

PJ Bureau EPLS

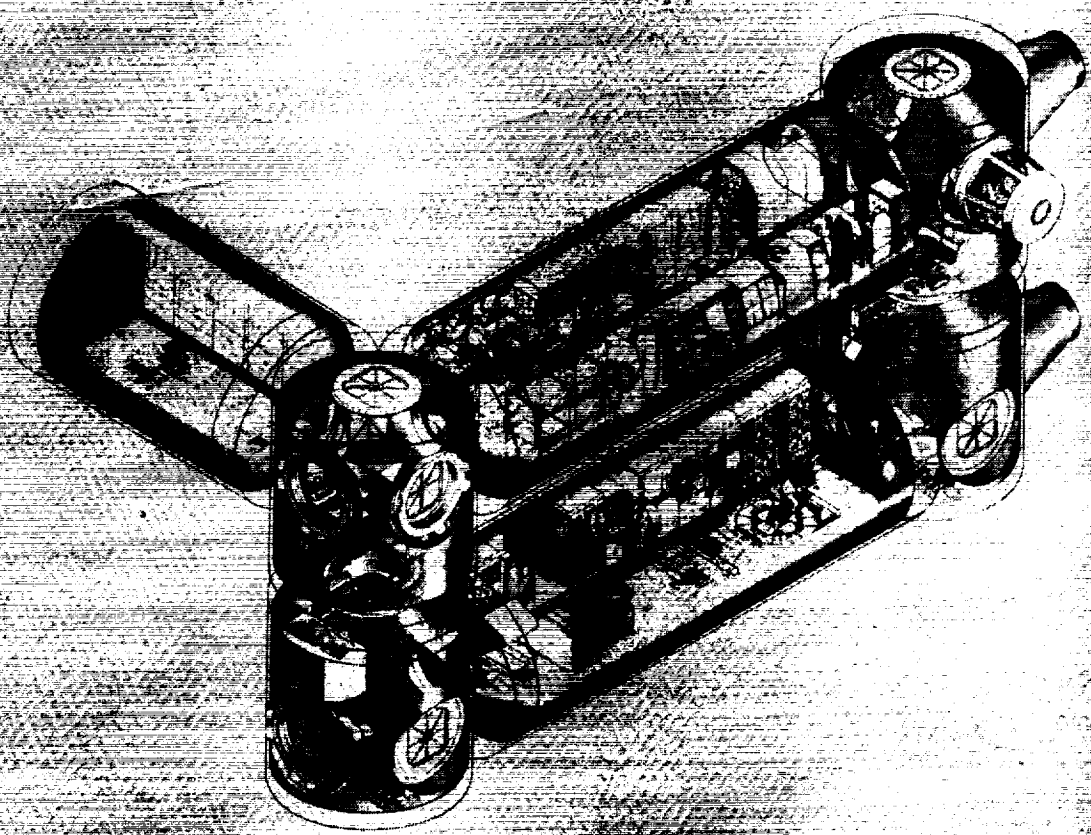
# FINAL REPORT

## SPACE STATION GAS COMPRESSOR TECHNOLOGY STUDY PROGRAM PHASE I

Contract NAS 8-37747

89-62104(6)

JUNE 16, 1989



Prepared for

**George C. Marshall Space Flight Center  
National Aeronautics and Space Administration  
Marshall Space Flight Center, Alabama 35812**

(NASA-CR-183755) SPACE STATION GAS  
COMPRESSOR TECHNOLOGY STUDY PROGRAM, PHASE I  
Final Report (Allied-Signal Aerospace Co.)  
76 0 CSCL 22B

N70-13491

Unclas  
63/13 0222720

# **FINAL REPORT**

## **SPACE STATION GAS COMPRESSOR TECHNOLOGY STUDY PROGRAM PHASE I**

**Contract NAS 8-37747**

**89-62104(5)**

**JUNE 16, 1989**

This document contains information which is the property of Allied-Signal Aerospace Company, a unit of Allied-Signal Inc. Except for rights expressly granted by contract to the United States Government, this document may not, in whole or in part, be duplicated, disclosed, or used for design or manufacturing purposes without prior written permission of Allied-Signal Aerospace Company.

**Prepared for**

**George C. Marshall Space Flight Center  
National Aeronautics and Space Administration  
Marshall Space Flight Center, Alabama 35812**



# Report Documentation Page

<b>1. Report No.</b> 89-62104(5)		<b>2. Government Accession No.</b>		<b>3. Recipient's Catalog No.</b>	
<b>4. Title and Subtitle</b> Space Station Gas Compressor Technology Study Final Report for Phase I				<b>5. Report Date</b> June 16, 1989	
				<b>6. Performing Organization Code</b>	
<b>7. Author(s)</b> B. W. Hafele R. R. Rapozo				<b>8. Performing Organization Report No.</b>	
				<b>10. Work Unit No.</b>	
<b>9. Performing Organization Name and Address</b> Allied-Signal Aerospace Company AiResearch Los Angeles Division 2525 West 190th Street Torrance, CA 90509-2960				<b>11. Contract or Grant No.</b> NAS 8-37747	
				<b>13. Type of Report and Period Covered</b> Final Report	
<b>12. Sponsoring Agency Name and Address</b> George C. Marshall Space Flight Center National Aeronautics and Space Administration Marshall Space Flight Center, AL 35812				<b>14. Sponsoring Agency Code</b>	
				<b>15. Supplementary Notes</b>	
<b>16. Abstract</b> <p>The objectives of this study are to identify the space station waste gases and their characteristics, and to investigate compressor and dryer types, as well as to transport and storage requirements with tradeoffs leading to a preliminary system definition.</p>					
<b>17. Key Words (Suggested by Author(s))</b> Waste gases			<b>18. Distribution Statement</b> Unclassified-unlimited		
<b>19. Security Classif. (of this report)</b> Unclassified		<b>20. Security Classif. (of this page)</b> Unclassified		<b>21. No. of pages</b> 69	<b>22. Price</b>

## FOREWORD

This report is submitted by AiResearch Los Angeles Division of Allied-Signal Aerospace Company in response to George C. Marshall Space Flight Center, National Aeronautics and Space Administration Contract NAS 8-37747. This is the final report for the Phase I study effort of the Space Station Freedom gas compressor technology study program.

In accordance with the contract requirements, monthly progress reports have been submitted, and technical coordination meetings have taken place. The following progress and technical coordination meeting (TCM) reports have been issued.

<u>AiResearch Document</u>	<u>Title</u>	<u>Content Overview</u>
CCJW:80243:1201	Monthly Progress Report, October 1988	Describes the work performed, problem areas, work for next period, schedule, and cost items.
CCJW:80268:1209	Monthly Progress Report, November 1988	Describes the work performed, problem areas, work for next period, schedule, and cost items.
CCJW:90015:0110	Monthly Progress Report, December 1988	Describes the work performed, problem areas, work for next period, schedule, and cost items.
89-62104(1)	Monthly Progress Report, January 1989	Describes the work performed, problem areas, work for next period, schedule, and cost items.
89-62104(2)	Monthly Progress Report, February 1989	Describes the work performed, problem areas, work for next period, schedule, and cost items.
89-62104(3)	Monthly Progress Report, March 1989	Describes the work performed, problem areas, work for next period, schedule, and cost items.
89-62104(4)	Monthly Progress Report, April 1989	Describes the work performed, problem areas, work for next period, schedule, and cost items.
89-61900	Technical Coordination Meeting 1	Describes the overview of the program.
89-62037	Technical Coordination Meeting 2	Covers program schedule review, Phase I status review, and facilities tour.

AiResearch  
Document

Title

Content Overview

89-62496

Technical Coordination  
Meeting 3

Covers Phase 1 status review,  
Phase 2 proposed program, and  
program schedule review.

## CONTENTS

<u>Section</u>		<u>Page</u>
1.	SUMMARY	1-1
2.	SOURCES OF DATA	2-1
3.	WASTE GAS IDENTIFICATION	3-1
4.	WASTE GAS EVALUATION	4-1
5.	COMPRESSOR DESIGN REQUIREMENTS	5-1
6.	FILTER/DRYER REQUIREMENTS	6-1
7.	DESIGN CONCEPTS	7-1
	7.1 Compressor Tradeoff Studies	7-1
	7.1.1 Number of Stages	7-1
	7.1.2 Design Studies	7-5
	7.1.3 Drive Systems	7-6
	7.2 Review of Available Equipment	7-12
	7.3 Preliminary Design	7-12
	7.3.1 Compressor Profile	7-16
	7.3.2 Schematic	7-16
	7.3.3 Conceptual Layout	7-19
	7.3.4 Outline	7-19
	7.3.5 Compressor Design Technology Base	7-19
	7.3.6 Filter/Dryer Design	7-25
	7.4 Risk Assessment	7-29
8.	DESIGN SPECIFICATIONS	8-1
9.	TEST PLAN	9-1
<u>Appendix</u>		
A	DESIGN SPECIFICATIONS	A-1
B	DESCRIPTION OF TEST PROGRAM	B-1

## 1. SUMMARY

The Space Station Freedom gas compressor technology Phase I study has defined the system requirements, design concepts, and test requirements for a multigas compressor and filter/dryer system in order to establish the design specification for the application. The three primary Space Station Freedom systems with compressor interface are: (1) the environmental control and life support system (ECLSS) (2) the process materials management system (PMMS) and (3) the fluid management system (FMS).

The Phase I technology study accomplished the following major tasks:

- Sources of data: The key systems interfaces were established and the contractors and NASA system personnel were identified and consulted.
- Waste gases identified: The types and quantities of gases were identified for each system.
- Waste gases evaluated: The pressure, temperatures, and flow rates of the identified gases were established.
- Compressor design requirements: The design requirements for each compressor application were established.
- Filter/dryer requirements: The filter and dryer design requirements for each systems application were established.
- Compressor design concepts: Various compressor design concepts were evaluated for the waste gas compressor.
- Design specifications: A preliminary compressor design specification was prepared.
- Test plan: A preliminary test plan was prepared for Phase II system testing.
- Phase II recommendations: A Phase II demonstration program is proposed to develop the technology required for a waste gas compressor.

The Phase I analysis and data identified the waste gas compressor requirements for the FMS, ECLSS, and the PMMS systems for Space Station Freedom. It was also established that the unique requirements of these systems would required new compressor technology development to optimize a design for maximum efficiency and minimum Space Station Freedom power utilization. AiResearch has proposed a Phase II program which will build upon existing flight-proven compressor design technology to create a design concept that will meet all of the identified Space Station Freedom multigas requirements.

## 2. SOURCES OF DATA

A major part of the Phase I program was to identify the gases and compressor interfaces and to identify and interface with the sources of this data. The identification of data and system interfaces and the research of subject reports and publications were covered in the monthly progress reports referenced on pages ii and iii. The primary sources of data for this study were the following:

- WP-01, Boeing (ECLSS and PMMS)
- WP-02, McDonnell Douglas (FMS)
- NASA, Level 2, MSFC and JSC
- Grumman (Reston, Va.)
- Published NASA data

Although many NASA reports were obtained and reviewed, the key sources of information were the following reports:

- (a) A87-32457: Gas and Water Recycling System for IOC Vivarium Experiments, National Aerospace Laboratory, Tokyo, May 19, 1986
- (b) CPIA-PUB-455V-1: Hydrogen/Oxygen Economy for Space Station, Rockwell International, Rocketdyne Division, August 26, 1986
- (c) DRO2 DATA DUMP: Minutes of Fluids Technical Integration Panel, Martin Marietta, Boeing, October 29, 1986
- (d) PIR 0191: Preliminary Information Report, Solar Dynamic Power Module Division, March 25, 1987
- (e) NAS8-36122: Microgravity and Materials Processing Study, Teledyne Brown Engineering, March 3, 1988
- (f) MSFC: Space Station Freedom Program Review, MSFC, November 10, 1988
- (g) Carbon Dioxide Reduction Subsystem Trade Study, MSFC, October 5, 1988
- (h) JSC 9-BE2-10-8-C8P, REV. 1.00/1.31: On-Orbit Compressor Technology Program, JSC, January 12, 1989
- (i) TAH-125-89: List of Consumables for Process Fluids Distribution/Storage System, Teledyne Brown Engineering, February 1, 1989
- (j) PSH-522-RP89-148: Waste Fluid Processing, Program Support Contract (PSC), February 13, 1989



### 3. WASTE GAS IDENTIFICATION

The reports in para. 2, "Sources of Data," provided the information to identify the waste gases from the ECLSS and PMMS systems. Table 3-1 identifies the specific waste gases from the ECLSS And PMMS source.

TABLE 3-1  
WASTE GAS IDENTIFICATION

Source	Gases	Remarks
ECLSS	hydrogen	ECLSS based on Bosch system
PMMS	argon carbon dioxide helium nitrogen oxygen xenon krypton	PMMS gases are those identified as MWG constituents

The molecular weight for the modular waste gases (MWG) listed in Table 3-1 are averaged. Table 3-2 indicates the gas percentage by gravimetric analysis.

TABLE 3-2  
GAS PERCENTAGES BY GRAVIMETRIC ANALYSIS

Gas	Mass, percent	Moles, no.	Moles, percent	MW, lb/mol	Co, Btu/mol	Co, FBtu/lb <sup>o</sup> F	Gamma
N <sub>2</sub>	48.0	1.71	51.7	28.01	7.4	0.263	1.382
Ar	30.0	0.75	22.7	39.94	5.0	0.125	1.667
O <sub>2</sub>	8.0	0.25	7.5	32.00	7.9	0.247	1.394
CO <sub>2</sub>	5.0	0.11	3.4	44.01	10.6	0.240	1.246
He	1.7	0.42	12.8	4.00	5.0	1.244	1.667
Kr	1.3	0.02	0.5	83.80	5.0	0.060	1.667
Xe	6.0	0.05	1.4	131.30	5.0	0.038	1.667
MWG	100.0	3.3	100.0	30.17 (average)	6.64	0.220	1.485

Analysis of the subject reports revealed that, in addition to the identified waste gases, certain trace contaminants have to be taken into account. The contaminants fall into the following categories:

- Organics
- Acids and bases
- Oxidants
- Halogens
- Others

Some of these contaminants can cause corrosive reaction problems if they are present in sufficient quantity and condense, particularly in the presence of water.

The latest information concerning Space Station waste gas contaminants, contained in NASA PSC Report PSH-522-RP89-148, dated February 13, 1989, indicates trace contaminant levels much lower than previous information given in NASA JSC Report 9-BE2-10-8-08P. Whereas formerly individual trace contaminants were identified to be in the range of 0.2 percent by mass (2000 ppm) or less, current values for entire classes of contaminants (e.g., acids and organic solvents) are listed as 5 ppm (max.). Moisture, at an expected concentration of 0.5 percent by mass (5000 ppm), must be removed prior to compressing the gases.

#### 4. WASTE GAS EVALUATION

Evaluation of the waste gas data listed in the source information reports referenced in para. 2, "Sources of Data," indicated the maximum waste gas quantities per year for the ECLSS and labs (USL, Columbus, JEM) which have to be taken into account.

The waste gas quantities of the ECLSS and labs from three source inputs, Boeing WP-1, MDSSC-Space Station Division WP-2, and Grumman of Reston, Va., are listed in Table 4-1. AiResearch has reviewed the quantitative waste gases of these source inputs and the latest MSFC information on the ECLSS (Bosch system). The column "AiResearch-Proposed" in Table 4-1 represents the up-to-date consensus figures of maximum waste gas quantities that were used for this study.

TABLE 4-1

WASTE GAS EVALUATION

System	AiResearch-Proposed		Boeing WP-1(1)		MDAC WP-2(2)		Grumman (Reston, Va.)(5)	
	LBM/Year (Max.)	kg/Year (Max.)	LBM/Year (Max.)	kg/Year (Max.)	LBM/Year (Max.)	kg/Year (Max.)	LBM/Year (Max.)	kg/Year (Max.)
ECLSS (H <sub>2</sub> ) (H <sub>2</sub> O vapor)	215(3) 27(3)	98 12	176	80	270	122	146	66
LABS (MWG)(4)								
USL	3,767(1)	1,709	3,767	1,709			3,500	1,588
CoLumbus	797(1)	362	797	362			1,590	721
JEM	777(1)	352	777	352			1,251	567
Total LABS	5,341	2,533	5,341	2,423	9,504	4,311	6,341	2,876

NOTES:

- (1) Based on data from G. Schmidt, FMS presentation, June 1988.
- (2) Based on data from preliminary specification for Type I and II compressors, Space Station waste gas system. Received February 1989 from MDSSC-Space Station Division, Huntington Beach, CA
- (3) Based on data (block diagram of Bosch CO<sub>2</sub> reduction subsystem) received November 29, 1988 from environmental control systems group, MSFC.
- (4) Module waste gas (MWG): Argon, CO<sub>2</sub>, freon, helium, H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, xenon, krypton, air.
- (5) Based on data from PSH-522-RP89-148, waste fluid processing, February 13, 1989. Based on data for IWGS design requirements, to be included in ACD document.

## 5. COMPRESSOR DESIGN REQUIREMENTS

The compressor design requirements encompass two major Space Station subsystems, the ECLSS and the PMMS. Based on the source information reports referenced in para. 2.4, the candidate compressor units will have to meet the design requirements listed in Table 5-1.

TABLE 5-1  
COMPRESSOR DESIGN REQUIREMENTS

Gases	Subsystem		Remarks
	ECLSS H <sub>2</sub>	PMMS	
Flow rate, lbm/hr (max.)	0.05	1.22	Based on compressor operation of 12 hr per day
Inlet pressure, psia, nominal	20	15	As defined by WP-01 ECLSS and PMMS subsystems
Outlet pressure, psia (max.) (min.)	1200 1000	1200 1000	As defined by WP-02 FMS subsystem
Inlet temp, °F (max.) (min.)	90 60	90 60	As defined by WP-01 ECLSS and PMMS subsystem
Duty cycle	12 hr/day	12 hr/day	Daily compressor operating time (min.)
Operating life, years (min.)	10	10	Recommended service life for compressor
Power, w	300	350	Estimated allocated electrical power

## 6. FILTER/DRYER REQUIREMENTS

The presence of trace contaminants and dust particles in the waste gas circuit mandates location of a contaminant/moisture sorbent filter upstream of the compressor. The objective is to remove or limit these contaminants to levels acceptable to the compressor in order to meet life and reliability criteria.

The filter/dryer design requirements for the ECLSS and PMMS are illustrated in Table 6-1. For example, under the ECLSS (Bosch) subsystem column, the hydrogen waste gas is listed at an inlet pressure of 20 psia and an inlet temperature of 90°F (max.). Trace contaminants (i.e., acids and organic solvents) are listed at 5 parts per million (max.). The filter requirements of 10 microns (max.) should provide adequate filtration of particulates. A relatively high moisture content of 26.23 lb of H<sub>2</sub>O/year within the hydrogen gas necessitates a dryer system since the compressor inlet maximum allowable humidity content is approximately 18.9 grains of H<sub>2</sub>O per lb of dry gas ( $2.46 \times 10^{-3}$  lb). This level has been established to eliminate the possibility of condensing water within the compressor during the compression of the gases.

TABLE 6-1  
FILTER/DRYER REQUIREMENTS

Gases	Subsystem	
	ECLSS H <sub>2</sub>	PMMS MWG
Inlet pressure, psia (nominal)	20	15
Inlet temperature, °F (max.)	90	90
Trace contaminants, parts per million	5	5
Particulates, microns	10	10
Specific humidity (outlet), grains H <sub>2</sub> O per lb of dry gas	18.9	0.46
Moisture removal H <sub>2</sub> O/year, lb	26.23	TBD

## 7. DESIGN CONCEPTS

The following conceptual research and analysis has been conducted on the basis of the basic design requirements described in the previous paragraphs. This consisted of:

- Compressor tradeoff studies
- Review of available equipment
- Preliminary design analysis
- Design risk assessment

### 7.1 COMPRESSOR TRADEOFF STUDIES

The objective of this study was to analyze and trade off compressor design concepts best suited for the waste gas application. The following concepts were explored:

- Number of stages
- Design types
  - Piston
  - Diaphragm
- Drive systems
  - Electrical
  - Electromechanical
  - Hydraulic

#### 7.1.1 Number of Stages

The compressor tradeoff studies involved parametric evaluation of the effect of several input quantities on the system size, power, and efficiency. The summary, Table 7-1, lists and compares the key variables as a function of the number of compression stages used to achieve the final pressure. Bar charts are provided in Figures 7-1 and 7-2 to show typical power levels versus number of stages. The ideal number of compressor stages is determined by the total compressor pressure ratio required. The maximum allowable pressure ratio per stage for a particular compressor type then determines the minimum number of stages required. Maximum pressure ratios per stage are typically limited by the type of compressor, isentropic gas temperature rise in the chamber, and the volumetric efficiency.

