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FINAL REPORT
DESIGN DEVELOPMENT AND TEST
TWO-GAS ATMOSPHERE CONTROL SUBSYSTEM

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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FINAL REPORT

Prepared in Accordance with Line Item 6,
Data Requirements List
Contract NAS9-12924

Two Gas Atmosphere Control Subsystem

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FOREWORD

A Two-Gas Atmosphere Control Subsystem was developed by the Biotechnology and Space Sciences Department, Engineering Division, of the McDonnell Douglas Astronautics Company (MDAC), Huntington Beach, California, under NASA Contract NAS9-12924.

This contract effort was performed under the technical direction of Mr. A. C. Copeland, Jr., of the Experiment Systems Division, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration, Houston, Texas.

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Section 1

SUMMARY

An Atmosphere Control Subsystem has been developed for NASA-LBJSC under Contract NAS9-12924 which is designed to measure the major atmospheric constituents in the manned cabin of the Space Shuttle Orbiter and control the addition of oxygen and nitrogen to maintain the partial pressures of these gases within very close limits.

The ACS includes a Mass Spectrometer Sensor (MSS) which analyses the atmosphere of a Shuttle vehicle pressurized cabin, and an Electronic Control Assembly (ECA). The MSS was built by Perkin Elmer Corporation for NASA and tested under Contract NAS9-9799 to meet the requirements for flight equipment for the M-171 Metabolic Analyzer experiment for the Skylab flight program. This instrument analyzes an atmospheric gas sample and produces continuous 0-5 vdc analog signals proportional to the partial pressures of H_2, O_2, N_2, H_2O, CO_2 and total hydrocarbons having a m/e ratio between 50 and 120. The ECA was designed and fabricated by McDonnell Douglas Astronautics Company (MDAC) under the present contract. It accepts signals from the MSS proportional to the partial pressures of N_2 and O_2 and controls the supply of these gases to the closed cabin.

The ECA is designed to meet requirements for man-rating and flight qualification. Wherever possible, electronic components having known high reliability have been utilized; in only a few instances has it been necessary to substitute MIL-STD parts where procurement lead times have prevented use of equivalent high reliability parts.

The ACS was subjected to functional checkout, high and low temperature tests, and a 60-day endurance test. During the endurance test the unit was used to control the atmosphere in a closed chamber having 876 cu ft volume, simulating the Shuttle Orbiter cabin. A sample of the chamber atmosphere was provided to the MSS which provided continuous output signals. The O_2 and N_2 signals were provided as inputs to the ECA. Outputs from the ECA were used to control valves in gaseous O_2 and N_2 supplies to make up for chamber leakage. A diaphragm compressor was used to draw the atmosphere sample through the MSS and return it to the chamber. A portion of this flow was released through a micrometer metering valve and measured by a positive displacement meter to simulate cabin leakage.

Portions of the endurance test were performed at 5 and 10 psia set points. 48 days were spent at the 14.7 psia set point, and data obtained for a variety of simulated leakage values. An automatic data recording system was used to document performance during transients and obtain statistically significant samples at each stable operating condition.

Performance of the ACS in controlling the partial pressures of O_2 and N_2 and the total pressure within the chamber was well within specification requirements. The accuracy of all data for N_2 control was within $\pm$ 0.31 percent during the 14.7 psia segment of the test. The bandwidth of the O_2 control was 3.3 torr (0.064 psi). The total pressures were slightly low since there was no source of metabolic H_2O and CO_2 within the chamber, as there would be in a manned application. All values of total pressure were between 748.0 torr (14.47 psia) and 755.5 torr (14.61 psia), compared with required limits of 749.6 torr (14.5 psia) and 770.3 torr (14.9 psia). Only 4 percent of the data points fell below the minimum level of 749.6 torr, even without the H_2O and CO_2 in the atmosphere.

The ability of the control to perform gas flow measurements by counting N_2 pulses was evaluated. The overall error in N_2 usage was approximately 4 percent. There is reason to believe that this could be improved considerably by improved design of the pneumatics section of the system, which was not covered in the present contract.

A method of measuring cabin leakage by monitoring N_2 pulse frequency was evaluated. It was found that a short term (1/2 hour or less) accuracy of $\pm$ 2.75 lb/day of leakage from the Shuttle cabin could be expected with existing performance. Some methods of design improvements were indicated that probably would reduce this value. The long term accuracy, of course, approaches that of the flow measurement mentioned in the previous paragraph.

The ability of the ACS to perform fault detection was illustrated by an incident in which loss of the gaseous N_2 supply could have been detected within 1/2 hour if the system were continuously monitored. Fault detection of this sort is relatively simple to incorporate in the system.

Although the ACS has been developed for use of the MSS as an atmosphere composition sensor, it is entirely possible to use the control assembly with other types of sensors (pp O_2, total pressure) where system requirements do not result in use of the Mass Spectrometer.

Section 2

INTRODUCTION

The development of the pulse-modulated proportional method of controlling the oxygen and nitrogen partial pressures in a spacecraft cabin atmosphere has been undertaken by McDonnell Douglas Astronautics Company since 1964.

The first unit was made from commercially available components in 1964. This unit used a strain gage sensor, measuring total pressure in the cabin, as an input to the nitrogen control channel; and a Beckman polarographic O_2 partial pressure sensor as input to the oxygen control channel. It was used initially during a 12 day and then a 30 day closed chamber manned test during January, 1965. After refurbishment it was then used in a series of shorter tests and finally in a 60-day closed-chamber manned test during February-April 1968. During this latter test period, a prototype mass spectrometer atmosphere analyzer, manufactured by Perkin-Elmer of Pomona, California, was provided as GFE by NASA, Langley, for evaluation. During the initial portion of the 60-day test period it was observed that operation of the mass spectrometer atmosphere sensor was very good, and the O_2 and N_2 signals of the mass spectrometer were substituted for the polarographic and total pressure signals originally used. Performance of the control was equally good with either sensing methods.

In 1970, a 90-day manned test was conducted for NASA-Langley under Contract NAS1-8997. In preparation for this test, a more compact version of the atmosphere control was built. This unit, the Mark II, was capable of accepting inputs from either the mass spectrometer or the polarographic and total pressure sensors.

This unit was completed, checked out, and installed in the Space Vehicle Simulator chamber for the 90-day test. However, a flight type control was built on Contract NAS1-8997. The Mark II was therefore used as a backup unit during the test and the Mark III, flight-type unit was used as the primary control. The Mark III unit was also capable of accepting signals from either the mass spectrometer or the O_2 partial pressure-total pressure sensors. Since the entire 90-day test period was completed without any malfunction of either the Mark III control or the mass spectrometer, the alternate sensors or backup Mark II control were never actually used for controlling the atmosphere in the chamber.

At the start of the effort on the current contract, a study was undertaken to review previous test experience, especially with the Mark III unit during the 90-day test. This study was reported in Reference 1. During this study system design constants were determined which would insure best possible performance of the ACS. Although the design philosophy was developed relative to the Space Station Prototype requirements, which reflected the original application of the ACS, they have been upgraded to comply with the Space Shuttle which is the application presently intended.

During the 90-day test it was noted that variations in cabin leakage, as indicated by changes in cabin total pressure, appeared to correlate frequently with equipment or crew operations. The long time constant associated with pressure decay measurement made it nearly impossible to detect and correct leakage sources in a timely manner. Typical sources of leakage that were suspected were: the weekly operation of the pass-through airlock for removing samples from the cabin, operation of the fecal drier overboard vent valve, operation of the VD/VF water recovery unit overboard vent valve, installation of the Sabatier reactor after replacing the catalyst, sealing the commode after replacing the liner, etc. From these observations it appeared that development of a methodology for detecting cabin leakage changes by means of related output of the atmosphere control would be very beneficial in indicating the need for corrective action. This could result in considerable reduction in cabin gas losses.

Such a methodology was investigated analytically and reported in Reference 2. The results of this study were used to guide the test planning for the 60-day endurance test reported herein. This involved the automatic collection of data for a significant period of time to measure transient and steady state performance while a series of cabin leakage values were imposed. The test was successful in providing these data, and improvements in the methodology can now be made on the basis of empirically determined performance.

Section 3

PROGRAM OBJECTIVES

The objective of the effort described in this report was to design, fabricate and test a 2-gas Atmosphere Control Subsystem (ACS) which monitors the major constituents in a space cabin atmosphere and controls the addition of oxygen and nitrogen to keep the atmosphere composition within prescribed limits.

The ACS includes the Mass Spectrometer Sensor (MSS) developed by the Aerospace Division of Perkin Elmer Corporation under NASA Contract NAS9-9799 (Serial Number 006) and the Electronic Control Assembly (ECA) designed and built by MDAC under the present Contract (NAS9-12924). The atmosphere composition is sensed by the MSS which generates 0-5 vdc analog signals proportional to the partial pressures of O_2, N_2, H_2, H_2O, CO_2, and total hydrocarbons having a mass/charge (m/e) ratio between 50 and 120. The sampling point is chosen to insure a flow of gas to the MSS having a composition representative of that of the cabin; typically, the inlet duct of the atmosphere thermal control unit.

The O_2 and N_2 signals are provided to the ECA, which compares them with fixed reference voltages and generates output signals for controling the addition of O_2 and/or N_2 to the cabin. Either gas can be supplied from high pressure storage; the oxygen may alternatively be supplied from a water electrolysis unit. In the case of nitrogen, the output signal consists of pulses of predetermined duration, with a frequency which is proportional to the difference between sensed N_2 pressure and the set point. In the case of oxygen, a discrete voltage will be generated at a low level set point and deactivated at a high level set point. These two set points represent two levels of output from the oxygen generation unit. The O_2 and N_2 are added to the atmosphere at a point somewhat remote from the mass spectrometer sensing point to avoid getting a reading not representative of the cabin atmosphere. Typically, this gas is added into the atmosphere distribution duct.

At the start of the program, the ACS was to supply the Atmosphere Control function for the Environmental and Thermal Control/Life Support System (ETC/LSS) for the Space Station Prototype (SSP), and meet all the interface requirements of that system. That requirement was cancelled at the mid-point of the program, shortly after CDR. The program was then redirected to provide for Atmosphere Control of the Space Shuttle Orbiter. At the point in which the program was redirected, many of the interfaces originally defined for the ETC/LSS were deleted. However, some of these were retained. As a result, this report must review both sets of requirements in order to show where final system design definition was derived from.

Section 4

REQUIREMENTS

System requirements were established initially for the ETC/LSS of the Space Station Prototype program. These requirements were later changed to those of the Space Shuttle Orbiter. Both sets of requirements will be presented here since those for the ETC/LSS resulted in some interface and performance requirements definition that were carried forward to the final design, and the necessary equipment to modify the final design to meet Space Station requirements could be readily added if this is ever desired.

In addition to System Requirements, design studies have been conducted to define functional and interface requirements, which will also be reported in this section.

4.1 System Requirements

4.1.1 Space Station Prototype

The Space Station Prototype program was to provide an ETC/LSS for a modular space station to be launched and serviced by the Space Shuttle Orbiter. The key requirements to be met by the Atmosphere Control are listed in Table 1. In addition, subsystems of critical importance to the mission were to provide fail operational capability and automatic checkout, with crew notification and onboard checkout system cognizance of any anomoly in performance until correction.

A system requirement of significant impact was that for operation from 115 v, 400 Hz power supply. Accordingly, the ACS was designed with external solid state power supplies for conversion of this ac voltage to the required precision regulated dc voltages. Also, ACS output was to be

Table 1

REPRESENTATIVE SSP DESIGN REQUIREMENTS*

Spacecraft Operational Lifetime	2 to 10 years
Module Size (maximum)	14 ft diam x 58-ft length
Pressurized volumes	
Power Module (1)	1,600 ft^3
Standard Module (4)	3,600 ft^3
Core Module (1)	5,500 ft^3
Pressure isolatable volume (for crew survival during emergency conditions)	8,000 to 15,000 ft^3
Number of independent habitable volumes	2
Crew number (each habitable volume)	2 to 6 crewmen
O_2 consumption	
Design point	1.84 lb/man-day
Maximum for 6 men (8 hours)	0.64 lb/hr
Maximum normal atmospheric leakage	
at 5.0 psia	6 lb/day
at 10.0 psia	12 lb/day
at 14.7 psia	18 lb/day
Power supply charactersitics	115/200 volts, 3 phase, 400 Hz ac
N_2 Supply	High Pressure Storage
O_2 Supply	Water Electrolysis Unit

* NOTE: Reference 3

solid state zero crossover switches to energize the 400 Hz motor operated control valves, with power to be removed upon closing a limit switch on attainment of the desired valve position.

On the basis of SSP operating requirements, the ACS was to provide for operation at three selectable settings of total pressure: 5, 10 and 14.7 psia. The allowable band for total pressure is $\pm$ 0.2 psi. At each total pressure, three set points are provided. One setpoint provides a pulse-frequency modulated output to the nitrogen control valve with the frequency being proportional to error in nitrogen partial pressure from a preset reference value. The other two setpoints are used for control of oxygen admission, with the lower to activate a discrete signal and the upper set point to deactivate the discrete signal. In the closed, manned cabin, it was intended that this signal would switch the output of a water electrolysis unit so that the presence of the signal would cause oxygen production to be about 120 percent of nominal and the absence of the signal, about 80 percent of nominal. The nominal atmosphere compositions and allowable variations are given in Table 2. It was specifically required that the O_2 and N_2 partial pressures fall within the indicated ranges; the set points were considered as nominal design values.

The ACS was to be designed as close to flight configuration as possible, to meet the requirements for operation in a closed chamber during manned testing. All components were to be of established high reliability, or MIL-STD parts having high reliability equivalent parts which are functionally interchangeable.

Acceptance testing of the ACS was to include Functional Checkout, operation at high temperature (100°F, +5, - 0°F) and low temperature (40°F, +0, -5°F), and 60 days of endurance testing. Random vibration and electromagnetic interference tests were also originally required but were deleted due to budgetary limitations. Also, the EMI tests were designed to determine system effects on the power supply and were not meaningful when the design requirements to use external 400 Hz-to dc converters and specified solid

Table 2

ATMOSPHERE CONTROL SUBSYSTEM ACCURACY AND SET POINT REQUIREMENTS

Operating Condition	Pressure Low PSIA	(TORR)			High PSIA	(Torr)
5 PSIA (258.5 Torr)						
Total Pressure	4.80	(248.2)			5.20	(268.8)
Oxygen	3.49	(180.4)			3.64	(188.2)
Water	0.15	(7.8)			0.23	(11.9)
Nitrogen	1.16	(60)			1.27	(65.7)
Carbon Dioxide	0.00	(0.0)			0.06	(3.0)
Oxygen Set Points	3.56	(183.8)			3.58	(184.8)
Nitrogen Set Point			1.17	(60.5)		
10 PSIA (517.0 Torr)						
Total Pressure	9.80	(506.6)			10.20	(527.3)
Oxygen	3.14	(162.3)			3.29	(170.1)
Water	0.15	(7.8)			0.23	(11.9)
Nitrogen	6.51	(336.6)			6.62	(342.3)
Carbon Dioxide	0.00	(0.0)			0.06	(3.0)
Oxygen Set Points	3.21	(165.7)			3.23	(166.7)
Nitrogen Set Point			6.54	(338.1)		
14.7 PSIA (760.0 Torr)						
Total Pressure	14.50	(749.6)			14.90	(770.3)
Oxygen	3.14	(162.3)			3.29	(170.1)
Water	0.15	(7.8)			0.23	(11.9)
Nitrogen	11.21	(579.6)			11.32	(585.2)
Carbon Dioxide	0.00	(0.0)			0.06	(3.0)
Oxygen Set Points	3.21	(165.7)			3.23	(166.7)
Nitrogen Set Point			11.28	(583.2)		

state 400 Hz switches on the output stages were imposed. As an alternate, the EMI design constraints of Reference 3 were imposed.

4.1.2 Space Shuttle Orbiter Requirements

Upon redirection of the ACS to application in the Space Shuttle Orbiter, the requirements outlined in Table 3 were derived. The requirements for operation at 5 and 10 psia were retained, but the 14.7 psia setpoint was emphasized since that is the nominal operating condition for the Space Shuttle. The fail operational requirement was retained. There was to be no in-flight repair or replacement of components, and the need for preventitive maintenance was to be minimized.

As a result of these changes, the following decisions were made:

The ECA would operate from power supplied from external 115 v, 400 Hz ac converters, and would control external solid state switches selected for the available solenoid valves.

The MSS would operate from a 28 vdc power source.

The oxygen channel would operate a solenoid valve to control O_2 admission in the on-off mode already selected and designed into the ECA.

A Pressure Control Panel used in previous tests would be provided by MDAC to include the solenoid valves and pressure regulators in order to perform the closed-loop endurance test.

The normal Shuttle Orbiter atmosphere requirements are summarized in Table 4.

Table 3

REPRESENTATIVE SPACE SHUTTLE ORBITER DESIGN REQUIREMENTS

Operational Lifetime:	100 mission; 7 to 30 days duration
Pressurized Volume:	Main Cabin 2000 cu ft
	Airlock 250 cu ft
Crew Size:	4
Normal Operating Pressure	14.7 psia $\pm$ 0.2 psia
Avionics Bay Bleed Flow	1 lb/day each for 3 bays
Cabin Leakage	9 lb/day
Power Supply	115 v, 400 Hz ac or 28 vdc
N_2 Supply	High Pressure Storage
O_2 Supply	Cryogenic or High Pressure Storage

Table 4

SPACE SHUTTLE ORBITER ATMOSPHERE REQUIREMENTS

(lbs per day)

	Oxygen	Nitrogen	Total
Metabolic Consumption	8	0	8
Cabin Leakage	2.25	6.75	9
Avionics Bay Vent Flow	0.75	2.25	3
Total	11.0	9.0	20.0

The nominal atmosphere composition in the orbiter cabin is given in Table 5.

Table 5

NOMINAL ATMOSPHERE COMPOSITION

	Partial Pressure Torr	Volume Fraction	Weight Fraction	Wt. in Cabin lbs
Nitrogen	582	.766	.744	111.0
Oxygen	165	.217	.242	36.0
Water vapor	10	.0131	.0080	1.2
Carbon Dioxide	3	.0039	.0060	0.8
Total	760	1.0000	1.0000	149.2

Average molecular weight: 28.8

Average density at 70°F: 0.0745 lb/cu. ft.

4.2 Performance Characteristics

The Atmosphere Control Subsystem includes the equipment required to measure the major atmospheric constituents and control the oxygen and nitrogen additions to the Shuttle closed loop atmospheric environment. Essentially this subsystem consists of the Mass Spectrometer Sensor (MSS) and the Electronic Controller Assembly (ECA). The Mass Spectrometer contains that equipment required to sample the cabin atmosphere and provide output voltage levels proportional to major constituents. The output voltages proportional to O_2 and N_2 partial pressures are monitored by the Electronic Controller Assembly and compared with desired operational limits. When additional nitrogen gas is required to maintain the desired level an electrical signal is output to the Nitrogen Resupply System and a metered amount of nitrogen gas is allowed to enter the closed system through a control valve. In a similar fashion the controller commands the Oxygen Resupply System to operate in a high or low mode dependent upon the O_2 input voltage from the Mass Spectrometer.

4.2.1 Mass Spectrometer Sensor

The MSS is described in Reference 4. Its performance characteristics may be summarized as follows:

The MSS is a self-contained, sealed system and is intended for use in monitoring and/or controlling a multigas atmosphere within a spacecraft cabin. The MSS is capable of performing direct measurements of the partial pressures of hydrogen, water vapor, nitrogen, oxygen and carbon dioxide, as well as providing an indication of the level of total contaminants within an enclosed environment.

The MSS is an aluminum cylinder having basic dimensions of 7.2 inches diameter and 12.5 inches in length. It weighs approximately 22 lbs and requires about 15 watts of 28 vdc power. Two mounting feet are located at each end of the cylinder and extend 4 inches from the centerline of the cylinder. The mounting holes are spaced 6 inches apart at each end and 11.5 inches from end to end. Two of the mounting holes, located at the gas inlet and valve end, are 0.266 inch diameter clearance holes. The mounting holes at the electrical connector end are elongated holes, 0.366 inch by 0.266 inch. In one end of the cylinder are located the SAMPLE INLET and PUMP OUT valve actuation handles, as well as the SAMPLE INLET, SAMPLE OUTLET, and PUMP OUT interface connections. The electrical interface connections necessary for the power inputs, command functions, data output, and test requirements are located in the other end of the cylinder.

The SAMPLE INLET and SAMPLE OUTLET interface connections allow a representative gas sample to be exposed to the MSS. The system thus requires either a pumping means to pull the sample through the line or a pressure head to force the sample through the line. In either case, the SAMPLE INLET line is to be connected to the sample to be analyzed.

The electrical interface connections consist of three electrical connectors, two of which are utilized during operation of the MSS. The POWER IN connector, J1, provides the interfaces for all of the input power and command functions necessary to operate the MSS. The SIGNAL OUT connector, J2, provides the interfaces for all of the data outputs required of the MSS. The CONTRACTOR'S TEST connector, J3, remains sealed during operation of the MSS.

Operation of the MSS requires provision of an external control switching and indication capability. This function was provided by an Interface Buffer Assembly (IBA), described in Reference 5. Interconnection of the MSS and the IBA is through connectors J1 and J2 of the MSS. The IBA provides indicator lights for the following functions:

Excessive Pump Pressure: This indicates that the internal pressure of the MSS is too great to allow starting of the internal ion pump. When present, operation of the ion pump and MSS electronics are inhibited.

Electronics Inhibited: May be indicated if the ion pump is operating but the pressure is too high to allow turning on the ion source filament.

Open Loop: Shows that the MSS is operating in the OPEN LOOP mode.

Switching capability is provided in the IBA for the following functions:

Ion Pump on-off

MSS Electronics on-off

Open-Closed control mode selection

Filament Selection

The characteristics of the output signals of the MSS are given in Table 6.

Table 6

SIGNAL CHARACTERISTICS OF MASS SPECTROMETER SENSOR

Sample Constituent	Partial Pressure Range (torr)	Accuracy (torr)	Output Sensitivity (torr/volt)	Voltage Range (volts)
Hydrogen (H_2)	0 to 3.3	$\pm$ 0.66	0.66	0 to 5
Water Vapor (H_2O)	0 to 33	$\pm$ 1.65	0.60	0 to 5
Nitrogen (N_2)	0 to 660	$\pm$ 13.20	132.0	0 to 5
Oxygen (O_2)	0 to 330	$\pm$ 6.60	66.0	0 to 5
Carbon Dioxide (CO_2)	0 to 23.1	$\pm$ 0.70	4.62	0 to 5
Total Contaminants (TC)*	0 to 0.33**	N/A	N/A	0 to 5

* Monitored by measuring all constituents which give m/e ratios between 50 and 120.

**Based upon 1000 ppm full scale assuming compounds have an equivalent sensitivity to that of Nitrogen (N_2) at m/e 28.

In addition to the sample inlet and outlet connections, a PUMP OUT connection is provided, and valve actuation handles for PUMP OUT and SAMPLE INLET.

The PUMP OUT interface connections allow the analyzer to be evacuated to a pressure low enough to initiate operation of the ion pump, should internal vacuum be lost. A vacuum source is then required to perform this function.

The PUMP OUT valve actuation handle is used to expose the MSS to the vacuum source connected to the PUMP OUT interface connection, and to seal the analyzer from the vacuum source once operation of the MSS has been initiated.

The SAMPLE INLET valve actuation handle is used to: (a) allow a minute portion of the sample passing through the sample line to be introduced into the analyzer when open and (b) reduce the pressure rise within the mass spectrometer during periods of storage, when closed.

