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## ORBITER INTEGRATED ACTIVE THERMAL CONTROL SUBSYSTEM TEST

James R. Jaax\*

### ABSTRACT

Integrated subsystem level testing of the systems within the Orbiter Active Thermal Control Subsystem (ATCS) was conducted at the Johnson Space Center during January-February 1979. Testing was performed in a thermal vacuum chamber capable of simulating ground, orbital, and entry temperature and pressure profiles. The test article was in a closed loop configuration that included flight-type and functionally simulated portions of all ATCS components for collecting, transporting and rejecting orbiter waste heat. Specially designed independently operating equipment simulated the transient thermal input from the cabin, payload, fuel cells, freon cold plates, hydraulic system and space environment. Test team members using data, controls and procedures available to a flight crew controlled the operation of the ATCS. ATCS performance met or exceeded all thermal and operational requirements for planned and contingency mission support.

### INTRODUCTION

Most components within the ATCS had successfully completed development testing. However, because of the complex heat load sharing, manual and automatic control and sequencing of ATCS heat sinks, multiple transient heat loads imposed by the heat sources, and high degree of crew involvement in ATCS operations, an integrated test for design verification data was required to complete operational certification of the ATCS. Chamber A of the Space Environment Simulation Laboratory at the Johnson Space Center offered the space environment simulation and physical volume necessary for layout and thermal isolation of the systems in the ATCS. Special support equipment capable of simulating the thermal response of four major Orbiter subsystems and the transient orbital environments were needed. Within the ATCS, hardware to fully assemble and test one of the two coolant loops was obtained; however, for closure of both coolant loops simulators for Orbiter coldplate and radiator functions were needed. Instrumentation, displays and controls duplicating flight configuration and data processing in addition to engineering evaluation data were drivers on the development of the test data management system. Test conduct followed established scenarios for nominal and contingency activities allowing for real time development of flight procedures and control functions.

### FLIGHT SYSTEM DESCRIPTION

The ATCS collects, transports and rejects waste heat from Orbiter subsystems, equipment, and payloads from prelaunch through post-landing for

\*NASA, Johnson Space Center, Houston, Texas 77058

each mission. Heat transport fluid (Freon-21) is pumped through twenty-seven centralized heat collection devices (liquid to liquid heat exchangers and pin-fin coldplates) and twelve expendable and radiative heat sinks. Two separate but parallel routed coolant loops are required to perform the ATCS thermal management function. The ATCS components are located in the midbody and aft sections of the Orbiter as shown in Figure 1. A simplified fluid schematic containing external views of the major ATCS components is shown in Figure 2. Displays on Cathode Ray Tubes (CRT), meters and controls for the ATCS are located on the Orbiter flight deck.

Systems within the ATCS providing heat rejection include the Ground Support Equipment (GSE) heat exchanger, flash evaporator system, radiator system and ammonia boiler system. During ground operations (prelaunch and within 15 minutes after landing) the Orbiter heat load is rejected through the GSE heat exchanger to a ground coolant unit. The Flash Evaporator System (FES) is the Orbiter's sole heat sink during ascent until the payload bay doors are opened and during entry down to 30,480m (100,000 feet) altitude. During orbital operations the FES supplements the radiator system to provide a constant coolant temperature to the Orbiter. The FES removes heat by evaporating in a heat exchanger at low ambient pressure water generated as a byproduct by the fuel cells in the Orbiter's electrical power system. The radiator system includes 8 radiator panels attached to the inside of the payload bay doors. Four of the panels can be deployed away from the doors to allow radiation from both sides of a panel. The ammonia boiler system (ABS) is the Orbiter's heat sink during entry, below 36,576m (120,000 feet), and post-landing until ground cooling is provided through the GSE heat exchanger. The ABS removes heat by boiling liquid anhydrous ammonia and venting the vapor overboard. A detailed description of the ATCS is provided in reference 1.

#### TEST FACILITY

The test was conducted in Chamber A of the Space Environment Simulation Laboratory. The working volume of the Chamber is 16.8m (55 feet) in diameter and 27.4m (90 feet) in height. A schematic representation of the test article layout is shown in Figure 3. Test article elements were mounted at floor level elevation inside the chamber as shown in Figure 4. Special test support elements supporting the test article were located on the first level around the chamber. Roughing cryogenic and diffusion pumping was used to obtain  $1.3 \times 10^{-4}$  N/M<sup>2</sup> ( $10^{-5}$  torr) chamber pressure. One zone of helium with occasional use of an additional zone when test article fluid leaks were encountered was able to maintain chamber pressure. The chamber's entire liquid nitrogen shroud was cooled to liquid nitrogen temperatures to obtain the required environment for radiator performance evaluation and handle the water vapor load during FES operation. Six controlled partial chamber repressurizations down to  $266.6$  N/M<sup>2</sup> (20 torr) using dry nitrogen were conducted which simulated the ambient pressure environment during Orbiter entry. A slower (12 hour) method, sublimation repressurization, using dry nitrogen and heaters to minimize water condensation on the radiator panels and insulated surfaces, was used to bring the chamber to sea level conditions. During repressurization television and high voltage

equipment (infrared simulators) operation was prohibited to prevent corona effected damage. Facility chilled water, hot water, steam, gaseous nitrogen, liquid nitrogen and compressed air were supplied to elements of the test support equipment. Special user AC and DC power requirements were supplied by a 400-Hertz motor-generator set, regulated power supplies and special support hardware.

#### TEST ARTICLE

Development, qualification, flight and inhouse ATCS hardware were assembled in a test configuration which represented one (loop 2) of the Orbiter's two coolant loops. The other loop was simulated to provide proper conditions at the points in the ATCS where the two loops have common thermal interfaces. A summary list of the test article components and their source is shown in Table 1.