The analysis summary, Table 7-1, lists eight variables of interest for each of the gases and their values as a function of the number of compressor

TABLE 7-1

TRADEOFF STUDY SUMMARY,  
KEY VARIABLES VS COMPRESSION STAGES

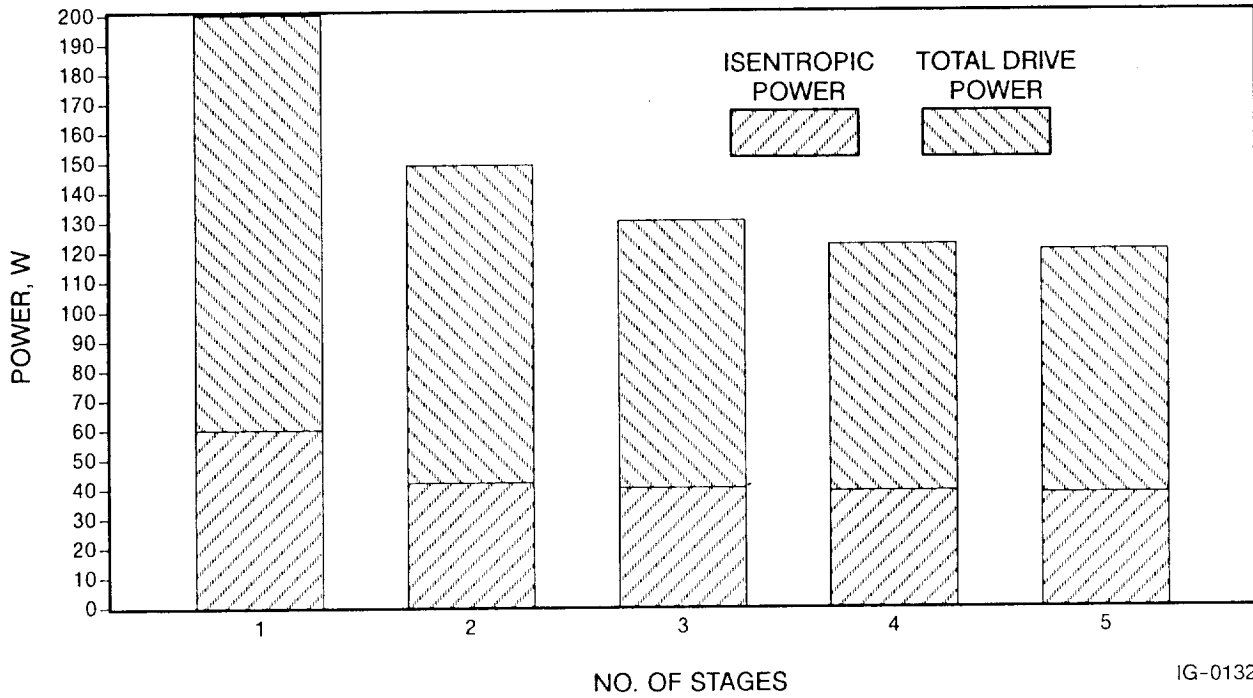
	1 Stage	2 Stage	3 Stage	4 Stage
Hydrogen gas				
Inlet pressure, psia	20	20	20	20
Outlet pressure, psia	1200	1200	1200	1200
Press. ratio per stage	60.000	7.746	3.915	2.783
Mass flow rate, lbm/hr	0.050	0.050	0.050	0.050
Inlet volumetric flow rate, cfm	0.117	0.117	0.117	0.117
Volumetric efficiency, percent	--	66.39	83.31	89.12
Total adiabatic power, w	59.6	43.0	38.7	36.8
Total system power, w	198.8	143.2	129.2	122.8
Modular waste gases				
Inlet pressure, psia	15	15	15	15
Outlet pressure, psia	1200	1200	1200	1200
Press. ratio per stage	80.000	8.944	4.309	2.991
Mass flow rate, lbm/hr	1.236	1.236	1.236	1.236
Inlet volumetric flow rate, cfm	0.259	0.259	0.259	0.259
Volumetric efficiency, percent	--	66.27	83.26	89.09
Total adiabatic power, percent	134.4	88.3	77.4	72.7
Total system power, w	448.1	294.3	258.1	242.2

\*For inlet temperatures of 70°F



### POWER vs NO. OF STAGES

HYDROGEN GAS, ECLSS

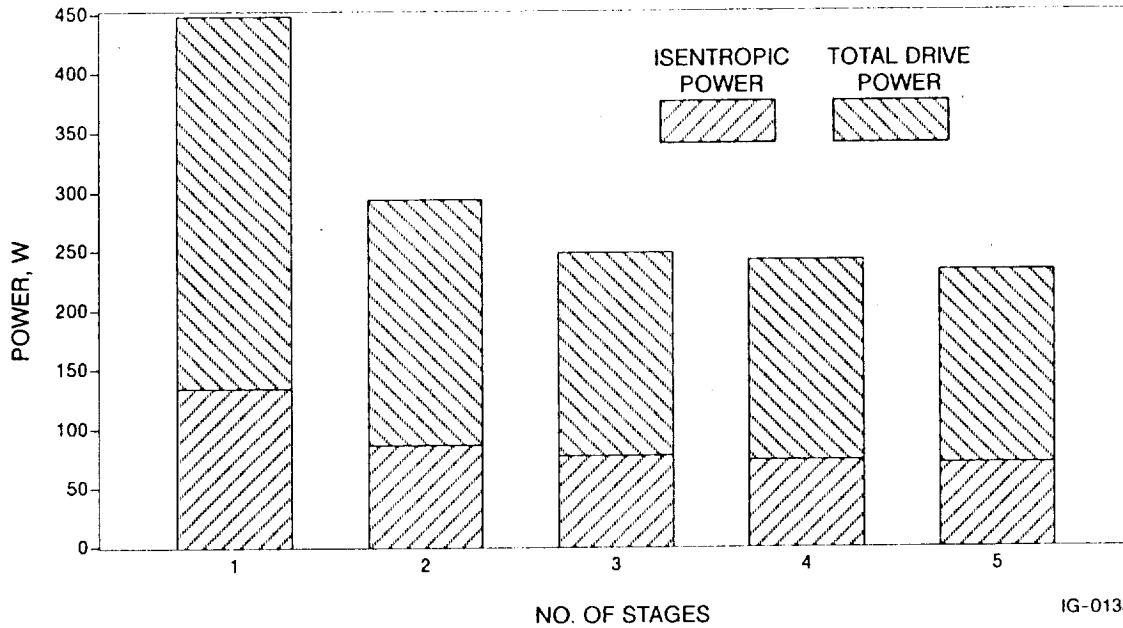


IG-01329

Figure 7-1. Tradeoff Study Summary, Hydrogen Gas (ECLSS), Power vs Number of Stages

### POWER vs NO. OF STAGES

MODULAR WASTE GASES, PMMS



IG-01330

Figure 7-2. Tradeoff Study Summary, Modular Waste Gases (PMMS), Power vs Number of Stages

## POWER vs NO. OF STAGES

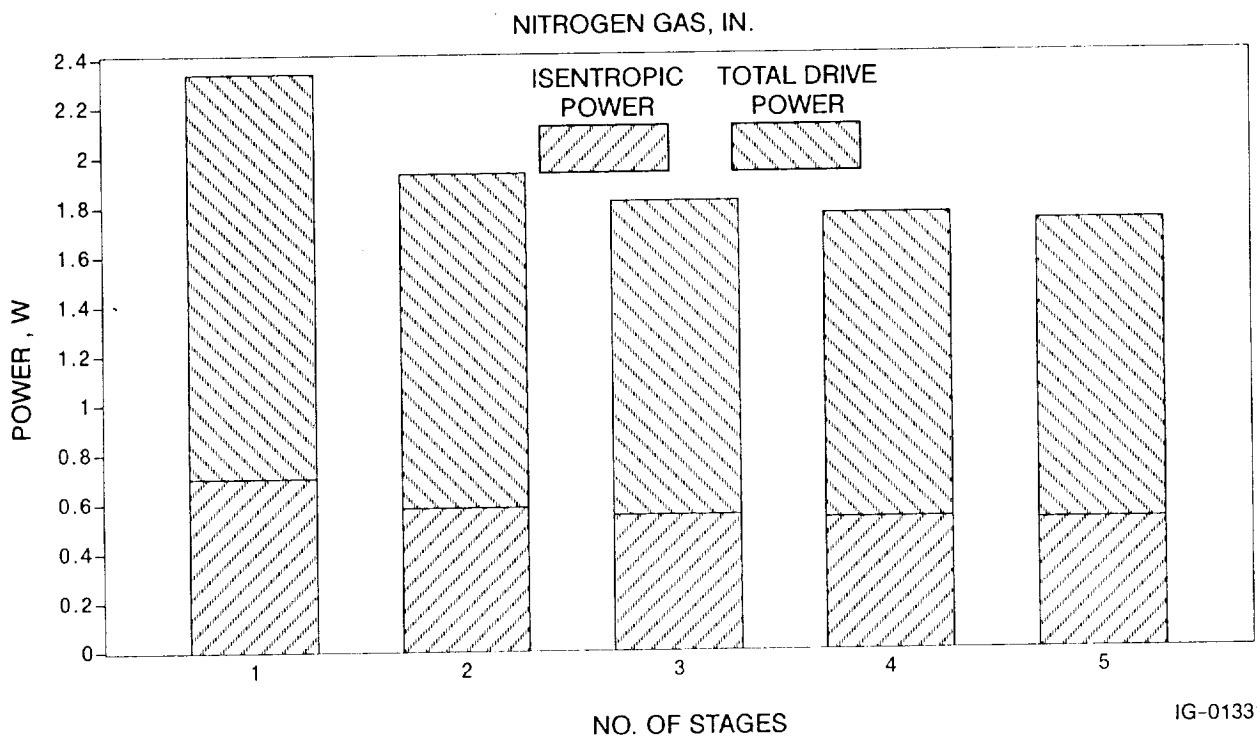


Figure 7-3. Tradeoff Study Summary, Nitrogen Gas (INS), Power vs Number of Stages

stages. The gases studied were: hydrogen from the ECLSS system, and the modular waste gases from the PMMS system. The modular waste gases are a combination of several inert, diatomic, and other gases. The input and output pressures, mass flow rates, and inlet temperatures used in Table 7-1 are referenced from the latest data. Comparisons are made from the results of using 1 to 4 stages with the same fluid media and inputs. Of these eight variables, the inputs are: the mass flow rate, and the input and output pressures. The outputs are: the pressure ratio per stage, inlet volumetric flow rate (based on first stage inlet conditions), volumetric efficiency, total isentropic power, and total system power. The total system power assumes an overall efficiency of 30 percent.

The tradeoff study has analyzed several types of gas compressors, optimized the number of stages required. The methods developed in the study resulted in an excellent candidate design with several options based on the exact requirements of the system.

In summary, the analysis of compressive stages leads to the following conclusions:

- Required total overall pressure ratio,  $1200/15 = 80$
- Pressure ratio/per stage; 3 stages, 4.31/1, 4 stages, 2.99/1

- Key design considerations were:
  - Lower pressure ratio results in lower compressor power
  - Lower pressure ratio results in higher volumetric efficiency
  - Lower pressure ratio results in lower adiabatic temp. rise
  - Lower pressure ratio lowers cyclic pressure loads
  - Higher pressure ratio reduces weight and size
  - Higher pressure ratio reduces stages and hardware
  - Higher pressure ratio does not allow for growth

### 7.1.2 Design Types

Compressors fall into two broad categories: dynamic compressors and positive displacement machines. Dynamic compressors include axial, radial, and vortex types. Generally, the lower-speed, positive-displacement machines include reciprocating piston or diaphragm compressors, multilobe, sliding vane, liquid liner, and helical screw rotary compressors.

Dynamic compressors depend on high impeller velocity to impart momentum to the gas. An efficient diffuser is required to convert this kinetic energy to pressure rise. The positive displacement machines by contrast, ingest a volume of gas and decrease its volume, usually at low speed, to create the pressure rise. The inherently lighter weight of the high-speed, dynamic compressors promises a substantial benefit in launch weight. However, a careful evaluation of the suitability and power consumption characteristics of both types of compressors is required.

Dynamic compressors offer light, compact designs because they run at high speed (usually not needing a gearbox). They also have the functional advantage of not requiring cycling intake and exit valves because they are steady-flow machines. However, the low-flow, high-pressure requirements suggest that dynamic compressors are not suitable for the present application.

To confirm this idea, the specific speed has been evaluated for a candidate having an inlet volumetric flow rate of 0.3 acfm for the PMMS low-pressure compressor. Assuming a motor speed of 100,000 rpm and a first-stage pressure ratio of 3.5 leads to  $n_s = 0.021$ . According to AiResearch experience, this specific speed is in the range of the lowest specific speed dynamic machine, the drag compressor. However, preliminary sizing indicates a first-stage drag compressor tip diameter of 0.9 in., requiring 0.001 in. radial and axial clearances. Subsequent stages would need to be scaled down from this size. Overall efficiency and leakage of such a small multistage machine present several obstacles to the success of a drag compressor and, as such, it becomes impractical. Therefore, no further consideration was given to dynamic compressors for this application.

Positive displacement rotary machines generally are used for much higher flow rates than the present application. They become inefficient for very low

flow because the clearances typically do not scale down at the same rate as machine characteristic dimensions. Other objections to these compressors concern service life or gas contamination, as follows:

<u>Type</u>	<u>Disadvantage</u>
Helical screw	Male rotor drives female rotor, causing abrasive wear and gas contamination. Lubrication required.
Sliding vane	Vane wear along the outer wall and rotor grooves and lubrication required.
Liquid liner	Liquid loss through seals and valves.

For these reasons, the rotary compressors are considered noncompetitive for these applications.

Because of the relatively low flow requirements for the ECLSS and PMMS, however, a positive displacement reciprocating piston design or a diaphragm design are attractive candidates. Paragraph 7.3 presents a diaphragm compressor design which would perform well in both the PMMS and ECLSS. Analysis reveals the following basic characteristics for the two candidates:

- Diaphragm compressor advantages
  - Better able to handle lower flow rates
  - No dynamic seals
  - Better able to handle high pressure ratio
  - Lower frictional losses
  - No wear particles introduced to gas
  - Handles high temperatures better
  - Lower self-induced vibration
- Piston compressor advantages
  - Better able to handle high flow rates
  - Higher volumetric efficiency
  - More highly developed technology
  - Can produce higher pressure ratio

Figure 7-4 illustrates a cross section of a developed four-stage piston type gas compressor design used for airborne applications. The cross section defines the inlet/outlet gas interfaces of Stages 1 through 4, as well as the

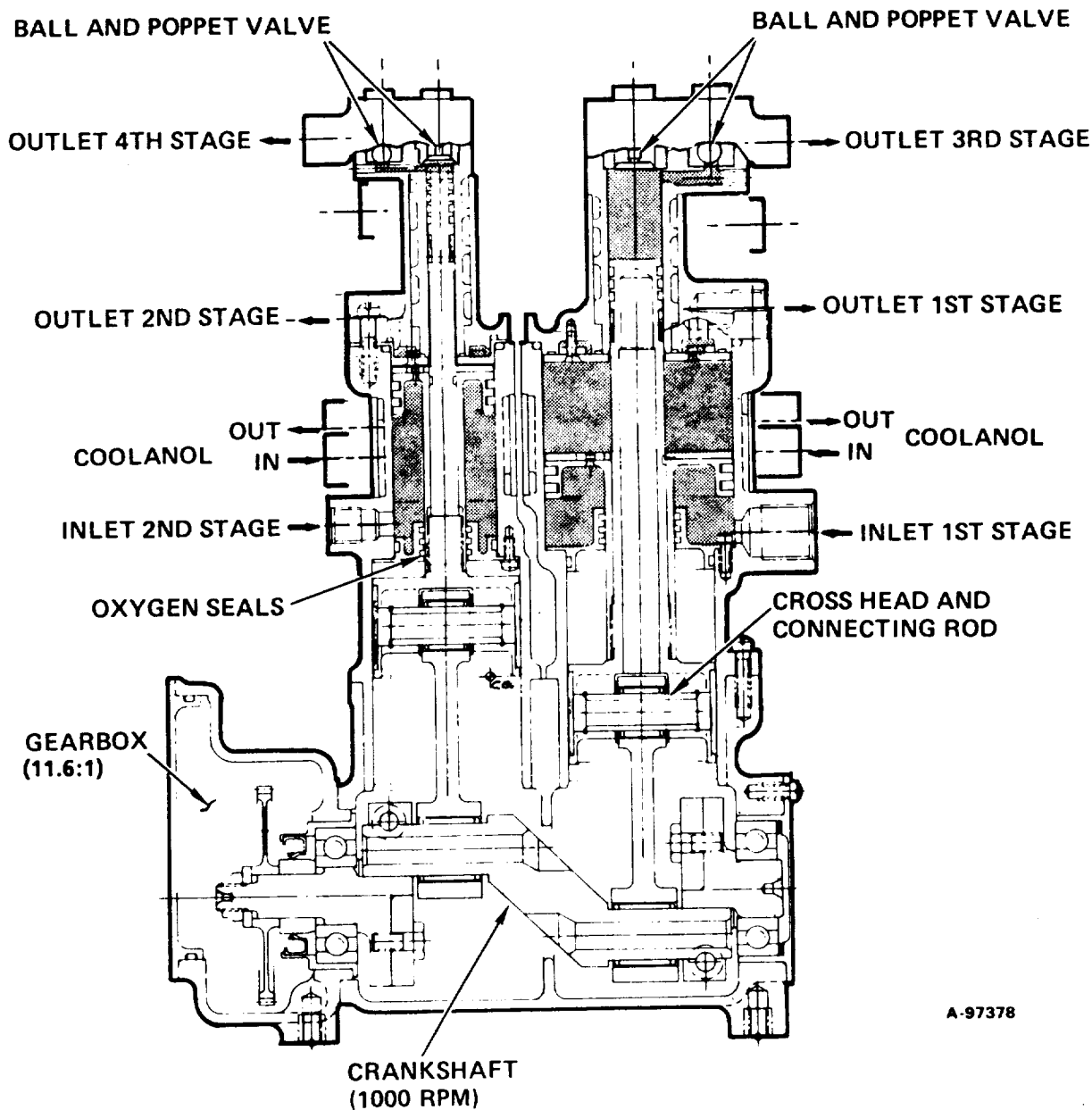


Figure 7-4. Cross Section of a Four-Stage Piston Compressor

gas intercooler provisions using coolanol for cooling media. The ball and poppet valves are indicated in the head section. The pistons are mounted to a connecting rod which is tied to a crankshaft. The crankshaft is coupled to a gearbox which interfaces with a drive motor.

### 7.1.3 Drive Systems

Compressor drive systems can be placed into three basic categories: linear-electrical, electromechanical, and hydraulic. For the linear-electrical drive system, a linear resonant motor was analyzed. The electro-mechanical drive system was matched with a latest technology permanent magnet

motor with gear reduction and magnetic coupling. For the hydraulic drive system, a servo valve-driven hydraulic piston was used. The results of the drive system study are summarized in Table 7-2.

TABLE 7-2

TRADEOFF STUDY SUMMARY,  
COMPRESSOR DRIVE SYSTEMS

Parameter	Linear-Electrical(1)	Electromechanical(2)	Hydraulic(3)
Reliability	very good	very good	good
Efficiency	good	very good	good
Life	very good	very good	good
Vibration	high	low	low
Size	large	medium	medium
Weight	high	medium	medium

NOTES:

- (1) Linear resonant motor
- (2) PM dc motor with gear reduction and magnetic coupling
- (3) Servo-valve-driven hydraulic piston

7.1.3.1 Drive Motor

As indicated in Table 7-2, it appears that the electromechanical drive system would be best suited for the application. Based on the Space Station 120-vdc supply source, the compressor can be driven by a 120-vdc, brushless, dc permanent magnet motor which would use the latest technology for brushless permanent magnet motor design to maximize efficiency and performance. The high efficiency of a permanent magnet motor allows the maximum amount of pumping power to be transmitted for the fixed amount of electrical input power available. A relatively new type of machine, the two-pole, toothless-stator, permanent magnet motor could be proposed for this application. The toothless-stator design concept was developed to take advantage of the recent availability of high-energy product permanent magnets.

