HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SVHSER 7182

FINAL REPORT

FLIGHT PROTOTYPE CO_2 AND HUMIDITY CONTROL SYSTEM

BY

KAREN M. RUDY

PREPARED UNDER CONTRACT NO. NAS 9-13624

BY

HAMILTON STANDARD
DIVISION OF UNITED TECHNOLOGIES CORPORATION
WINDSOR LOCKS, CONNECTICUT

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

SEPTEMBER, 1977

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ABSTRACT

A regenerable CO_2 and humidity control system is presently being developed for potential use on Shuttle as an alternative to the baseline lithium hydroxide (LiOH) system. The system utilizes a sorbent material (designated "HS-C") to adsorb CO_2 and water vapor from the cabin atmosphere and desorb the CO_2 and water vapor overboard when exposed to a space vacuum. Continuous operation is achieved by utilizing two beds which are alternately cycled between adsorption and desorption.

A Shuttle Vehicle Integration Study showed that the HS-C system offers substantial weight advantages compared to the baseline Shuttle Orbiter expendable lithium hydroxide CO_2 removal system for extended missions beyond the nominal design of four men for seven days. This study defined a system packaging envelope in the area presently occupied by the LiOH cartridges.

A flight prototype system was fabricated, and system performance was proven by simulated mission testing over the full range of Shuttle crew sizes and metabolic loadings. Component testing of a flight prototype canister and flight prototype vacuum valves demonstrated the feasibility of these full-size, flight weight components.

FOREWORD

This report has been prepared by Hamilton Standard, Division of United Technologies Corporation, for the National Aeronautics and Space Administration's Lyndon B. Johnson Space Center in accordance with Contract NAS 9-13624, "Breadboard and Flight Prototype CO_2 and Humidity Control Systems." The report covers work accomplished on the flight prototype phase of the program between September 1, 1975 and November 1, 1977. Work on the breadboard system was described in the Interim Report, SVHSER 7103, published October, 1976.

Appreciation is expressed to the Technical Monitors, Mr. Frank Collier, Mr. Robert J. Cusick, and Mr. L. D. Kissinger of the NASA, Johnson Space Center, for their guidance and advice.

This program was conducted under the direction of Mr. Harlan F. Brose, Program Manager, and Ms. Karen M. Rudy and Mr. Albert M. Boehm, Program Engineers, with the assistance of Mr. John E. Steinback, Design.

The design and fabrication sections of this report are based upon the technical papers and presentations of Mr. A. M. Boehm during his term as HS-C Program Engineer.

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SUMMARY

The Flight Prototype System development effort was divided into the major tasks of design, fabrication, and test.

The design task was initiated by the vehicle integration study defining the installation of the prototype system into the Shuttle vehicle. The resultant system design was packaged in an envelope presently occupied by the LiOH cartridges. The study showed that the regenerable HS-C system is competitive with the existing Shuttle LiOH system for the baseline mission and offers increased savings up to 431 kg (950 lb) for a seven-man, 30-day mission.

The design phase also formulated the system schematic and defined the design specifications for all major components of the flight prototype system. The canister, vacuum valves, airflow and vacuum ducting were designed to form the flight prototype system and fabricated. Commercial units were selected for the remaining components and assembled into an auxiliary support package.

Both the vacuum valve and valve actuator were successfully tested for 45,000 cycles, which is 2.5 times the projected 10-year design life of Shuttle.

The flight prototype system performance was proven by the simulated Shuttle mission testing. This test demonstrated the ability of the HS-C material, which was three and one-half years old, and the full-size system to maintain acceptable CO_2 and humidity levels in a simulated Shuttle volume when varying metabolic loads, from four men to ten men, were introduced.

Performance testing also demonstrated that the HS-C system can perform acceptably under a minimum water dump mode of operation.

Contaminant testing showed that the HS-C material does not have the ability to remove carbon monoxide.

INTRODUCTION

A regenerable CO_2 and humidity control system is being developed for potential use on Shuttle as an improvement to the baseline Lithium Hydroxide (LiOH) and condensing heat exchanger system especially for extended duration missions. The system uses a sorbent material (designated "HS-C") to adsorb CO_2 and water vapor from the cabin atmosphere. The CO_2 and water vapor are subsequently desorbed overboard when exposed to the space vacuum. Continuous adsorption from the cabin and desorption to space is achieved by utilizing two beds which are alternately closed between adsorption and desorption. The HS-C system is especially desirable because it requires no liquid loop connections, needing only space vacuum and electrical connections to perform within the cabin environment.

This program is the fourth in a series designed to develop HS-C to a status acceptable for use on Shuttle. This program was designed to develop unique HS-C components and test a flight prototype system to simulated Shuttle mission profiles.

The HS-C sorbent material has been developed and reported in previous programs, NAS 9-11971 and NAS 9-12957. The breadboard system fabrication and testing was accomplished during the first phase of the present program and reported in the Interim Report, SVHSER 7103, October, 1976. The report presented herein concentrates on the flight prototype phase of the program.

As part of the design phase of the flight prototype system, a comprehensive vehicle integration study was conducted. This information, as well as a description of the design, fabrication, and testing of the flight prototype package, is presented in this report.

The calculations in this report were made in US customary units and converted to SI metric units.

OBJECTIVES

The primary objective of the flight prototype phase of this program was to demonstrate the performance of the flight prototype system under simulated Shuttle requirements. The program was divided into three tasks: flight prototype design, fabrication, and test. The objectives of each task are listed below.

FLIGHT PROTOTYPE DESIGN OBJECTIVES

- To formulate a design for the prototype system that accurately represents the flight system operation.
- To formulate a design for the prototype canister and vacuum valve that accurately represents the flight configuration and construction.
- To define a system design that is compatible with available installation envelope on the Shuttle Orbiter.

FLIGHT PROTOTYPE FABRICATION

- To procure, manufacture, and assemble the prototype system and all its components.
- To demonstrate the ability to fabricate the flight configuration canister.

FLIGHT PROTOTYPE TEST

- To demonstrate acceptable CO_2 and humidity control performance on a simulated Shuttle mission.
- To establish the ability of the canister, vacuum valves, and valve actuator to meet Shuttle requirements.
- To determine the effect of age and previous use of the HS-C sorbent material on system performance.
- To evaluate the ability of the HS-C material to absorb trace levels of carbon monoxide.

CONCLUSIONS

1. The flight prototype system design provides complete CO_2 and humidity control for Shuttle application as demonstrated by the mission testing of the prototype system.

2. Design drawings for the fabrication and assembly of the flight configuration canisters and vacuum valves have been formulated. Design specifications for all major components have been prepared.

3. The Shuttle Vehicle Integration Study has defined the installation of the flight prototype system in an acceptable envelope within the Shuttle Orbiter.

4. The Shuttle Vehicle Integration Study has shown that the regenerable HS-C system offers many advantages for extended Shuttle missions.

5. The life characteristics of the flight prototype vacuum valves and actuator have been proven by endurance testing for 45,000 cycles, or 2.5 times the projected 10-year design life of Shuttle.

6. Fabrication has been demonstrated for the HS-C canister which employs the unique design of duocell foam and integral screens.

7. Testing has shown that carbon monoxide absorption by HS-C is negligible.

8. Performance testing has demonstrated that the HS-C system can also be operated in a minimum water dump mode while controlling CO_2 level.

9. The HS-C sorbent material has demonstrated acceptable life characteristics.

RECOMMENDATIONS

1. A new batch of HS-C sorbent material should be prepared and performance tested in the prototype system to measure any variations from the three and one-half year old material tested under the current contract phase.

2. The full-size flight prototype canister should be subjected to Shuttle vibration loads and subsequently performance tested to ascertain any degradation of the HS-C chemical.

3. The flight prototype system should undergo extensive testing to define optimum operation for minimum water dump and evaluate the design impact on the prototype system.

4. A complete mapping of the affect of vacuum desorption vacuum levels should be conducted on the flight prototype system.

5. The flight prototype canister design should be modified to incorporate larger fill ports.

6. The fabrication of a second flight prototype canister should be performed in order to further demonstrate the manufacturing technique.

7. The design and fabrication of flight prototype ancillary components should be performed.

8. The HS-C prototype system should undergo more endurance testing; specifically, the system should demonstrate a 30-day mission with four or seven man metabolic loading.

RESULTS

The results of the flight prototype phase of this program were the definition, fabrication, and testing of a Shuttle flight prototype regenerative CO_2 and humidity control system.

The projected flight system is shown schematically in Figure 1. The basis of the HS-C system is the unique canister design, which consists of two separate beds in a single unit. This concept uses the heat of adsorption to balance the heat of desorption in a nearly adiabatic process. A breakaway view of the canister is shown in Figure 2.

At the initiation of the design phase, a Shuttle vehicle integration study was conducted to establish all parameters affecting the integration of an HS-C system into the Orbiter vehicle. This comprehensive study considered the parameters of: available packaging envelopes, mounting constraints and locations, operational performance in conjunction with the existing ARS, interfacing plumbing locations, routings, and sizes. The study defined the system envelope as the area presently occupied by the LiOH cartridges. The available packaging envelope was also shown to be sufficient to stow all expendables exclusive of cryogenic fuel cell power expendables necessary for 30-day extended missions.

As part of the operational portion of the vehicle integration study, three trade-offs were performed. The first was the plumbing integration trade-off that evaluated various methods of operating the HS-C system in conjunction with ARS to minimize overall power penalties. The other two trade-offs were conducted within the HS-C system to further optimize the operational performance. These involved a fan selection trade-off and an ullage-save trade-off.

The plumbing integration study concluded that the approach shown in Figure 3 offered the lowest overall penalties. By virtue of the HS-C plumbing interface location, the dew point through the cabin heat exchanger is maintained much lower than the actual cabin level, and condensing in the heat exchanger is precluded with a minimum airflow.

The conclusion of the fan study was the selection of a two speed fan designed for the ten and seven-man flow rates. The fan is power optimized at the seven-man case. For crews less than seven men, the low speed is used with the bypass valve controlling the actual airflow through the HS-C canister.

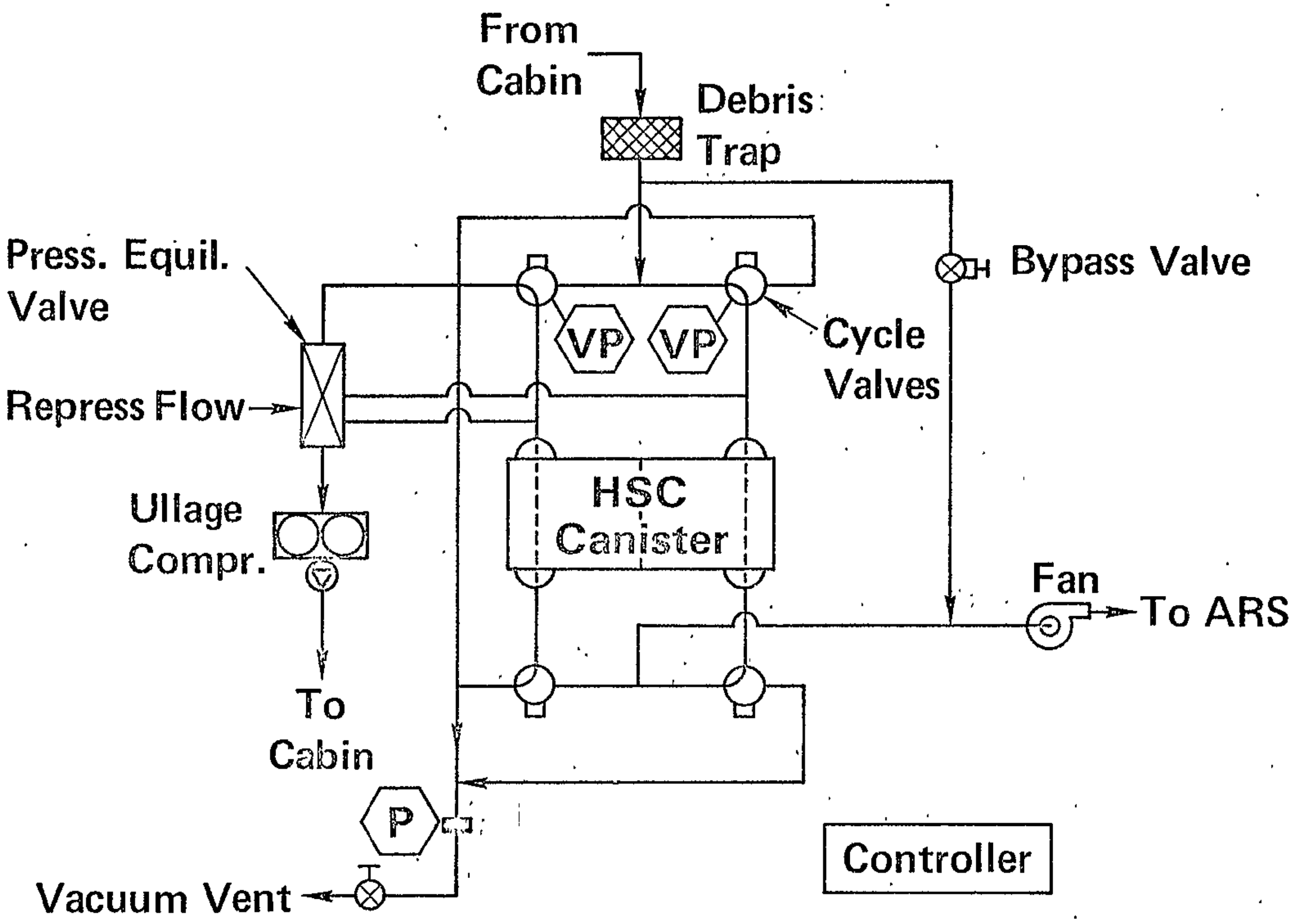

FIGURE 1
HS-C FLIGHT SCHEMATIC

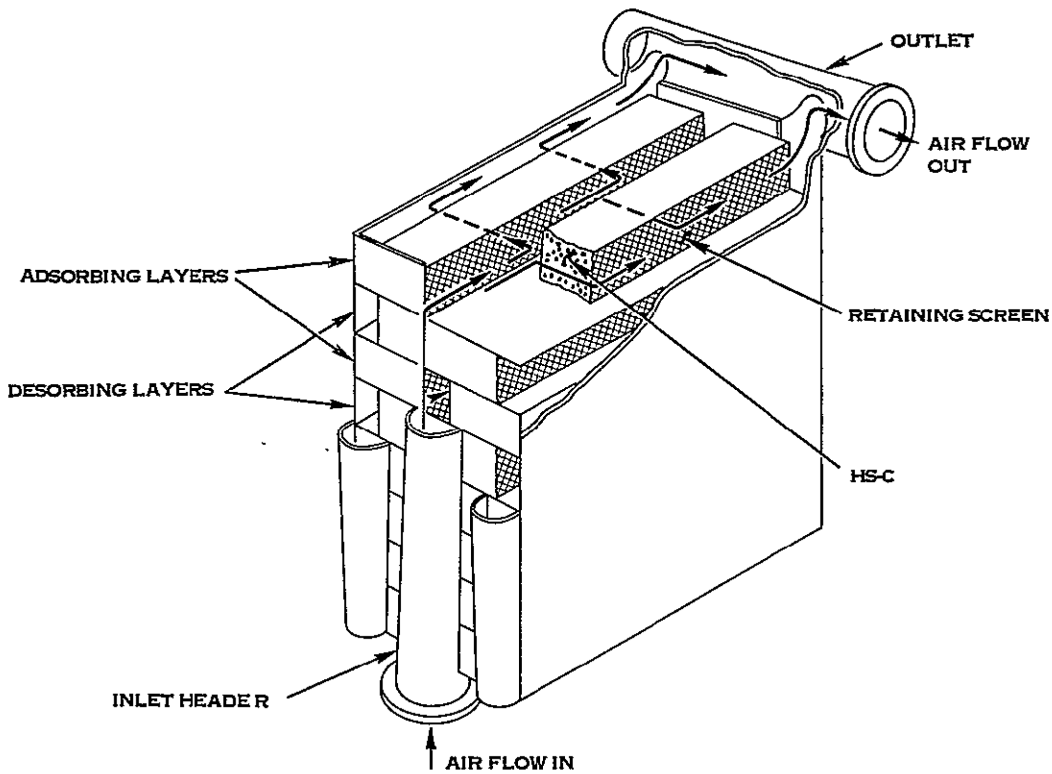

FIGURE 2

HS-C FLIGHT CANISTER CONCEPT

. HS-C DILUTES CONDENSING HX INLET AIR DEW POINT BELOW CONDENSING HX OUTLET TEMPERATURE

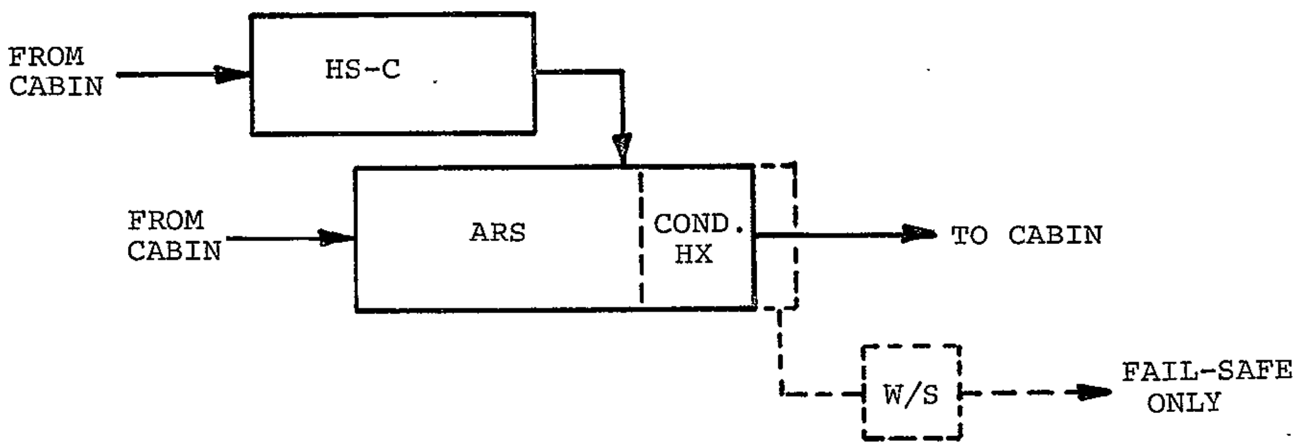

FIGURE 3

HS-C PLUMBING INTEGRATION INTO SHUTTLE ARS

The ullage-save trade study evaluated a method to reduce ullage penalties by using a vacuum compressor to pump the air, trapped in the isolated adsorption bed, back to the cabin. The approach selected uses the compressor to pump the adsorption bed down to 13.8 kPa (2.0 psia). The evacuated volume of the desorption bed is then used to reduce the adsorption bed pressure to 6.9 kPa (1.0 psia) before it is cycled over to space vacuum.

The HS-C flight concepting effort is best summarized by totaling all elements of integration on a weight basis and comparing it with the baseline Shuttle system. This produces the trade-off curves shown in Figure 4. The trade-off curves are based on the weights and associated penalties listed in Tables 1, 2, and 3. The Shuttle LiOH system is superimposed on the same graph for a direct comparison. For a four-man crew, the HS-C system trades even with the LiOH system for a nine day mission. HS-C offers increasing advantages up to 121 kg (267 lb) for a 30-day mission.

For the seven-man crew, the HS-C system trades even at three days and offers increasing weight advantages for longer missions; 75 kg (165 lb) for the seven-day mission and up to 431 kg (950 lb) for the maximum 30-day mission.

The HS-C curves represent all elements of the integration, being comprised of: the HS-C package and mounting structure, the vehicle plumbing and vacuum ducts, the LiOH backup cartridges, odor cartridges, cartridge stowage racks, ullage gas and tank penalties, and power penalties.

The Shuttle curve consists of LiOH cartridges and storage penalties, plus the power penalty of the condensate fan/separator.

The trade-off curves of Figure 4 show fairly conclusively the full impact of the HS-C integration on vehicle launch weight. The HS-C system offers significant advantages for all seven-man missions and for all extended four man missions.

The flight prototype system was designed upon the conclusions of the vehicle integration study. Design specifications were defined for all major components. A detailed design was made for the canister and vacuum valves. The vacuum valve and valve actuator design was proven by endurance testing for 45,000 cycles, which is equivalent to 2.5 times the projected 10-year life of the Shuttle vehicle.

The assembled flight prototype system is shown in Figure 5. The system was installed on the test setup as shown in Figure 6. Ancillary components were assembled in the support package, which is visible to the left of the prototype system.

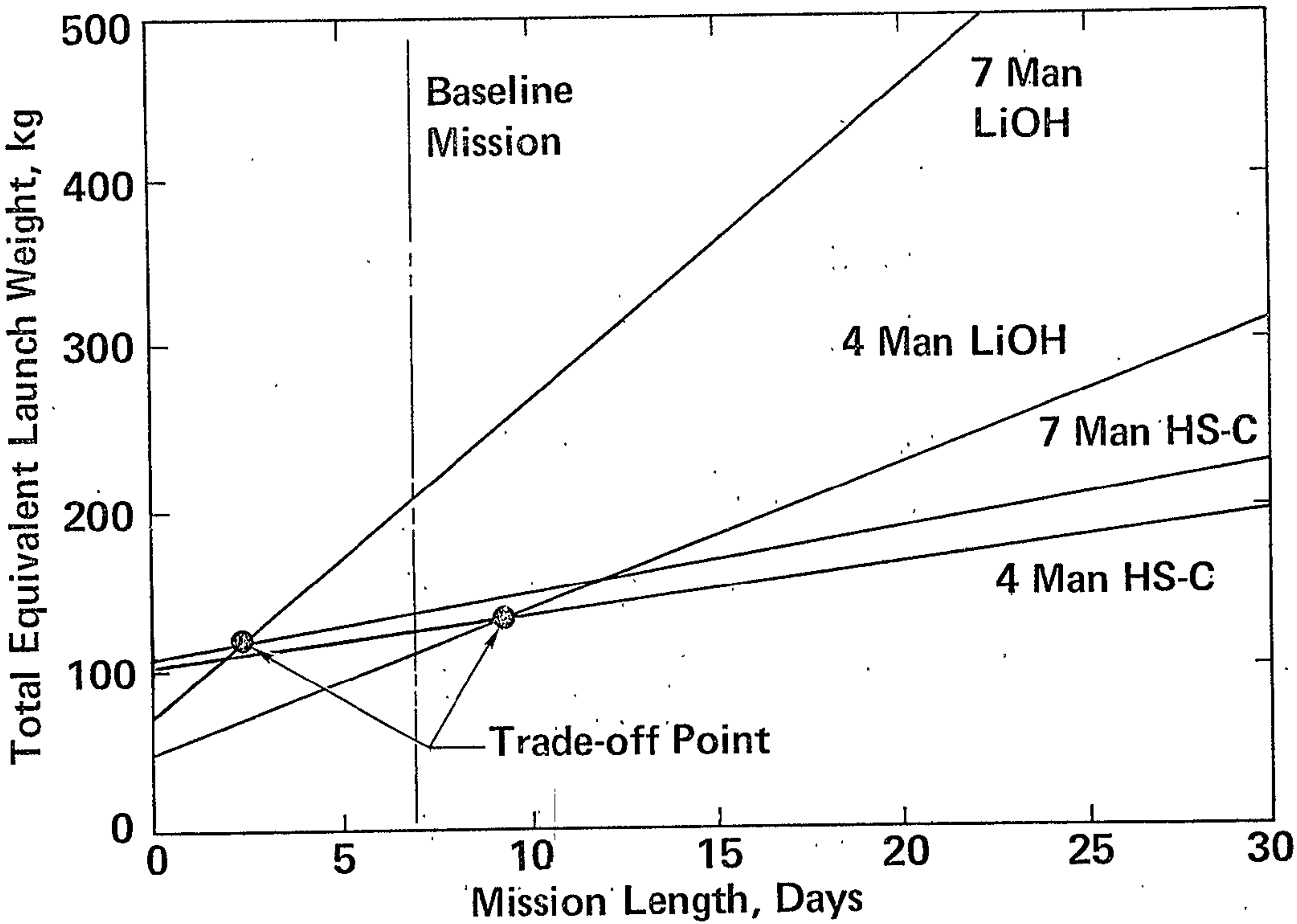

FIGURE 4
VEHICLE INTEGRATION TRADE-OFF SUMMARY

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TABLE 1

FLIGHT SYSTEM WEIGHT CHART

Component	Quantity	Weight (Kg)	Weight (Lbs)
HS-C HX	1	48.8	107.6*
Cycle Valves	4	7.7	17.0
Cycle Valve Linkage	AR	2.0	4.5
Bypass Valve	1	0.8	1.8
Fan	1	1.6	3.5
Controller	1	2.2	4.8
Isolation Valve	1	1.4	3.0
Press. Equil. Valves	1	2.0	4.5
Compressor	1	1.6	3.5
Subtotal		68.1	150.2
Packaging		9.6	21.1
Total		77.7	171.3

4 can LiOH rack = 3.2 lbs (1.5 Kg)

AR = As Required

*Includes 42 pounds of HS-C chemical

TABLE 2

HS-C WEIGHT SUMMARY

Fixed Weight	4 Men kg	4 Men (lb)	7 Men kg	7 Men (lb)
HS-C Package	77.5	(171)	77.5	(171)
LiOH Backup	7.7	(17)	13.1	(29)
Vehicle Plumbing	18.1	(40)	18.1	(40)
	503.3	(228)	108.7	(240)
Expendables				
7 Days + 4 Contin.				
Ullage	1.4	(3.1)	2.8	(6.2)
Odor Filter	2.9	(6.5)	5.9	(13.0)
Power, Fan	22.7	(50.0)	22.7	(50.0)
Power, Compress.	1.6	(3.6)	3.3	(7.2)
Power, Misc.	2.5	(5.5)	2.5	(5.5)
	31.1	(68.7)	37.2	(81.9)
30 Days + 4 Contin.				
Ullage	9.2	(20.4)	18.4	(40.5)
Odor Filter	8.8	(19.5)	19.5	(43.0)
Power, Fan	69.4	(153.0)	69.4	(153.0)
Power, Compress.	5.0	(11.0)	10.0	(22.0)
Power, Misc.	7.7	(17.0)	7.7	(17.0)
	100.1	(221.0)	125.0	(275.5)

TABLE 3

LiOH BASELINE

Fixed Weight	4 Men[1] Kg	(Lb)	7 Men[2] Kg	(Lb)
None	0	(0)	0	(0)
Expendable Weight				
7 Days + 4 Contin.				
LiOH Cartridges	64	(140)	137	(302)
LiOH Storage	36	(80)	64	(142)
Power Penalty (Fan/Sep)	9	(21)	9	(21)
	109	(241)	210	(465)
30 Days + 4 Contin.				
LiOH Cartridges	194	(428)	425	(938)
LiOH Storage	91	(201)	200	(400)
Power Penalty (Fan/Sep)	29	(65)	29	(65)
	314	(694)	654	(1,443)

(1) Based on changeout time of 12 hours/cartridge.
(2) Based on changeout time of 5.5 hours/cartridge.

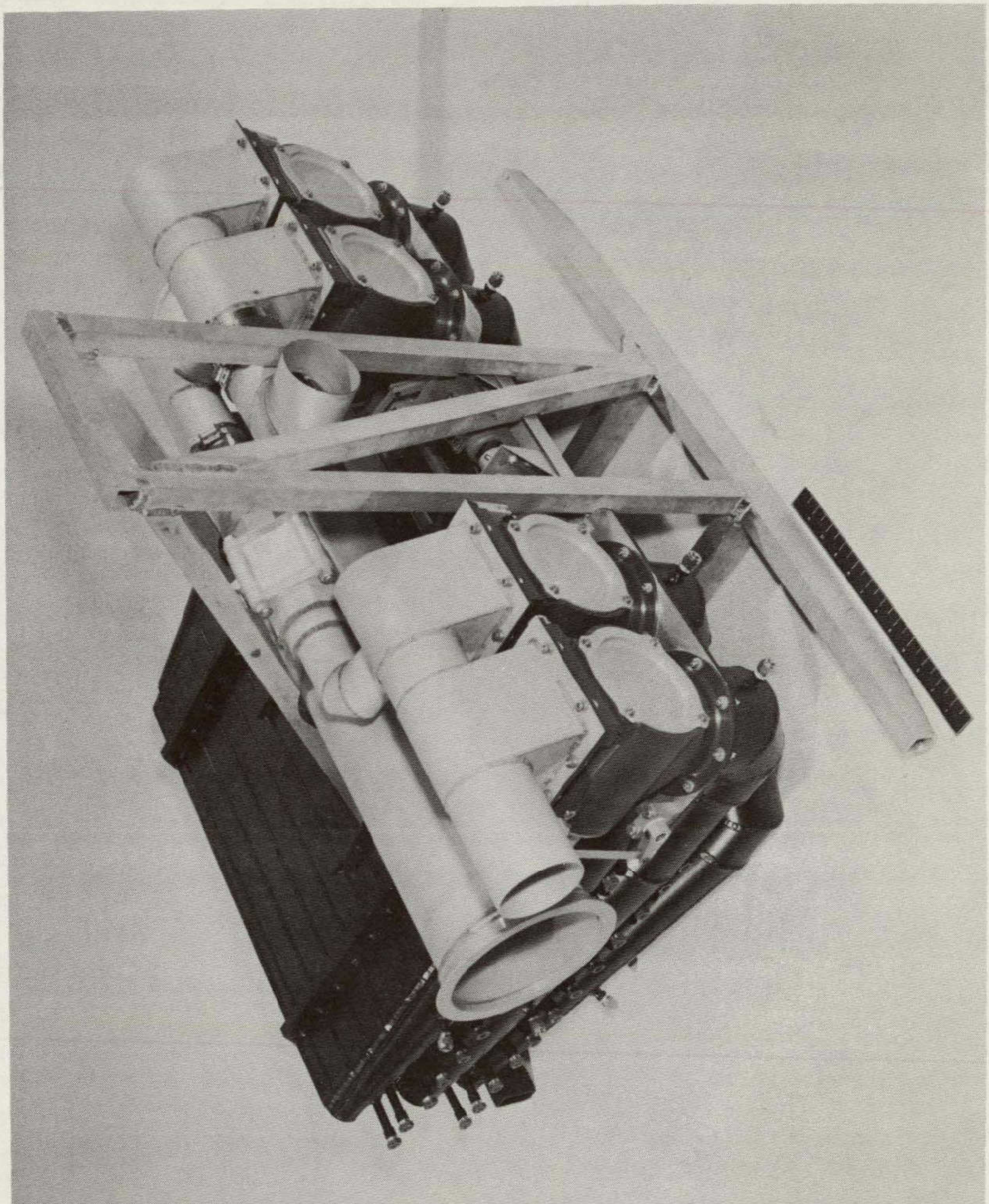


FIGURE 5

FLIGHT PROTOTYPE SYSTEM

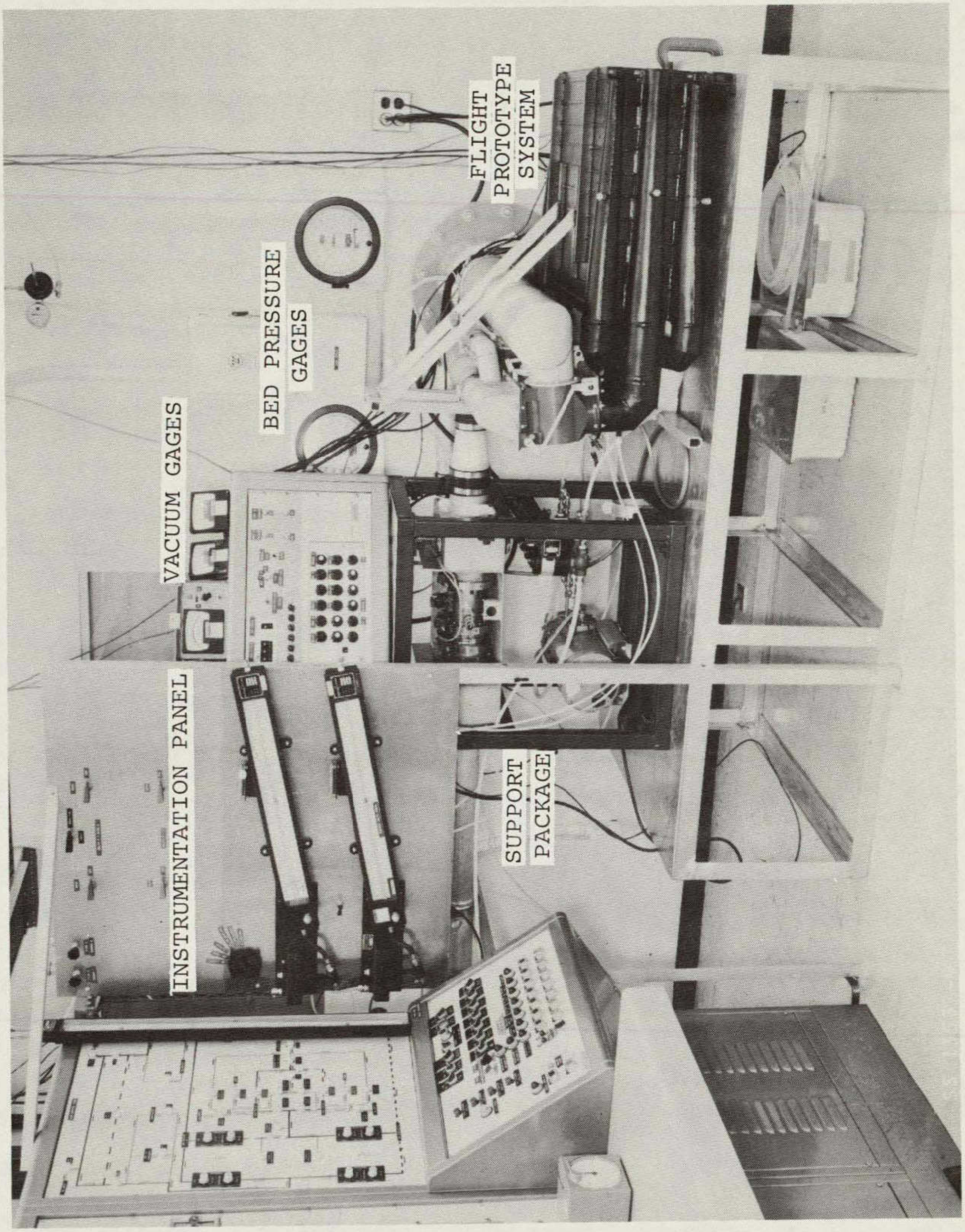


FIGURE 6

THE FLIGHT PROTOTYPE SYSTEM DURING TESTING

TABLE 4

FLIGHT PROTOTYPE CONTROL SETTINGS

Controller Setting	Fan* Airflow	Cycle Time**	Orbiter Crew Size
(Max Crew Size)	m^3/s (cfm)	(Min Adsorb/Min Desorb)	(Men)
4	0.024 (50)	40/40	1-4
7	0.024 (50)	18/18	5-7
10	0.033 (70)	8/8	8-10

*Bypass valve modulates air flow through the HS-C canister based upon cabin dew point.

**Cycle time is the minutes adsorbed/minutes desorbed for each canister bed and includes the switchover time.

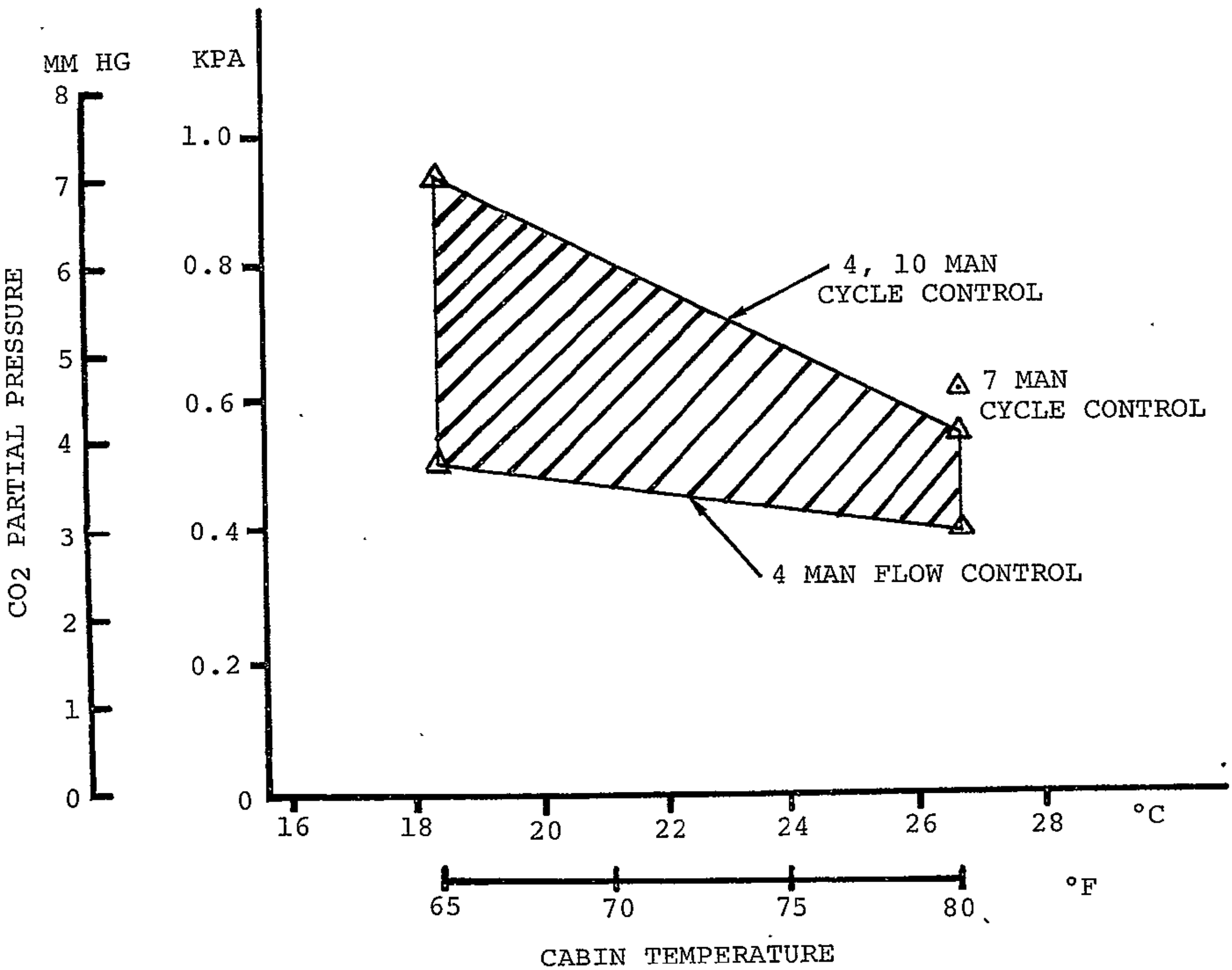


FIGURE 7 - CO_2 PERFORMANCE MAP

The humidity control performance map is shown in Figure 8. These curves were generated based on the breadboard data and updated for the flight prototype system. The map shows that airflow is the exclusive parameter affecting humidity control at cycle times of less than 30 minutes. Only a four-man crew has a cycle time greater than 30 minutes and is specifically shown by the 40/40 cycle curve. The humidity level for any operating condition can be found from the performance map by knowing the fan speeds of Table 1. Use of the bypass valve can further reduce airflow through the canister down to 0.014 m^3/sec (30 cfm) and establishes the total operating regime of the map.

The HS-C regenerable system was also tested to determine its performance with a minimum water dump mode of operation. As apparent in Figure 9, the removal ratio of water to carbon dioxide can be minimized with decreased airflow. This testing confirmed that the system can maintain acceptable CO_2 levels while dumping only 20-40% of the metabolic water. However, if low water dump becomes a Shuttle requirement, the system design should be optimized.

Performance testing was concluded by an investigation into carbon monoxide (CO) removal capacity of the prototype system. The HS-C sorbent material has no apparent capability of removing the carbon monoxide contaminant. In addition, the CO_2 and H_2O capacity of the system was not affected at CO levels three times higher than allowed in the spacecraft.

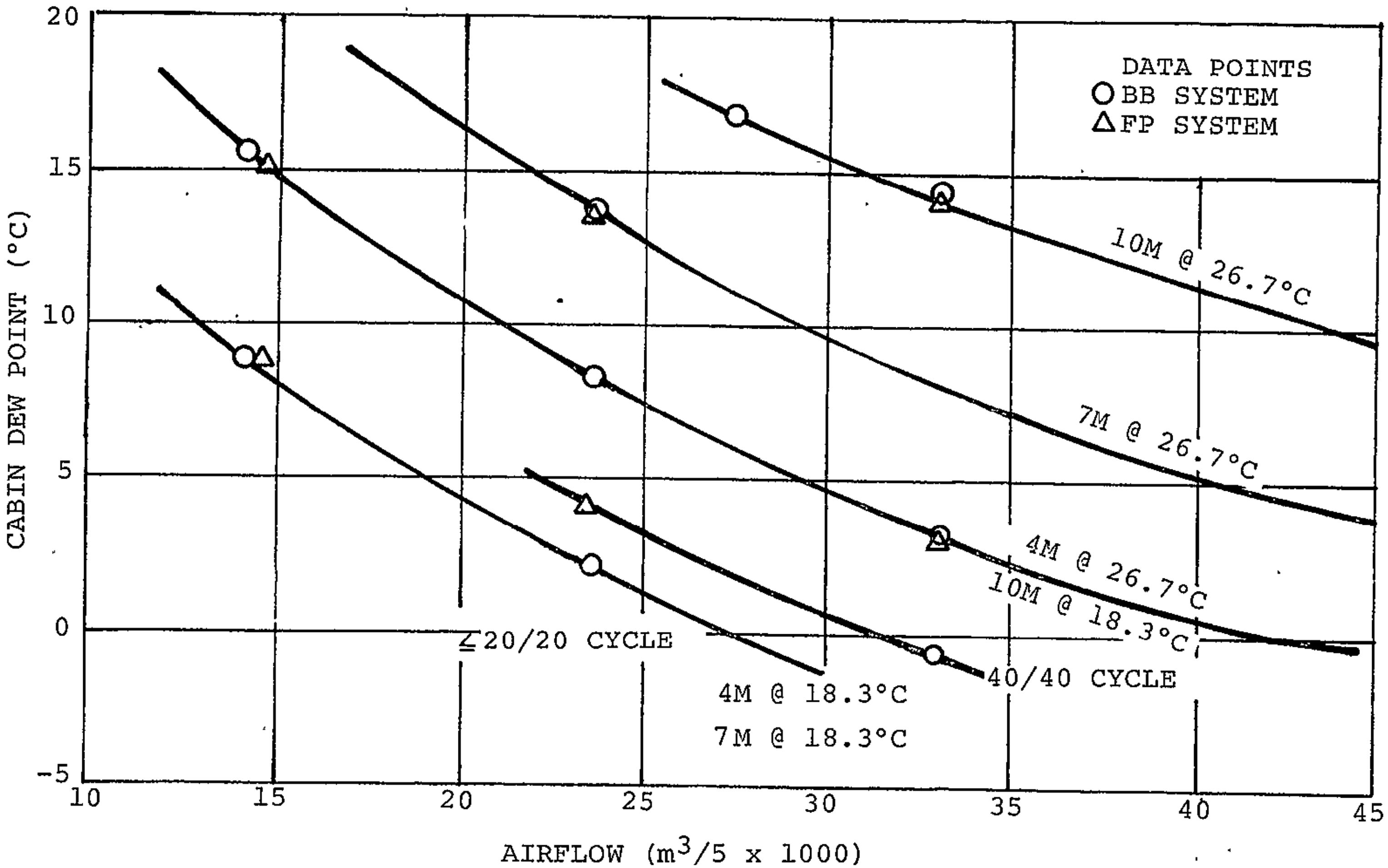


FIGURE 8A
HUMIDITY CONTROL PERFORMANCE MAP

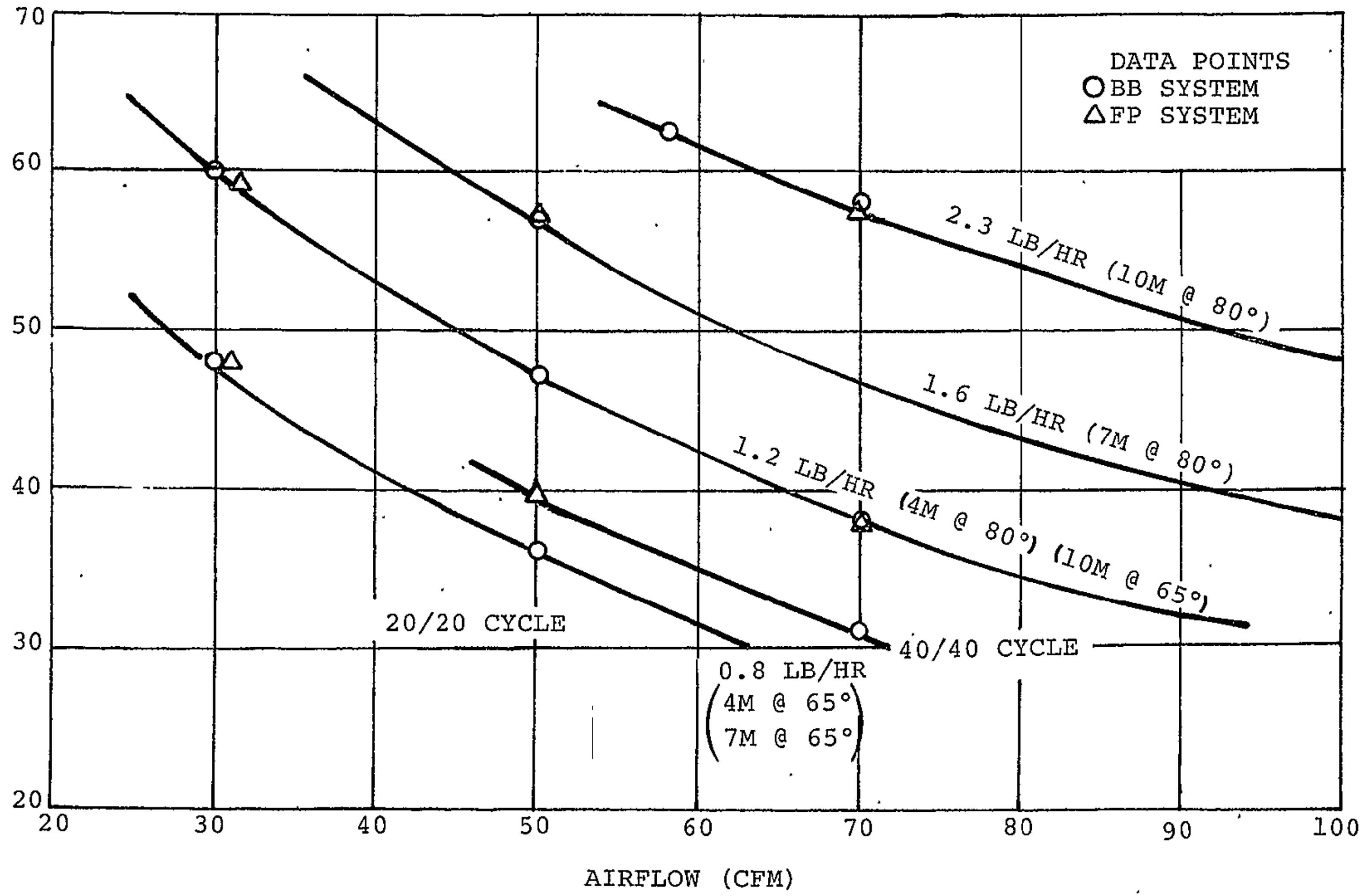


FIGURE 8B
HUMIDITY CONTROL PERFORMANCE

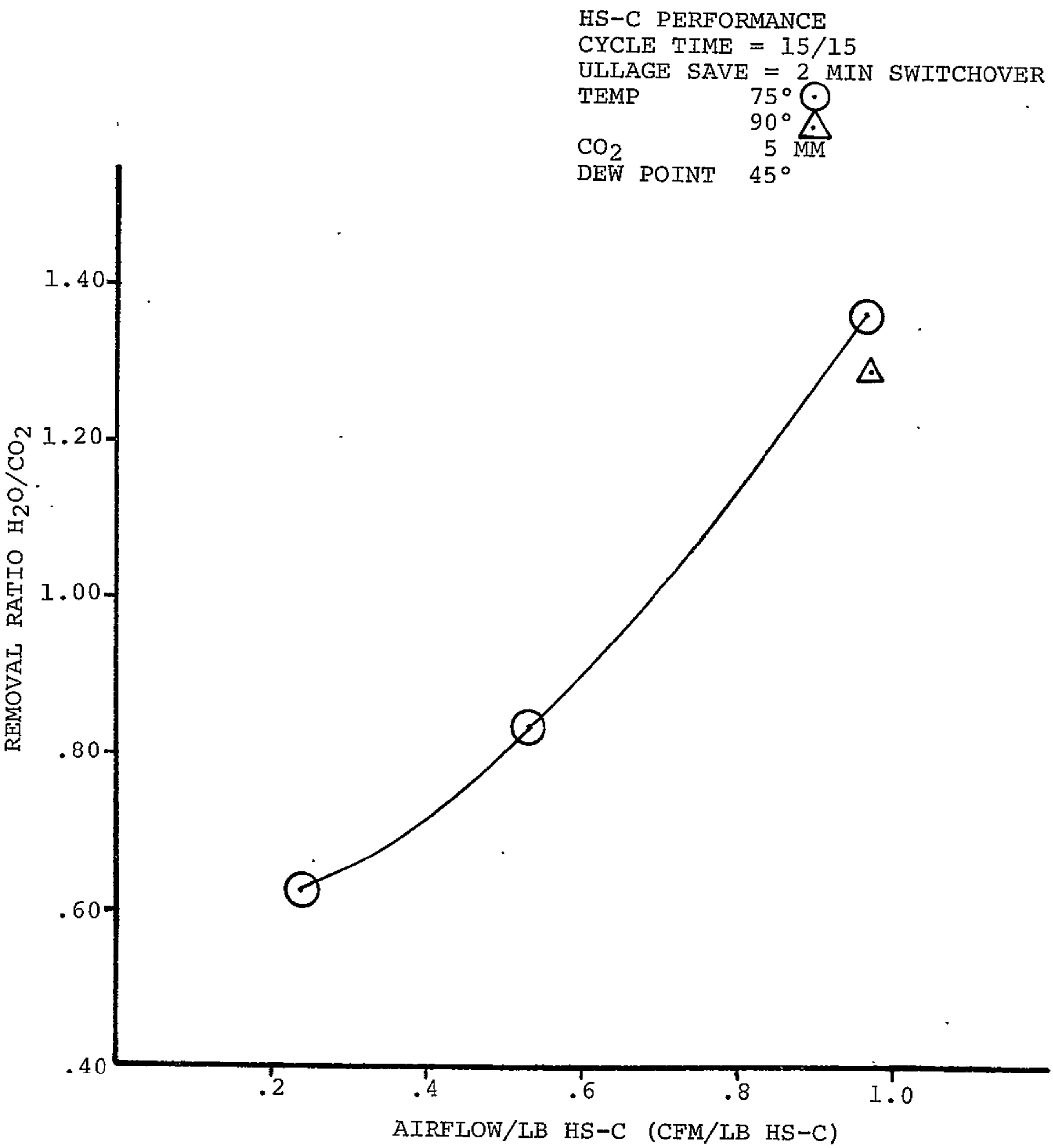


FIGURE 9

SYSTEM PERFORMANCE REMOVAL RATIO

DISCUSSION

The NASA Statement of Work defines four major flight prototype system tasks in its Work Breakdown Structure. Hamilton Standard, in preparing the Program Operating Plan (POP), renumbered these tasks to agree with their expanded breadboard tasks. A comparison of both lists is shown in Table 5. All tasks are presented in the following subsections in their numberical order.