#### Radiator System

Four radiator panels were installed in the configuration shown in figures 3 and 4. To minimize gravity effects the aft panels were aligned with the plane formed by the panel edges tilted at an angle of 0.15 radians (8.75 degrees) with respect to the horizontal with the outboard edge above the inboard edge. The forward panels were placed behind the aft panels with the plane formed by the panel edges in a horizontal position. A liquid nitrogen shroud was installed between the forward and aft panels to prevent radiant interchange between the upward tilted aft panels and the forward panels. The radiator panels were suspended by cables attached to the environment simulator structure. Payload bay door simulators were installed below the two forward panels forming an angle of 0.62 radians (35.5 degrees) between the planes of the upper surfaces of the panels and doors representing the deployed position of the panels during on-orbit operations. Heaters on the door simulators, simulating the infrared flux originating from the doors, were controlled from a power console located outside the test chamber. The back side of the aft panels and the door simulators were insulated with multilayer insulation to minimize heat leak from these surfaces. Guard heaters were installed beneath the back side insulation of the aft radiator (panel 4) to prevent freezing during test points that required isolation of panel 4 from the coolant loop.

Earth and solar environment simulation was provided by infrared lamps capable of simulating both skewed and orbital cycle flux environments. Flux from the lamps was input through the upper surface of the radiators by an array of nine rows of lamps each under separate computer control. Radiometers to measure heat flux were mounted flush with the upper surface of the radiators in the plane of the radiator. Two radiometers were placed in the opening of the cavity, formed by the forward radiators and the door simulators, directed into the chamber to determine chamber background flux. Structure holding the environment simulator was designed to minimize blockage thereby maximizing radiator panels view to chamber. Shutoff valves and a

modified flight type adapter tube to bypass the aft radiator panel were installed to allow 3-panel radiator system testing. Selection of either the 3- or 4-panel configuration was made from a control panel in the facility control room.

The radiator panels were plumbed into coolant loop 2. An Orbiter design interchanger heat exchanger was plumbed into loop 1 to simulate its radiator heat rejection capacity by either providing a constant "set point" outlet temperature of 3.3°C (38°F) or tracking the loop 2 radiator outlet temperature. Special valving allowed simulation of the 3 and 4 radiator flow characteristics.

Two radiator flow control assemblies (FCA) were installed to control flow to the radiator panels and simulator. Remote controlled motors allowed selection of 3 or 4 panel configuration for the two FCA mode control valves while at vacuum conditions. Activation and mode selection for FCA operation during testing was provided by a control panel located in the facility control room. A detailed description of the configuration and performance of the radiator system during this test is provided in references 2 and 3.

#### Flash Evaporator System

A special support stand as shown in Figure 4 housed the FES test article. The evaporator assembly was mounted in the horizontal position to minimize gravity effects on both evaporators. A thermal blanket of multilayer insulation protected the assembly from the chamber environment. A feedwater supply system duplicating the dual 30.48m (100 feet) lines of the flight configuration was provided. Thermal conditioning of the water in the feedwater supply lines, simulating orbital conditions, was provided by a counterflow concentric tube heat exchanger. A combination of computer and set point controlled heater circuits protected the feedwater system during nonflowing periods. The three exhaust duct nozzles were oriented to direct water vapor at the chamber cold walls. Four 1.8m by 3.7m (6 feet by 12 feet) liquid nitrogen panels were installed between the duct nozzles and the radiator panels to ensure that the water vapor plumes impinged directly upon the cold walls. Both the high load and topping evaporator ducts and nozzles were equipped with heaters subdivided into discrete zones. Each heater circuit was independently powered by a computer controlled power supply having the preset heat density and temperature control bands specified for the early Shuttle flights. Activation and controls for FES operation during testing was provided by an evaporator power and control console located in the facility control room. A detailed description of the configuration and performance of the FES during this test is provided in references 3 and 4.

#### Ammonia Boiler System

The impact of the extensive facility modifications identified for handling ammonia vapor prior to release into the local atmosphere exceeded the benefits foreseen by including a functional ammonia boiler system in the test. Thus, only the boiler heat exchanger was included in the test planning. During installation activities this passive device was found to have

unrepairable internal leaks and was deleted from the test configuration. The heat removal function of the ammonia boiler was simulated by the GSE heat exchanger based on analytical correlation with prior test experience.

#### Freon Coolant Loop

The five ATCS heat exchangers (interchanger, payload, fuel cell, hydraulics and GSE) were mounted on special support stands of aluminum unistrut and teflon blocks to provide accessibility, common elevation (reduce gravity effects) and thermal isolation from the structure of the test chamber. Special actuation motors and television cameras were installed to allow remote changing of the two flow proportioning module configuration during testing. Individual controls for both flow proportioning modules were provided on a control panel located in the facility control room.

Orbiter coldplates were unavailable, thus four simulators representing the cumulative coldplate fluid volume and thermal input for each coolant loop in the aft and midbody sections of the Orbiter was provided. Each simulator contained a low wattage heater element submerged in a cylinder with baffles to obtain turbulent fluid flow. The simulators used high voltage (220 volt) power, thus were located outside the test chamber, satisfying safety concerns about possible corona discharge from high voltage components in a vacuum. The simulators were located as a lumped mass at the position of the last coldplate in the flight configuration of each coolant loop. A thermal cutout attached to each heater element monitored fluid/element temperature to prevent flashing and fluid decomposition. Variable power setting controls were provided on a control panel located outside the test chamber.

Both freon pump packages were mounted on special support, thermal isolation stands. A control panel was provided in the facility control room for activating and deactivating the pump packages.

All plumbing between ATCS components used flight design stainless steel (CRES 21-6-9) thin wall tubing, 0.0004m (0.016 inch) thickness, covered with a minimum of seven layers of multilayer insulation. Line lengths between components were identical to the Orbiter except for the radiator simulator portion of loop 1. Approximately 290m (950 feet) of 0.019m (0.75 inch) diameter and 130m (425 feet) of 0.0095m (0.375 inch) diameter tubing was installed. Special structural supports were used for routing line lengths longer than the available distance between components. Flared 0.65 radian (37.5 degree) "AN" fittings specially modified (bored to tubing internal diameter) to reduce pressure drop were used to connect the tubing. All system components were cleaned or verified to level 300. All lines were leak tested at  $1.38 \times 10^6$  n/m<sup>2</sup> gage pressure (200 psig) with helium gas and proof pressure tested at  $1.72 \times 10^6$  n/m<sup>2</sup> gage pressure (250 psig).