Use of a toothless stator in a PM motor improves machine power density (power output per unit of volume) by reducing the losses associated with motors of a more conventional design. This reduction is accomplished by (1) eliminating stator iron tooth losses and the associated high-frequency losses in the back iron due to individual tooth high-frequency pulsations penetrating into the core, (2) eliminating rotor losses due to tooth ripple, and (3) lowering copper winding resistance. In addition, rotor cogging is eliminated, resulting in smoother startup and operation. A cross section of a two-pole, toothless-stator machine is shown in Figure 7-5.

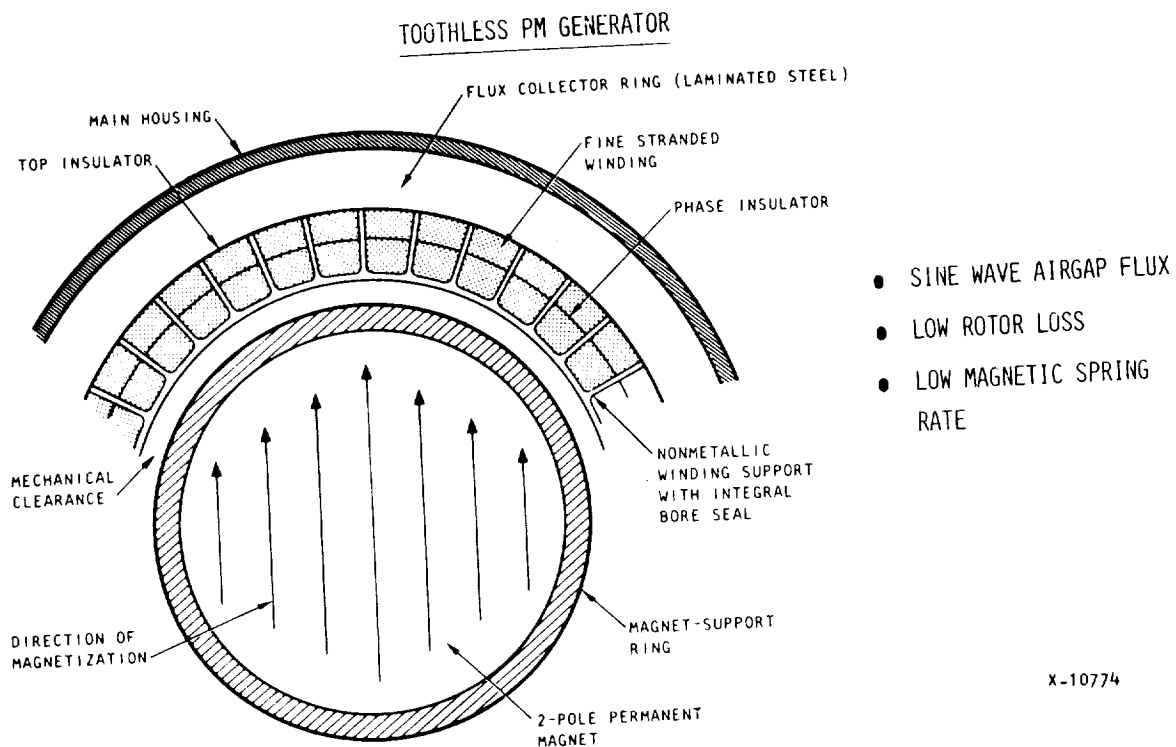


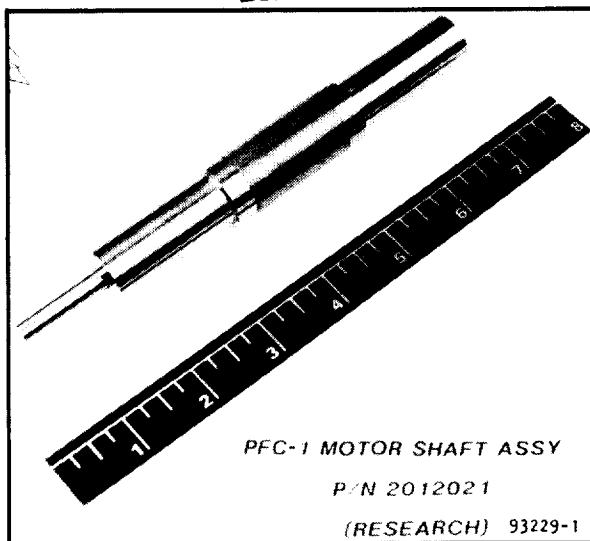
Figure 7-5. Cross Section of Two-Pole Toothless Machine

The use of a two-pole, permanent magnet rotor in conjunction with a toothless stator in the electrical machine further reduces the size and weight of the machine without reducing efficiency at the same output. The diametrically magnetized, solid, cylindrical, two-pole magnet construction provides the maximum possible magnetomotive force for a given rotor size; this allows a larger magnetic air gap than rotors using a higher number of poles. The large magnetic air gap allows the stiffest possible rotor sleeve with minimum effect on the electromagnetic design. The "straight through" diametrically magnetized rotor, as compared with the radially magnetized configuration, will result in a sinusoidal air gap flux distribution, which eliminates losses and heating due to harmonics.

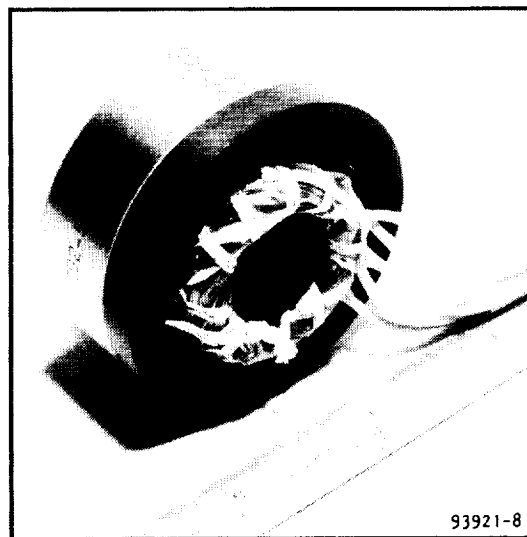
AiResearch has used this new toothless machine technology in several applications, including a cryocooler turboalternator, a turbocompressor, and an aircraft fuel pump, covering speed ranges up to 250,000 rpm and power ranges up to 33 kw. The power rating and speed requirement for this application (approximately 1.0 shp at 12,000 rpm), therefore, is well within the capabilities of this type of machine. A typical two-pole PM rotor assembly and a toothless-stator assembly are shown in Figure 7-6.

Commutation logic is derived without the use of a separate position sensor. Startup is accomplished by a controlled frequency ramp. When approximately 10 percent of maximum speed is achieved, the commutation logic is derived from the back emf at the machine terminals.

ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH



a. Two-Pole Rotor Assembly



b. Two-Pole Toothless-Stator Assembly

Figure 7-6. Motor Rotor and Stator Assemblies

### 7.1.3.2 Motor Controller

A 120-vdc motor controller can be used to provide drive power to the motor that is suitable for operation in a speed range of 2:1 at constant torque. It also provides starting torque with a suitable current limit. Figure 7-7 shows the operating range of the motor speed/torque relationship.

Figure 7-8 shows that the motor is started and stopped by an ON/OFF signal to the controller. The controller also performs the system safety protective shutdown of the motor and system upon receiving a discrete NO-GO signal from the system. This signal could be the logical sum of four different failure conditions.

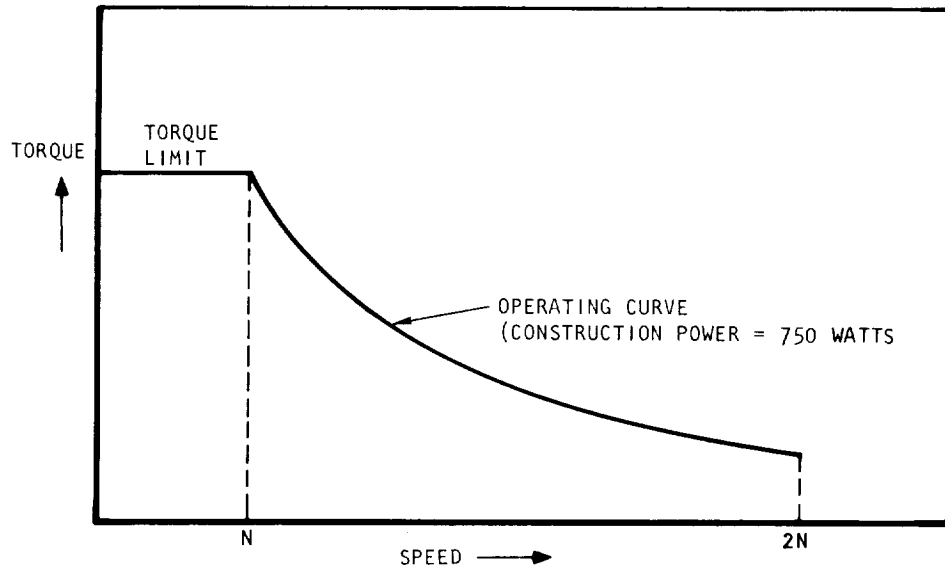
The brassboard control electronics is composed of three functional elements: the controls, the power amplifier, and the power supply.

#### 7.1.3.2.1 Controls

The control system has two nested loops: the speed loop and the current loop. The speed loop is shown in Figure 7-9. A ramp generator provides a speed command when it receives the ON signal. The low-wins circuit selects the lowest of the active speed limit inputs. The selected speed command is compared with the feedback from the motor speed sensor. The speed error signal is amplified and converted to current (or torque) command, which forms the input to the current loop shown in Figure 7-10.

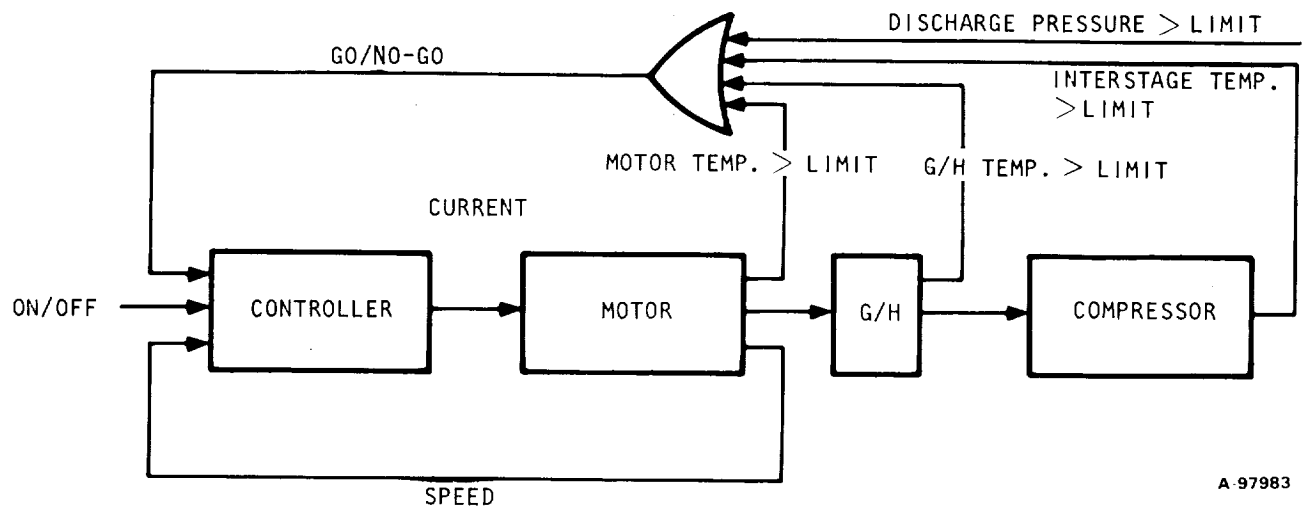
The power is limited by dividing the fixed desired power by the existing motor voltage, which is proportional to motor speed, and limiting the commanded current to a value less than the quotient. A fixed current limit is





A-97982-A

Figure 7-7. Motor Speed/Torque Relationship



A-97983

Figure 7-8. Motor Control Function

also generated based on the motor stall condition. A low-wins circuit selects the lowest active current limit. The selected current command is compared with the actual current, and the error signal is converted to an equivalent voltage that is fed into the pulsewidth modulator (PWM). As the error grows, the pulsewidth out of the PWM also grows. Thus, the subsequent drive voltage through the control logic and the power stage gets larger, sending more current to the motor and vice versa. The control logic controls the firing of the power stage in a logical sequence to turn the motor.

7.1.3.2.2 Power Amplifier

The power amplifier stage (Figure 7-11) resembles a full-wave bridge inverter, although it actually energizes only one phase of the motor at any

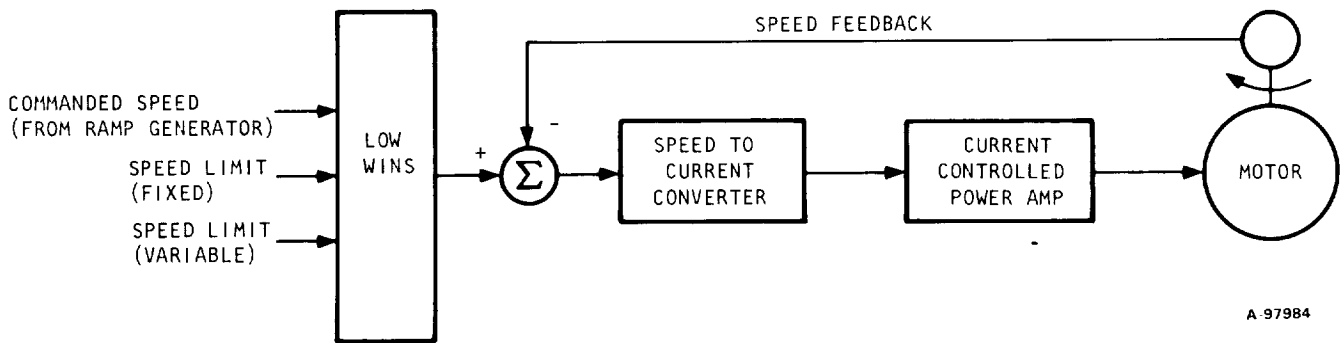


Figure 7-9. Motor Control System Speed Loop

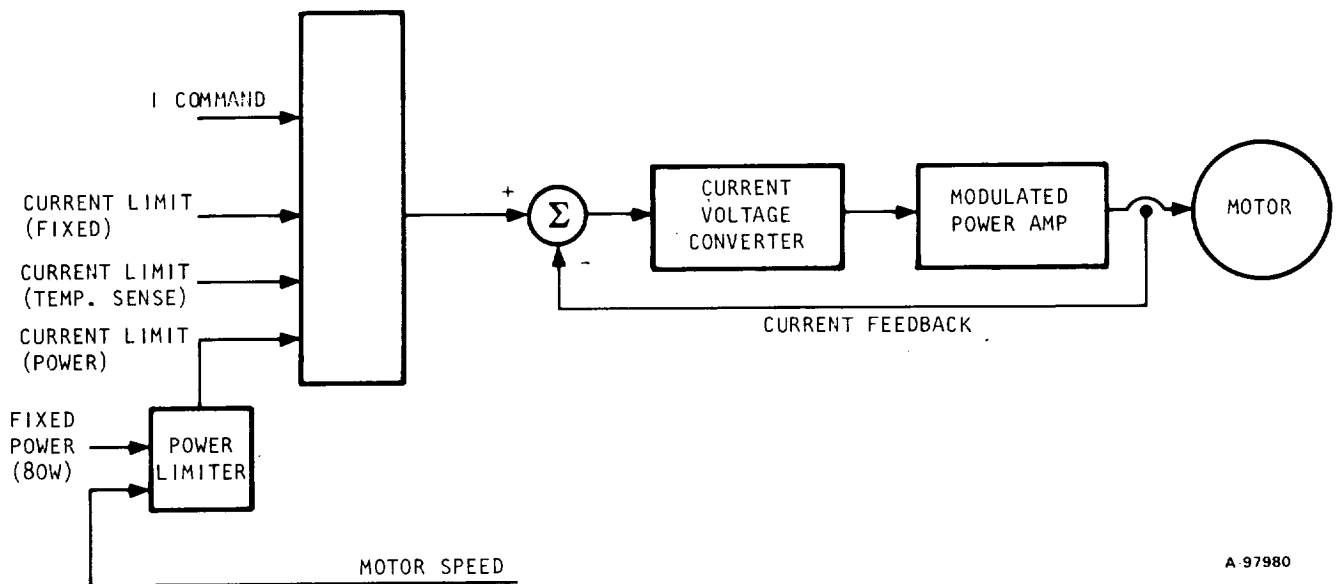


Figure 7-10. Motor Control System Current Loop

one instant. Each switching element of the bridge circuit performs high-frequency switching for the motor voltage and current control, as well as low-frequency switching for motor commutation. The power output to the motor can be cut off by inhibiting the power amplifier. This is accomplished by a low (logic 0) discrete signal to all the channels.

The power supply section of the electronics energizes the controller and the power amplifier.