In order to provide an accurate analysis of atmospheric constituents including partial pressures of each compound measured, a representative sample of the cabin atmosphere must be provided at the MSS sample inlet port. The following factors have an adverse effect on the MSS analysis capability:

a. Inadequate mixing of cabin gas at the inlet of the sample collection line will provide a sample that does not have an accurate representative composition.

b. Pressure drop in the sampling line will cause a corresponding reduction in all component partial pressures.

c. Adsorption of constituents within the sampling line may occur. This may be related to condensation of water vapor along the walls of the sample line, which may in turn cause removal of some of the carbon dioxide or trace hydrocarbons. Since adsorption may be followed by desorption, errors both above and below true values may be observed.

d. Transport time from the sample line inlet may cause significant lag in response. Maintenance of an adequate velocity in the line and use of a sample line of short length will minimize this effect. If lines are maintained at too high a velocity, pressure drop along the line may become significant.

The loss of sample gas from the cabin is stated in Reference 4, Section 3.1.1.8, to be less than one-tenth (0.1) gram per hour. Analysis of the ACS has shown that sample line flow must be considerably greater; the excess gas is to be returned to the cabin.

The above requirements can be met satisfactorily by obtaining the sample in a main air conditioning duct in a relatively high pressure region (e.g., downstream of a blower) and returning the sample to a relatively low pressure region (e.g., upstream of the same blower, or possibly directly to the cabin).

4.2.2 Electronic Control Assembly

The Electronic Control Assembly will consist of a nitrogen control channel, an oxygen control channel, and associated circuitry. The nitrogen and oxygen analog signals from the MSS will be input to the respective channels. Each input signal will be compared with a reference setpoint voltage at the input of an operational amplifier circuit.

4.2.2.1 Nitrogen Channel

A schematic representation of the pulse frequency modulated N_2 control channel is shown in Figure 1. The analog voltage output of the N_2 partial pressure sensor is applied at the input terminal. A precision reference voltage of opposite polarity is applied to the other terminal of the summing network. When the input voltage is lower than the reference voltage (indicating a pressure below the setpoint) the error signal is integrated in the amplifier producing a ramp voltage output having a rate of increase proportional to

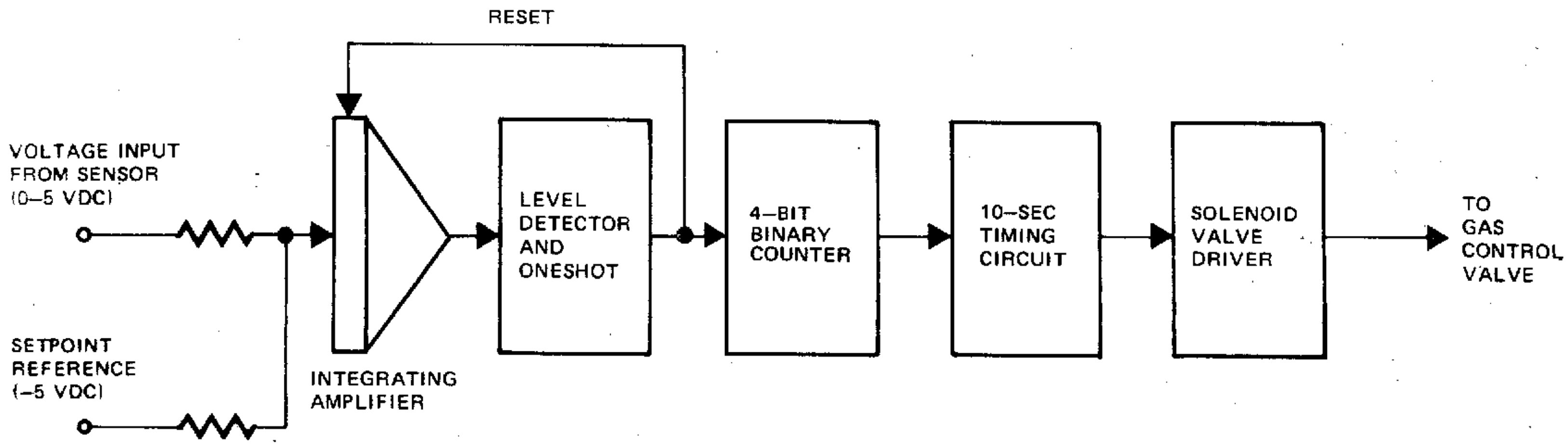


Figure 1. Schematic of Pulse-Modulated Proportional Control Channel

the magnitude of the error signal. A clamping diode is used to prevent pressures above the setpoint causing negative integrator output. When the integrator output reaches the preset voltage of the level detector a pulse is produced which resets the integrator to initial conditions and increments the 4-bit binary counter by one count. After sixteen input pulses are accumulated the binary counter will reset to zero and produce an output pulse which causes the ten second precision timing circuit to start and opens the solenoid operated gas control valve. After the ten-second period the valve will be de-energized and will close.

Typically, the solenoid valve will control gas admission from a precision regulated source through a calibrated orifice so that the mass flow of gas per pulse is closely regulated. Flow measurement can then be readily accomplished by counting pulses of gas flow. This measurement method can be very precise if desired, since it is controlled by the accuracy of the pressure regulator (at a constant flow rate) and the 10 second timing circuit.

As in the past, the gas admission system has been designed to operate at a pulse frequency of about 10 per hour. This results in a solenoid duty cycle of 1 to 36 and thereby conserves power. The flow rates involved are normally low enough so that the size of the pneumatic components is not appreciably increased as compared with continuously flowing systems. More detail on system design characteristics and performance of previous models is presented in Reference 1.

A closed loop system including the controller, the valve (and gas flow), the cabin volume, and the sensing system exists, therefore each parameter must be considered in determining the system accuracy. The system accuracy, response time, and stability depend upon the open loop gain of the system. The open loop gain is a function of the following design parameters:

a. The ECA Scale Factor which is defined as the number of pulses allowed per unit time per unit error of nitrogen partial pressure.

b. The nitrogen valve flow rate and the "ON" time per pulse.

c. The cabin volume.

Analysis has shown that if loop gain is insufficient as a result of decreased flow rates, reduced scale factor or increased cabin volume, the response time will increase and system accuracy will degrade. Conversely, a high loop gain can cause system instability as evidenced by oscillation or excessive overshoot of the controlled gas partial pressure with respect to the desired set point. This condition is more critical if transport time of the gas sample to the Mass Spectrometer is abnormally high due, for example, to delayed mixing of cabin atmosphere.

The system dynamics of the N_2 channel are shown in Figure 2.

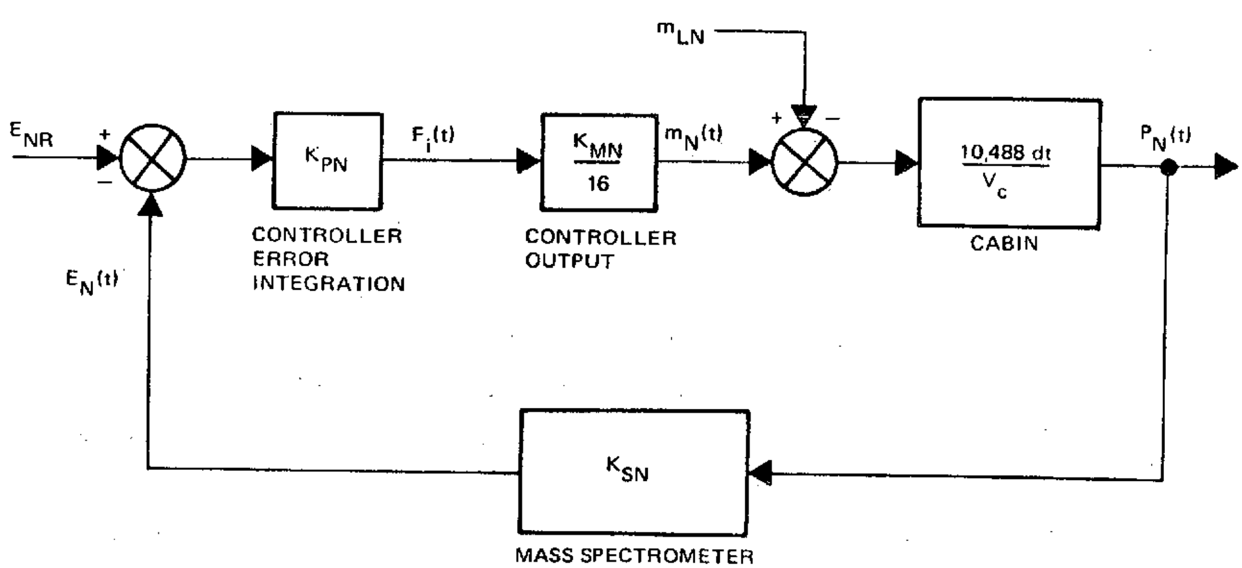


Figure 2. Simplified Dynamic Diagram, Nitrogen Channel

The constants noted in Figure 2 are derived as follows:

a. Controller Output

The pulse train actuating the nitrogen solenoid valve is generated by a 4-bit binary counter from the internal pulse generator. Hence, the solenoid actuation frequency is $\frac{Fi(t)}{16}$, or the controller output gain is $\frac{K_{MN}}{16}$.

b. Cabin

The specific density of nitrogen at standard conditions of 760 torr and 70°F is 13.8 cu. ft/lb. By the gas law, then

$$p_N = p_{N_i} + \int \frac{13.8 \times 760}{V_c} (m_N(t) - m_{LN})\, dt$$

or $$p_N = p_{N_i} + \int \frac{10488}{V_c} (m_N(t) - m_{LN})\, dt \qquad (1)$$

c. Mass Spectrometer

The nitrogen channel calibration of the mass spectrometer is given as $K_{SN} = \frac{1}{132}$ volt/torr.

d. Leakage Rates

Cabin leakage values are normally given in terms of total flow rate in lbs. per day. It is necessary to determine the portion of this leakage that is nitrogen (m_{LN}). From Table 5 the weight ratio of nitrogen (R_N) at nominal conditions is given as 0.744. The value for nitrogen leakage, m_{LN}, at nominal conditions is therefore approximately 0.375 lb per hour.

The dynamic system shown in Figure 2 can be represented by the following equations

$$\frac{dp_N(t)}{dt} = \frac{10,488}{V_c} \left(\frac{K_{MN}}{16} F_i(t) - m_{LN}\right) \quad (2)$$

and

$$F_i(t) = K_P \left(E_{NR} - K_s \, p_N(t)\right) \quad (3)$$

These linear differential equations can be combined and it can be shown that the solution is given by the following equation:

$$P_N(t) = \frac{E_{NR}}{K_{SN}} - \frac{16 \, m_{LN}}{K_{MN} \, K_{PN} \, K_{SN}} \left(1-e^{-t/\tau_N}\right) \quad (4)$$

in which

$P_N(t)$ is the time variation of nitrogen partial pressure

E_{NR} is the reference voltage of the nitrogen control channel

K_{MN} is the mass flow of gas per solenoid valve pulse

K_{PN} is the control integrator output in pulses per hr per volt of input error signal

K_{SN} = the sensor output in volts/torr

m_{LN} is the leakage of nitrogen from the cabin

e is the base of natural logarithms

t is the time in hrs

τ_N is the system time constant, defined as

$$\tau_N = \frac{V_c}{655.5 \, K_{MN} \, K_{PN} \, K_{SN}} \quad (5)$$

The constant 655.5 = $\frac{1}{16 \text{ x lbs of gas per torr pressure change per cu ft}}$

The constant 16 is the number of integrator pulses per gas pulse.

For nitrogen, using $K_{SN} = 1/132$, equation 4 becomes

$$P_N(t) = 132\ E_{NR} - \frac{2112\ m_{LN}}{K_{MN}\ K_{PN}}\ (1-e^{-t/\tau_N})\ \text{(torr)} \qquad (6)$$

For the 2000 cu ft Shuttle cabin volume, and Equation 5,

$$\tau_N = \frac{2000 \times 132}{655.5 \times K_{MN}\ K_{PN}} = \frac{403}{K_{MN}\ K_{PN}}\ \text{(hours)} \qquad (7)$$

Previous experience with earlier models of the pulse modulated control concept has indicated that a two torr difference should exist between the design flow rate and the zero flow rate condition. This provides good control accuracy with a minimum risk of instability. The set point for the N_2 channel for design flowrate, in accordance with Table 2 for 14.7 psia setpoint, should be 583.2 torr and therefore for zero flow, 585.2 torr. From Equation (6), in the steady state solution for zero gas flow ($t \to \infty$, $m_{LN} = 0$),

$$P_N(t) = 132\ E_{NR}$$

and $$E_{NR} = \frac{585.2}{132} = 4.433 \text{ volts} \qquad (8)$$

The design value of N_2 consumption is $m_{LN} = 0.375$ lb per hr. As previously noted, the design pulse frequency has been chosen at about 10 per hour. The size of the nitrogen gas pulse was therefore selected as $K_{MN} = 0.0375$ lb per pulse.

In order to achieve the required 2 torr decrease in controlled pressure at the design flow rate, the last term of Equation 6 must reach a steady state value of 2.0 when m_{LN} is the design value of 0.375 lb/per hour. Therefore:

$$\frac{2112 \times 0.375}{0.0375\ K_{PN}} = 2.0 \text{ torr}$$

or

$$K_{PN} = \frac{2112 \times 0.375}{0.0375 \times 2.0}$$

$$K_{PN} = 10560 \text{ pulses/hour/volt}$$

The system time constant can then be found by substituting these values in Equation 7 as follows:

$$\tau_N = \frac{403}{0.0375 \times 10570}$$

$$\tau_N = 1.018 \text{ hours}$$

This relatively short time constant indicates how responsive the system is with the proposed control constants. It is noted that the control bandwidth is inversely proportional to the control system gain ($K_M\ K_P$) and so also is the system time constant (τ). It follows that less accurate control results in proportionately longer time constants. Achieving a short time constant is very important in leakage detection in which the amount of leakage is inferred from the inflow of makeup nitrogen to the cabin.

To summarize the nitrogen channel design constants derived above,

The reference voltage for the 14.7 psia set point, $E_{NR} = 4.433$ volts
The N_2 flow per 10 second gas pulse, $K_{MN} = 0.0375$ lb/pulse
The integrator output $K_{PN} = 10560$ pulses/hr/volt

When designed to these values, the partial pressure of N_2 at the control point for zero N_2 flow will be 585.2 torr; the design point flow rate of 9 lb/day will be reached at a partial pressure of N_2 of 583.2 torr; the integrator pulse frequency will be 160 per hour at this condition; the valve pulse frequency will be 10 per hour; and the system response will be a first order lag having a time constant of 1.018 hours (for a 2000 cu ft cabin volume).

Reference voltages for the 5 and 10 psia set points can also be found, similar to Equation 8, to be 0.498 volts and 2.593 volts respectively.

4.2.2.2 Oxygen Channel

One objective of the oxygen channel design was to use similar circuit design concepts to those of the N_2 channel. However, it is required to provide a discrete signal, activated at a low level set point and deactivated at a high level. The purpose of this requirement was to control a Water Electrolysis Unit which was to furnish oxygen to the cabin, operating in a high output mode when the discrete signal is present and a low mode when it is absent.

The resulting design is shown schematically in Figure 3. It is essentially a dead band control but retains the advantages of the integrating input amplifiers which reduce the sensitivity to input noise levels and thereby results in minimizing the dead band required for proper operation without false actuations or chatter. Its operation may be described as follows:

If the partial pressure of oxygen is below the lower setpoint, the lower setpoint integrator receives an error signal and provides a ramp voltage output with a rate of change proportional to the input error. The upper integrator, meanwhile, remains inactive since it is clamped by a shorting diode. When the lower integrator output reaches a voltage equal to that preset in the level detector, a pulse is generated and the integrator reset to initial conditions. The pulse is transmitted by the channel

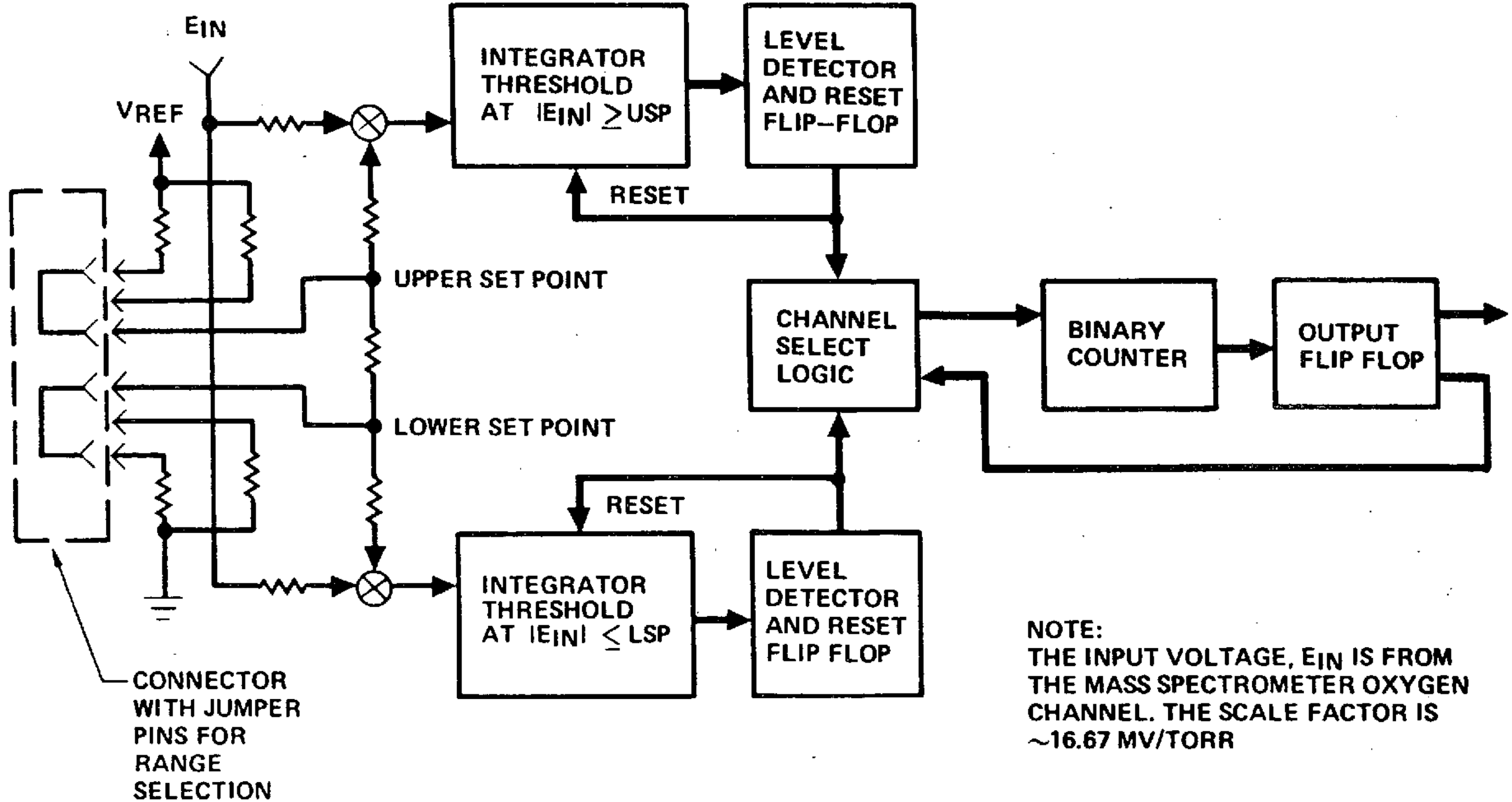


FIGURE 3. SIMPLIFIED BLOCK DIAGRAM OF OXYGEN CONTROL CHANNEL

select logic to the 4-bit binary counter. When 16 pulses have been received by this counter, the output flipflop assumes the ON condition, energizing the discrete signal output of the channel and reversing the channel select logic to receive pulses from the upper set point integrator.

The presence of the discrete output signal causes the water electrolysis unit to operate in the high output mode, or opens an O_2 supply solenoid valve, causing the cabin O_2 partial pressure to increase. When the MSS signal proportional to PPO_2 reaches the upper set point, the upper integrator starts to integrate as the lower integrator previously did. The operation of the upper level detector is the same as the lower level detector, producing an output pulse and resetting the integrator when the preset voltage is reached. The pulse output of this level detector is now transmitted through the channel select logic to the binary counter. Upon accumulating 16 counts, the output flip-flop switches to the OFF condition, de-energizing the discrete output and again switching the channel select logic.

The water electrolysis unit then assumes the low output mode, or the O_2 solenoid valve closed, causing the cabin pp O_2 to decrease, until the lower limit is again reached.

As a result of this operating characteristic, it is abvious that successful control operation depends upon the ability of the O_2 supply system to meet the requirements imposed by cabin leakage and high crew metabolic loads when in the high mode, while in the low mode the O_2 generation rate must be less than the minimum O_2 consumption.

The dynamics of the oxygen channel can be described by the following equation, similar to Equation 1,

$$p_o(t) = p_{oi} + \int \frac{12.08 \times 760}{V_c} \; m_o(t) - m_{co}) \; dt \qquad (9)$$

in which the specific volume of O_2 at standard conditions is 12.08 lb/cu ft and the time dependent addition of oxygen is represented by $m_o(t)$ which is assumed to have one of two possible values; higher or lower than the oxygen consumption, m_{co}.

The nominal oxygen consumption is given in Table 4.as 11.0 lb/day or 0.458 lbs/hr. The mass spectrometer output on the O_2 channel is given in Table 6 as $K_{SO} = \frac{1}{66}$ volts/torr.

Differentiating Equation 9 gives the rate of change of ppO_2, and substituting the nominal value for m_{co} and the cabin volume V_c = 2000 cu ft for the Shuttle Orbiter results in the following expression:

$$\frac{dP_o(t)}{dt} = \frac{12.08 \times 760 \times 0.458}{2000} \left[\frac{m_o(t)}{m_{co}} -1\right]$$

$$= 2.102 \left[\frac{m_o(t)}{m_{co}} -1\right] \text{ torr/hr} \qquad (10)$$

For constant O_2 consumption (e.g., the nominal rate), and constant O_2 supply rate at either a high or low value, the resulting rate of change in PPO_2 is seen to be a constant. This rate is shown for several typical values of $\dot{m}_o(t)$ in Table 7.

Table 7

RATE OF CHANGE OF PPO_2 FOR VARIOUS RATES OF O_2 GENERATION

$\frac{m_o(t)}{m_{co}}$ high mode	low mode	$\frac{d\,P_o(t)}{dt}$ torr/hr.
1.10	0.90	± 0.210
1.25	0.75	± 0.526
1.50	0.50	± 1.051
2.00	0.00	± 2.102

For the water electrolysis unit, in which design capacity establishes the unit size and weight, it was planned to use values of $\frac{m_o(t)}{m_{co}}$ close to unity. It can be seen that, for $\frac{m_o(t)}{m_{co}} = 1.10$, the rate of pressure change is quite low, requiring 4.76 hrs for 1 torr. For a gaseous or cryogenic system, larger values of gas in-flow are more convenient since the risk of transient errors due to high metabolic loads is reduced. For this type of system, it is typical to select $m_o(t) = 2\ m_{co}$ or $m_o(t) = 0$ (an on-off system). There is no reason to restrict the high flow condition to 2 x the nominal, but this does result in a 50% on-time for the O_2 valve.

Referring back to the description of O_2 channel operation, it is seen that the operating band of ppO_2 is composed of three parts. First, in order to cause switching to HIGH mode, the ppO_2 must be below the lower set point long enough to cause 16 integrator pulses. While in the high mode, the ppO_2 must increase by this amount. Second, it must increase by the amount of the difference between the lower set point and the upper set point. Third, it must exceed the upper set point long enough to cause 16 pulses from the upper integrator.