The number and types of line bends did not duplicate the Orbiter configuration. Therefore, remote controlled air actuated metering valves were installed near each pump inlet for adjusting total system flow. Manual metering valves were located in both loops upstream of the interchanger,

payload heat exchanger, aft coldplate simulator and midbody coldplate simulator for pretest adjustment of flow distribution to obtain flight flowrates for the baseline flow configuration. Ball type shutoff valves (selected for low flow resistance when fully opened) were installed to permit open loop testing of the portion of the ATCS loops containing the heat rejection devices. A "jumper" line connected the remaining components permitting closed loop circulation by the pump packages for preventing coolant freezing during open loop testing. An additional shutoff valve was installed in loop 1 to isolate the coolant accumulators in the two loops from the small intercoolant loop leakage occurring in the FES during single coolant loop testing. During thermal vacuum testing several Jamesbury ball type shutoff valves developed internal leaks. Inspection of the valves following the test revealed the leaks were at the teflon seals which were deformed when coolant trapped in the valve body froze. To prevent this from reoccurring in future tests a hole will be drilled in the valve ball that allows the trapped fluid to "see" the upstream fluid.

Fully charged the test article contained approximately 272kg (600 pounds) of coolant (Freon-21). Special dryer filters were used to reduce the moisture level in the coolant to less than 10 parts per million prior to servicing. Coolant loop service ports were located outside the test chamber near the coldplate simulators. This easy accessibility allowed real time "topping off" of the coolant loops between test points for leakage makeup.

Duplication of flight thermal environment at each component location in the Orbiter was not required. Therefore, all nonradiator test article components were wrapped in multilayer insulation blankets to minimize heat leaks.

Prior to entering the test chamber after each chamber repressurization air samples were taken to measure Freon-21 concentration. The chamber was vented with ambient air until an acceptable concentration level (less than 10 parts per million) was obtained. Daily air samples were also taken outside the chamber at the test support equipment operators' stations.

#### TEST SUPPORT HARDWARE

Eight independently controlled support systems located outside the test chamber provided the thermal, pressure and consumable profiles required to simulate the operation of the Orbiter interfaces with the ATCS. Copper and stainless steel tubing insulated with 6 wraps of mylar inside the chamber and 0.013m (0.5 inch) thick armafex outside the chamber provided the supply and return lines to the test article components. Pressure relief valves were provided in each line.

The Cabin Thermal Simulator delivered deionized water at 431 kg/hr (950 lb/hr) to the interchanger conditioned from 7.2°C (45°F) to simulate cabin heat loads up to 14,078 joule/sec (48,000 Btu/hr). Manual and automatic (drum recorder) temperature control capable of introducing ramps up

to 5.6°C (10°F) per minute was provided. Manual valves outside the chamber permitted selection of either or both of the supply lines to the interchanger.

The Payload Thermal Simulator delivered Freon-21 at rates up to 907 kg/hr (2000 lb/hr) to the payload heat exchanger conditioned from 7.2°C (45°F) to simulate payload heat loads up to 8,505 joule/sec (29,000 Btu/hr). Manual and automatic (drum recorder) temperature control capable of introducing ramps up to 5.6°C (10°F) per minute was provided. Manual valves outside the chamber permitted selection of either or both supply lines to the payload heat exchanger. Facility support requirements included water at 0.15 m<sup>3</sup>/minute (40 gal/minute) and 29°C (85°F), liquid nitrogen and gaseous nitrogen.

Hamilton Standard, the fuel cell heat exchanger vendor, provided, on loan, the test rig used to simulate the fuel cell subsystem thermal interface. The test rig was capable of delivering fuel cell fluid (fluorinated FC40) at flow rates of 181 to 1089 kg/hr (400 to 2411 lbs/hr) in each of 3 loops to the fuel cell heat exchanger at temperatures up to 121°C (250°F) to simulate fuel cell heat loads up to 14,078 joule/sec (48,000 Btu/hr). Manual valves outside the chamber controlling flowrate were capable of introducing ramps equivalent to a 11,732 joule/sec (40,000 Btu/hr) change within 1 minute. Facility support requirements included steam at 23 kg/hr (50 lbs/hr) and 1.2 x 10<sup>-6</sup> n/m<sup>2</sup> gage pressure (175 psig) and gaseous nitrogen.

Hamilton Standard, the hydraulics heat exchanger vendor, provided, on loan, the test rig used to simulate the hydraulic subsystem thermal interface. The test rig was capable of delivering Orbiter hydraulic fluid flowrates from 0 to 907 kg/hr (0 to 2000 lb/hr) in each of 3 loops to the hydraulics heat exchanger over a temperature range of -18 to 21°C (0 to 70°F) to simulate heat removal by the hydraulic loops of up to 5866 joule/sec (20,000 Btu/hr). Manual valves outside the chamber controlled flowrate. Remote controlled bypass valves next to the test article allowed the hydraulic fluid to be conditioned prior to "shocking" the heat exchanger with an "instantaneous" heat load. Facility support requirements included ethylene glycol at 0.03 m<sup>3</sup>/minute (8 gallon/minute) and -26°C (-15°F), Freon-11 2.268 kg/hr (5000 lb/hr) at -1 to 85°C (30 to 185°F) and gaseous nitrogen.