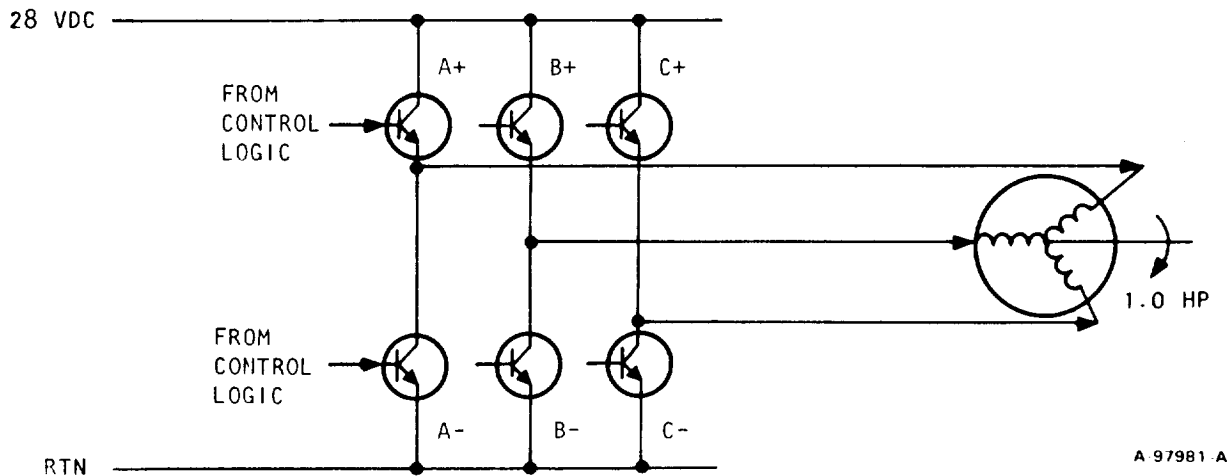


Figure 7-11. Motor Controller Power Amplifier

## 7.2 REVIEW OF AVAILABLE EQUIPMENT

The review of available equipment for the waste gas application focused on four possibilities:

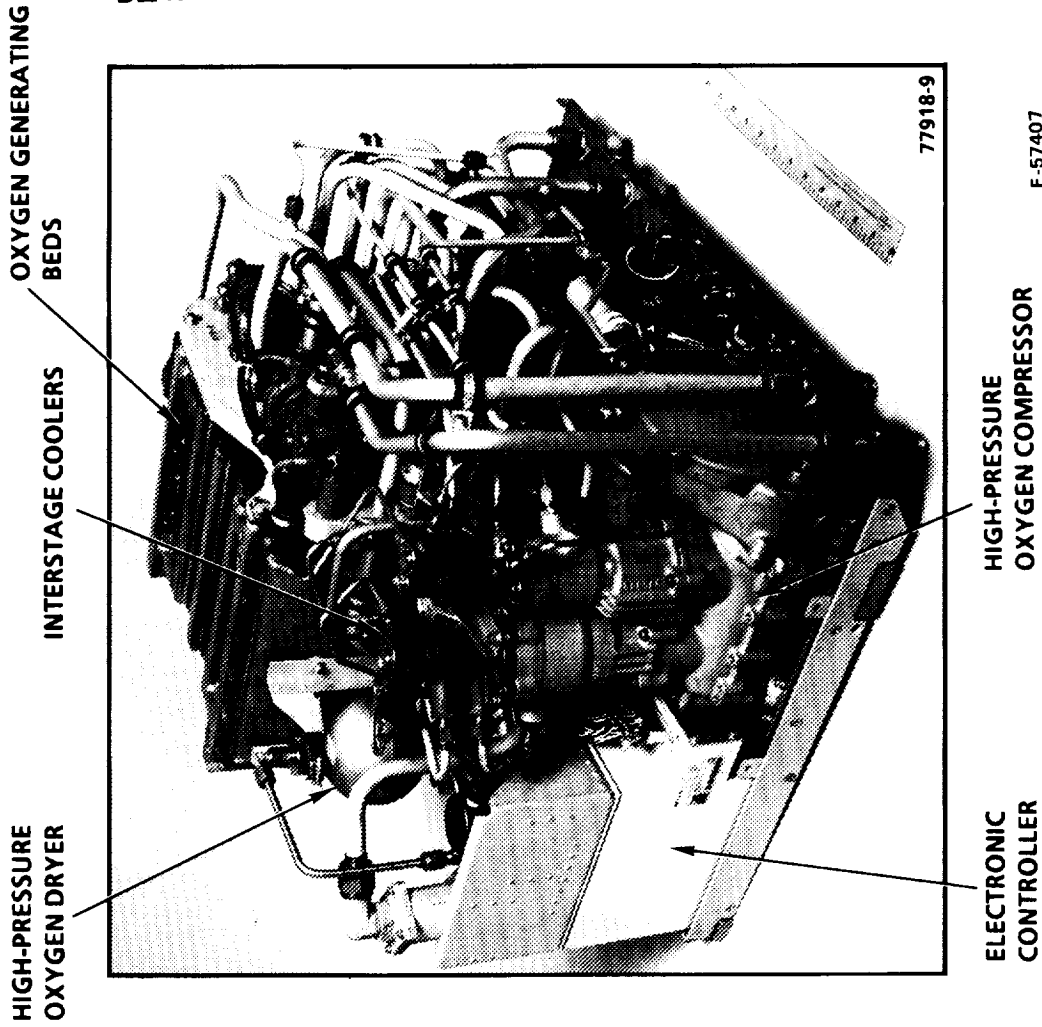
- (a) B1A OLOGS compressor
- (b) EA-6B NAOGS compressor
- (c) F101-106 closed cycle N<sub>2</sub> cryocompressor
- (d) Modifications to existing flight-proven designs

The type, performance, advantages, and disadvantages are illustrated in Figures 7-12 through 7-14. Modifications to these existing flight-proven designs are possible; however, it appears that a new design would be the more economical approach. This new compressor system design is discussed in the following paragraphs.

## 7.3 PRELIMINARY DESIGN

The design selected as the best for this application is a modular, two-stage diaphragm compressor that can be utilized in series or in parallel to achieve many combinations of overall pressure ratios and flow rates. The flexibility of a modular unit is desirable for the way many systems are still defined and for meeting the requirements of new systems that have emerged with the progression of Space Station design and construction. Each unit will have a common heat exchanger for the intercooler and aftercooler to reduce volume and weight. The aftercooler will increase densities of compressed gases, thereby reducing storage volume and reservoir weight. The aftercooler in each unit will also function as an intercooler when succeeding compressor units are used in series. A magnetic coupling isolates the compressor from the driving system and allows easy repair and interchanging of the driver system.

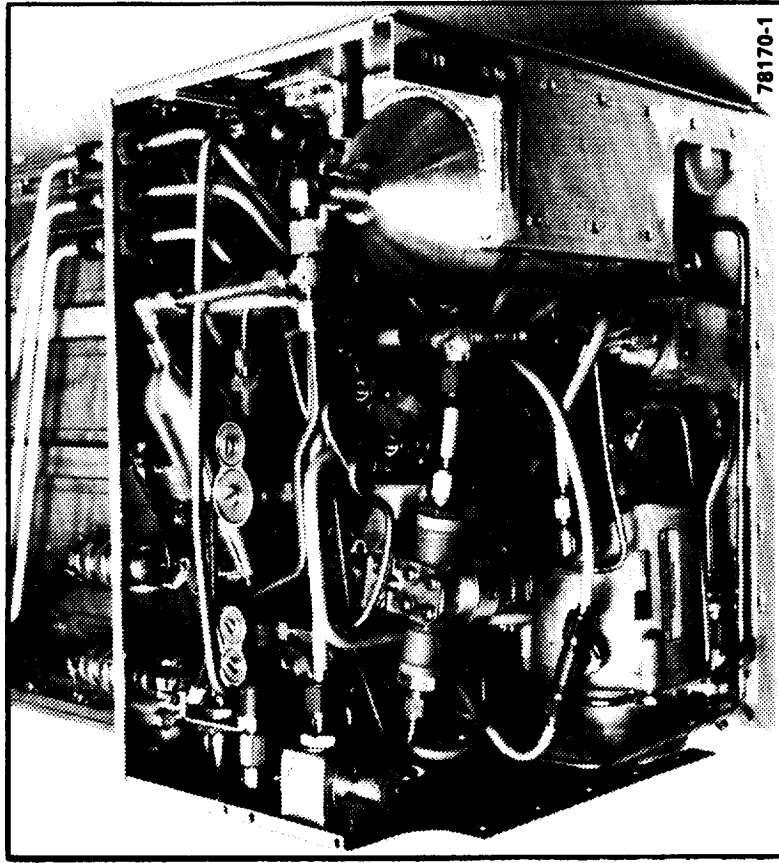
ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH



- TYPE
  - PISTON
  - 4 STAGES
- PERFORMANCE
  - 5.5 LB/HR
  - 8 PSIA INLET
  - 1800 PSIA OUTLET
- ADVANTAGES
  - QUALIFIED
  - MAN-RATED O<sub>2</sub> SYSTEM
  - FLIGHTWORTHY
- DISADVANTAGES
  - CAPACITY TOO LARGE
  - LIFE LIMITED (5K HR)

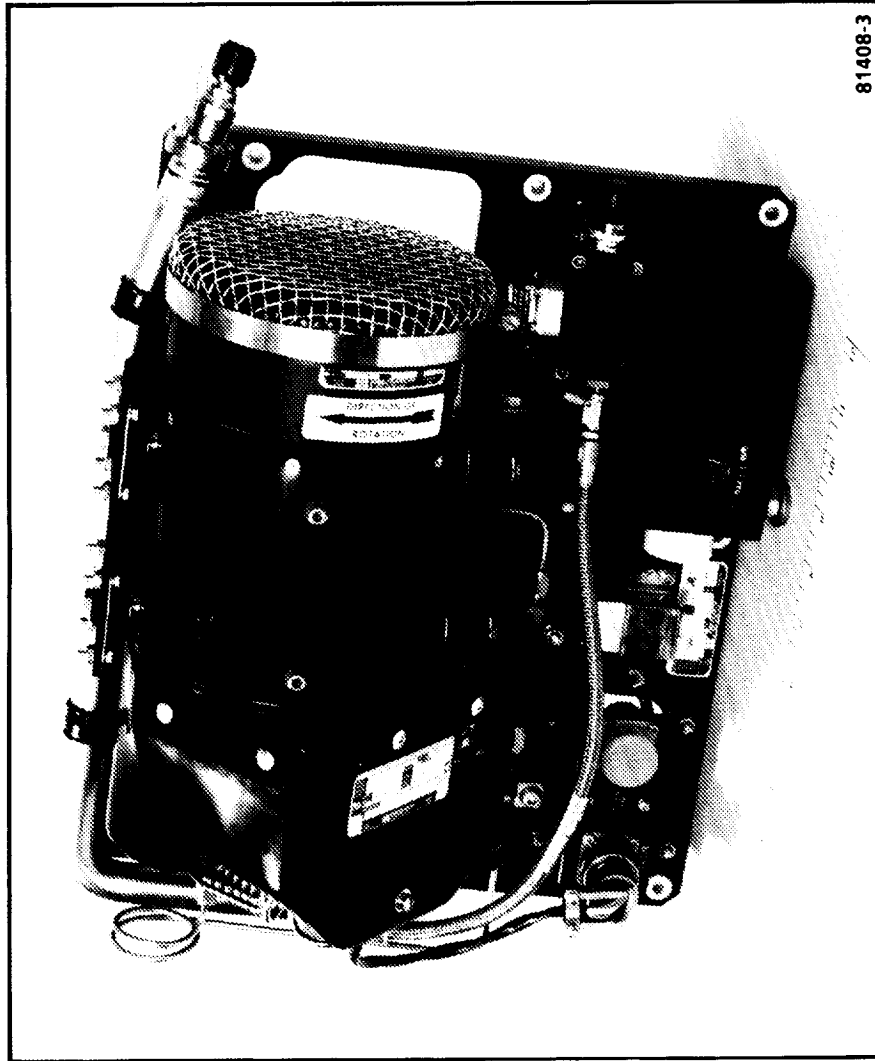
Figure 7-12. B1A 0L06S Compressor

ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH



- TYPE
  - DIAPHRAGM/BELLOWS
  - 3 STAGES
- PERFORMANCE
  - 5 LB/HR
  - 8 PSIA INLET
  - 1800 PSIA OUTLET
- ADVANTAGES
  - SEMIDEVELOPED
- DISADVANTAGES
  - REQUIRES IMPROVED DRIVE SYSTEM
  - LOW-PRESSURE BELLOWS STAGES
  - LIFE-LIMITED
  - CAPACITY TOO LARGE

Figure 7-13. EA-6B NAOGS Compressor



81408-3

- TYPE
  - PISTON
  - 3 STAGES
- PERFORMANCE
  - 0.9 LB/HR
  - 14.7 PSIA INLET
  - 1800 PSIA OUTLET
- ADVANTAGES
  - QUALIFIED FLIGHT UNIT
  - CURRENTLY IN PRODUCTION
- DISADVANTAGES
  - LIFE-LIMITED
  - NOT LUBE FREE

PRECEDING PAGE BLANK NOT FILMED

Figure 7-14. F101-106 Closed-Cycle N<sub>2</sub> Cryogenic Cooling System Compressor

F-57404  
WEG-07825

The diaphragm concept for the compressor was selected based on the infinite life of the membrane, no wear particles introduced downstream, and low flow rates required of the ECLSS and PMMS systems. Earlier tradeoff studies concluded that three- to four-stage compressors would be ideal for both the ECLSS (hydrogen gas) and PMMS (modular waste gas) systems (see Table 7-1). This was based upon the required inlet and outlet pressures for these two systems, which are closely related in overall pressure ratios. Using two modular two-stage compressor units in series will meet the requirements with conservative pressure ratios of less than 3:1 per stage for both systems. This allows for minor unexpected changes in problem requirements. Major changes would only affect the configuration of the modular compressor units in the system and not the individual unit.

The modular unit can operate at different frequencies and duty cycles to accommodate several systems within the Space Station environment. If a system requires that more than one modular unit is needed in series, then only frequency or duty cycles need to be adjusted for the succeeding series units to achieve efficiencies that are equal to the first unit. Corrosion-resistant materials allow many gases to be compressed by a single common unit.

### 7.3.1 Compressor Performance

Table 7-3 describes the performance profile of the recommended compressor design that is best suited for the H<sub>2</sub> and MWG application.

### 7.3.2 Schematic

Figure 7-15 contains a schematic of the recommended diaphragm compressor. The gas enters the first stage and accumulator at 135 psia. The rotary motion of the motor-driven cam, applied to the Condition 2 requirement in Table 7-3, actuates a hydraulic piston which forces the fluid to deflect the diaphragm to compress the gas up to a pressure of 403 psia. Uniform pressure on the diaphragm is obtained by area distribution of multiple ducts from the hydraulic cylinder. One-way check valves compensate fluid pressure differentials into the accumulators. The 350-psi compressed gas at the first-stage outlet is directed through an interstage gas cooler until reaching the second inlet stage. The second-stage diaphragm is actuated and pressure compensated by the same means as described for the first stage. The second-stage gas is compressed to 1200 psia outlet pressure.

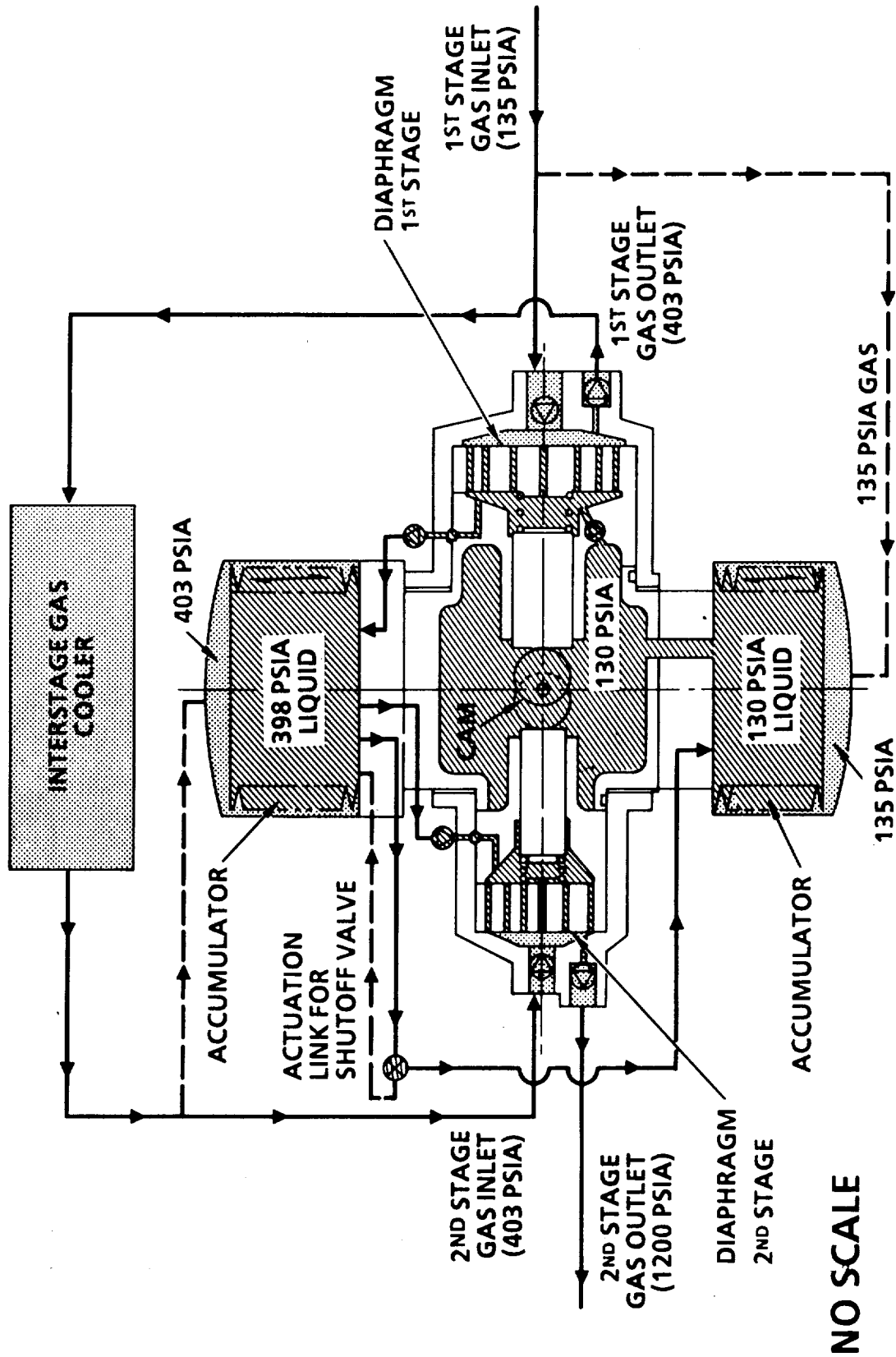
### 7.3.3 Conceptual Layout

Figure 7-16 represents a cross section of the conceptual compressor layout. The motor/gearbox drive system is connected via magnetic coupling to the compressor drive shaft. The magnetic coupling isolates the hydraulic fluid within the compressor housing from the gearbox. This concept enables easy removal of the motor/gearbox for maintenance. Note, however, that the motor itself can be removed easily from the gearbox if required. The unique arrangement of the oppositely located first- and second-stage diaphragms features force cancellations during the cam lifting process, resulting in low unit vibrations. The first- and second-stage accumulators are packaged side by side opposite to the motor/gearbox (see Figure 7-17). All ducting to and from the accumulators is integrated into the housing. The check valves are located in the head section of the diaphragm assemblies.

TABLE 7-3  
RECOMMENDED COMPRESSOR DESIGN

Type: Motor-driven two-stage diaphragm compressor	
Performance (H <sub>2</sub> )	Performance (MWG)
Condition 1	Condition 1
0.05 lb/hr	1.22 lb/hr
20 psia inlet	15 psia inlet
135 psia outlet	135 psia outlet
20-Hz frequency	25-Hz frequency
12 hr per day	12 hr per day
Condition 2	Condition 2
0.18 lb/hr	4.39 lb/hr
130 psia inlet	130 psia inlet
1200 psia outlet	1200 psia outlet
10-Hz frequency	10-Hz frequency
4.0 hr per day	3.3 hr per day
Advantages	
<ul style="list-style-type: none"> <li>● Common compressor for 4 applications</li> <li>● Design based on proven technology</li> <li>● Lowest development risk</li> </ul>	