TABLE 5

WORK BREAKDOWN STRUCTURE

NASA Nomenclature		Hamilton Standard Nomenclature	
No.	Task	No.	Task
6.0	Flight Prototype Design	10.0	Flight Prototype Design
7.0	Flight Prototype Fabrication	11.0	Flight Prototype Fabrication
8.0	Component and Flight Prototype Test	12.0	Flight Prototype Test
9.0	Final Report	9.0	Management and Reporting

FLIGHT PROTOYPE DESIGN

The Flight Prototype Design Task is defined in the Statement of Work by Section 3.2.2 and WBS 10.0. The objective of this task was to formulate a design for the flight prototype system that represents flight configuration and operation.

The approach to this task was to utilize the results of the system analysis task (WBS 1.0), the breadboard design task (WBS 2.0), the breadboard test task (WBS 4.0), and the engineering data developed under contracts NAS 9-11971 and NAS 9-12957. The flight prototype components were required to meet Shuttle performance requirements as specified in the Statement of Work by Section 3.3.

The HS-C system design was based on the following requirements/ assumptions:

- System Requirements Specification per Appendix A.
- HS-C to provide total CO_2 and humidity control
- Charcoal to provide odor control
- Atmosphere Revitalization Subsystem (ARS) to remain intact (slurper and the LiOH canisters available for backup)
- HS-C to be located in LiOH storage area
- HS-C vacuum hardware not to interfere with removal of the waste water tanks.

The design was divided into six major areas: System Schematic, Shuttle Vehicle Integration Study, System Design, Component Design, Supporting Package, and Preliminary Design Review. Each of these will be discussed in the following subsections.

System Schematic

The flight system schematic was defined by the design studies and is shown in Figure 10.

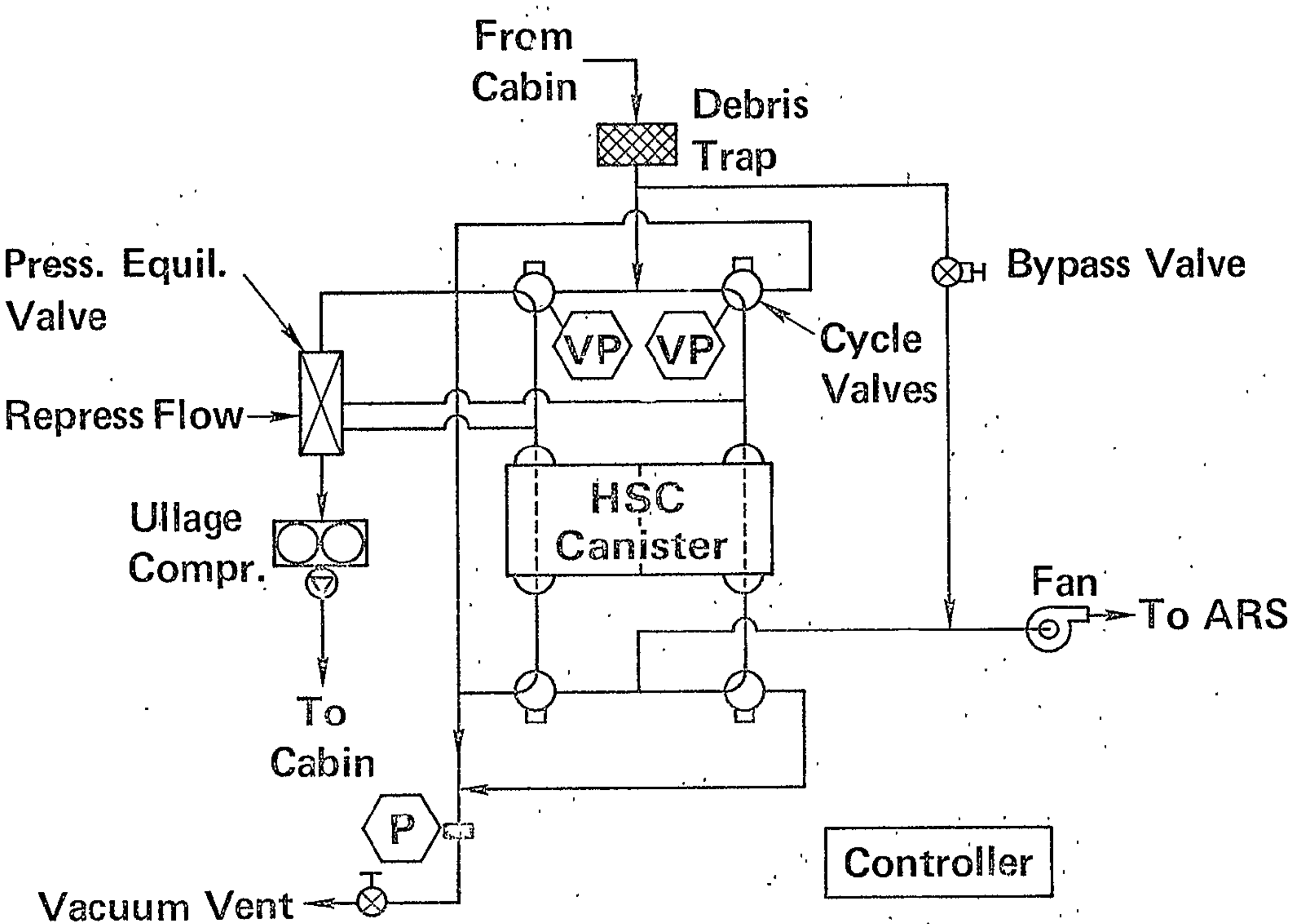


FIGURE 10
SYSTEM SCHEMATIC

Cabin air first enters the system through a debris trap which protects the vacuum cycle valves from contamination and loose cabin objects. The air then flows through a set of vacuum cycle valves where it is directed into and through the adsorbing bed of the HS-C canister. The air exits the canister through an identical set of vacuum cycle valves. A two-speed fan mounted to the outlet manifold of the cycle valves forces the air into the nearby ARS plumbing for distribution throughout the cabin. Both sets of vacuum cycling valves act in unison to select and direct airflow through the adsorbing bed of the canister while exposing the desorbing bed to space vacuum.

In addition to flow through the canister, a bypass circuit is plumbed in parallel with the canister and is used to reduce the airflow through the canister by modulating a flow control bypass valve. An electronic controller, sensing cabin temperature or humidity, regulates the position of the bypass valve to maintain acceptable humidity levels in the cabin. (If unchecked, the HS-C system has the ability to over-dry the cabin to below specified dewpoints.) Other major control variables are cycle time and fan speed, but these depend on crew size. As such, they are predetermined and dialed into the control circuit prior to launch, although they are accessible for adjustment during flight. The other major activity of the controller is the proper phasing and cycling of the valves to switch the beds from adsorption to desorption and vice versa.

The bed switch-over operation is fairly involved in order to minimize cabin gas loss. It starts at the end of a cycle by the closing of all ports on all four vacuum cycle valves, thus isolating both beds of the canister. The fan is also turned off at this time. The desorption bed is at vacuum, and the adsorption bed is at ambient pressure (101.4 kPa (14.7 psia)). The primary objective now is to retrieve the ambient gas filling the adsorption bed volume before cycling to space vacuum and losing this gas overboard. Gas lost in this fashion is called ullage loss, and some loss is inevitable because the adsorption bed will always be at some absolute pressure prior to switch-over. The objective is to minimize the ullage loss. Therefore, a vacuum pump called an ullage-save compressor is turned on and valved to the adsorption bed through the five-port, pressure equalization valve. When the absolute pressure of the bed has been reduced to 13.8 kPa (2.0 psia), the pressure equalization valve indexes to the next position, which interconnects the adsorption bed (loaded with CO_2 and water) and the desorption bed (regenerated or free of CO_2 and water). In this way the beds equalize pressure at 6.9 kPa (1.0 psia). The pressure equalization valve indexes again to allow ambient air to pressurize the regenerated bed to 101.4 kPa (14.7 psia) and then it indexes again to a shutoff position. The vacuum cycle valves are now ready for actuation to complete the switch-over operation. The regenerated bed is opened to the cabin airflow, while the loaded bed is exposed to the overboard vacuum. The entire switch-over operation takes 2.0 minutes to complete, during which 1.7 minutes are needed for the pump-down operation.

Shuttle Vehicle Integration Study

The Shuttle Vehicle Integration Study was conducted to establish the packaging and system constraints within the Shuttle Orbiter vehicle. The study objective was to verify and/or modify the assumptions, requirements, and conclusions of the Study and Assessment of Advanced ETCLSS Application to the Space Shuttle, Contract NAS 9-13964. Results of the Vehicle Integration Study were incorporated into the Preliminary Design Review in December, 1975.

The integration study investigated all parameters that affected the physical installation of an HS-C package on board the Shuttle vehicle and the operational incorporation of HS-C as a contributing factor in air revitalization. The physical integration portion of the study required:

a. To locate, on the Orbiter, an envelope space sufficient to package the HS-C system

b. To identify the structural mounting of the HS-C package

c. To identify the plumbing routings of HS-C vehicle ducting

d. To locate and mount backup expendables for the HS-C system.

The operational integration portion of the study required the investigation of how an independent HS-C system would affect the operation of other equipment on the Orbiter, specifically, the ARS (Air Revitalization Subsystem); and more importantly, how the HS-C could best be integrated to minimize the overall weight and power penalties of the combined HS-C/ARS. The operational integration identifies many of the requirements needed for the physical integration and, as such, was conducted first.

The first step in conducting the operational integration was to identify the basic operational requirements and parameters. The most important of these are mission (man-loading) requirements and functional requirements. The mission requirements are shown in Table 6. The primary requirements are for four (4) and seven

TABLE 6

MISSION REQUIREMENTS

Crew Size (Men)	Baseline Mission (Days)	Extended Mission (Days)	Metabolic Loading
4	7	30	Max
7	7	30	Nom
10	2	N/A	Nom

(7) men for up to thirty (30) days. In addition, four (4) extra days of expendables are required for all missions should a vehicle failure preclude landing. It is assumed that a rescuing vehicle can rendezvous with a stranded vehicle within this four (4) day period. On return to earth, the rescuing vehicle may have as many as ten (10) occupants, with a maximum return time of two (2) days. Therefore, the ten-man requirement becomes a unique case. It represents the maximum metabolic loading rates, but it is for such a short period of time that expendable penalties becomes less critical. This allows optimization of the system design around the seven-man case for long mission phases rather than the ten-man case.

In identifying the functional requirements of HS-C integration the existing ARS system was reviewed to assess what functions were being performed by the hardware that the HS-C system was attempting to replace. HS-C performs two functions: CO_2 control and humidity control. On Shuttle, CO_2 control is presently provided by LiOH. In addition to CO_2 control, the LiOH cartridge also provides the only active odor control for the vehicle. Each cartridge has a distinct bed containing activated charcoal, exclusively for odor removal. Therefore, in replacing LiOH on Shuttle the HS-C integration must also provide the odor control function. Humidity control is provided by the cabin heat exchanger, which removes both the cabin latent and sensible loads. With HS-C doing humidity control, the latent load is removed, but the heat exchanger is still needed for the cabin sensible load. It was, therefore, concluded that a regenerable HS-C system must provide CO_2, humidity, and odor control.

The physical requirements for the integration study involved the defining of an available packaging envelope and mounting structure in the Orbiter vehicle and defining any access and maintenance requirements of surrounding hardware. Since HS-C replaces LiOH, locating a packaging space was relatively simple because LiOH requires a generous storage volume (.566 m^3 (20 ft^3)) for its replaceable cartridges. On Shuttle the LiOH storage bay is located below the floor in the crew compartment of the Orbiter vehicle, adjacent to the ARS to which the HS-C package must ultimately interface. As such, this LiOH storage bay was considered the only practical space for HS-C packaging.

Presently, the LiOH cartridges are stored in removable racks to allow access and removal of waste water tanks for sterilization after each mission. The LiOH bay represents the only access to these tanks because of the location of the airlock directly above the tanks. However, it would be undesirable to remove the HS-C package after each mission because of its critical plumbing connection to overboard vacuum. As such, an additional requirement was established that the HS-C package be configured so that all vacuum portions of the system remain intact and in-place during the tank removal/installation operation.

Another physical requirement of the integration involved the existing ARS hardware. As this hardware will be flight qualified at the time HS-C is ready for retrofitting, the ARS will remain intact. As such, optimization of ARS components was not to be considered during the study. The positive side of this requirement, however, was that all of these components were available at no penalty to fail-safe backup for HS-C.

The major vehicle integration requirements were summarized as follows:

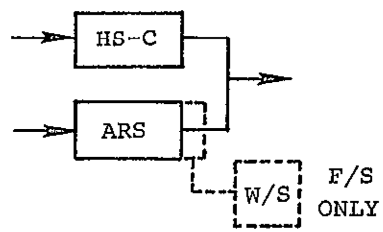
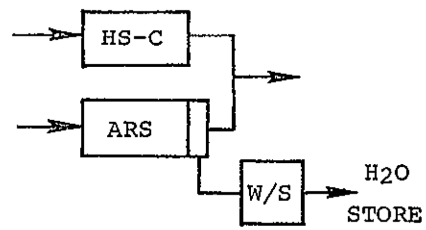
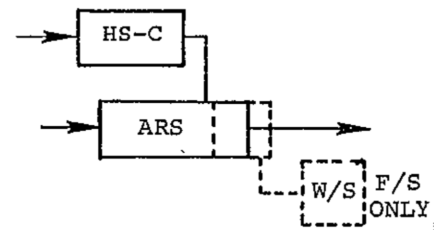
- HS-C to provide total CO_2 control.
- HS-C to provide total humidity control.
- HS-C integration must account for odor control and assume all penalties.
- HS-C to be fail-safe.
- ARS to remain intact.
- ARS to be available for fail-safe backup.
- HS-C to be located in LiOH storage area.
- HS-C vacuum hardware not to interfere with removal of waste water tanks.

Three trade-off studies were performed as part of the operational portion of the vehicle integration study. The first, and most important, was the plumbing integration trade-off that evaluated various methods of operating the HS-C system in conjunction with the ARS to minimize overall power penalties. The other two trade-offs were conducted within the HS-C system to further optimize the operational performance of the HS-C system itself. These involved a fan selection trade-off and an ullage-save trade-off.

In reviewing various methods of operating the HS-C system in conjunction with the Orbiter ARS, humidity control stood out as the overriding parameter. Humidity control is affected by the cabin condensing heat exchanger, which will continue to condense water vapor unless the HS-C system maintains a dew point lower than the outlet air temperature of this heat exchanger. Of the several methods investigated to alleviate this potential, three approaches were selected for final evaluation. These approaches are shown schematically in Table 7.

TABLE 7

PLUMBING INTEGRATION TRADE SUMMARY

APPROACH	I		II		III	
						
CREW	FLOW M^3/S (CFM)	POWER PENALTY KG/DAY (LB/DAY)	FLOW M^3/S (CFM)	POWER PENALTY KG/DAY (LB/DAY)	FLOW M^3/S (CFM)	POWER PENALTY KG/DAY (LB/DAY)
4	.025 (52)	2.18 (4.8)	.014 (30)	1.50 (3.3)	.019 (40)	1.23 (2.7)
7	.034 (72)	4.90 (10.8)	.021 (45)	2.50 (5.5)	.024 (50)	2.09 (4.6)
10	.042 (88)	6.72 (14.8)	.028 (60)	4.13 (9.1)	.033 (70)	4.59 (10.1)

The first approach operated in parallel with the ARS and maintained a cabin dew point below the cabin heat exchanger coolant temperature. The water separator is shown in phantom because it operates as a fail-safe backup only.

The second approach assumed that to eliminate condensing in all possible operating modes was impractical and that the condenser would have to operate continually to share the humidity load with the HS-C system. As shown schematically in Table 7, the HS-C system is plumbed in parallel with the ARS, and the water separator must be operated continuously. The HS-C airflow is minimized to provide only CO_2 control, but the ARS fan/separator has to operate to assist with the humidity load. The power required to run both the HS-C fan and the ARS fan/separator more than offset the HS-C savings when compared to the third approach.

The third approach took advantage of the low dew point (< 1.11°C (< 30°F)) air exiting the HS-C system to dilute the dew point of the heat exchanger inlet air below the condensing temperature of the heat exchanger. As shown schematically in Table 7, the outlet of the HS-C system plumbs directly to the inlet the cabin heat exchanger. The Shuttle water separator does not operate and is used for fail-safe backup only.

All three systems were evaluated with the help of the performance curves shown in Figure 8. These curves were generated from the breadboard test program and have subsequently been updated for the flight prototype system data. The curves show the effect of airflow on water removal performance of the Orbiter sized HS-C system. Given a crew size and cabin temperature (or required removal rate), the airflow required to maintain any given dew-point can be selected. This method was used to evaluate the first approach.

The second approach required a trial and error solution to establish the water split between the HS-C system and the condensing heat exchanger. In effect, the airflow could be reduced to the minimum allowable for CO_2 control since the condensing heat exchanger is designed to maintain total humidity control. However, in maintaining CO_2 control, the HS-C will also remove 100% of the humidity load for all moderate and low temperature (< 23.9°C (< 75°F)) cabin conditions. It is only at the higher cabin temperatures and higher metabolic loadings that the dew point will rise above the condensing temperature.

Approach III also required a trial error solution to establish the minimum airflow rate. First, from known heat exchanger and cabin conditions, the HS-C airflow rate would be roughly calculated by the formula:

$$\dot{V}_{HS-C} = \dot{V}_{HX} \frac{(PH_2O \text{ cabin} - PH_2O \text{ HX outlet})}{(PH_2O \text{ cabin} - PH_2O \text{ HS-C outlet})}$$

where $\dot{V}$ is the volumetric airflow and PH_2O is the partial pressure of water vapor at the conditions given. This formula gives the airflow required from HS-C to dilute the dew point of the total heat exchanger flow below the heat exchanger outlet temperature. However, as shown in the humidity performance map, each flow rate has a specific cabin dew point characteristic. Therefore, the airflow would be further refined by the same formula until a balance existed between the HS-C airflow/dew point relationship and the cabin heat exchanger flow/condensing temperature relationship.

A summary of the trade-off comparison between these three approaches is shown in Table 7. The third approach was selected because it had the lowest overall penalties. It controls both CO_2 and humidity with a minimum HS-C airflow. The second approach actually has the lowest HS-C penalties but only provides partial humidity control. The extra power required to operate the water separator more than offset the HS-C savings with the combined power penalty of the HS-C and the water separator being greater than the selected approach. The first approach required the most airflow and subsequently had the highest power penalties.

In addition to establishing the optimum operational integration of the HS-C system into the Orbiter, the plumbing integration trade-off also established the airflow requirements of the HS-C system. With the airflows identified for the three basic crew sizes, a fan selection trade study was conducted to choose the optimum fan approach.

An optimization is needed because a one fan system which provides the maximum airflow results in excessive penalties for smaller crew sizes. A variable speed fan reduces flow rate but does not reduce power which is the critical parameter. In an effort to find the optimum approach, six concepts were evaluated. These consisted of combinations of similar fans, dissimilar fans, and multiple speed fans and are listed in Table 8A. The corresponding fan trade-off and power penalties for each combination are tabulated in Table 8B for the crew requirements.

The conclusion of the fan study was that optimization of power alone was impractical since it would involve the costly development of three separate fans, one for each airflow. The selected approach utilizes one multiple speed fan designed for the ten-man and seven-man flow rates (Concept II). The fan performance curve is shown in Figure 11. The fan is power optimized at the seven-man case but, when operated at the high speed, will provide the

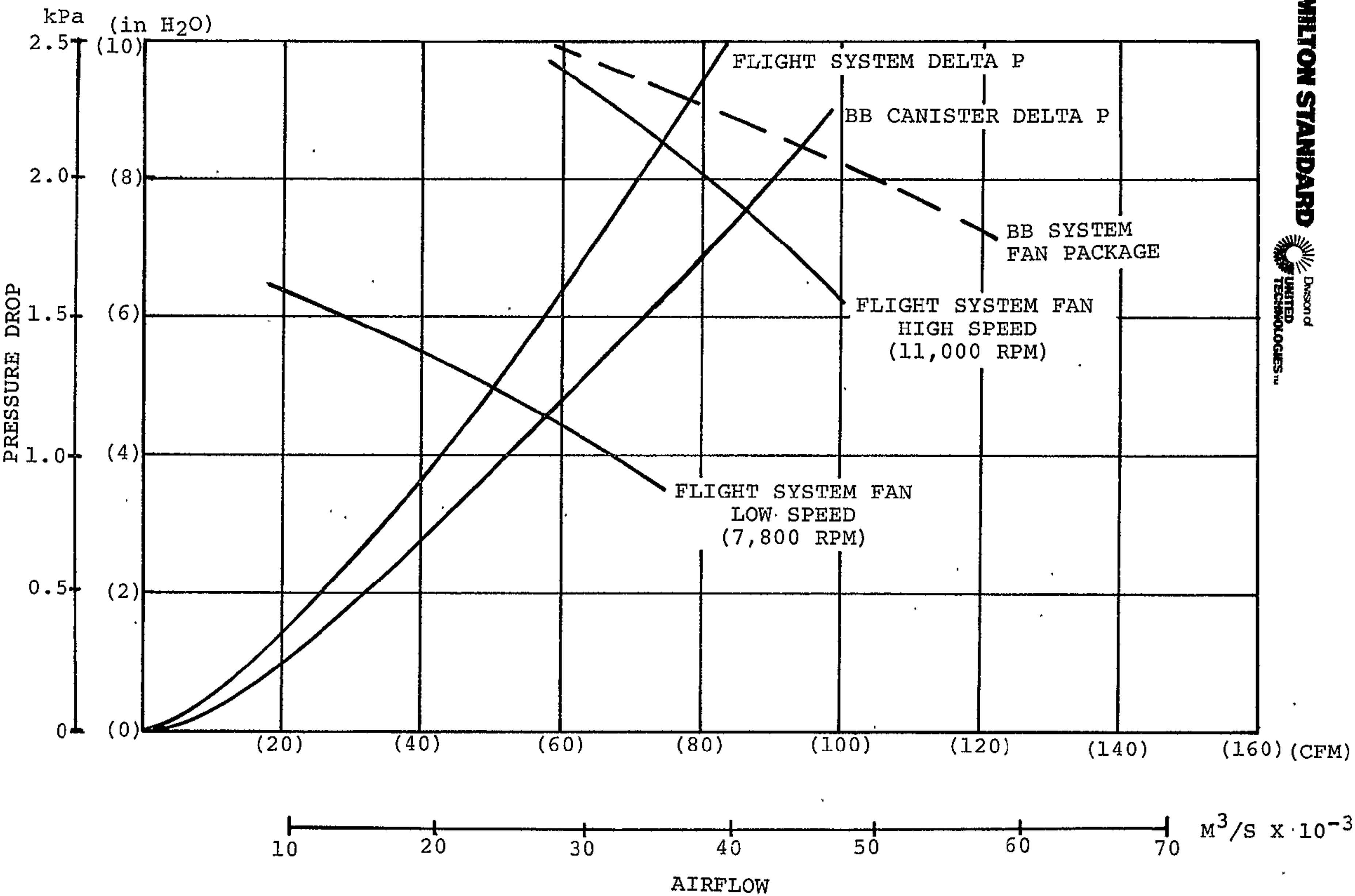


FIGURE 11
FLIGHT SYSTEM FAN PERFORMANCE

TABLE 8A

FAN CHOICES

Flow Requirements:

- 10 Men = 70 cfm
- 7 Men = 50 cfm
- 4 Men = 40 cfm

Possibilities:

I. One 70 cfm Fan (Bypass Flow Control)

II. One 70/50 cfm, Two-Speed Fan

III. Two Fans: One 70 cfm Fan
One 50 cfm Fan

IV. Two 60 cfm Fans: One On = 60 cfm
Two On = 70 cfm

V. Two 50 cfm Fans: One On = 50 cfm
Two On = 60 cfm+

VI. Two 50/40 cfm, Two-Speed Fans: One Fan = 50/40 cfm
Two Fans = 60 cfm+

+Requires slurper operation for 10 men

TABLE 8B

FAN TRADE-OFF/POWER PENALTIES

Fan Possibiities	4 Men Daily (lb/day)	4 Men 7 Days+ (lb)	4 Men 30 Days+ (lb)	7 Men Daily (lb/day)	7 Men 7 Days+ (lb)	7 Men 30 Days+ (lb)	10 Men Daily (lb/day)	10 Men 2 Days (lb)
I) 70 cfm	9.6	106	326	9.6	106	326	9.6	19.2
II & III) 70/50 cfm	4.5	50	153	4.5	50	153	9.6	19.2
IV) 70/60 cfm	6.7	74	228	6.7	74	228	13.4	26.8
V) 60/50 cfm	4.5	50	153	4.5	50	153	10.9*	21.8*
VI) 60/50/40 cfm	2.7	30	92	4.5	50	153	10.9*	21.8*

*Includes W/S penalty

+ Includes 4 days contingency

ten-man flow rate with only a marginal reduction in efficiency. For crews of less than seven men, the low speed will be used with the bypass valve controlling the actual air flow through the HS-C canister. For a four-man crew, the extra airflow provided by the fan is equivalent to a .82 kg/day (1.8 lb/day) power penalty compared to having a separate four-man airflow fan. In addition to development costs, the extra space required to package multiple fans also affected the choice of one multiple speed fan.

The final trade study evaluated various approaches to optimizing ullage penalties. Ullage is a measure of the gas lost during the switch-over cycle when the adsorption bed, being an isolated volume at some absolute pressure, is opened to space vacuum. The ullage penalty is a measure of the ullage gas loss, plus the tankage required to store a replacement amount of gas.

The ullage trade study evaluated a method to reduce ullage penalties by using a vacuum compressor to pump the air, trapped in the isolated adsorption bed, back to the cabin. A formula was established relating ullage gas penalties with compressor weight and power penalties. It was evident from this formula that the compressor penalties were considerably less than the ullage penalties at high pumping pressures but that the compressor penalties would increase above the ullage penalties at lower pumping pressures. By equating the derivative of this formula to zero, an optimization relationship was obtained, whereby pumping the adsorption bed to 1.72 kPa (0.25 psia) would produce the overall minimum weight approach. However, this pressure had to be evaluated against two other variables before selecting the final pump-down pressure. These were the physical design of a vacuum compressor and the effect of the pump-down time on the performance of the HS-C system. The pressure ratio in going from 101.4 kPa (14.7 psia) to 1.72 kPa (0.25 psia) is relatively large (60 to 1) and would require a complex multistage compressor design. The time required to reduce the pressure to such a low value would detrimentally affect the time the HS-C beds are available for adsorption/desorption, thus degrading performance. The evaluation of these two variables together with the ullage compressor penalty formula produced the selection of the present approach which uses the compressor to pump the adsorption bed down to 13.8 kPa (2.0 psia). The evacuated volume of the desorption bed is then used to reduce the adsorption bed pressure to 6.9 kPa (1.0 psia) before it is cycled over to the space vacuum.

The penalties associated with the ullage-save approach are tabulated in Table 9. The overall impact of using a compressor to save ullage is shown in Figure 12. The selected compressor approach is compared to the best non-compressor approach that dumps the adsorption bed at 51.7 kPa (7.5 psia). As can be seen

TABLE 9

ULLAGE SAVE COMPRESSOR PENALTIES

	4 Men	7 Men	10 Men
Pressure Equalization			
Gas Lost (lb/day)	2.13	4.25	8.5
Ullage Penalty (lb/day)	5.57	11.1	22.2
Ullage Save Compressor			
Gas Lost (lb/day)	.282	.564	8.5
Gas Lost in 30 Days (lb) (+ 4 Days Contingency)	9.6	19.0	17.0 (2 days)
Ullage Penalty (lb/day)	.60	1.19	
Compressor Power Penalty (lb/day)	.325	.65	
Compressor Fixed Weight (lb)	6.5	6.5	
4 Day Contingency Penalty (lb)	3.7	7.4	
Total USC Penalty (lb)	10.2 + .93 x days	13.9 + 1.84 x days	

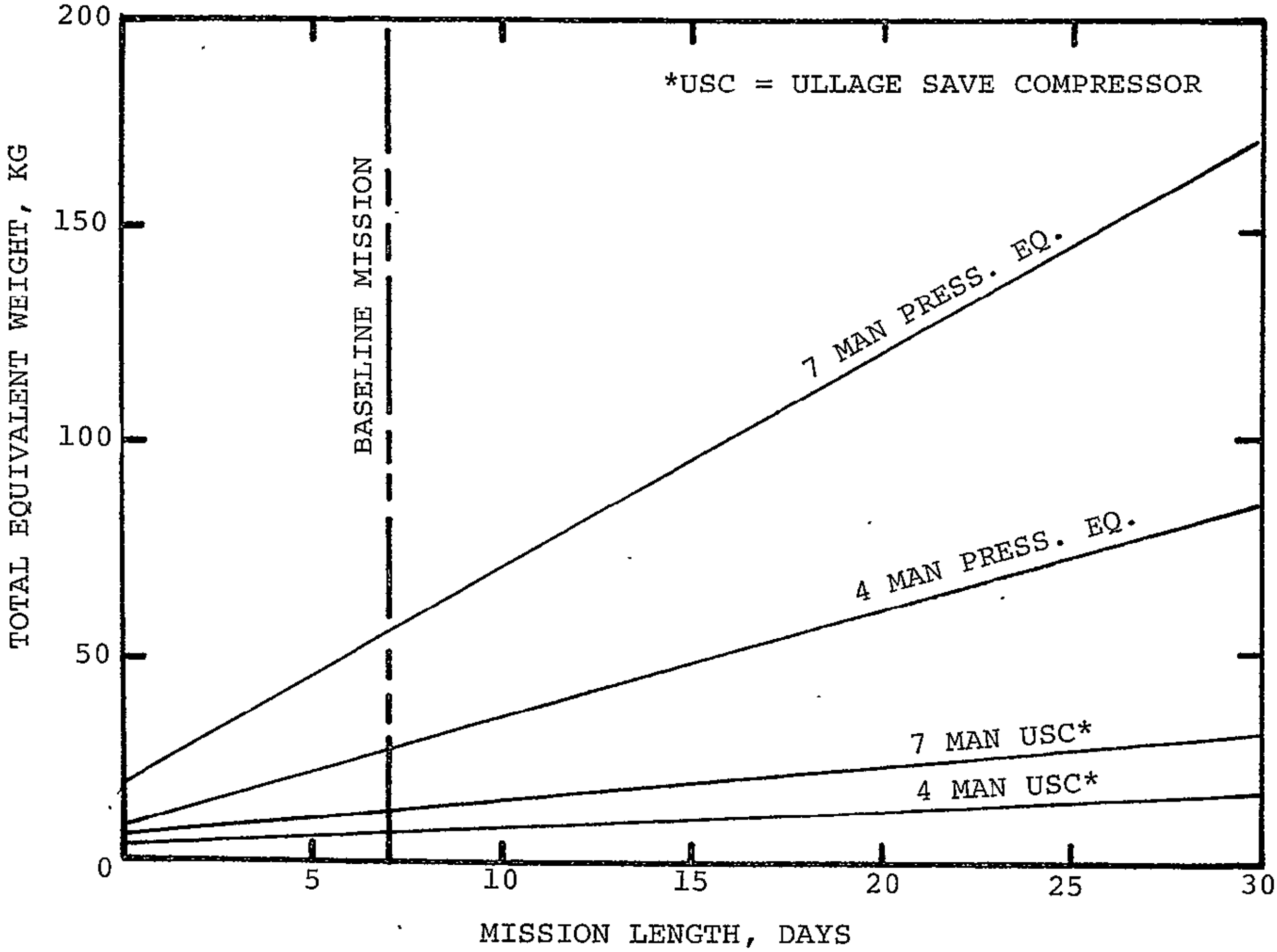


FIGURE 12

THE USE OF THE ULLAGE-SAVE COMPRESSOR TO REDUCE ULLAGE PENALTIES.

CONVERSION FACTOR: (LB) = 2.205 (KG)

by these curves, an advantage of up to 140 kg (308 lb) can be realized by the use of the ullage-save compressor approach.

In completing the vehicle integration study, a number of other topics had to be considered. These include waste water storage, odor control cartridges, backup LiOH cartridges, and overall cartridge stowage requirements.

Waste water storage is impacted because, with HS-C providing humidity control, the storage requirements of the tanks are greatly reduced. The original Orbiter baseline had three waste water tanks with a combined capacity of 43 man-days. With HS-C on board, one tank could be eliminated with a resultant capacity of 47 man-days on the two tanks. However, the waste water storage baseline has since been reduced from a three tank, 43 man-day capacity approach to a two tank, 28 man day capacity approach. Integrating HS-C into such a system would no longer allow the elimination of waste tank because a one tank/HS-C system would only have a 24 man-day capacity. But, with HS-C on board, the two waste tank systems would increase its capacity from 28 man-days to 47 man-days. This increase results in a two tank capacity which is actually 10% greater than the original three tank system. The conclusion of the tankage study is that only two waste tanks are needed with integration of HS-C for humidity control. In addition, the HS-C integration can be credited with an operational advantage (47 man-days without dumping) but not a weight advantage.

Atmospheric odor control must also be considered in the HS-C integration because the present LiOH cartridge (being replaced by the HS-C) also includes an activated charcoal section exclusively for this function. The HS-C integration concept offers an attactive approach, using an LiOH cartridge filled entirely with charcoal. These odor cartridges install in the existing LiOH airflow circuit in the ARS and offer an 88 man-day capacity for two installed cartridges. The baseline loading for odor control is 56.75 gm/man-day (.125 lb/man-day) of charcoal. This allows 44 man-days capacity for each cartridge, which holds 2.5 kg (5.5 lb) of charcoal. Table 10, line 1, shows the cartridge requirements for various crew sizes and various mission lengths. An advantage of retaining the functional use of the LiOH airflow circuit is that quick conversion back to LiOH operation is guaranteed for fail-safe backup to HS-C.

Should the HS-C system fail on Orbit, backup operation must be generated for 20 hours. The use of LiOH is the simplest approach for CO_2 control since the airflow canisters will be available for quick conversion to LiOH cartridges. The cartridges required for various crew sizes are shown in Table 10, line 4. They are based on present predictions of cartridge change-out times. One of the two installed cartridges must be replaced every 12 hours for four men and every 5.5 hours for seven men.

TABLE 10

CARTRIDGE STOWAGE REQUIREMENTS

	Cartridge	4 Men 7 Days*	4 Men 30 Days*	7 Men 7 Days*	7 Men 30 Days*
1)	Odor Required	1	3	2	6
2)	Odor Installed	1	1	2	2
3)	Odor Stored	0	2	0	4
4)	LiOH Stored	2	2	4	4
5)	Total Stored Cartridges	2	4	4	8

*Includes 4 days contingency.

Combining the results of odor removal with those of LiOH backup give the overall cartridge stowage requirements of HS-C integration as shown in Table 10, line 5. Not all cartridges have to be stowed since some odor cartridges will be installed into the airflow canisters at launch. This table was used during the design phase to establish the cartridge stowage within the HS-C package itself. Theoretically, all expendables for greater than four men or for longer than seven days can be charged against the payload. This establishes the minimum stowage requirement within the HS-C package for two cartridges. However, a design requirement was set for storage of four cartridges in the HS-C package since this would satisfy all four-man missions, and seven-man missions for up to seven days. In addition, a design goal was set for storage of eight cartridges to accommodate all missions.

Combining all aspects of the vehicle integration study results in the following summary chart:

Functional Integration: Normal Operation

- HS-C provides CO_2 control.
- HS-C provides total humidity control with no condensing in cabin heat exchanger.
- Charcoal cartridges replace LiOH in ARS canisters to provide odor control.

Function Integration: Fail-Safe Backup

- LiOH provides CO_2 control.
- Cabin HX/slurper provides humidity control.
- Charcoal in LiOH provides odor control.

Physical Integration:

- LiOH storage area is used for packaging envelope.
- Vacuum portions of package do not interfere with removal of waste water tanks.
- Package will include storage for at least four cartridges.

To visualize the HS-C integration into the vehicle, the physical requirements and conclusions have been superimposed on a floor plan view of the Orbiter vehicles' crew quarters in the vicinity of the ARS, as shown in Figure 13. Air enters the HS-C package from the cabin and exits into the inlet of the cabin heat exchanger for distribution throughout the cabin. The vacuum desorption line plumbs into the unpressurized area behind the crew quarters where it is assumed it will be combined with the airlock and waste management line.

ARS operation starts with cabin air being ducted to the cabin fan package. From here it is forced through one of the redundant cabin fans and into the odor control assembly. Part of the flow passes through the odor control cartridges installed in the previous LiOH canisters and reunites with the mainstream flow. The flow is again split in the temperature control valve. This valve regulates the proportion of flow to be cooled by the cabin heat exchanger with the portion that bypasses the heat exchanger in order to maintain the crew selected cabin temperature. The flow through the heat exchanger is mixed with the HS-C outlet flow to preclude condensation in the heat exchanger. The total flow is reunited and having been scrubbed of CO_2, humidity, contaminants, and heat, is ready for distribution throughout the cabin.

System Design

Using the requirements and conclusions of the vehicle integration study, the design of the flight packaging concept was conducted. The basic requirements affecting the HS-C package were envelope dimensions of the LiOH storage area, available mounting structure in the envelope, maintenance access required for waste water tank removal, and plumbing interface orientations. All of these requirements had an impact on the final packaging configuration as shown in the mock-up photograph of Figure 14. The HS-C canister is located at the bottom of the package and also acts as a major structural member, supporting both component mounting loads and structural frame loads. Mounting directly to the canister are the four vacuum cycle valves ganged in pairs on each side of the canister. One pair is fed by a common inlet manifold located on top, while the other pair is connected to a common outlet manifold. All valves are connected to a common vacuum desorption duct. The two-speed centrifugal fan is mounted to the outlet manifold. The bypass valve and bypass plumbing interconnects the inlet and outlet manifolds. The ullage-save compressor and pressure equalization valve are mounted to the end of the canister below the vacuum cycling valves.

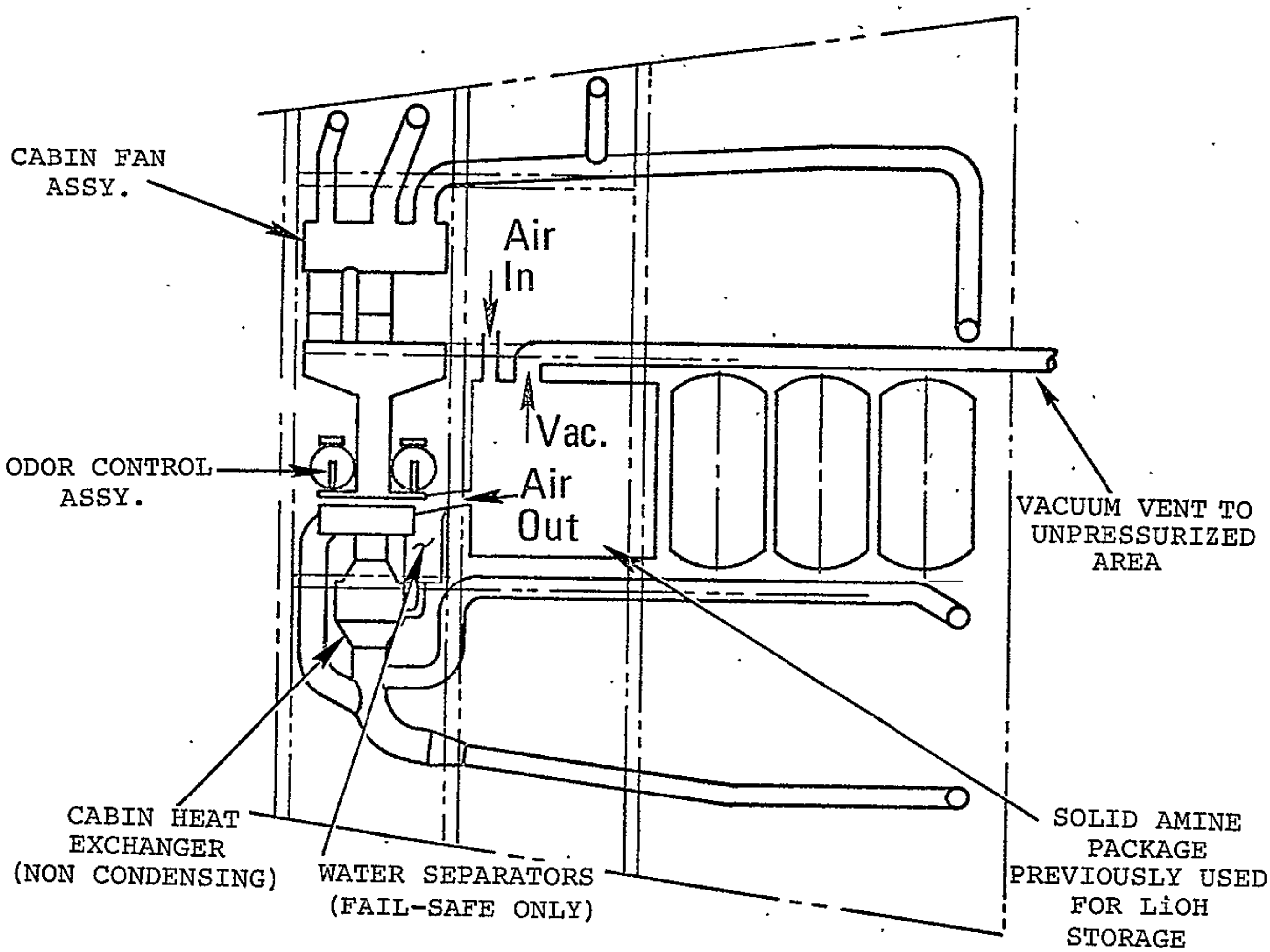


FIGURE 13

VEHICLE INTEGRATION SUMMARY

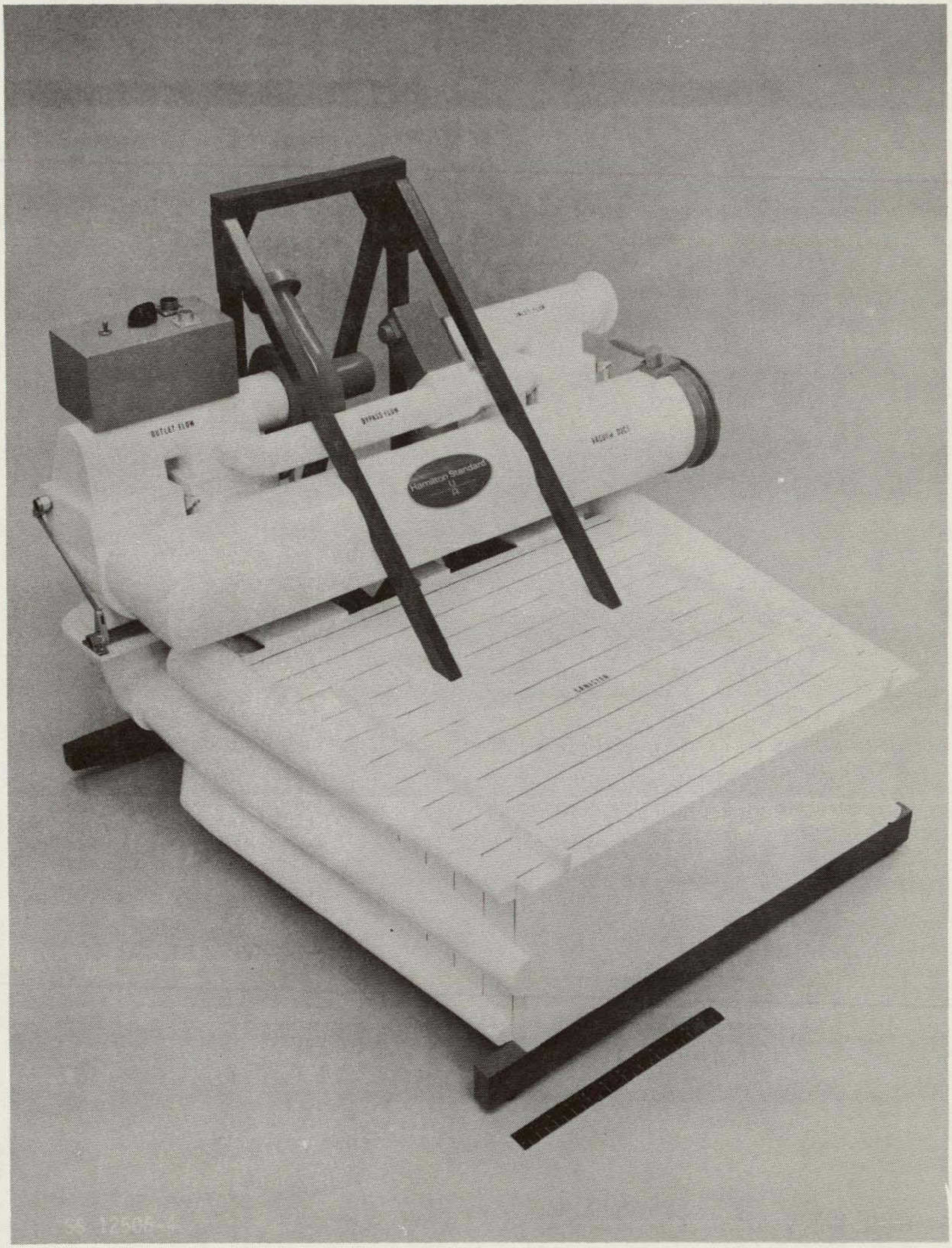


FIGURE 14(A)

MOCK-UP VIEW OF FLIGHT PROTOTYPE SYSTEM

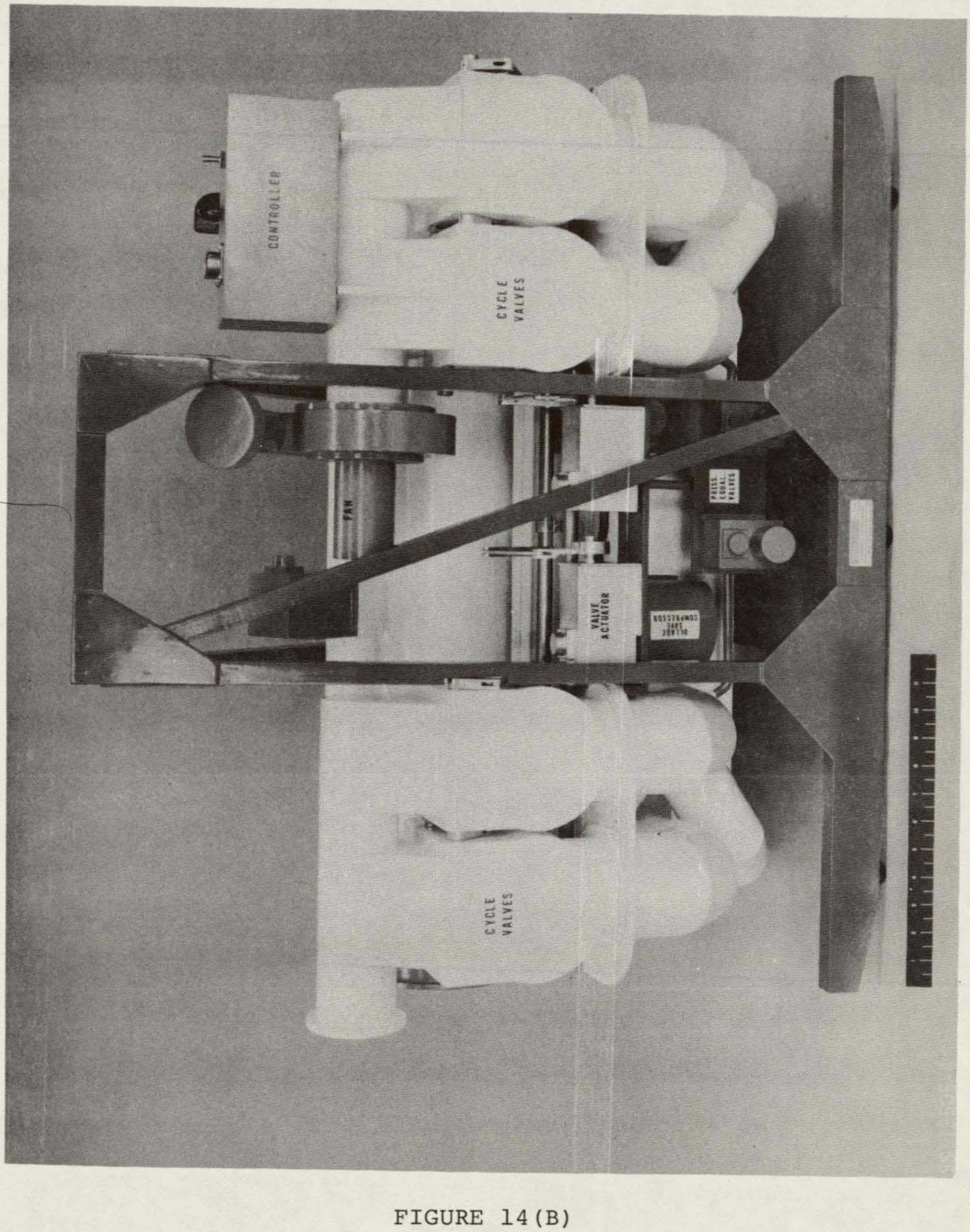


FIGURE 14(B)

MOCK-UP VIEW OF FLIGHT PROTOTYPE SYSTEM

The triangular frame is used to support ducting, wire routing, and certain components; but it is configured specifically to protect the HS-C components from damage during the waste water tankage removal/installation operation. This can be better visualized from Figure 15 which shows a profile of the installed package. From this sketch it can be seen that the frame members form a ramp that, in addition to protecting the package, actually aid in the tank removal/installation operation.