Since the integrators of the O_2 channel have the same design as that of the N_2 channel,

$$K_{po} = 10560 \text{ pulses/hr/volt}$$

The integrator output frequency, after the O_2 partial pressures has reached the upper set point, is given by

$$F_i(t) = K_{PO}\ K_{SO}\ (p_o(t) - p_{ou})$$

$$F_i(t) = \frac{10560}{66}\ (p_o(t) - p_{ou})$$

$$F_i(t) = 160\ (p_o(t) - p_{ou}) \tag{11}$$

Differentiating,

$$\frac{d\,F_i(t)}{dt} = 160\,\frac{d\,p_o(t)}{dt}$$

and substituting Equation 10,

$$\frac{d\,F_i(t)}{dt} = 160 \times 2.102 \left(\frac{m_o(t)}{m_{co}} - 1\right)$$

$$= 336.3 \left(\frac{m_o(t)}{m_{co}} - 1\right) \tag{12}$$

Since $\frac{m_o(t)}{m_{co}}$ is a pre-selected constant value on increasing pp O_2,

Equation 12 can be integrated:

$$F_i(t) = 336.3 \left(\frac{m_o(t)}{m_{co}} - 1\right) (t - t_{ou}) \text{ pulses/hr.} \tag{13}$$

The pulse frequency is therefore proportional to the time since crossing the upper set point. The total number of pulses can be found by integrating again with respect to time:

$$\int F_i(t)\,dt = \frac{336.3}{2} \left(\frac{m_o(t)}{m_{co}} - 1\right) (t - t_{ou})^2$$

and setting this expression equal to 16 determines the time required to switch off the discrete output signal,

$$16 = 168.2 \left(\frac{m_o(t)}{m_{co}} - 1\right) (t - t_{ou})^2$$

$$\text{or} \quad t - t_{ou} = \sqrt{\frac{16}{168.2\left(\frac{m_o(t)}{m_{co}} - 1\right)}}$$

$$= \sqrt{0.09512/\left(\frac{m_o(t)}{m_{co}} - 1\right)} \tag{14}$$

Equation (14) as derived above is subject to the restriction that pp O_2 is increasing, or $\frac{m_o(t)}{m_{co}} > 1$. By a similar analysis it can be shown that, when $\frac{m_o(t)}{m_{co}} < 1$, the time required to switch to high mode after crossing the lower set point is also given by Equation (14).

The time delays caused by the integration are listed on Table 8, along with the resulting overshoot or undershoot in pp O_2.

According to Table 2, for 14.7 psia operation the lower integrator set point is to be 165.7 (2.511 volts) and the upper integrator set point, 166.7 torr (2.526 volts). For an oxygen flow of 2 m_{co} when HIGH, and zero when LOW, the O_2 channel will switch to HIGH at 165.03 torr and remain until the pp O_2 reaches 167.37 torr. The time required for this period will be 1.11 hrs. The control will then switch to LOW, and an additional 1.11 hrs will be required to decrease the pp O_2 to 165.03 torr, at which time the control will switch to HIGH. The O_2 flowrate during HIGH mode operation should be 0.916 lb/hr, or 22 lb/day. The above analysis assumes that the oxygen consumption remains constant at 11 lb/day.

Table 8

OVERSHOOT/UNDERSHOOT DUE TO INTEGRATOR TIME CONSTANT

O_2 Inflow Factor $\frac{m_o(t)}{m_{co}} - 1$	Rate of Pressure Change torr/hr.	Switching Time $t-t_{ou}$ (Eqn. 14) hrs.	Overshoot/ Undershoot torr
$\pm$ 0.10	$\pm$ 0.210	1.007	0.211
$\pm$ 0.25	$\pm$ 0.526	0.637	0.335
$\pm$ 0.50	$\pm$ 1.051	0.451	0.474
$\pm$ 1.00	$\pm$ 2.102	0.319	0.671

4.2.3 Packaging Considerations

When designing to meet the SSP requirements, the ACS control unit was to be put into an ATR relay rack housing and to include 400 Hz to dc power converters, output devices to operate 400 Hz motor driven valves, all interface equipment to provide signals to the data management system, and the capability to operate in either a primary or backup position. It was required to provide, insofar as possible, a control which was flight qualifiable. However, most of the auxiliary devices, including the ATR rack, input/output connectors, power supplies, and valve switching devices, were not flight type equipment. At this time it was decided to package the basic controls in the Electronic Control Assembly, which was a flight qualifiable unit, and include the other auxiliary devices, along with the ECA, in the ATR case.

When the SSP requirements were deleted, it was decided to leave the ECA design unchanged, to retain the power supplies, and to substitute available valves for the 400 Hz operated valves originally planned. The auxiliary components, not included in the ECA, were mounted in a Bench Checkout Unit, which also served for data system interface and as a distribution point for the various circuits involved.

Section 5

DETAIL DESIGN

Design of the ACS included circuit design, circuit boards, packaging, prototype testing, final design and interface definition. A significant effort was devoted to auxiliary circuit design and interface definition for the SSP program. However, since that program was cancelled before final design was completed, this section will describe only that portion of the system design related to the Space Shuttle application.

5.1 Circuit Design

Circuit design effort for the Shuttle application was primarily associated with the ECA. It included the input circuit selection, integrating amplifier, logic circuit, clock and timing and circuit boards. These will be discussed in turn.

5.1.1 Input Circuit Selection

The input stages of both channels of the control are analog integrating amplifiers. The basic circuit for such an amplifier is shown in Figure 4. The function of the amplifier, A, is to present relatively very high impedance to the input circuit and amplify the voltage at the input node by a factor that approaches infinity. In the application shown, the output voltage will have the opposite polarity to the input voltage.

The equation for an analog integrating amplifier, as shown in Figure 4, based on the assumption that the amplifier input voltage is held at zero by the high gain characteristic, is:

$$\frac{d_{eo}}{dt} = -\left[\frac{e_i}{R_2C} + \frac{e_R}{R_1C}\right] \qquad (15)$$

The condition for the set point is satisfied when the integrator output voltage is constant, and no pulses are being produced. Therefore,

$$\frac{e_i}{R_2 C} + \frac{e_R}{R_1 C} = 0$$

and

$$\frac{e_1}{-e_R} = \frac{R_2}{R_1} \qquad (16)$$

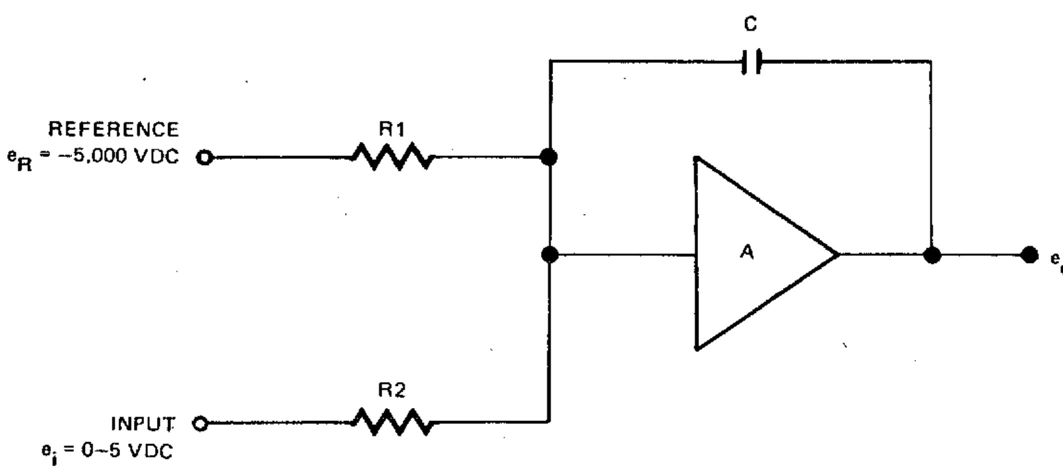


Figure 4. Typical Basic Integrating Amplifier Circuit

In this application, e_R is fixed at -5.000 volts and set point selection is done by varying the values of R_1 and/or R_2. Three set points are required for the N_2 channel. It is desirable to accomplish the set point selection by using a minimum of circuitry external to the ECA. It was assumed that preselected fixed resistors would be used with external shorting jumpers to select the set point. It was preferred not to use potentiometers due to the resulting loss in reliability.

There are two basic methods of accomplishing the set point selection within these ground rules. One is to use a fixed resistor on the reference voltage and vary the resistance of the input signal leg. This is shown in Figure 5. The other is to leave the input signal leg resistance fixed and to vary the resistance of the reference voltage input, as shown on Figure 6.

For the first method, in which the input signal is attenuated, the equivalent to Equation 16 is

$$\frac{e_1}{5.000} = \frac{R_2 + R_3 + R_4}{R_1} \tag{17}$$

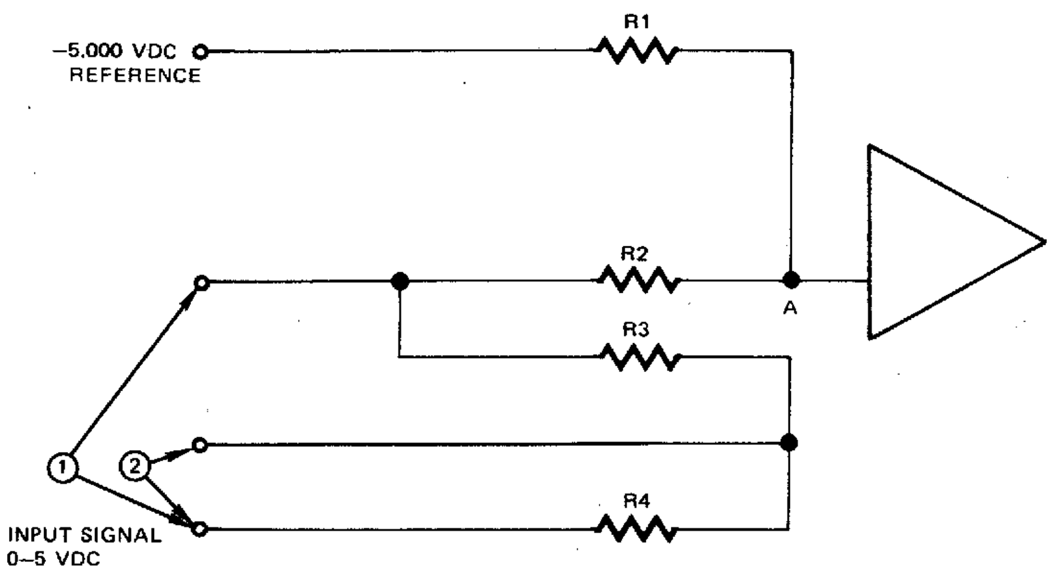
in which shorting jumpers are applied to eliminate R_4 to obtain the 10 psia set point and $R_3 + R_4$ for the 5 psia set point. No shorting jumper is used for the 14.7 psia set point.

For the second method, Equation 16 becomes:

$$\frac{e_1}{5.000} = \frac{R_4}{R_1 + R_2 + R_3} \tag{18}$$

and shorting jumpers are used to eliminate R_1 for 10 psia and $R_1 + R_2$ for 14.7 psia. The 5 psia set point is obtained by removing shorting jumpers.

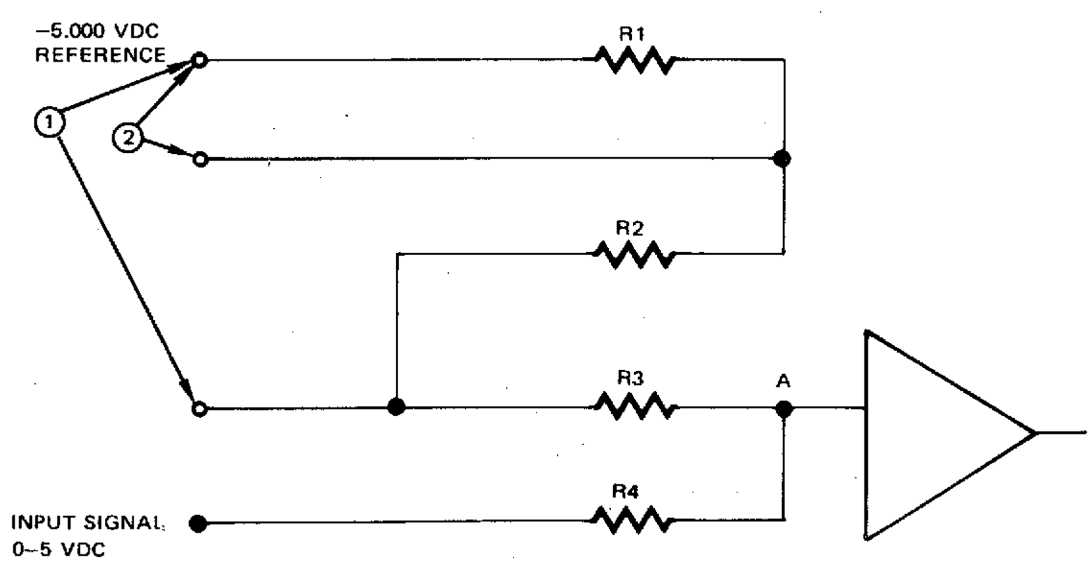
Since the 14.7 psia condition is most important, it was emphasized in circuit analysis. The required resistance ratios for the N_2 set points are listed on Table 9.



NOTES:

(1) INSERT SHORTING JUMPER HERE FOR 5 PSIA SET POINT
(2) INSERT SHORTING JUMPER HERE FOR 10 PSIA SET POINT
(3) REMOVE SHORTING JUMPER FOR 14.7 PSIA SET POINT

Figure 5. Set Point Selection By Attenuating Input Signal



NOTES:

(1) INSERT SHORTING JUMPER HERE FOR 14.7 PSIA SET POINT
(2) INSERT SHORTING JUMPER HERE FOR 10 PSIA SET POINT
(3) REMOVE SHORTING JUMPER FOR 5 PSIA SET POINT

Figure 6. Set Point Selection By Attenuating Reference Voltage

Table 9

RESISTANCE RATIOS FOR N_2 SET POINT SELECTION

Set Point psia	pp N_2 torr	MSS output e_i volts	Resistance Ratio $e_i/5.000$
5	65.7	0.498	.0996
10	342.3	2.593	.5186
14.7	585.2	4.433	.8866

In accordance with the amplifier design requirements, as explained in the next section, a feedback capacitor value of C = 0.1μf was selected, and the required value for reference voltage resistor is 614 K for the 14.7 psia set point. The corresponding value for the input signal resistor is therefore 544.3 K. Using these values as a basis, the resistor values shown in Table 10 were calculated for the three set points and two comparative methods of input circuit design.

It is shown in Table 10 that, with the input signal attenuation method, the input impedance of the amplifier (load on the MSS) varies between 61.2K and 544.3K over the required range of set points. Referring to Equation 15, it is seen that this causes the integrator gain to vary over a range of almost 10:1. The second method, of reference voltage attenuation, was therefore selected, since it results in constant input gain as well as constant loading of the MSS.

Table 10

RESISTOR VALUES FOR SET POINT SELECTION - N_2 CHANNEL

	Input Signal Attenuation	Reference Voltage Attenuation
R_1	614 K	4.4 M
R_2	61.2 K	432 K
R_3	257.2 K	614 K
R_3	226. K	544.3 K

The same input circuit scheme was selected for the O_2 channel, but there are only two set points required: for 5 psia and for 10 and 14.7 psia, with an upper and lower limit at each set point. By following the same analytical procedures as with the N_2 channel and using the same amplifier characteristics, the circuit constants were derived as shown in Table 11. It is noted that an arbitrary decision was made to design the 5 psia set point without builtin dead-band, since the dynamic analysis previously presented indicated that adequate protection against false actuations was provided by the integrating amplifiers, and it was desired to evaluate this design. The other set point was designed with a nominal dead-band of 1.3 torr. The resulting input circuit is shown on Figure 7.

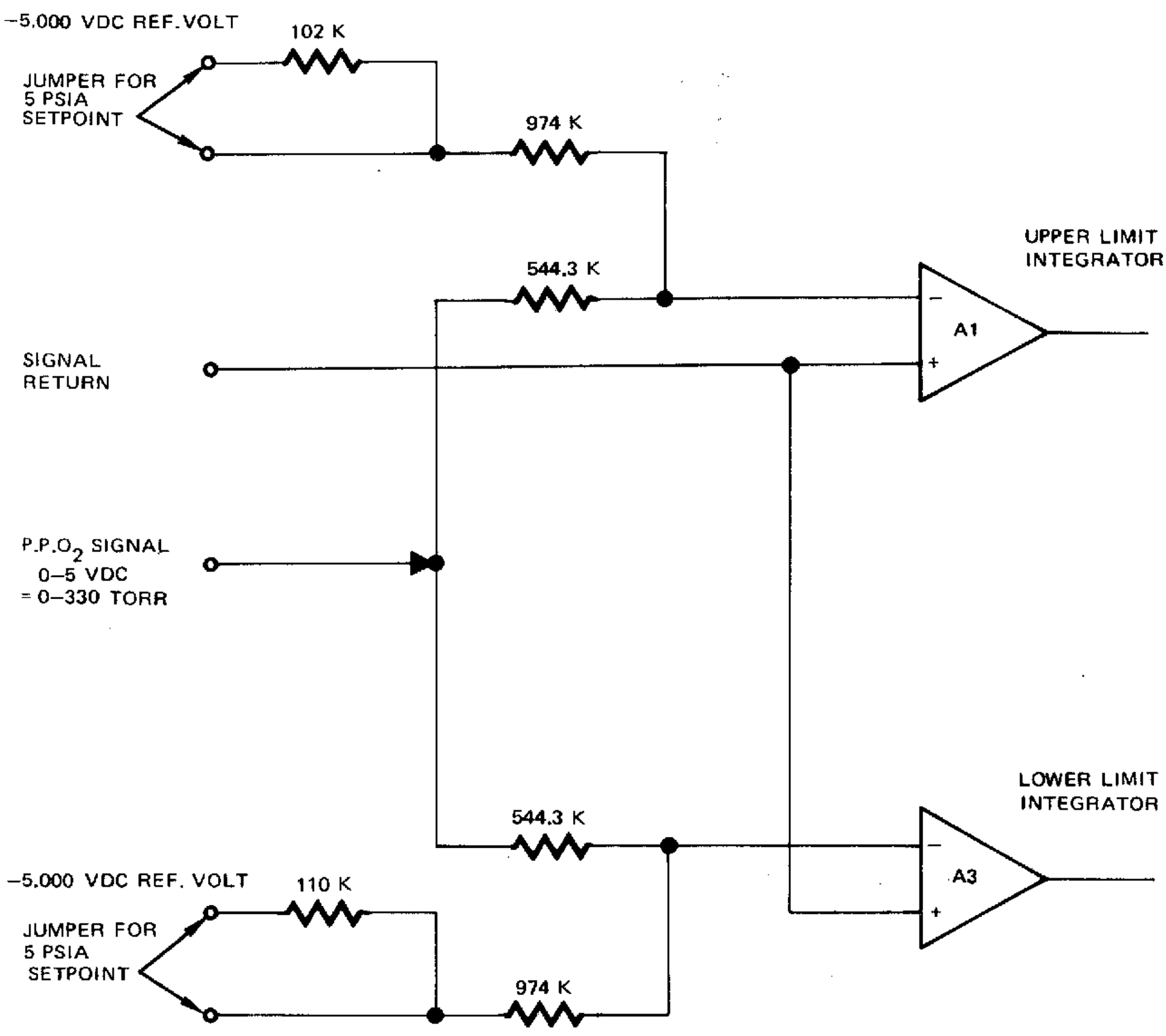


Figure 7. Oxygen Channel Input Circuit

Table 11

RESISTOR VALUES FOR SET POINT SELECTION - O_2 CHANNEL

Set Point		PP O_2 torr	MSS Output e_i volts	Resistance ratio $e_i/5.000$	Resistance* ohms
10 and 14.7 psia	Upper Limit	167.0	2.530	0.5059	1076 K
	Lower Limit	165.7	2.511	0.5021	1084 K
5 psia	Upper Limit	184.4	2.794	0.5588	974 K
	Lower Limit	184.4	2.794	0.5588	974 K

5.1.2 Integrating Amplifiers

Figure 8 shows the complete circuit associated with the N_2 integrating amplifier. The input circuit values selected in the previous section are shown. The 0.1 µf feedback capacitor was selected as a convenient size for circuit board application, using a precision polystyrene capacitor. The amplifier output goes to a zero crossing detector which momentarily actuates the solid state reset switch. The resulting input causes the amplifier output voltage to go negative. The limit is imposed by the upper diode circuit. The zener diode, D_2, is an LM 103 with a 5.6 volt breakdown. The diode D_1 prevents reverse current, the 10K resistor provides a minimal current at breakdown.

With the 5.6 v. breakdown across the zener diode and assuming a 0.6 v. drop across diode D_1, the limiting output voltage of the amplifier is -6.2 volts. This is the initial condition for integration. The rate of change of output voltage relative to input voltage is given by Equation 15 and is

$$\frac{d\,e_o}{dt} = + \frac{\Delta e_i}{R_4 C} \tag{19}$$

in which Δe_i is the input signal deviation from the set point.

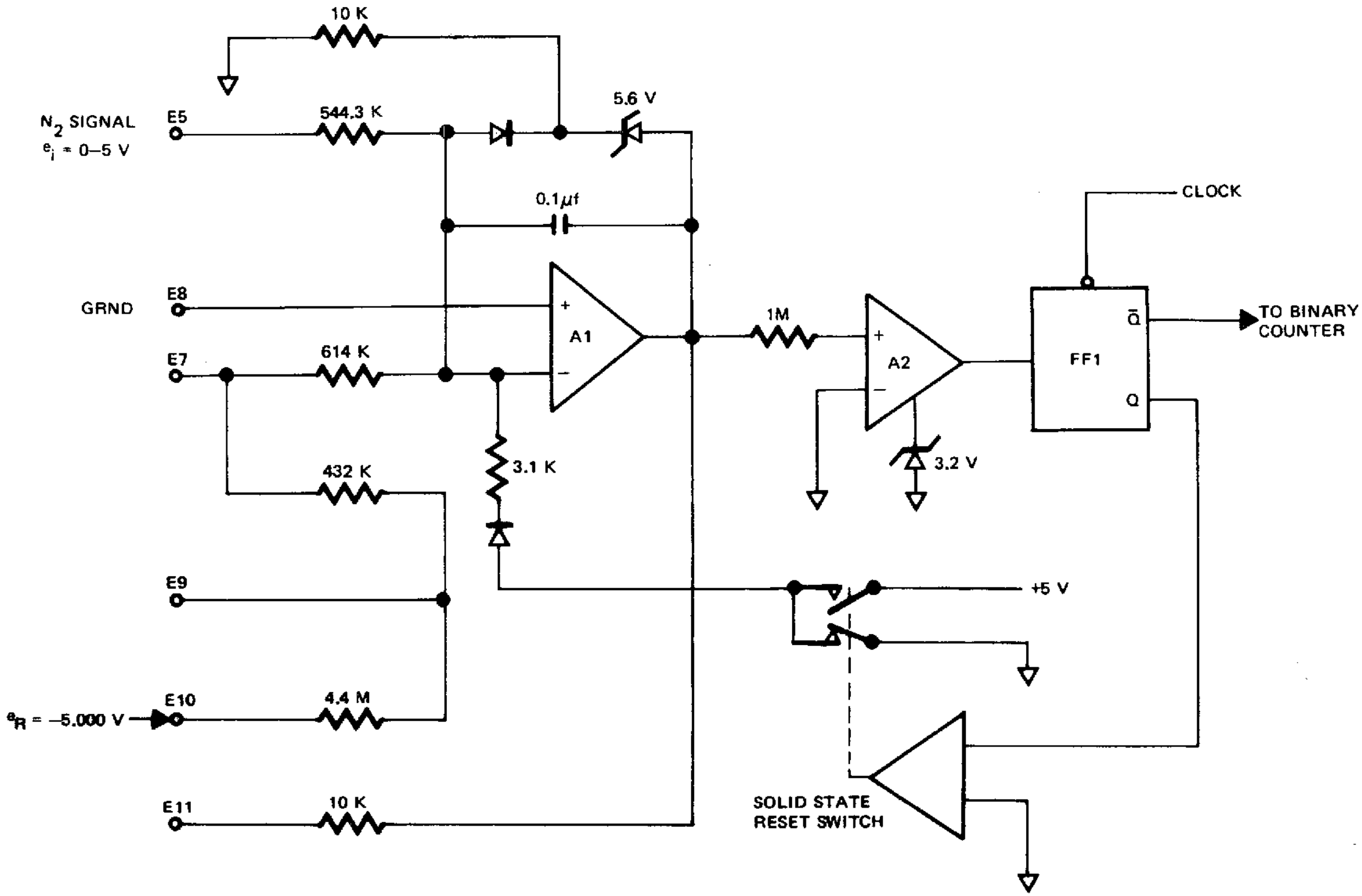


Figure 8. N_2 Channel Integrator Circuit

The integrator output voltage will increase to 0 and then the zero crossing detector will reset the amplifier to -6.2 volts and produce an output pulse. 16 of these cycles will cause a solenoid valve pulse. The design condition is 10 valve pulses or 160 integrator cycles per hour for a 2 torr error in input voltage. This corresponds to an integrator period of 22.5 seconds for an input error of -0.01515 volts. The rate of output voltage change is given by 6.2/22.5 = 0.2756 volts/sec. Substituting in Equation 19,

$$0.2756 = \frac{0.01515}{R_4 \times 0.1 \times 10^{-6}}$$

$$\text{or} \quad R_4 = \frac{0.01515}{0.2756 \times 0.1 \times 10^{-6}}$$

$$= 0.5497 \times 10^{6} \text{ ohms}$$

$$= 0.549.7 \text{ K ohms}$$

This corresponds well with the selected value of R_4 which was used in the previous section. The corresponding gain of the nitrogen channel is given by the ratio of integrator pulses per volt input, or

$$K_{PN} = \frac{160}{.01515}$$

$$K_{PN} = 10560 \text{ pulses/hour/volt}$$

This is in good agreement with the required design value for K_{PN}.