B-16014-A

Figure 7-15. Diaphragm Compressor Schematic

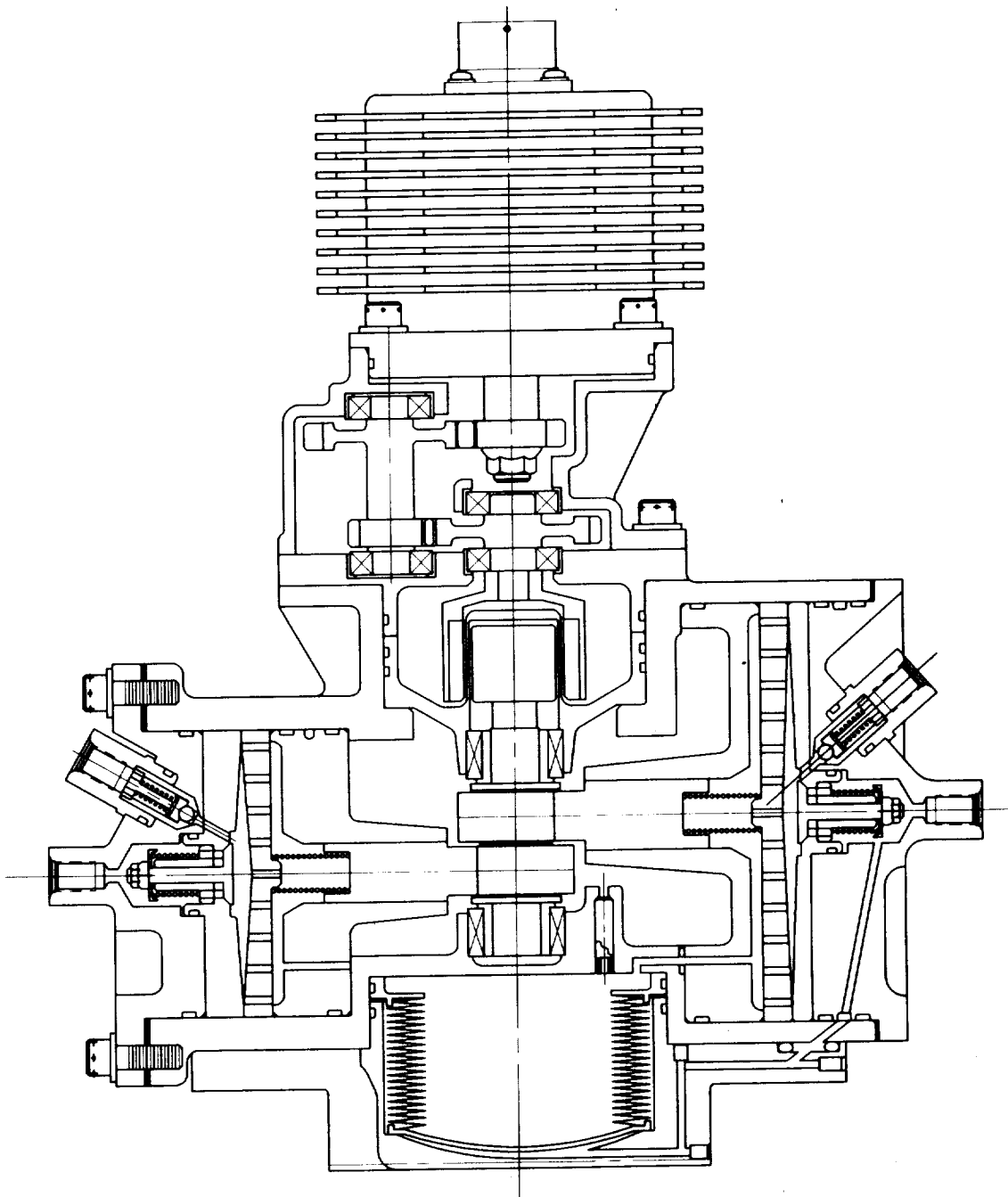
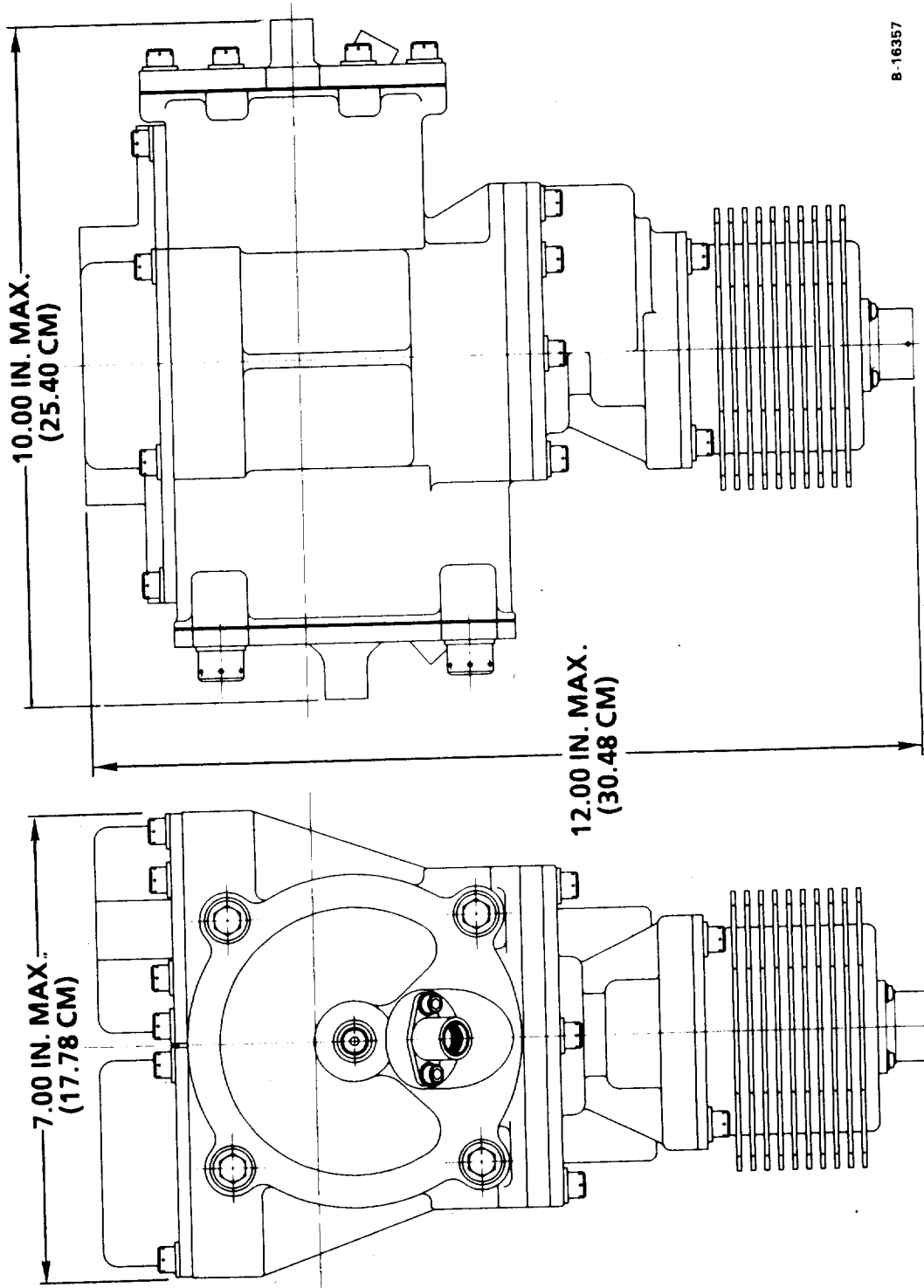


Figure 7-16. Compressor Conceptual Layout



B-16357

Figure 7-17. Compressor Outline

#### 7.3.4 Outline

Figure 7-17 outlines the compressor assembly maximum dimensions of 12 x 10 x 7 in., or 30.48 x 25.40 x 17.78 cm. The estimated weight is 16.80 lb, or 7.62 kg.

#### 7.3.5 Compressor Design Technology Base

The recommended compressor design is based on the technology listed in Table 7-4. As shown, all of the basic AiResearch design technology is based on existing and proven concepts.

##### 7.3.5.1 Valving Design

Design considerations such as leakage, temperatures, response, porting, and gas velocities must be taken into account for the valve components. AiResearch has had good experience in similar applications with a spring-loaded, lapped-poppet design for the inlet valves and with a spring-loaded, ball-check design for the outlet valves. Figure 7-18 shows a typical inlet/outlet valve set used on previous programs (OLOGS) for similar applications.

##### 7.3.5.2 Diaphragm Design

A preliminary analysis for the diaphragm component has been performed. The analysis highlights the following design criteria:

- Design considerations:
  - Select material with high endurance limit and corrosion resistance
  - Design for a low pressure differential, high d/t ratio, and maximum deflection for a given allowable stress
  - Design diaphragm and operating stroke frequency to avoid resonances and minimize vibration response
- Fatigue life:
  - Design for infinite life
  - Design for single direction deflection for increased fatigue strength
  - Select 17-4 PH stainless steel sheet or similar steel for high fatigue strength
- Stress analysis:
  - Stress analysis performed using finite element model (FEM) to determine stresses and deflections

TABLE 7-4  
COMPRESSOR DESIGN TECHNOLOGY BASE

Component	New	Modified	Existing	Similar to
1. Valving			X	OLOGS/NAOGS
2. Seals			X	OLOGS/NAOGS
3. Diaphragm		X		NAOGS
4. Materials			X	Various
5. Hydrodynamics		X		NAOGS
6. Cam/lifters		X		NAOGS/Various
7. Magnetic coupling			X	Various pumps
8. Gearbox			X	Various
9. Dc motor/controller			X	Various
10. Compressor design	X			OLOGS/NAOGS
11. Filter/dryer design		X		4EMS tech demo

- Effects of stress stiffening and large deflection included in diaphragm FEM

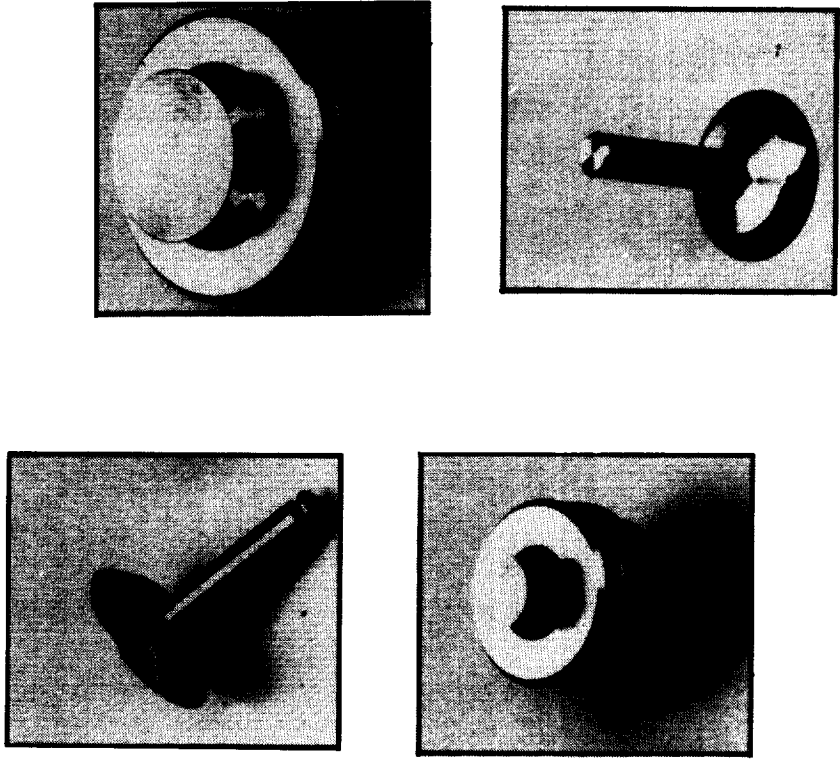
Figure 7-19 summarizes the stress results of a sample diaphragm analysis.

### 7.3.5.3 Magnetic Coupling Design

As mentioned in para. 7.3.3, Conceptual Layout, the use of a magnetic coupling hermetically seals and isolates the hydraulic fluid within the compressor housing from the drive system (motor/gearbox).

The magnetic coupling concept is shown schematically in Figure 7-20, along with a photograph of an existing unit developed at AiResearch for a similar application. The photograph at the top of Figure 7-20 shows a pump housing to the left with its shaft protruding to the right. The cylinder on the protruding shaft is an annular samarium cobalt magnet. This is the driven magnet. The piece in the center of the photograph is the bore seal. This nonmagnetic sleeve slips over the driven magnet and is bolted to the pump housing. The pump seal is, thus, a static flanged affair, sometimes with an

ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH



● DESIGN CONSIDERATIONS:

- LEAKAGE
- TEMPERATURES
- RESPONSE
- PORTING
- GAS VELOCITIES

● INLET VALVES:

- LAPPED-POPPET DESIGN
- SPRING LOADED

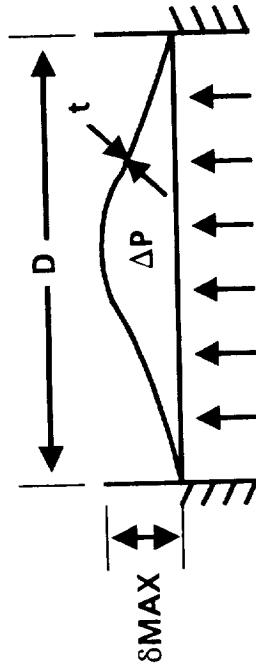
● OUTLET VALVES:

- BALL-CHECK DESIGN
- SPRING LOADED

Figure 7-18. Valving Design

- FOR  $\frac{t}{D} = .005$

D = 4.00 IN    t = .020 IN



PRESSURE DIFFERENTIAL ΔPSI	δMAX	MAXIMUM STRESS	
		@ CENTER, KSI	@ EDGE, KSI
12 PSI	.040	25	49
36 PSI	.060	54	107

**CONCLUSION**

- ABOVE F.E.A. RESULTS DIFFER SIGNIFICANTLY FROM SOLE USE OF CLASSICAL SMALL DEFLECTION THEORY.
- FOR 17-4 PH (STAINLESS STEEL); 120 KSI WAS USED AS THE ENDURANCE LIMIT.

**CHARACTERISTICS**

**MAGNET MATL: SAMARIUM COLBALT  
(27 MGO)**

**MULTI-POLE CONSTRUCTION**

**LOSSES:**

**EDDY AND WINDAGE: TYPICALLY 1-2%  
OF TRANSMITTED POWER**

**TORQUE:**

**PEAK TORQUE = 3 TIMES  
MAXIMUM OPERATING**

WEG-07835

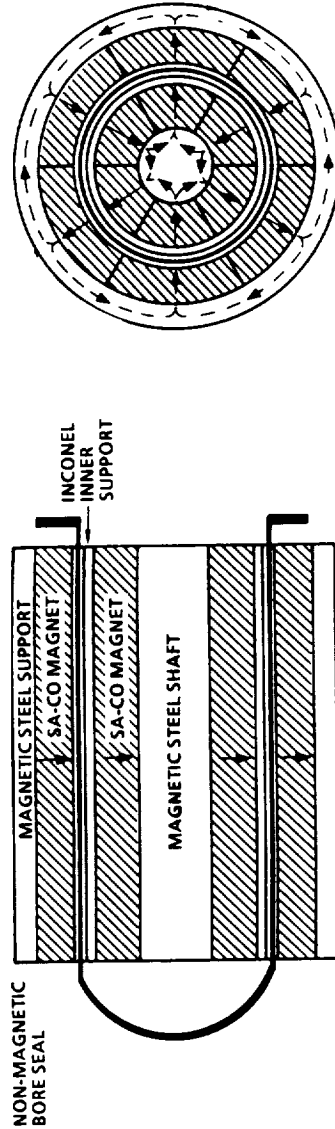
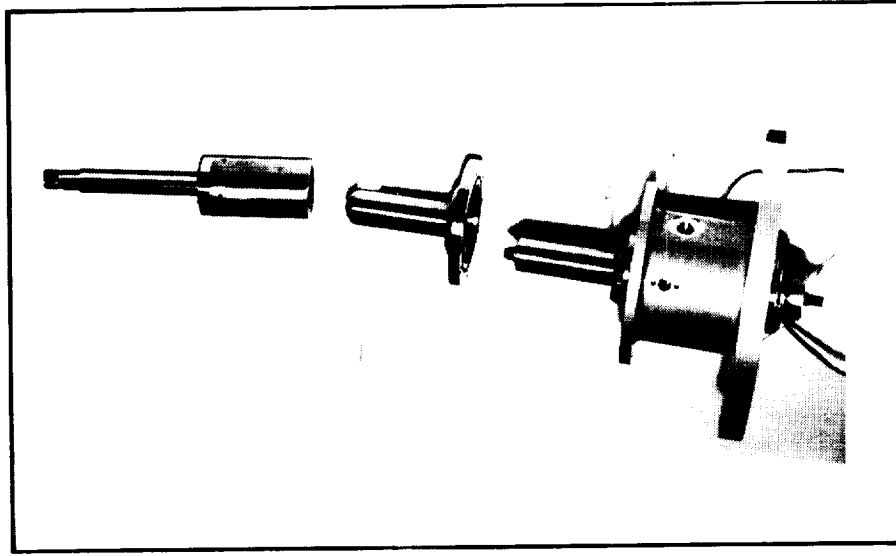


Figure 7-20. Magnetic Drive Coupling for Compressor



O-ring. The hydraulic fluid is contained inside this housing with no gaps or clearances to allow leaks. The member on the far right in the photograph is the driving magnet. It surrounds the bore seal and, as it rotates, draws the driven magnet along with it.

### 7.3.6 Filter/Dryer Design

As mentioned in para. 6, Filter/Dryer Requirements, the presence of trace contaminants and dust particles requires a contaminant/moisture sorbent filter to be located upstream of the compressor.

A design approach has been taken to consider two candidate filter systems: nonregenerative and regenerative. In terms of maintainability, the two systems compare in the following manner:

- Nonregenerative
  - 90-day replacement
  - Yearly replacement
- Regenerative (thermal purge)
  - Daily purge
  - Monthly purge

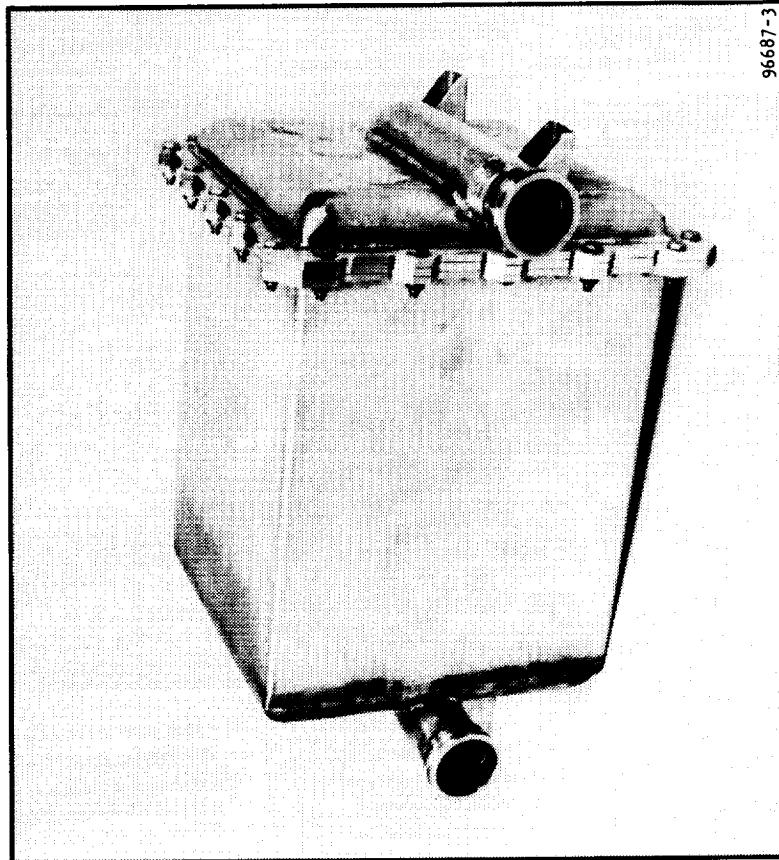
Figure 7-21 shows a nonregenerative dryer unit which has been used on a current carbon dioxide removal technology demonstration program. As indicated, the unit is capable of removing 27 lb/yr water vapor at 10.7 mm Hg, 90°F. The unit uses commercially available zeolite molecular sieve 13X. The filter cartridge requires annual replacement. The nonregenerative dryer unit is rather heavy since it requires approximately 200 lb of zeolite 13X.

The schematic shown in Figure 7-22 represents a regenerative dryer approach. The system is more complex than the nonregenerative unit, but features substantial weight savings.

## 7.4 RISK ASSESSMENT

The results of a risk assessment on the recommended compressor design in terms of life, vibration, power requirements, acoustics, performance, and maintainability are indicated in Table 7-5. As shown, the design concept falls into the low to moderate risk category for most of the key areas required. The only high-risk aspect is that of attaining long life in space. This risk can be minimized, however, by specifically scheduled maintenance for the life-limiting motor bearings at approximately once each 5 years.