The package, with its low center of gravity, mounts directly to the outside skin frame members as shown in Figure 15. Although the top frame on the package is close to the floor structure joists, it was strictly forbidden to tie the floor to the skin because these two structures are designed to move independently in this area. As such, the package ties only to the skin structure.

The cartridge storage racks, however, do mount to the floor structure similar to the present LiOH storage racks. These racks must be easily removable to allow access to the waste tanks, and they should be located as close to the floor as possible for easy access to the cartridges themselves. As such, floor structure mounting for the independent cartridge racks is a logical conclusion. The present concept utilizes a four cartridge rack to provide baseline and many extended missions. Room is available to install a second, identical rack to allow storage of eight cartridges for the maximum mission requirements.

The full impact of the proposed vehicle design concept is that enough space is available on the present Orbiter vehicle to install a complete HS-C regenerable system together with enough on-line and backup expendables to accommodate the maximum projected mission of Shuttle (seven-man x 30-days) with the only penalty overflowing to the payload being that of fuel cell power expendables.

The present Shuttle Orbiter can accommodate four men for 10.5 days before using up its cabin stored expendables. A seven-man crew can only go 2.7 days before overflowing cabin storage into the payload area. This is one of the more significant comparisons between the expendable approach versus the regenerable approach; 2.7 days of mission capacity versus 30 days utilizing the same packaging envelope. A seven-man crew would need a volume 5.5 times as large as the present LiOH storage area to store enough cartridges for a 30-day mission. The only other storage volume is for power expendables. The increase in power expendables of HS-C over the LiOH approach of 0.65 m^3 (2.3 ft^3) or only 11% of the LiOH storage area volume.

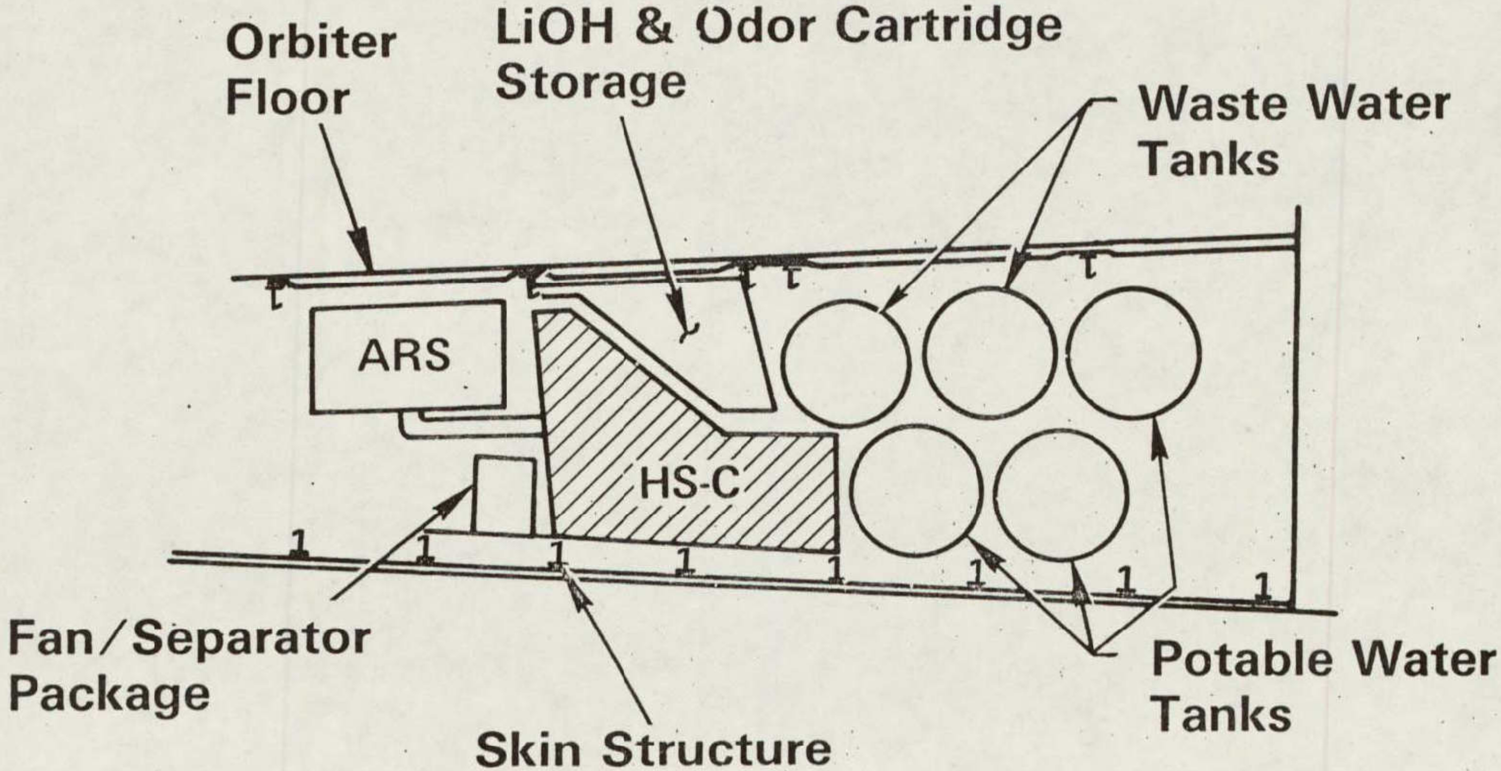


FIGURE 15
VEHICLE INSTALLATION - PROFILE VIEW

The operational performance of the flight system concept is based on actual test results of the breadboard system test program. The breadboard system tested a half-size flight configuration canister to Shuttle operational parameters as projected by the Vehicle Integration Study. The resulting flow charts for the four, seven, and ten man crews are shown in Figures 16, 17, and 18 respectively.

The resultant flight prototype system is defined by the Hamilton Standard drawing number SVSK 91725, which is shown in a reduced form as Figure 19. This system is consistent with the base system schematic shown in Figure 10. The prototype system drawing does not include the ancillary hardware, such as fan, compressor, and controller since commercial components were used for the prototype testing. These components were assembled in a separate support package and are described in that subsection. The flight prototype system and its interface with the support package are shown schematically in Figure 20.

Component Design

The component design subtask was comprised of the following requirements: Design Specifications, Canister Design, Vacuum Valve Design, and Ducting Design. Each requirement is discussed in detail in the following paragraphs.

The performance requirements for Design Specifications were prepared for specified components as listed in Table 11. These specifications are presented in Appendix B.

Canister Design

The canister was designed to flight configuration and weight requirements and is defined by Hamilton Standard drawing number SVSK 91722, which is shown in a reduced form as Figure 21.

The canister core is a configuration identical to the half-size breadboard test hardware. The canister concept is a double stack of twelve, 5.08 cm (2 inch) high and two, 2.54 cm (1 inch) high, aluminum "Duocell" foam blocks. Every other layer, or block, is headered together, providing an adsorb and desorb bed. The foam blocks are a parallelogram, having an air flow width of 7.62 cm (3 inches) as prescribed and a length of approximately 70 cm (24 inches).

Two heights of foam were used to maintain the axis of symmetry for heat transfer at the ends. One of the 2.54 cm (1 inch) high beds is headered to six of the 5.08 cm (2 inch) high beds. These thin layers are located at each end of the stack.

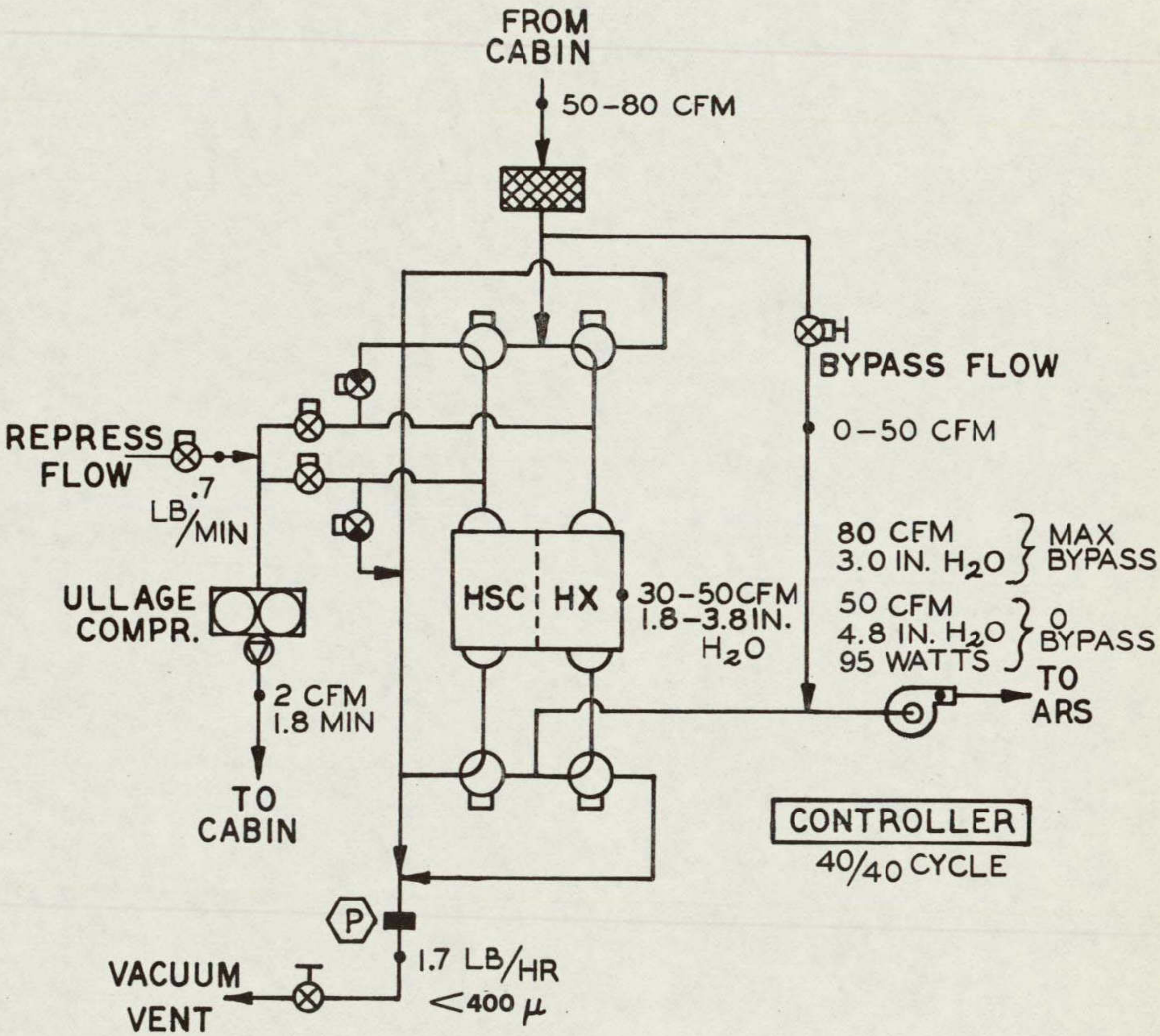


FIGURE 16

HS-C FLOW CHART 4 MAN CREW

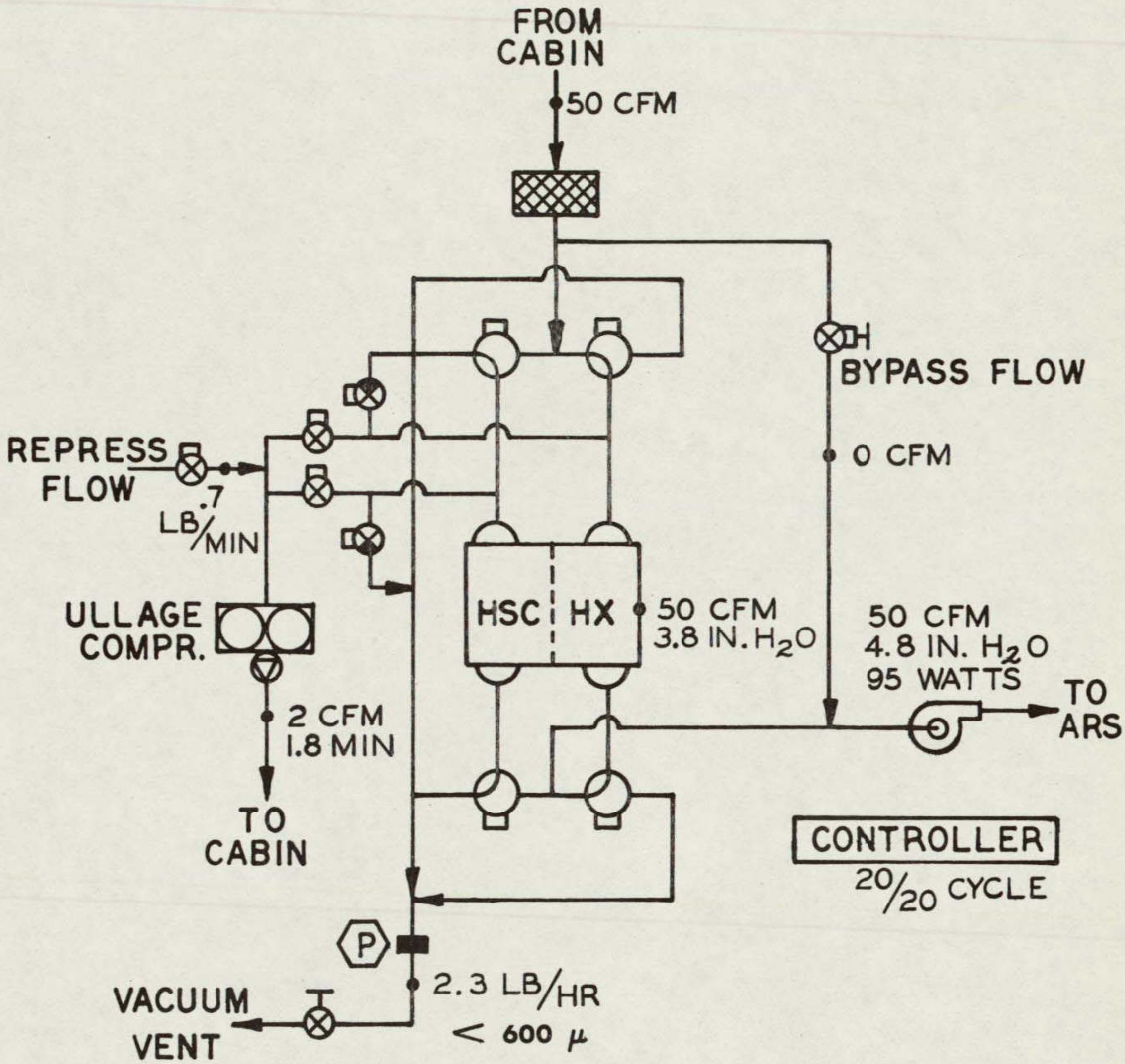


FIGURE 17

HS-C FLOW CHART 7 MAN CREW

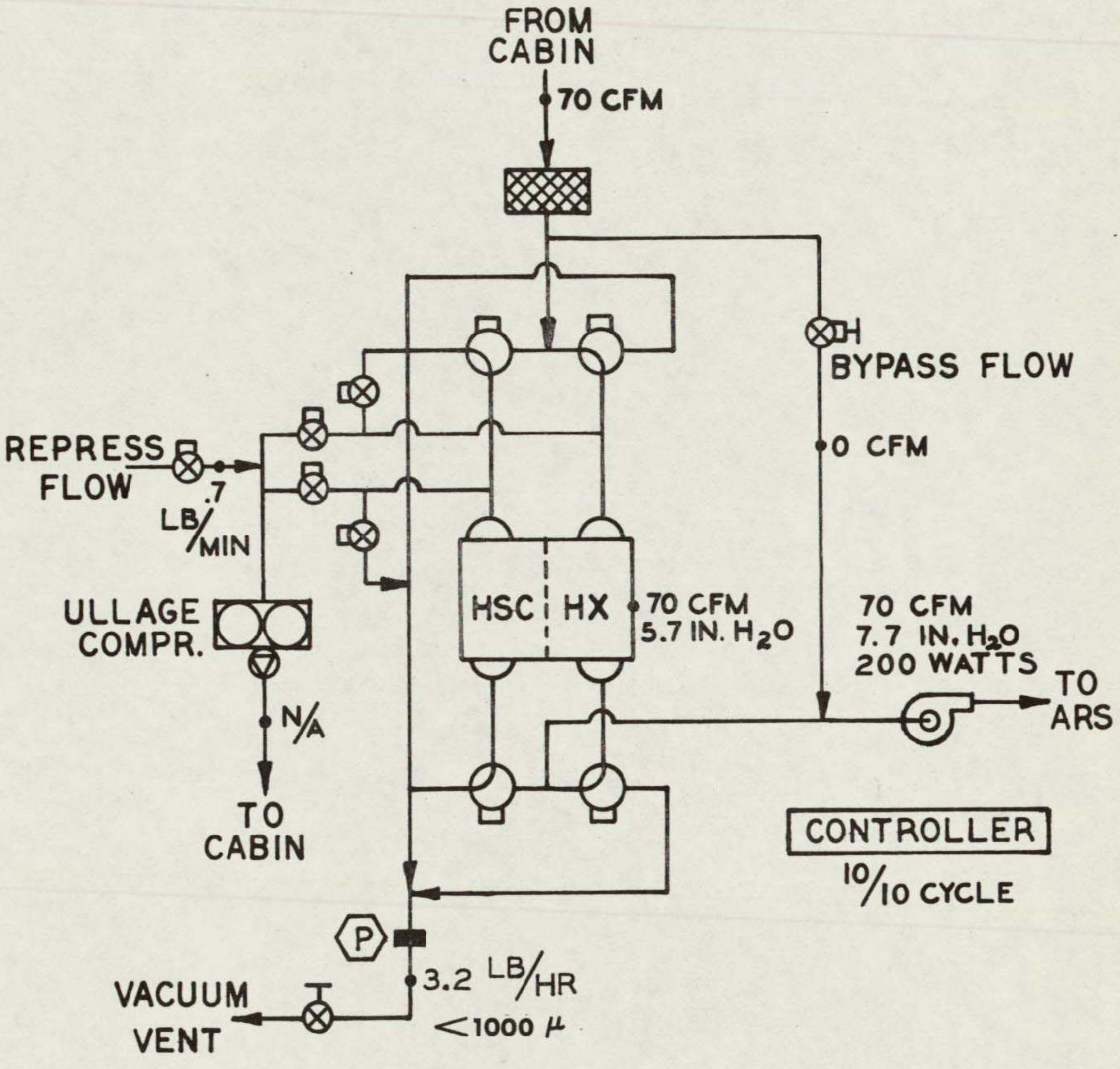


FIGURE 18

HS-C FLOW CHART 10 MAN CREW

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

FOLDOUT FRAME 2

FOLDOUT FRAME 1

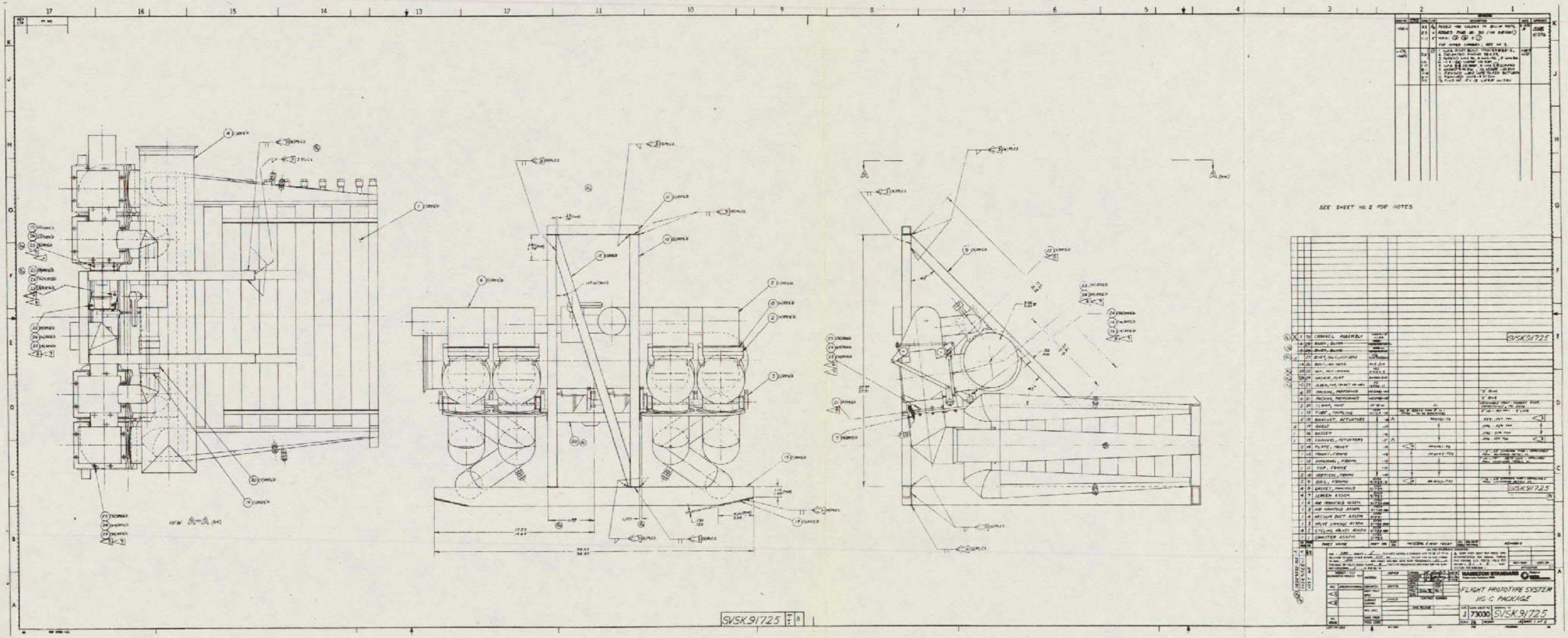


FIGURE 19

FLIGHT PROTOTYPE SYSTEM

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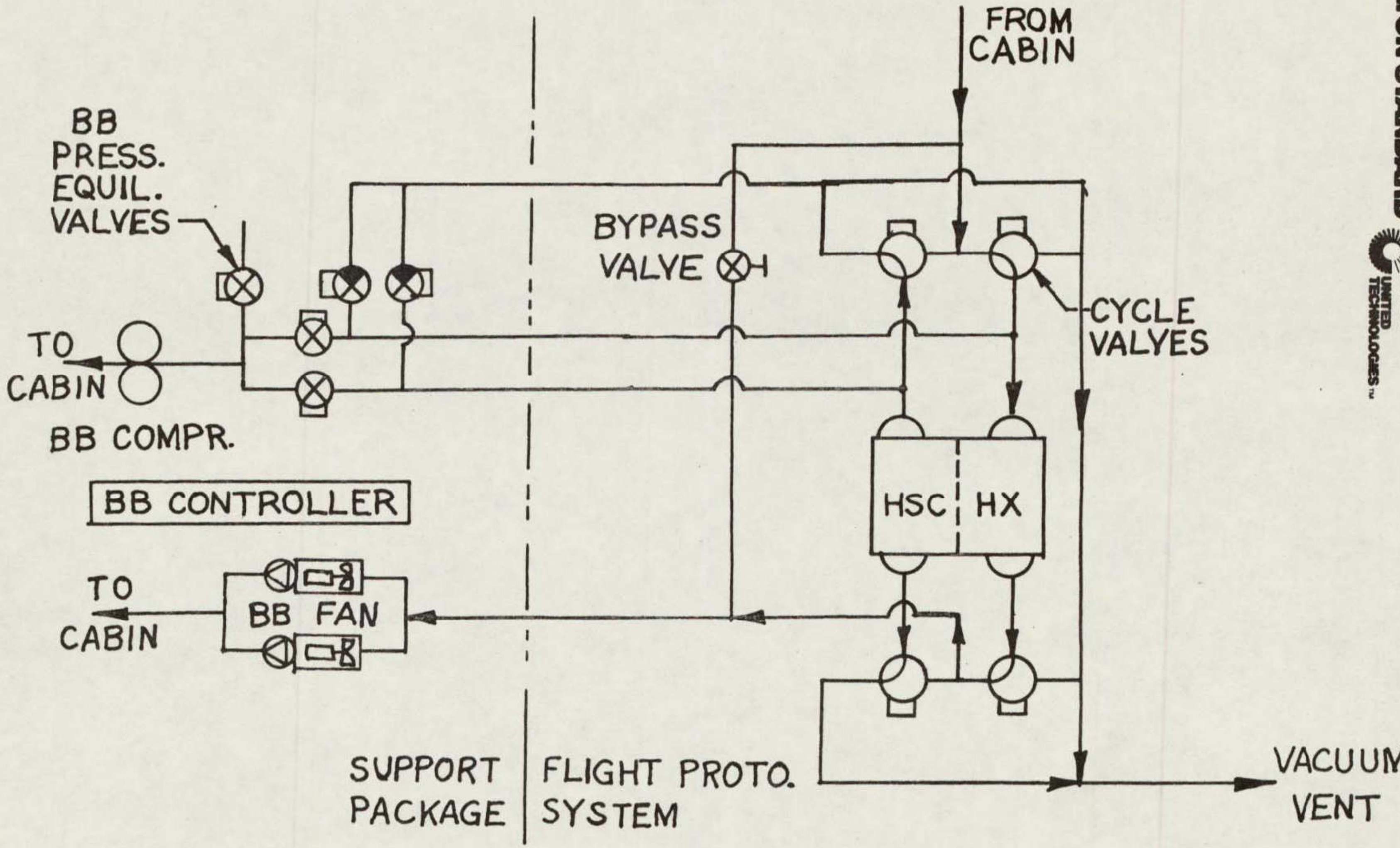

FIGURE 20
SUPPORT PACKAGE INTERFACE WITH SYSTEM

TABLE 11

COMPONENT DESIGN SPECIFICATIONS

Component	Design Specification
Canister	SVSKDR 91722
Vacuum Cycle Valve	SVSKDR 91723
Bypass Valve	SVSKDR 91796
Ullage-Save Compressor	SVSKDR 91798
Controller	SVSKDR 91948
Fan	SVSKDR 91797

FOLDOUT FRAME 1

FOLDOUT FRAME 2

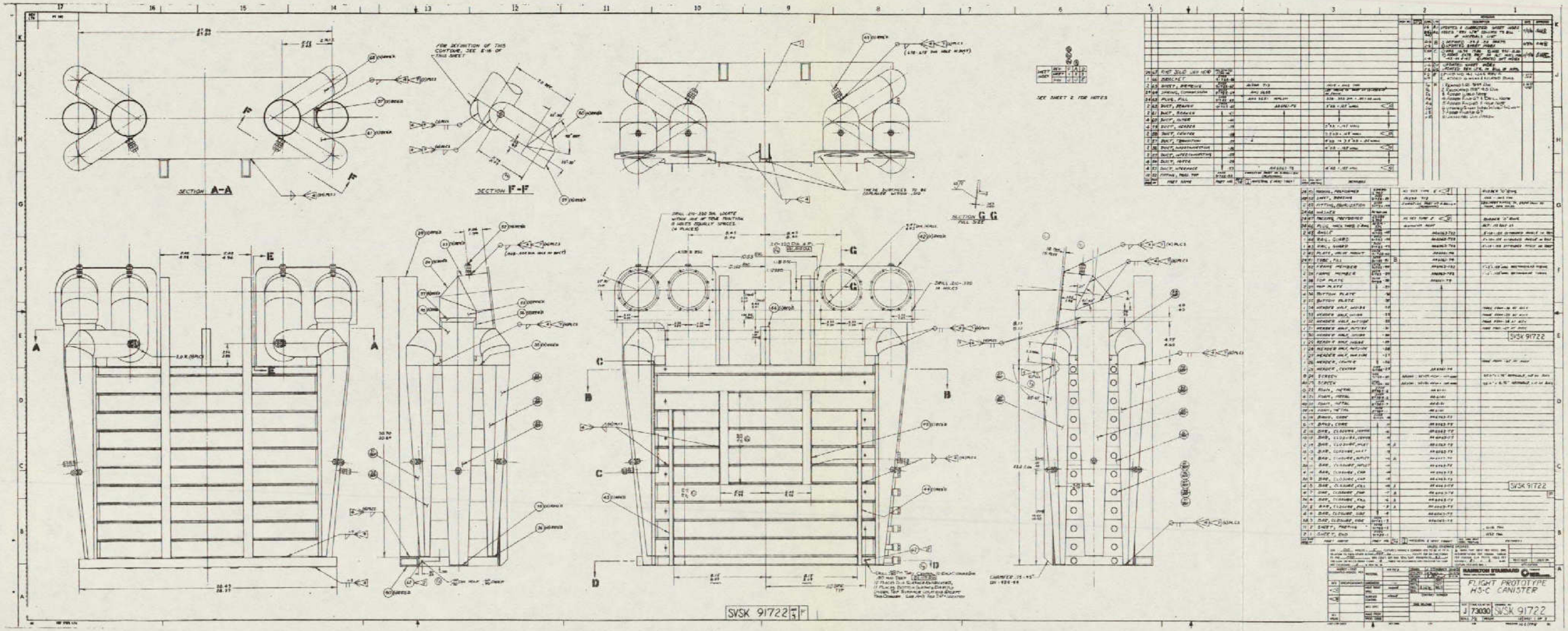

FIGURE 21

HS-C FLIGHT PROTOTYPE CANISTER DRAWING (SHEET 1)

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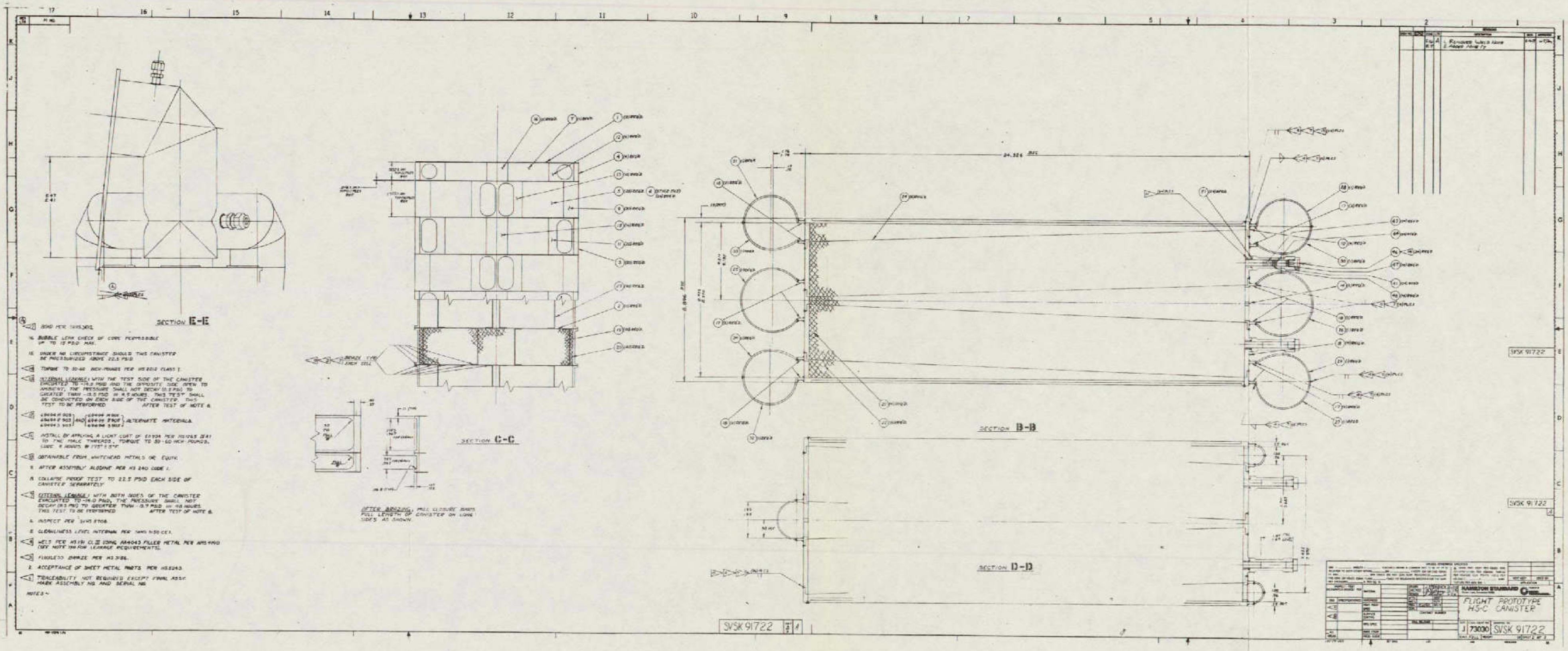

FIGURE 21

HS-C FLIGHT PROTOTYPE CANISTER DRAWING (SHEET 2)

The layers are separated by .46 mm (.018 inch) thick parting sheets. These parting sheets are supported by the extension of separate foam sections into the header area, thereby supporting the parting sheets over their entire area. This portion of the aluminum foam will not be filled with HS-C.

Retention of the HS-C material is by means of 50 x 35 mesh aluminum screen. The screen is supported on both sides by the aluminum foam, with HS-C material trapped on the inside. This design precludes buckling of the screen with resulting looseness found in test units.

The headers are located on each side of the core and connect with vacuum valve mounting plates. The three headers on the left side of the core, in Figure 22, carry the inlet flow to the bed. The larger middle header carries full flow while the two smaller outer headers each carry half flow. The outer headers are manifolded to connect to one vacuum valve. The inlet flow from the outer headers passes through the core and feeds the middle header on the outlet side of the canister while the inlet middle header feeds the outer headers on the outlet side. In this way even flow distribution and pressure drops are achieved in the canister core.

The HS-C is packed into screened sections of the core through fill tubes located in two rows between the inlet flow headers of Figure 22. Once the canister is completely full, the fill tubes are capped with a spring loaded piston to maintain a preload on each bed section.

The flight prototype canister design was based on the breadboard canister; design calculations are documented in the Interim Report, SVHSER 7103, Appendix D. The full size core is produced by joining two breadboard cores and removing the adjoining closure bars to reduce weight. The resulting core has the same height and length but twice the width of the test hardware.

Vacuum Valve Design

The vacuum valves were designed to meet the performance requirements of the vacuum valve specification, with emphasis on minimum weight, long seal life capability, and low leakage.

Each vacuum valve is a three-way swing poppet valve designed to the specific requirements of the HS-C system. The four valves are identical and are defined by the Hamilton Standard drawing number SVSK 91723, shown in Figure 23.

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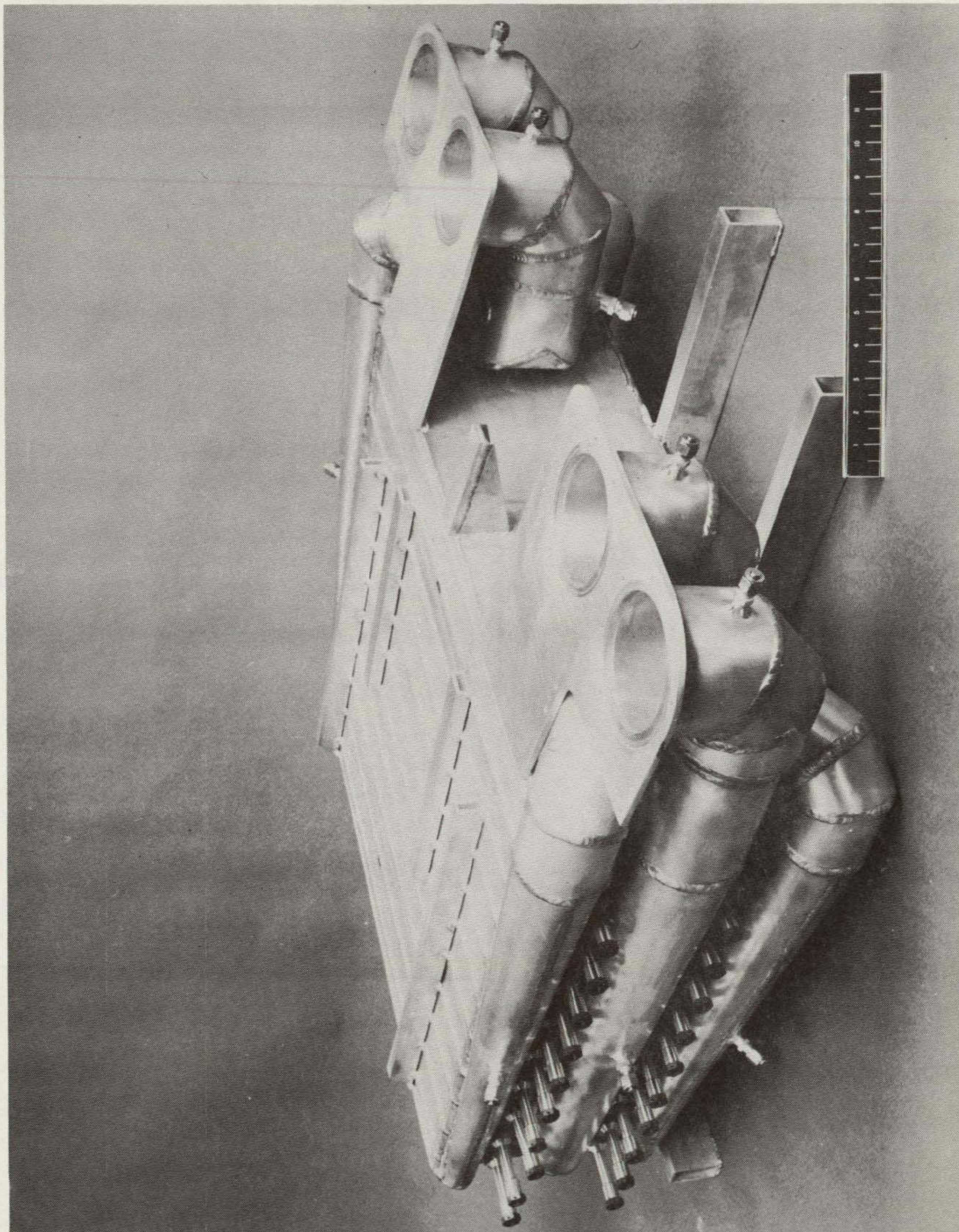

FIGURE 22

FLIGHT PROTOTYPE CANISTER

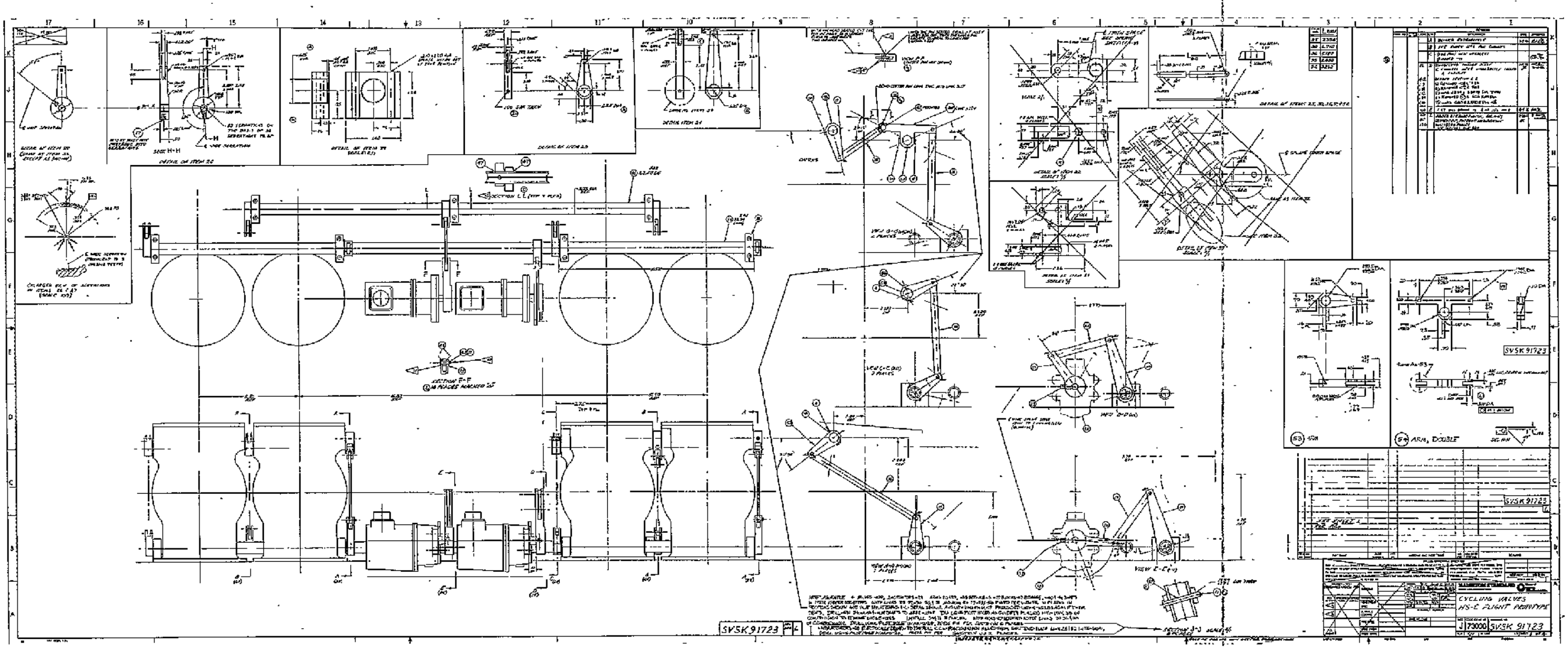

FIGURE 23

FLIGHT PROTOTYPE CYCLING VALVES (SHEET 3)

The valves mount directly to the valve mounting plate of the canister. The poppet on top of the valve allows the cabin airflow into or out of the canister. The vacuum poppet operates inside the body of the valve and closes against the large port. The airside poppet has a flow opening of 64 mm (2.5 in), whereas the vacuum poppet has a larger opening (89 mm (3.5 mm)) to allow the desorbed gases to pass freely at the low desorption pressure.

The valve poppets are operated by two independent linkage assemblies mounted to the canister. Each linkage assembly is operated by an electrical actuator and interconnects the airside poppets of one canister bed and the vacuum poppets of the other. These poppets then act in unison. To operate the canister flow, one actuator is energized to the open position. This one actuation opens one bed to adsorption and the other bed to desorption. At the end of the cycle the actuator is energized to the closed position. With all poppets in the closed position, the switchover pressure equalization and ullage-save operations are undertaken. The second actuator is then energized to operate its poppets and reverse the adsorption/desorption beds.

The protection of the cabin atmosphere has been carefully considered in the design of the entire valve setup since an accidental valve actuation could dump the cabin atmosphere directed overboard. The actuators are sized such that they cannot overcome the vacuum pressure load used to seal the poppets. Once one valve linkage assembly has been actuated, the other actuator cannot provide enough torque to open its poppets. This design feature protects against both an erroneous signal to the wrong actuator or opening an actuator if the other actuator had failed to close on the previous cycle. This latter failure is also detected by valve position indicators that interlock open/close signals in the controller and preclude out of sequence operation.

Ducting Design

The package vacuum ducting, which connects the canister vacuum valves and main vacuum duct, was designed to flight configuration size and wall thickness. The vacuum duct is defined by Hamilton Standard drawing number SVSK 91731 and is shown in reduced form in Figure 24.

The air inlet manifold and air outlet manifold were also designed to flight configuration and weight. The bypass valve that interconnects the two manifolds is a commercial valve, but its ducting is flight size and weight.

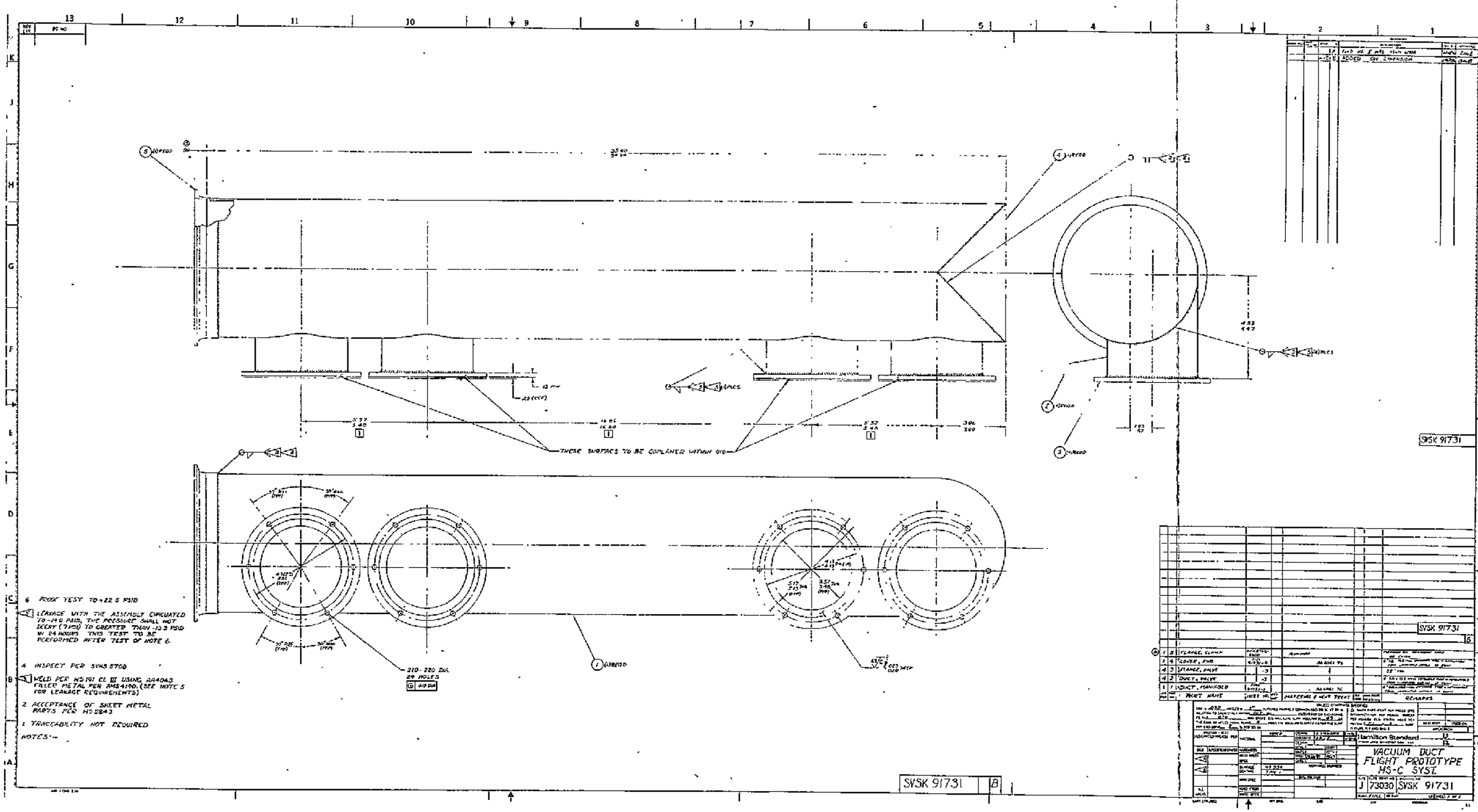

FIGURE 24

FLIGHT PROTOTYPE VACUUM DUCT

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Support Package

Where volume limitations precluded the installation of commercial items into the flight prototype package, a supporting package was designed to contain those commercial components. The support package is defined by Hamilton Standard drawing number SVSK 91726, shown in Figure 25.

The support package consists of the controller, fan, pressure equalization valves, and compressor. The support package and its interface with the HS-C flight prototype system are shown in Figure 26. This is also shown schematically in Figure 20.

Preliminary Design Review

The Preliminary Design Review was held at NASA/JSC on December 18, 1975. At this meeting a Shuttle flight concept design was presented by a full scale mock-up. In conjunction with the mock-up, an installation drawing showing mounting and plumbing of the flight package into the Shuttle Orbiter vehicle was presented. The results of the Vehicle Integration Study were also presented. This study investigated operational integration, constraints, and penalties associated with retrofitting a Shuttle Vehicle with a regenerable HS-C system and is discussed in detail in that sub-section. The flight prototype system assembly drawing and support package assembly drawing, together with detailed drawings of the canister and vacuum valves were also presented.