The Radiator Thermal Simulator delivered Freon-21 at rates up to 1361 kg/hr (3000 lb/hr) to the loop 1 radiator system simulator conditioned from -1°C (30°F) to 21°C (70°F) for simulating radiator heat removal rates up to 16,131 joule/sec (55,000 Btu/hr). Manual and automatic (tracking) temperature control capable of introducing ramps up to 3°C (5°F) per minute was provided. A thermal cutout attached to each heater element monitored fluid/element temperature. Manual valves outside the chamber permitted selection of either or both supply lines to the radiator simulator heat exchanger. Facility support requirements were the same as required for the Payload Thermal Simulator.

The Ground Cooling Simulator delivered Freon-21 at 4,535 kg/hr (10,000 lb/hr) to the GSE heat exchanger conditioned from -12°C (10°F) to -1°C (30°F) for simulating ground cooling rates up to 43,995 joule/sec (150,000 Btu/hr). The flight method of manual temperature control by tracking test article response was used. Manual valves outside the chamber permitted selection of

either or both supply lines to the GSE heat exchanger. Remote controlled bypass valves next to the test article allowed the ground coolant to be conditioned prior to "shocking" the heat exchanger with an instantaneous heatsink. Facility support requirements included water at  $0.19 \text{ m}^3/\text{minute}$  (50 gallon/minute) and  $30^\circ\text{C}$  ( $86^\circ\text{F}$ ) and gaseous nitrogen.

The Flash Evaporator Feedwater Supply Cart delivered deionized water from two  $0.04 \text{ m}^3$  (10 gallon) tanks at pressures up to  $10.4 \times 10^5 \text{ n/m}^2$  gage (150 psig) and rates up to 91 kg/hr (200 lb/hr) to the flash evaporator. Manual controls capable of simulating the ascent pressure transients and electronic weight scales for measuring water consumption rate were provided. Facility support requirements included gaseous nitrogen and deionized water.

The feedwater thermal conditioning system conditioned the feedwater to obtain  $7.2^\circ\text{C}$  ( $45^\circ\text{F}$ ) to  $66^\circ\text{C}$  ( $150^\circ\text{F}$ ) delivered water to the FES at demand rates up to 91 kg/hr (200 lb/hr). Computer and set point controllers were used to introduce ramps up to  $5.6^\circ\text{C}$  ( $10^\circ\text{F}$ ) per minute. Multilayer insulation blankets and heaters provided freeze protection for the feedwater lines during no-flow test periods.

During buildup, servicing and operation of the ATCS test additional test support equipment was provided.

- a. In-chamber closed circuit television coverage by 8 cameras of the 3 FES exhaust nozzles, 2 flow proportioning valves position indicators, 2 FCA mode control valve position indicators, forward and aft radiator panels coatings, environment simulator configuration and overall test configuration.
- b. Vacuum pump with cryo trap and micro gage for servicing the freon, water, FC-40 and hydraulics loops.
- c. Helium leak check test equipment.
- d. Pneumatic pressure control system for automatic valve positioning
- e. Gas analyzer, first aid and protective equipment for handling leaks or spills of Freon-21 or FC-40.
- f. Heaters and temperature controllers to maintain FES exhaust duct pressure instrumentation lines above  $10^\circ\text{C}$  ( $50^\circ\text{F}$ )
- g. Digital meters for the critical parameters that monitor health of test article and support equipment during test facility power or data system outages.
- h. Wang 2200 and Hewlett-Packard 9830 mini-computer systems for off-line processing of test data for anomaly investigations and FES water carry-over determination.

#### DATA MANAGEMENT

Space Environment Test Division's Flexible Data System (FLEX) using Hewlett-Packard 2112 and 2117 computers was the primary real time processor of ATCS test data. Raw data from temperature, pressure, flow rate, frequency, current and voltage instrumentation was simultaneously displayed, used in calculations and stored.



## Instrumentation

Within the test article flight and engineering test instrumentation were co-located for evaluation of response, recovery, and amplitude of changed change during transient operations. Additional engineering test instrumentation were selected and installed to obtain detailed system performance data and evaluate the timelines and meaningfulness of flight data. The following is a summary of the instrumentation required for the test article and support equipment:

440 Surface Thermocouples	7 Pressure transducers
114 Immersion Platinum Probes	6 Baratron Pressure Sensors
73 Current transducers	2 Wattmeters
61 Voltage transducers	2 Quantity sensors
30 Radiometers	2 Thermisters
21 Turbine flowmeters	1 Frequency meter

Data system sample rate of the 26 flight measurements was set at the flight level of 2 seconds. The remaining test instrumentation was sampled at 2, 3, 5, 10, 15 or 30 second intervals depending on the dynamic response required from that measurement.

## Real Time Processing

FLEX software was configured to acquire and process 1068 real measurements, calculate 424 pseudo measurements and compute stimuli for 116 control channels for the test article, support equipment and facility systems. Formats for 162 pages were defined and available for display on 12 CRT's in the control rooms. Additional pages could be constructed real time. Data displays could be made into hard copy through "instantaneous" system or single page SCOOPS (upon keyboard command). Two TV cameras monitored a FLEX terminal display for retransmission of 2 FLEX data displays to several TV monitors installed at operator stations near the test support hardware.

Data logs, maintained by test team members, were used to record real time observations and impressions of test article performance. FLEX made a permanent record of the processed measurements on test history magnetic tapes for post-test point data evaluation. During the test, 24-hour processing of selected portions of the test history tapes was provided by the IDSD (Institutional Data Systems Division) on the UNIVAC 1110 and 1108 EXEC 8 computer systems. Post-test time history plots of key parameters for assessing selected component and subsystem performance were prepared by IDSD from the FLEX test history tape for each test point. Up to 6 measurements were put on a plot, 217 plots were formatted and combined into 25 performance evaluation groups. Microfilm and hard copy were provided of each plot.

## TEST CONDUCT

Test chamber occupancy began in June 1978, and ended in March 1979 after 4 weeks of testing which included four 24-hour days of integrated closed loop testing. Test article fluid charging began in late December 1978 followed by 2 weeks of ambient checkout testing and 2 days of vacuum checkout testing. A 3 week "open loop" test of portions of the ATCS was completed prior to configuring the test article for "closed loop" testing. A 3 day vacuum checkout test preceded the "closed loop" test.