- UTILIZES EXISTING TECHNOLOGY EMPLOYED ON CURRENT CARBON DIOXIDE REMOVAL "TECHNOLOGY" DEMONSTRATOR PROGRAM
- REMOVES 27 LB/YR WATER VAPOR AT 10.7 mm Hg AND 90°F
- REQUIRES REPLACEMENT/REGENERATION ONCE YEARLY
- USES COMMERCIALY AVAILABLE ZEOLITE MOLECULAR SIEVE 13X
- REQUIRES 200 LB 13 X



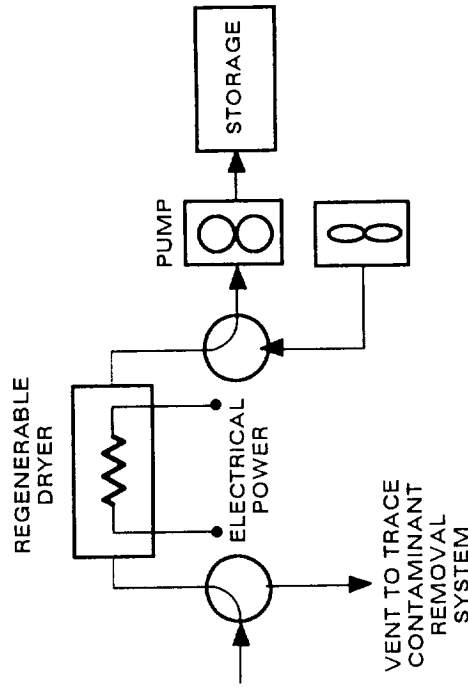
96687-3

WEG-07834\*

F-57157

Figure 7-21. Nonregenerative Dryer Approach

- UTILIZES EXISTING TECHNOLOGY
- REMOVES 30 LB/YR WATER VAPOR AT 10.7 mmHG AND 90°F (3 LB/YR EXTRA DUE TO PURGE)
- USE COMMERCIALY AVAILABLE ZEOLITE MOLECULAR SIEVE
- REGENERATE DURING COMPRESSOR DOWN-TIME USING IMBEDDED ELECTRICAL PLATE-FIN HEATER AND 10-% PURGE
- REQUIRES 0.8 LB 13X AND 1-LB CANISTER/HEATER CORE
  - TOTAL CANISTER ASSY. WT.: 1.8 LB
  - VALVE WT.: 8 LB
  - TOTAL SYSTEM WT.: 9.8 LB
- HEATER POWER CONSUMPTION: 20 W DURING 6-HR HEATUP/PURGE
- AFTER THERMAL REGENERATION 2-HR COOL-DOWN



IG-01093

Figure 7-22. Regenerative Dryer Approach

TABLE 7-5  
COMPRESSOR DESIGN RISK ASSESSMENT

Item	Low	Moderate	High
Life (reliability)			X
Vibration		X	
Power requirements	X		
Acoustics		X	
Performance		X	
Maintainability	X		

## 8. DESIGN SPECIFICATIONS

The scope of the design specifications is to establish the requirements for prototype compressor systems to be used for ECLSS and PMMS waste gas applications. The design specifications (see Appendix A) cover the following areas:

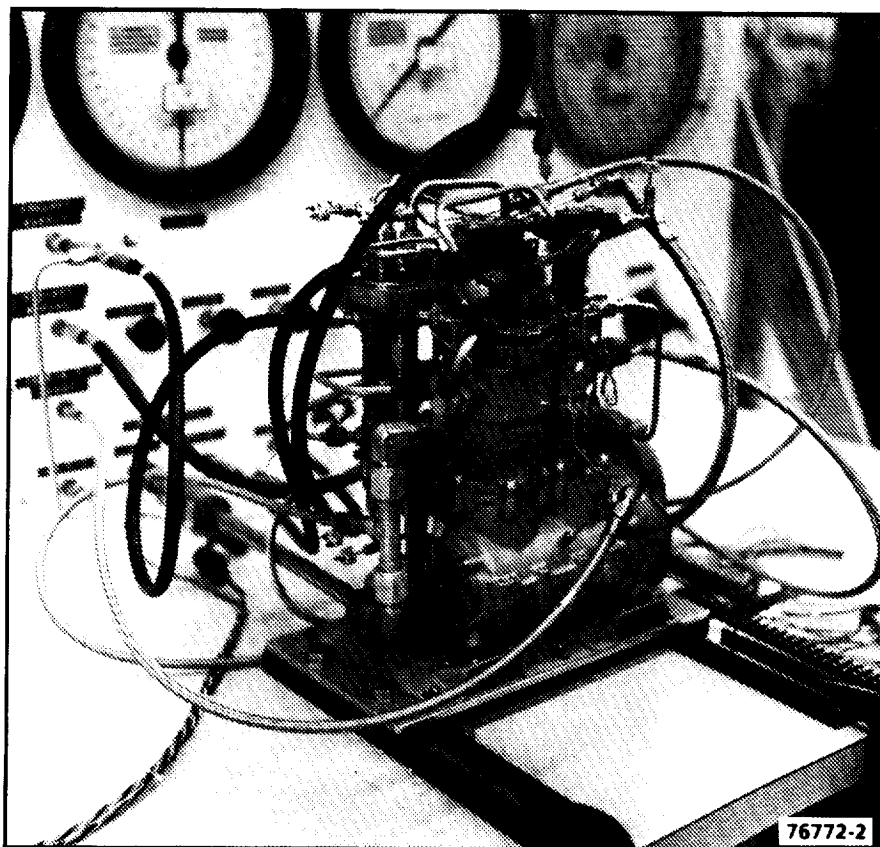
- Performance
- Duty cycle
- Life/reliability
- Environmental
- Power usage
- Weight/outline
- Thermal load
- Strength margins

ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH

9. TEST PLAN

Figure 9-1 shows a typical compressor unit (OLOGS) under test. The test plan (see Appendix B) covers the following areas:

- Component tests
  - Compressor
  - Dryer/filter
- System verification tests
  - Functional checkout
  - Performance evaluation
- Acceptance test



F-57406

Figure 9-1. OLOGS Compressor Unit Under Test

## 10. RECOMMENDATIONS

In summary, the basic contents of this final report were presented to NASA during Technical Coordination Meeting 3 at MSFC, Huntsville. The consensus of the participants was that there is an important need to develop the outlined compressor technology for the Space Station Freedom gas compressor.

As Phase I data have shown, the Space Station Freedom gas compressor requirements are unique, and no existing compressor designs are available for this application.

AiResearch recommends continuation of the proposed Phase 2 compressor design and development program to develop the necessary technology. Phase 2 would consist of the following three major tasks:

- Task I - System engineering and design
- Task II - Hardware development
- Task III - Test program

Task I, system engineering and design, is broken down into the following subtasks:

- Specification review
- Interface coordination
- Design analysis
  - Performance
  - Thermal
  - Stress/vibration
  - Materials and process
  - System interface
  - System performance
- Engineering drawings
  - Outline
  - Assembly, detail parts
- Reliability program
- Maintainability program
  - Serviceability
  - Support requirements

Task II, hardware development, will consist of the following activities:

(Two prototype units)

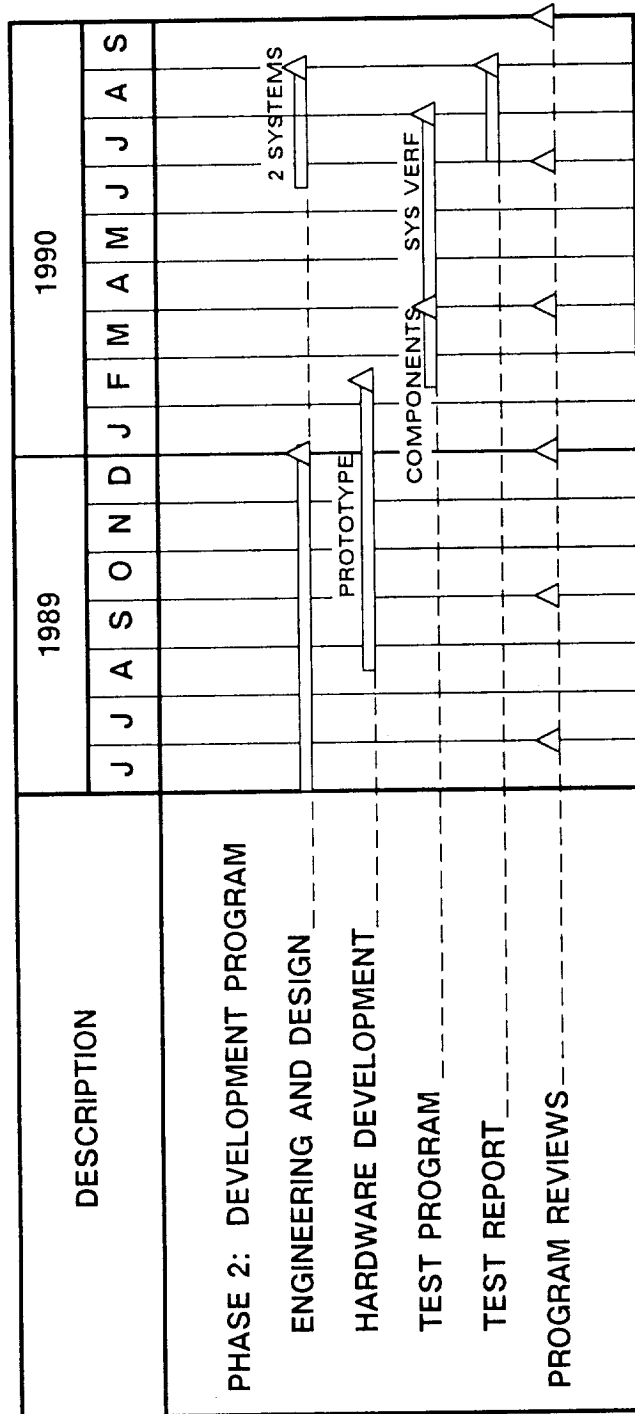
- Procurement planning
- Long-lead procurement
- Tooling
- Manufacturing
- Hardware delivery

Task III, test program, is categorized into the following subtasks:

- Test planning and procedures
- Special test equipment
  - Design
  - Mod, fab, or procurement
- Component test
  - Proof of concept
  - Performance verification
- System verification test
  - Functional
  - Performance
- Test result analysis
  - Performance
  - Data analysis
- Acceptance test

The timeframe for the major tasks of the Phase 2 development program is indicated in Figure 10-1, Phase 2 Development Program Schedule.





IG-01092

Figure 10-1. Phase 2 Development Program Schedule

APPENDIX A  
DESIGN SPECIFICATIONS

## A1. DESIGN SPECIFICATIONS

These specifications establish the requirements for the development, prototype fabrication, and limited testing (see Appendix B) of one waste gas compressor system for the environmental control and life support system (ECLSS) and one waste gas compressor system for the process materials management system (PMMS).

### A1.1 APPLICABLE DOCUMENTS

The following documents of the exact issue shown form a part of this specification to the extent specified herein. In the event of a conflict between the referenced documents and the contents of this specification, the contents of this specification shall take precedence.

Specifications and standards for the design and construction of the compressor shall be selected in the order of precedence in accordance with MIL-STD-143, except that NASA documents, when suitable for the purpose, shall take precedence.

#### A1.1.1 Specifications

- National Aeronautics and Space Administration

JSC-30213	Space Station Program Design Criteria and Practices
SSP-30233	Space Station Requirements for Materials and Processes
JSC-30482	Space Station Electrical Power Characteristics
JSC-30237	Space Station Electromagnetic Emission and Susceptibility
JSC-30482	Electrical Power Standard
JSC-20527	Space Station EVA User Interface Design Guidelines Document
JSC-30243	Space Station Specification, System Electromagnetic Compatibility Requirement
NASA Reference	Design Guide for High Pressure Oxygen Systems
Publication 1113	
NHB-1014 (Latest)	Outgassing Data, Compilation of Spacecraft Materials

NSTS-22206 Instructions for the Preparation of Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL)

SE-F-0044 (Latest) Filters, Wire Cloth Type

- Military

DOD H4-1 (Latest) Federal Supply Code of Manufacturers Name to Code

MIL-P-27407 Propellant, Pressurizing Agent Helium

#### A1.1.2 Standards

- Federal

FED-STD-209B (1) Clean Room and Work Station Requirements, Controlled

FED-STD-H28 Environment  
Screw Thread Standards for Federal Services

- Military

DOD-STD-100C Engineering Drawing Practices

MIL-STD-12D Abbreviations for Use on Drawings, Specifications, Standards, and in Technical Documents

MIL-STD-143B Standards and Specifications, Orders of Precedence for the Selection of

MIL-STD-889B Dissimilar Metals

- American National Standards Institute

ANSI Y14.5M-82 Dimensioning and Tolerancing

- Industry Standards

ASME PTC 8 Test Code for Displacement Compressors, Vacuum Pumps and Blowers

ASME PTC 19.8 Supplement on Instrumentation and Apparatus

## A2. TECHNICAL REQUIREMENTS

The scope of these technical requirements is the creation or adaptation of a prototype compressor system design and fabrication of prototype hardware applicable to the waste gas storage requirements of the ECLSS and PMMS systems. Each compressor system for the ECLSS and PMMS is comprised of the following units:

- (a) Low pressure compressor and drive system
- (b) High pressure compressor and drive system
- (c) Filter/dryer

Limited design evaluation testing (Appendix B) shall be performed on the fabricated ECLSS and PMMS prototype compressor systems. In addition to the specific requirements specified in paras. 2.1 and 2.2, the following shall be considered design objectives for this program.

- (a) Maximization of service life
- (b) Minimization of electric power usage
- (c) Minimization of maintenance
- (d) Materials compatibility
- (e) Physical interchangeability of common hardware assemblies where possible
- (f) Similarity or hardware design where physical interchangeability is not possible
- (g) Minimization of contaminants in the flow path
- (h) Method of unloading compressor before starting and stopping, if necessary
- (i) Minimization of compressor vibration
- (j) Minimization of motor torque oscillation

### A2.1 GENERAL DESIGN AND CONSTRUCTION

#### A2.1.1 Metals

All metals used for construction shall meet the requirements of this subparagraph. Metals shall be used that feature high fatigue strength, low friction coefficients where sliding fits are required. Depending on the application, the parts should be readily machineable and weldable.

#### A2.1.1.1 Surface Treatments

Surface treatments, protective coatings, or coatings required to reduce friction, shall not crack, chip, or scale with age or extremes in temperature.

#### A2.1.1.2 Surface Wear

Surfaces shall be sufficiently smooth where sliding fits are required. This is to preclude the generation of metal or seal particles in the fluid flow path. Where sliding or rolling fits are redundantly sealed from the primary fluid medium, the generation of particles shall be minimized.

#### A2.1.1.3 Dissimilar Metals

Dissimilar metals shall be in compliance with MIL-STD-889.

#### A2.1.2 Nonmetals

The use on nonmetallic parts shall not result in a corrosive effect on other materials when exposed to normal service conditions.

#### A2.1.2.1 Elastomeric Materials

Elastomeric seals may be utilized for static seal applications where the seal is in contact with the fluid medium. Materials selected must be compatible with the fluid media.

#### A2.1.3 Prohibited Materials

The following materials shall not be used:

- (a) Unalloyed, electrodeposited tin
- (b) Corrosive solder fluxes
- (c) Mercury or mercury compounds

#### A2.1.4 Material Compatibility

Materials and lubricants shall be suitable for use with the following gases at the temperatures and pressures prevailing during operation or storage:

- (a) Argon
- (b) Carbon dioxide
- (c) Helium
- (d) Hydrogen
- (e) Nitrogen

- (f) Oxygen
- (g) Xenon
- (h) Krypton
- (i) Trace contaminants (see para. A2.1.2)

#### A2.1.5 Workmanship

The Type I and Type II prototype compressor manufactured to this specification shall be constructed in accordance with the highest standards of aerospace manufacturing practice. All manufactured parts shall be smooth and free from fins, spurs, scales, burrs, and other defects detrimental to system performance.

#### A2.1.7 Maintainability

Minimization of maintenance requirements shall be a design goal. The compressor drive system (motor, gearbox, controller) shall be easily removable to allow replacements by suited EVA astronauts.

#### A2.1.8 Lubrication

The compressor design may employ the use of dry lubricants provided they comply with the following limitations:

- (a) Do not introduce contamination into the fluid flow path.
- (b) Are not destroyed and do not degrade when exposed to any combination of operating conditions.

#### A2.1.9 Compressor Heating and Cooling

The compressor design shall incorporate heating and cooling capabilities as required; however, power consumption shall be minimized. The fluid medium may be cooled by compressor jacketing, interstage cooling, and after-cooling as required. The cooling medium, if required, shall be controlled by an active closed-loop, self-contained system in which ammonia or other coolant may be employed.

#### A2.1.10 Motive Power

The compressor shall be driven by one or more rotary electric motors. The contractor shall determine the motor type based on compressor design, required speed, horsepower, control of motor speed, minimization of electric power usage, minimization of gearing, and soft motor start characteristics. Radiant cooling shall be used. Electrical insulation shall withstand a maximum temperature of 175°F.

### A2.1.11 Compressor Controls

The compressor shall provide automatic control of compressor capacity, gas temperature, and switching as a function of inlet and discharge pressures.

### A2.1.12 Fluid Media

#### A2.1.12.1 ECLSS Fluid Medium

The working fluid medium shall be a hydrogen gas mixture consisting of the following:

- (a) Hydrogen (H<sub>2</sub>) >84%
- (b) Freon (22,113) <2% (primarily cleaning solution vapors)
- (c) Trace oxidants <13% (or reacted oxidizers: H<sub>2</sub>O, etc.)
- (d) Trace inerts <0.1%
- (e) Trace contaminants <1.41% (Composition to be determined)

#### A2.1.12.2 PMMS Fluid Medium

The working fluid medium shall be a gas mixture consisting of the following:

- (a) Nitrogen (N<sub>2</sub>) >48%
- (b) Argon (Ar) >29%
- (c) Oxygen (O<sub>2</sub>) >8%
- (d) Carbon Dioxide (CO<sub>2</sub>) <5%
- (e) Helium (He) >1.0% (Could increase significantly with Space Station Freedom evolution)
- (f) Krypton (Kr) <1.3%
- (g) Xenon (Xe) <6%
- (h) Trace reductants <0.1% (or reacted reductants: H<sub>2</sub>O, etc)
- (i) Trace contaminants <1.41% (composition to be determined)

### A2.1.13 Leakage

External leakage of any fluid or particulate contaminant shall be zero. Leakage paths may be blocked by mechanical seals.



#### A2.1.14 Fluid Interfaces

The prototype compressor may interface with fluid lines by standard ports and fluid fittings.

#### A2.1.15 Filters

The compressor design shall incorporate an inlet filter of sufficient rating and capacity to protect the compressor from deterioration due to particle contamination.

#### A2.1.16 Dryers

The compressor design shall incorporate an inlet dryer of sufficient rating and capacity to protect the compressor from deterioration due to humidity contamination.

#### A2.1.17 Final Media Contamination Levels

Potential contaminants of the gaseous media are metal particles from wear of dynamic parts, non-metal particles from wear of dynamic parts such as seals, and fluids such as lubricants and outgassing. The following limits have been established for levels of contaminants downstream of the ECLSS and PMMS compressors and shall not be exceeded:

Compressor Application	Metallic	Non-Metallic	Fluid
ECLSS	10 PPM	100 PPM	100 PPM
PMMS	10 PPM	100 PPM	200 PPM

All contaminants and impurities in the flow path downstream of the compressors shall be inert or chemically non-reactive with the primary fluids in any operating combination of pressure and temperature.

#### A2.1.18 Electrical Power Availability

Space Station Freedom will have the following electrical power available: 120 vdc.

#### A2.1.19 Flight Environments (Reference Only)

#### A2.1.20 Assent/On-Orbit

- (a) Temperature: maximum 170°F, minimum -250°F
- (b) Pressure: maximum 15.23 psia, minimum  $1 \times 10^{-10}$  torr

(c) Shock transient: swept sinusoidal vibration imposed in the frequency range from 5 to 35 Hz at an acceleration amplitude of plus and minus 0.25 g peak.

(d) Random vibration:

Plus 6.0 dB/Octave from 20 to 60 Hz

Constant 0.3 g<sup>2</sup>/Hz from 60 to 400 Hz

Minus 9.0 dB/Octave from 400 to 2000 Hz

RMS g's = 12.86

Duration 18 minutes in each axis

(e) Acceleration: Plus or minus 5g in any direction

## A2.2 DESIGN AND FUNCTION

### A2.2.1 Shelf Life

The minimum non-operating shelf life shall be 10 years.

### A2.2.2 Service Life

#### A2.2.2.1 Operating Life

The minimum operating life shall be 10 years.

#### A2.2.2.2 Duty Cycle

The compressor units shall meet the following duty cycles:

ECLSS: 12 hr/day

PMMS: 12 hr/day

The above duty cycles represent the minimum daily operating time of the compressor.

## A2.3 STRENGTH MARGINS

The following minimum safety factors shall be used in addition to vibration amplification factors, casting factors, and other factors relating to stress:

(a) Proof pressure and yield factor of safety: 1.50

(b) Burst and ultimate factor of safety: 2.50

#### A2.4 CREEP STRAIN

The compressor design shall preclude cumulative creep strain leading to detrimental deformation during the operating life.