All action items pertaining to the designs were incorporated prior to the fabrication effort.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

SVHSER 7182

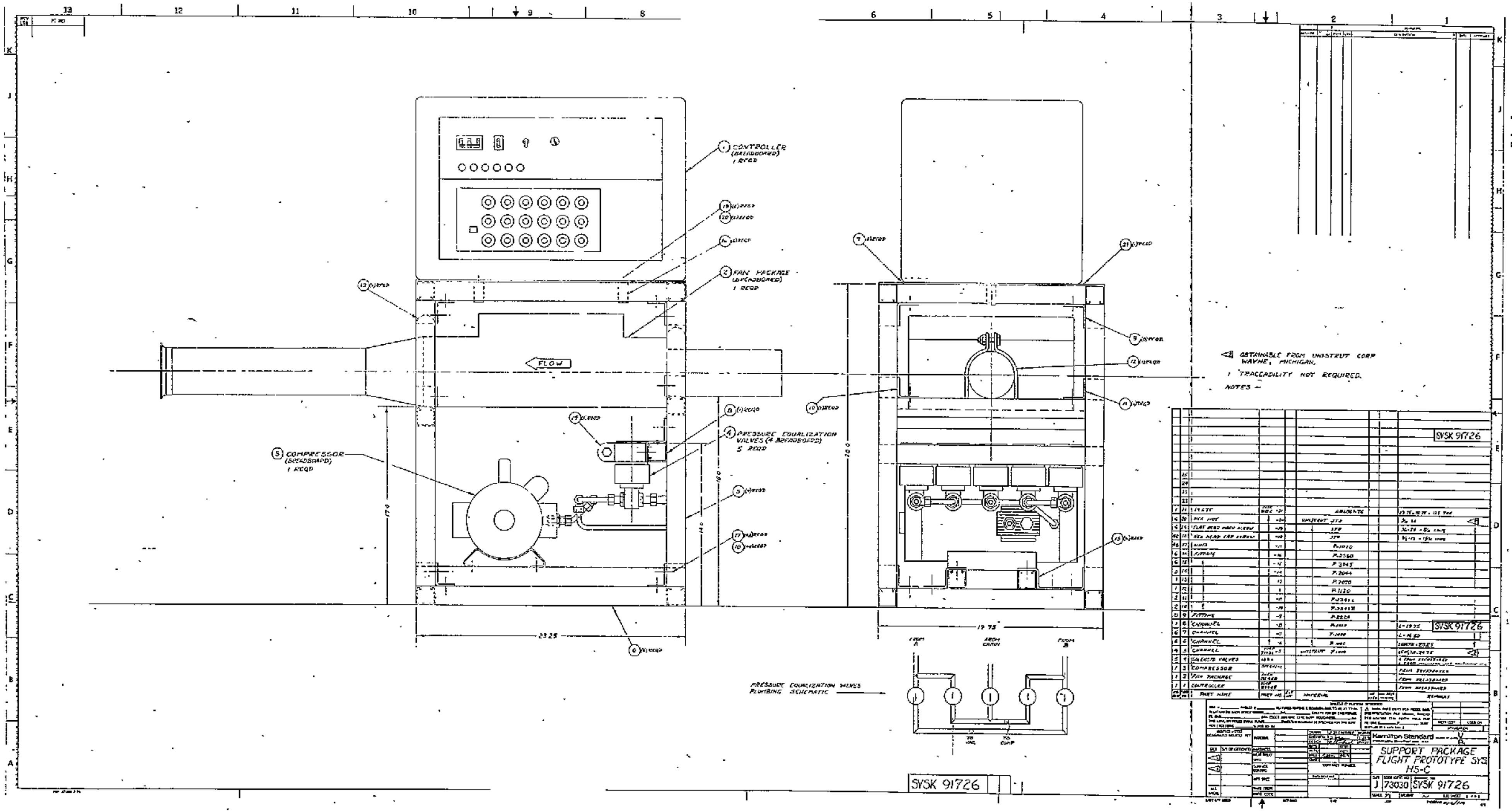

FIGURE 25

FLIGHT PROTOTYPE SUPPORT PACKAGE

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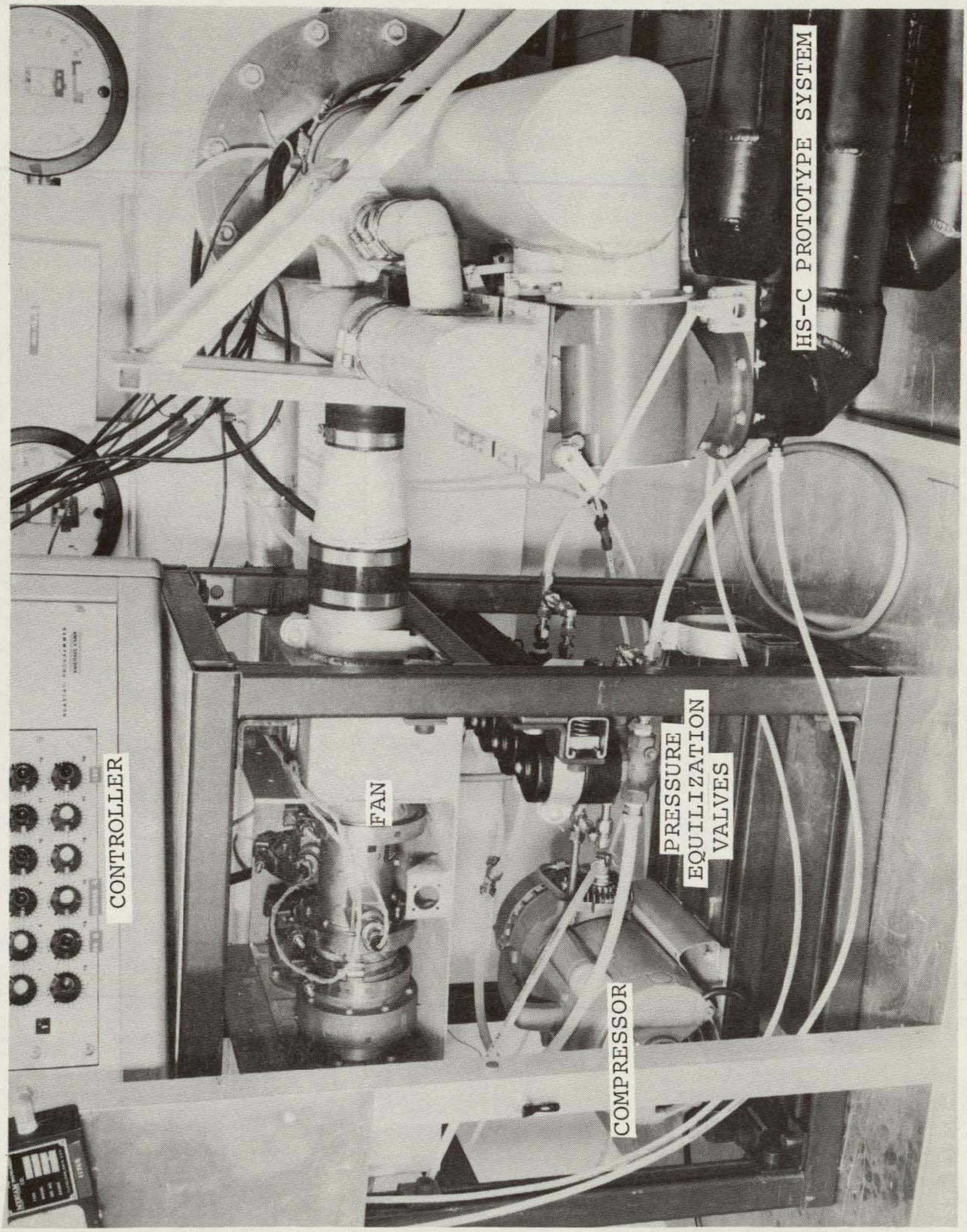

FIGURE 26

SUPPORT PACKAGE AND FPS INTERFACE

FLIGHT PROTOTYPE FABRICATION

The Flight Prototype System Fabrication Task was WBS 11.0 and identified in the Statement of Work by Section 3.2.3. The purpose of this task was to procure, manufacture, and assemble the flight prototype system and all its components. The system was assembled to the requirements of the packaging drawing, SVSK 91725, shown previously in Figure 19. The fabrication of the subassemblies is discussed in the following paragraphs.

Flight Prototype Canister

Prior to fabricating the full size prototype canister, a half-size module was fabricated to provide the manufacturing techniques and overall braze quality of the canister materials. The use of a module allowed destructive testing and analysis, as well as micro-examination of all detail areas of the core.

As part of the module effort, the woven aluminum screen was evaluated. Potential screen choices were tested for strength and also for flow pressure drop characteristics as an HS-C retention device. The screens were then installed in the canister module.

The prototype module was initiated in April, 1976. The module details were assembled and tackwelded at the layer subassembly level. All screen types were judged acceptable from an installation (cutting and folding) and assembly aspect. The module was then brazed.

Leaks were experienced in the module because of an improper technique of attaching core bands. Two of the three leaks were successfully sealed. It was decided that further leak repairs would not be productive as this type of leak would be eliminated by the correct attachment of core bands.

The HS-C canister module was cut up for detailed examination. The internal braze was excellent. The only leakage was caused by a thermocuple which had poked a hole in a screen; otherwise, all screens were leaktight. Since the thermocouple holes would be predrilled in the foam details prior to assembly of the canister, the module was considered a success. The decision was made to proceed with the full-size canister using the AA 1100 woven aluminum screening.

The canister core was started in June, 1976. The details were cleaned and assembled at the layer level. The outside closure bars of each layer were tackwelded together. The subassemblies were then stacked into the braze fixture. The core was then prepared for brazing. Thermocouples were installed into the predrilled holes in the foam. The top plate of the braze fixture was weighted with a load of 335 pounds to apply a 1.54 psi load during brazing. A photo of the instrumented stacking is shown in Figure 27 prior to brazing.

The entire fabrication process including assembly, stacking, instrumenting, weighting, and brazing was identical to the successful module effort. Unfortunately, this successful effort was not duplicated. A leak check revealed that the outside closure bars were only marginally brazed to the parting sheets. When weld repair operations were undertaken, several leaks were caused by thermal stresses of adjacent welding.

A MIG (Metal Inert Gas or gas metal-arc) welding technique was selected for further repairs. Sections of the canister module were used to establish the schedule (feed rates and heat rates) of the automatic welding equipment. MIG welding was chosen because it minimizes the heat input to the canister, also minimizing the thermal stresses and heat distortion. The test welds were analyzed by micro-examination to be excellent, and the technique was used on the canister. The welded canister is shown in Figure 28.

The second leak check revealed that excessive leakage existed under the weld repair areas to such an extent that further weld repair would be unproductive. With NASA concurrence, a heat exchanger epoxy fix operation was attempted. The epoxy was applied along the perimeters of all parting sheets along the closure bars. The leakage was reduced to 2.5×10^{-6} m^3/s (0.024 lb/hr) of STP air, which was less than the breadboard canister.

The prototype canister was then machined per the drawing to reduce the weight of the long closure bars for a weight reduction of nine pounds. A leak check showed no change due to the machining stresses and vibration.

The header pieces were successfully fabricated, fitted, and welded to the core per the canister drawing. The header configuration was complex; the headers were tapered with a skewed centerline to minimize ullage and allow access for HS-C filling. The fabrication of the canister was completed with the welding of the transition ducting and valve mounting plates.

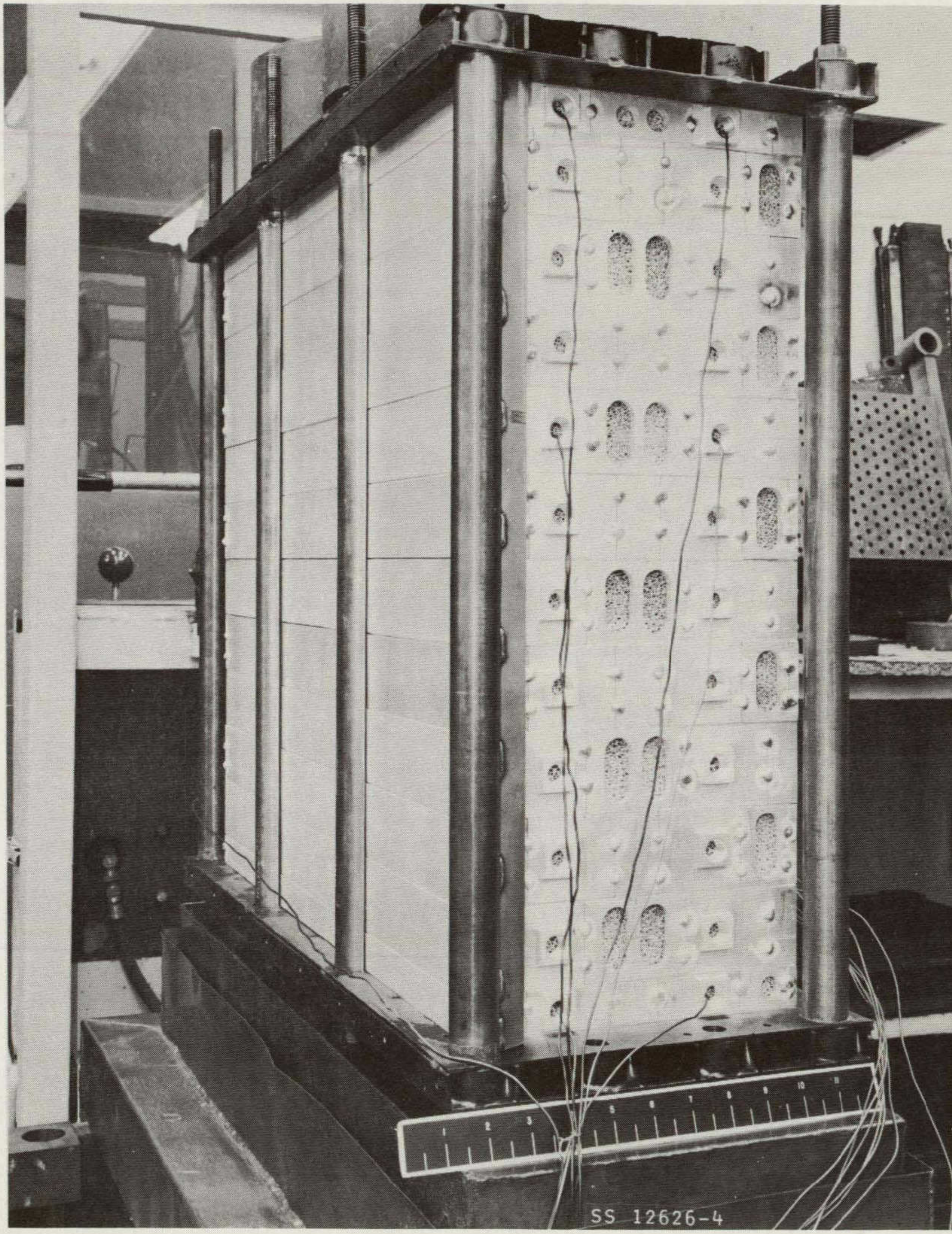

FIGURE 27
PROTOTYPE CANISTER PRIOR TO BRAZING

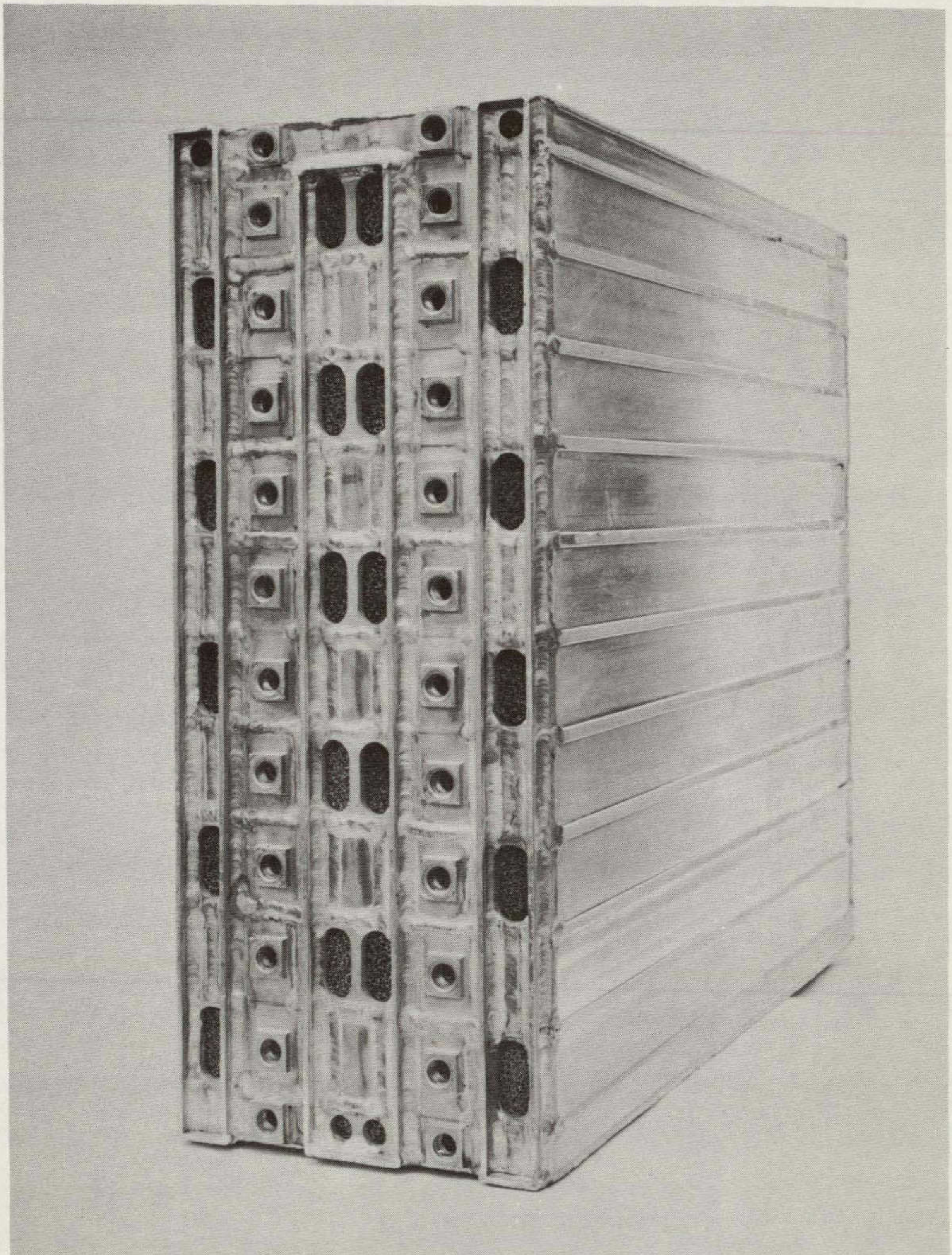

FIGURE 28

COMPLETED CANISTER CORE

The final welding operations reopened some of the previous leaks in the core. The leaks were again sealed using the epoxy technique. The final canister internal leakage was 3.99×10^{-7} m^3/s (3.8×10^{-3} lb/hr) while external leakage was 4.2×10^{-8} m^3/s (4×10^{-4} lb/hr).

The completed canister was weighed at 95 pounds which is 29 pounds above design weight. Approximately eight pounds is due to the weight of the frame. The closure bars were not weight reduced by machining as much as the design specified because of slight distortions in the core due to the excessive welding. The poor braze of the canister unit was later determined to be due to a braze oven contamination problem. As such, it is believed that the canister full-size module successfully demonstrated the manufacturing technique and that an acceptable prototype canister can be made.

The canister was then filled with the HS-C chemical. The chemical in each layer was weighed as it was loaded into the canister. The canister was filled in two steps: first, the odd layers were charged through funnels and vibrated until settling of the chemical had stopped; and second, the even layers were charged in the same procedure. The odd layers were filled with the HS-C material used during the breadboard testing; this bed was designated Bed "A". The even layers were filled with unused HS-C from the same manufacturing batch and was designated Bed "B". All layers were then fitted with glass fill tubes. These tubes were filled with chemical, and the canister was rocked and rotated in all planes while being vibrated. The vibration load was applied to different points on the canister, and settling in all tubes was noted. This process was repeated until no settling was noted. The total weight of HS-C added was 18.8 kg (41.4 lb) compared to the target of 19.0 kg (42.0 lb).

During the filling procedure, it was noted that the rate at which the HS-C material flowed into the canister was slower than that experienced during the breadboard filling operation. It was concluded that the smaller diameter fill tubes of the flight prototype canister allow the static charge of the HS-C spheres to impede the flow of the material into the canister core. It is, therefore, recommended that the fill port design be modified to incorporate larger diameter fill tubes.

The completed flight prototype canister is shown in Figure 29. The fill ports are easily recognized on the canister side.

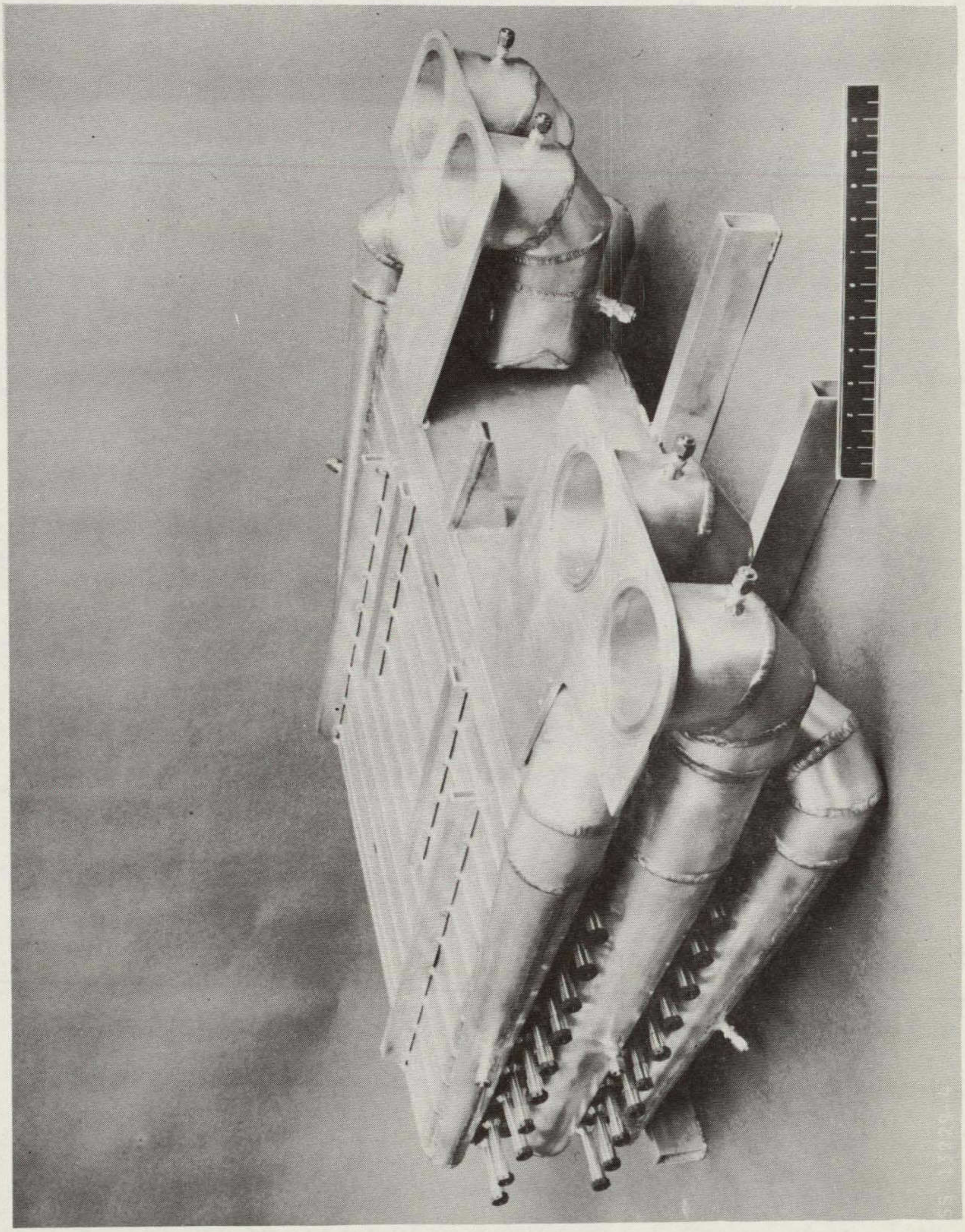

FIGURE 29

FLIGHT PROTOTYPE CANISTER ASSEMBLY

Vacuum Valve

Assembly of the first two vacuum valves was begun in June, 1976. Careful examination of the valves showed an unexpected seating action of the poppet. The poppet was expected to engage the valve seat in an axial direction with no lateral motion between the poppet and seat. However, the poppet actually slid 0.020 inches in a lateral direction as the leaf spring loaded the poppet. This valve seating action was unacceptable, and the leaf spring configuration was redesigned. The revised spring produced an acceptable poppet seating action, and the valve assembly was completed.

The assembled vacuum valves were weighed and were 1.92 kg (4.25 lbs) each for a total system weight of 7.7 kg (17 lbs). This verified the 7.7 kg (17 lbs) in Table 1 for the total prototype system weight. The valves, together with the linkage and actuators, are expected to meet the 9.7 kg (21.5 lb) target weight.

The completed vacuum valve assembly is shown in Figure 30.

Support Package Fabrication

The support package fabrication was completed in January, 1976. This package contains the ancillary components needed to supplement the flight prototype package in providing a total system. The electrical controller used during breadboard testing was modified and rewired for use with the flight prototype system. The components were assembled per the blueprint SVSK 91726.

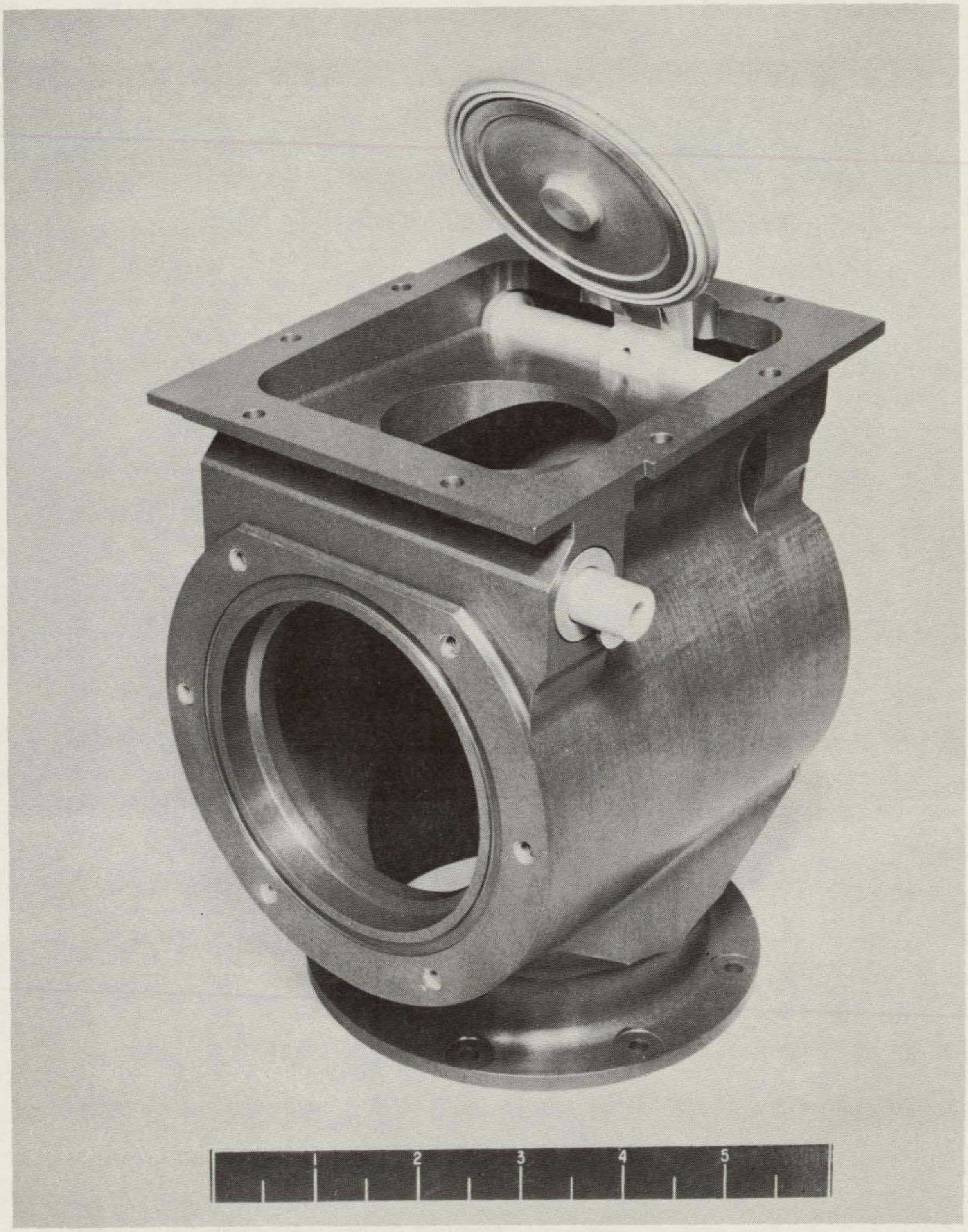

FIGURE 30

FLIGHT PROTOTYPE VACUUM VALVE

Leakage was calculated from the ideal gas formula and factored according to the full pressure differential recorded.

$$\text{Leakage} = 0.3\ \frac{(\text{Volume})(\text{Delta Pressure})}{\text{Time}} \quad \frac{(14.7)}{(14.7\text{-Press.})}$$

where: Leakage = lb/hr
Volume = ft^3
Delta Pressure = psi
Time = minutes
Press. = Evacuated Press. = psia

The prototype canister leakage was measured on April 6, 1977 upon completion of filling the canister with the HS-C material. The leakage was slightly higher than the specified limits. Both beds were approximately 3.5 times the maximum internal leakage allowed and four times the external leakage specification, as shown in Table 12. However, the internal leakage measured on May 20, 1977 for the flight prototype system was within the canister leakage, indicating that the blank-off tooling may have had a slight leak. The canister leakage probably resulted from the marginal brazing of the unit, as discussed previously. It is believed that a properly brazed unit would be within leakage specifications.

TABLE 12

PROTOTYPE CANISTER VACUUM LEAKAGE

	Leakage m^3/s (lb/hr) Specification	Actual
Bed A*	1×10^{-7} (1×10^{-3})	3.4×10^{-7} (3.3×10^{-3})
Bed B*	1×10^{-7} (1×10^{-3})	4.0×10^{-7} (3.8×10^{-3})
Bed A & B+	1×10^{-8} (1×10^{-4})	4.2×10^{-7} (4.0×10^{-4})

*Internal plus external leakage
+External leakage only

Vacuum Valve Testing

The purpose of this test was to demonstrate the ability of the valve to satisfy the design requirements over the projected Shuttle ten-year life.

The vacuum valve was tested per the Plan of Test, SVSKTR 91723. The test sequence was Examination of Product (EOP), Proof, Leakage, Life, and Post-Test EOP. Each test is described in detail in the following paragraphs.

The objective of the EOP was to establish that the valves meet the blueprint requirements prior to initiating testing. Since only half of the system was to be tested, two valves were assembled. One valve was assembled with the air side hardware, while the second valve had the vacuum poppet subassembly. The assembled valves met the blueprint requirements.

The purpose of the Proof Test was to verify the pressure integrity of the test hardware. The test setup is shown in Figure 31. The valves were installed on the tooling fixture and blanking plates installed at each valve's vacuum port. The valves were connected with the flight prototype linkage operating the vacuum poppet in one valve and the air side poppet in the other valve. A pneumatic actuator was used to operate the linkage. The valve housings were capped and plumbed to a regulated gas supply. A close-up of the valves and actuation setup is shown in Figure 32.

Testing of the valves was initiated on September 23, 1976. The vacuum valves easily passed the Proof Pressure Test. After maintaining a pressure of 255 kPa (37 psia) for seven minutes, the valves showed no visible or audible sign of deformation or damage. The valves actuated normally after the test and, therefore, passed all criteria of the Proof Test.

The objective of the Leakage Test was to demonstrate the initial and lifetime leakage integrity of the test items. In order to perform the pressure decay leakage test accurately, the internal volume of the valves was calculated by using a known volume of gas and measuring the pressure differences when the two volumes were in equilibrium. The leakage was then measured by recording the changes in pressure and temperature with respect to time. The external leakage recorded for valve #1 was 2.57×10^{-10} m^3/s (2.45×10^{-6} lb/hr) and for valve #2 was 1.75×10^{-10} m^3/s (1.67×10^{-6} lb/hr). This was 1/10 of the allowable leakage rate. Internal leakage was 1.75×10^{-10} m^3/s (1.67×10^{-6} lb/hr) and 4.2×10^{-10} m^3/s (4.01×10^{-6} lb) for valves 1 and 2 respectively, well within the specified 1.05×10^{-9} m^3/s (1×10^{-4} lb/hr) limit.

Endurance testing of the vacuum valves was then initiated on September 30, 1976. The objective of the Life Test was to demonstrate a life capability of 45,000 cycles for both the valve and valve linkages. This 45,000 cycle requirement represented 2.5 times the projected 10-year, 100-flight mission life of the Shuttle.

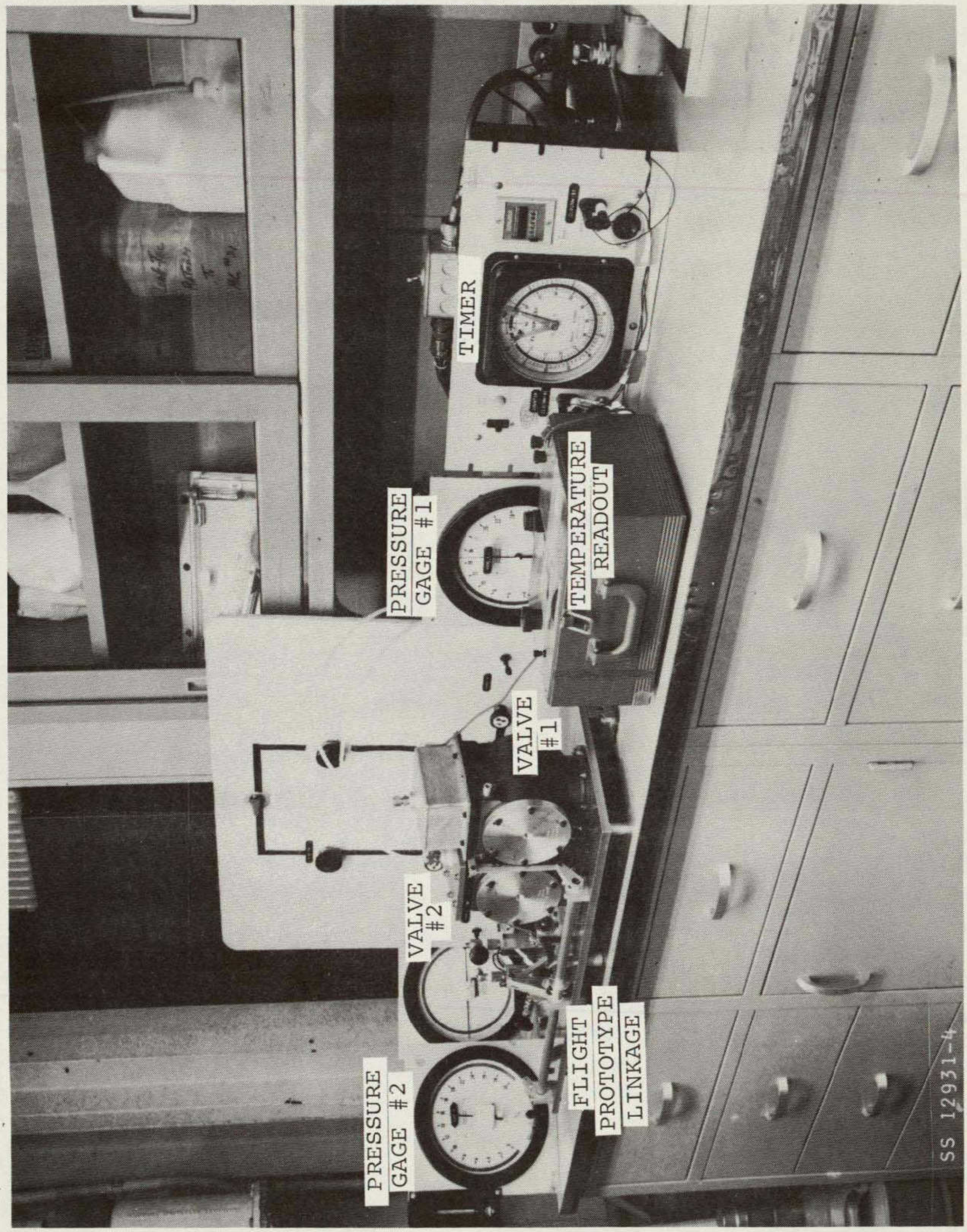

FIGURE 31
VACUUM VALVE TEST SETUP

C-2

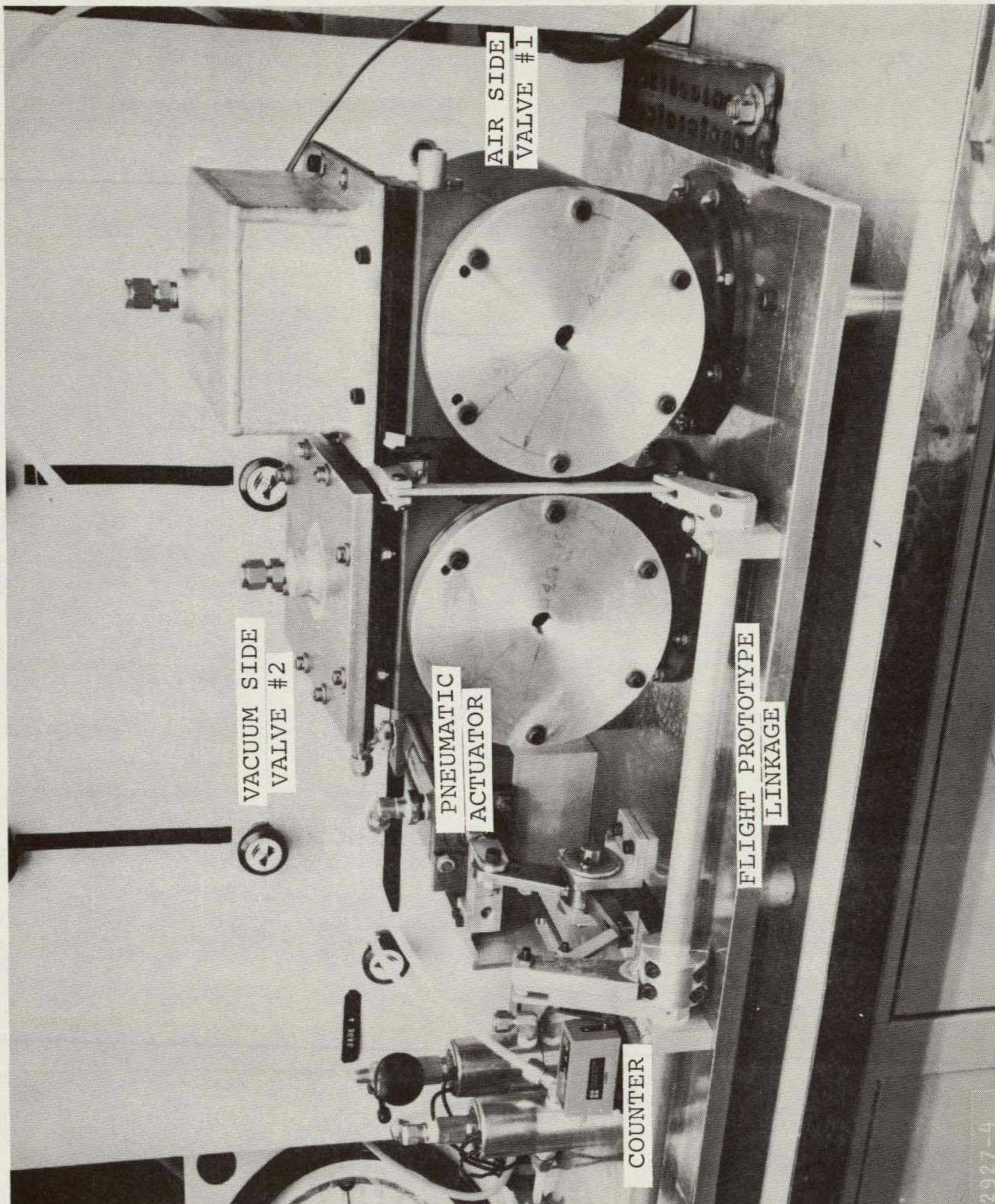

FIGURE 32

VACUUM VALVES ON TEST

As seen in Figures 31 and 32, the valve housings were capped off and plumbed to a regulated gas supply. The valves were interconnected with the flight prototype linkage system, thus assuring operation identical to flight prototype design. The valve poppets were pressure closed on each cycle and opened against a higher than normal opening pressure to assess the effect on seal wear. The system was tested for internal leakage after every 5,000 cycles.

A visual inspection of both valves after 5,000 cycles revealed corrosion contamination of the poppet and seat of the air side test valve, as shown in Figures 33 and 34. The corrosion or corrosive environment was introduced into the test setup by a pressure gage which contained water from a previous test. This accident is considered a freak since under the normal operation the valves are being continually vacuum dried, and the environment is non-corrosive. As such, this condition was not considered a valve failure. The valve leakage rate at 2.97×10^{-5} lb/hr of STP air was only one third of the allowable level after 5,000 cycles. The decision was made to continue testing the good valve and replace the contaminated valve at the first convenient point.

The test valve with the vacuum side poppet was tested for 20,000 cycles when the contaminated valve was replaced. An inspection of the rig plumbing showed the same corrosion deposits as found in the test valve. As a result, the entire rig plumbing circuit was replaced, as well as the pressure gage at fault. The vacuum side test valve, with 20,000 accumulated cycles, was not disturbed or adjusted during this operation.

The endurance testing was then continued with 20,000 cycles on the vacuum side test valve and zero cycles on the air side test valve. The vacuum side test valve had successfully completed testing with 45,000 cycles, while the air side test valve had accumulated 25,000 cycles. It was decided to continue testing the vacuum side test valve until the air side valve achieved 45,000 cycles since no degradation in performance was measured over its 45,000 cycles test life.

The endurance test was successfully completed on November 12, 1976. The leakage history during testing is shown in Figure 35. At the end of the test period, the vacuum poppet had a leakage rate of 1/100 the allowable amount after 60,000 cycles. The air-side poppet had a leakage rate of 1/50 the allowable level after the design goal of 45,000 cycles. Both poppets far exceeded the requirement and no degradation was detected during the test. The drop in leakage at the end of testing was due to a more accurate

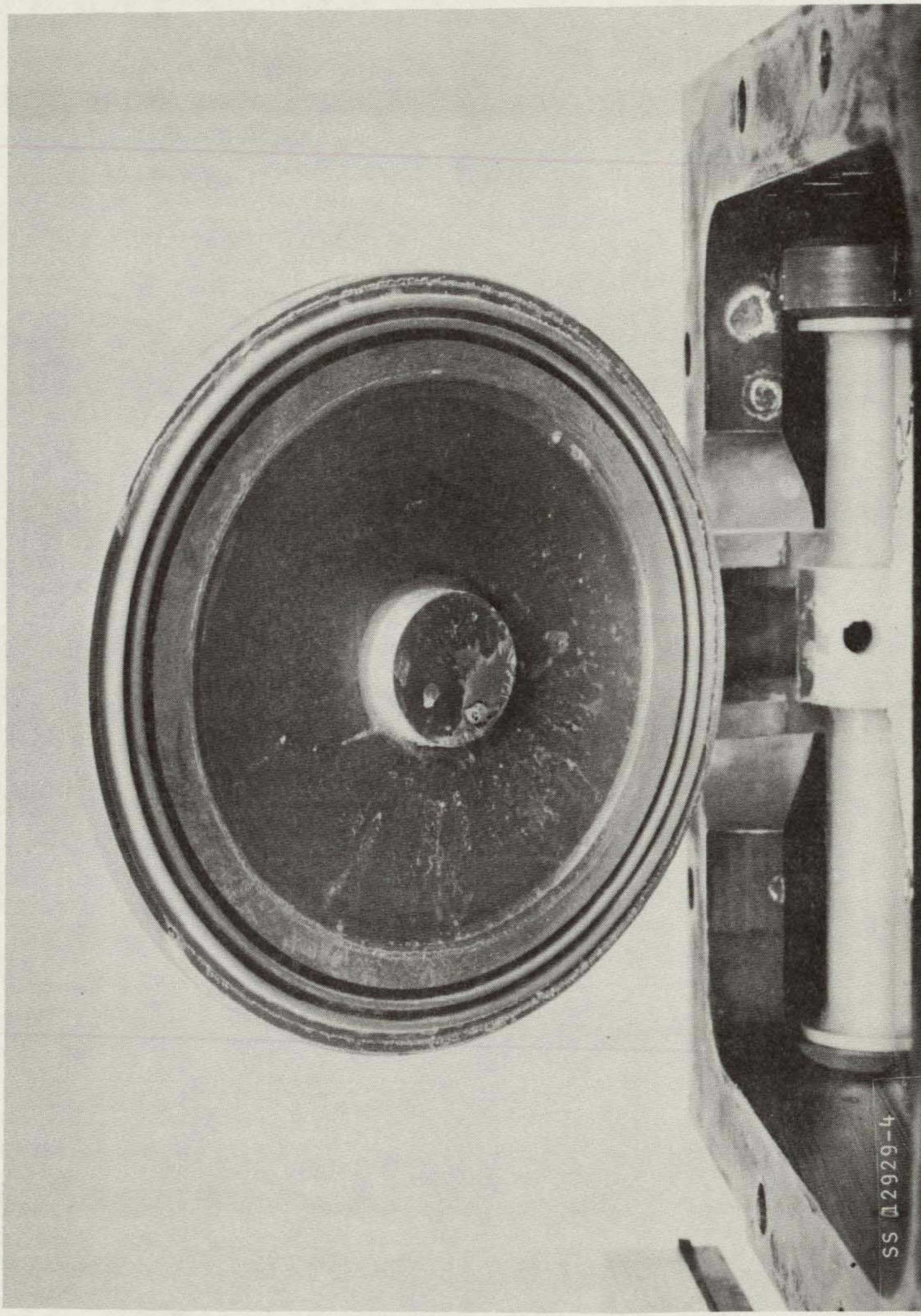

FIGURE 33

CORRODED AIR SIDE POPPET OF VACUUM VALVE

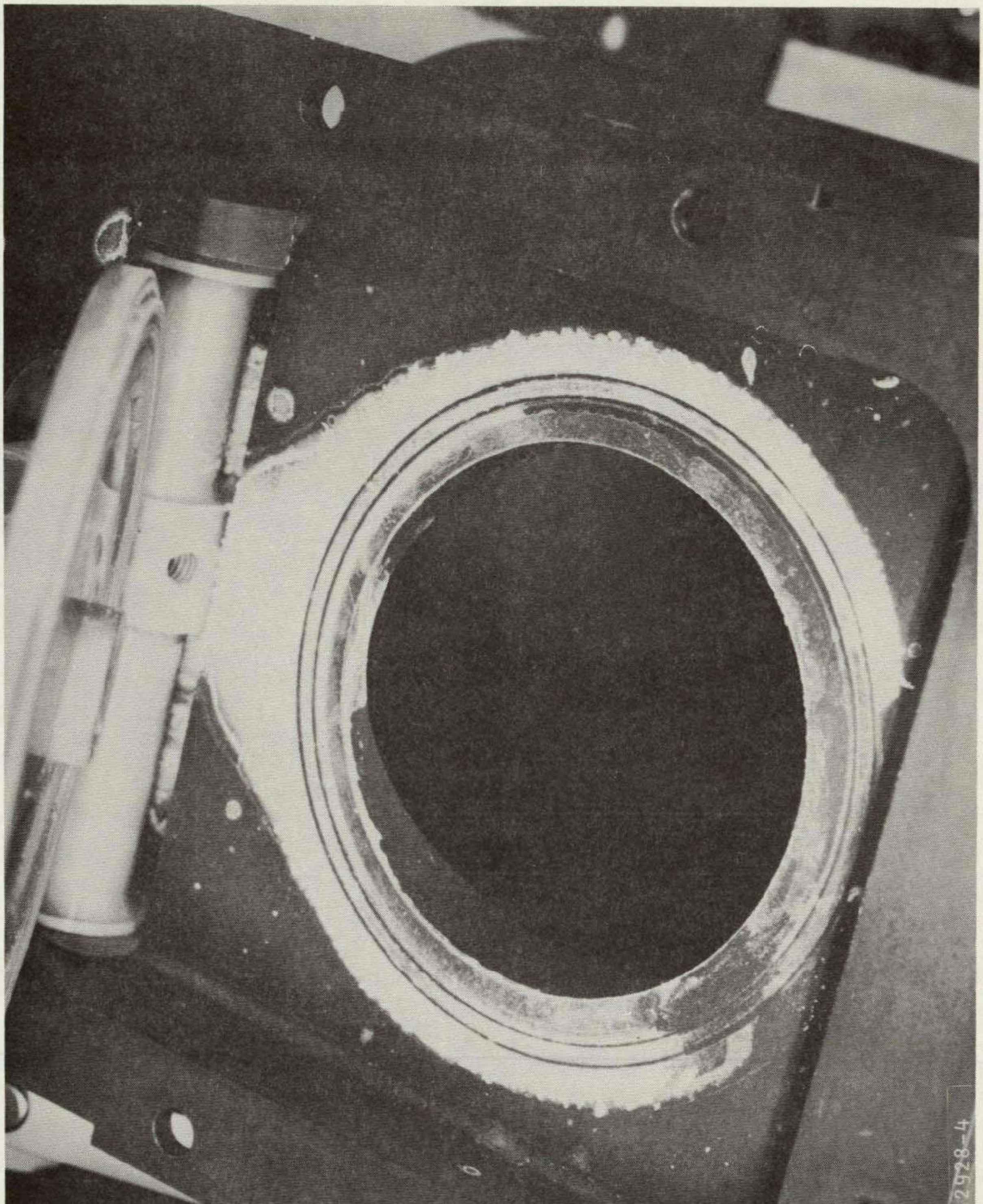

FIGURE 34

CORRODED VACUUM VALVE - AIR SIDE SEATING SURFACE

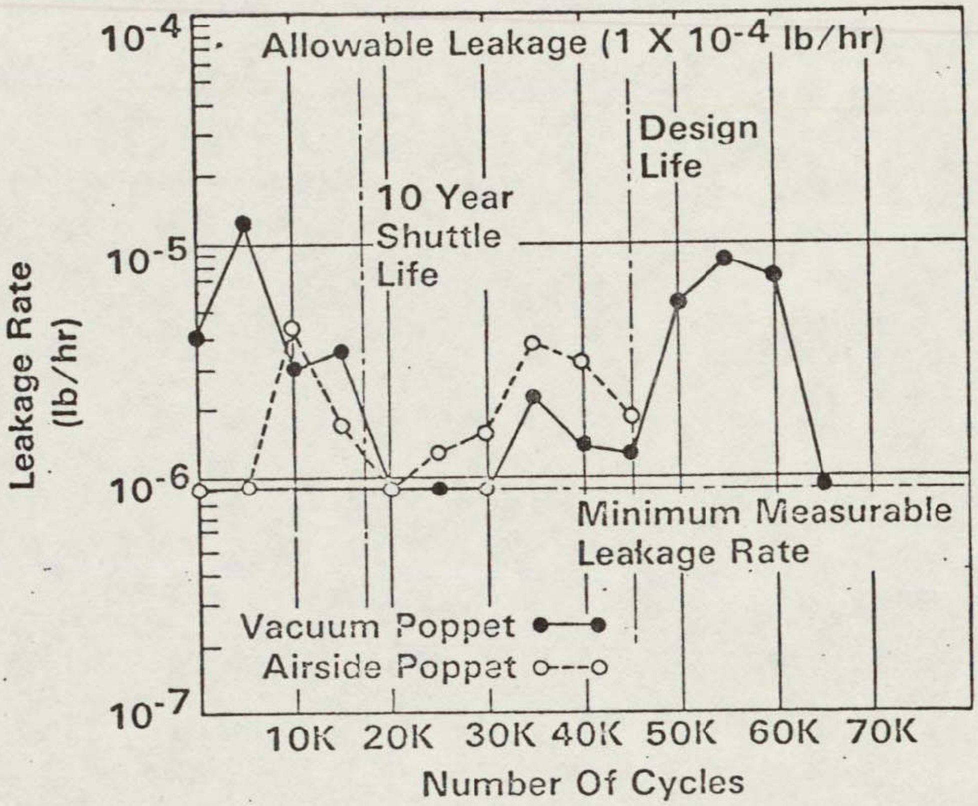

FIGURE 35

VACUUM VALVE ENDURANCE TESTING

leakage test at the end than existed during testing. The leakage test used during the cycle test was designed to measure leakage accurately at the failure condition. Inaccuracies were introduced when the hardware was actually 100 times better than required.