The 130 members of the test team manned 40 stations, providing 24-hour coverage with three 8-hour shifts. The test team included two control groups located in separate control rooms. The 15 stations of the test control group included the test director and were responsible for the conduct of the test, technical supervision and control of the systems within the test article and the operation of the test support and facility systems. The 5 stations of the data analysis control group were responsible for the test procedures, test sequencing, data collection and evaluation and success/failure assessment for each test point. Standard hardline communication network protocol was observed by all test team members. A voice record tape of all communication channels was obtained.

One CRT display in the test control room was dedicated for a "flight/test control" test team member to monitor ATCS performance. Flight measurements on a page identical to flight data format and ATCS controls similar to onboard controls were used by the "flight controller" to configure and control the ATCS. Pretest analytical predictions of the transient heat loads seen at the ATCS interfaces with other Orbiter systems were used to simulate the ascent, on-orbit and entry portions of a typical mission. Credible failures of selected components within the ATCS and of subsystems that interface with the ATCS that may occur during ascent, on-orbit and entry mission phases were simulated. During each situation the "flight controller" used current flight procedures, instrumentation and displays to assess the situation, reconfigure and stabilize the ATCS. When necessary during the conduct of the test special procedures were developed to assist in diagnostic activity, problem resolution and timeline constraints.

Timelining of the 30 closed loop test points followed the guidelines that test points requiring similar conditions shall be grouped in priority order and that proceeding from one group to another shall take the path of minimum change in existing conditions. Radiator environment and chamber pressure were the most time consuming parameters to establish. Using "drum plotters" to input transient heat load profiles at the various Orbiter interfaces to ATCS provided uniformity, repeatability and "first time" success for the majority of the test points. The successfulness of the simultaneous independent operation of the 8 heat sources was due largely to the time taken by the test team to understand the interrelationship (e.g., line lag, heat loss, etc.) of each supporting system with the test article during the checkout periods.

## TEST RESULTS

The integrated ATCS achieved all planned test objectives, demonstrated the full compatibility of the integrated ATCS hardware and controls and demonstrated that the ATCS can meet or exceed all performance requirements. During the conduct of the test hardware, instrumentation and procedure changes which would improve subsystem performance, reduce crew involvement, streamline subsystem operation and reduce weight, power and volume requirements were noted and are described in reference 3.

The ATCS successfully supported the prelaunch, ascent, on-orbit, entry and post-landing portions of a typical Shuttle mission. All ATCS fluid systems and mechanical hardware were functional throughout the test. No evidence of subsystem or component performance degradation with 6 cycles between sea level conditions and thermal vacuum exposure was found. The scheme for heat load sharing and manual/automatic control and sequencing of ATCS heat sinks met all requirements. ATCS thermal capacity and response during all mission phases met or exceeded requirements. All normal and failure related transients caused by interfacing Orbiter and payload subsystems were accommodated without requiring configuration changes or special procedures. The test demonstrated that the current flight controls and procedures are satisfactory (with minor changes) for properly sequencing, monitoring and controlling the ATCS during normal mission and simulated failure operations. However, several "system transients" found to occur during normal ATCS operation will require both procedural and crew warning limit value changes. Several special procedures developed during the test to assist diagnostic activity, problem resolution and timeline constraints are recommended for inflight use. The test demonstrated that the current ATCS flight instrumentation, displays and warning limits are adequate for flight crew and real time ground controller monitoring of subsystem status. Routine and contingency activities were found in which crew time would be significantly reduced by making minor changes to existing instrumentation. The flight instrumentation was also verified to be adequate for satisfying flight test objectives and post-flight data evaluation. ATCS thermal characteristics during transient operation and flight test configurations were obtained for flight verification and math model correlation.

## CONCLUSIONS

The integrated ATCS test program reaffirmed the value of system level testing under thermal vacuum conditions. The tangible benefits are the improvements to the hardware and procedures cited in the test report. Equally important are the intangible benefits derived from the confidence and experience gained in the understanding of the signature of the ATCS by the personnel who will train the flight crews and monitor ATCS performance during the Shuttle missions. Daily coordination and cooperation by members of the user and service organizations made possible the successful planning, buildup, integration, checkout, operation and timely completion of the ATCS test without compromising either the technical objectives or financial constraints of the test.

