TR-1738-5)
- Preliminary Interface Control Document (TR-1738-21)
- Layout Drawings[(a)]
- Preliminary Safety Hazards Analysis (TR-1738-8)
- Mechanical Schematic with Sensors[(b)]
- Assembly Drawings[(a)]
- Preliminary End-Item Specification (SS-0042)
- Retrofit Package Definition Document (TR-1738-27)
- Safety, Reliability and Quality Assurance Plan (TR-1738-24)
- Preliminary Failure Modes and Effects Analysis (TR-1738-9)
- Preliminary Critical Items List (TR-1738-10)
- Preliminary Metallic/Nonmetallic Materials List (TR-1738-11)
- Preliminary Thermal Analysis Report (TR-1738-37)
- Preliminary Loads Analysis Report (TR-1738-35)
- Preliminary Stress Analysis Report (TR-1738-38)

(a) Presented in Appendix 1 of the PDR Data Package (TR-1738-25-2).
(b) Presented in Section 2.0 of the PDR Data Package (TR-1738-25-2).

Review Item Discrepancies

As a result of the review process there were seven (7) RIDs defined. Table 10 provides a list of these RIDs. Following a review of the responses prepared by Life Systems, a RID Preboard Meeting was held at the Marshall Space Flight Center on April 12, 1995. As a result of this meeting it was determined that a Board Meeting would not be necessary and that Life Systems stated future course of action would be accepted for eventual RID closure.

CONCLUSIONS

The stated objectives of this Preliminary Design program effort were to:

1. Define an experiment to accomplish the overall program goals.
2. Develop and document a design through a PDR that can be efficiently implemented in hardware.

Information included in under the heading of Mission Test Plan presents the experiment plan defined to accomplish Objective No. 1. As described this experiment plan will provide extensive data, that when compared to earth-based test data, will verify the readiness of VCD technology for application to ISSA or other long-duration missions.

Objective No. 2 was accomplished by the PDR described herein. At this review the design documentation was presented that, with resolution of open RIDs, was evaluated to be capable of performing the experiment test plan.

The successful implementation of the PDR shows that an VCD Flight Experiment can be implemented within the resource constraints of the available flight vehicles that will accomplish the goals of the program.

RECOMMENDATION

Information presented in this final report documents the design of an experiment and test hardware that when carried through to flight testing will accomplish the overall program goal of risk mitigation for the ISSA. Based on the successful conclusion of the Preliminary Design and successful demonstration of operation of VCD technology in cyclic mode of operation, it is recommended that the experiment proceed as planned into the second phase of the program which will culminate with flight testing of VCD technology in a microgravity environment.

TABLE 10 VCD WWP ELECTROLYZER FLIGHT EXPERIMENT
REVIEW ITEM DISCREPANCIES

RID No.	Description	Status
VCD-01	Insufficient Loads Analysis for PDR	(a)
VCD-02	Insufficient Stress Analysis for PDR	(a)
VCD-03	Insufficient Identification of Fracture Critical Parts for PDR	(a)
VCD-04	Specification Collector RID	(a)
VCD-05	Inadequate Ersatz (synthetic urine) Formulation	(a)
VCD-06	Insufficient Thermal Analysis for PDR	(a)
VCD-07	Inconsistent Identification of Critical Items	(a)

(a) Contractor response accepted. Final implementation of all design activities in Phase C/D of program.

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15. Supplementary Notes

16. Abstract

This document provides a description of the results of a program to prepare a Preliminary Design of a Flight Experiment to demonstrate the function of a Vapor Compession Distillation (VCD) Wastewater Processor (WWP) in microgravity. This report describes the test sequence to be performed and the hardware, Control/Monitor Instrumentation and software designs prepared to perform the defined tests. The purpose of the Flight Experiment is to significantly reduce the technical and programmatic risks associated with implementing a VCD based WWP on board the International Space Station Alpha.

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