The post-test examination of the hardware was conducted at the completion of the endurance cycles. The air side hardware is shown in Figures 36 and 37 and is typical of the condition of both valves. No seal wear was detectable on either valve after testing. Therefore, all requirements per the Plan of Test were completed, and the design integrity of the vacuum valve was confirmed.

Valve Actuator Testing

Testing of the valve electrical actuator was conducted separately to simulate full actuation loadings rather than the half loading that would have been encountered with the valve test setup. The test setup is shown in Figure 38. The actuator fixture simulated the poppet loading force which occurs only at the end of the actuator stroke.

Endurance testing of the actuator was started on August 3, 1976, with a target goal of 10,000 cycles. After 8,657 cycles, the actuator could not be restarted. The actuator was analyzed by the vendor, General Design of Sun Valley, California, who concluded that the starting capacitor was defective. The electrical actuator is similar to Shuttle with the exception of this capacitor. On Shuttle, the actuators are purchased without this capacitor since a high reliability capacitor cannot fit into the actuator envelope. The starting capacitors are packaged in the electrical controllers, as would be the case for a flight HS-C design. The defect was, therefore, considered non-applicable to a flight actuator. The test actuator was reworked to replace the capacitor without disturbing any other parts. Endurance testing was then continued until an additional 46,000 cycles were performed, for a total of 54,662 cycles. This cyclic test confirmed the ability of the vacuum electrical actuator to perform over three times as long as the projected Shuttle life.

Flight Prototype System Test

The purpose of the flight prototype system test was to verify the design of the system and to demonstrate system performance when subjected to Shuttle metabolic load requirements.

This test demonstrated that the HS-C canister, vacuum valves, and system concept were ready for application in the Shuttle vehicle.

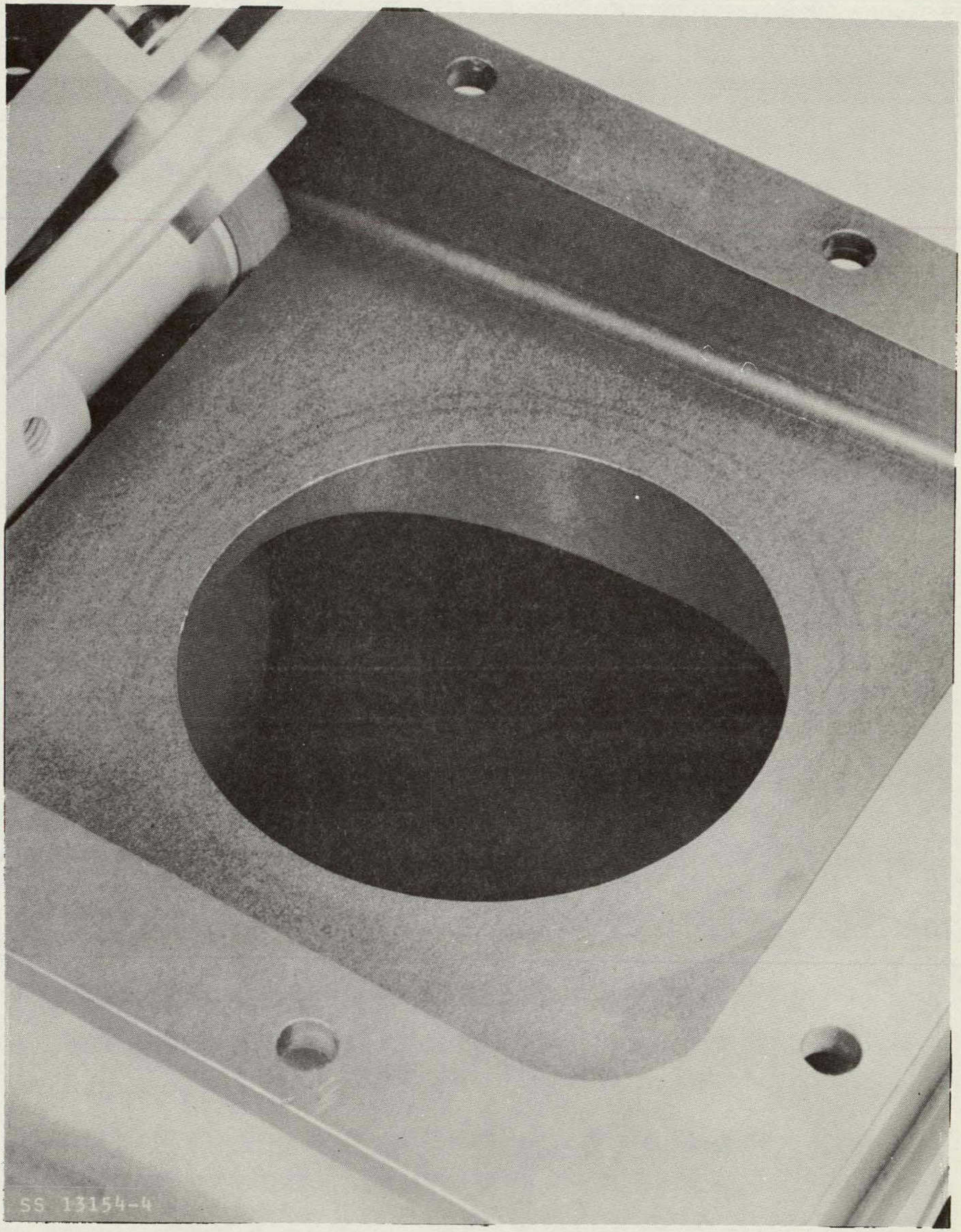

FIGURE 36

VACUUM VALVE AIRSIDE SEAT AFTER 45000 CYCLES

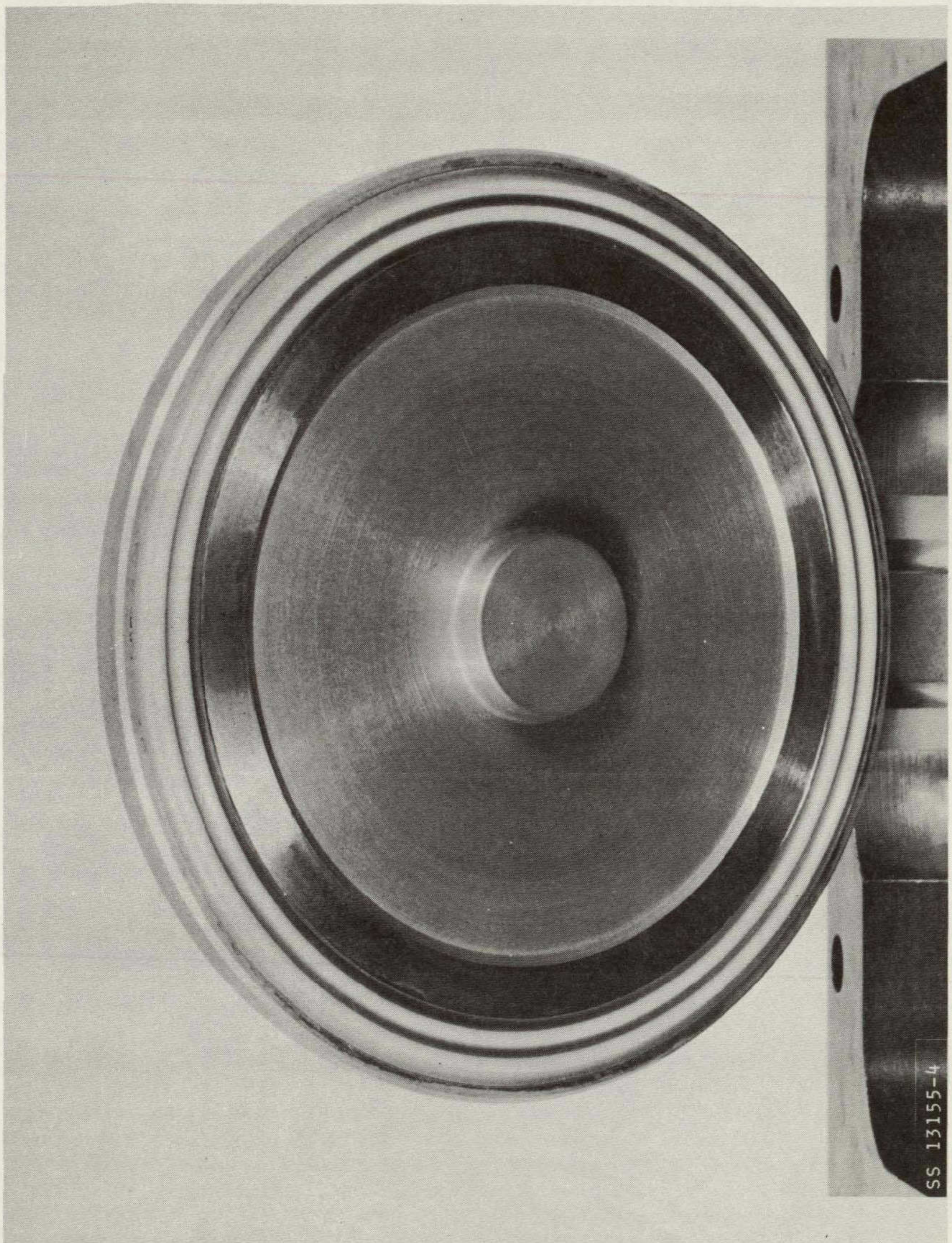

FIGURE 37
VACUUM VALVE AIRSIDE POPPET AFTER 45,000 CYCLES

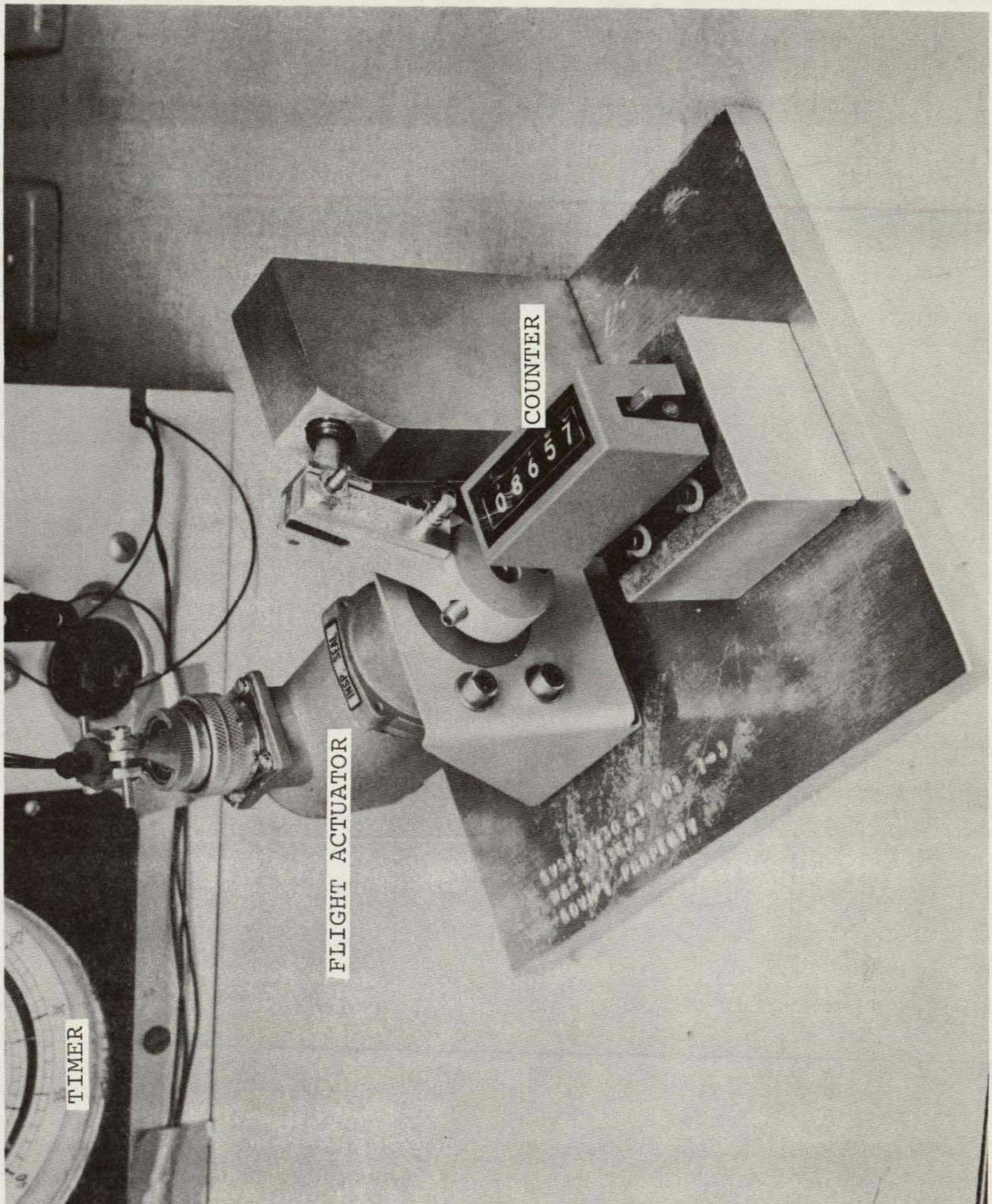

FIGURE 38

VALVE ACTUATOR TEST SETUP

System Test Setup

The completed and integrated test setup is shown schematically in Figure 39. The test setup was similar to that used for testing the breadboard system.

Air from the simulated Shuttle volume (facility antichamber of Figure 41) is ducted to Rig 88 where it is first sampled for CO_2 partial pressure and dew point. The air then passes through a blower which provides part of the head for the plumbing loop. The air passes through a series of heat exchangers and electric reheaters which provide the temperature conditioning of the air. The air next passes through a annubar/manometer and valve arrangement which measures and controls flow rate.

The air is then plumbed to the prototype system where it passes through the adsorbing bed and is returned to the simulated Shuttle volume. The prototype system is shown in the test setup photographs of Figures 6, 41, and 42. Figure 42 shows the CO_2 and dewpoint monitoring equipment in the foreground.

The metabolic CO_2 feed gas is introduced into the airstream in the return duct between the system and the simulated Shuttle volume. The CO_2 flow is regulated by a needle valve and flow rater. The feed rate is accurately measured by time averaging the decreasing weight of the high pressure CO_2 storage bottle.

The metabolic water feed system injects steam directly into the simulated Shuttle volume. The feed rate is controlled by a calibrated micro-metering valve mounted on the outlet of the constant water volume steam generator. Water flow to the steam generator is measured by time averaging the weight of a separate water storage tank. The storage tank is not plumbed to a water supply but is batch filled with triple distilled water.

The inside of the simulated Shuttle volume is arranged to guarantee adequate mixing of air. Return air from the breadboard system, rich in CO_2, exhausts at one side of the chamber near the steam injection flow. A fan is used to mix the steam and return air with the chamber air. The air intake to the breadboard system is located at the opposite side of the chamber so that it draws the mixed air. It is the CO_2 and humidity levels of this intake air that are used as the primary measurements of HS-C performance.

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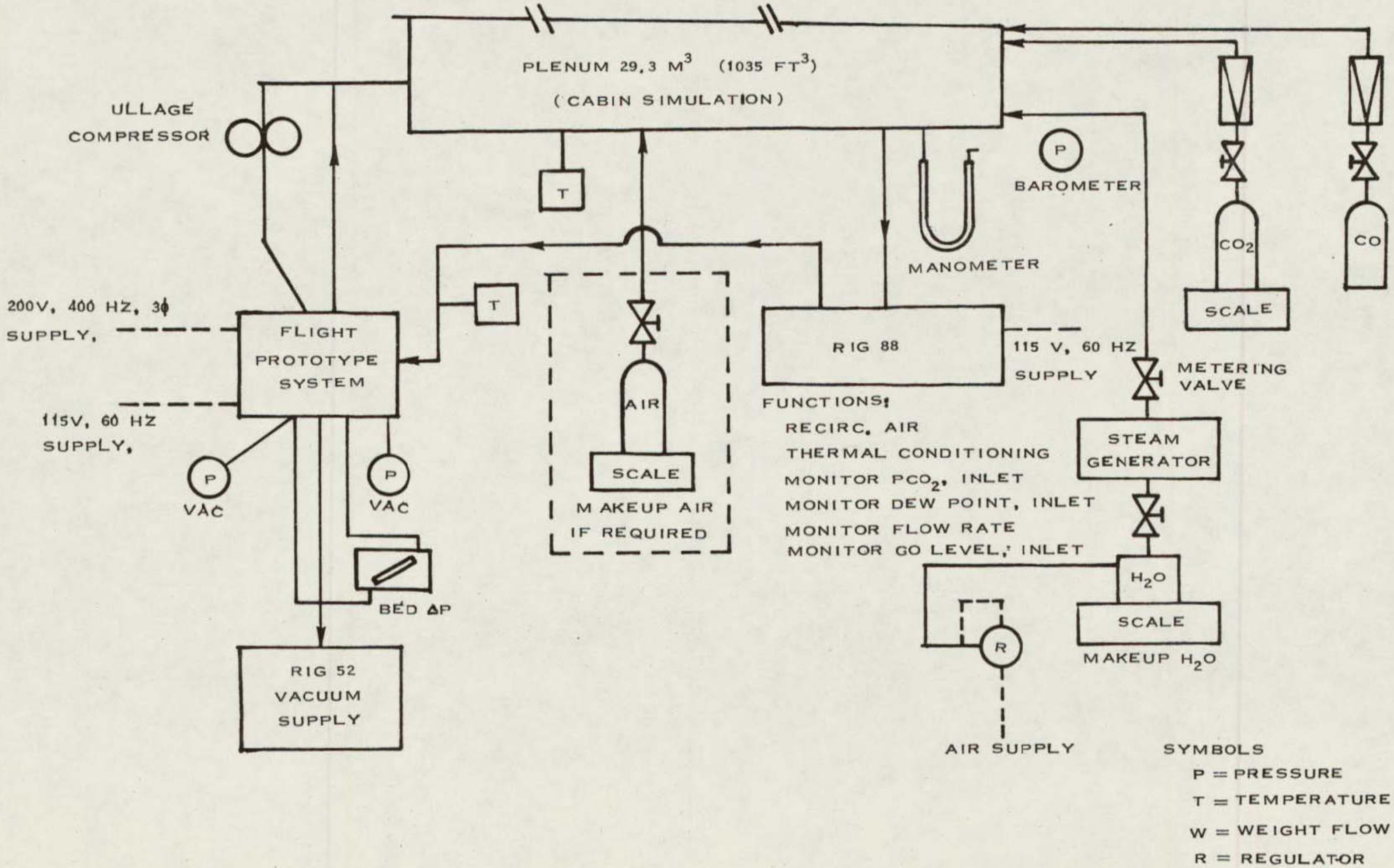


FIGURE 39

SYSTEM TEST SETUP SCHEMATIC

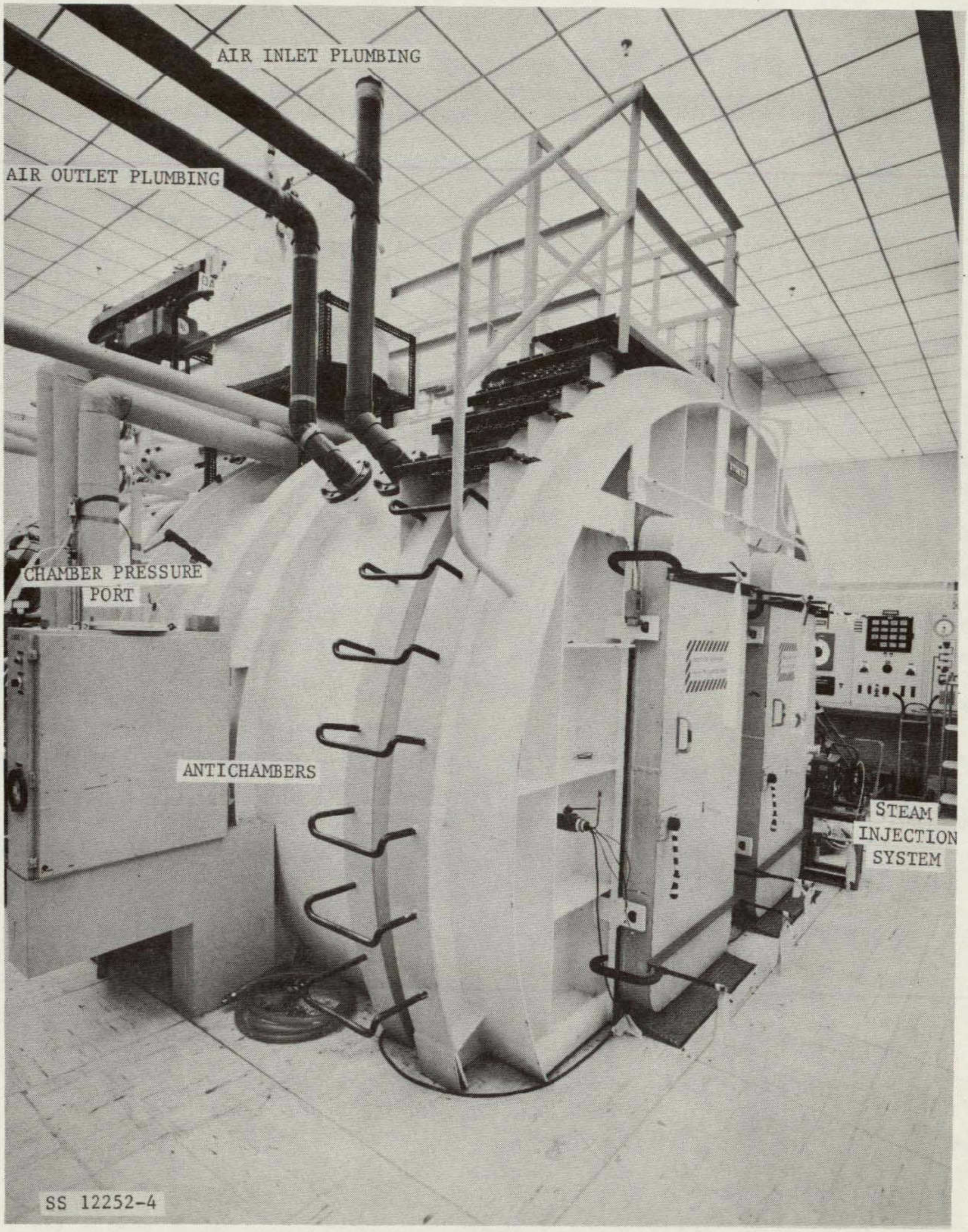


FIGURE 40
ANTICHAMBERS (USED AS SIMULATED SHUTTLE CABIN)

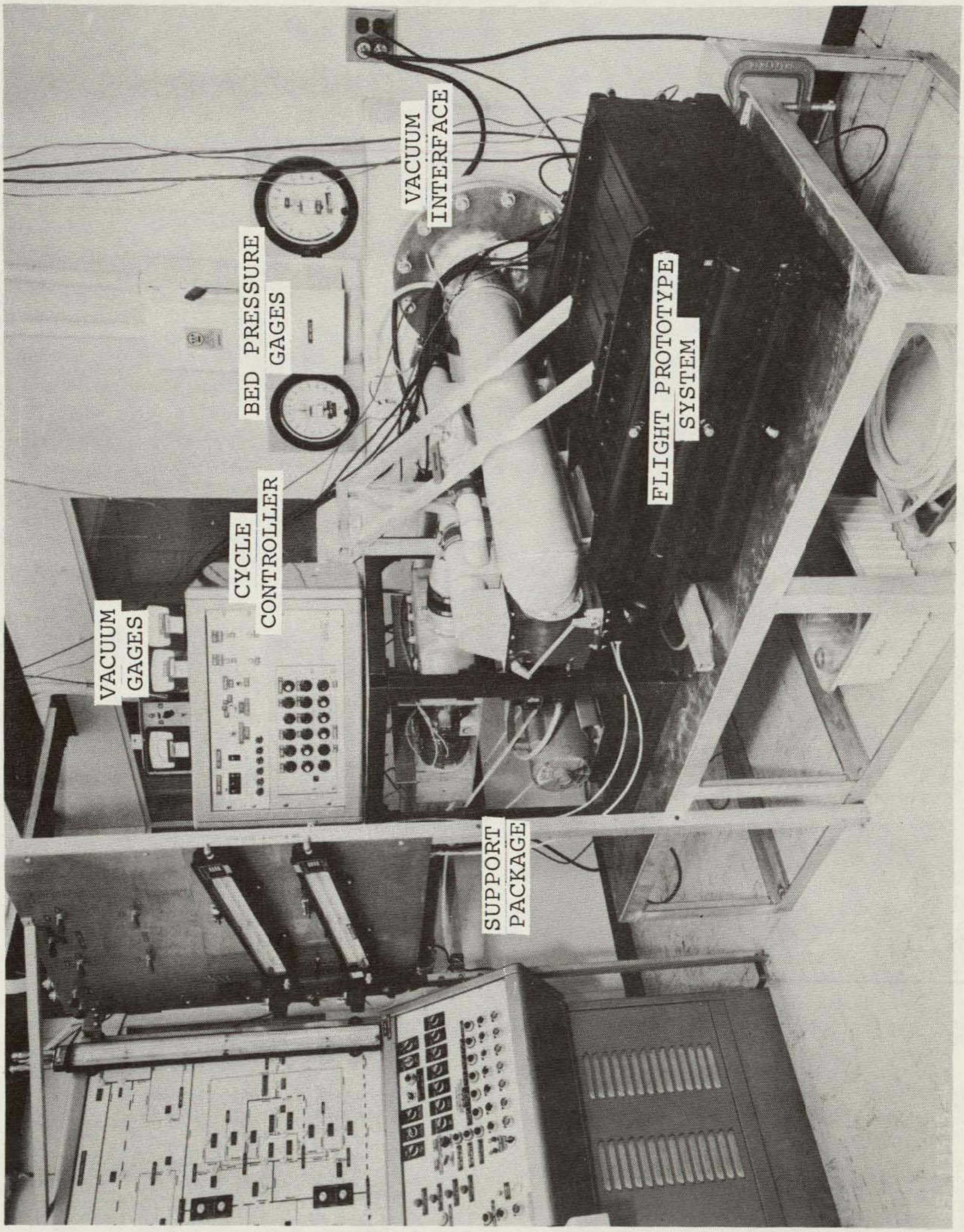


FIGURE 41

FLIGHT PROTOTYPE SYSTEM TEST SETUP

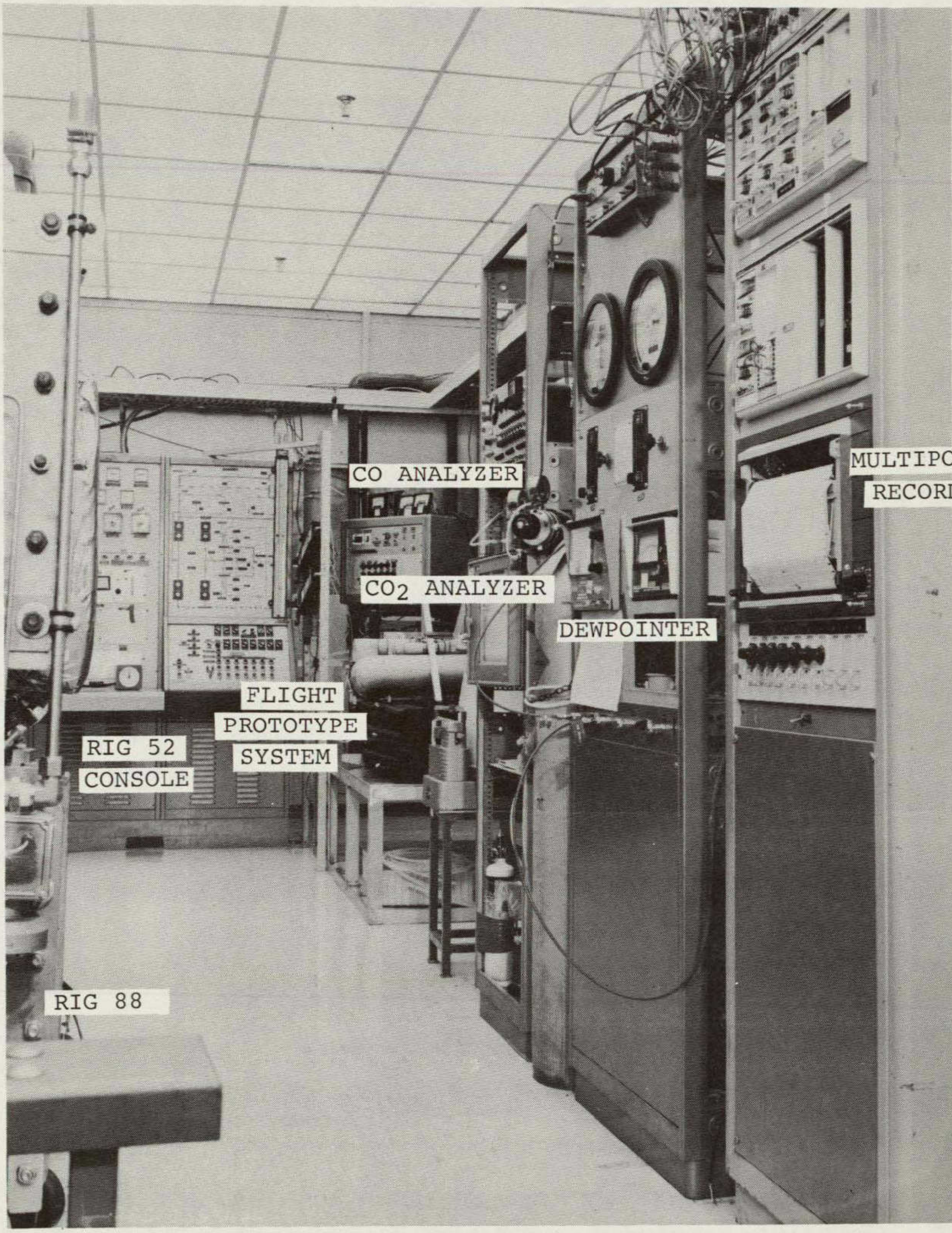


FIGURE 42 - TEST SETUP SHOWING DATA COLLECTION EQUIPMENT

TABLE 13

DATA REQUIREMENTS AND INSTRUMENTATION LIST

Parameter	Units	Accuracy	Instrument	Range and Units	Note
Rig 88 and HS-C Flow	cfm	± 10%	Annubar Manometer	0 to 30 in H_2O	
Rig 88 Outlet Temperature	°F	± 2°	Thermocouple	20 to 150°F	
Makeup CO_2 Flow	lb/hr	± 2% Full Scale	Flowrater	0 to 1.2 lb/hr	
Makeup H_2O Flow	lb/hr	± 5%	Metering Valve	0 to 3.3 lbm/hr	
HS-C Inlet Temperature	°F	± 2°	Thermocouple	20 to 150°F	
HS-C System Cycle Time	minutes	± 1% Cycle	Stop Clock	0 to 60	
HS-C System Vacuum		± 5% Non-Linear Scale	Hastings Gage and Pickup or Equivalent	0 to Atmos	
HS-C Bed Press. Delta	in H_2O	± 0.05	U-Tube Manometer	0 to 20 inches	
Plenum Temperature	°F	± 2°	Thermocouple	20 to 150°F	
Plenum Dew Point	°F	± 2°	Hygrometer	-40 to 120°F	Indigenous to Rig 88
Plenum PCO_2	mmHg	± 2% Full Scale	Infra-Red Analyzer	0 to 100% (100% = 7.6 mmHg)	Indigenous to Rig 88
Plenum CO Level	ppm	± 1% Full Scale	Ecolyzer	0-50 ppm	
Plenum/Ambient Press. Delta	in H_2O	± 0.2	U-Tube Manometer	0 to 30 inches	Indigenous to Rig 88
Weight Makeup Air	lbm	± 0.02	Scale	0 to 300 lb	
Weight Makeup CO_2	lbm	± 0.02	Scale	0 to 300 lb	
Weight Makup H_2O	lbm	± 0.02	Scale	0 to 300 lb	
Ambient Pressure	in. Hg	± 0.05	Barometer		
Ambient Temperature	°F	± 2°	Thermometer	20 to 400°F	

Leakage and Instrument Calibration

The objective of this test series is to verify that all elements of system leakage are understood and accounted for during testing and that all instruments are calibrated within acceptable accuracies.

This test series involved four specific test areas as follows:

- Vacuum System Leakage
- Air System Leakage
- CO_2 and H_2O Permeation
- Instrument Calibration

Vacuum System Leakage

The purpose of this test was to insure that the leakage of the vacuum portion of the flight prototype system, including the canister and vacuum valves, was sufficiently below the vacuum pumping rate to allow desorption of the HS-C beds.

A pressure decay test was conducted on each bed separately. The tests were run with each isolated volume being pumped down to a 100.6 kPa (14.6 psi) negative pressure. The vacuum system was operating to assure proper seating of the poppet valves. The leakage is calculated from the ideal gas formula:

$$\text{Leakage} = \frac{\text{Delta M}}{\text{Time}} = \frac{V}{RT} \quad \frac{\text{Delta P}}{\text{Time}}$$

The resultant leakage is factored according to the full pressure differential experienced in actual testing. The prototype system was evaluated before performance testing on May 20, 1977; the test was repeated after completion of all system testing on August 4, 1977. The results of the leakage tests are shown in Table 14.

TABLE 14

FLIGHT PROTOTYPE SYSTEM VACUUM LEAKAGE

	Before Testing	After Testing
Test Date	5/20/77	8/4/77
Leakage Units	cm^3/s (lb/hr)	cm^3/s (lb/hr)
Bed A	.157 (.0015)	.147 (.0014)
Bed B	.357 (.0034)	.682 (.0065)

The system leakage was well within the limit of 1.05 cm^3/s (.01 lb/hr). Bed A leakage remained unchanged throughout the test period; the leakage measured for Bed B had increased after the tests but was within the limit specified in the Plan of Test.

The post-test leakage check verified the structural and functional integrity of the valves and canister.

Air System Leakage

The purpose of this test was to establish the leakage rate of the overall air circuit which included the flight prototype system air circuit, Rig 88, the Shuttle simulated cabin volume chamber, and all interconnecting plumbing. This test was essential to establish the use of makeup air to the system as a true measure of ullage loss during the mission test phase.

If the system could be shown to be totally leak tight, then all makeup air (required to maintain a constant system pressure) would be a true measure of ullage loss after accounting for already measured vacuum leakage. Conversely, if the air system leakage is such that the system cannot hold pressure, then ullage measurements become unfeasible. In addition, adjustments may be required in both CO_2 and H_2O feed rates to account for losses due to excessive leakage.

The air system, excluding the canister assembly, was pressurized to 2.49 kPa (10 in H_2O) and the pressure decay recorded. The leakage was checked prior to testing on May 23, 1977 and measured at 862 g/hr (1.9 lb/hr); the post-test leakage on August 1, 1977 agreed with this leakage rate. Since this leakage rate was high compared to the ullage loss of 284 g/hr (.626 lb/day) for seven men, no attempt was made to measure ullage loss with makeup air per Section 4.2.1.2 of the Plan of Test.

Air system leakage was periodically checked during the test phase and found to be minimal. However, during the CO removal test, a system pressure decay check indicated increased system air leakage. The rate at which the closed test volume gained pressure with time is plotted in Figure 43 . The maximum leakage measured was 2.0 lb/hr. The leak was located at the plumbing interface between the HS-C system outlet and the RSECS fan. The leakage experienced during the CO test did not affect the operational performance of the system. The imbalance between the CO_2 feed rates and removal rates is corrected for the largest leakage valve by increasing the feed rates by 1.5% or reducing the CO_2 performance rates by 1.5%. The effect on the H_2O rates is negligible (.1%) because the leakage air entering the test system had a dew point close to that leaking out of the test system.

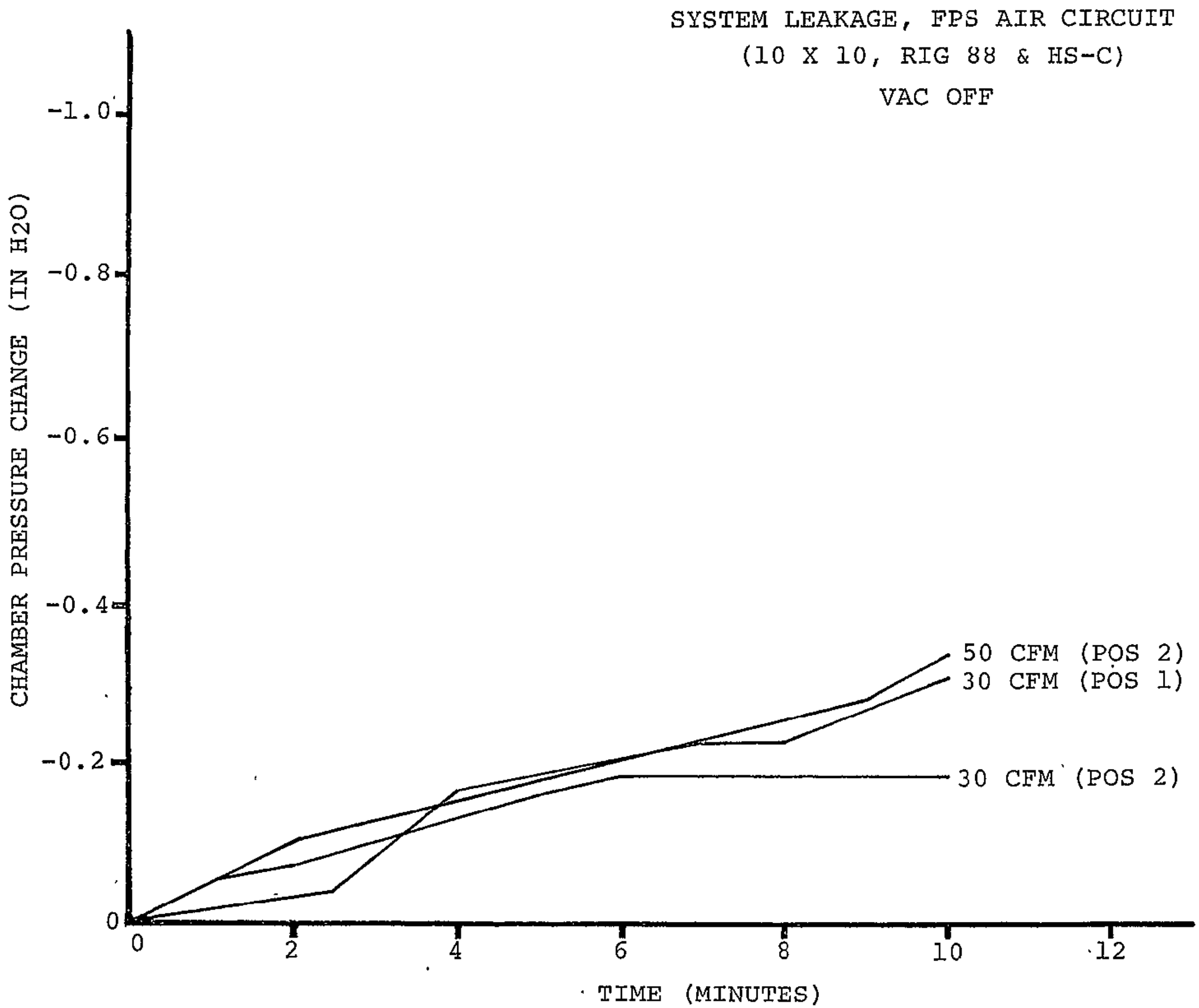


FIGURE 43 - SYSTEM LEAKAGE

CO_2 and H_2O Permeation

The purpose of this test was to calibrate the rate of CO_2 and H_2O partial pressure change within the air circuit due to permeation. The permeation test called for setting predetermined levels of CO_2 and dew point in the air circuit and monitoring these levels for a minimum of 16 hours. A test was run with a CO_2 level of .93 kPa (7.0 mmHg) and a dew point of 15.6°C (60°F). The change in dew point and CO_2 level was negligible. The test was also run with a CO_2 level of 0.5 kPa (3.75 mmHg) and a dew point of 10.6°C (51°F) and similar results noted. It was, therefore, concluded that no adjustments were needed to account for permeation.

Instrument Calibration

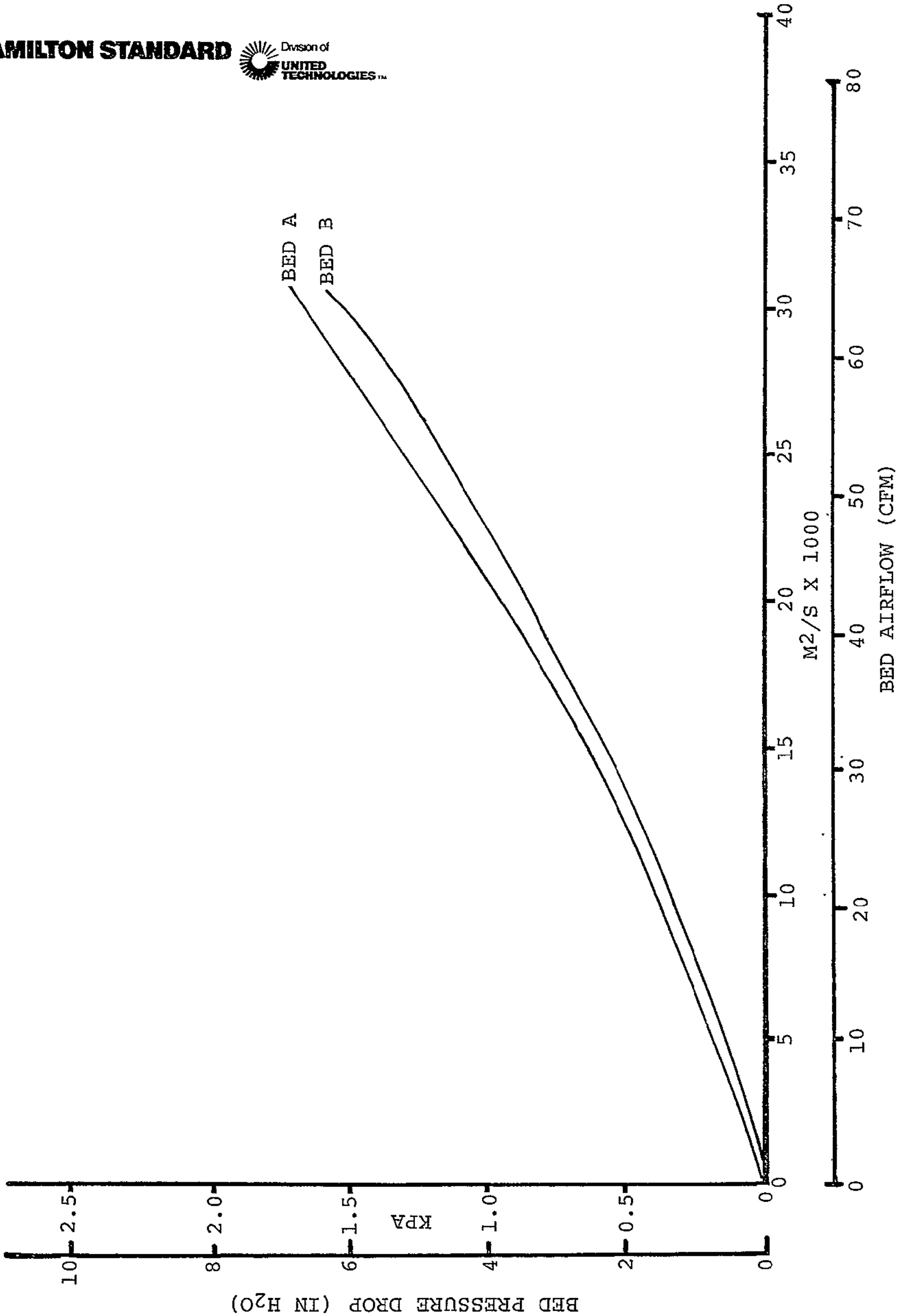
The purpose of this calibration was to verify test measurements by demonstrating calibration before and after data collection.

All instrumentation was calibrated prior to testing by the Instrumentation and Metrology Department. All instruments were recalibrated as required by accepted standards during the test period. By the end of mission testing, all instruments were still within accepted time limits for their calibration. Instrumentation was recalibrated, if necessary, prior to the CO test. In addition, the CO_2 analyzers, dew pointers, and vacuum pressure instruments received special attention because of the critical nature of their readings. The Infra-Red CO_2 Analyzers (Liras) were calibrated each morning and before any detailed data collection period. The hygrometer (dew pointer) was balanced (null check) each morning and before any detailed data collection period. The CO analyzer (Ecolyzer) was calibrated each day of testing and at the conclusion of testing.

System and Bypass Flow Calibration

The purpose of this test was to establish air flow through the HS-C bed and thus bypass flow as a function of pressure drop across the bed.

The airflow was increased in eight increments from 0 to 0.031 m^3/s (0 to 65 cfm). The airflow was then decreased in the same increments to measure any hysteresis in the instrumentation. A slight hysteresis was encountered, and the data was averaged to produce the curves in Figure 44.



FLIGHT PROTOTYPE CANISTER FLOW CHARACTERISTICS

FIGURE 44

It is noted that Bed A and Bed B have different flow characteristics; however, the overall performance of the beds was essentially equal.

The pressure drop recorded across the prototype canister was greater than the specification limits, as shown in Table 15. The specification was based on actual measurements from the breadboard testing. There is no conclusive explanation to explain the discrepancy between the breadboard and prototype canisters.

TABLE 15

CANISTER FLOW PRESSURE DROP

Bed	Flow m^3/s (cfm)	Delta P Maximum Pa (in H_2O) Specified	Measured
A	.0236 (50)	946 (3.8)	1,207 (4.85)
A	.033 (70)	1,443 (5.8)	1,891 (7.6)
B	.0236 (50)	946 (3.8)	1,095 (4.4)
B	.033 (70)	1,443 (5.8)	1,791 (7.2)

System Performance Calibration Testing

The purpose of this test is to define the timing and bypass flow required to maintain performance for use in subsequent mission tests and to assess the effect of using the ullage save compressor on these requirements. It was the intent of this test phase to run only long enough to establish equilibrium performance at each condition. The subsequent mission tests would verify the long term effect at each condition.

The environmental conditions to be used during testing were the same as those used as design points during the analysis and design phase. These are crew sizes of four and ten men and cabin temperature extremes of 18.3°C (65°F) and 26.7°C (80°F). The combinations of these variables produce four baseline test conditions which are also identified by "Environment Number." The points and nomenclature are as follows:

Test Condition (Environment No.)	Crew Size (Men)	Cabin Temperature °C (°F)
1	10	26.7 (80)
2	4	26.7 (80)
3	10	18.3 (65)
4	4	18.3 (65)

This phase of the test program was used to calibrate and optimize the cycle times and airflow rates necessary to meet each of the environments. The results of performance calibration testing are presented in Table 16. Detailed data is presented in Table 17, Test Nos. 1-12. This table identifies the parameters to be used and the performance to be expected during mission testing. The impact of this data on the feasibility of each control scheme is discussed in the following subsections.

Timing Control

Timing control operates with a fixed airflow rate and varies cycle time to accommodate varying metabolic loadings. An airflow rate of 2.0 m^3/min (70 cfm) was established as the minimum required for the 10 man crew. For 4 man tests, 1.42 m^3/min (50 cfm) was used because it corresponds to the lower speed of the flight fan.

The CO_2 performance of the prototype system at the high temperature condition was better than that previously recorded for the breadboard system. However, at low temperatures, the prototype system had a higher PCO_2 equilibrium level. No conclusive explanation can be given for these differences.

In addition, the requirements for the ten-man conditions could not be maintained with the ten-minute cycle since the switchover was much longer than the 15 seconds on the breadboard test. A switchover time of 40 seconds was required by the breadboard controller when programmed for the flight prototype system. The cycle time was reduced to eight minutes for Environments 1 and 3. With the eight-minute cycle (eight-minute absorb/eight-minute desorb), the maximum CO_2 level was maintained at .95 kPa (7.1 mmHg).

Flow Control

Flow control operates the opposite of timing control. Flow control uses a fixed cycle time and varies the airflow through the HS-C canister to accommodate varying metabolic loadings. The performance with flow control is exceptional as indicated in Table 16. The ten-man cases are identical with the timing control, but the four-man cases provide exceptionally low PCO_2 equilibrium points. The CO_2 performance of crew between four and ten men would be proportional to those experienced for the four and ten man loading.

Despite the obvious improvement in CO_2 performance offered by the flow control scheme, there are other parameters affecting the final choice of HS-C control. A thorough evaluation of these indicates that a combination of flow control and timing control actually produce the overall optimum system.