## REFERENCES

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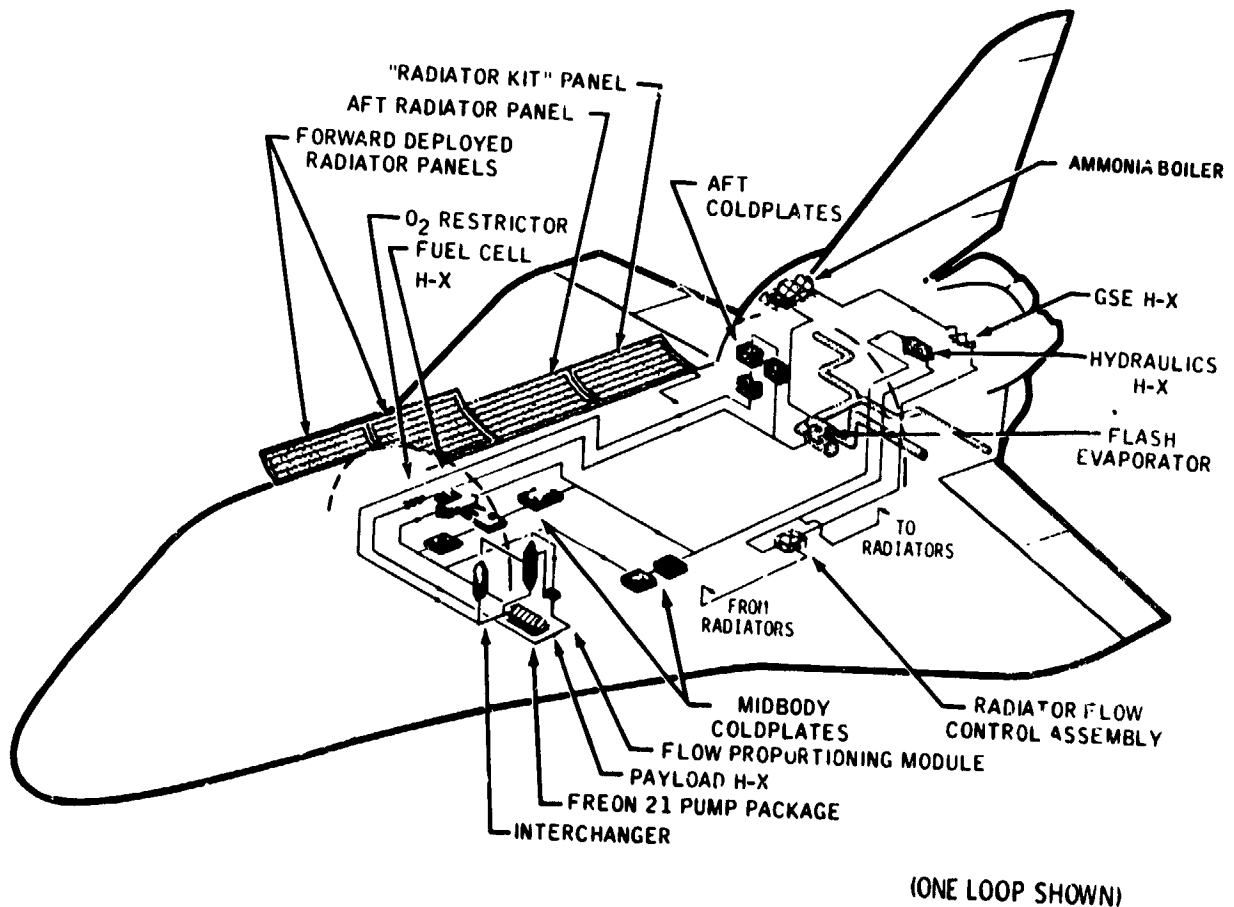