The amplifier A2 is used as a zero crossing detector. The value of the input resistor (1M) was selected on the recommendation of the manufacturer to limit the input current. When the voltage out of amplifier A1 is negative, the output of A2 remains clamped at logic 0 by the forward drop across the zener diode and FFL remains in the reset state. When the output of A1 becomes greater than zero, the output of A2 becomes positive and is clamped at logic 1 by the zener diode. On the next clock pulse, FF1 changes state, producing an output pulse and reversing the position of the contacts on the double pole FET solid state switch. The integrator amplifier is reset to its initial condition during one clock pulse and FF1 is returned to the reset state on the next clock pulse, at which time the FET switch returns to its original state and the integrator is reset to initial conditions (about -6.2 v.).

The amplifiers used for the upper and lower integrators, the zero crossing detectors, and reset circuits for the O_2 channel are designed exactly the same as the N_2 channel.

5.1.3 Clock Circuit

The ECA is provided with an internal clock circuit which is used for controlling the binary logic elements and for timing the 10 second N_2 pulse to the solenoid valve. The clock circuit uses 2 one-shot multivibrators which are available in a single integrated circuit flat-pack. The pulse repetition rate is chosen so that a 12 bit binary counter can be used to provide the 10 second timing function required to control the nitrogen valve "ON" time. The following calculations are applicable:

$$\text{12 bit counter} = 2^{12} \text{ states} = 4096 \text{ counts}$$

$$\text{Repetition rate} = \frac{4096 \text{ counts}}{10 \text{ seconds}} = 409.6 \text{ counts/second}$$

$$T = \frac{1}{409.6} = 2.44 \text{ msec.}$$

Figure 9 shows the clock circuit which was selected. The pulse width of the clock output, tw, is given by

$$t_w = 0.32 \, R_T \, C_{EXT} \left(1 + \frac{0.7}{T_T}\right) \qquad (19)$$

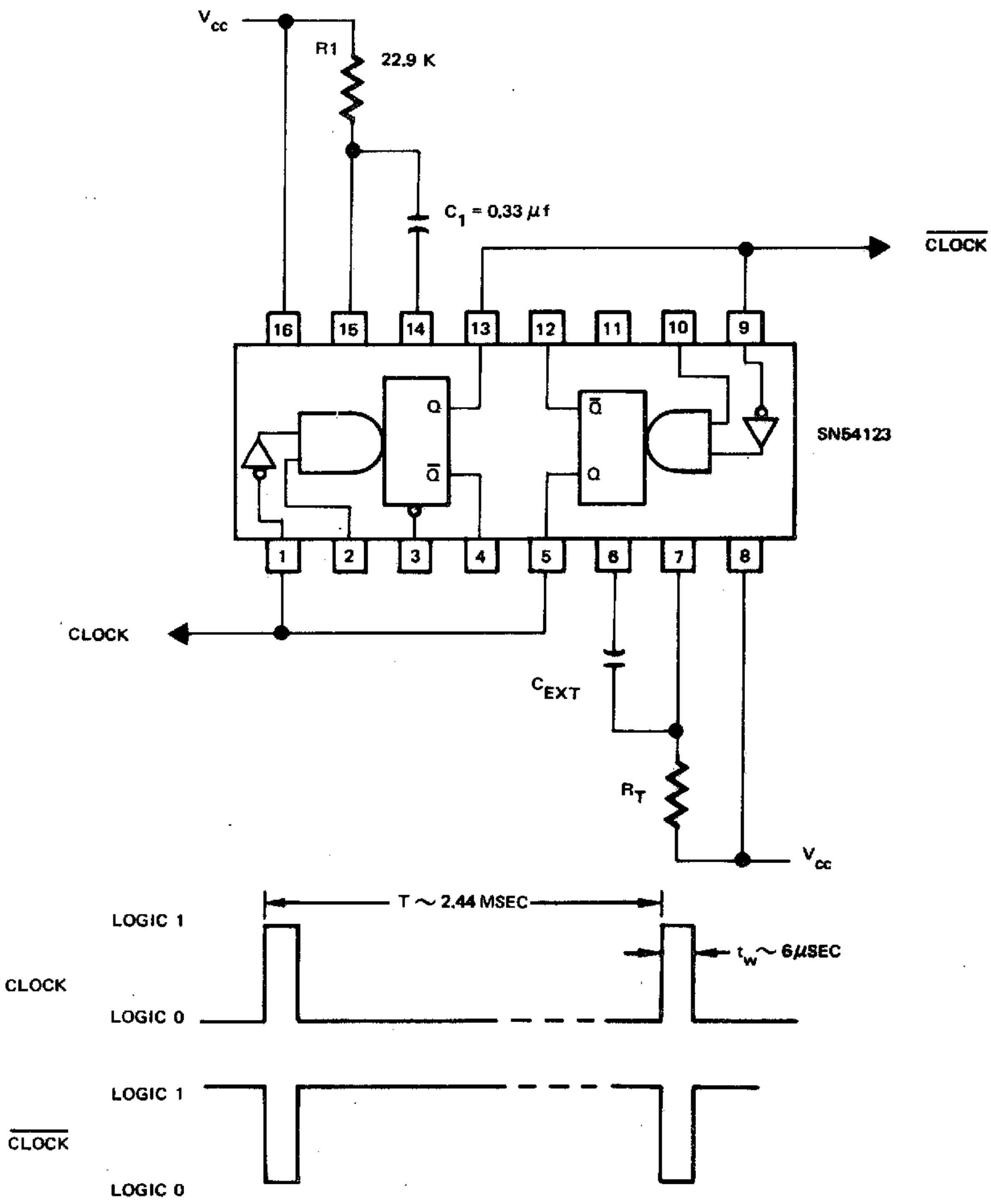


Figure 9. Clock Circuit and Timing

in which the following values were chosen:

$R_T = 5K$

$C_{EXT} = 3300\ \rho f$

Using the dimensions noted, t_w is expressed in nanoseconds. For the selected values, it is found that $t_w = 6019$ nsec $\sim 6\mu$sec.

The clock period, T, is also given by Equation 19, using the values of R_1 and C_1 for R_T and C_{EXT}. Assuming a value for $C_1 = 0.33\,\mu f$ and a required clock period of 2.44 msec or 2.44×10^6 nsec previously derived, it is found that R_1 should be 22.9K.

5.1.4 Logic and Output Circuits

The output pulses from the N_2 integrator circuit are accumulated in a 4-bit binary counter. Upon reaching a count of 16, a pulse to the output flip flop turn it ON. The 10 second period established by the clock counter circuit is then started. When completed, the output flip flop is turned OFF. This is the signal output for the N_2 channel. This signal is compatible with TTL logic and should be interfaced with a National Semiconductor DM 7820A line receiver or equivalent to drive the appropriate solid state switching circuit for energizing the solenoid valve.

The operation of the O_2 channel is similar except that integrator output pulses are received from either the HIGH or LOW channel depending upon the status of the channel select logic and accumulated in the 4-bit binary counter. The channel select logic will transfer pulses from the high channel if the output flip flop is in the HIGH state, and from the low channel if the output is in the LOW state. The output flip flop is switched from the HIGH to the LOW state upon receipt of the 16th pulse from the high channel, and conversely from LOW to HIGH state upon receipt of the 16th pulse from the low channel. As with the N_2 channel, this output flip flop produces a signal compatible with TTL logic and should be interfaced with a National Semiconductor DM 7820A line receiver or equivalent.

5.1.5 Circuit Boards

The electronic circuits of the EAC are mounted upon two circuit cards, each about 4 3/4 by 5 1/2 in. The boards are epoxy-fiberglass material and are composed of four layers. One of these layers is used as a ground plane. After fabrication they were conformal coated (not to exceed 0.010 in) with NASA Spec. MSC 393 circuit card coating material. All wiring is to terminal lugs. All wiring is 20 gage, teflon insulated.

5.1.6 Component Selection

Wherever possible, all components in the ECA are of known high reliability and procurred in accordance with MDAC Source Control Drawings. Where necessary because of lack of availability in accordance with schedule requirements, MIL-STD components were substituted. Major components where this was necessary included the 3 Deutsch output connectors on the ECA and the 3 0.1 μf capacitors used for feedback in the integrating amplifiers.

5.2 Prototype Testing and Final Design

Prototype circuit cards were built and tested to evaluate the circuit design and prove out the circuit board layouts. These boards were subjected to functional tests and high and low temperatures. Several minor changes to circuit board layout were made as a result of these tests but they generally verified satisfactory performance in all respects.

Corrections were made to design drawings and the final circuit cards were made from second generation prints, in accordance with normal manufacturing procedures. As a result, there were very few corrections to be made in the final boards.

5.3 Set Point Adjustment

As explained previously, it was intended to provide all required set-point circuit components on the boards by selecting proper resistance values, and determining the proper set point by inserting shorting jumpers in external leads to the ECA. Early in the Functional Checkout it was found that the selection of resistors had not resulted in adequate accuracy of control. It was found that resistive jumpers could be used in place of shorting jumpers, for the set points in which jumpers are used, and correction of the set point could be obtained. This is possible for the 10 and 14.7 psia set point of the N_2 channel and the 5 psi set point of the O_2 channel. A decrease in set point will result, depending on the jumper resistance. The input circuits were analyzed to determine the effect of jumper resistance and the results are presented in Table 12. On the N_2 channel it was found that the set point will decrease one torr for each 3100 ohms at the 10 psi set point and for each 1066 ohms at the 14.7 psia set point. On the O_2 channel, at the 5 psia set point, a decrease of one torr requires 1750 ohms for the low limit integrator and 1820 ohms for the high limit integrator.

Table 12

EFFECT OF EXTERNAL RESISTANCE ON CONTROL SET POINT

Jumper Resistance	N_2 Channel Set Point				Oxygen Channel 5.0 psia Set Point			
	10.0 psia		14.7 psia		Low Limit		High Limit	
K ohms	Volts	Torr	Volts	Torr	Volts	Torr	Volts	Torr
0	2.602	343.5	4.432	585.1	2.794	184.4	2.794	184.4
5	2.589	341.8	4.397	580.4	2.781	183.5	2.781	183.5
10	2.577	340.2	4.361	575.7	2.768	182.7	2.768	182.7
15	2.565	338.6	4.327	571.1	2.757	182.0	2.757	182.0
20	2.553	337.0	4.293	566.7	2.746	181.3	2.747	181.3

5.4 Interface Definition

The interfaces between the ACS and related equipment are described in detail in Reference 6, and will be summarized in this section.

5.4.1 Mass Spectrometer Sensor

The Mass Spectrometer Sensor is contained in a cyclindrical package 7.2 inches in diameter by 15.72 inches in length. Feet are provided for support in the normal operating position.

Input power and control functions are supplied to the MSS through the electrical connector labeled J1. Connections to the Mass Spectrometer Sensor Input Connector J1 are accomplished by interconnection with the Perkin Elmer Interface Buffer assembly. The output signals from the MSS are obtained from connector J2 on the MSS assembly. The output connector is Microdot P/N MD5300H9-19P-N and mates with cable connector MD5306E9-19S-N. Pin assignments are as shown in Table 13.

The MSS must be supplied with a gas sample representative of the cabin atmosphere through a sampling line having adequate velocity to minimize transient time without excessive pressure drop. Typically a 1/4 in OD tube has been used, with a length of about 20 ft and a flow rate of 100-200 cc/min. Flow through the tube may be induced by locating the intake downstream of an air conditioning blower and returning the sample to the blower inlet or to the main chamber.

The output signal sensitivity and accuracy of the MSS has been previously presented (Table 6).

TABLE 13. MASS SPECTROMETER ELECTRICAL INTERFACE

Connector Designation: J2

Connector Part Number: MD 5306E9-19S-N (Microdot)

Use: Output Connector, Mass Spectrometer Sensor

Pin No.	Function	Characteristics
1	Signal return	Isolated return to MSS
2	H_2 Partial Pressure	0-5 VDC, Source Impedance 10 ohms
3	H_2O Partial Pressure	0-5 VDC, Source Impedance 10 ohms
4	N_2 Partial Pressure	0-5 VDC, Source Impedance 10 ohms
5	O_2 Partial Pressure	0-5 VDC, Source Impedance 10 ohms
6	CO_2 Partial Pressure	0-5 VDC, Source Impedance 10 ohms
7	Total Hydrocarbons	0-5 VDC, Source Impedance 10 ohms
8-19	Not Used	No Connection

5.4.2 Interface Buffer Assembly

The Interface Buffer Assembly was used with the MSS and was built by Perkin Elmer Corporation. It is described in Perkin Elmer Specification 342927. It is primarily a control unit and signal buffer for the MSS. The control unit portion provides power mode, control loop mode and filament selection. All power is provided from external sources to the Buffer Power Input Connector. Operation of the IBA in this program did not use the System Test Unit (STU); therefore, all operation was in the LOCAL mode. The Buffer amplifiers were not used so that the ± 15 vdc power input was not required. The MSS output signals were patched from the buffer amplifier "input" taps to corresponding taps on the face of the BCU. The IBA therefore introduce a 1000 Ohm resistor into the output of each MSS channel.

5.4.3 Electronic Control Assembly

The ECA is contained in an aluminum housing 7.0 x 6.0 x 2.25 inches. Mounting of the ECA is accomplished by using four (4) #10 Hex Bolts (Part No. AN-32A) and four (4) 0.25 inch spacers (Part No. NAS 43DD3-16). The mounting hole pattern is 0.25 inch holes or nut plates in a 4.0 inch x 5.5 inch pattern. Three electrical connectors are provided on the ECA, for input signals from the MSS, power input, and output signals. Pin assignments are given in Reference 6.

Input signals to the ECA are provided through the connector J1. The J1 connector is MDAC controlled part number ST201R10N19SN. The cable mounted mating connector is MDAC Number ST186R10N19PN which is the high reliability equivalent of Deutsch part Number RTK06-10-19PN. The impedance looking into the nitrogen or oxygen inputs is a function of the range selected and in all cases exceeds 1×10^5 ohms.

Electrical power is supplied to the ECA through connector J2. The J2 connector is a MDAC controlled part with the designation ST201R8N7PN. The cable mounted mating connector is designated ST186R8N7SN. This is a high reliability equivalent of Deutsch Part Number RTK06-8-7SN.

Power requirements of the ECA are $\pm$ 15 vdc and + 5.0 vdc. The $\pm$ 15 vdc power source must be capable of supplying 20 mA from each source, with a tolerance of 0.15 vdc. The 5.0 vdc power source is required to provide 100 mA. Combined line and load regulation must be 0.5% or better. The RMS value of ripple voltage must be less than 5 mv. The output signals from ECA are accessible from the J3 connector. This connector is MDAC Number ST201R10N19PN which mates with a cable terminated with a MDAC Number ST186R10N19SN or the equivalent Deutsch Number RTK06-10-19SN.

The following is a discussion of the output signals on connector J3 and include a description of the signal characteristics as applicable:

a. Change of operation of the nitrogen channel for total pressure of 5.0, 10.0 and 14.7 PSIA is controlled by pins 1, 2 and 6 of J3. For 5.0 PSIA total pressure, pins 1 and 2 are not connected (open circuit). For 10.0 PSIA total pressure operation, jumper pin 2 to pin 6 (Reference Voltage). For 14.7 PSIA total pressure operation, remove the jumper from pin 2 and jumper pin 1 to pin 6.

b. The nitrogen integrator reset pulse is provided on J3-4 for test purposes. This signal is buffered by a TTL gate whose output is not used internally, however, it should not be connected to direct wire interconnections of more than 6 inches. When the logic level of this output is low the voltage presented to the nitrogen channel is integrated. A reset pulse is indicated by a transition to logic one and back to low. Under nominal conditions this pulse recurs every 22.5 seconds. The pulse width is 2.44 milliseconds (one clock time).

c. The nitrogen integrator output is connected to J3-5 and is used for test purposes. A 10K isolation resistor is connected internally to prevent damage or degradation due to inadvertent shorting of this signal to ground. The output voltage is a ramp voltage changing from about -6.0VDC to 0VDC in the nominal 22.5 second integration period.

d. The upper oxygen integrator channel set point is changed by jumpering J3-9 to J3-7. This provides the required O_2 partial pressure upper limit for operation at 5.0 PSIA total pressure. When operated without the jumper, the setting will be correct for 10 and 14.7 PSIA operation.

e. The lower oxygen integrator channel set point is changed by jumpering J3-8 to J3-10. This provides the required O_2 partial pressure lower limit for 5.0 PSIA total pressure. As above, the 10 and 14.7 PSIA set points are obtained without the jumper.

f. The oxygen resupply control signal is output on J3-11 and J3-12. The source of this signal is a TTL differential line driver in the ECA. Several types of transmission lines and terminations may be used.

The choice is dependent upon the length of the line. For this application a pair of No. 26 or 28 wires approximately 20 feet in length with thin insulation twisted about 30 turns per foot is recommended. The terminating device is the National DM7820A connected as a differential line receiver using its internal terminating resistor.

g. The nitrogen resupply control signal is output on J3-13 and J3-14. This source of signal is also a TTL differential line driver as described in (f) above. Transmission line and termination should be handled as described above.

h. The oxygen channel lower set point integrator output is connected to J3-15 through a 10K isolation resistor. This voltage is brought out for test purposes only.. The characteristics of this signal is a ramp output voltage varying from -6 volts to ground. When the voltage crosses zero it is rapidly reset to the -6.0 volt level. The repetition rate is a function of the input to the channel.

i. The oxygen channel upper set point integrator is output on J3-16 through a 10K resistor. This voltage is similar to the lower oxygen integrator output except the ramp voltage varies from approximately +6.0V to 0 when the oxygen partial pressure input is greater than the upper set point.

j. J3-17 is used for test purposes and is connected directly to the +5.0VDC logic supply input.

5.4.4 Bench Checkout Unit

The Bench Check Unit (BCU) has been designed to be used in the checkout and test of the Atmosphere Control System. Although it has not been developed specifically as part of the ACS it may be used to provide power supply voltages and valve interface circuitry at the option of the user. Therefore a description of the unit and its interfaces is included.

The BCU is contained within a standard commercial enclosure and provides test point access, power converters, valve drivers, and a method to select the ACS total pressure operation point (5.0, 10.0 or 14.7 PSIA). The external dimensions are approximately 17.5" x 18" x 6".

Test points are brought out to front panel banana jacks. The following is a discussion of the front panel test points, which is shown on Figure 10:

a. Mass Spectrometer Outputs - These seven test points are directly wired to the Mass Spectrometer Outputs. All signals are 0 to 5 VDC level signals with low impedance output (10 ohms are less).

b. ECA Inputs - The inputs to the Electronic Control Amplifier Oxygen Channel, nitrogen channel and common are brought out to three banana jacks. These jacks are located directly below the MSS outputs so that jumpers may be inserted to connect the MSS outputs to the ECA inputs. When the jumpers are removed, inputs from an external precision voltage source may be substituted for calibration or test purposes.

c. ECA Test Signals - This group of test points provide access to those ECA output signals discussed in Paragraph 5.4.3 above. These terminals are used primarily for test and calibration purposes.

d. N_2 Range - The purpose of bringing these four points to the test panel is to provide a remote method of changing the nitrogen channel input for operation at selected total pressure. With no jumper in place the nitrogen channel will provide proper operation