TABLE 16

TEST RESULTS
PERFORMANCE CALIBRATION TESTING

Environment Pot No.	Crew Size Men	Cabin Temp. °C (°F)	Air Flow m^3/min (cfm)	Cycle Time Min Ads/Min Des	Dew Point °C (°F)	PCO_2 kPa (mmHg)
Timing Control						
1	10	26.7 (80)	1.98 (70)	8/8	14.4 (58)	.547 (4.1)
2	4	26.7 (80)	1.42 (50)	40/40	15.0 (59)	.547 (4.1)
3	10	18.3 (65)	1.98 (70)	8/8	2.8 (37)	.946 (7.1)
4	4	18.3 (65)	1.42 (50)	40/40	3.6 (38.5)	.760 (5.7)
Flow Control						
1	10	26.7 (80)	1.98 (70)	8/8	14.4 (58)	.547 (4.1)
2	4	26.7 (80)	0.85 (30)	20/20	14.4 (58)	.39 (2.9)
3	10	18.3 (65)	1.98 (70)	8/8	2.8 (37)	.946 (7.1)
4	4	18.3 (65)	0.88 (31)	20/20	9.2 (48.5)	.427 (3.2)

The detailed tests that were run during the performance calibration phase of the test program are tabulated and presented in Table 17, test number 1-12. The total test hours for performance calibration testing were 56.3 hours.

Water-Save Testing

The purpose of this test was to determine if the water adsorbed by the HS-C material while adsorbing CO_2 could be minimized and if the prototype system could maintain acceptable CO_2 levels with a minimum water removal mode of operation. This low water dump (LWD) system would be advantageous for extended Shuttle missions.

The 15 minute adsorb/15 minute desorb cycle was used as the basis for all testing. For each set of air temperature and air flow conditions, the CO_2 and H_2O feed rates were adjusted to maintain a stable CO_2 level of 5 mmHg and dew point of 45°F. Results are shown in Figure 45 and Figure 9. The removal ratio of H_2O to CO_2 was reduced to only 24% of the nominal metabolic ratio of 2.61 at 80°F. The data, tabulated in Table 17, tests 13-16, confirms that the HS-C system has great flexibility in water removal capability and can be effective in a low water dump mode of operation.

Mission Testing

The purpose of this test was to demonstrate CO_2 and humidity control during a simulation of a Shuttle mission. The mission test first required ten hours of continuous operation at Environment No. 1 followed by a minimum of 20 continuous hours at Environment No. 2. These 26.7°C (80°F) conditions were to log a minimum of 60 hours. The test setup was then reset to 18.3°C (65°F) conditions for an additional 60 hours of testing, including a minimum of 10 continuous hours at Environment No. 3 and a minimum of 20 continuous hours at Environment No. 4.

The mission test phase proved the ability of the prototype system to operate continuously and provide acceptable performance for extended periods. The test was divided into two sixty-hour segments for a total of 121 hours. During the test period the HS-C humidity performance was compatible with the Shuttle ARS (Air Revitalization Subsystem); however, the HS-C CO_2 performance was considerably better than the existing Shuttle ARS. Both systems remove CO_2 at the metabolic production rate, but the HS-C system maintains lower cabin PCO_2 levels than the Shuttle baseline system.

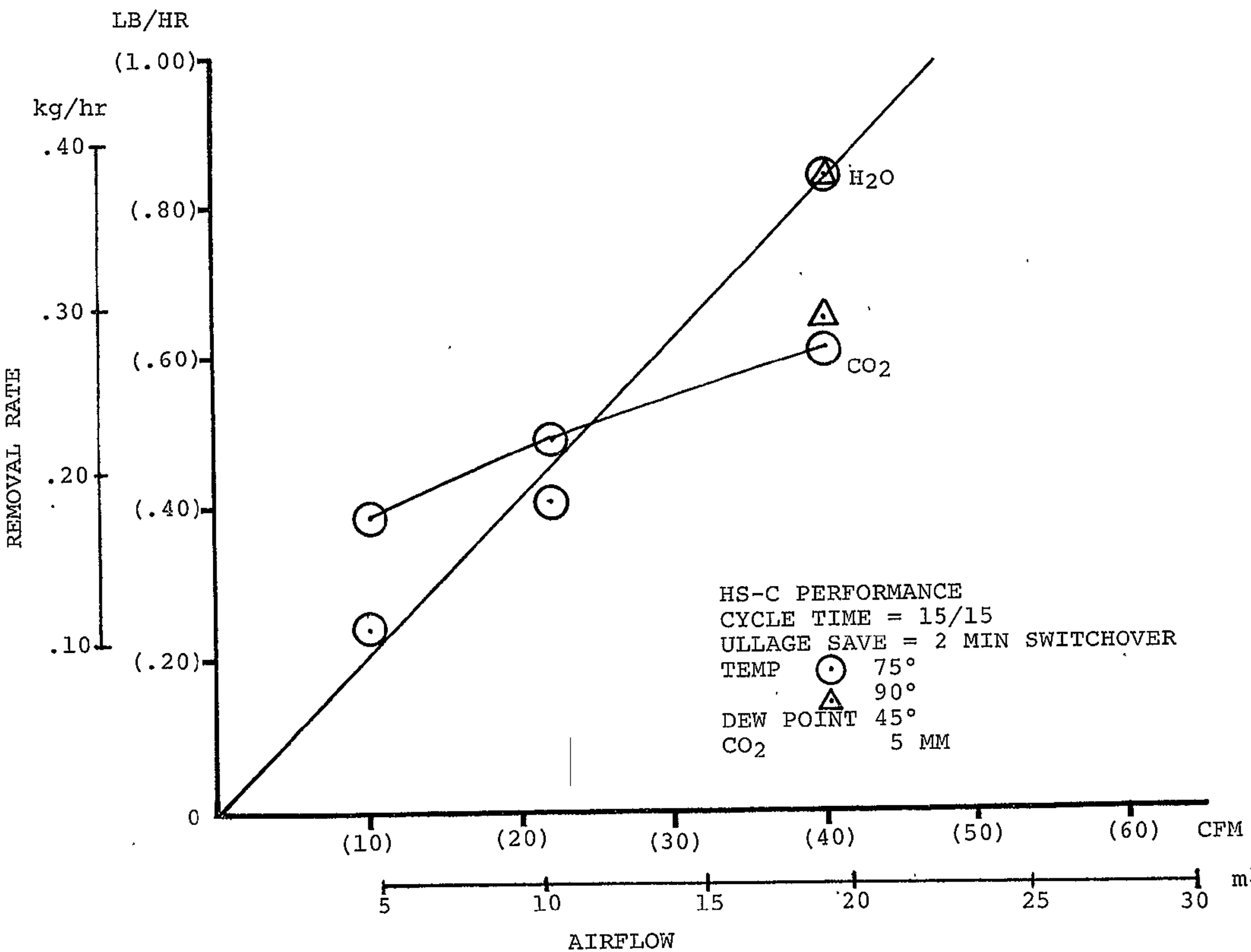


FIGURE 45

TEST RESULTS - WATER SAVE TESTING

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SVHSER 7182

TABLE 17A

DATA SUMMARY
PERFORMANCE CALIBRATION TESTING AND WATER SAVE TESTING

TEST NO.	TEST DATE	CYCLE TIME (MIN)	P_{CO_2} INITIAL (KPA)	P_{CO_2} FINAL (KPA)	PH_2O INITIAL (KPA)	PH_2O FINAL (KPA)	AIR IN TEMP (°C)	FLOW (M^3/MIN)	TEST TIME (HRS)	SWITCH TIME (MIN)	EXP H_2O REM (KG/HR)	EXP CO_2 REM (KG/HR)	A MAX ADS T (°C)	B MAX ADS T (°C)	A MIN DES T (°C)	B MIN DES T (°C)	STABILITY
1	5-26	40	0 586	0 586	1 702	1 702	26.7	0.023	6.6	2	0 599	0 208					D
2	5-27	20	0.586	0 400	1.550	1.669	26.7	0.014	6 9	2	0 526	0.208					S
3	5-31	20	0.413	0 426	1.116	1 243	18.3	0 014	5.9	2	0.372	0 199					
4	6-1	40	0.706	0.800	1.158	0 817	18 3	0.023	11.4	2	0 340	0.186	23.3	34 8	13.4	11.4	S
5	6-3	10	0 760	0 933	0.713	0.754	18.3	0 033	2 8	1	0.508	0.367					RI
6	6-3	9	0 933	0 966	0.744	0 761	18.9	0 033	2 2	1	0.503	0.399	23 3	24.4	26.8	13 9	RI
7	6-7	9	0.773	1.000	0.744	0 782	18.3	0 033	3.5	1	0 485	0.363	21.9	23 3	26.8	12.8	RI
8	6-7	8	1 000	1.066	0 772	0 782	18 9	0.033	2.5	1	0 503	0 395	22.2	23.0	15 5	13.0	SI
9	6-8	8	0 973	0 966	0.887	0.754	18.3	0 033	4.3	0 67	0.517	0 404	22.2	22.5	15.5	27 0	S
10	6-8	9	0 966	1 013	0 754	0 754	18.3	0.033	2.0	0 67	0 503	0 395	22 2	23 3	15.5	13.3	RI
11	6-9	8	0 786	0 546	1.634	1 669	26.7	0 033	6 5	0.67	1.089	0 413	31.1	31.6	18.6	18.6	S
12	6-10	8	0 566	0.566	1.702	1 669	26 7	0 033	1.7	0.67	1.116	0 395	31.1	31 5	18.9	.	SD
13	6-13	15	0 691	0 786	0.915	1 026	32.2	0 019	6.5	0 67	0.377	0.287	33 9	33.9	23.3	22 2	
14	6-14	15	0 666	0.653	1.110	1 033	23.9	0.019	5.5	0 67	0 381	0 278	27.8	28 3	17 2	17.2	
15	6-15	15	0 600	0.600	1 068	1 027	23.9	0 010	7.5	0.67	0 187	0 223	27.2	25 0	25 8	22.7	
16	6-17	15	0 693	0 673	1.026	1 089	23.9	0 005	5 5	0.67	0.108	0.178	25 5	25.0	21.7	21 6	

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TABLE 17B

DATA SUMMARY
PERFORMANCE CALIBRATION TESTING AND WATER SAVE TESTING

TEST NO.	TEST DATE	CYCLE TIME (MIN)	P_{CO_2} INITIAL (MM HG)	P_{CO_2} FINAL (MM HG)	PH_2O INITIAL (PSI)	PH_2O FINAL (PSI)	AIR IN TEMP (°F)	FLOW (CFM)	TEST TIME (HRS)	SWITCH TIME (MIN)	EXP H_2O REM (LB/HR)	EXP CO_2 REM (LB/HR)	A MAX ADS T (°F)	B MAX ADS T (°F)	A MIN DES T (°F)	B MIN DES T (°F)	STABILITY
1	5-26	40	4.4	4 4	0.247	0.247	80	50	6.6	2	1.32	0.46					D
2	5-27	20	4.4	3.0	0.222	0 239	80	30	6.9	2	1.16	0.46					S
3	5-31	20	3.1	3 2	0.162	0 178	65	31	5.9	2	0.82	0.44					
4	6-1	40	5.3	6.0	0.168	0.117	65	50	11.4	2	0.75	0.41	74	76.8	56.2	52.5	S
5	6-3	10	5.7	7.0	0.115	0.108	65	70	2.8	1	1.12	0.81					RI
6	6-3	9	7 0	7.25	0.108	0.106	66	70	2.2	1	1 11	0.88	74	76	59	57.0	RI
7	6-7	9	5.8	7.5	0.108	0.112	65	70	3.5	1	1.07	0.80	71.5	74	59	55	RI
8	6-7	8	7 5	7.55	0.112	0 112	66	70	2.5	1	1.11	0.87	72	73.5	60	55.5	SI
9	6-8	8	7.3	7.25	0.127	0.108	65	70	4.3	0.67	1.14	0.89	72	72.5	60	59.5	S
10	6-8	9	7.25	7 6	0.108	0.108	65	70	2.0	0.67	1.11	0.87	72	74	60	56	RI
11	6-9	8	5.9	4.1	0 234	0 239	80	70	6.5	0.67	2.40	0.91	88	89	65.5	65.5	S
12	6-10	8	4.25	4 25	0 247	0.239	80	70	1.7	0.67	2.46	0.87	88	88.8	66		SD
13	6-13	15	5.2	5.9	0 131	0.147	90	40	6.5	0 67	0.832	0.633	93	93	74	72	
14	6-14	15	5.0	4 9	0 159	0.148	75	40	5.5	0.67	0 841	0.613	82	83	67	63	
15	6-15	15	4.5	4 5	0.153	0.147	75	22	7.5	0.67	0 412	0.493	81	77	69	73	
16	6-17	15	5 2	5 05	0.147	0.156	75	10	5.5	0.67	0.238	0.393	78	77	72	71	

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The detailed presentation of the mission test is divided into two subsections. The first is the high temperature, 26.7°C (80°F), cases of Environment Nos. 1 and 2. The second subsection presents the low cabin temperature, 18.3°C (65°F), Environments identified as No. 3 and No. 4.

High Cabin Temperature Mission

The high cabin temperature, 26.7°C (80°F), portion of the mission test was accomplished on June 22 through 24, 1977. The test data and performance profiles are presented in Figure 46 and also numerically tabulated in Table 18. Table 18 provides the background data for each curve of Figure 46 and also provides actual metabolic feed rates.

Figure 46 presents the test data in the following order, starting from the top and progressing downward.

Environment Number: This is the environmental condition as specified in the Plan of Test and described in a previous subsection.

Crew Size: The actual design point metabolic feed rate condition; either ten or four men.

Cycle Time: The time each bed is on the adsorption cycle compared to the time each bed is on the desorption cycle. Two minutes is required out of each cycle for the switchover of adsorption/desorption beds with the ullage save/pressure equalization/repressurization processes.

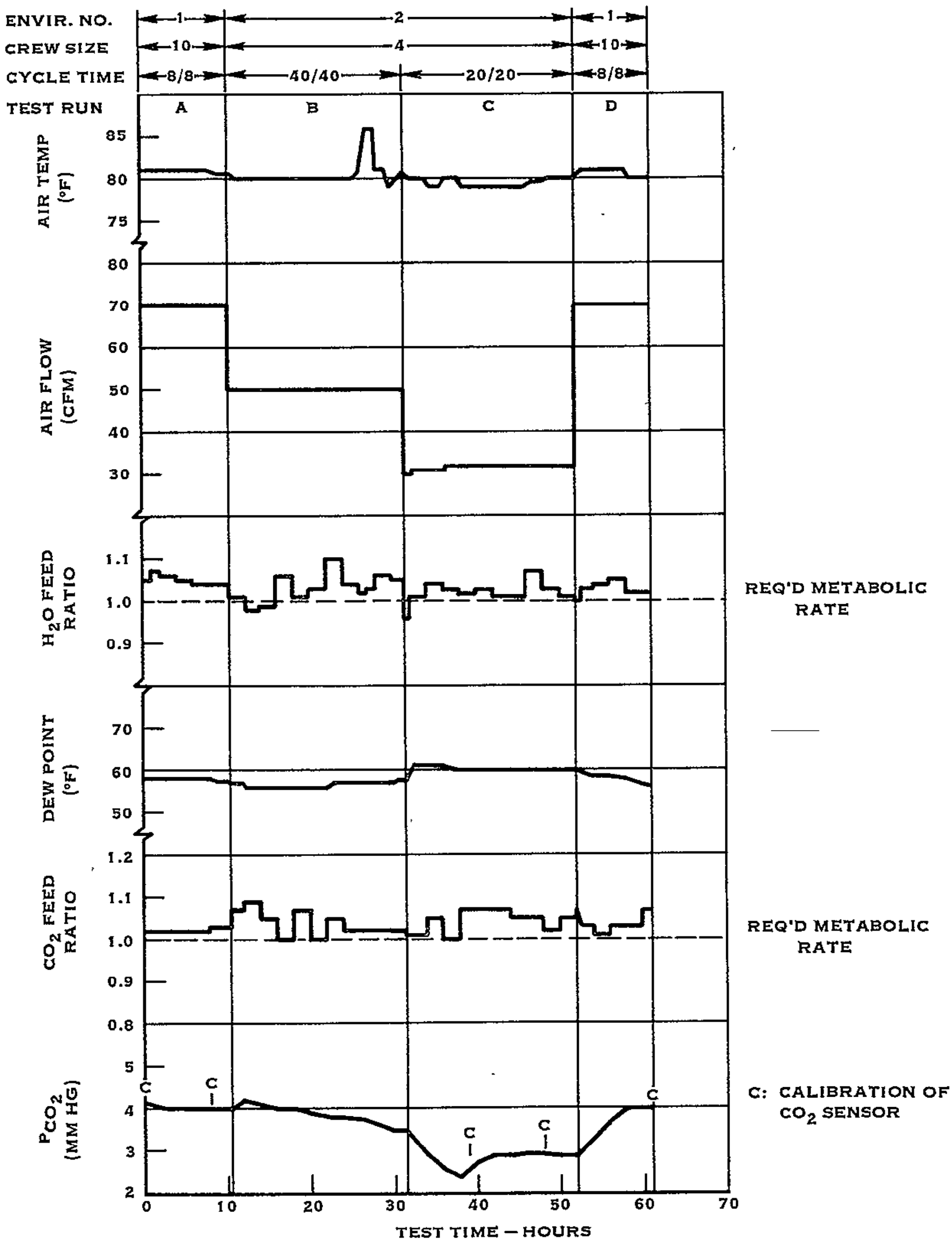
Test Run: This is an identification code letter assigned to each separate test run and is used to code all data sheets and strip charts from either raw or refined data.

Air Temperature: This was the actual temperature of the airflow entering the HS-C canister.

Airflow: This is actual airflow rate passing through the HS-C canister.

H_2O Feed: This is a normalized ratio of the actual water feed rate divided by the desired metabolic feed rate of the given crew size. A value of 1.0 is a perfect feed rate, while 1.1 represents a feed rate 10% too high, and 0.9 represents only 90% of the required feed rate.

Dew Point: This is a measure of humidity control performance and represents the actual dew point of the simulated Shuttle cabin volume.



MISSION HIGH TEMP PROFILES

FIGURE 46

DATA SUMMARY
MISSION I, HIGH TEMPERATURE

ENV. NO.	TIME INTO MISSION (HR)	TEST IDENT	TIME ON ENV. (HR)	TEMP (°C)	FLOW (M^3/S)	CYCLE TIME (MIN/MIN)	P_{CO_2} (KPA)	CO_2 FEED (KG/HR)	CO_2 FEED / CO_2 REQD	DEW POINT (°C)	H_2O FEED KG/HR	H_2O FEED / H_2O REQD
1	0	A	0	27.2	0.033	8/8	0.546	0.408	1.02	14.4	1.102	1.05
	2	A	2	27.2	0.033	8/8	0.533	0.408	1.02	14.4	1.115	1.07
	4	A	4	27.2	0.033	8/8	0.533	0.408	1.02	14.4	1.106	1.06
	6	A	6	27.2	0.033	8/8	0.533	0.408	1.02	14.4	1.102	1.05
	8	A	8	27.2	0.033	8/8	0.533	0.408	1.02	14.4	1.093	1.04
	10.5	A	10.5	26.9	0.033	8/8	0.533	0.412	1.03	14.2	1.088	1.04
2	10.5	B	0	26.9	0.024	40/40	0.533	0.190	1.00	14.2	0.566	1.01
	12	B	1.5	26.6	0.024	40/40	0.560	0.204	1.07	13.9	0.566	1.01
	14	B	3.5	26.6	0.024	40/40	0.546	0.208	1.09	13.3	0.553	0.98
	16	B	5.5	26.6	0.024	40/40	0.533	0.199	1.05	13.3	0.557	0.99
	18	B	7.5	26.6	0.024	40/40	0.533	0.190	1.00	13.3	0.594	1.06
	20	B	9.5	26.6	0.024	40/40	0.520	0.204	1.07	13.3	0.566	1.01
	22	B	11.5	26.6	0.024	40/40	0.506	0.190	1.00	13.3	0.580	1.03
	24	B	13.5	26.6	0.024	40/40	0.506	0.199	1.05	13.9	0.616	1.10
	26	B	15.5	26.9	0.024	40/40	0.500	0.195	1.02	13.9	0.585	1.04
	27	B	16.5	30.0	0.024	40/40	0.480	0.195	1.02	13.9	0.585	1.02
	28	B	17.5	27.2	0.024	40/40	0.466	0.195	1.02	13.9	0.580	1.03
	30	B	19.5	26.1	0.024	40/40	0.466	0.195	1.02	13.9	0.594	1.06
	31.7	B	21.2	26.9	0.024	40/40	0.466	0.195	1.02	14.4	0.596	1.05
2	31.7	C	0	26.9	0.014	20/20	0.466	0.195	1.02	14.4	0.539	0.96
	34	C	2.3	26.6	0.015	20/20	0.386	0.190	1.01	16.1	0.566	1.01
	36	C	4.3	26.1	0.015	20/20	0.346	0.199	1.05	16.1	0.585	1.04
	38	C	6.3	26.6	0.015	20/20	0.319	0.195	1.00	15.5	0.580	1.03
	40	C	8.3	26.1	0.015	20/20	0.366	0.195	1.07	15.8	0.571	1.02
	42	C	10.3	26.1	0.015	20/20	0.386	0.195	1.07	15.5	0.580	1.03
	44	C	12.3	26.1	0.015	20/20	0.386	0.195	1.07	15.5	0.566	1.01
	46	C	14.3	26.1	0.015	20/20	0.393	0.199	1.05	15.5	0.566	1.01
	48	C	16.3	26.4	0.015	20/20	0.393	0.199	1.05	15.5	0.603	1.07
	50	C	18.3	26.6	0.015	20/20	0.386	0.195	1.02	15.5	0.580	1.03
	52.2	C	20.5	26.6	0.015	20/20	0.386	0.199	1.05	15.5	0.566	1.01
1	52.2	D	0	26.6	0.033	8/8	0.400	0.426	1.07	15.5	1.047	1.00
	54	D	1.8	27.2	0.033	8/8	0.446	0.412	1.03	14.7	1.079	1.03
	56	D	3.8	27.2	0.033	8/8	0.493	0.403	1.01	14.7	1.088	1.04
	58	D	5.8	27.2	0.033	8/8	0.533	0.412	1.03	14.4	1.097	1.05
	60	D	7.8	26.6	0.033	8/8	0.540	0.412	1.03	13.9	1.061	1.02
	60.8	D	8.6	26.6	0.033	8/8	0.540	0.426	1.07	13.6	1.061	1.02

TABLE 18A

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TABLE 18B

DATA SUMMARY
MISSION I, HIGH TEMPERATURE

ENV NO.	TIME INTO MISSION (HR)	TEST IDENT	TIME ON ENV. (HR.)	TEMP (°F)	FLOW (CFM)	CYCLE TIME (MIN/MIN)	P_{CO_2} (MM HG)	CO_2 FEED (LB/HR)	CO_2 FEED / CO_2 REQD	DEW POINT (°F)	H_2O REQD (LB/HR)	H_2O FEED / H_2O REQD
1	0	A	0	81	70	8/8	4.1	0.90	1.02	58	2.43	1.05
	2	A	2	81	70	8/8	4.0	0.90	1.02	58	2.46	1.07
	4	A	4	81	70	8/8	4.0	0.90	1.02	58	2.44	1.06
	6	A	6	81	70	8/8	4.0	0.90	1.02	58	2.43	1.05
	8	A	8	81	70	8/8	4.0	0.90	1.02	58	2.41	1.04
	10.5	A	10.5	80.5	70	8/8	4.0	0.91	1.03	57.5	2.40	1.04
2	10.5	B	0	80.5	50	40/40	4.0	0.42	1.00	57.5	1.25	1.01
	12	B	1.5	80	50	40/40	4.2	0.45	1.07	57	1.25	1.01
	14	B	3.5	80	50	40/40	4.1	0.46	1.09	56	1.22	0.98
	16	B	5.5	80	50	40/40	4.0	0.44	1.05	56	1.23	0.99
	18	B	7.5	80	50	40/40	4.0	0.42	1.00	56	1.31	1.06
	20	B	9.5	80	50	40/40	3.9	0.45	1.07	56	1.25	1.01
	22	B	11.5	80	50	40/40	3.8	0.42	1.00	56	1.28	1.03
	24	B	13 5	80	50	40/40	3.8	0.44	1.05	57	1.36	1.10
	26	B	15.5	80.5	50	40/40	3.75	0.43	1.02	57	1.29	1.04
	27	B	16.5	86	50	40/40	3.6	0.43	1.02	57	1.26	1.02
	28	B	17.5	81	50	40/40	3.5	0.43	1.02	57	1.28	1.03
	30	B	19.5	79	50	40/40	3.5	0.43	1.02	57	1.31	1.06
	31.7	B	21.2	80.5	50	40/40	3.5	0.43	1.02	58	1.30	1.05
2	31.7	C	0	80.5	30	20/20	3.5	0.43	1.02	58	1.19	0.96
	34	C	2.3	80	31	20/20	2.9	0.42	1.01	61	1.25	1.01
	36	C	4.3	79	32	20/20	2.6	0.44	1.05	61	1.29	1.04
	38	C	6.3	80	32	20/20	2.4	0.42	1.00	60	1.28	1.03
	40	C	8.3	79	32	20/20	2.75	0.45	1.07	60	1.26	1.02
	42	C	10.3	79	32	20/20	2.9	0.45	1.07	60	1.28	1.03
	44	C	12.3	79	32	20/20	2.9	0.45	1.07	60	1.25	1.01
	46	C	14.3	79	32	20/20	2.95	0.44	1.05	60	1.25	1.01
	48	C	16.3	79.5	32	20/20	2.95	0.44	1.05	60	1.33	1.07
	50	C	18.3	80	32	20/20	2.9	0.43	1.02	60	1.28	1.03
	52.2	C	20.5	80	32	20/20	2.9	0.44	1.05	60	1.25	1.01
1	52.2	D	0	80	70	8/8	3.0	0.94	1.07	60	2.31	1.00
	54	D	1.8	81	70	8/8	3.35	0.91	1.03	58.5	2.38	1.03
	56	D	3.8	81	70	8/8	3.7	0.89	1.01	58.5	2.40	1.04
	58	D	5.8	81	70	8/8	4.0	0.91	1.03	58	2.42	1.05
	60	D	7.8	80	70	8/8	4.05	0.91	1.03	57	2.34	1.02
	60.8	D	8.6	80	70	8/8	4.05	0.94	1.07	56.5	2.34	1.02

CO_2 Feed: This is a normalized ratio of the actual CO_2 feed rate divided by the desired metabolic feed rate of the given crew size. The resultant value converts directly to percentage of required feed as described above in the H_2O definition.

PCO_2: This is a measure of the actual PCO_2 level in the simulated Shuttle cabin volume and represents the CO_2 control performance parameter.

The high temperature phase of the mission test was run continuously for 60.8 hours. Test Run "A" ran for 10.5 hours at Environment No. 1. The air temperature and flow were maintained within required limits. The water feed rate averaged 5% high resulting in an equilibrium dew point of 14.2°C (57.5°F). This equilibrium dew point correlates with the performance calibration presented earlier and the breadboard system data. The CO_2 feed rate for Test Run "A" was 2% high. The CO_2 level in the simulated cabin was a stable 0.53 kPa (4 mmHg) for the last eight hours at this environment.

At the completion of the Environment No. 1 test requirement, the CO_2 and H_2O feed rates were adjusted to Environment No. 2 levels. The airflow was lowered to the 0.024 m^3/s (50 cfm) level for the four-man timing control cycle; the cycle time was increased to 40 minutes with a two minute switchover. Air temperature remained the same.

With the test setup adjusted to the four-man crew size, the transient effect on the two performance parameters, PCO_2 level and dew point, was plotted. The dew point drifted to a minimum 13.3°C (56°F), then rose to 14.4°C (58°F) despite the fact that the water feed rate had not been adjusted for 20 hours. The changes in the feed ratio, as graphed in Figure 47, are the measured changes in the water supply tank weight. Ideally, this curve would be a straight line representing the average 3% high water feed rate. The CO_2 feed rate was high for the first four hours on condition but averaged 2% high for the next 17 hours. Similarly, the PCO_2 level started at 0.560 kPa (4.2 mmHg) and stabilized at 0.466 kPa (3.5 mmHg). The only problem encountered was a rig refrigeration problem that caused the air temperature to be over limit for one hour. No effect on the system performance was apparent.

After 21 hours of continuous operation at Environment No. 2 conditions, the flow control mode of operation was introduced; this is identified as Test Run "C". Air flow was reset to 0.14 m^3/s (30 cfm); the cycle time was changed to 20 minutes with a two-minute switchover. Air temperature and CO_2 and H_2O feed rates remained the same. Both feed rates were not adjusted for 37 hours; fluctuations were due to data recording and valve flow regulating variations.

The dew point rose to 16.1°C (61°F) at which time the airflow was increased to .0146 m^3/s (31 cfm). The airflow was again increased to .015 m^3/s (32 cfm) to bring the dew point to an acceptable 15.5°C (60°F). The dew point was stable at 15.5°C (60°F) for over 14 hours. The water feed rate was an average 2.6% high; the dew point would have been 14.7°C (58.5°F) for a perfect feed rate. This agreed with the system performance calibration data.

When the flow control mode of operation was introduced, the CO_2 level dropped sharply, then increased to a stable 0.386 kPa (2.95 mmHg). This PCO_2 level verified that previously recorded during the performance calibration.

For the final eight hours of mission testing the ten-man conditions were again introduced to the system. The airflow, cycle time, and H_2O and CO_2 feed rates were reset to Environment No. 1. Air temperature remained the same.

With the ten-man conditions the dew point decreased to 13.6°C (56.5°F), while the CO_2 level climbed to 0.54 kPa (4.05 mmHg). Both feed rates were 3% high. When corrected for the proper feed rates, the dew point and CO_2 level were consistent with previous test data.

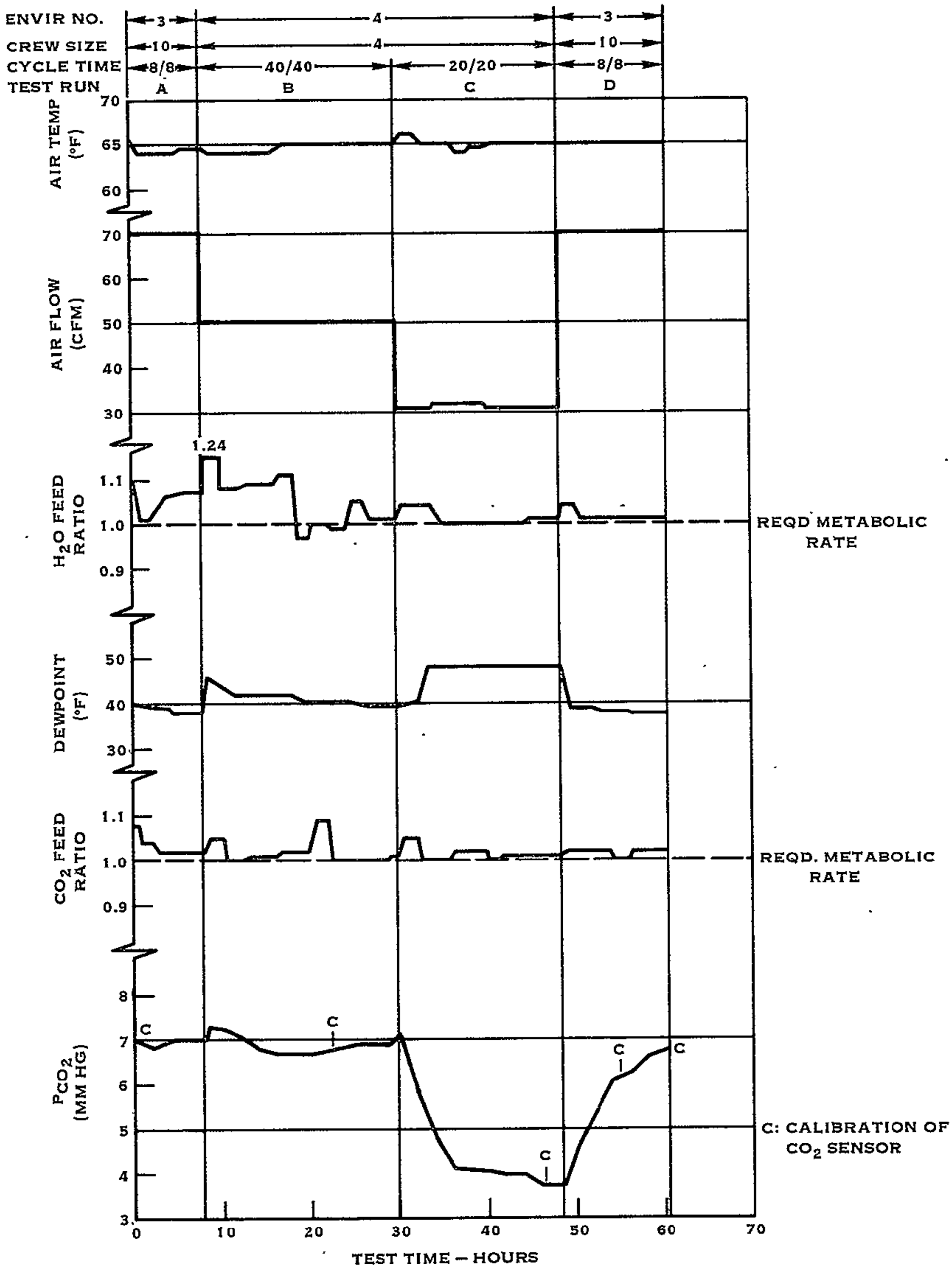
The HS-C system performance at high temperature was considered excellent. The data confirmed previous test results. The HS-C system maintained much lower PCO_2 levels at high temperatures than the baseline Shuttle LiOH system.

Low Cabin Temperature Mission

The low cabin temperature, 18.3°C (65°F) portion of the mission test was accomplished on June 28 through July 1, 1977. The test parameters and performance profiles are summarized in Figure 47. The data for the curves of Figure 48 is presented in Table 19, which also includes the actual metabolic feed rates. Figure 47 presents the test data in the same order and units as Figure 46 in the High Cabin Temperature Mission subsection. For a detailed description of each parameter please refer to that subsection.

The low temperature portion of the mission test was initiated per the Plan of Test at Environment No. 3. The air temperature into the system was controlled within 0.5°C (1°F) of 18.3°C (65°F); the airflow rate was controlled almost exactly at 2 m^3/min (70 cfm) for the test duration.

The water feed rate was 6% high; the dew point stabilized at 3.3°C (38°F). The CO_2 feed rate was 4% high with an equilibrium value of 0.933 kPa (7.0 mmHg). The ten-man conditions were run for a total of eight hours.



MISSION LOW TEMP PROFILES

FIGURE 47

TABLE 19A

DATA SUMMARY
MISSION I, LOW TEMPERATURE

ENV NO.	TIME INTO MISSION (HR)	TEST IDENT	TIME ON ENV. (HR)	TEMP (°C)	FLOW (M^3/MIN)	CYCLE TIME (MIN/MIN)	P_{CO_2} (KPA)	CO_2 FEED (KG/HR)	CO_2 FEED / CO_2 REQD	DEW POINT (°C)	H_2O FEED (KG/HR)	H_2O FEED / H_2O REQD
3	0	A	0	18.8	0.033	8/8	0.933	0.435	1.09	4.4	0.553	1.11
	2	A	2	17.7	0.033	8/8	0.913	0.417	1.04	4.2	0.508	1.01
	4	A	4	17.7	0.033	8/8	0.926	0.408	1.02	3.9	0.531	1.06
	6	A	6	18.05	0.033	8/8	0.933	0.408	1.02	3.3	0.535	1.07
	8.1	A	8.1	18.05	0.033	8/8	0.933	0.408	1.02	3.3	0.535	1.07
4	8.1	B	0	17.7	0.023	40/40	0.973	0.177	0.93	7.8	0.508	1.44
	10	B	1.9	17.7	0.023	40/40	0.966	0.199	1.05	6.7	0.440	1.24
	12	B	3.9	17.7	0.023	40/40	0.946	0.190	1.00	5.5	0.381	1.08
	14	B	5.9	17.7	0.023	40/40	0.906	0.190	1.01	5.5	0.385	1.09
	16	B	7.9	17.7	0.023	40/40	0.893	0.190	1.01	5.5	0.385	1.09
	18	B	9.9	18.3	0.023	40/40	0.893	0.195	1.02	5.5	0.395	1.11
	20	B	11.9	18.3	0.023	40/40	0.893	0.195	1.02	4.7	0.344	0.97
	22	B	13.9	18.3	0.023	40/40	0.900	0.208	1.09	4.7	0.354	1.00
	24	B	15.9	18.3	0.023	40/40	0.913	0.190	1.00	4.7	0.349	0.99
	26	B	17.9	18.3	0.023	40/40	0.920	0.190	1.00	4.4	0.372	1.05
	28	B	19.9	18.3	0.023	40/40	0.920	0.190	1.00	4.2	0.358	1.01
	30	B	21.9	18.3	0.023	40/40	0.946	0.190	1.01	4.2	0.358	1.01
4	30	C	0	18.3	0.014	20/20	0.946	0.186	0.98	4.2	0.335	0.95
	32	C	2	18.8	0.014	20/20	0.773	0.199	1.05	4.4	0.367	1.04
	34	C	4	18.3	0.015	20/20	0.633	0.190	1.00	8.9	0.367	1.04
	36	C	6	18.3	0.015	20/20	0.546	0.190	1.00	8.9	0.354	1.00
	38	C	8	17.7	0.015	20/20	0.540	0.195	1.02	8.9	0.354	1.00
	40	C	10	18.0	0.015	20/20	0.540	0.195	1.02	8.9	0.354	1.00
	42	C	12	18.3	0.014	20/20	0.533	0.190	1.00	8.9	0.354	1.00
	44	C	14	18.3	0.014	20/20	0.533	0.190	1.01	8.9	0.354	1.00
	46	C	16	18.3	0.014	20/20	0.500	0.190	1.01	8.9	0.358	1.01
	48.3	C	18.3	18.3	0.014	20/20	0.500	0.190	1.01	8.9	0.358	1.01
3	48.3	D	0	18.3	0.033	8/8	0.500	0.408	1.02	8.9	0.540	1.08
	50	D	1.7	18.3	0.033	8/8	0.613	0.403	1.02	3.6	0.521	1.04
	52	D	3.7	18.3	0.033	8/8	0.720	0.403	1.02	3.6	0.503	1.01
	54	D	5.7	18.8	0.033	8/8	0.813	0.408	1.02	3.3	0.508	1.01
	56	D	7.7	18.3	0.033	8/8	0.833	0.403	1.01	3.3	0.503	1.01
	58	D	9.7	18.3	0.033	8/8	0.880	0.408	1.02	3.0	0.503	1.01
	60.3	D	12.0	18.3	0.033	8/8	0.900	0.403	1.01	3.0	0.503	1.01

DATA SUMMARY
MISSION I, LOW TEMPERATURE

ENV. NO.	TIME INTO MISSION (HR)	TEST IDENT	TIME ON ENV. (HR)	TEMP (°F)	FLOW (CFM)	CYCLE TIME (MIN/MIN)	P_{CO_2} (MM HG)	CO_2 FEED (LB/HR)	CO_2 FEED / CO_2 REQD	DEW POINT (°F)	H_2O FEED (LB/HR)	H_2O FEED / H_2O REQD
3	0	A	0	66	70	8/8	7.0	0.96	1.09	40	1.22	1.11
	2	A	2	64	70	8/8	6.85	0.92	1.04	39.5	1.12	1.01
	4	A	4	64	70	8/8	6.95	0.90	1.02	39	1.17	1.06
	6	A	6	64.5	70	8/8	7.0	0.90	1.02	38	1.18	1.07
	8.1	A	8.1	64.5	70	8/8	7.0	0.90	1.02	38	1.18	1.07
4	8.1	B	0	64	50	40/40	7.3	0.39	0.93	46	1.12	1.44
	10	B	1.9	64	50	40/40	7.25	0.44	1.05	44	0.97	1.24
	12	B	3.9	64	50	40/40	7.1	0.42	1.00	42	0.84	1.08
	14	B	5.9	64	50	40/40	6.8	0.42	1.01	42	0.85	1.09
	16	B	7.9	64	50	40/40	6.7	0.42	1.01	42	0.85	1.09
	18	B	9.9	65	50	40/40	6.7	0.43	1.02	42	0.87	1.11
	20	B	11.9	65	50	40/40	6.7	0.43	1.02	40.5	0.76	0.97
	22	B	13.9	65	50	40/40	6.75	0.46	1.09	40.5	0.78	1.00
	24	B	15.9	65	50	40/40	6.85	0.42	1.00	40.5	0.77	0.99
	26	B	17.9	65	50	40/40	6.9	0.42	1.00	40	0.82	1.05
	28	B	19.9	65	50	40/40	6.9	0.42	1.00	39.5	0.79	1.01
	30	B	21.9	65	50	40/40	7.1	0.42	1.01	39.5	0.79	1.01
4	30	C	0	65	31	20/20	7.1	0.41	0.98	39.5	0.74	0.95
	32	C	2	66	31	20/20	5.8	0.44	1.05	40	0.81	1.04
	34	C	4	65	32	20/20	4.75	0.42	1.00	48	0.81	1.04
	36	C	6	65	32	20/20	4.1	0.42	1.00	48	0.78	1.00
	38	C	8	64	32	20/20	4.05	0.43	1.02	48	0.78	1.00
	40	C	10	64.5	32	20/20	4.05	0.43	1.02	48	0.78	1.00
	42	C	12	65	31	20/20	4.0	0.42	1.00	48	0.78	1.00
	44	C	14	65	31	20/20	4.0	0.42	1.01	48	0.78	1.00
	46	C	16	65	31	20/20	3.75	0.42	1.01	48	0.79	1.01
	48.3	C	18.3	65	31	20/20	3.75	0.42	1.01	48	0.79	1.01
3	48.3	D	0	65	70	8/8	3.75	0.90	1.02	48	1.19	1.08
	50	D	1.7	65	70	8/8	4.6	0.89	1.02	38.5	1.15	1.04
	52	D	3.7	65	70	8/8	5.4	0.89	1.02	38.5	1.11	1.01
	54	D	5.7	66	70	8/8	6.1	0.90	1.02	38	1.12	1.01
	56	D	7.7	65	70	8/8	6.25	0.89	1.01	38	1.11	1.01
	58	D	9.7	65	70	8/8	6.6	0.90	1.02	37.5	1.11	1.01
	60.3	D	12.0	65	70	8/8	6.75	0.89	1.01	37.5	1.11	1.01

TABLE 19B

The Environment No. 4 conditions were then introduced to the system; airflow, cycle time, and metabolic feed rates were changed. The dew point increased to 7.8°C (46°F), then gradually decreased to an equilibrium of 4.2°C (39.5°F) after 22 hours on condition. This initial jump in dew point was due to a high feed rate for the first four hours on this environment. The 4.2°C (39.5°F) dew point was consistent with previous data.

The CO_2 level did not decrease sharply as expected from the performance calibration data. The PCO_2 level dropped to 0.893 kPa (6.7 mmHg), then rose to 0.946 kPa (7.1 mmHg). The feed rate was an average of 1.9% high; the feed setting was not adjusted after the inital readjustment for Environment No. 4. The HS-C system removed the maximum four-man metabolic CO_2 load but did not appear to have sufficient reserve capacity to decrease the PCO_2 level in the plenum. This is verified by reviewing the performance calibration data in which the system stabilized at 0.80 kPa (6 mmHg) with the correct metabolic loading.

After 30 hours of continuous testing the controller settings were reset for flow control. The airflow was reduced to 0.014 m^3/min (31 cfm); cycle time was changed to 20 minutes. The dew point increased to a very stable 8.9°C (48°F). The CO_2 level dropped sharply to 0.546 kPa (4.1 mmHg), then reached an equilibrium at 0.500 kPa (3.75 mmHg). Both the CO_2 and H_2O feed rates were within 1% of the four-man maximum metabolic rates.

For the final 12 hours of mission testing, Environment No. 3 conditions were reset. Airflow, cycle time, and metabolic feed rates were changed to the ten-man loads. The dew point decreased to an equilibrium value of 3°C (37.5°F), while the PCO_2 level rose to 0.90 kPa (6.75 mmHg). Both the H_2O and CO_2 feed rates were a fairly constant 1.5% high. When adjusted for the feed rate difference, the dew point agrees with that recorded during the first portion of the mission test. The PCO_2 level was lower than the initial test level, but the PCO_2 level was still increasing slight after 12 hours on condition. This completed the 120-hour mission requirement.

In reviewing both the high and low temperature profiles for the dew point and PCO_2, it is evident that the dew point increases as the PCO_2 level decreases with decreasing flow and shorter cycle times. The dew point increases because the low airflow rate does not allow enough water to enter the HS-C bed. The bed has a much higher capacity for water than it can actually see. Conversely, the CO_2 capacity of the HS-C bed is well satisfied under the same operating conditions. The bed becomes fully loaded with CO_2 only at the end of each cycle and is, therefore, operating at maximum efficiency.

The mission test successfully demonstrated the ability of the HS-C prototype system to effectively maintain humidity and CO_2 levels during the simulated Shuttle mission. The HS-C system maintained an average CO_2 level below the 1.01 kPa (7.6 mmHg) level for the existing Shuttle LiOH system.

CO Removal Test

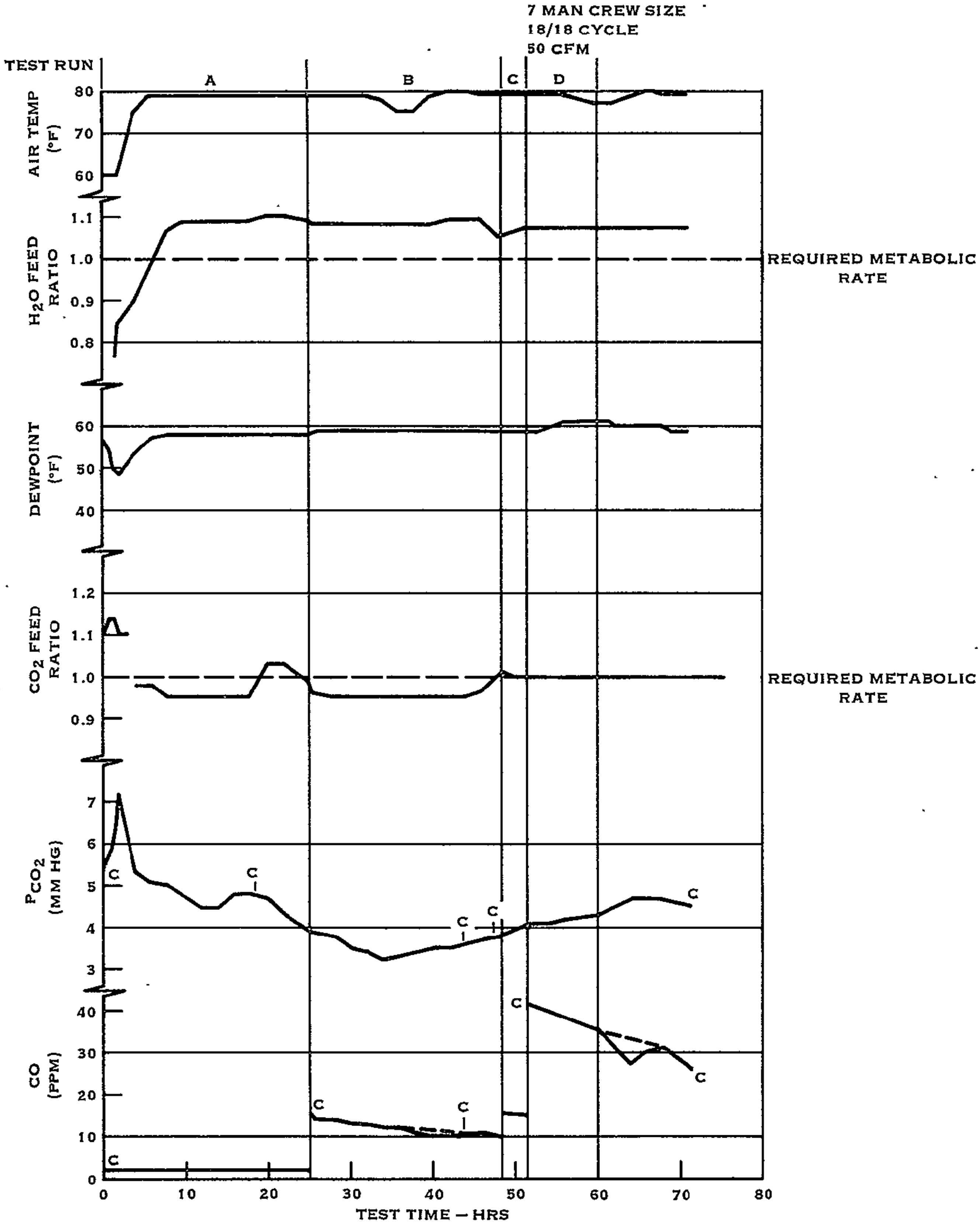
The purpose of this test was to determine the effectiveness of the HS-C system to control the carbon monoxide level in the cabin atmosphere.

The CO removal testing was accomplished during the week of July 26 through July 29, 1977. The test data and performance profiles are presented in Figure 48 and tabulated in Table 20. The following discussion references the profiles of Figure 48. The data is presented in the same format and units as the mission data. For a detailed description of each parameters please refer to the High Cabin Temperature Mission subsection.

A performance baseline was established for the seven-man crew, 26.7°C (80°F) environment. The air flow was a constant 0.236 kPa (50 cfm). The cycle time was 16 minutes adsorb/16 minutes desorb with a two-minute switchover. These conditions, with the seven-man nominal metabolic rates for CO_2 and H_2O, were run continuously for 24.9 hours.

Instrumentation problems caused the low initial temperature setting. However, the corrected temperature was constant for the final 19 hours of Test Run "A". The H_2O feed rate was an average 7% high; the dew point was a stable 14.4°C (58°F). The CO_2 feed rate averaged a value 5% below the nominal metabolic rate; the apparent increase in feed rate of 20 hours was due to changing the CO_2 supply cylinder. With the overabundance of water and the low CO_2 feed rate, the CO_2 level dropped from .706 kPa (5.3 mmHg) to .520 kPa (3.9 mmHg).