#### A2.5 OPERATING PRESSURES

	Inlet, psia	Discharge, psia
ECLSS: low pressure	20	100
high pressure	100	1200
PMMS: low pressure	15	100
high pressure	100	1200

#### A2.6 OPERATING TEMPERATURES

	Inlet, °F	Discharge, °F
ECLSS: low pressure	60 to 90	60 to 120
high pressure	70 to 120	60 to 120
PMMS: low pressure	60 to 90	60 to 140
high pressure	70 to 120	60 to 120

#### A2.7 OPERATING FLOW RATES

ECLSS: 0.05 LBM/hr (max.)

PMMS: 1.2 LBM/hr (max.)

The flow rates are based on a compressor operation of 12 hr per day.

#### A2.8 WEIGHT

Minimum weight shall be a design objective. The total weight of the ECLSS or PMMS compressor system shall not exceed 60 lb.

#### A2.9 ENVELOPE

Minimum envelope volume shall be a design objective. The maximum envelope shall be 2 cu ft.

#### A1.10 POWER USAGE

ECLSS: 300 w (max.)

PMMS: 350 w (max.)

APPENDIX B  
COMPRESSOR TEST PROGRAM DESCRIPTION

## B1. TEST PROGRAM

The test program will consist of two major test categories: component and system verification. Figure B-1 shows the basic subtasks for the component and system verification tests. The overall test plan is designed to provide hardware delivery that satisfies the requirements while minimizing costs. This will be accomplished by establishing practical guidelines throughout all test phases, by keeping the hardware configuration and test procedural controls commensurate with the specific tasks, and by eliminating any costly test duplication. The proposed approach will provide the high degree of confidence required to demonstrate the capabilities of the system under test to handle all the waste gases identified.

## B2. FACILITY REQUIREMENTS

AiResearch has complete assembly and laboratory facilities on site to support the gas compressor technology study (GCTS) program. Special cleanroom assembly areas feature the latest equipment for ultraclean handling, leak detection, final processing, and assembly. Precision tooling and inspection facilities contribute to product quality.

The GCTS will be tested in the environmental and aerospace systems laboratory (Figure B-2). This 8500-sq-ft laboratory is a versatile facility providing support for the development, qualification, and acceptance testing of a vast range of aerospace components and systems. The OLOGS, NAOGS, and all spacecraft environmental control systems were tested in this laboratory. Capabilities include: altitude simulation, high-pressure gas, cleanrooms, helium leak check, and cryogenic handling.

Of special interest to the GCTS program is the laboratory high-pressure test facility. The high-pressure test facility provides the pneumatic and hydrostatic pressurization systems required to perform manufacturing and functional tests on components and subsystems in a cleanroom environment. The facility pneumatic/hydrostatic pressurization sources are located inside an enclosed concrete-block patio outside the test area. Two Westinghouse down-flow test benches (Figure B-3a) are located within a safety enclosure in the high-pressure test room. These benches are rated Class 100,000 in cleanliness level and permit testing in a cleanroom environment. An open-ended cylindrical test well (Figure B-3b) located in the downflow test bench is used for high-pressure oxygen and nitrogen test parts. A control console (Figure B-3c), located outside of the safety enclosure, controls specimen pressures and also provides controls and monitoring for all pressure sources from the equipment patio. Hydrostatic testing is accomplished in a pit, with the control console also controlling and monitoring hydrostatic pressure.

## B3. SPECIAL TEST EQUIPMENT

The proposed testing will be conducted in the environmental and aerospace systems laboratory as described in Section 1.7, Facility Requirements. Figure B-4 shows a typical compressor test setup similar to the proposed application. The test setup shown in Figures B-5 was used for the open loop oxygen generating system (OLOGS). Figure B-6 indicates the elaborate test panel for the unit under test. The dryer test setup shown in Figure B-7 was used on the AiResearch molecular sieve carbon dioxide removal system technology demonstrator program.

# PHASE II; PART C, DEVELOPMENT TESTING

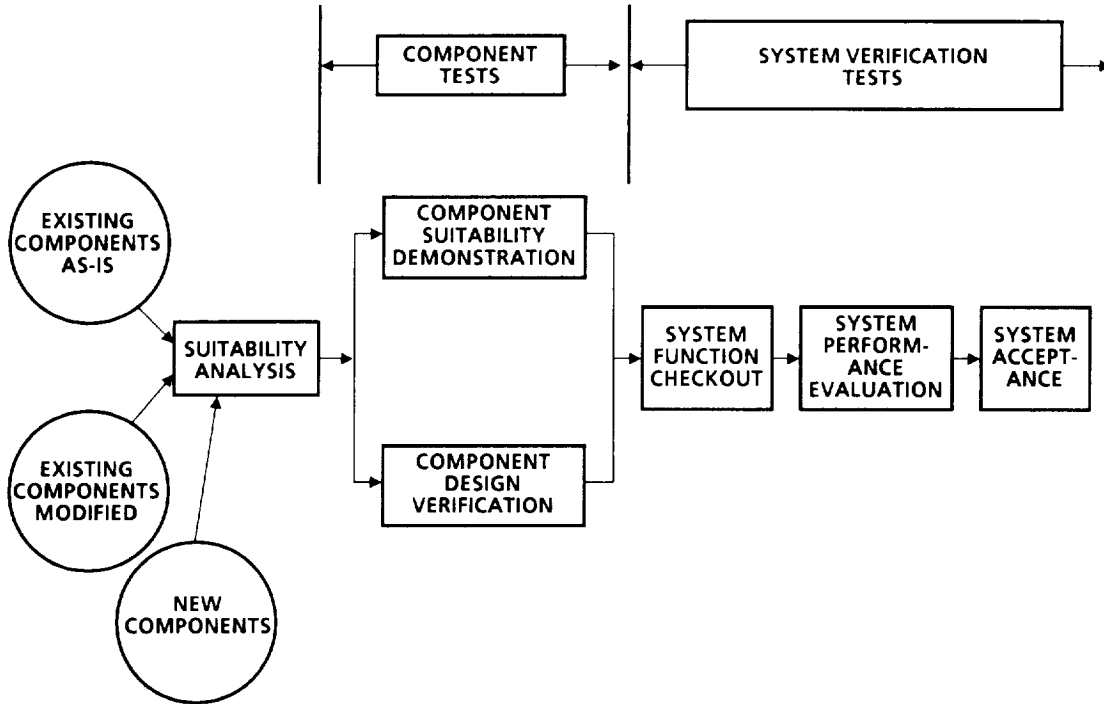
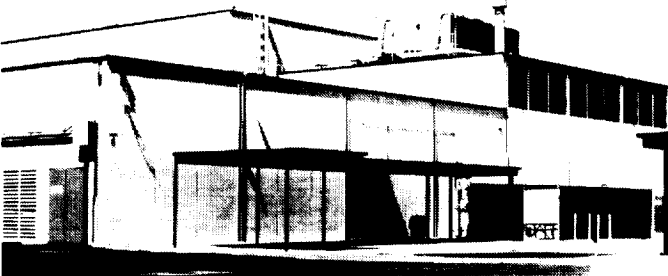


Figure B-1. Proposed Component and System Verification Test Program

### ENVIRONMENTAL AND AEROSPACE SYSTEMS LABORATORY



- SUPERCONDUCTING SYSTEMS DEVELOPMENT
- OXYGEN GENERATING SYSTEMS TEST
- HIGH ALTITUDE SIMULATION
- SPACE SIMULATION
- HIGH PRESSURE TEST ROOM
- LIQUID AND GASEOUS NITROGEN, GASEOUS OXYGEN (TO 10,000 PSIG), AND HIGH PURITY WATER SUPPLY CAPABILITIES

F-51138

F-57002

Figure B-2. Environmental and Aerospace Systems Laboratory

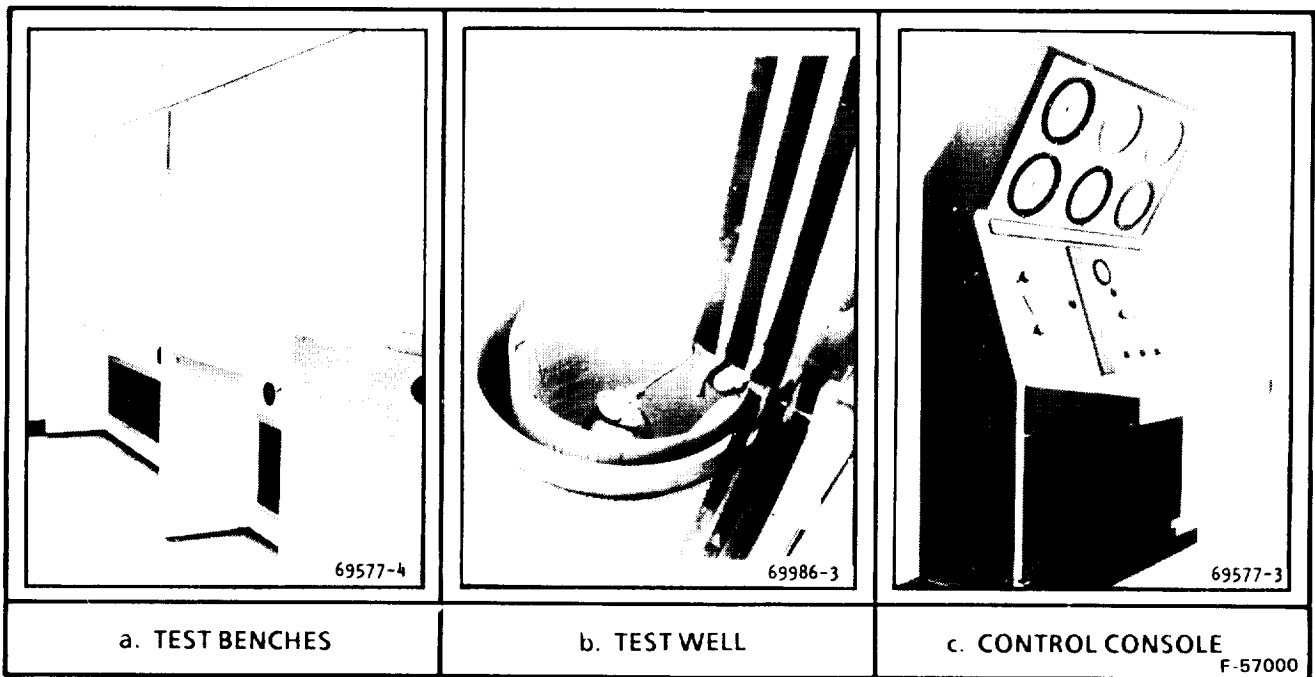


Figure B-3. High-Pressure Test Facility

The following equipment and instrumentation will be used:

- Upstream filter, 10 microns
- Inlet accumulator, 215 IN3 or equivalent
- Outlet accumulator, 214 IN3 or equivalent
- Gas supply
- Gas analyzer
- Power supply, 120 vdc
- Compressor intercooler supply
- Check valves
- Outlet pressure relief valve, 1200 psi
- Vent valves

ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH

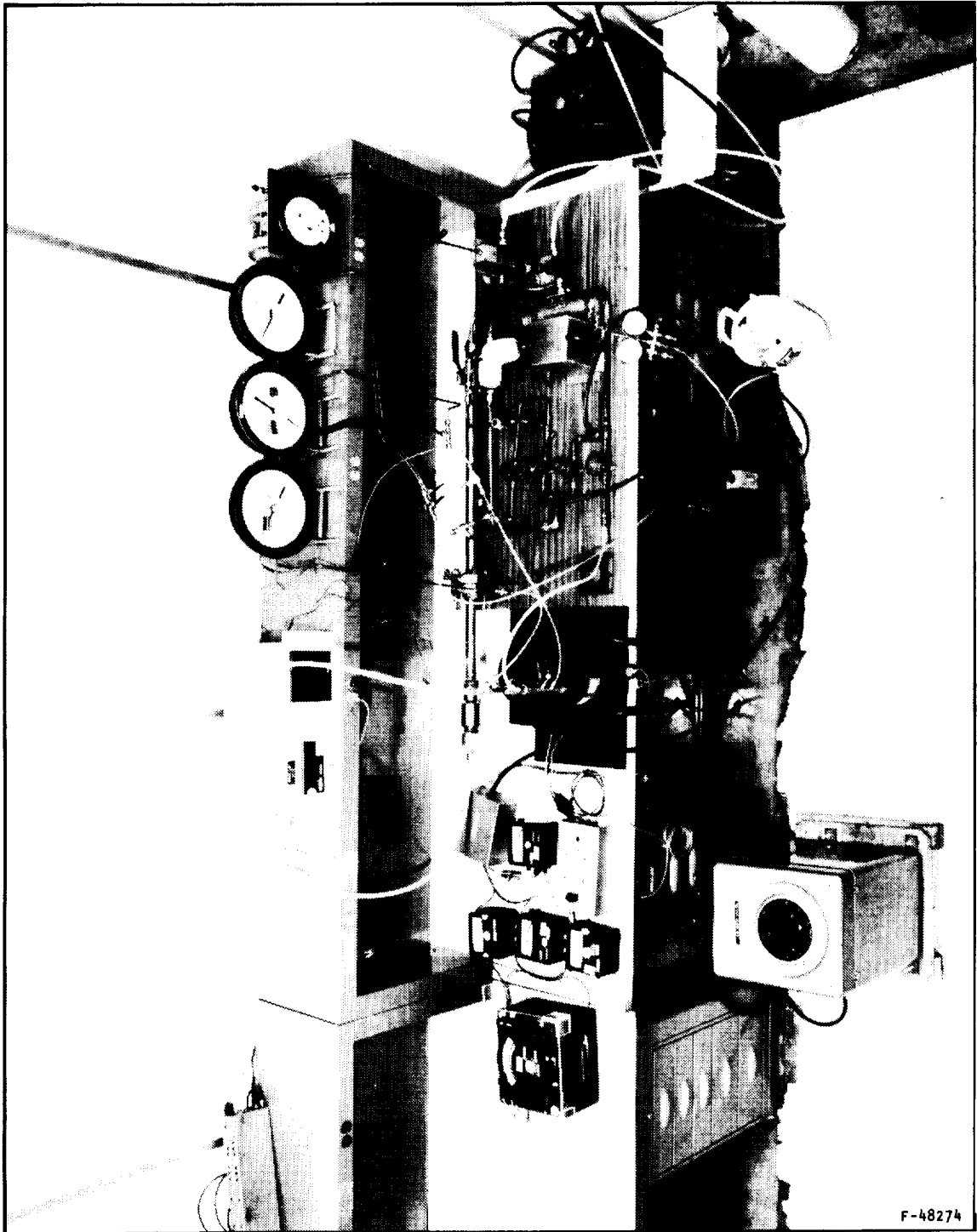
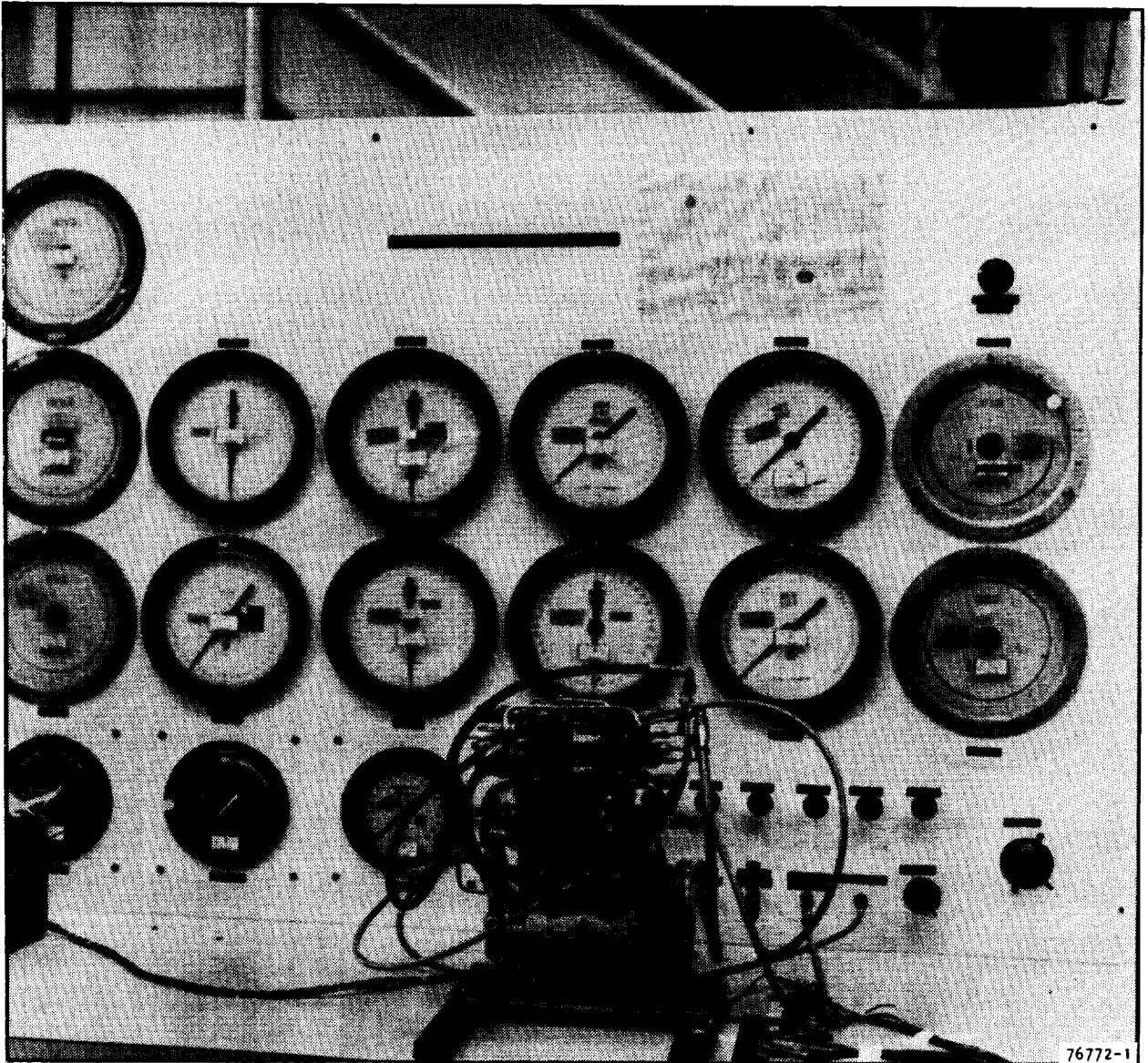


Figure B-4. Compressor Test Setup

F-48274

F-57005



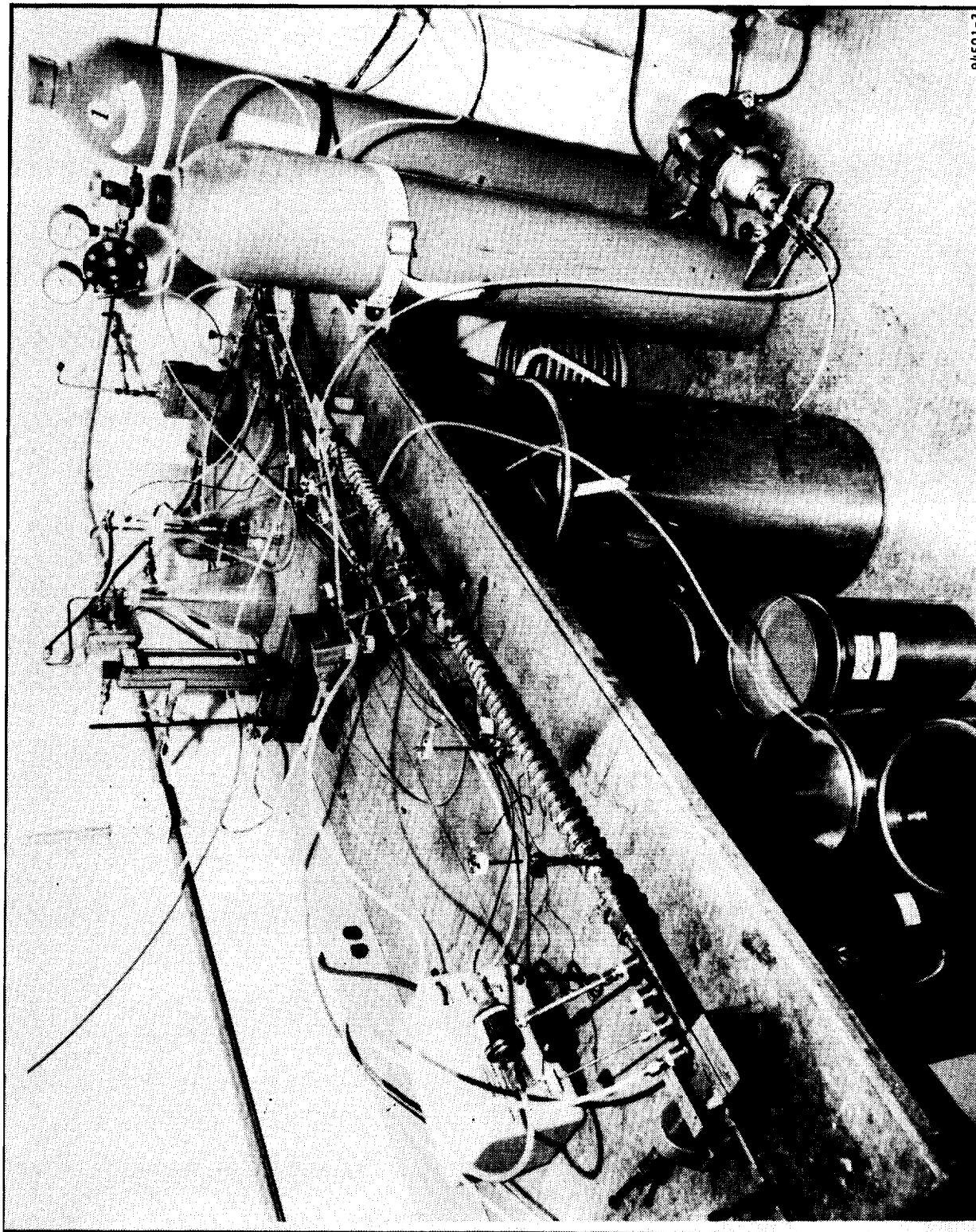


76772-1

F-57001

Figure B-5. OLOGS Compressor Test Panel

ORIGINAL PAGE  
BLACK AND WHITE PHOTOGRAPH



94501-3

F-57003

Figure B-6. Dryer Test Setup

- Inlet pressure relief valve, 100 psi
- Sequencing valves
- Flow meters
- Pressure gages
- Thermocouple readouts
- Speed counter
- Voltmeter, 0 to 200 vdc
- Ammeter
- Dewpoint hydrometer (panametrics)
- Humidity temperature control
- Heat input supply
- H<sub>2</sub>O supply

#### B4. TESTS TO BE PERFORMED

The major tests to be performed will consist of component and system verification testing.