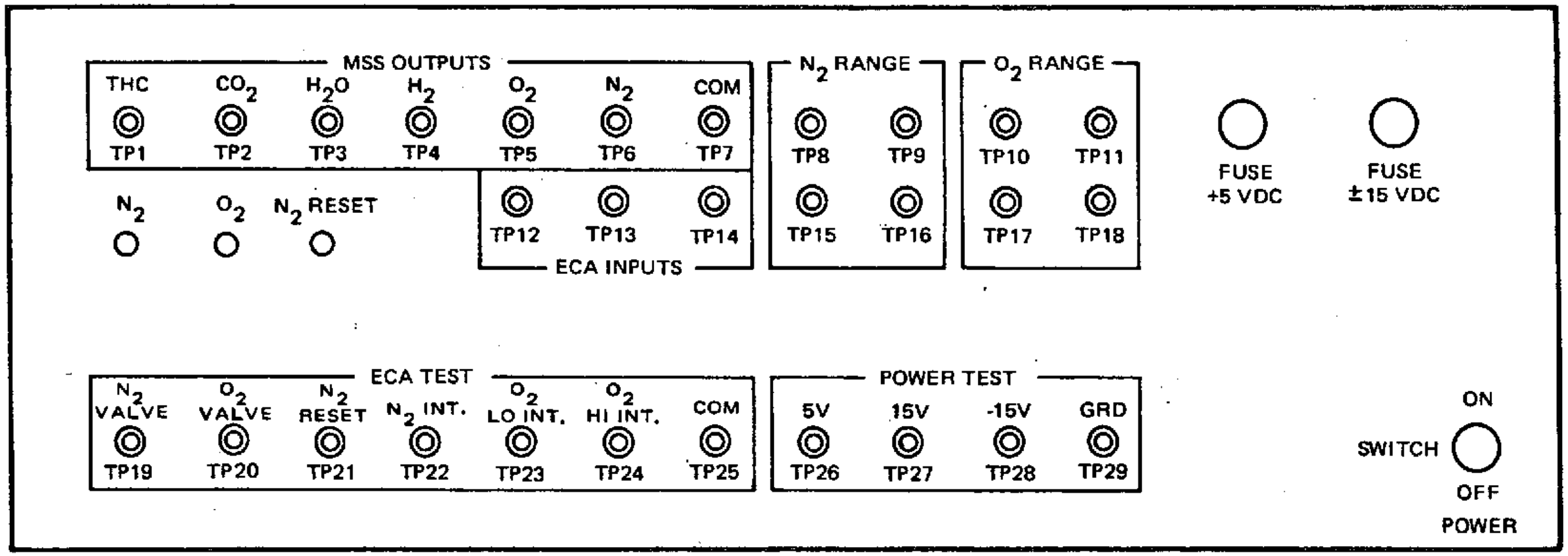


FIGURE 10. BENCH CHECK UNIT FRONT PANEL

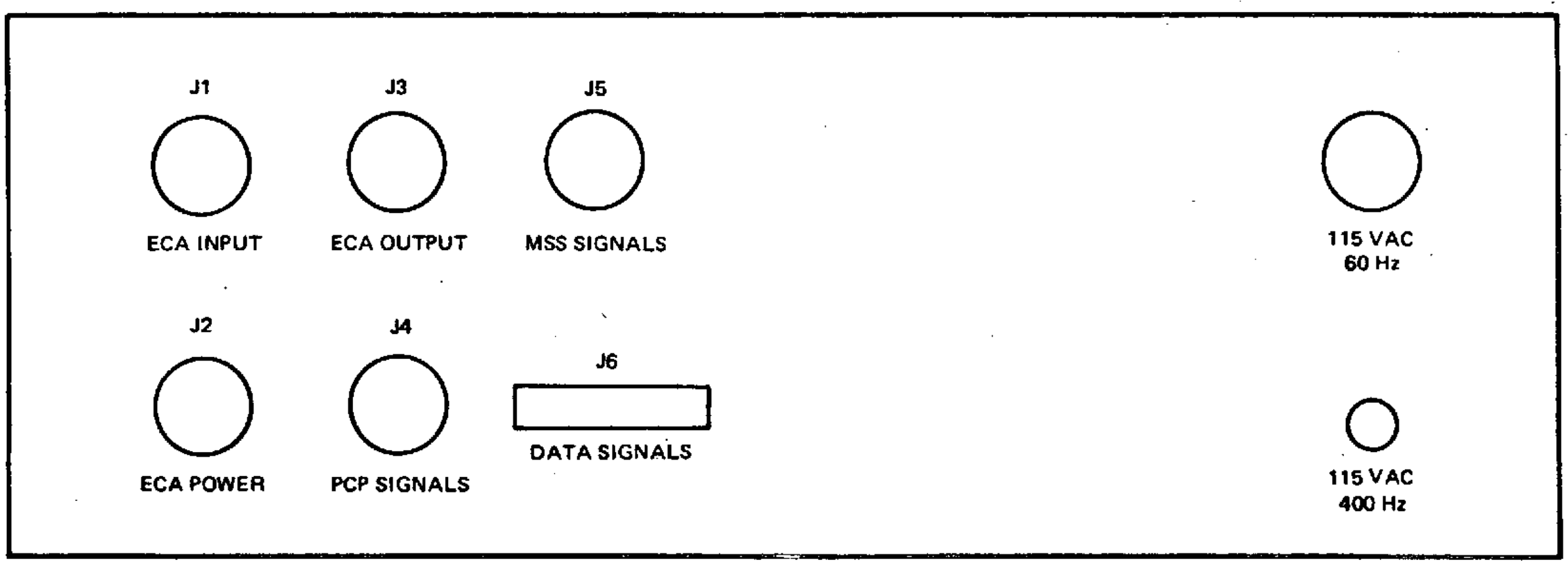


FIGURE 11. BENCH CHECK UNIT BACK PANEL

for 5.0 PSIA total pressure. For operation at selected total pressure of either 10.0 PSIA or 14.7 PSIA a jumper is placed between the appropriate terminal and the reference terminal.

e. O_2 Range - These test points provide a method of remotely changing oxygen channel operation for 5.0 PSIA total pressure. Jumpers are installed from the reference voltages to the upper and lower test points for correct O_2 partial pressure at 5.0 PSIA.

f. Power Test Points - The +5 VDC, +15 VDC, -15 VDC and power ground are brought out to these test points for monitor purposes.

The front panel also includes fuses for the +5 VDC and the ± 15 VDC power supplies, a power switch for the 115 V 400 Hz ac power input, and 3 light emitting diodes (LED). From left to right the first light indicates when the N_2 solenoid valve is energized, the second when the O_2 solenoid valve is energized and the 3rd flashes each time an N_2 reset pulse occurs. The O_2 light stays on until the O_2 level reaches the set point. This duration can vary between a few minutes and a few hours. The N_2 light is normally on only 10 seconds. The on period of the flashing light is about 0.2 seconds.

Electrical connections are provided on the rear panel of the BCU, shown on Figure 11. The connectors and their functions are described in Table 14. In addition there are provisions for input of 115 VAC, 400 Hz for the precision power converters and 115 VAC, 60 Hz for operating the O_2 and N_2 solenoid valves. Details of pin assignments are given in Reference 6.

In addition to the interconnecting wiring provided in the BCU, there are also two power converter modules and drivers for the O_2 and N_2 solenoid valves. The power converter modules transform 115 V 400 Hz to +5 VDC and ± 15 VDC respectively. These DC voltages are used to supply power to the ECA.

The logic level signals from the ECA oxygen and nitrogen channels are received by Integrated Circuit Line Receivers. The output of the line receivers are used to drive solid state relays which control the operation of the solenoid valves. The present configuration of the BCU provides control of 115V 60 Hz solenoid valves. The output solid state relay can be changed to drive other types of valves if desired.

Table 14

ELECTRICAL CONNECTORS OF THE BENCH CHECKOUT UNIT

Connector	Manufacturer	Part Number	Function
J1	Deutsch	RTK00-10-19 SN	MSS signals for O_2 and N_2 to the ECA
J2	Deutsch	RTK00-8-7PN	Power to the ECA
J3	Deutsch	RTK00-10-19PN	Signals from the ECA
J4	Bendix	PT07A-12-10S	Power output to O_2 and N_2 valves
J5	--	MD 5300H9-19P-N	Signals from MSS
J6	--	DCMA 37S-A106	Signals to Data System

5.4.5 Pressure Control Panel

A Pressure Control Panel (PCP) was furnished by MDAC for use in testing the ACS, providing the pulse counters and pneumatic components required for O_2 and N_2 flow control. The unit contains 2 solenoid valves that are driven by the signals from the BCU. Each solenoid is connected as shown in Figure 12. A pressure regulator maintains a fixed, known pressure high enough to produce sonic flow through the metering orifice when the solenoid valve is opened. The sonic flow condition yields a constant flow rate through the orifice. For this test the upstream pressure was regulated at approximately 20 psig. The quantity of gas admitted per pulse is then determined from the regulated upstream pressure and the timed pulse duration. The electric counter, in parallel with the solenoid valve coil, registers one count per pulse. Total gas usage can be found by multiplying the number of pulses times the quantity of gas admitted per pulse. An additional pair of counters is provided for counting pulses of the O_2 and N_2 solenoid valves when adequate gas pressure is not available. The PCP includes pressure switches in the O_2 and N_2 lines to stop gas flow and switch counters when supply pressures are low, and indicating lights to show the operating mode. The PCP operates on 28 vdc for the logic circuitry and 115V 60 Hz power for the solenoid valves.

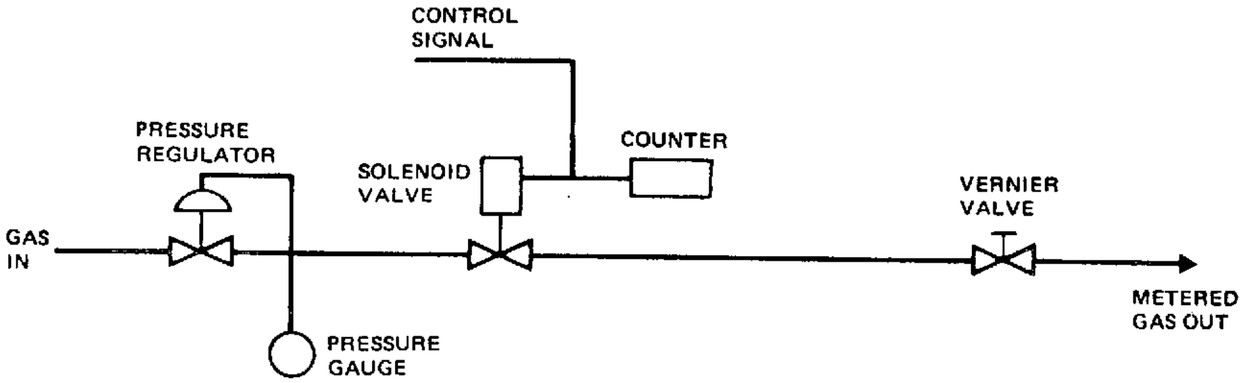


Figure 12. TYPICAL PNEUMATIC CIRCUIT

Section 6

TEST EQUIPMENT AND PROCEDURES

Test procedures included a functional checkout test, high and low temperature operation, and a 60 day endurance test. The functional checkout test procedures were performed on the ECA, using a precision voltage source to simulate inputs from the MSS. The endurance test was performed in a closed chamber simulating the Space Shuttle cabin volume, and the MSS was used to measure atmosphere composition. The test was performed in a closed loop mode, with commercial high pressure storage for O_2 and N_2. The equipment and procedures for these tests are described in the following sections.

6.1 FUNCTIONAL CHECKOUT TEST

The Functional Checkout Test was performed on the ECA to verify that basic functional requirements were met. The test was first performed upon receipt of the unit from production, then repeated during high and low temperature exposure, prior to start of the 60 day endurance test, and upon completion of the endurance test. The Functional Checkout Test used a variable precision power source to provide input signals to the ECA, substituting for the O_2 and N_2 partial pressure signals of the MSS. The test setup and procedures are relatively simple and are recommended for any subsequent check of the unit prior to placing it in operation.

6.1.1 Functional Checkout Test Setup

The BCU, previously described, was used as a test adapter to perform the functional checkout test on the ECA. In addition, the following commercial instrumentation was required:

Qty	Type	Model
1	Precision Power Source (PPS)	Power Design Model 2205A
1	Digital Voltmeter (DVM)	H. P. 3440A w/3443A Plug-In
1	Stopwatch	

A 115V 400 Hz source was required to provide power to the BCU during the performance of these tests. A 115V 60 Hz source was required to provide power for test equipment.

6.1.2 Functional Checkout Test Procedure

During the Functional Checkout Test the procedure described in detail in Section 4.4 of Reference 7 was followed. This procedure determined the threshold voltage of each of the three input integrating amplifiers (O_2 LOW, O_2 HIGH, and N_2) at each set point of the ECA. There are two set points for each of the O_2 integrators, since 10 and 14.7 psia total pressures require the same O_2 partial pressures, and three set points for the N_2 integrator. The checkout test also measured output of the +15, -15 and +5 Vdc power supplies in the BCU, and the -5.00 Vdc precision power supply in the ECA which establishes the set point reference. It verified that 16 counts of each O_2 integrator are required to change the output state of the O_2 channel. The integrator gain and time constants were shown to be within limits when a predetermined error, equivalent to a 2 torr difference in input signal, was applied to each. Finally, the duration of the N_2 valve ON pulse was measured. Data was recorded on forms like that shown in Figure 13. Nominal required readings and allowable tolerances are indicated on Figure 13.

6.2 HIGH AND LOW TEMPERATURE TESTS

Following the initial functional test, the ECA was subjected to tests under high and then low ambient temperature conditions. The high temperature test was performed at 100 to 105°F; the low temperature test at 35 to 40°F. The functional checkout test procedure was repeated after stabilization at each temperature. The same tolerances were applicable as at room temperature.

ECA FUNCTIONAL TEST DATA SHEET

Engineer______________________ Quality Assurance________________Date____________Time____________

Test Identification: Functional________________High Temperature_______Low Temperature____________(check one)

Reference (1) Paragraph		Nominal Value	Tolerance	Measured Value
4.3.4	Power Supply DC voltages from BCU, TP27	+15 VDC	±0.15 VDC	
	Power Supply DC voltages from BCU, TP28	-15 VDC	±0.15 VDC	
	Power Supply DC voltages from BCU, TP26	+5 VDC	±0.2 VDC	
4.4.1	Reference Voltage from ECA	-5.000 VDC	±0.015	
4.4.2.2	O_2 Channel Low Set Point Integrator Threshold, 5.0 Psia	2.794 VDC	±0.030 VDC	
4.4.2.3	O_2 Channel Upper Set Point Integrator Threshold, 5.0 Psia	2.794 VDC	±0.030 VDC	
4.4.2.4	O_2 Channel Upper Set Point Integrator Threshold, 10.0 and 14.7 Psia	2.529 VDC	±0.030 VDC	
4.4.2.5	O_2 Channel Lower Set Point Integrator Threshold, 10.0 and 14.7 Psia	2.529 VDC	±0.030 VDC	
4.4.2.6	O_2 Channel Reset Logic Count for Lower Integrator	16	None	
4.4.2.7	O_2 Channel Reset Logic Count for Upper Integrator	16	None	
4.4.2.8	O_2 Channel Upper Integrator Period for 2 Torr Error	11.25 Sec	±2 Sec	
4.4.2.9	O_2 Channel Lower Integrator Period for 2 Torr Error	11.25 Sec	±2 Sec	
4.4.3.2	N_2 Channel Integrator Threshold, 5.0 Psia	0.498 VDC	±0.022 VDC	
4.4.3.3	N_2 Channel Integrator Threshold, 10.0 Psia	2.593 VDC	±0.022 VDC	
4.4.3.4	N_2 Channel Integrator Threshold, 14.7 Psia	4.433 VDC	±0.022 VDC	
4.4.3.5	N_2 Channel Integrator Period for 2 Torr Error	22.5 Sec	±4 Sec	
4.4.3.6	N_2 Valve ON Period	10 Sec	±0.5 Sec	

ECA Case Temperature: Start of Test____________ °F

End of Test______________ °F

FIGURE 13 - SAMPLE ECA FUNCTIONAL TEST DATA SHEET

The ECA was installed in a Sears Coldspot Refrigerator equipped with a Precision Scientific Company Refrigerator Control, Catalog Number 31211, for performance of the high and low temperature tests. The signal generating unit and data collecting and recording equipment was located outside the chamber. The chamber temperature was raised to 100°F (+5, -0°F) and held until stabilization was reached, as indicated by achieving an ECA case temperature change of less than 2°F per hour. The set points for the oxygen and nitrogen channels were determined by repeating the Functional Checkout Test. Data was recorded as shown on Figure 13. ECA case temperature was recorded at the start and end of each test.

The test chamber temperature was then reduced to 40°F (+0, -5°F) and held until stabilization was reached. Stabilization was indicated by achieving an ECA case temperature change of less than 2°F per hour. The set points for the oxygen and nitrogen channels were determined by repeating the Functional Checkout Test. Data was recorded as shown on Figure 13. ECA case temperature was recorded at the start and end of the test.

6.3 60-DAY ENDURANCE TEST

The ECA was then installed in a closed chamber and used to control the chamber atmosphere during a 60 day Endurance Test. The MSS was installed external to the chamber. An atmosphere sample line was used to provide a continuous flow of chamber atmosphere to the MSS sample port. The analog outputs signals of the O_2 and N_2 channels of the MSS were then used as inputs to the ECA. The discrete output signals of the ECA were used to control solenoid valves in the pressure control panel (PCP), modulating the gas input to the chamber. A micrometer valve was used to produce a controlled leak to simulate cabin leakage. Operation included 6 days at 5 and 10 psia respectively at nominal leakage, followed by operation at a variety of leakage conditions at 14.7 psia for the remaining 48 days of the test. During this period the ACS was required to hold the O_2 and N_2 partial pressures within the limits specified in Table 2. Measurements were made to demonstrate control response times when changing from one leakage level to a higher or lower level as well as determination of long term accuracy.

During the endurance test it was possible to simulate only cabin leakage, but not metabolic O_2 consumption. For purposes of test evaluation a nominal flow rate for Space Shuttle cabin leakage of 12 lbs per day was selected, of which about 9 lbs per day would be N_2 and 3 lbs per day, O_2. The O_2 system would therefore be required to provide approximately 6 lbs per day in the high mode and zero flow in the low mode.

Previous system analysis has indicated (Reference 2) that dynamic response time of the ACS is a significant operating parameter, especially in leakage measurement studies. To obtain dynamic similitude during the endurance test, it was necessary to operate at actual flow rates which were proportional to Shuttle flow rates in the same ratio as the test chamber volume was to the Shuttle Orbiter cabin volume. The Shuttle vehicle has an expected pressurized volume of about 2000 cubic feet. Using the data and equations developed in Reference 2 for a 14.7 psia total pressure oxygen/nitrogen atmosphere and a 12 pound per day nominal atmospheric leak rate, the time constant for the system is 1.031 hours. This is the system transient response to a change in input to reach 63.2 percent of its eventual steady state value. Calibration of the test chamber used in this test showed that it had a volume of approximately 876 cubic feet.

The condition of dynamic similarity can then be met if the test flow rates are equal to 0.438 times the simulated flow rates. Table 15 lists the resulting leakage values for the values of simulated Shuttle leakage and cabin pressures that were planned for the Endurance Test.

Although the Shuttle is not intended to operate at the 5 and 10 psia set points, it was necessary to check ACS performance at these conditions to conform with design requirements, and it was arbitrarily decided to operate at the same cabin leakage as the nominal value for 14.7 psia set point.

Table 15

RELATIONSHIP OF ENDURANCE TEST LEAKAGE RATES TO SPACE SHUTTLE CABIN LEAKAGE

Total Pressure Set Point psia	Simulated Shuttle Leakage Rate lb/day			Endurance Test Leakage Rate lb/day		
	Total	N_2	O_2	Total	N_2	O_2
5	12	3.1	8.9	5.26	1.36	3.90
10	12	7.8	4.2	5.26	3.42	1.84
14.7	2	1.5	0.5	0.88	0.66	0.22
14.7	6	4.5	1.5	2.63	1.97	0.66
14.7	10	7.5	2.5	4.38	3.29	1.10
14.7	12	9.0	3.0	5.26	3.94	1.31
14.7	14	10.5	3.5	6.13	4.60	1.53
14.7	18	13.5	4.5	7.88	5.91	1.97

At the design point the ACS will produce 10 N_2 valve pulses per hour. It was intended to use the same frequency at the design leakage value for the endurance test. Each N_2 pulse should therefore admit the following quantity of N_2 to the chamber.

$$\frac{3.94}{24\text{x}10} = 0.0164 \text{ lb}$$

Since, at the design condition, the O_2 valve flow rate should be approximately 2x the required flow rate, the metering valve should be set for approximately 7.80 lb/day at the 5.0 psia set point, 3.68 lb/day at 10.0 psia, and 2.62 lb/day at 14.7 psia.

6.3.1 Endurance Test Setup

Figure 14 shows the test facility configuration that was used for the endurance test program. The figure shows in block diagram format, the electronic control assembly, the laboratory failities used to support the test and the mechanical and electrical interfaces existing between major assemblies. Power for the test facility included 28 Vdc, 115 Vac at 60 Hz and 115 Vac at 400 Hz. All other power requirements were provided from sources internal to the equipment being tested or supporting the test. Excess gases simulating a space vehicle leak rate were vented into the laboratory through a wet test meter. Pressurized sources of oxygen and nitrogen were available to make up the simulated leakage of gases.

The data management system automatically monitored, recorded and printed 16 channels of data pertinent to the performance of the ECA. The test stand and integral sensors were designed to monitor the ECA continuously without human surveillance. Engineers observed performance of the test, checked calibrations, made adjustments and repairs, changed data tapes, analyzed data collected, prepared documentation and otherwise maintained system operation only during normal working hours (first shift).

The principal components of the data acquisition system were a signal conditioning unit, a status monitor, multiplexer unit, low speed data system, magnetic tape recorder, PDP-15 computer and teletype unit. Figure 15 presents a simplified block diagram of the data acquisition system. A test measurement list of parameters monitored by the data acquisition system is shown on Table 16.

The signal conditioning assembly translated low level test parameters into measurable voltages. It included a 150°F temperature reference junction and a strain gage balance-normalize and calibration panel and auxiliary equipment necessary to set up and standardize (calibrate) the measurement.