At the start of Test Run "B", carbon monoxide was added to the plenum until a level of 15 ppm (maximum allowable Shuttle level) was recorded by the CO detector (Ecolyzer). The other parameters (air temperature, H_2O, and CO_2 feed rates) were not readjusted in order that a direct comparison of the performance parameters could be made.



CO REMOVAL TEST

FIGURE 48

DATA SUMMARY
CO TEST
7 MAN 80°

TIME ON TEST (HR)	TEST IDENT	TEMP (°C)	FLOW (KPA)	CYCLE TIME (MIN/MIN)	P_{CO_2} (KPA)	CO_2 FEED (KG/HR)	CO_2 FEED / CO_2 REQD	DEW POINT (°C)	H_2O FEED (KG/HR)	H_2O FEED / H_2O REQD	CO (1) (PPM)	REMARKS
0	A		0.0236	20/20	0 719	0 308	1.11	14.2	0.403	0.55	2	
1	A		0.0236	20/20	0.773	0 317	1.14	12.2	0.403	0.55	2	
1.3	A	15.5	0 0236	18/18	0.866	0 317	1.14	10.0	0.403	0.55	2	
2	A	15 5	0.0236	18/18	0.960	0.308	1.11	9.2	0.612	0 84	2 (3)	
4	A	34.0	0.0236	18/18	0.706	–	–	11.7	0.658	0 90	2	
6	A	35.8	0.0236	18/18	0.680	0.272	0.98	14.2	0.726	0 99	2	
8	A	35.8	0.0236	18/18	0.666	0.265	0.95	14 4	0.785	1.07	2	
10	A	35.8	0.0236	18/18	0.626	0.265	0.95	14.4	0.794	1.09	2	
12	A	35.8	0.0236	18/18	0.600	0.265	0.95	14 4	0.794	1.09	2	
14	A	35.8	0.0236	18/18	0.600	0.265	0.95	14.4	0.794	1.09	2	
16	A	35.8	0.0236	18/18	0 640	0 265	0.95	14 4	0.794	1.09	2	
18	A	35.8	0.0236	18/18	0 640	0 265	0.95	14.4	0.794	1.09	2	
20	A	35.8	0.0236	18/18	0 626	0.285	1.03	14.4	0.812	1 11	2	
22	A	35.8	0.0236	18/18	0 573	0.285	1.03	14 4	0.812	1.11	2	
24.9	A	35.8	0.0236	18/18	0 520	0.272	0.98	14.4	0.794	1 09	2	
24.9	B	35.8	0.0236	18/18	0.520	0.272	0.98	14.4	0.794	1 09	15	
26	B	35.8	0.0236	18/18	0.513	0.267	0 96	14.7	0.789	1 08	14.2	
28	B	35.8	0.0236	18/18	0 506	0 263	0 95	14.7	0.789	1.08	14	
30	B	35.8	0.0236	18/18	0.466	0 263	0 95	15.0	0 789	1 08	13.2	
32	B	35.8	0.0236	18/18	0.453	0.263	0 95	15.0	0.789	1.08	13	
34	B	35.4	0.0236	18/18	0.433	0.263	0.95	15.0	0.789	1.08	12 5	
36	B	34.0	0.0236	18/18	0.440	0.263	0 95	15.0	0.789	1.08	12.5 (2)	
38	B	34.0	0.0236	18/18	0.453	0.263	0.95	15.0	0.789	1.08	10.8	
40	B	35.8	0.0236	18/18	0.466	0 263	0.95	15.0	0.789	1.08	10	
42	B	36 3	0.0236	18/18	0.466	0 263	0 95	15.0	0.794	1 09	10	
44	B	36.3	0 0236	18/18	0.480	0 263	0.95	15.0	0.794	1.09	11	
46	B	35.8	0 0236	18/18	0.493	0 267	0.96	15.0	0.794	1.09	11	
48.5	B	35.8	0 0236	18/18	0.506	0.281	1 01	15.0	0.766	1.05	10	
48.5	C	35 8	0.0236	18/18	0.506	0.281	1.01	15 0	0.766	1.05	15.5	
50	C	35 8	0.0236	18/18	0 520	0.280	1.00	15 0	0.775	1.06	15	
51.2	C	35.8	0.0236	18/18	0 546	0.279	1.00	15.0	0 780	1 07	15	
51 2	D	35.8	0.0236	18/18	0 546	0.279	1.00	15.0	0.780	1.07	42	
54	D	35.8	0.0236	18/18	0 546	0 279	1.00	15 0	0.780	1.07		
56	D	35.8	0 0236	18/18	0.560	0.279	1.00	15 5	0.780	1.07		
58	D	35.4	0.0236	18/18	0.566	0.279	1.00	15.8	0.780	1 07	37	
60	D	34 9	0.0236	18/18	0.573	0.279	1.00	15.8	0.780	1 07	35.8	
62	D	34.9	0.0236	18/18	0.599	0.279	1.00	15.5	0.780	1.07	(2)	
64	D	35.4	0.0236	18/18	0 626	0.279	1.00	15.5	0 780	1.07	27 (2)	
66	D	36.3	0.0236	18/18	0 626	0.280	1.00	15.5	0 780	1 07	30	
68	D	35.8	0.0236	18/18	0 620	0 280	1.00	15.3	0.780	1.07	31	
70	D	35.8	0.0236	18/18	0 613	0 280	1.00	15 3	0.780	1.07		
71 4	D	35.8	0.0236	18/18	0.599	0.280	1.00	15 3	0 780	1 07	26.5	

(3) CO_2 OFF FOR 1 HOUR
(2) CO DETECTOR PROBLEM WITH ELECTROLYTE
(1) CO LEVEL AFFECTED BY SYSTEM LEAKAGE – SEE DATA REDUCTION

TABLE 20A

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DATA SUMMARY
CO TEST
7 MAN 80°

TIME ON TEST (HR)	TEST IDENT	TEMP (°F)	FLOW (CFM)	CYCLE TIME (MIN/MIN)	P_{CO_2} (MM HG)	CO_2 FEED (LB/HR)	CO_2 FEED / CO_2 REQD	DEW POINT (°F)	H_2O FEED (LB/HR)	H_2O FEED / H_2O REQD	CO PPM (1)	
0	A		50	20/20	5.4	0.68	1.11	57 5	0.89	0.55	2	BASELINE TEST
1	A		50	20/20	5.8	0.70	1.14	54	0.89	0.55	2	
1.3	A	60	50	18/18	6.5	0.70	1.14	50	0.89	0.55	2	
2	A	60	50	18/18	7.2	0 68	1.11	48.5	1.35	0.84	2 (3)	
4	A	75	50	18/18	5.3	—	—	53	1.45	0.90	2	CO OFF FOR ~1 HR
6	A	79	50	18/18	5.1	0.60	0.98	57.5	1.60	0.99	2	
8	A	79	50	18/18	5 0	0.585	0.95	58	1.73	1.07	2	
10	A	79	50	18/18	4.7	0.585	0 95	58	1.75	1.09	2	
12	A	79	50	18/18	4.5	0.585	0.95	58	1.75	1.09	2	
14	A	79	50	18/18	4.5	0.585	0 95	58	1.75	1.09	2	
16	A	79	50	18/18	4.8	0.585	0 95	58	1 75	1.09	2	
18	A	79	50	18/18	4.8	0.585	0.95	58	1.75	1.09	2	
20	A	79	50	18/18	4.7	0.63	1 03	58	1.79	1 11	2	
22	A	79	50	18/18	4.3	0.63	1.03	58	1.79	1.11	2	
24.9	A	79	50	18/18	3.9	0.60	0 98	58	1.75	1.09	2	
24.9	B	79	50	18/18	3.9	0.60	0.98	58	1 75	1.09	15	CO ADDED
26	B	79	50	18/18	3.85	0.59	0 96	58.5	1 74	1 08	14.2	
28	B	79	50	18/18	3.8	0 58	0.95	58.5	1 74	1.08	14	
30	B	79	50	18/18	3.5	0.58	0.95	59	1.74	1.08	13.2	
32	B	79	50	18/18	3 4	0.58	0.95	59	1.74	1.08	13	
34	B	78	50	18/18	3.25	0 58	0 95	59	1 74	1.08	12.5	
36	B	75	50	18/18	3.3	0.58	0 95	59	1.74	1.08	12.5 (2)	
38	B	75	50	18/18	3.4	0.58	0.95	59	1.74	1.08	10.8	
40	B	79	50	18/18	3.5	0.58	0.95	59	1.74	1.08	10	
42	B	80	50	18/18	3.5	0.58	0.95	59	1 75	1.09	10	
44	B	80	50	18/18	3 6	0.58	0.95	59	1 75	1 09	11	RECALIB. INSTR.
46	B	79	50	18/18	3.7	0 59	0.96	59	1.75	1.09	11	RESET 7 MAN CONDITIONS
48.5	B	79	50	18/18	3.8	0.62	1 01	59	1.69	1.05	10	
48.5	C	79	50	18/18	3 8	0.62	1.01	59	1 69	1.05	15.5	RESET CO LEVEL
50	C	79	50	18/18	3.9	0.618	1.00	59	1.71	1.06	15	
51.2	C	79	50	18/18	4 1	0.616	1.00	59	1.72	1.07	15	
51.2	D	79	50	18/18	4.1	0 616	1.00	59	1 72	1 07	42	RESET CO LEVEL
54	D	79	50	18/18	4.1	0.616	1 00	59	1.72	1.07		
56	D	79	50	18/18	4.2	0.616	1.00	60	1.72	1.07		
58	D	78	50	18/18	4 25	0.616	1.00	60.5	1.72	1.07	37	
60	D	77	50	18/18	4.3	0 616	1 00	60.5	1.72	1.07	35.8	
62	D	77	50	18/18	4.5	0 616	1 00	60	1.72	1 07	(2)	
64	D	78	50	18/18	4.7	0.616	1.00	60	1 72	1.07	27 (2)	
66	D	80	50	18/18	4.7	0.618	1.00	60	1 72	1.07	30	
68	D	79	50	18/18	4.65	0 618	1.00	59.5	1.72	1 07	31	
70	D	79	50	18/18	4.6	0 618	1 00	59.5	1.72	1.07		
71 4	D	79	50	18/18	4.5	0.618	1 00	59.5	1.72	1.07	26.5	

(3) CO_2 OFF FOR ONE HOUR
(2) CO DETECTOR PROBLEM WITH ELECTROLYTE
(1) CO LEVEL AFFECTED BY SYSTEM LEAKAGE SEE DATA REDUCTION

TABLE 20B

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

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With the feed rate 8% high, the dew point stabilized at 15°C (59°F), a slight increase from 14.4°C (58°F) over 23 hours of testing. The CO_2 level continued to decrease to a minimum 0.433 kPa (3.25 mmHg), then rose to 0.493 kPa (3.7 mmHg). At this time (46 hours of continuous testing), the H_2O and CO_2 feed rates were readjusted for the correct metabolic rates. The CO_2 level continued to increase; at the end of Test Run "B", the level was 0.506 kPa (3.8 mmHg).

The carbon monoxide level slowly decreased throughout the 23 hours of Test Run "B". During this test a system leakage check was run to determine if this decrease was due to leakage. With the plenum valve closed, the leakage calculated from manometer readings accounted for the drop in CO level. Figure 49 compares the predicted versus the recorded readings of carbon monoxide level. It is evident that the carbon monoxide level was affected by the leakage; there was no apparent effect due to the HS-C system.

Test Run "C" was a 2.7 hour run. Carbon monoxide was again added until the Ecolyzer recorded 15 ppm. Metabolic feed rates remained constant; the water feed averaged 6% high, while carbon dioxide feed was the correct metabolic rate (ratio = 1.0). The dew point remained at 15°C (59°F). As expected, the CO_2 level increased to 0.546 kPa (4.1 mmHg) due to the increased feed rates.

As a final check on the CO removal capacity of HS-C, the carbon monoxide level was increased to 42 ppm (almost three times the maximum allowable Shuttle level). The CO level again decreased at a rate consistent with the predicted leakage effect, as shown in Figure 50.

The water feed rate was a constant 7% high; the dew point reached an equilibrium value of 15.3°C (59.5°F). With the CO_2 feed rate at the exact seven-man nominal metabolic rate, the PCO_2 level rose to 0.626 kPa (4.7 mmHg), then decreased to 0.599 kPa (4.5 mmHg). The CO_2 level was decreasing slightly after 20 hours on conditions; the test was concluded at this time when vacuum rig problems developed. This CO_2 level would probably have stabilized near the .573 kPa (4.3 mmHg) recorded on the breadboard system during parametric testing. The 18/18 cycle was not increased to the 19-minute cycle used for the breadboard system test since the PCO_2 and dew point approximated the same levels recorded for the previous test. This represented an approximate 3% degradation in cyclic capacity of the HS-C bed.

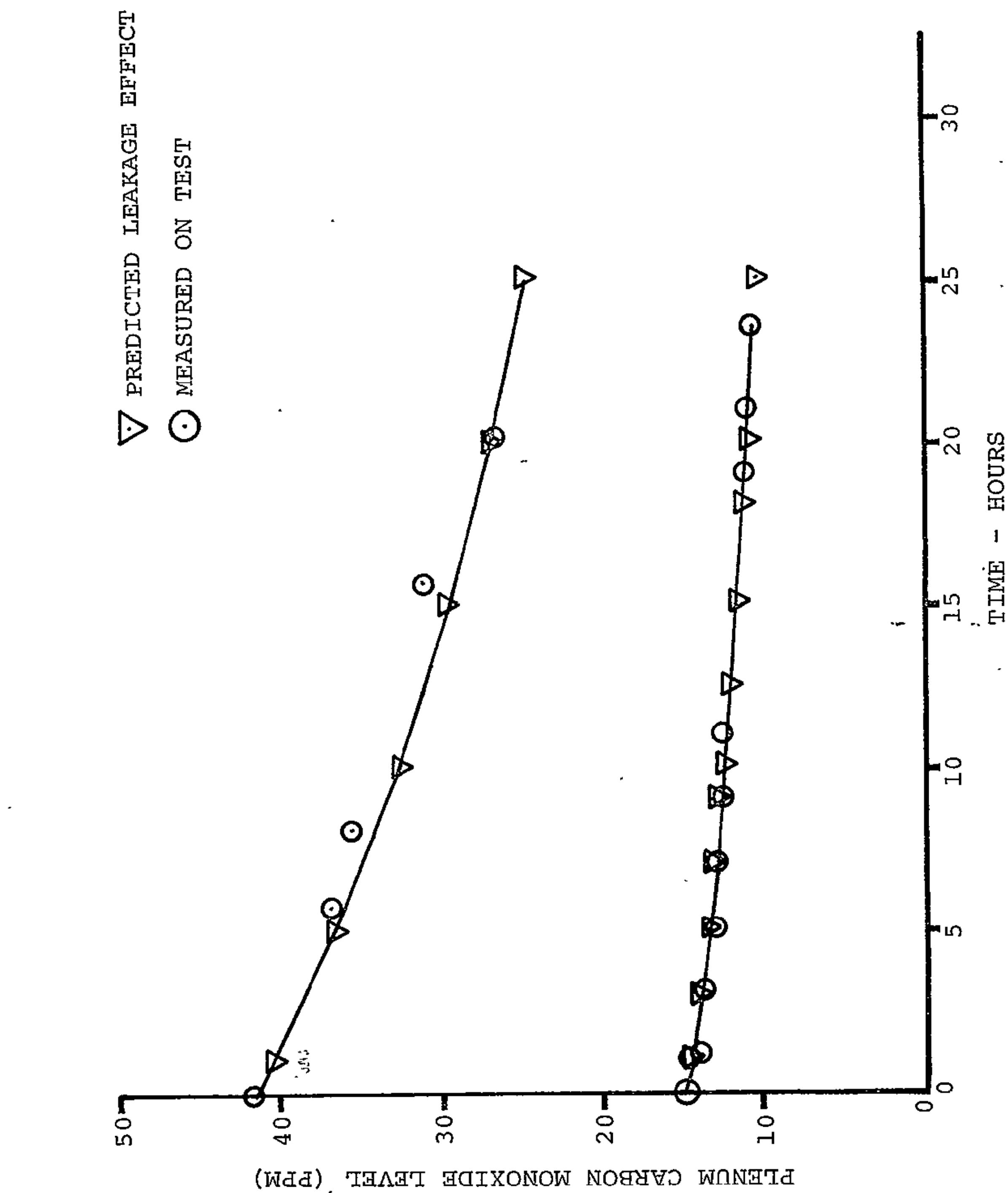

FIGURE 49

CARBON MONOXIDE LEVELS DURING TESTING

It was concluded that the HS-C prototype system can successfully maintain acceptable PCO_2 and dew point conditions for the seven-man crew loads. The presence of carbon monoxide in the air circuit had no apparent effect on system performance. Conversely, the HS-C system had no effect on the level of carbon monoxide in the air circuit and has no removal capacity for this Shuttle contaminant.

APPENDIX A

SYSTEM REQUIREMENTS SPECIFICATION

TABLE I

SHUTTLE CABIN ENVIRONMENT

Parameter	Range	
Cabin Temperature - °C (°F)	18.3-26.7	(65-80)
Cabin Dew Point - °C (°F)	1.7-16.1	(35-61)
CO_2 Partial Pressure - kN/m^2 (mmHg)	0.67-1.01	(5.0-7.6)
Fail Safe	1.33	(10)
Emergency, 2 hour max.	2.00	(15)
Cabin Volume - m^3 (ft^3)	56.6	(2000)
Cabin Air Pressure - kN/m^2 (psia)	101.4	(14.7)

Reference: NAS 9-13624, SOW paragraph 3.3
SSP Document A22, Revision D, Amendment No. 1

TABLE II

CREW METABOLIC RATES

Cabin Temperature °C (°F)	Heat Output kJ/Man-Day (Btu/Man-Day) Nominal Latent	Nominal Sensible	Maximum Latent	Maximum Sensible
18.3 (65)	2962 (2805)	8371 (7928)	5174 (4900)	8341 (7900)
21.1 (70)	3838 (3635)	7495 (7098)	6040 (5720)	7476 (7080)
23.9 (75)	4986 (4722)	6347 (6011)	7155 (6776)	6361 (6024)
26.7 (80)	6198 (5870)	5135 (4863)	8350 (7908)	5165 (4892)

CO_2 PRODUCTION

kg/Man-Day (lb/Man-Day)

Nominal	Maximum
.96 (2.11)	1.14 (2.51)

APPENDIX B

COMPONENT SPECIFICATIONS

APPLICATION		REVISIONS				SVHSER 7182
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED	

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SHEET INDEX	REV.																						
	SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ______
ANGLES ± ______ EXCEPT FOR DRILL END FORMS, FILLET RADII ____ TO ____. SURFACES HAVING A COMMON AXIS CONC WITHIN ______ TIR ______
BREAK EDGES .025 MAX.
△MARK PART IDENT HS333, DWG INTERPRETATION ______
CLEANING, PRESERVATION AND HANDLING: HS1550-C ____ P ____
SURFACE CHARACTERISTICS: USAS B 46.1

APPROVAL SIGNATURES			
DRAWN	A Boender	3/1/76	
CHECKED			
DESIGN			
DFTG		COST	
MAT'L		FCTY	
PROJ	AWB	Q & R	

CONTRACT NUMBER

EXP MFG	PRE PROD.	PROD.

+ DENOTES ORIGINAL ISSUE

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT · U.S.A.

HS-C REGENERABLE CANISTER

SIZE	CODE IDENT NO.	
A	73030	SVSK DR 91722

PROD. CODE

~~csp item~~ | REV | SHEET 1 OF 5

1070 SSP-1

1.0 SCOPE

This specification establishes the performance and design requirements for the HS-C Regenerable Canister.

The units used in this specification are shown in both the International System of Units (SI) and U.S. customary units. The U.S. customary units are in parenthesis "( )". The values were computed in U.S. customary units and converted to SI units.

2.0 FUNCTION

The HS-C regenerable canister adsorbs carbon dioxide (CO_2) and humidity (H_2O) from the cabin airstream at atmospheric pressure. When exposed to space vacuum, the canister desorbs the carbon dioxide (CO_2) and humidity (H_2O) overboard, thus regenerating itself for future adsorption. By combining two (2) separate beds into the same canister, the HS-C regenerable canister continuously and simultaneously absorbs and desorbs carbon dioxide and humidity from the spacecraft atmosphere.

By controlling both the airflow rate through the adsorption side of the canister and the time interval between switching the adsorption/desorption sides of the canister, the canister's removal rate for carbon dioxide and humidity can balance the metabolic production rate of the spacecraft crew up to a maximum of 10 men.

3.0 DESCRIPTION

The HS-C regenerable canister is arranged to contain two separate chemical beds, containing the absorbent material known as HS-C. The canister is constructed similar to a heat exchanger in which alternating layers are connected by headers to form the two separate beds. Each bed is supplied with separate inlet and outlet headers resulting in four (4) total interface ducts. Screens are incorporated inside the heat exchanger core to contain the HS-C material inside the canister.

4.0 PERFORMANCE AND DESIGN REQUIREMENTS

4.1 Fluid Media

The working fluid shall be Shuttle Orbiter cabin air or an equivalent mixture of oxygen or nitrogen.

4.2 Mechanical Interfaces

The HS-C regenerable canister is an integral part of the Regenerable CO_2 and Hmidity Control System structure and provides a structural link between the system frame and the vehicle structure as defined by SVSK 91721. In addition, the canister may serve as the mounting structure for miscellaneous components if a packaging and structural study can show that such a mounting scheme is feasible and will not

4.2 (Continued)

jeopardize canister performance or life.

The canister shall have four (4) plumbing interfaces per the following:

Duct	Size
Bed "A" Inlet	.0953m (3.75 in) I.D. minimum
Bed "A" Outlet	.0953m (3.75 in) I.D. minimum
Bed "B" Inlet	.0953m (3.75 in) I.D. minimum
Bed "B" Outlet	.0953m (3.75 in) I.D. minimum

The plumbing interface locations must be compatible with the overall packaging configuration of the Regenerable CO_2 and Humidity Control System and must interface directly with the cycle valves per SVSK 91721.

4.3 Electrical Interface

None required.

4.4 Flow and Pressure Drop

The pressure head loss (pressure drop, ΔP) of air [at 101.4 kPa (14.7 psia) and 21.1°C (70°F)] flowing through the canister when charged with HS-C material shall not exceed the following values:

Bed	Flow [m^3/s (cfm)]	ΔP Maximum [Pa (in H_2O)]
A	.0236 (50)	946 (3.8)
A	.033 (70)	1443 (5.8)
B	.0236 (50)	946 (3.8)
B	.033 (70)	1443 (5.8)

4.5 Leakage

The maximum internal leakage between the two beds when either bed is evacuated (101.4 kPa (14.7 psi) differential pressure) shall be 6×10^{-10} m^3/s (1×10^{-3} lb/hr) of STP air.

The maximum external leakage from ambient into canister when either bed is evacuated (101.4 kPa (14.7 psi) differential pressure) shall be 6×10^{-11} m^3/s (1×10^{-4} lb/hr) of STP air.

4.6 Weight

The maximum weight of the HS-C regenerable canister shall be 48.8 kg (107.6 lb) when the canister is charged with a minimum of 9.3 kg (20.5 lb) of HS-C material in each bed (18.6 kg (41 lb) of HS-C total).

4.7 Power

None required.

4.8 Configuration

This component shall be configured to enhance the overall packaging of the Regenerable CO_2 and Humidity Control System as defined by SVSK 91721. Plumbing interfaces, electrical interfaces, and structural mounting shall be compatible with SVSK 91721 and paragraph 4.2 and 4.3 of this document.

4.9 Life Requirements

As a design objective, the equipment shall be capable of performing all operations specified herein for a minimum of 10 years.

4.10 Environmental Conditions

4.10.1 Ambient Operating Environment

a. Temperature

The cabin temperature range shall be from 1.7 °C to 49 °C. (35°F to 120°F)

b. Pressure

The cabin pressure range shall be from 93 KPa to 103 KPa (13.5 psia to 14.9 psia)

c. Humidity

The cabin humidity shall be from a dew point of -18 °C (0°F) to a dew point of 29 °C. (84°f)

4.10.2 Induced Environment

a. Acceleration

Spacecraft generated acceleration shall be ± 3 g's in any direction.

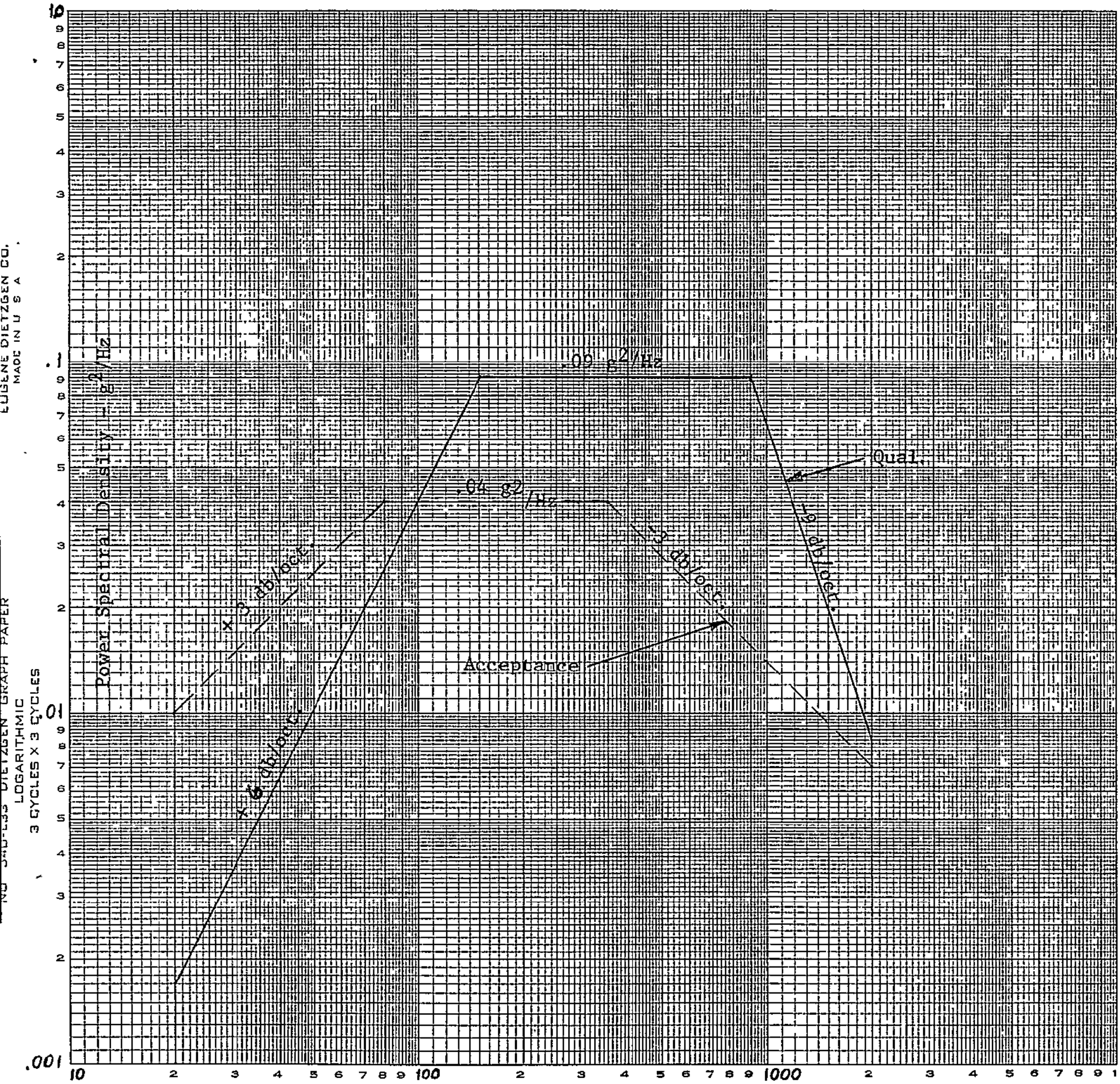
b. Vibration

Spacecraft induced vibration shall be as shown in Figure 1.

c. Shock

See Space Shuttle General Specification SVHS 6400, paragraph 3.2.5.2.1.

Qual. Duration 48 min/axis
Acceptance Duration 30 sec. min/axis
5 min. max/axis



Freq. - Hz

Figure 1

Random Vibration Levels

SVHSER 7182

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ____
ANGLES ± ____ EXCEPT FOR DRILL END FORMS, FILLET RADII ____ TO ____. SURFACES HAVING A COMMON AXIS CONC WITHIN ____ TIR ____
BREAK EDGES .025 MAX.
△MARK PART IDENT HS333, DWG INTERPRETATION ____.
CLEANING, PRESERVATION AND HANDLING: HS1550-C ____ P ____
SURFACE CHARACTERISTICS: USAS B 46.1

PROD. CODE

APPROVAL SIGNATURES				
DRAWN	ABoehm			3/1/76
CHECKED				
DESIGN				
DFTG		COST		
MAT'L		FCTY		
PROJ	AWB	Q & R		

CONTRACT NUMBER

EXP MFG	PRE PROD.	PROD.

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Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

VACUUM CYCLE VALVE

SIZE	CODE IDENT NO.	
A	73030	SVSK DR 91723

~~ssp item~~ | REV | SHEET 1 OF 6

1.0 SCOPE

This specification establishes the performance and design requirements for the vacuum cycle valve.

The units used in this specification are shown in both the International system of units (SI) and U S. customary units. The U.S. customary units are in parenthesis "( )". The values were computed in U.S. customary units and converted to SI units.

2.0 FUNCTION

The vacuum cycle valve provides the valving function to control the adsorption/desorption mode of the HS-C regenerable canister (canister). The valve allows cabin air to flow into and out of the adsorbing bed while venting the desorbing bed to space vacuum. Upon a signal from the controller, the valve cycles the adsorption bed onto desorption and the desorption bed onto ~~an~~ adsorption. When cycling between the adsorption/desorption modes, the valve must first go into an off position where the canister interface is isolated from both the cabin atmosphere and the space vacuum. This off position must be discrete and the length of time in this position controlled independently by an electrical controller. The function of the off position is to allow time for some independent action to retrieve as much of the adsorption bed cabin air as possible before the valve cycles the adsorption bed over to the desorption mode and thus loses the trapped cabin air overboard to space (the gas lost in this manner is referred to as ullage). The off position is also used for system isolation and non-operating modes including launch.

3.0 DESCRIPTION

It is recognized that multiple vacuum cycling valves may be required to fulfill the functional requirements per section 2.0 of this document. The following table should be used as guide of the possible number and arrangements of cycle valves needed:

Number of Valves	Number of Interface Ports	Number of Valve Positions
1	7	3
2	4	3
4	3	3
8	2	2

The cycle valve(s) is a critical item in the overall packaging arrangement of the Regenerable CO_2 and Humidity Control System and must be designed in conjunction with the canister and packaging effort to produce the optimum valving arrangement and minimum weight and sized package.

Although multiple valves may be selected, together they represent one valving function and as such, they may be gang mounted and interconnected by a common

3.0 (Continued)

actuation device. The actuator should be electrical if torque and stroke levels permit. A pneumatic actuator is only acceptable if its gas usage balances the ullage requirements of the Regenerable CO_2 and Humidity Control System.

4.0 PERFORMANCE AND DESIGN REQUIREMENTS

4.1 Fluid Media

The working fluid shall be Shuttle Orbiter cabin air or an equivalent mixture of oxygen or nitrogen.

4.2 Mechanical Interfaces

The valve(s) should mount directly to the HS-C canister but may rely on structural support from the Regenerable CO_2 and Humidity Control System package structural frame.

The valve(s) shall have the following interface plumbing connections.

Duct	Size
Cabin Air Inlet	0.070m (2.75 in) I.D. minimum
Cabin Air Outlet	0.070m (2.75 in) I.D. "
Vacuum Vent	0.0953m (3.75 in) I D. "
Bed "A" Inlet	0.0953m (3.75 in) I.D. "
Bed "A" Outlet	0.0953m (3.75 in) I.D. "
Bed "B" Inlet	0.0953m (3.75 in) I.D. "
Bed "B" Outlet	0.0953m (3.75 in) I.D. "

If multiple valves are selected, the interconnection of the various ports shall be in compliance with the above table.

4.3 Electrical Interface

115 VAC (volts, alternating current)
400 Hertz (cycles/second)
3 phase or 1 phase

4.4 Flow and Pressure Drop

The maximum airflow pressure drop through the valve as measured from the inlet flow duct interface (or outlet flow duct interface) to the canister interface duct shall be accordance with the following:

$$\Delta P = 125 \text{ Pa } (0.5 \text{ in } H_2O) \text{ @ } .033 \text{ m}^3/\text{s } (70 \text{ SCFM})$$

4.4 (Continued)

The maximum desorption pressure drop through the valve as measured from the canister interface to the vacuum vent interface shall be in accordance with the following:

ΔP = 6.67 Pa (50 microns) when
Flow = 2 x 10^{-4} kg/s (1.6 lb/hr) and
Pressure = 40 Pa (300 microns) absolute pressure
at the canister interface

4.5 Leakage

The maximum internal leakage shall be 6 x 10^{-11} m^3/s (1 x 10^{-4} lb/hr) of STP air from the adsorption portion of the valve to the desorption portion. The internal leakage shall be measured when the valve is positioned so that the adsorption passages are at 101.4 Pa (14.7 psi) and the desorption passages are below 6.9 Kpa (1.0 psia).

The internal leakage shall also be measured when the valve is cycled to reverse the adsorption/desorption position.

The maximum external leakage shall be 6 x 10^{-12} m^3/s (1 x 10^{-5} lb/hr) of air at STP when the internal portion of the valve is evacuated below (1.0 psia) and the external atmosphere is at 101.4 kPa (14.7 psia).

4.6 Weight

The maximum weight of the vacuum cycle valve shall be 9.76 kg (21.5 lb).

4.7 Power

The maximum power drawn by the vacuum cycle valve shall be 100 W (100 watts).

4.8 Configuration

This component shall be configured to enhance the overall packaging of the Regenerable CO_2 and Humidity Control System as defined by SVSK 91721. Plumbing interfaces, electrical interfaces, and structural mounting shall be compatible with SVSK 91721 and sections 4.2 and 4.3 of this document.

4.9 Life Requirements

As a design objective, the equipment shall be capable of performing all operations specified herein for a minimum of 10 years.

In addition, the operating life of the vacuum cycle valve shall be a minimum of 45,000 cycles. (A cycle is defined as the opening and closing of the vacuum valve plus the opening and closing of the cabin air valve.)

If the actuation device is independently replaceable, it may have an operating life of 10,000 cycles.

4.10 Environmental Conditions

4.10.1 Ambient Operating Environment

a. Temperature

The cabin temperature range shall be from 1.7 °C to 49 °C. (35°F to 120°F)

b. Pressure

The cabin pressure range shall be from 93 KPa to 103 KPa. (13.5 psia to 14.9 psia)

c. Humidity

The cabin humidity shall be from a dew point of -18°C (0°F) to a dew point of 29 °C. (84°F)

4.10.2 Induced Environment

a. Acceleration

Spacecraft generated acceleration shall be ± 3 g's in any direction.

b. Vibration

Spacecraft induced vibration shall be as shown in Figure 1.

c. Shock

See Space Shuttle General Specification SVHS 6400, paragraph 3.2.5.2.1.

Qual. Duration 48 min/axis
Acceptance Duration 30 sec. min/axis
5 min. max/axis

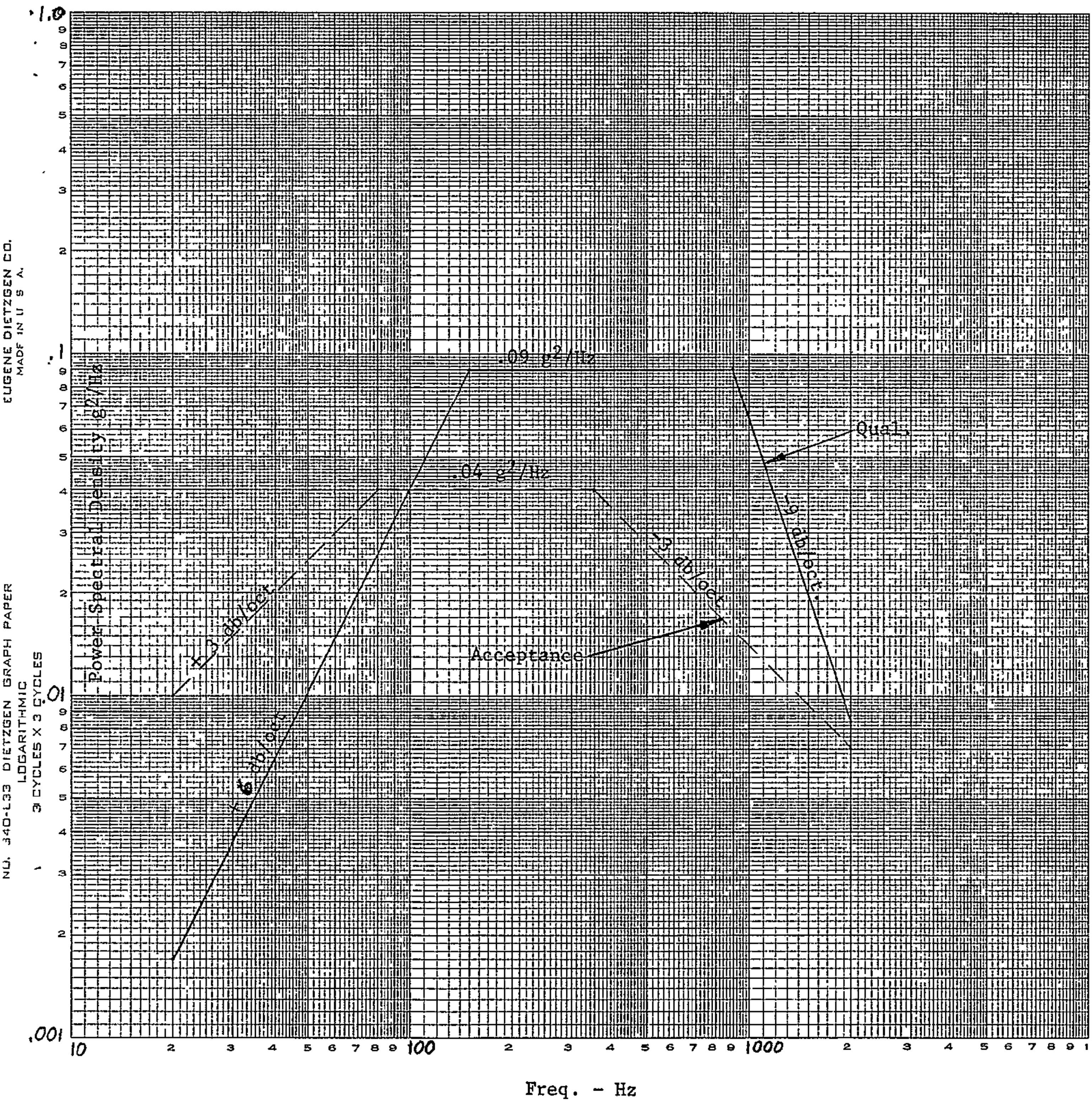

Figure 1

Random Vibration Levels

SVHSER 7182

APPLICATION		REVISIONS			
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ANGLES ± ____ EXCEPT FOR DRILL END FORMS, FILLET RADII ____ TO ____. SURFACES HAVING A COMMON AXIS CONC WITHIN ____ TIR ____
BREAK EDGES .025 MAX.
△MARK PART IDENT HS333, DWG INTERPRETATION ____
CLEANING, PRESERVATION AND HANDLING. HS1550-C ____ P ____
SURFACE CHARACTERISTICS: USAS B 46.1

APPROVAL SIGNATURES			
DRAWN	A Boehm	3/1/76	
CHECKED			
DESIGN			
DFTG		COST	
MAT'L		FCTY	
PROJ	AMR	Q & R	

CONTRACT NUMBER

EXP MFG	PRE PROD.	PROD.

PROD. CODE

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BYPASS VALVE

SIZE	CODE IDENT NO.	
A	73030	SVSK DR 91796

~~ssp item~~ | REV | SHEET 1 OF 5

.1070 SSP-1

1.0 SCOPE

This specification establishes the performance and design requirements for Bypass Valve.

The units used in this specification are shown in both the International Systems of Units (SI) and U.S. customary units. The U.S. customary units are in parenthesis "( )". The values were computed in U.S. customary units and converted to SI units.

2.0 FUNCTION

The bypass valve is plumbed into the Regenerable CO_2 and Humidity Control System to control the airflow rate through the HS-C regenerable canister. The valve is located in a duct plumbed in parallel with the canister. With the valve closed, all airflow is forced through the canister. With the valve in a partial or full opened position, a portion of the airflow will bypass the canister and flow through the bypass valve plumbing loop.

3.0 DESCRIPTION

The bypass valve is an electrically controlled flow regulation valve with a manual override. The valve flow characteristic is such that it allows uniform increases in flow as it opens. The valve position is controlled by an electrical actuator. The valve position may be manually overriden should the actuator fail.

4.0 PERFORMANCE AND DESIGN REQUIREMENTS

4.1 Fluid Media

The working fluid shall be Shuttle Orbiter cabin air or an equivalent mixture of oxygen or nitrogen.

4.2 Mechanical Interfaces

The bypass valve shall be structurally mounted by its interface duct connections.

The inlet and outlet flow interface connections shall be 0.047 m (1.85 in.) inside diameter minimum.

4.3 Electrical Interface

115 VAC (volts, alternating current)
400 Hertz (cycles/second)
3 phase or 1 phase

4.4 Flow and Pressure Drop

The bypass valve shall have the following pressure drop characteristics:

4.4 (Continued)

Valve Position	Air Flow [m^3/s (cfm)]	Pressure Drop [Pa (in H2O)]
Closed	0 (0)	0 (0)
Full Open	.033 (50)	448 Pa (1.8)

With a constant pressure drop across the valve, the valve shall allow a uniform increase in flow through the valve as it is opened from the closed position to the full open position.

4.5 Leakage

The valve shall have a maximum internal leakage (from inlet to outlet interface) in the closed position, of 4.7×10^{-4} m3/5 (1.0 cfm) at 995 Pa (4.0 in H_2O) pressure head.

4.6 Weight

The maximum weight of the bypass valve shall be 0.8 kg (1.8 lb).

4.7 Power

The maximum power drawn by the bypass valve shall be 30 W (30 watts).

4.8 Configuration

This component shall be configured to enhance the overall packaging of the Regenerable CO_2 and Humidity Control System as defined by SVSK 91721. Plumbing interfaces, electrical interfaces, and structural mounting shall be compatible with SVSK 91721 and section 4.2 and 4.3 of this document.

4.9 Life Requirements

As a design objective, the equipment shall be capable of performing all operations specified herein for a minimum of 10 years.

In addition, the operating life of the actuator shall be a minimum of 10,000 cycles.

4.10 Environmental Conditions

4.10.1 Ambient Operating Environment

a. Temperature

The cabin temperature range shall be from 1.7 °C to 49 °C. (35°F to 120°)

b. Pressure

The cabin pressure range shall be from 93 KPa to 103 KPa. (13.5 psia to 14.9 psia).

4.10.1 (Continued)

c. Humidity

The cabin humidity shall be from a dew point of -18°C (0°F) to a dew point of 29°C. (84°F)

4.10.2 Induced Environment

a. Acceleration

Spacecraft generated acceleration shall be ± 3 g's in any direction.

b. Vibration

Spacecraft induced vibration shall be as shown in Figure 1.

c. Shock

See Space Shuttle General Specification SVHS 6400, paragraph 3.2.5.2.1.

Qual. Duration 48 min/axis
Acceptance Duration 30 Sec. min/axis
5 min. max./axis

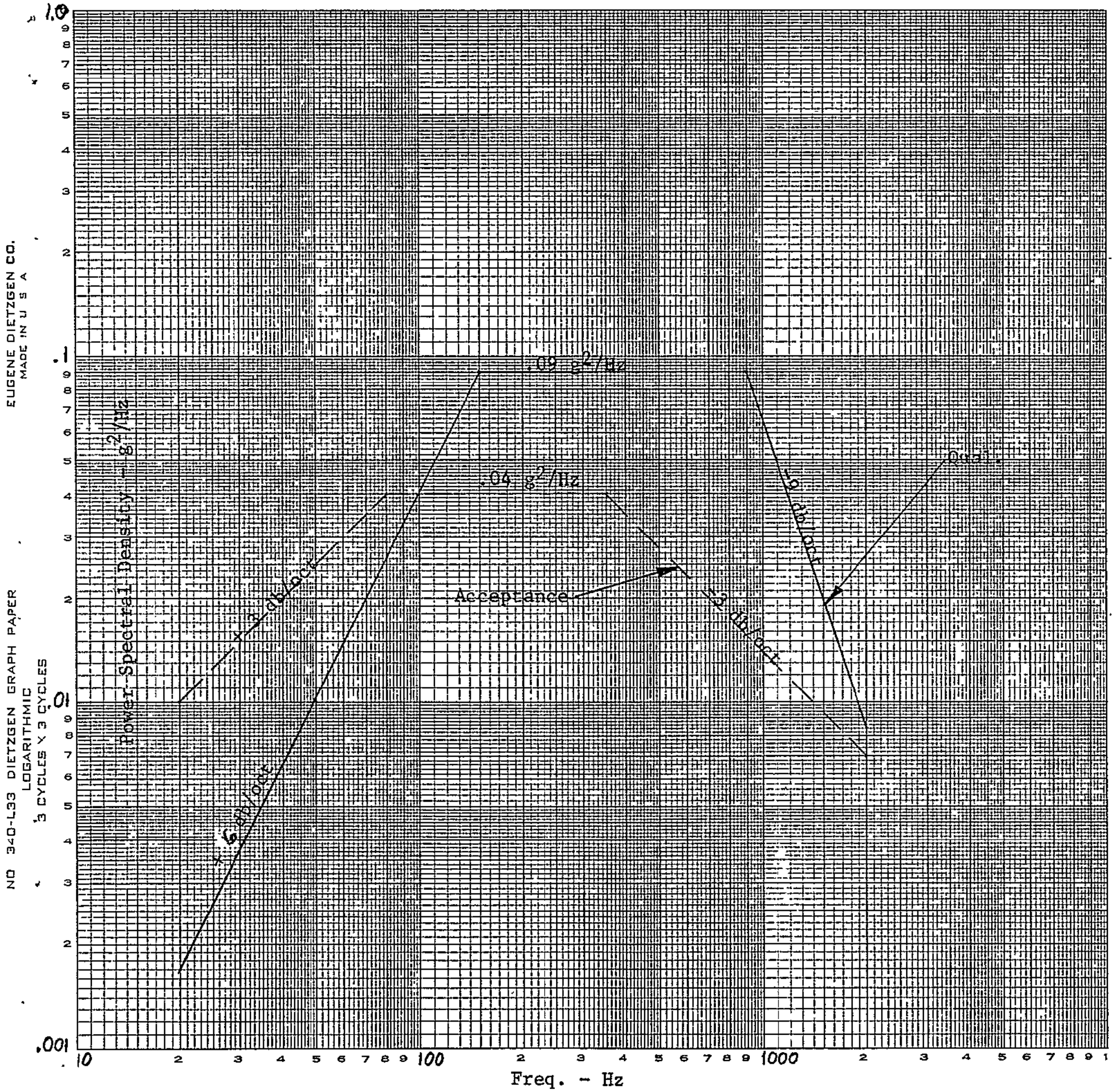

Figure 1

Random Vibration Levels

SVHSER 7182

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UNLESS OTHERWISE SPECIFIED:
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ANGLES ± ______. EXCEPT FOR DRILL END FORMS, FILLET RADII ____ TO ____. SURFACES HAVING A COMMON AXIS CONC WITHIN ____ TIR
BREAK EDGES .025 MAX.
△MARK PART IDENT HS333, DWG INTERPRETATION ______.
CLEANING, PRESERVATION AND HANDLING: HS1550-C ____ P ____
SURFACE CHARACTERISTICS: USAS B 46.1

APPROVAL SIGNATURES			
DRAWN	A Boehm	3/1/76	
CHECKED			
DESIGN			
DFTG		COST	
MAT'L		FCTY	
PROJ	AMR	Q & R	

CONTRACT NUMBER

EXP MFG	PRE PROD.	PROD.

PROD. CODE

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Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT · U.S.A.

ULLAGE - SAVE COMPRESSOR

SIZE	CODE IDENT NO.	
A	73030	SVSK DR 91798

ssp item | REV | SHEET 1 OF 4

1070 SSP-1

1.0 SCOPE

This specification establishes the performance and design requirements for the ullage-save compressor.

The units used in this specification are shown in both the International System of Units (SI) and U.S. customary units. The U.S. customary units are in parenthesis "( )". The values were computed in U.S. customary units and converted to S.I. units.

2.0 FUNCTION

At the completion of the adsorb cycle, when the vacuum cycle valves are in the off position, the ullage-save compressor's function is to retrieve as much of the adsorption bed cabin air as possible before the valve cycles the adsorption bed over to the desorption mode, thus minimizing the loss of the trapped cabin air overboard to space.

3.0 DESCRIPTION

The ullage-save compressor shall be an electrically driven pump encased in one housing. In an effort to minimize the inherent noise of this type device, it is desireable that the compressor be of a vane-type design.

4.0 PERFORMANCE AND DESIGN REQUIREMENTS

4.1 Fluid Media

The working fluid shall be Shuttle Orbiter cabin air or an equivalent mixture of oxygen or nitrogen.

4.2 Mechanical Interfaces

The ullage-save compressor shall be mounted to the HS-C canister by four (4) 8-32 UNF-3B bolts. The inlet port shall be per MS33649-6

The outlet port shall be per MS33649-6

4.3 Electrical Interface

115 VAC (volts, alternating current)
400 Hertz (cycles/second)
3 phase

4.4 Flow and Pressure Drop

The ullage-save compressor shall have the capacity to pump a .0538 m^3 (1.9 ft^3) volume from 103 KPa (14.9 psia) to below 13.7 KPa (2.0 psia) in 1.7 minutes.

4.5 Leakage

N/A

4.6 Weight

The maximum weight of the ullage-save compressor shall be 1.6 Kg (3.5 lb).

4.7 Power

The maximum power drawn by the ullage-save compressor shall be 150 W (150 watts).