Figure 1 Active Thermal Control Subsystem Location in Space Shuttle

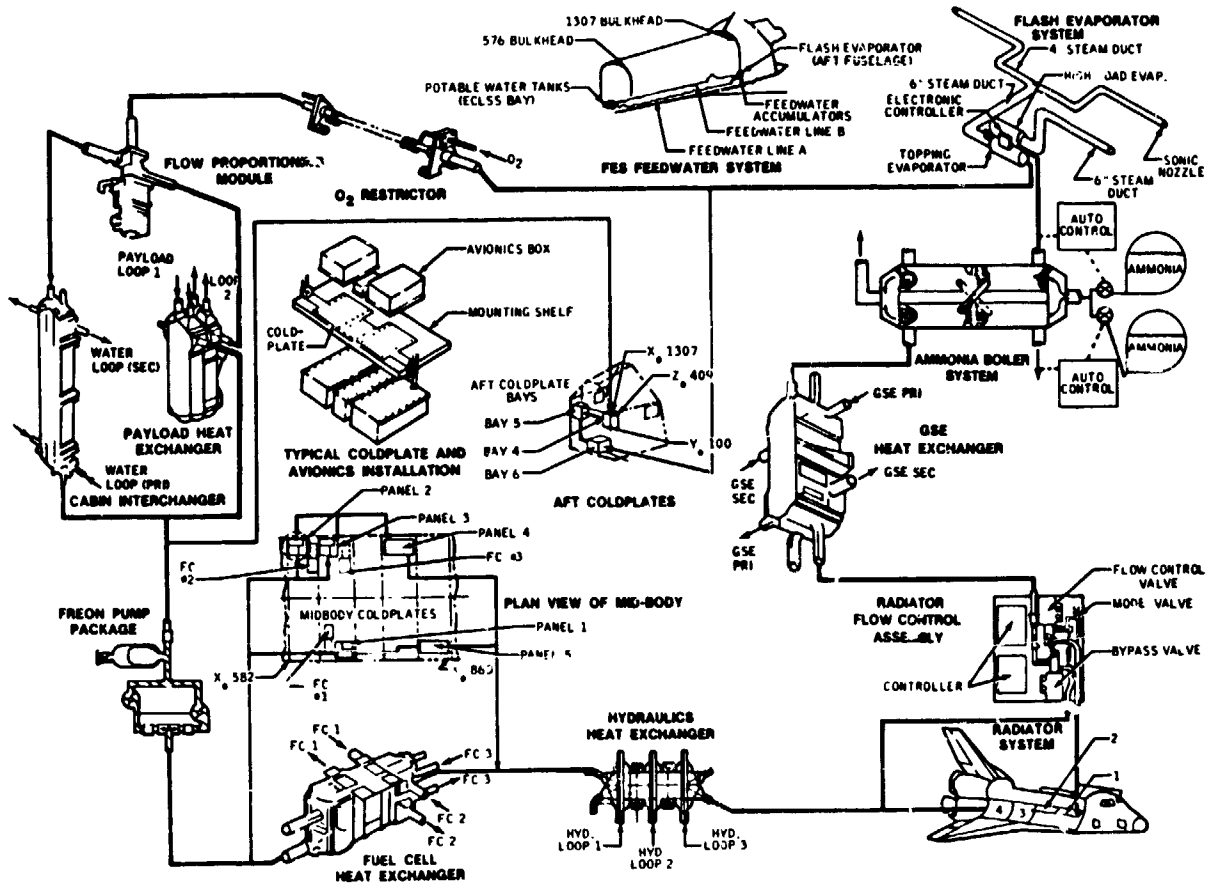


Figure 2 Orbiter Active Thermal Control Subsystem Schematic

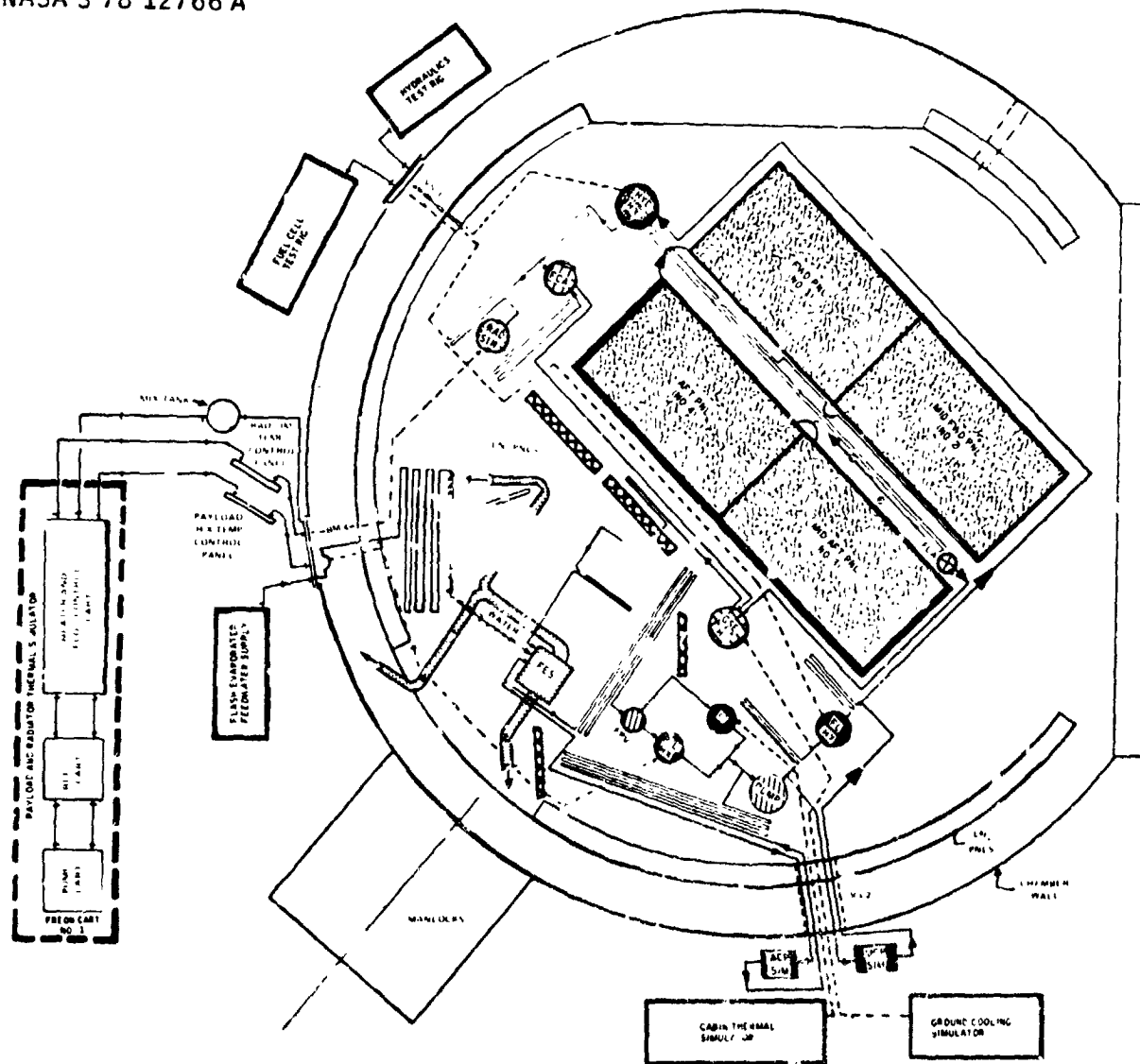


Figure 3 Layout of Integrated ATCS in Test Chamber A

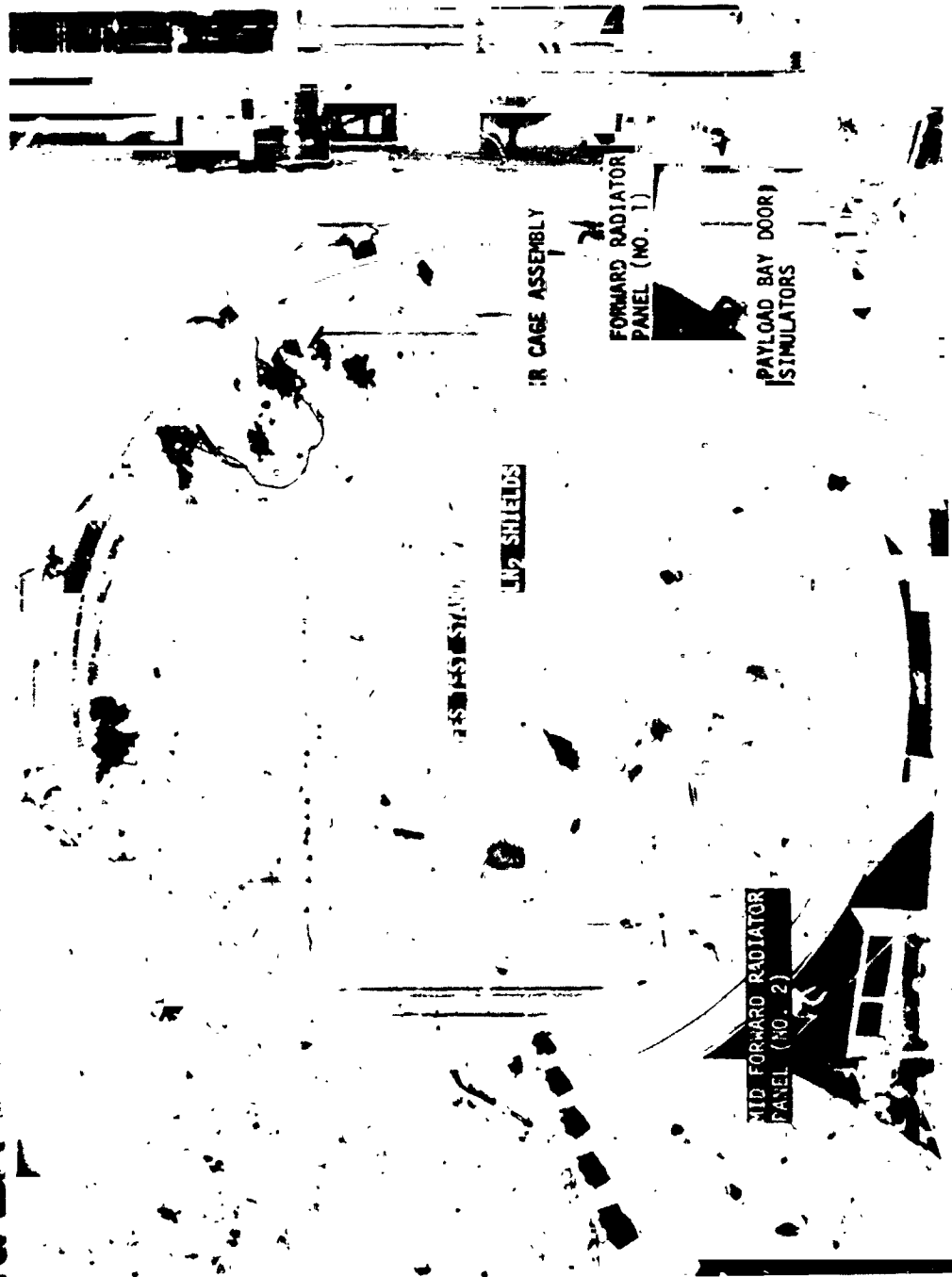


Figure 4 View of ATCS Test Configuration

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Table I Integrated ATCS Test Hardware

NASA-S-80-1528

- RADIATOR SYSTEM
  - FLIGHT TYPE FLOW CONTROL ASSEMBLIES (DEVELOPMENT AND QUALIFICATION)
  - FLIGHT TYPE RADIATOR PANELS (RIGHT SIDE-LOOP 2)
    - TWO "FLIGHT/TEST" PANELS (FORWARD AND AFT)
    - TWO DEVELOPMENT PANELS (MIDFORWARD AND MIDAFT)
  - FLIGHT TYPE INTERPANEL PLUMBING
  - SIMULATED LEFTSIDE LOOP 1 RADIATOR SYSTEM
    - \*RSECS INTERCHANGER)
- FLASH EVAPORATOR SYSTEM
  - FES PACKAGE (DEVELOPMENT UNIT)
    - FLIGHT TYPE HIGH LOAD AND TOPPING CORES
    - FLIGHT TYPE VALVE/NOZZLE ASSEMBLIES
    - FLIGHT TYPE CONTROLLERS
  - EXHAUST DUCT/NOZZLE SYSTEM
    - FLIGHT TYPE STRUCTURE/BELLOWS
    - FLIGHT TYPE EXHAUST NOZZLES
    - FLIGHT TYPE HEATERS (REDUCED REDUNDANCY)
    - FUNCTIONALLY SIMULATED HEATER CONTROL
  - FEEDWATER SYSTEM
    - FLIGHT TYPE PLUMBING LINE (SIZE AND LENGTH)
    - FUNCTIONALLY SIMULATED THERMAL CONTROL