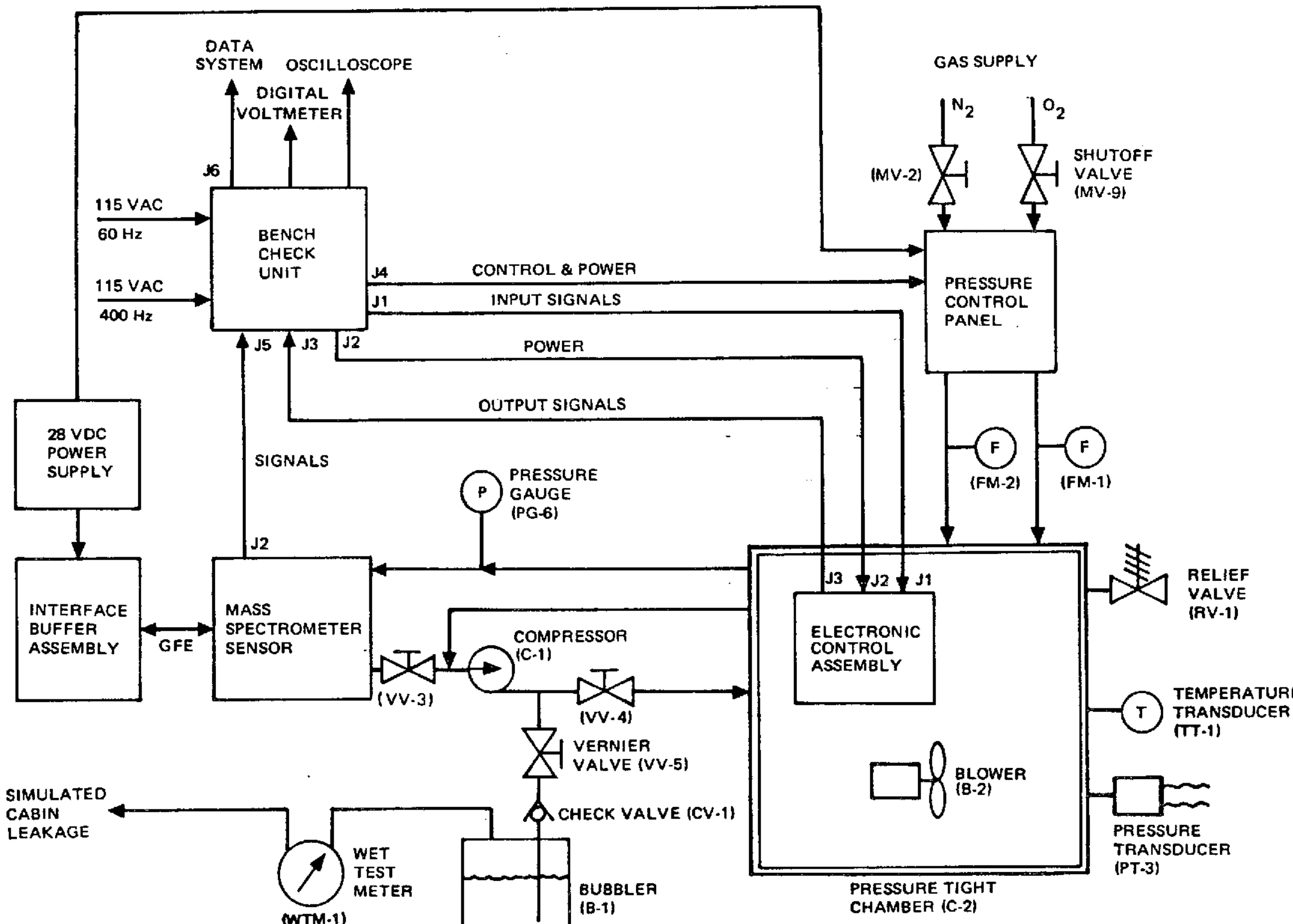


FIGURE 14. ENDURANCE TEST SCHEMATICS, ACS

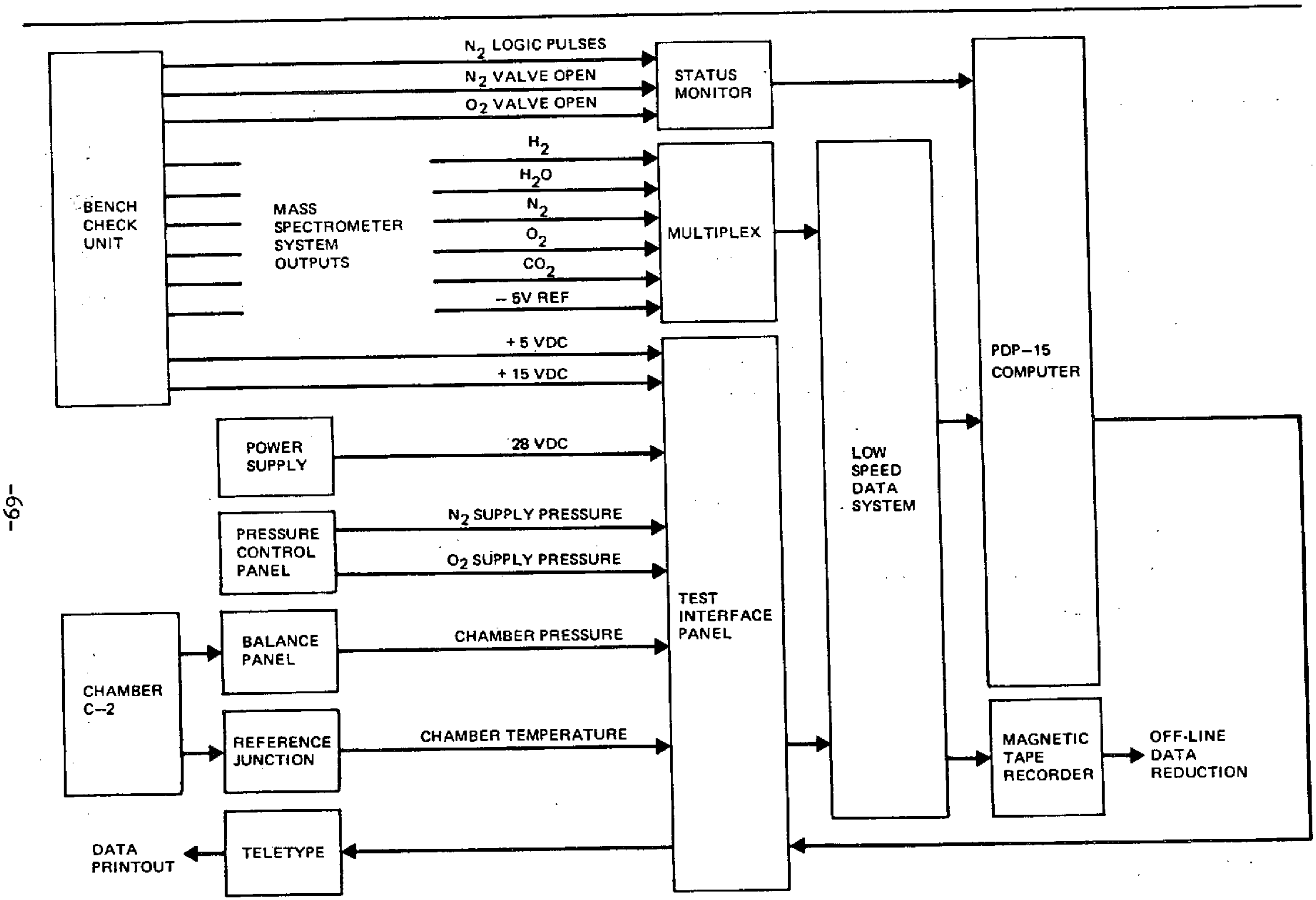


FIGURE 15. DATA SYSTEM SCHEMATIC

TABLE 16 TEST MEASUREMENT LIST

Measurement Code	Data System Channel Assignment	Measurement or Element Title	Measurement Units	Remarks
BVN01	C-180	+ 5 VDC Power Supply	VDC	
BVN02	C-181	+ 15 VDC Power Supply	VDC	
BVZ00	C-182	Spare	---	
BVN05	C-183	+ 28 VDC Power Supply	VDC	
MVN01	C-184	Balance normalize and calibrate power supply	VDC	
MVG01	C-185	Calibration Pressure	psig	
BVH01	C-186	N_2 supply regulated pressure	psig	
BVH02	C-187	O_2 supply regulated pressure	psig	
BVG06	C-188	Test chamber pressure	torr	
BVA01	C-189	Test chamber temperature	Deg F	
MVA01	C-190	Calibration temperature	Deg F	
BVZ01	NR	TTY cable	---	Interface status
BVZ02	NR	Patch cable	---	Interface status
BVW01	SM-A2-4-01	N_2 Logic Integrator Status	---	Pulse counting
BVW02	SM-A2-4-02	O_2 Valve Status	---	Pulse counting
BVW03	SM-A2-4-03	N_2 Valve Status	---	Pulse counting
BVW05	SM-A2-4-05	Sample rate select A	---	Identify data selection rate

TABLE 16 TEST MEASUREMENT LIST (Cont.)

Measurement Code	Data System Channel Assignment	Measurement or Element Title	Measurement Units	Remarks
BVW06	SM-A2-4-06	Sample rate select B	---	Identify data selection rate
BVG01	0-401X01	Mass spectrometer H_2	torr	
BVG02	0-451X01	Mass spectrometer H_2O	torr	
BVG03	0-501X01	Mass spectrometer N_2	torr	
BVG04	0-551X01	Mass spectrometer O_2	torr	
BVG05	0-601X01	Mass spectrometer CO_2	torr	
BVN04	0-651X01	-5VDC Reference Voltage	VDC	

The status monitor is a multi-user device that converts contact closures to computer compatible words. System software responded to these inputs under program control.

The multiplexer (MUX) is a 100 channel data acquisition system in which analog data are convered to binary values that are input to the PDP-15 computer via the Low Speed Digital System (LSDS). Ten channels of MUX data are encoded into one LSDS data frame. Resultant raw data words are processed by active PDP-15 software.

The LSDS consists of a modified version of a Systron-Donner Model 160E6 Data Acquistion Console which can receive data from 700 analog input channels. The LSDS scans, digitizes and records the data on a magnetic tape. These data consist of subsystem status of system pressures, temperatures, voltages and valve positions.

A PDP-15 Computer and Peripheral equipment were used in a time-sharing mode with other test programs in the laboratory to receive raw data from the LSDS and Status Monitor, process it, and provide data print-out on a teletype printer located in the test area. Data print-outs were normally provided each hour and all valve operations were recorded except for relatively short periods when the computer was down for maintenance. The test engineer could also obtain data print-outs every ten minutes to record transients or on command when desired.

In addition to automatically recorded data, manual records were made at least twice each working day to provide information not recorded on the automatic system, to back that system up during non-operational periods, or to record changes in test operating conditions. A sample endurance test log sheet is shown in Figure 16. Typical of data to be recorded includes the time, date, and elapsed time of the test. Also the parameters listed on Table 17 were recorded. The readings of the pulse counters on the PCP were entered. Settings

ELECTRONIC CONTROL ASSEMBLY DATA SHEET

TYPE OF TEST__________ ENGINEER__________ PAGE NO_____

TIME OF DAY__________ SYSTEM ETR__________ DATE__________

PRESSURES		
CHAMBER (TORR.)	O_2 SUPPLY TANK (PSIG)	N_2 SUPPLY (PSIG)

TEMPERATURES		28V POWER SUPPLY	
CHAMBER (°F)	AMBIENT (°F)	VOLTS	AMPS.

FLOWMETERS								
OXYGEN			NITROGEN			MSS		WTM
% F.S.	#/MIN.	TIME	% F.S.	#/MIN.	TIME	% F.S	#/MIN.	TOTAL (Liters)

COUNTERS			
N_2 NORMAL	O_2 NORMAL	O_2 OFF	N_2 OFF

METER VALVE SETTING				
O_2 FLOW	N_2 FLOW	MSS BYPASS	CABIN RETURN	LEAKAGE

COMMENTS

FIGURE 16 SAMPLE OF ENDURANCE TEST DATA SHEET

Table 17

TEST SYSTEM INSTRUMENTATION AND EQUIPMENT LIST

Measured By	Data System Measurement Identification	Measurement Type	Measurement Units	Measurement Range	Accuracy Tolerance	Notes
Precision Wet Test Meter - Precision Scientific Co.	--	Leakage gas flow	Liters	3000 liters 180 liters/hr	±1.0%	Simulated shuttle leakage
Pressure gauge - Marsh Instrument Co.	BVH01	N_2 pressure	psig	0-30	±5% F.S.	
	BVH02	O_2 pressure	psig	0-30	±5% F.S.	
Absolute pressure -Wallace & Tiernan Model 1500	BVG06	Chamber pressure	torr	0-800	±0.1% F.S.	
Linurmass Flowmeter - Technology/Versatronics Inc. MFG 10-12T	--	N_2 flow	%	0-100% 0.3 lbs/min	±2% F.S.	
	--	O_2 flow	%	0-100% 0.6 lbs/hr	±2% F.S.	
Victor Equipment Company 1424-0048	--	N_2 tank pressure	psig	0-4000	±2% F.S.	
1424-0057	--	O_2 tank pressure	psig	0-4000	±2% F.S.	

of the micrometer valves for O_2 flow control and cabin leakage were recorded. Other valves did not provide a visual indication of position; although the data sheet provided for their entry, readings of those valve positions were not possible. The test log sheets were also used to record pertinent comments on the test operations, changes that were made, and other data for backup of the automatic recording system.

6.3.2 Endurance Test Procedures

During the first period of the test the selected set point was 5.0 psia total pressure, requiring a nominal O_2 partial pressure of 184.3 torr and N_2 partial pressure of 62.8 torr. The chamber was initially pumped down (July 25, 1973) until both partial pressures were lower than the desired set points. A total pressure of 73.0 torr was reached, and the control was energized. Manual addition of oxygen was required to reach the desired value due to the low inflow rate of O_2 when under automatic control. After stabilization the test was continued for the planned 6 days. It was found, however, that the inlet lines for O_2 and N_2 addition discharged gas near the sampling part for the MSS. Also, it was suspected that leakage existed in some of the external lines of the system. Accordingly, after the 6-day period was completed at 5 psia, the chamber pressure was returned to sea level on August 1, to correct the sample line location and perform leakage checks.

The test was restarted after 3 1/2 hours shutdown in a manner similar to the initial start. The desired nominal operating conditions were: total pressure, 10 psia or 517 torr; O_2 partial pressure, 166.2 torr; and N_2 partial pressure, 339.4 torr. The initial pump-down was to a total pressure of 439 torr and manual addition of O_2 was again required to achieve stable O_2 operating conditions in a reasonable time. The planned six days at this operating condition were completed at noon on August 7.

Since the subsequent operation at 14.7 psia required only a change of nitrogen partial pressure, it was decided to perform the transition under control by initiating a step change in set point at the end of the previous period of 10 psia operation. The nominal set points were to be: total pressure, 14.7 psia or 760 torr; O_2 partial pressure, 166.2 torr; and N_2 partial pressure, 582.4 torr. Of course, since only O_2 and N_2 partial pressures were controlled and there was no source of CO_2 or water vapor in the chamber, it was expected that total pressures would be somewhat lower than 760 torr due to the absence of these gases.

The balance of the test was completed at the 14.7 psia set point. A schedule of changes in leakage was adopted to provide increasing and decreasing step changes of several sizes. Transient performance was measured following each change, and sufficient time (4 to 7 days) was allowed between each change to allow stabilization and recording of statistically significant steady state performance data.

During the endurance test, special procedures were followed to obtain calibrations of chamber volume, N_2 gas pulse size, and chamber leakage. Upon completion of the endurance test, the Functional Checkout Test was again performed on the ECA to determine changes in operating level that might have occurred.

Section 7

TEST RESULTS

The results of tests performed on the ACS are persented below. These tests included a Functional Checkout, High and Low Temperatures, 60-day Endurance Test, and a final Functional Checkout. Functional Checkout Test Procedures were also performed while at high and low temperatures and prior to the Endurance Test. Test requirements, setup, and procedures have been described in previous sections.

7.1 TEST CHRONOLOGY

The chronological sequence of the test is listed in Table 18, which shows scheduled events and also includes other significant occurrances during the test. No failures of the equipment under test were encountered. Table 18 also shows the values of set point selected and the actual and simulated chamber leakage rates that were tested.

Significant events included a shutdown for leakage check and rearrangement of the MSS sample line location on August 1. Initial test results indicated that the O_2 and N_2 inflow lines were located too close to the MSS sample line inlet and inadequate mixing was occurring. This situation was corrected, several leaks were found, and the test continued.

On August 3 a loss of the high pressure N_2 supply occurred. Data was automatically recorded during the failure and recovery from this fault which is an important confirmation of analytically predicted fault detection capability of the ACS.

After transition to the 14.7 psia set point, a large relief valve was found to have opened, and was then fastened securely closed. It was not possible to ascertain whether the improperly closed relief valve had been contributing to chamber leakage prior to this time (during the 5 and 10 psia portions of the test).

Table 18

Chronology of Test Procedures

Date	Time	Event	New Set Point Total Pressure PSIA (Torr)	New Leakage Rate lb/day Actual (Simulated)
July 19, 1973	1445	Initial Functional Checkout		
July 20	1300	High Temperature Test		
July 21	0940	Low Temperature Test		
July 24	0930	Pre-Endurance Functional Test		
July 26	0900	Start of 60-day Endurance Test	5.0(258.5)	4.38(10.0)
August 1	0900	Complete 5 psia period; repressurize for leakage check, recalib. flows, and change sample line location		
August 1	1200	Resume test at new set point using 10.4 Kohm jumper	10.0(517)	5.32(12.15)
August 1	1425	Replaced jumper with 19 Kohm (reduced N_2 set point 0.020 v)	10.0(517)	
August 3	1130	N_2 supply failure and correction	10.0(517)	
August 6	0806	Reduced leakage rate	10.0(517)	3.56(8.13)
August 7	1200	Changed set point	14.7(760)	
August 8	0800	Found 6 in. relief valve had opened as chamber pressure approached atmospheric		
August 8	1425	Installed 4.7 Kohm jumper in N_2 set point	14.7(760)	3.12(7.12)

Table 18 (Continued)

Chronology of Test Procedures

Date	Time	Event	New Set Point Total Pressure PSIA (Torr)	New Leakage Rate lb/day Actual (Simulated)
August 9	0800	Reduced leakage rate	14.7(760)	2.01(4.59)
August 10	0800	Reduced leakage rate	14.7(760)	1.69(3.86)
August 13	1130	Increased leakage rate	" "	4.36(9.95)
August 16	0900	Inserted 22µF capacitors in MSS O_2 and N_2 output	" "	" "
August 20	1130	Increased leakage rate	" "	6.45(14.73)
August 27	1130	Increased leakage rate	" "	8.15(18.61)
August 31	1130	Reduced leakage rate	" "	4.07(9.29)
Sept. 5	1630	Stopped O_2 and N_2 inflow for chamber volume and N_2 pulse calibration	-	-
Sept. 6	1200	Resumed test	14.7(760)	6.50(14.84)
Sept. 7	1130	Reduced leakage rate	" "	2.90(6.62)
Sept. 14	0930	Increased leakage rate	" "	4.40(10.05)
Sept. 19	1130	Increased leakage rate	" "	5.96(13.61)
Sept. 25	0800	Completed Endurance Test	" "	-
		Shut off N_2 and O_2 gas supply and started pumpdown to recheck chamber volume	-	-
Sept. 25	1630	Shut off leakage valve to measure overnight chamber pressure rise for leakage check	-	-
Sept. 26	0800	Chamber pressure showed no in-leak in 15-1/2 hours	-	-
Sept. 26	1400	Performed Post-Endurance Functional Checkout Test		

Early in the 14.7 psia segment of the test, statistical analysis of recorded PP N_2 and PP O_2 data showed a significant increase in standard deviation. Troubleshooting indicated a high frequency (60 Hz) noise level of about 0.050 volts on the MSS output signals. On August 16, it was found that insertion of 22 μf capacitors as filters on the output terminals for O_2 and N_2 of the Interface Buffer Assembly would reduce this noise level to about 0.010 volt. Apparently this noise level had appeared on the MSS signal at the start of 14.7 psia operation. Statistical deviations recorded in PP O_2 and PP N_2 between August 8 and August 16 were therefore invalid since they did not actually represent pressure fluctuations.

The calibration of chamber volume and N_2 pulse size was done between 1630 on September 5 to 1200 on September 6.

The endurance test was completed at 0800 on September 25. The chamber leakage test was then performed by pumping down to 730 torr and measuring pressure change overnight. This confirmed that chamber leakage had been essentially zero at least since August 8, when the relief valve was corrected.

The final functional checkout of the ECA was performed on September 26.

7.2 FUNCTIONAL CHECKOUT AND EXTREME TEMPERATURE TESTS

Functional Checkout Tests were performed on the ECA upon initial receipt, during operation at high and low temperatures, and before and after the 60-day Endurance Tests. The data obtained, along with nominal values and tolerances, is presented in Table 19. In addition, data was taken on the pulse frequency of the N_2 channel as a function of input voltage error. Also it was found that the set point voltages sometimes resulted in operation outside the desired control band. As noted in Section 5.3, when shorting jumpers were used to establish the set point (5 psia for O_2 and 10 and 14.7 psia for N_2) it was found that these set points could be corrected by using fixed resistors in place of shorting jumpers. The resulting relationship of decrease in set point to resistance value was then determined. These data are presented below.

Table 19

FUNCTIONAL CHECKOUT TEST DATA SUMMARY

Function	Nominal Value	Tolerance	Initial	Measured Values High Temp (103°F)	Low Temp (36°F)	Pre-Endur.	Post Endur.
Power Supply Output	+15 vdc	±0.15 vdc	+15.09 vdc	15.09	15.09	15.08	15.13
Power Supply Output	-15 vdc	±0.15 vdc	-15.11 vdc	-15.10	-15.12	-15.09	-15.11
Power Supply Output	+5 vdc	±0.2 vdc	+5.008 vdc	+5.008	+5.011	5.012	+5.019
Reference Voltage Supply	-5 vdc	±0.015 vdc	-5.001 vdc	-5.007	-5.000	-5.002	-5.013
O_2 Channel:							
Low set point threshold, 5 psia	2.794 vdc	±0.030 vdc	2.784 vdc	2.787	2.784	2.786	2.811
High set point threshold, 5 psia	2.794 vdc	±0.030 vdc	2.797 vdc	2.800	2.796	2.798	2.824
High set point threshold, 10 and 14.7 psia	2.529 vdc	±0.030 vdc	2.532 vdc	2.535	2.532	2.534	2.559
Low set point threshold, 10 and 14.7 psia	2.529 vdc	±0.030 vdc	2.504 vdc	2.506	2.504	2.505	2.529
Upper integrator period for 2 torr error	11.25 sec	± 2 sec	10.94 sec	10.90	11.10	--	10.78
Lower integrator period for 2 torr error	11.25 sec	± 2 sec	10.60 sec	10.34	10.93	--	10.17
N_2 Channel:							
Integrator threshold, 5.0 psia	0.498 vdc	±0.022 vdc	0.481 vdc	0.481	0.482	0.482	0.519
Integrator threshold, 10.0 psia	2.593 vdc	±0.022 vdc	2.613 vdc	2.616	2.612	2.615	2.640
Integrator threshold, 14.7 psia	4.433 vdc	±0.022 vdc	4.442 vdc	4.447	4.440	4.445	4.474
Integrator period for 2 torr error	22.5 sec	± 4 sec	20.6 sec	20.12	20.55	21.46	21.17
Valve ON period	10 sec	± 0.5 sec	10.0 sec	10.0	10.2	10.2	9.8

7.2.1 EFFECT OF TEMPERATURE EXTREMES

As shown in Table 19, the ECA was operated at 103°F and 36°F as well as room temperature. The changes in set point were very small, being 2 to 4 millivolts on the O_2 channel and 1 to 7 millivolts on the N_2 channel. The observed variations are summarized on Table 20 and are found to be 0.2% of actual value or less. The reference voltage was found to vary 0.14 percent, which accounts for most of the observed change in set point, since this reference voltage is used to establish the input error to the control channels.

The timing functions are also included in Table 20. These are established by the clock circuit in the ECA and are shown to fall within reasonable operating tolerances.

Table 20

DEPENDENCE OF ECA UPON AMBIENT TEMPERATURE

(36°F to 103°F)

	Nominal Value	Variation	Variation Percent
O_2 set point, 5 psia	2.794 volts	.004 volts	0.14
O_2 set point, 10 and 14.7 psia	2.529	.003	0.12
N_2 set point, 5 psia	0.498	.001	0.2
N_2 set point, 10 psia	2.593	.004	0.15
N_2 set point, 14.7 psia	4.433	.007	0.16
Reference voltage supply	-5.00	.007	0.14
O_2 upper integrator period	11.25 sec.	0.20 sec.	1.78
O_2 lower integrator period	11.25 sec.	0.59 sec.	5.33
N_2 integrator period	22.5 sec.	0.48 sec.	2.14
N_2 valve ON period	10.0 sec.	0.2 sec.	2.0

7.2.2 Comparison of Pre- and Post-Test Data

Comparing functional test data taken before and after the 60-day Endurance Test from the two right-hand columns of Table 19, it is found that a substantial shift occurred during this time. This amounts to about 0.025 volts (upward) on the O_2 channel and about 0.035 volts (upward) on the N_2 channel. All set points shifted nearly the same amount. Since the MSS scale factor is about 0.015 volts/torr on the O_2 channel and 0.0075 volts/torr on the N_2 channel, these shifts correspond to about 1.6 torr (O_2) and 4.6 torr (N_2) respectively.

Upon reviewing test records, it appears that at least most of the shift occurred at the start of the Endurance Test. A possible explanation is that this is caused by installing a feed-thru connector for the wire bundle connecting the BCU and the ECA, so that the latter could be installed in the test chamber. The shift may therefore be caused by ground-loop currents. In any event, no significant change in operating set point occurred during the Endurance Test, as will be shown by data presented later.

7.2.3 Correction of Set Points by Jumper Resistors

During system design it was decided to incorporate fixed resistors to establish control settings. Each channel therefore has a resistor network at its input. It was intended to provide set point changes by inserting shorting plugs across proper points of these resistor networks. Wiring was provided so these shorting connectors could be installed on the front panel of the BCU to obtain the 5 psia O_2 channel and 10 and 14.7 psia N_2 channel settings.