4.8 Configuration

This component shall be configured to enhance the overall packaging of the Regenerable CO_2 and Humidity Control System as defined by SVSK91721. Plumbing interfaces; electrical interfaces, and structural mounting shall be compatible with SVSK91721 and section 4.2 of this document.

4.9 Life Requirements

As a design objective, the equipment shall be capable of performing all operations specified herein for a minimum of 10 years.

The operating life of the ullage-save compressor shall be 20,000 hours minimum. The ullage-save compressor motor bearing life shall be 10,000 hours minimum.

4.10 Environmental Conditions

4.10.1 Ambient Operating Environment

a. Temperature

The cabin temperature range shall be from 1.7°C to 49°C. (35°F to 120°F)

b. Pressure

The cabin pressure range shall be from 93 KPa to 103 KPa. (13.5 psia to 14.9 psia)

c. Humidity

The cabin humidity shall be from a dew point of -18 C (0°F) to a dew point of 29°C. (84°F)

4.10.2 Induced Environment

a. Acceleration

Spacecraft generated acceleration shall be ± 3 g's in any direction.

b. Vibration

Spacecraft induced vibration shall be as shown in Figure 1.

c. Shock

See Space Shuttle General Specification SVHS 6400, paragraph 3.2.5.2.1.

Qual. Duration 48 min/axis
Acceptance Duration 30 sec. min/axis
5 min max/axis

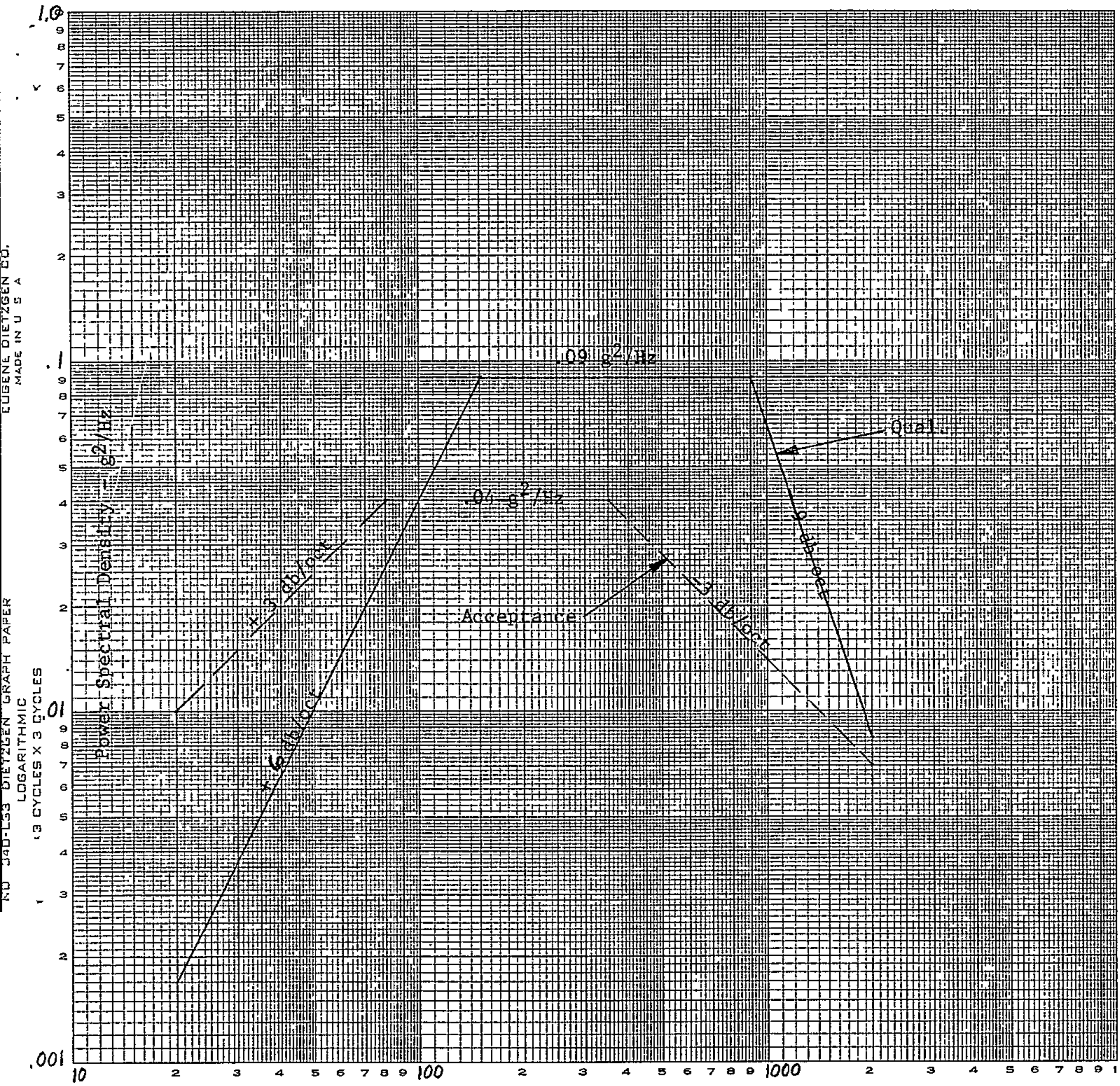

Figure 1

Random Vibration Levels

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SHEET INDEX	REV.																						
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ______
ANGLES ± ______ EXCEPT FOR DRILL END FORMS, FILLET RADII ____ TO ____. SURFACES HAVING A COMMON AXIS CONC WITHIN ____ TIR. ____
BREAK EDGES .025 MAX.
△MARK PART IDENT HS333, DWG INTERPRETATION ______.
CLEANING, PRESERVATION AND HANDLING: HS1550-C ____ P ____
SURFACE CHARACTERISTICS: USAS B 46.1

APPROVAL SIGNATURES			
DRAWN	a Boehm	3/1/71	
CHECKED			
DESIGN			
DFTG		COST	
MAT'L		FCTY	
PROJ	AWB	Q & R	

CONTRACT NUMBER

EXP MFG	PRE PROD.	PROD.

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CONTROLLER

SIZE	CODE IDENT NO.	
A	73030	SVSK DR 91948

PROD. CODE | ~~ssp item~~ | REV | SHEET 1 OF 5

.1070 SSP-1

1.0 SCOPE

This specification establishes the performance and design requirements for the electrical controller.

The units used in this specification are shown in both the International System of Units (SI) and U.S. customary units. The U.S. customary units are in parenthesis "()". The values were computed in U.S. customary units and converted to SI units.

2.0 FUNCTION

The electrical controller shall automatically time and sequence the vacuum cycle valve actuators, the pressure equalization valve actuator, and the ullage-save compressor. It will also control the two speed process flow fan and modulate the bypass valve actuator.

3.0 DESCRIPTION

The electrical controller shall perform its sequencing function according to the logic shown in Table 1. A three position switch, mounted to the controller, will be used to select the operating mode per Table 1.

The bypass flow control logic is TBD.

4.0 PERFORMANCE AND DESIGN REQUIREMENTS

4.1 Fluid Media

The working fluid shall be Shuttle Orbiter cabin air or an equivalent mixture of oxygen or nitrogen.

4.2 Mechanical Interfaces

The electrical controller shall be mounted on the air duct manifold as defined by SVSK 91721.

4.3 Electrical Interface

115 VAC (volts, alternating current)
400 Hertz (cycles/second)
3 phase

4.4 Flow and Pressure Drop

N/A

4.5 Leakage

N/A

4.6 Weight

The maximum weight of the electrical controller shall be 2.2 Kg (4.8 lb.).

TABLE 1
ELECTRICAL CONTROLLER LOGIC

STEP NO.	CONDITION	ACTUATORS A	ACTUATORS B	P/E VALVE	U/S COMPR.	4 MAN CREW TIME+	4 MAN CREW FAN	7 MAN CREW TIME+	7 MAN CREW FAN	10 MAN CREW TIME+	10 MAN CREW FAN
1	LAUNCH *	OFF	OFF	8	OFF		OFF		OFF		OFF
2	START - UP	—	—	1	—		—		—		—
3	" "	—	—	2	—		—		—		—
4	" "	—	—	3	—		—		—		—
5	" "	—	—	4	—		—		—		—
6	SEQUENCE ACTUATORS	O	—	—	—	.08	LOW	.08	LOW	.08	HIGH
7	ADSORB BED "A"	—	—	—	—	40.0	—	17.0	—	9.67	—
8	ISOLATE	C	—	—	—	.08	OFF	.08	OFF	.08	—
9	ULLAGE - SAVE	—	—	5	ON	1.70	—	1.70	—	0	—
10	EQUALIZE PRESSURE	—	—	6	OFF	.10	—	.10	—	.10	—
11	REPRESS BED "B"	—	—	7	—	.10	—	.10	—	.10	—
12	ISOLATE	—	—	8	—	.05	—	.05	—	.05	—
13	SEQUENCE ACTUATORS	—	O	—	—	.08	LOW	.08	LOW	.08	—
14	ADSORB BED "B"	—	—	—	—	40.0	—	17.0	—	9.67	—
15	ISOLATE	—	C	—	—	.08	OFF	.08	OFF	.08	—
16	ULLAGE - SAVE	—	—	1	ON.	1.70	—	1.70	—	0	—
17	EQUALIZE PRESSURE	—	—	2	OFF	.10	—	.10	—	.10	—
18	REPRESS. BED "A"	—	—	3	—	.10	—	.10	—	.10	—
19	ISOLATE	—	—	4	—	.05	—	.05	—	.05	—
20	REPEAT STEPS NO. 6 THRU NO. 19 CONTINUOUSLY										

EMERGENCY SHUT-DOWN 1) ACTUATORS A & B CLOSED, P/E VALVE 4 OR 8.
2) KILL ALL POWER.

* SYSTEM ISOLATED (NO POWER REQ'D)

+ ALL TIMES ARE IN MINUTES

O = OPEN
C = CLOSE
HIGH / LOW } FAN SPEED
1-8 = VALVE POSITION
— = NO ACTION REQ'D

SVSK DR 91948
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4.7 Power

The maximum power drawn by the electrical controller shall be 15 W max. (15 watts max.).

4.8 Configuration

This component shall be configured to enhance the overall packaging of the Regenerable CO_2 and Humidity Control System as defined by SVSK 91721.

4.9 Life Requirements

As a design objective, the equipment shall be capable of performing all operations specified herein for a minimum of 10 years.

4.10 Environmental Conditions

4.10.1 Ambient Operating Environment

a. Temperature

The cabin temperature range shall be from 1.7 °C to 49 °C (35 °F to 120 °F).

b. Pressure

The cabin pressure range shall be from 93 KPa to 103 KPa (13.5 psia to 14.9 psia).

c. Humidity

The cabin humidity shall be from a dew point of -18 °C (0 °F) to a dew point of 29 °C (84 °F).

4.10.2 Induced Environment

a. Acceleration

Spacecraft generated acceleration shall be ± 3 g's in any direction.

b. Vibration

Spacecraft induced vibration shall be as shown in Figure 2.

c. Shock

See Space Shuttle General Specification SVHS 6400, paragraph 3.2.5.2.1.

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Qual. Duration 48 min/axis
Acceptance Duration 30 sec, min/axis
5 min. max/axis

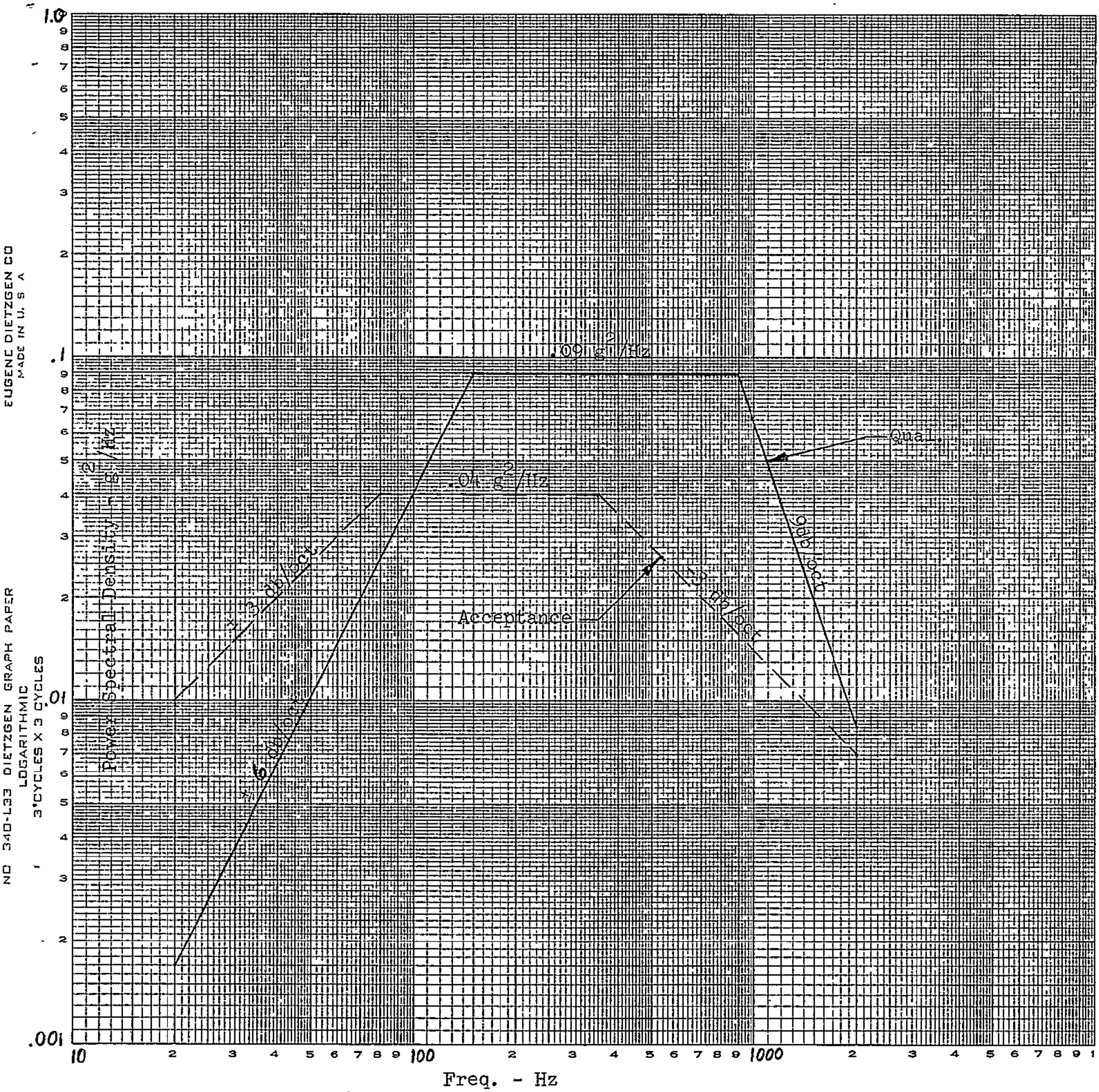

Figure 2

Random Vibration Levels

SVHSER 7182

APPLICATION	
NEXT ASSY	USED ON

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

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SHEET INDEX																							
	REV.																						
	SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

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△MARK PART IDENT HS333, DWG INTERPRETATION ______
CLEANING, PRESERVATION AND HANDLING. HS1550-C ____ P ____
SURFACE CHARACTERISTICS: USAS B 46.1

APPROVAL SIGNATURES			
DRAWN	Q Boehm	3/1/72	
CHECKED			
DESIGN			
DFTG		COST	
MAT'L		FCTY	
PROJ	[illegible]	Q & R	

CONTRACT NUMBER

EXP MFG	PRE PROD.	PROD.

PROD. CODE

+ DENOTES ORIGINAL ISSUE

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT · U.S.A.

PROCESS FLOW FAN

SIZE	CODE IDENT NO.	
A	73030	SVSK DR 91797

ssp item | REV | SHEET 1 OF 5

1070 SSP-1

1.0 SCOPE

This specification establishes the performance and design requirements for the process flow fan.

The units used in this specification are shown in both the International System of Units (SI) and U.S. customary units. The U.S. customary units are in parenthesis "( )". The values were computed in U.S. customary units and converted to SI units.

2.0 FUNCTION

The function of the process flow fan is to impart the energy necessary to move the required airflow through the adsorption portion of the Regenerable CO_2 and Humidity Control System and primarily through the adsorption bed of the HS-C regenerable canister.

3.0 DESCRIPTION

The process flow fan is a two speed, centrifugal type fan. The choice of a centrifugal type is dictated by the flow and pressure rise requirements of the Regenerable CO_2 and Humidity Control System. The fan shall be driven by a two (2) speed motor having a separate winding for each speed. The fan/motor assembly shall be optimized at the low speed and hence, low flow condition.

4.0 PERFORMANCE AND DESIGN REQUIREMENTS

4.1 Fluid Media

The working fluid shall be Shuttle Orbiter cabin air or an equivalent mixture of oxygen or nitrogen.

4.2 Mechanical Interface

The fan shall be mounted directly by its inlet interface duct or by brackets that are located on the volute as required by the Regenerable CO_2 and Humidity Control System packaging and frame locations.

The inlet duct shall have a 0.070 m (2.75 in.) inside diameter.

The outlet duct diameter shall be whatever size is dictated by an optimum fan design. The outlet will be transitioned to 0.070 m (2.75 in.) inside diameter by the plumbing duct connected to the fan outlet.

4.3 Electrical Interface

115 VAC (volts, alternating current)
400 Hertz (cycles/second)
3 phase

4.4 Flow and Pressure Rise

The process flow fan shall have the following flow and pressure rise characteristics.

Low Flow (Optimum Design Point)
Flow = .0236 m^3/s (50 SCFM)
ΔP = 1195 Pa (4.8 in. H_2O)

High Flow
Flow = .033 m^3/s (70 SCFM) minimum
ΔP = 1917 Pa (7.7 in H_2O) minimum

4.5 Leakage

N/A

4.6 Weight

The maximum weight of the process flow fan shall be 1.6 kg (3.5 lb).

4.7 Power

The maximum power drawn by the process flow fan shall be:

Low Flow (low speed) = 95 W (95 watts)
High Flow (high speed) = 200 W (200 watts)

4.8 Configuration

This component shall be configured to enhance the overall packaging of the Regenerable CO_2 and Humidity Control System as defined by SVSK 91721. Plumbing interfaces, electrical interfaces, and structural mounting shall be compatible with SVSK 91721 and sections 4.2 and 4.3 of this document.

4.9 Life Requirements

As a design objective, the equipment shall be capable of performing all operations specified herein for a minimum of 10 years.

The operating life of the process flow fan shall be 20,000 hours minimum. The process flow fan motor bearing life shall be 10,000 hours minimum.

4.10 Environmental Conditions

4.10.1 Ambient Operating Environment

a. Temperature

The cabin temperature range shall be from 1.7°C to 49 °C (35°F to 120°F)

4.10.1 (Continued)

b. Pressure

The cabin pressure range shall be from 93 KPa to 103 KPa. (13.5 psia to 14.9 psia)

c. Humidity

The cabin humidity shall be from a dew point of -18 °C (0°F) to a dew point of 29 °C (84°F)

4.10.2 Induced Environment

a. Acceleration

Spacecraft generated acceleration shall be ± 3 g's in any direction.

b. Vibration

Spacecraft induced vibration shall be as shown in Figure 1.

c. Shock

See Space Shuttle General Specification SVHS 6400, paragraph 3.2.5.2.1.

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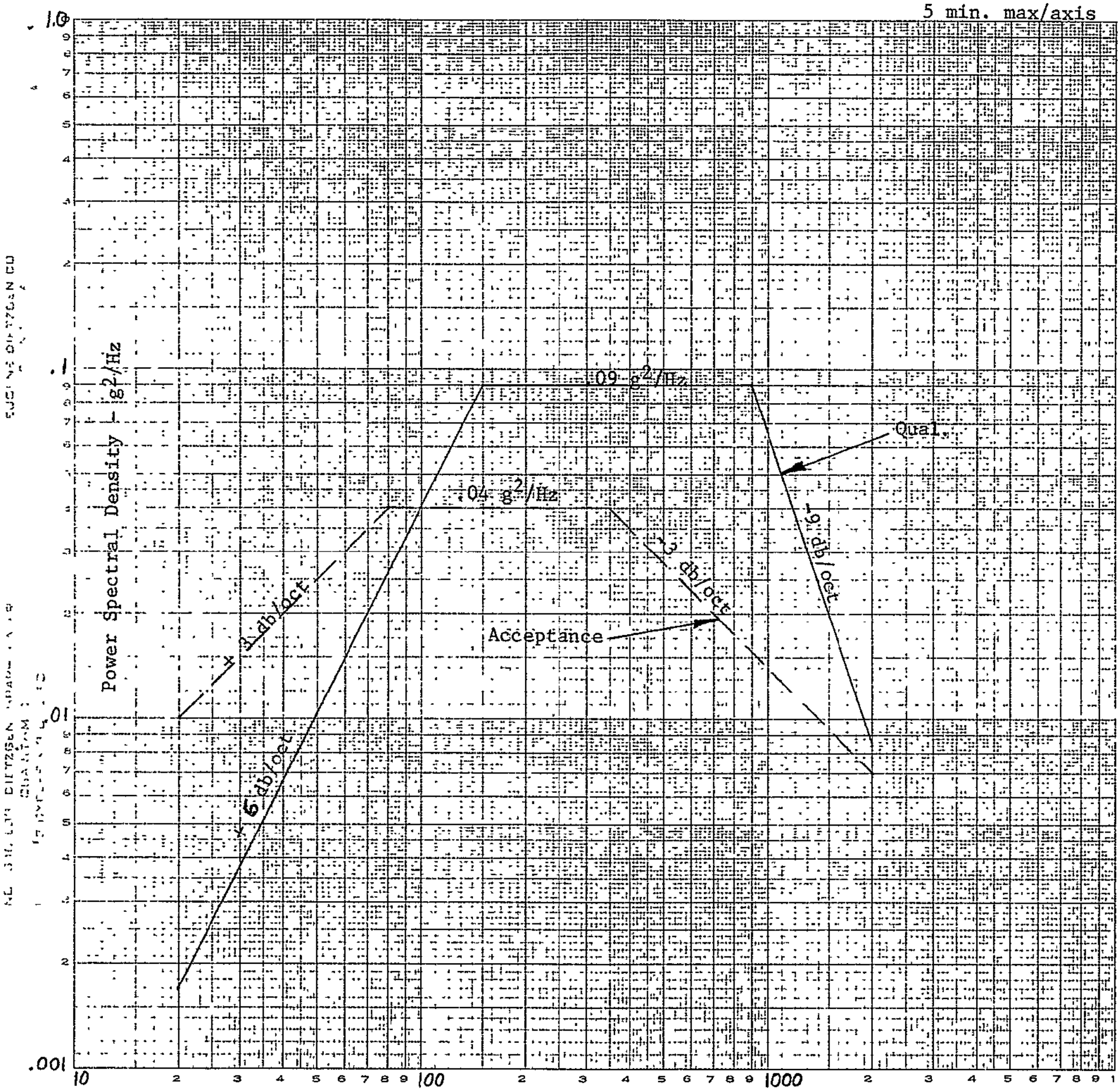
Qual. Duration 48 min/axis
Acceptance Duration 30 sec. min/axis
5 min. max/axis



Freq. - Hz

Figure 1

Random Vibration Levels

APPENDIX C

MASTER TEST PLAN

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SVHSER 7182
Revision A
April 28, 1977

FLIGHT PROTOTYPE REGENERABLE CO_2 AND H_2O CONTROL SYSTEM

MASTER TEST PLAN

PREPARED UNDER CONTRACT NAS 9-13624

BY

HAMILTON STANDARD

DIVISION OF UNITED TECHNOLOGIES CORPORATION

WINDSOR LOCKS, CONNECTICUT

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS

JUNE 1976

PREPARED BY: A. M. Boehm
A. M. BOEHM
PROGRAM ENGINEER

E. K. Moore
E. K. MOORE
R&D ENGINEERING MANAGER

APPROVED BY: H. F. Brose
H. F. BROSE
PROGRAM MANAGER

HAMILTON STANDARD
PLAN OF TEST

JOB: Flight Prototype Regenerable CO_2 and H_2O Control System

PLAN PREPARED BY: A. M. Boehm

PROJECT & ORDER: NAS 9-13624

APPROVED BY: ____________

INSTRUCTION: ____________

TEST ENGINEER: A. M. Boehm

TIME PERIOD: November 1976 TO February 1977

1. WHAT IS ITEM BEING TESTED
2. WHY IS TEST BEING RUN WHAT WILL RESULTS SHOW OR BE USED FOR
3. DESCRIBE TEST SET UP INCLUDING INSTRUMENTATION. ATTACH SKETCH OF INSTALLATION.
4. ITEMIZE RUNS TO BE MADE GIVING LENGTH OF EACH AND READINGS TO BE TAKEN.
5. SPECIAL INSTRUCTIONS SAFETY PRECAUTIONS FOR OPERATORS AND HANDLING EQUIPMENT. OBSERVATIONS BY SIGHT, FEEL, OR HEARING. LIST POINTS OF OBSERVATION WHICH MIGHT CONTRIBUTE TO ANALYSIS OF (A) PERFORMANCE OF UNITS, (B) INCIPIENT TROUBLE BEFORE IT OCCURS, AND (C) CAUSE OF FAILURE.
6. HOW WILL DATA BE USED FOR FINALLY PRESENTED GIVE SAMPLE PLOT, CURVE, OR TABULATION AS IT WILL BE FINALLY PRESENTED.

NUMBER ENTRY AS LISTED ABOVE AND DESCRIBE BELOW

1.0 HS-C System, SVSK 91725

2.0 This test will verify the design of the HS-C canister, SVSK 91722, vacuum valves, SVSK 91723, and flight prototype system, SVSK 91725. The results of this test will demonstrate that the HS-C canister, valves and system concept are ready for application in the Shuttle vehicle.

3.0 The test setup shall be closed loop. The HS-C system and Rig 88 shall be plumbed in series and will feed into and out of a cabin volume simulation. Vacuum desorption will be accomplished using Rig 52 connected to the HS-C system. Makeup air, CO_2, and water must be supplied.

3.1 A list of required instrumentation is given in Table I.

3.2 A schematic test setup is given in Figure I.

4.0 Test Program

4.1 Test Sequence - Testing of the HS-C system shall consist of HS-C system evaluation and rig checkout in the following sequence:

Sequence	Test	Section Ref.	
1	Leakage and Instrument Calibration	4.2.1	
2	System and Bypass Flow Calibration	4.2.2	
3	System Performance Calibration	4.2.3	
4	Mission 1	4.2.4	
5	Leakage and Instrument Calibration	4.2.1	
6	System Flow Calibration	4.2.5	A
7	Canister Vibration	4.2.6	A
8	System Flow Calibration	4.2.7	A
9	System Performance	4.2.8	A

4.2 Description of Tests

4.2.1 Leakage and Instrument Calibration

4.2.1.1 Canister and System Vacuum Leakage

4.2.1.1.1 Purpose - The purpose of this test is to ensure that the leakage of the vacuum portion of the Flight Prototype System, including the canister, is sufficiently below the vacuum rig pumping rate to allow desorption of the HS-C beds.

4.2.1.1.2 Description of Test Setup

4.2.1.1.2.1 A schematic of the test setup is given as Figure 1 of this plan.

4.2.1.1.2.2 Instrumentation shall include a pressure gage readout for each side of the system and a stop clock. These instruments are defined in Table 1.

4.2.1.1.2.3 Test rigs and equipment are the Flight Prototype System.

4.2.1.1.3 Procedure

a) Rig 52 shall be off with its cold trap valves in the closed position.

b) Actuate the Flight Prototype System so that Bed "A" is in the desorb mode, and Bed "B" is in the adsorb mode.

c) Using the ullage-save compressor, evacuate Bed "A" below 2.0 psia.

d) Turn-off and valve-off the ullage-save compressor.

e) Measure and record the pressure rise in Bed "A" every 10 minutes for a 30 minute period.

f) Repeat steps (b) through (e) for Bed "B".

4.2.1.1.4 Special Instructions

a) Calculate the total evacuated volume by adding the known canister volume to the calculated plumbing volume.

b) Calculate the leakage by the formula:

$$\text{leakage} = 0.3\ \frac{(\text{Volume})(\text{Delta Pressure})}{\text{time}}\ \frac{(14.7)}{(14.7-\text{Press})}$$

where: leakage = lb/hr
Volume = ft^3
Delta Pressure = psi
time = minutes
Press. = Evacuated Press. = psia

c) This test shall be considered acceptable if each bed has a leakage of less than 0.01 lb/hr.

4.2.1.2 Pressure Capability of the Plenum

4.2.1.2.1 Purpose - The purpose of this test is to establish the ability of the plenum and interfacing rigs to hold pressure. This test is essential to establish the use of make-up air to the room as a true measure of ullage loss during mission testing.

4.2.1.2.2 Description of Test Setup

4.2.1.2.2.1 A schematic of the test setup is given as figure 1 of this plan.

4.2.1.2.2.2 Instrumentation shall include a barometer, U tube manometer, and thermocouples. These instruments are defined in Table 1.

4.2.1.2.2.3 Multipurpose Test Rig 88 and the flight prototype system shall be plumbed to the plenum. A shop air line shall be plumbed to the plenum for this test.

4.2.1.2.3 Procedure

a) The plenum shall first be calibrated for its ability to hold a positive pressure. The plenum shall be pressurized with "shop air" to ten inches of water pressure. A plot of the pressure decay of the plenum with time shall be taken.

b) All vacuum valves in the breadboard system shall be in the closed position for this test.

c) The test shall be terminated when ambient pressure is reached in the plenum or after sixteen hours. The time to reach ambient pressure shall be recorded together with pressure versus time data.

4.2.1.2.4 Special Instructions

a) The data generated in this test shall be compared against the theoretical removal rate of air from the system during mission testing.

b) If the plenum leaks the equivalent of one ullage cycle in less then 20 minutes, no attempt shall be made to provide make-up during any further testing.

c) If the leakage rate is such that make-up air is required, dry air shall be added to maintain pressure levels only.

d) If the leakage rate is so low that make-up is needed to provide greater than 80% of the ullage loss, the pressure decay test shall be repeated to verify the repeatability of the leakage rate and accurately establish the leakage rate versus pressure differential and time.

e) If step (d) is shown to be repeatable, ullage loss by make-up gas measurement shall be undertaken during mission testing. However, the leakage data along with CO_2 and water addition shall be used to correct actual make-up gas measurements.

4.2.1.3 CO_2 and H_2O Permeation

4.2.1.3.1 Purpose - The purpose of this test is to calibrate the rate of partial pressure change of the plenum due to permeation.

4.2.1.3.2 Description of Test Setup

4.2.1.3.2.1 A schematic of the test setup is given in figure 1 of this plan.

4.2.1.3.2.2 Instrumentation shall include an ambient barometer, U tube manometer, Infra-red CO_2 Analyzer and Hygrometer. These instruments are defined in Table 1.

4.2.1.3.2.3 Multipurpose Test Rig 88 shall be used to circulate the air within the plenum volume. A CO_2 (100%) supply bottle and steam injection system are required. CO_2 and water pressure shall be continuously recorded on a multipoint recorder throughout the test runs.

4.2.1.3.3 Procedure

a) During this test, the plenum pressure shall be maintained within ten inches of water of the external ambient pressure. The plenum air volume shall be continuously circulated by Rig 88.

b) After setting the initial partial pressure of CO_2 and H_2O, per Table 4.2.1.2, shut off the CO_2 and H_2O supplies and manually record the barometric, differential and partial pressures (PCO_2 and PH_2O) of both inside and outside the plenum.

c) Continuously record PCO_2 and PH_2O on the multipoint recorder. After 16 hours, record external data conditions. Reset the partial pressures to the second condition per Table 4.2.1.2 and repeat step (b) for an additional 16 hour period.

d) Using the partial pressure versus time data from both conditions, the permeation rate of water and CO_2 shall be plotted against the driving force (difference between internal and external partial pressures) of each constituent.

e) Reset the first condition per Table 4.2.1.2 and manually record the barametric, differential and partial pressures (PCO_2 and PH_2O) of both inside and outside the plenum.

4.2.1.3.3 (Continued)

f) Using the data generated in step (d), calculate the permeation rate of both CO_2 and H_2O. Set the CO_2 flow rate and steam injection rate to equal the calculated permeation rate. Run at this condition for 16 hours, continuously recording PCO_2 and PH_2O on the multipoint recorder. The purpose of this test is to verify the permeation data and verify that makeup gas can accurately compensate for permeation effects during mission testing. The PCO_2 and PH_2O levels should remain constant at the preset levels during the 16 hours.

g) Reset the partial pressures to the second condition per Table 4.2.1.2. Repeat steps (e) and (f) for a 16 hour period.

Table 4.2.1.2 Gas Partial Pressures

Condition	CO_2 mmHg	H_2O psia (ref)	H_2O dew point (^oF)
1	7.5	.26	60
2	5.0	.10	35

4.2.1.3.4 Special Instructions - The hygrometer shall be given a null check, per manufacturer's instructions, prior to recording data on a minimum daily basis. The Infra-red Analyzer shall be 0 and 100% checked, on a similar basis, using the appropriate calibration gases.

4.2.1.4 Instrument Calibration

4.2.1.4.1 Purpose - The purpose of this calibration is to verify test measurements by demonstrated calibration before and after data collection.

4.2.1.4.2 Description of Setup

a) The Infra-red CO_2 Analyzer shall be calibrated in place, using calibration gases.

b) The hygrometer shall be calibrated on the Advanced Engineering setup located in Advanced Engineering Laboratory.

c) The vacuum pressure transducers shall be calibrated, per accepted procedures, by the Instrumentation and Metrology department.

4.2.1.4.3 Procedure - The following instruments shall be calibrated per accepted procedures:

a) Infra-Red CO_2 Analyzer at 0, 0.5 and 1.0% CO_2.

b) Hygrometers, including readout, over a range of 0 to 75°F, approximately equally spaced.

c) Vacuum pressure transducers, including readouts, over their full scale.

4.2.1.4.4 Special Instructions

a) The Infra-Red Analyzer data shall be plotted, CO_2 pressure versus scale %, and used as a calibrated curve.

b) The hygrometer and pressure transducer data shall be presented as a tabulated error chart.

4.2.2 System and Bypass Flow Calibration

4.2.2.1 Purpose - The purpose of this test is to establish air flow through the HS-C bed and thus bypass flow as a function of pressure drop across the bed.

4.2.2.2 Description of Test Setup

4.2.2.2.1 A schematic of the test setup is given as figure 1 of this plan.

4.2.2.2.2 Instrumentation shall include thermocouples and readout, Rig 88 flow sensing venturi, and U tube manometer. These instruments are defined in Table 1.

4.2.2.2.3 Rig 88 and the HS-C system are required.

4.2.2.3 Procedure

a) Power Rig 88 and adjust the outlet valve to give 70 ± 2 cfm air flow. Measure the bed pressure drop at this condition for Bed A.

b) Adjust the Rig 88 outlet valve and measure Bed A pressure drop versus flow at a minimum of 10 flows from zero (0) to 80 cfm.

c) Repeat steps (a) and (b) for Bed B.

4.2.2.4 Special Instructions - A plot of flow versus bed pressure drop shall be prepared for each bed. The bypass valve can then be positioned to achieve the desired bed pressure drop for any given flow condition.

4.2.3 System Performance Calibration

4.2.3.1 Purpose - The purpose of this test is to define timing and bypass flow control required to maintain performance for use in subsequent mission tests and to assess the effect of using the ullage save compressor on these requirements.

4.2.3.2 Description of Test Setup

4.2.3.2.1 A schematic of the test setup is given as figure 1 of this plan.

4.2.3.2.2 All instrumentation shown on figure 1 and defined by Table 1 is required.

4.2.3.2.3 Rigs 52 and 88 are required. The Cabin Volume Simulation shall be utilized.

4.2.3.2.4 The canister shall be provided with special instrumentation. Two adjacent layers in the middle of the canister shall incorporate thermocouples, inserted to a depth of approximately 2 inches into the foam, connected so as to provide an absolute and differential reading. One layer shall be fitted with a pressure transducer to monitor vacuum levels at the end of the bed.

4.2.3.3 Procedure

4.2.3.3.1 General

a) During runs, the plenum pressure shall be maintained within +10 inches of water of ambient pressure. This shall be accomplished using the regulated makeup air supply, should it be required, per 4.2.1.2.4.

b) At the start and end of each run, the gross weight of CO_2, water, and makeup air, if required, shall be noted. Steam generator setting shall be maintained throughout each run.

c) As a minimum, the temperature and pressure, instrumented per paragraph 4.2.3.2.4, shall be recorded at two-minute intervals for two continuous cycles. These readings shall be taken once for each environment of Table 4.2.3. The test condition must be stabilized. This data shall also be recorded on the multipoint recorder whenever possible.

4.2.3.3.2 Timing Control

a) Establish the first "cabin environment" defined in Table 4.2.3. Establish 70 cfm air flow through the HS-C system.

b) Adjust the cycle timing starting at a slightly shorter time than predicted and increase the time until the dew point and CO_2 partial pressure are in equilibrium at the conditions given. Record cycle time.

c) Repeat for Environment No. 3.

4.2.3.3.3 Bypass Flow Control

a) Establish the second "cabin environment" defined in Table 4.2.3. Set cycle time to 40 minutes adsorb/40 minutes desorb including the ullage-save compressor cycle.

b) Set Rig 88 to maintain the required "cabin" temperature.

c) Adjust the bypass flow control to maintain dew point and CO_2 pressure in equilibrium at the conditions given. Record the airflow rate.

d) Repeat for the Environment No. 4.

4.2.3.3.3 (Continued)

Table 4.2.3 - Cabin Environments

Parameter	Environment* 1	2	3	4
Cabin Pressure (psia) ± 0.5	14.7	14.7	14.7	14.7
Cabin Volume (ft^3) ± 5%	1,035	1,035	1,035	1,035
HS-C Air Temperature (^oF) ± 2^o	80	80	65	65
Cabin Dew Point (^oF)	61 max.	61 max.	35 min.	35 min.
CO_2 Pressure (mmHg) nom.	5	5	5	5
CO_2 Flow (lb/hr) ± 0.5%	0.88	0.42	0.88	0.42
H_2O Flow (lb/hr) ± 2.0%	3.30	1.24	1.10	0.78

*Calibration sequence shall be determined by cognizant Engineer to provide maximum test efficiency. The timing calibration for environment #1 must precede flow calibration; but other calibrations may be mixed.

4.2.3.4 Special Instructions - Timing settings and flow settings shall be noted for each condition, Table 4.2.3.

4.2.4 Mission Simulation I

4.2.4.1 Purpose - The purpose of this test is to demonstrate CO_2 and humidity control during a simulation of a Shuttle mission.

4.2.4.2 Description of Test Setup

4.2.4.2.1 The test setup shall be as described by paragraph 4.2.3.2.

4.2.4.2.2 The Hygrometer, Infra-red Analyzer, and thermocouples shall be connected to a multipoint recorder.

4.2.4.3 Procedure

a) Using the timing and flow established by section 4.2.3, set "cabin environment" 1, Table 4.2.3. When equilibrium is attained, start time and test for a minimum of 10 hours.

b) Change CO_2 and H_2O flows to environment 2 and adjust flow and cycle time to environment 2 as established by section 4.2.3. Maintain conditions for a minimum of 20 hours.

c) Reset "environment" 1, including timing, and run until equilibrium is established, except a minimum of 60 hours shall be accumulated during steps (a), (b), and (c).

d) Using Rig 88, chill the cabin flow and reset conditions to "environment" 3.

e) When equilibrium is attained, start time and run for a minimum of 10 hours.

f) Reset conditions, including flow and timing, to "environment" 4 and maintain conditions for a minimum of 20 hours.

g) Reset condition, including flow and timing, to environment 3 and run until equilibrium is established, except a minimum of 60 hours shall be accumulated during steps (e), (f), and (g).

4.2.4.4 Special Instructions

4.2.4.4.1 Environments No. 2 and 4 shall utilize the ullage-save compressor.

4.2.4.4.2 Data shall be hand tabulated to show equilibrium as it is established and for a minimum of three cycles prior to changing conditions for each condition within a run. These data shall include ambient temperature and pressure, plenum temperature and CO_2 water pressure, plenum to ambient pressure differential, makeup H_2O and CO_2 weights, CO_2 flow rate, steam flow setting, system air flow, cycle time, and bypass flow setting. Times, absolute and elapsed, at which data is taken and/or conditions are changed shall be recorded.

4.2.4.4.3 HS-C Air Inlet Temperature, Rig 88 Inlet Hygrometer and Infra-red Analyzer data shall be recorded on multipoint recorder during the mission tests. Bed temperature and vacuum data as well as HS-C outlet PCO_2 data shall also be recorded on the multipoint recorder whenever possible but shall not be construed as a requirement for mission testing.

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4.2.5 <u>System Flow Calibration</u>

4.2.5.1 <u>Purpose</u> - The purpose of this test is to establish air flow through the HS-C bed as a function of pressure drop across the bed prior to vibration testing of the canister assembly.

4.2.5.2 The test shall be conducted per paragraph 4.2.2.

4.2.6 <u>Canister Vibration</u>

4.2.6.1 The flight prototype system will be removed from the test rig and disassembled.

4.2.6.2 The canister assembly, SVSK 91722, shall be subjected to vibration testing per SVSKTR 91722.

4.2.6.3 The flight prototype system, SVSK 91725, will be reassembled. The system shall be installed on rig 88.

4.2.7 <u>System Flow Calibration</u> A

4.2.7.1 <u>Purpose</u> - The purpose of this test is to establish air flow through the HS-C bed as a function of pressure drop across the bed after vibration testing of the canister assembly.

4.2.7.2 The test shall be conducted per paragraph 4.2.2.

4.2.8 <u>System Performance</u>

4.2.8.1 <u>Purpose</u> - The purpose of this test is to demonstrate the performance of the flight prototype system after canister vibration.

4.2.8.2 The cabin environment #4 as defined in Table 4.2.3 of the mission testing shall be repeated per paragraph 4.2.4 for a minimum of 20 hours.

5.0 SPECIAL INSTRUCTIONS FOR TESTING PROGRAM

5.1 Mission tests may be run continuously at a given temperature. Flight prototype system operation may be shut down when a change in temperature is required.

5.2 Operation of Rig 52 must be monitored by Operations personnel. Engineering shall advise Operations of the required periods of rig operation and shall instruct Operations personnel of procedures in the event of equipment problems.

5.3 "Equilibrium", as found in sections 4.2.3 and 4.2.4, shall be defined as the value of a parameter measured at consistent points in each cycle for three consecutive cycles whose trend extremes do not exceed ± 5%.

5.4 Instrumentation Calibration

5.4.1 All appropriate instrumentation indigenous to Rig 88 shall be calibrated prior to testing and shall be maintained per Rig Manual Form HSF-1881.

5.4.2 The Hygrometer and Infra-red Analyzer shall be calibrated prior to testing and as stipulated in the test sequence.

5.4.3 The Infra-red Analyzer shall be checked for 0 and 100% a minimum of once, prior to recording data, on each day of use. Similarly, the Hygrometer shall be "tested" a minimum of once, prior to recording data, on each day of use.

5.5 Air samples will be taken during testing of the flight prototype system to determine the background levels of any trace gases that might be present in the test environment. A
Samples will be taken using NIOSH charcoal tubes; sampling rates and time periods will be determined by the project engineer.

6.0 DATA USAGE AND PRESENTATION

6.1 Independent variables shall be time averaged and extremes of variation defined during steady state operation.

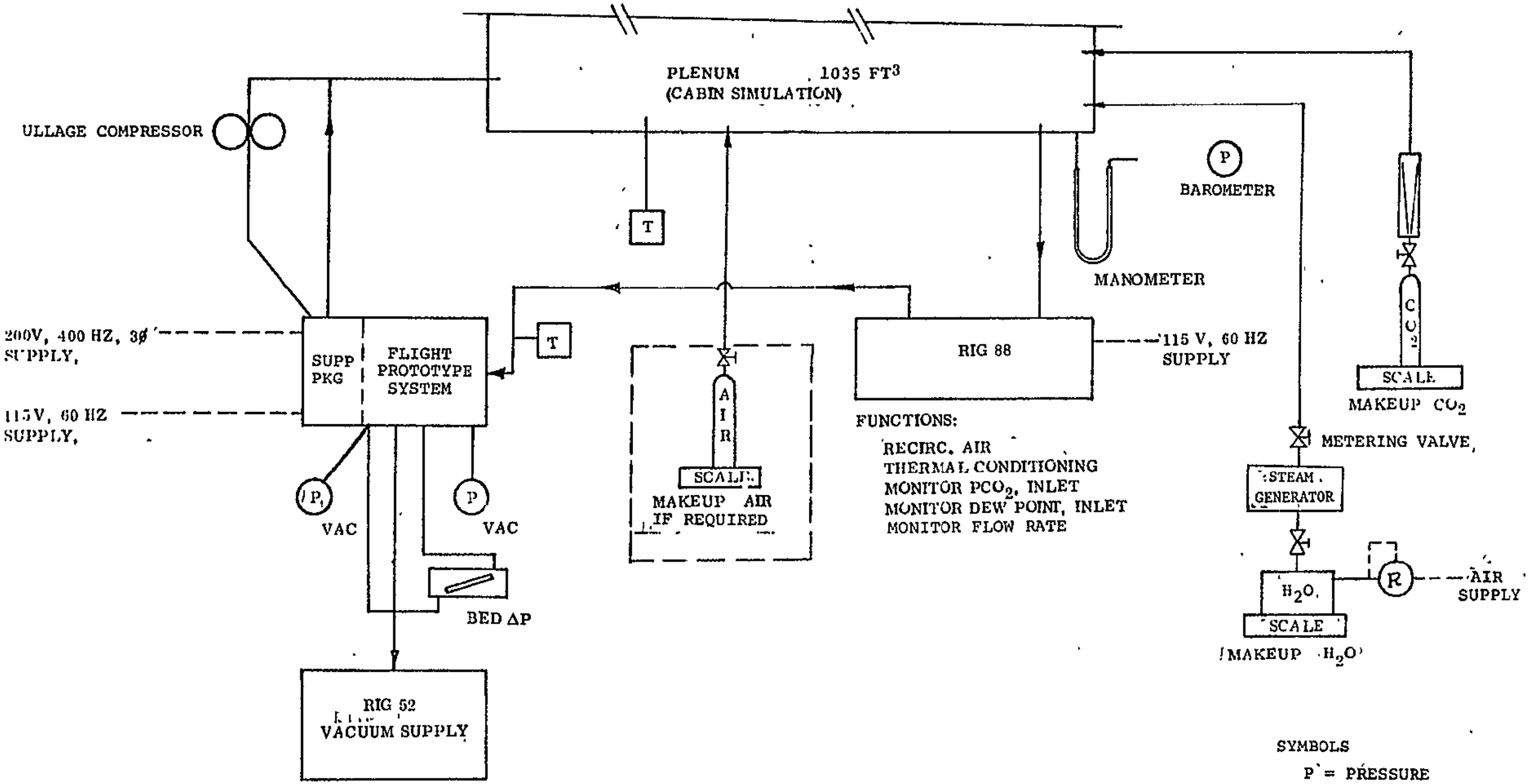
6.2 Dependent Variables

6.2.1 During steady state operation, dependent variables shall be time averaged with extremes defined.

6.2.2 Transients between different operating loadings shall be plotted versus time.

The permeation data, section 4.2.1.2, shall be plotted as rate of permeation versus the average partial pressure during the test. These rates shall be used to adjust raw data in the reduction of performance data.

SVHSER 7182



SYMBOLS

P = PRESSURE
T = TEMPERATURE
W = WEIGHT FLOW
R = REGULATOR

FIGURE 1 SCHEMATIC TEST SETUP

FLIGHT PROTOTYPE REGENERABLE O_2 AND H_2O CONTROL SYSTEM (HS-C)

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TABLE 1
DATA REQUIREMENTS AND INSTRUMENTATION LIST

Parameter	Units	Accuracy	Instrument	Range and Units	Notes
Rig 88 and HS-C Flow	cfm	± 10%	Venturi/Manometer	0 to 30 in H_2O	Indigenous to Rig 88
Rig 88 Outlet Temperature	°F	± 2°	Thermocouple	20 to 150°F	
Makeup CO_2 Flow	lb/hr	± 2% Full Scale	Flowrater	0 to 1.2 lbm/hr	
Makeup H_2O Flow	lb/hr	± 5%	Metering Valve	0 to 3.3 lbm/hr	
HS-C Inlet Temperature	°F	± 2°	Thermocouple	20 to 150°F	
HS-C System Cycle Time	minutes	± 1% Cycle	Stop Clock	0 to 60	
HS-C System Vacuum		± 5% Non-Linear Scale	Hastings Gage and Pickup or Equivalent	0 to Atmos	
HS-C Bed Press. Delta	in H_2O	± 0.05	U-Tube Manometer	0 to 20 inches	
Plenum Temperature	°F	± 2°	Thermocouple	20 to 150°F	
Plenum Dew Point	°F	± 2°	Hygrometer	-40 to 120°F	Indigenous to Rig 88
Plenum PCO_2	mmHg	± 2% Full Scale	Infra-Red Analyzer	0 to 100% (100% = TBD mmHg)	Indigenous to Rig 88
Plenum/Ambient Press. Delta	in H_2O	± 0.2	U-Tube Manometer	0 to 30 inches	Indigenous to Rig 88
Weight Makeup Air	lbm	± 0.02	Scale	0 to 300 lb	
Weight Makeup CO_2	lbm	± 0.02	Scale	0 to 300 lb	
Weight Makeup H_2O	lbm	± 0.02	Scale	0 to 300 lb	
Ambient Pressure	in. Hg	± 0.05	Barometer		
Ambient Temperature	°F	± 2°	Thermometer	20 to 400°F	

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. APPENDIX D

HS-C PUBLICATIONS

(1) Boehm, A. M., "A Regenerable CO_2 and Humidity Control System for Shuttle," ASME Paper No. 76-ENAS-60, July, 1976.

(2) Boehm, A. M., "The Development and Testing of a Regenerable CO_2 and Humidity Control System for Shuttle," ASME Paper No. 77-ENAS-27, July, 1977.

(3) Cusick, R. J. and Boehm, A. M., "A Prototype Carbon Dioxide and Humidity Control System for Shuttle Mission Extension Capability," IAF Paper No. IAF-76-045. October. 1976.