##### B4.1 COMPONENT TEST

The objective of component testing is to verify the performance of the critical compressor units, dryers/filters, and sequencing valves prior to integrating them into the system. These tests will act as acceptance tests for each component and will verify performance at the component level prior to the start of system-level testing.

AiResearch proposes that these tests be conducted using one of the defined waste gases such as helium for the test medium. Each component will be tested to the maximum limits of performance defined by its system requirements.

##### B4.1.1 Compressor Test

The compressor testing will consist of the following major test categories:

- (a) Pretest examination
- (b) Static leakage tests
- (c) Compressor break-in

(d) Development tests

- (1) Capacity
- (2) Power consumption and efficiency
- (3) Pressure pulsations
- (4) Life test

(e) Posttest examination

The compressor test setup is illustrated in Figure B-8. The diagram shows the unit under test with the required support equipment and instrumentation. The proposed component testing will follow the following test sequence.

B4.1.1.1 Pretest Examination

Each unit to be tested shall be subjected to a thorough pretest examination specified in the customer-approved acceptance test document.

The following guidelines shall apply:

B4.1.1.1.1 Test Methods

The test methods include all applicable methods specified in the following ASME performance test codes except as indicated herein:

- (a) PTC9 test code for displacement compressors, vacuum pumps, and blowers
- (b) PTC19.8 supplement on instruments and apparatus  
Part 8 measurement of indicated power

B4.1.1.1.2 Cleanliness of Unit Under Test and Test Equipment

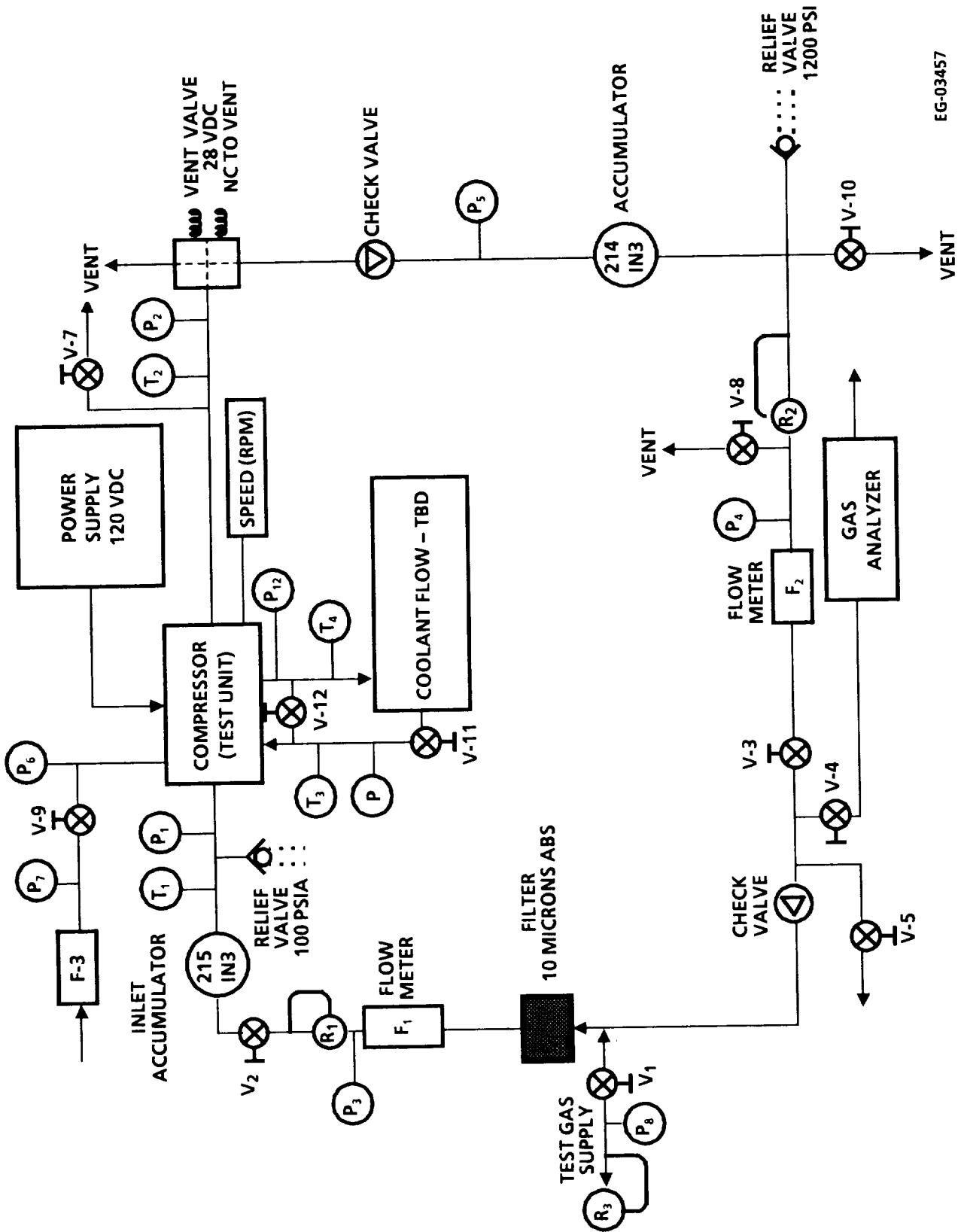
All test hardware that will be used in the test setup shown in Figure B-8 shall be cleaned internally prior to installation of the unit under test.

Figure B-7 shows a 10-micron upstream filter. All flow passages downstream of the filter shall meet the 400A cleanliness level prior to the start of tests. Before operating the compressor, the supply gas shall be tested for freedom of condensate.

Provisions will be made for blowing lines prior to operation of the compressor. When not in use and during temporary or overnight storage, the compressor shall be charged with a blanket pressure of 5 to 10 psig and all open ports sealed.

B4.1.1.1.3 Test Equipment Calibration

All test measurements shall be made using instruments calibrated against standards traceable to the National Bureau of Standards. Each test instrument



EG-03457

Figure B-7. Test Setup Diagram

shall bear a certification decal indicating current calibration by the AiResearch Metrology Laboratory. The calibration of the instruments shall be valid over the period of each test.

#### B4.1.1.1.4 Test Tolerances

The maximum allowable tolerances shall be:

- (a) Temperature:  $\pm 5.0^{\circ}\text{F}$
- (b) Pressure:  $\pm 0.5$  percent
- (c) Flow:  $\pm 5.0$  percent
- (d) Speed:  $\pm 0.5$  percent
- (e) Time: The smaller of  $\pm 1.0$  percent or  $\pm 1.0$  min

#### B4.1.1.1.5 Ambient Conditions

The tests shall be performed at the following laboratory ambient conditions:

- (a) Temperature  $75 \pm 15^{\circ}\text{F}$
- (b) Relative humidity: 90 percent maximum
- (c) Barometric pressure:  $30.2 \pm 1.5$  in Hg abs

#### B4.1.1.1.6 Test Medium

The test medium shall be helium, in accordance with MIL-P-27407.

#### B4.1.1.1.7 Adjustments and Repair

No adjustments or repairs shall be allowed during acceptance tests except such adjustments or repairs that are not caused by faults in design, material, workmanship, or obviously are not caused by the imposed test conditions.

#### B4.1.1.2 Static Leakage Tests

The following tests shall apply to each compressor stage, both high pressure and low pressure.

##### B4.1.1.2.1 Inlet-Pressurized Test

The test medium (helium) shall be measured across the piston and diaphragm seals and closed inlet valve seals under the following conditions:

- (a) Pressure: Nominal design inlet, each stage
- (b) Temperature: Ambient room

#### B4.1.1.2.2 Discharge-Pressurized Test

The test medium (helium) shall be measured across the piston and diaphragm seals and closed discharge valve seals under the following conditions:

- (a) Pressures: 10 percent of nominal design discharge, each stage  
50 percent of nominal design discharge, each stage  
100 percent of nominal design discharge, each stage
- (b) Temperature: Ambient room

#### B4.1.1.3 Compressor Break-In

The compressor shall be subjected to a break-in procedure prior to operation. The following steps shall be taken:

- (a) Directional check
- (b) Minimum inlet/discharge loading for 30 min
- (c) Incremental load increase
- (d) Full load operation for 4 hr
- (e) Flow path cleaning
- (f) Spectrographic analysis of a clean discharge sample

#### B4.1.1.4 Capacity

The compressor capacity shall be measured as a function of speed and inlet pressure in accordance with ASME test codes.

#### B4.1.1.5 Power Consumption and Efficiency

The overall electrical power consumption of the compressor in terms of nominal and worst-case conditions shall be measured as a function of speed, inlet temperature, capacity, inlet pressure, and discharge pressure in accordance with ASME test codes.

#### B4.1.1.6 Pressure Pulsations

The compressor inlet and discharge pressure pulsations shall be recorded with sufficient resolution to determine frequencies and amplitudes.

#### B4.1.1.7 Life Test

The life test covers continuous and start/stop operations.

#### B4.1.1.7.1 Continuous Operation Test

The continuous operation test shall consist of 1000  $\pm$ 10 hr of continuous high- and low-pressure operations with the specified inlet conditions of the unit under test.

The following minimum functions shall be recorded from all stages at 1-hr intervals:

- (a) Inlet pressure, psia
- (b) Outlet pressure, psia
- (c) Inlet temperature, °F
- (d) Outlet temperature, °F
- (e) Motor or shaft speed, rpm
- (f) Electric power dissipation, w

#### B4.1.1.7.2 Start/Stop Cycle Test

The start/stop cycle test shall consist of 3000 minimum start/stop cycles at 1.0  $\pm$ 0.5 min per cycle. Each cycle shall consist of one start and one stop operation with approximately equal on and off times.

#### B4.1.1.8 Posttest Examination

After completion of all testing, the unit under test shall be subjected to inspection in accordance with the customer-approved acceptance test procedure. For a development unit under test, however, a spectrographic analysis of the discharge sample constituents shall be performed and reported after completion of all tests. Furthermore, the development compressor shall be disassembled and inspected for wear and other degradation.

#### B4.1.2 Dryer/Filter Test

The dryer/filter testing will consist of the following major test categories:

- (a) Pretest examination
- (b) Static leakage test
- (c) Development tests
  - (1) Dryer performance
  - (2) Filter performance
  - (3) Life test
- (d) Posttest examination



The proposed component testing for the dryer/filter unit shall follow the following test sequence.

#### B4.1.2.1 Pretest Examination

Each unit to be tested shall be subjected to a thorough pretest examination specified in the customer-approved acceptance test document.

#### B4.1.2.2 Static Leakage Test

The dryer/filter assembly shall be pressurized to its design point with the test medium (helium) and measured for inlet/outlet-to-case leakage.

#### B4.1.2.3 Dryer Performance

The dryer unit shall be subjected to a humidity test (water vapor) to verify the design point of adsorption/desorption capability.

#### B4.1.2.4 Filter Performance

The filter unit shall be subjected to a particular test from (TBD by NASA) to 10-micron particle size.

#### B4.1.2.5 Life Test

The life test shall consist of 1000  $\pm$ 10 hr of continuous operation with the specified inlet conditions.

#### B4.1.2.6 Posttest Examination

The dryer/filter assembly shall be inspected after completion of all testing in accordance with the customer-approved acceptance test procedure.

#### B4.1.3 Sequencing Valve Test

All sequencing valves used in the system shall be subjected to a functional test consisting of open/close operations.

### B4.2 SYSTEM VERIFICATION TESTING

The objective of system verification testing is to confirm specified performance of the critical compressor units, dryer/filter assembly, and sequencing valves under system operation with the identified waste gases. The test program is divided into the following three phases:

- (a) System functional checkout
- (b) System performance evaluation
- (c) System acceptance

Each of the above phases shall be conducted to NASA preapproved test procedures. Following each test phase, complete test reports shall be prepared to present the data, data analysis, conclusions, and recommendations.

A schematic of the proposed system test setup is shown in Figure B-8. As shown, the laboratory test setup will provide the support equipment and gases required to test the system. The supply source will consist of a bank of identified waste gases. The test gas will flow into a humidity and temperature control module to set the temperature and dewpoint of the gas as it enters the system. Before entering the system and as it exits from the system, the temperature, pressure, and dewpoint of the gas shall be measured and recorded. The compressor coolant, electrical supply, gas analyzer, and storage accumulator are part of the laboratory support equipment.

#### B4.2.1 System Functional Checkout

The objective of this test is to identify any interface anomalies with the component or test support equipment after installation into the system. The testing shall include the following system-level checks:

- (a) Inspection
- (b) Leakage
- (c) Proof pressure
- (d) Performance

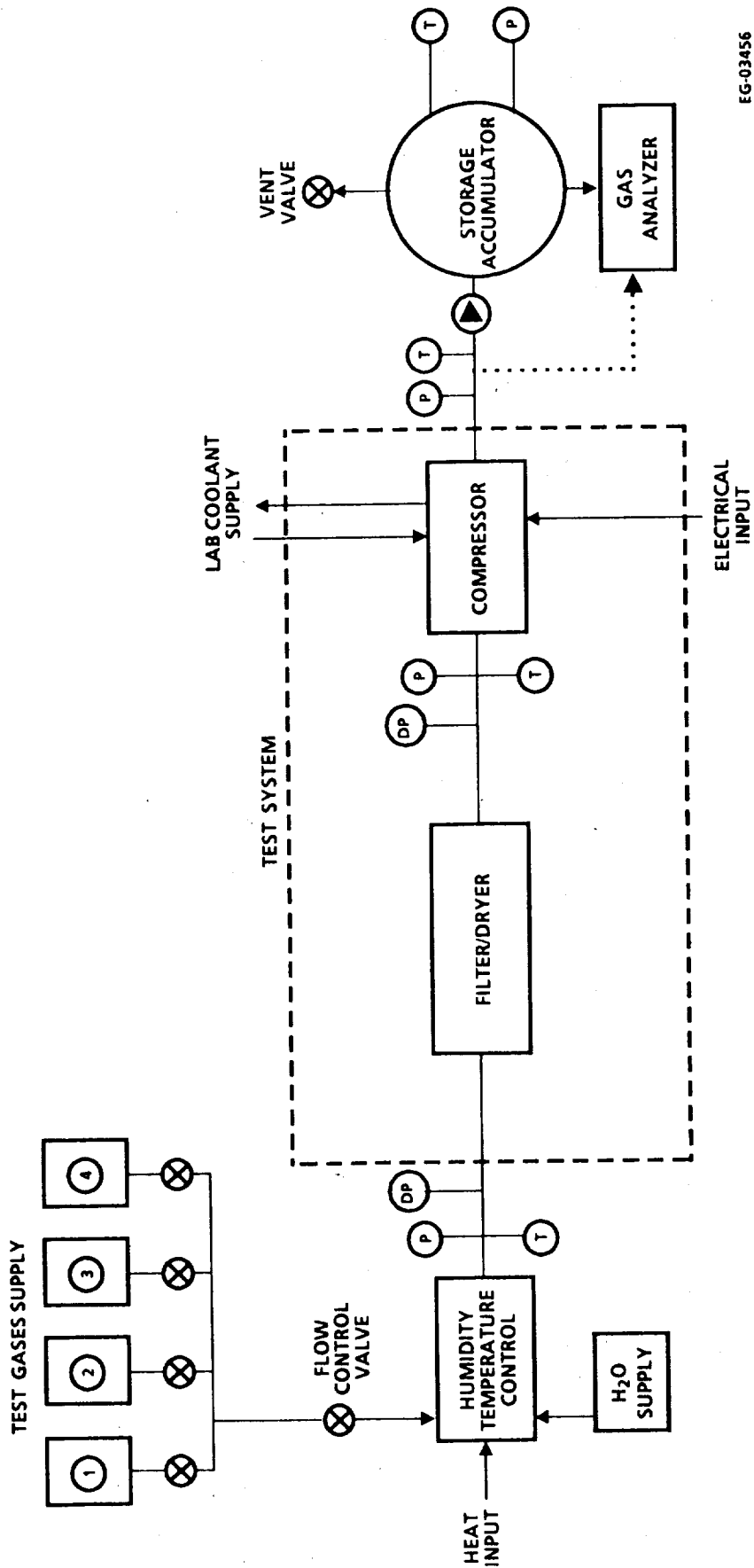
The inspection, leakage, and proof pressure tests verify system interfaces of the components and associated support equipment.

#### B4.2.2 System Performance Evaluation

The objective of this test is to verify system performance and compatibility with all of the waste gases identified for system handling in this Phase I program. This test will evaluate and provide test data for the following system design areas:

- (a) Materials compatibility
- (b) Dryer/filter performance
  - (1) Effectiveness
  - (2) Gas compatibility
- (c) Compressor performance
  - (1) Gas compatibility
  - (2) Electrical data
  - (3) Flow rates
  - (4) Pressure rise
  - (5) Temperatures
  - (6) Coolant loads

ORIGINAL FILED  
OF POOR QUALITY



EG-03456

Figure B-8. Proposed Demonstration Test Setup

The materials compatibility test will verify that multigas operation does not damage the unit. The dryer performance will be evaluated by its effectiveness in removing moisture from each of the various gases. The gas in and out of the dryer will be checked for all compatibility problems with the selected desiccant materials. Compressor performance will be mapped for each of the test gases. As part of the compressor tests, the seals, lubricants, and materials will be observed for any reaction with the various gases. Electrical performance data will be taken to establish motor performance and compressor efficiencies. To establish total compressor performance gas flow rates, pressure rises, temperature increases, and coolant loads, data will be collected.

All of the test data obtained will be compared to the analytical estimates and evaluated for Space Station compatibility.

#### B4.2.2 System Acceptance Test

The system acceptance test will recheck system performance with the gas used for initial system checkout. If no significant performance degradation is noted, the system will be prepared for delivery to NASA. If degradation is noted, AiResearch will recommend that the system components be refurbished prior to delivery to NASA.