It was determined prior to start of the Endurance Test that the set points, obtainable through the use of shorting jumpers, could be depressed by using fixed resistors in place of shorting resistors. The analytical basis for this is described in Section 5.3. Data was obtained for the N_2 channel on the effect of this resistor value in changing the set point. This data is summarized in Figure 17. It is shown that the reduction in set point is

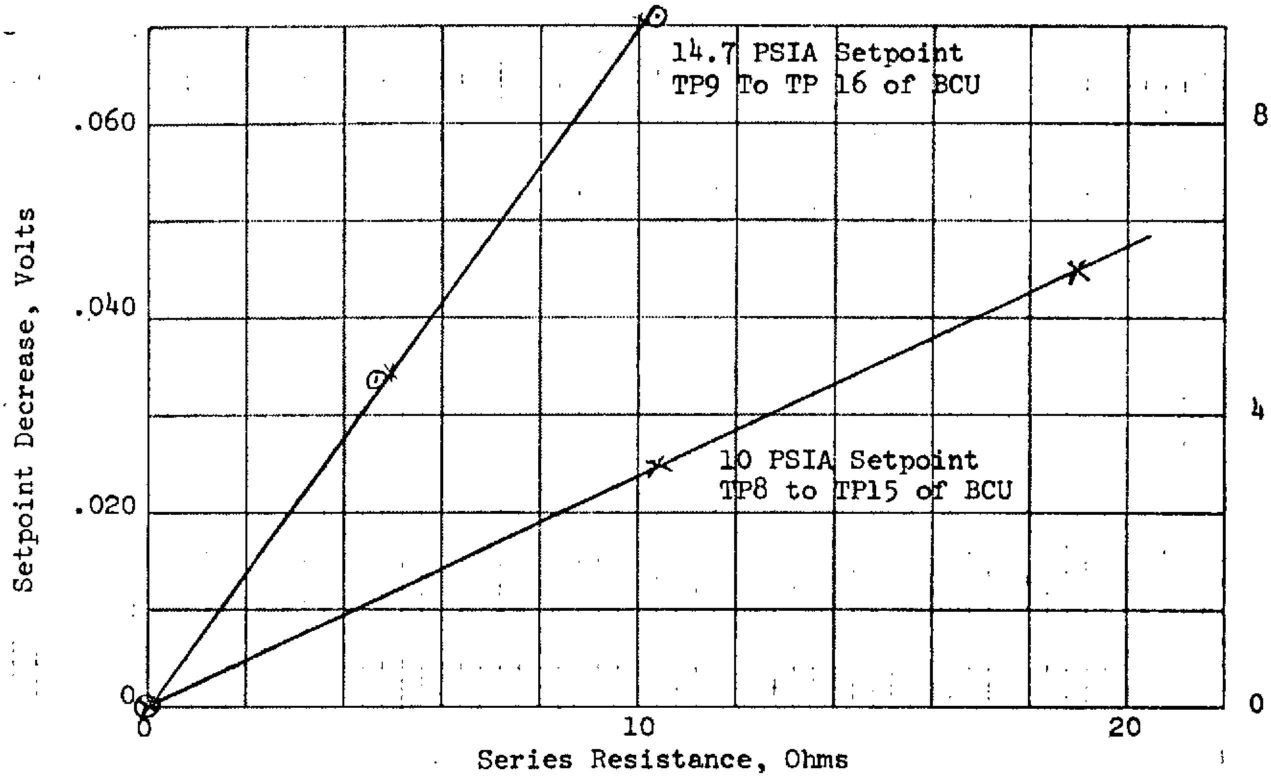


FIGURE 17 SETPOINT DECREASE OF N_2 CHANNEL BY USE OF SERIES RESISTANCE JUMPERS

proportional to resistance value, and amounts to about 1 torr (.0076 volts) for 3157 ohms at the 10 psia set point and 1 torr for 1114 ohms at the 14.7 psia set point. These are in close agreement with the analytically predicted values of Section 5.3.

7.2.4 Nitrogen Channel Pulse Frequency

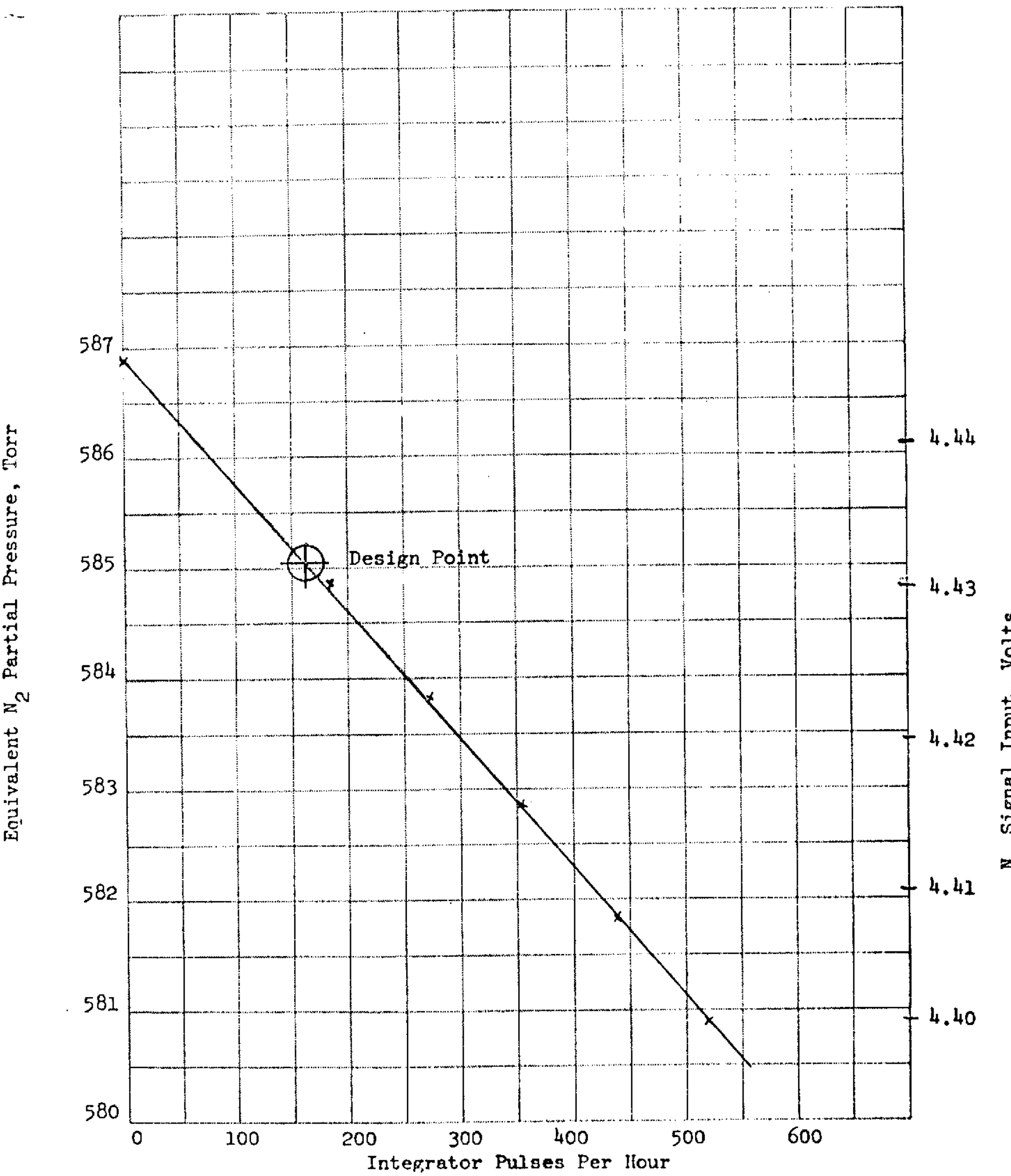
The N_2 channel is designed to produce an output pulse frequency proportional to the difference between the set point reference voltage and the N_2 input signal. Data was taken to determine this operating characteristic. Figure 18 summarizes this data, applying the MSS conversion factor of 132 torr per volt. The design value for integrator gain is given in Section 5.1.2 that 10560 pulses per hour per volt would be obtained. The performance data on Figure 18 is equivalent to 11,400 pulses per hour per volt. This is well within design requirements.

7.3 ENDURANCE TEST

The endurance test was performed for a period of 60 days (1440 hrs) and was designed to demonstrate the capability of the ACS to control the pressure and composition of the atmosphere in a closed chamber under a variety of operating conditions, in accordance with specification requirements and design criteria. The test chamber was actually a high vacuum test chamber in the Space Simulation Laboratory at MDAC. It was selected because it should be leak tight, enabling correlation of controlled input gas flow and simulated leakage, and it was reasonably close to the Shuttle cabin volume, so that the application of simple scaling relationships could provide dynamic similarity to actual operations.

7.3.1 Auxiliary Tests and Calibrations

During the course of the endurance test, auxiliary procedures were followed to provide system data on chamber volume, nitrogen pulse size, and chamber



INTEGRATOR PERFORMANCE AT 14.7 PSIA SETPOINT
ELECTRONIC CONTROL ASSEMBLY, ATMOSPHERE CONTROL SUBSYSTEM

FIGURE 18

leakage. Although not performed in chronological order, these tests will be reported first to provide background for the balance of the discussion of Test Results.

7.3.1.1 Chamber Volume Determination

At 1630 on September 5, all gas inflow to the chamber was stopped and the pump-out compressor allowed to continue running. By 0820 the next day, a total of 993.6 liters had been recorded on the wet test meter. The total pressure reading, by the Wallace and Tiernan precision gage, had decreased from 760.2 torr to 730.2 torr. The mass spectrometer indicated the following gas composition at the beginning of the pump-down:

	Torr	Wt. Fraction lb/lb
Nitrogen	582.53	0.7522
Oxygen	166.61	0.2458
Water	1.63	0.0013
Carbon Dioxide	0.29	0.0005
	751.06	0.9998

Assuming that the bubbler resulted in saturating the gas going through the WTM with water vapor, the weight fraction of water vapor was raised to 0.0155 lb/lb. The resulting density of the gas at the WTM was 0.0747 lb/cu ft. The gas passing through the WTM was then calculated by

$$w = \frac{993.6 \text{ (liters)} \times 0.0747 \text{ (lb/cu ft)}}{28.317 \text{ (liters/cu ft)}}$$

$$= 2.6211 \text{ lbs.}$$

The amount of water vapor added in the bubbler was

$$w_w = 2.6211\ (0.0155 - 0.0013)$$

$$= 0.0372 \text{ lbs.}$$

And the net gas removed from the chamber was

$$w_c = 2.6211 - 0.0372$$

$$= 2.5839 \text{ lbs}$$

The volume of the chamber was therefore given by

$$V = \frac{2.5839\ (\text{lbs}) \times 760\ (\text{torr})}{.0747\ (\text{lb/cu ft}) \times 30\ (\text{torr})}$$

$$= 876.3 \text{ cubic ft.}$$

7.3.1.2 Nitrogen Pulse Size Calibration

Before the endurance test started, the N_2 pulse size was determined to be 3.972 liters or 0.01055 lb per pulse by flowing 10 successive pulses through the WTM. However, there was some reason to doubt this reading since the mass balance data was not consistent and also the flow rate of gas - 24 liters per minute - was considerably higher than the rating of the WTM of 3 liters per minute. Therefore, at the conclusion of the pump-down test described in the previous section, the N_2 channel of the control was energized and pressure rise was determined for a known number of pulses.

A total of 89 N_2 gas pulses were added to the chamber, with an increase in N_2 partial pressure of 19.9 torr. This reading was obtained with both the MSS output and the precision pressure gage. For a chamber volume of 876.3 cu. ft. and a N_2 density at standard conditions of 0.07247 lb per cu ft, it was found that the amount of N_2 added was

$$\frac{876.3\ (\text{cu ft}) \times .07247\ (\text{lb/cu ft}) \times 19.9\ (\text{torr})}{760\ (\text{torr})}$$

$$= 1.6628 \text{ lb.}$$

Dividing this by the number of pulses, it was found that the size of each N_2 pulse was 0.018683 lb per pulse.

7.3.1.3 Chamber Leakage Check

Several attempts were made to perform leakage checks on the chamber. At the close of the 5-day portion of the test the chamber was returned to atmospheric pressure and the external lines were pressurized and leak checked with soap solution. Several small leaks were found and repaired. At the end of the 10 psia portion of the test, an automatic transition to the new set point was made. When chamber pressure reached about 750 torr a relief valve which had not previously been found, opened. It was not certain that this valve had been free of leakage prior to this time. It was fastened securely closed and the test continued.

At the close of the 60-day test the chamber was pumped down to an indicated pressure of 732.1 torr. The MSS circulating system was left operating but all leakage through the WTM was stopped at 1630. The next morning the chamber pressure was found to be 730.0 torr. Since the barometric pressure was 760.0 torr this may have been due to temperature decrease overnight, or to leakage in the segment of the MSS circulating line between the compressor and the return to the chamber, which was the only portion of the system above ambient pressure and therefore susceptible to out-leakage.

It was believed that the former (thermal change) had caused the pressure decrease of 2.1 torr. However, if it had been entirely due to leakage, the out flow rate would have been 0.28 lb per day, which is a relatively negligible value.

7.3.2 Control Accuracy

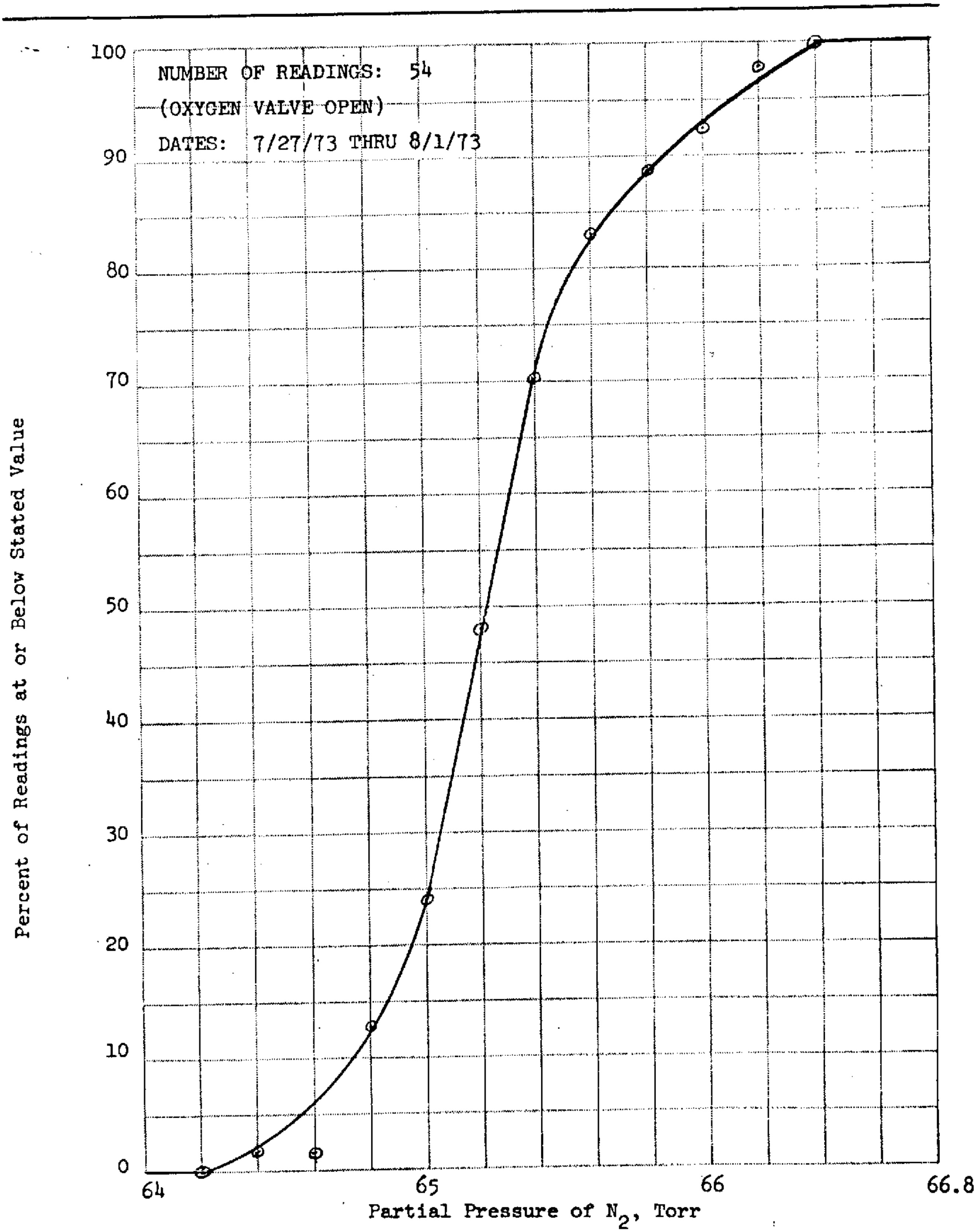
The ECA is required to directly control O_2 and N_2 partial pressures. The control of total pressure is secondary, since water vapor and CO_2 may vary, particularly in a test of this type in which bottled gases are used and abnormally low values of these parameters are encountered. Control performance data on each of these parameters will be discussed in turn.

Data for evaluation of control accuracy was obtained from the automatic data collection system, and was printed out usually at one-hour intervals. There were periods of computer down-time and otherperiods during which printed data was obtained at ten-minute intervals. However, the data presented herein was normally derived from the hourly data. Since it was characterized by small, random variations about a mean value and there was no apparent dependence upon run time, diurnal cycles, or other variables, a statistical method of presentation was adopted. Data points were read into a computer which calculated and printed a statistical analysis including means, standard deviation, extreme variations, and cumulative distributions. The data presented herein are summaries of each parameter. Detail test data is presented in Reference 8.

7.3.2.1 Nitrogen Channel

During the 5 psia portion of the test it was found that the sample line to the MSS was drawing gas from a region near the discharge of the O_2 and N_2 inflow lines. These readings were therefore influenced by the status of the valves. Data presented herein was taken while the oxygen valve was open which was the case most of the time. Figure 19 shows the cumulative distribution of N_2 partial pressures for this portion of the test. It may be noticed that the median value is about 65.2 torr and the extremes are 64.2 and 66.4 torr. This compares with requirements of 60.0 to 65.7 torr as given in Table 2.

At the end of the 5 psia segment, the MSS sample line inlet was relocated to a point in the chamber some distance from the gas inlet lines, and a small mixing fan installed, before starting operation at 10 psia. This resulted in eliminating the mixing problem. Also, a jumper was used as



CUMULATIVE FREQUENCY OF PPN_2 READINGS
5 PSIA PORTION OF ENDURANCE TEST

FIGURE 19

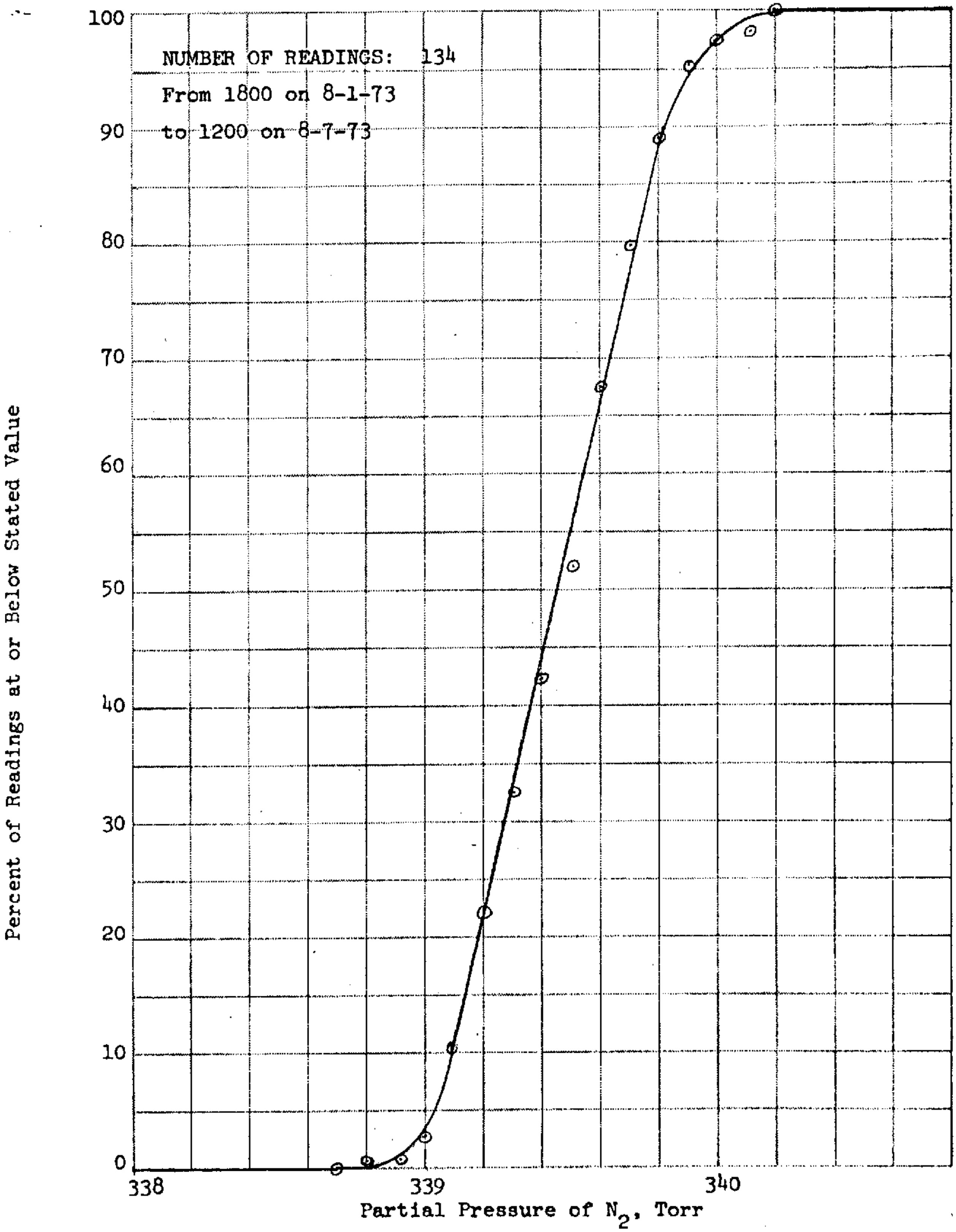
discussed earlier to correct the N_2 set point. Figure 20 shows the resulting data on N_2 control. All points lie between 338.8 torr and 340.2 torr. Table 2 shows the allowable range of 336.6 to 342.3 torr for this set point.

After transition to the 14.7 psia set point on August 7 (Day 13), the balance of the endurance test was performed at this setting with a variety of leakage values. A 4.7K ohm resistor was used in the set point jumper to achieve the desired operating value of N_2 partial pressure.

A summary of the data taken on the N_2 channel at each value of chamber leakage is shown in Table 21. The data at the 1.69 lb/day leakage value was taken before the 22μf capacitor was installed; therefore standard deviation and extreme values are not included. A cumulative frequency summary of 721 data points at all leakage values is in Table 22. Only 4 points are below 580.7 torr and one above 584.4 torr. All these occurred during the 5.96 lb/day leakage, which was at the end of the endurance test. The allowable limits for N_2 partial pressure variation according to Table 2 are 579.6 to 585.2 torr.

7.3.2.2. Oxygen Channel

Data for the O_2 channel during the first 6 days of the test at the 5.0 psia set point was influenced, as was that for the N_2 channel, by the improper mixing at the MSS sampling port. The effect was to depress readings with the O_2 valve closed and increase readings while it was open. This caused the valve to change state (open or closed) much more rapidly than would otherwise occur. The effect on control accuracy was not serious, however, but the operating condition was not realistic except to demonstrate the effect of improper sampling port design. The cumulative frequency of valve opening conditions is shown on Figure 21. All data lies between 185 and 187.2 torr; the required range was 180.4 to 188.2 torr.