    - FUNCTIONALLY SIMULATED ACCUMULATORS
- AMMONIA BOILER SYSTEM
  - NOT INCLUDED
- FREON COOLANT LOOP
  - FLIGHT TYPE FLOW PROPORTIONING MODULES (QUAL AND TEST UNITS)
  - FLIGHT TYPE INTERCHANGER (RSECS UNIT) - REDUCED PERFORMANCE CAPABILITY
  - FLIGHT TYPE PAYLOAD H-X (RSECS UNIT)
  - FLIGHT TYPE FREON PUMP PACKAGES - ONE PUMP PER PACKAGE (RSECS PUMPS, OV101 ACCUMULATORS)
  - FLIGHT TYPE FUEL CELL H-X (OV101 UNIT)
  - FLIGHT TYPE HYDRAULICS H-X (RSECS UNIT)
  - FUNCTIONALLY SIMULATED AFT COLDPLATES (HEAT, FLUID VOLUME AND  $\Delta P$ )
  - FUNCTIONALLY SIMULATED MIDBODY COLDPLATES (HEAT, FLUID VOLUME AND  $\Delta P$ )
  - FLIGHT TYPE GSE H-X (RSECS UNIT)
  - FLIGHT TYPE PLUMBING (LINE SIZE AND LENGTH)
  - FLIGHT TYPE INSTRUMENTATION EXCEPT FLOW RATE
- INTERFACING ORBITER SYSTEMS
  - FUNCTIONALLY SIMULATED CABIN WATER LOOP (HEAT, FLUID VOLUME, FLOW, FLUID)
  - FUNCTIONALLY SIMULATED PAYLOAD COOLANT LOOP (HEAT, FLOW, FLUID)
  - FUNCTIONALLY SIMULATED FUEL CELL COOLANT LOOPS (HEAT, FLOW FLUID)
  - FUNCTIONALLY SIMULATED HYDRAULICS COOLANT LOOPS (HEAT, FLOW, FLUID)
  - FUNCTIONALLY SIMULATED GSE COOLANT LOOP (HEAT, FLOW, FLUID)

\*RSECS - REPRESENTATIVE SHUTTLE ENVIRONMENTAL CONTROL SYSTEM (CREW SYSTEMS DIVISION) HARDWARE DEVELOPMENT, TEST AND EVALUATION PROGRAM