CUMULATIVE FREQUENCY OF PPN_2 READINGS
10 PSIA PORTION OF ENDURANCE TEST

FIGURE 20

Table 21

SUMMARY DATA ON N_2 CHANNEL AT 14.7 PSIA

Leakage lb/day	Mean torr	Std. Deviation torr	Min. torr	Max. torr	# Points
1.69*	583.25	-	-	-	-
2.90	583.01	0.57	581.5	584.0	155
4.07	582.69	0.43	581.8	583.5	105
4.36	582.51	0.26	581.9	583.0	76
4.40	582.37	0.42	581.5	583.2	55
5.96	582.03	0.76	579.3	585.2	110
6.45	581.89	0.32	581.2	582.6	145
8.15	581.48	0.39	580.7	582.2	75
					721

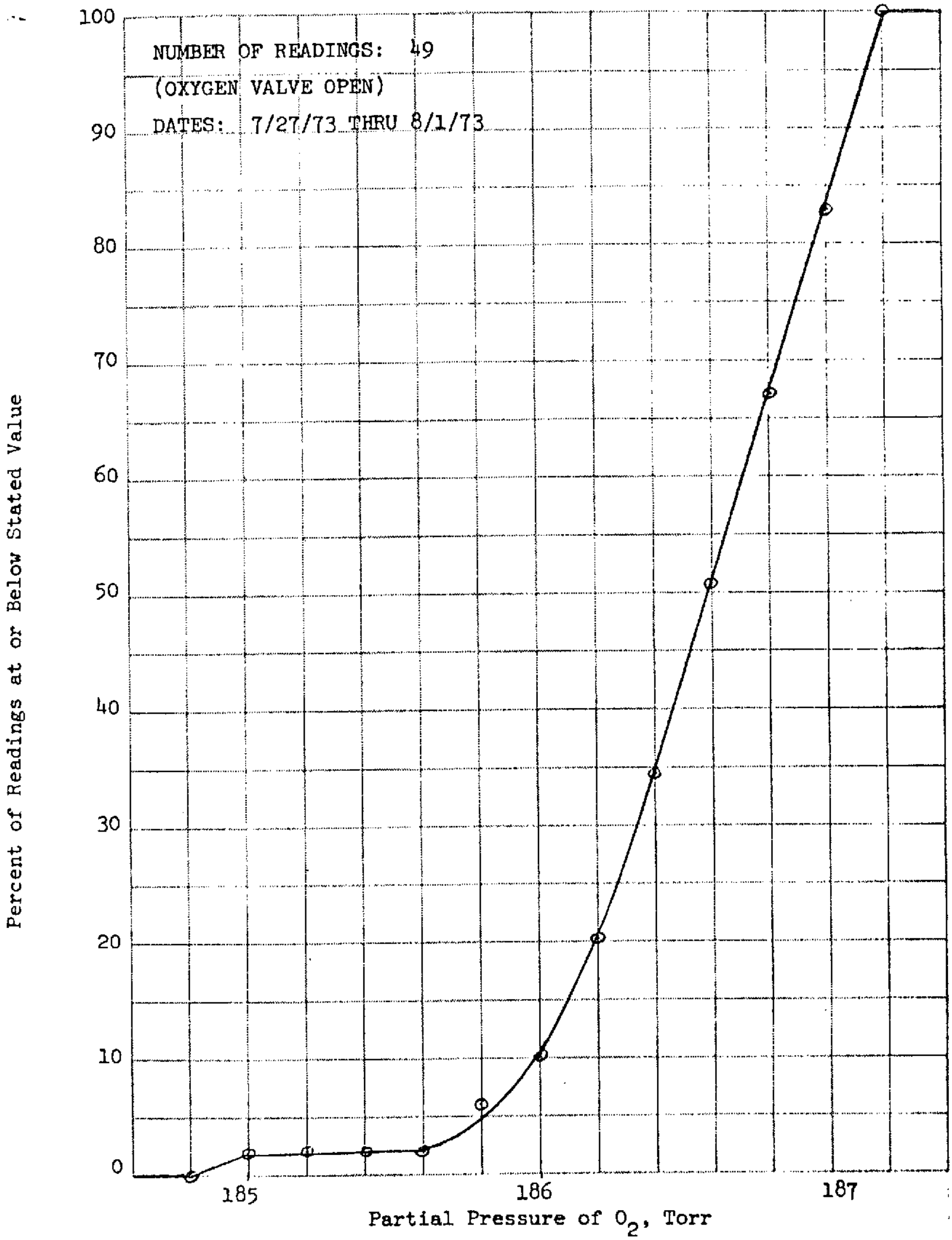
* Note: Prior to installation of capacitor.

Table 22

SUMMARY OF CUMULATIVE FREQUENCY OF PPN_2 DATA

14.7 PSIA SET POINT

Partial Pressure of N_2 Torr	Frequency of Observations Less Than Stated Value	Fraction of Observations Less Than Stated Value
579.25	0	0.0000
580.0	4	0.0055
580.7	4	0.0055
580.8	8	0.0111
581.2	27	0.0374
581.6	100	0.1387
582.0	229	0.3176
582.4	392	0.5437
582.8	554	0.7683
583.2	635	0.8807
583.6	694	0.9625
584.0	719	0.9972
584.4	720	0.9986
585.2	721	1.0000



CUMULATIVE FREQUENCY OF PPO_2 READINGS
5 PSIA PORTION OF ENDURANCE TEST

FIGURE 21

At the 10 psia set point the operation was normal due to the improved location of the MSS sampling port and chamber atmosphere mixing. Operating data is presented in Figure 22. The normal dead-band type of operation is illustrated, with valve opening and closing occurring within relatively narrow bands: 165.8 to 166.4 torr for opening and 168.1 to 168.8 for closing. The remainder of the data is uniformly distributed between these extremes. The required range of operation, from Table 2, is 162.3 to 170.1 torr; all operation is well within this range. The average time for the valve OPEN condition was 1.71 hours and for the CLOSED condition, 3.80 hrs.

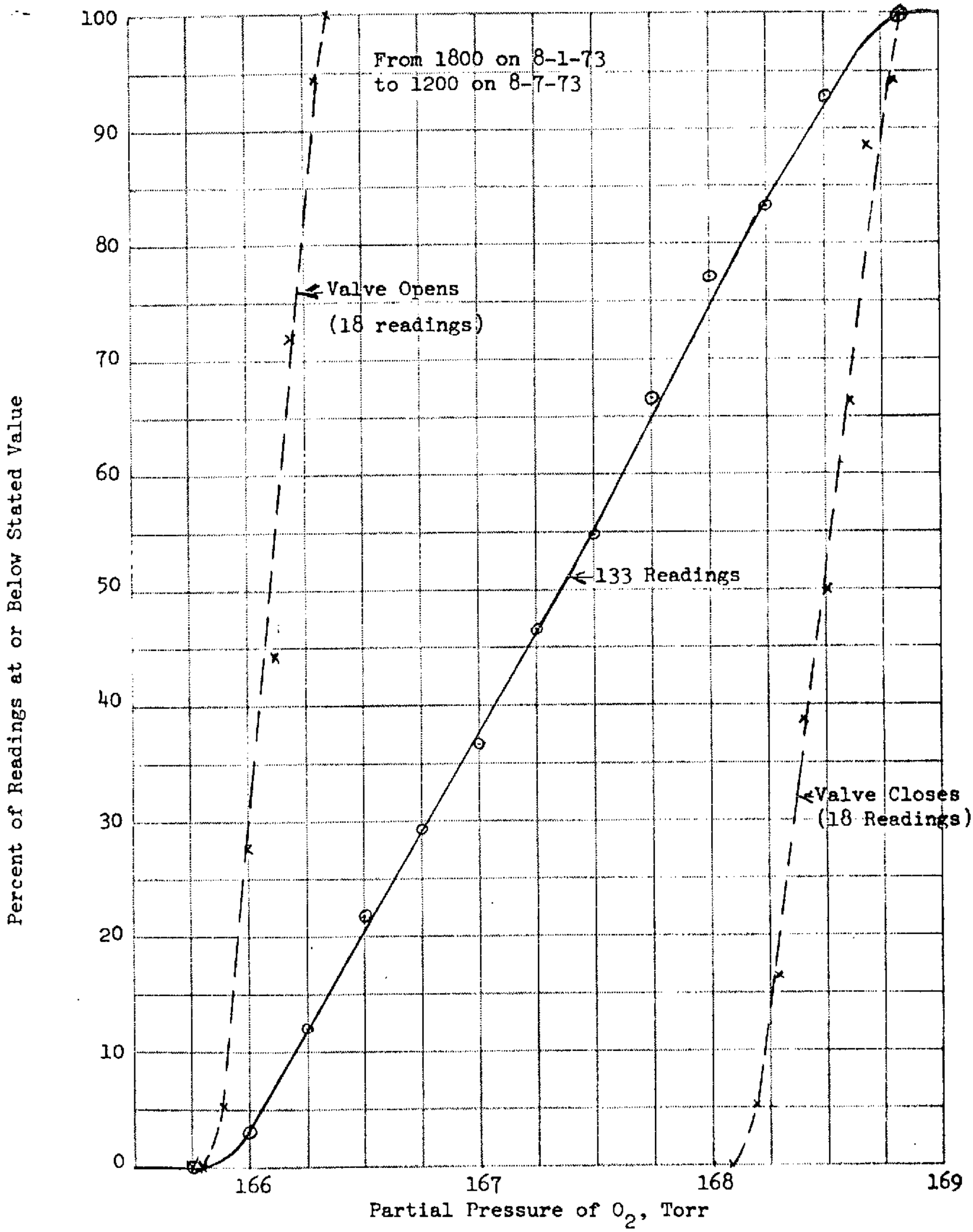
Data taken at the 14.7 psia set point is presented in Table 23. The statistical data for valve opening and valve closing is shown for each value of leakage after the MSS output noise problem was corrected. The required operating band was 162.3 torr to 170.1 torr. Values of PP O_2 between the valve opening and closing points were uniformly distributed over the range, as they were at 10 psia (see Figure 22).

The operating point of the O_2 channel is not dependent upon the leakage, as is the N_2 channel, but the influence of the dead-band is apparent. Values of valve opening range between 165.66 and 167.13 torr; for valve closing, between 167.97 and 168.88 torr. The distinct difference between the opening and closing suggests that the dead-band could be reduced for future applications - perhaps as much as 0.8 torr.

Table 24 summarizes the cumulative frequency of data taken for the O_2 valve opening and closing.

7.3.2.3 Total Pressures

The ACS was designed to control O_2 and N_2 partial pressures directly. Total pressure control was therefore indirect. Total pressure readings are subject to deviation due to the proportional band of the N_2 channel,



CUMULATIVE FREQUENCY OF PPO_2 READINGS
10 PSIA PORTION OF ENDURANCE TEST

FIGURE 22

Table 23

SUMMARY DATA ON O_2 CHANNEL AT 14.7 PSIA

Leakage Lb/day	Valve Opening (torr) Min.	Mean	Max.	Std. Deviation	Valve Closing (torr) Min.	Mean	Max.	Std. Deviation
2.90	165.91	166.23	166.71	0.23	168.06	168.62	168.88	0.22
4.07	166.60	166.26	166.44	0.14	168.20	168.52	168.83	0.17
4.40	165.93	166.22	167.13	0.36	167.97	168.28	168.54	0.18
5.96	165.79	166.18	166.68	0.26	168.19	168.47	168.73	0.16
6.45	165.66	166.12	166.36	0.18	168.26	168.42	168.63	0.12
8.15	165.89	166.16	166.56	0.19	168.07	168.31	168.59	0.15

Table 24

SUMMARY OF CUMULATIVE FREQUENCY OF O_2 CONTROL DATA

14.7 PSIA SET POINT

Partial Pressure of O_2 torr	Frequency of Observations Less Than Stated Value	Fraction of Observations Less Than Stated Value
For Valve Opening:		
165.6	0	0
165.8	2	0.0244
166.0	14	0.1708
166.2	41	0.5002
166.4	74	0.9028
166.6	78	0.9516
166.8	81	0.9882
167.0	81	0.0882
167.2	82	1.0000
For Valve Closing:		
167.9	0	0
168.0	1	0.0120
168.2	7	0.0843
168.4	35	0.4217
168.6	64	0.7711
168.8	77	0.9277
168.9	83	1.0000

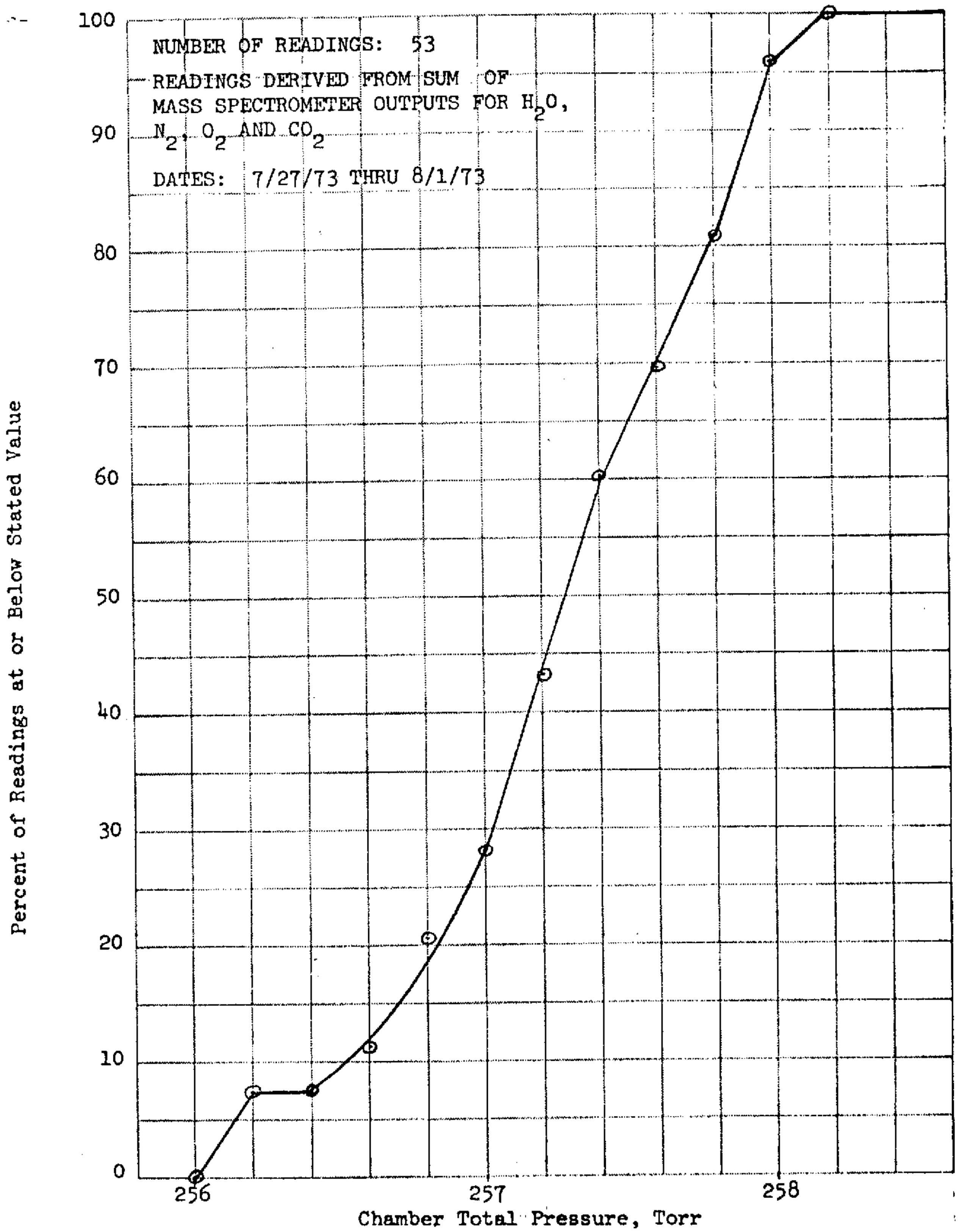
or cabin leakage; the dead band of the O_2 channel; errors in control of both O_2 and N_2 channels; variations in partial pressures of water vapor and CO_2, and inaccuracies in the MSS compensating circuit which adjusts channel gains to make the sum of partial pressures equal to total pressure.

During the endurance test, atmospheric O_2 and N_2 were provided from high pressure supplies and there was no source of H_2O or CO_2 as there would be in a manned cabin. Relatively low values of these gases were observed in the atmosphere at the beginning of the test and these gradually declined as initial residuals in the chamber were eliminated during the test. As a result, total pressure readings were generally lower than nominal values.

As will be discussed in a later section, a gradual drift occurred in the summation of MSS readings of H_2O, N_2, O_2 and CO_2 as compared with total pressure indicated by the precision pressure gage. Since the requirements emphasize control accuracy and eliminate the accuracy of the MSS as a subject of the test, data presented in this section are based upon summing the partial pressures indicated by the MSS.

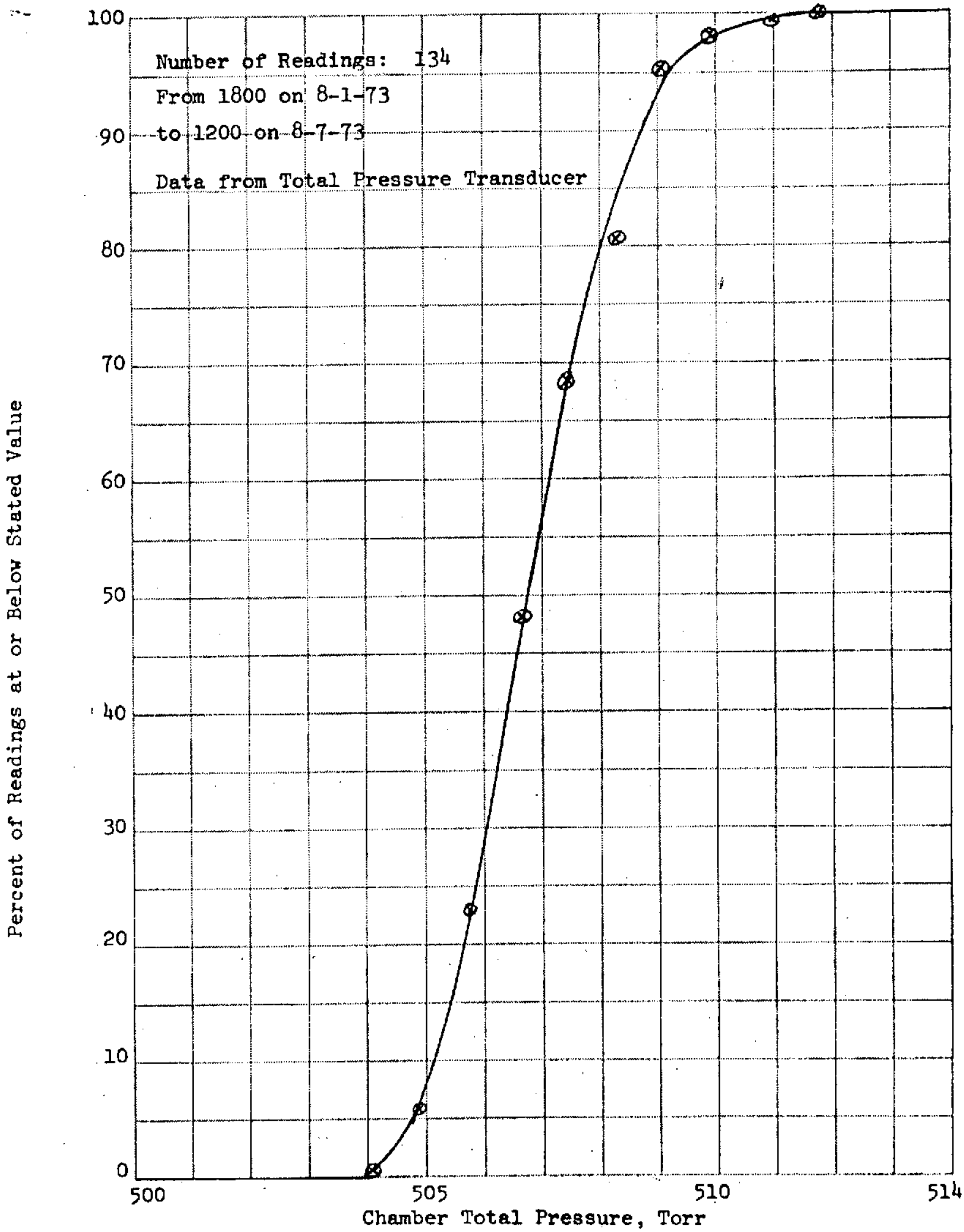
Figure 23 shows total pressures for the 5 psia portion of the test. All readings are between 256.0 and 258.2 torr. The desired nominal value is 258.5 with allowable extremes of 248.2 to 268.8 torr. All data points are well within allowable limits.

Readings of total pressure taken after stabilization at the 10 psia set point are on Figure 24. All readings are between 504 and 511 torr, compared with a specified range of 506.6 to 527.3 torr. Operation at the low end of the range is due to the lack of H_2O and CO_2 in the chamber. The operating band is only 7 torr, compared with the allowable band of 20.7 torr, showing the potential accuracy of the control in an actual manned cabin.



CUMULATIVE FREQUENCY OF TOTAL PRESSURE READINGS
5 PSIA PORTION OF ENDURANCE TEST

FIGURE 23



CUMULATIVE FREQUENCY OF TOTAL PRESSURE READINGS
10 PSIA PORTION OF ENDURANCE TEST

FIGURE 24

Total pressure data taken at the 14.7 psia set point is summarized for each leakage value in Table 25. Values range from 747.27 to 755.74 torr. The overall mean value of the 672 readings is 751.98 torr. The allowable range of total pressures is 749.6 to 770.3 torr. When allowance is made for the addition of water vapor and CO_2, the observed values are well within requirements.

Table 26 presents a cumulative frequency summary of all total pressure data. It is seen that only about 4 percent of the observed data points are below the specification minimum, even without the H_2O and CO_2 addition.

7.3.3 Mass Balance Data

The possibility of measuring gas usage by counting pulses of a pulse frequency proportional control has long been proposed. In order to evaluate this method, data was collected during the Endurance Test. Total flow out of the chamber was measured by the Wet Test Meter (WTM). The mass spectrometer provided a continuous analysis of the effluent gas so that the amount of nitrogen removed could be calculated. The nitrogen pulse size was calibrated as explained in Section 7.3.1.2, and each pulse was found to be 0.018683 lbs of gas. Using this value and recorded N_2 pulse counts, the N_2 inflow could be determined. The comparison of calculated N_2 inflow and outflow is presented in Table 27.

Some rather large discrepancies are indicated. The largest, at 5 psia, may be explained by atmospheric leakage into the chamber. Some leaks were found and repaired after this segment of the test. Other deviations emphasize the importance of careful design of the N_2 gas supply system when flow measurement is a requirement. In the present test, the system had several poor features. About 40 ft of 1/4 inch tube was run between the high pressure supply and the control panel. The pressure drop in this line was observed to be significant. The pressure regulator available was incapable of achieving a high enough setting; 19 psig was used during the

Table 25

SUMMARY DATA ON TOTAL PRESSURES AT 14.7 PSIA SET POINT

Leakage lb/day	Total Pressures (Torr) Minimum	Mean	Maximum	Standard Deviation	Number of Readings
2.90	749.37	752.42	755.74	1.42	133
4.07	749.75	752.27	754.65	1.23	105
4.36*	751.43	753.34	755.39	1.03	76
4.40	748.88	751.31	753.87	1.25	54
5.96	747.27	751.07	754.04	1.45	106
6.45	749.70	752.05	754.12	1.04	123
8.15	748.50	751.10	753.16	1.11	75

*NOTE: Readings only after installation of 22 μf filter capacitors in O_2 and N_2 channels.

TABLE 26

SUMMARY OF CUMULATIVE FREQUENCY OF TOTAL PRESSURE DATA

Total Pressure Torr	Frequency of Observations Less Than Stated Value	Fraction of Observations Less Than Stated Value
747.0	0	0
747.5	2	0.0030
748.0	2	0.0030
748.5	5	0.0075
749.0	10	0.0149
749.5	27	0.0403
750.0	59	0.0879
750.5	105	0.1565
751.0	172	0.2563
751.5	243	0.3621
752.0	340	0.5067
752.5	422	0.6289
753.0	501	0.7466
753.5	558	0.8316
754.0	616	0.9180
754.5	650	0.9687
755.0	663	0.9881
755.5	671	0.9985
756.0	672	1.0000

Table 27

MASS BALANCE SUMMARY

(N_2 Pulse Size = 0.018683 lb per pulse)

Pressure	Leakage	N_2 Flow Data Outflow lb/day	Inflow lb/day	Difference (Out-In) lb/day	Error (O-I/O) percent
5	4.38	1.0612	0.8558	+ 0.2054	+ 19.4 *
10	5.32	3.2423	3.3116	- 0.0693	- 2.1
10	3.56	2.2115	2.0465	+ 0.1650	+ 7.5
14.7	1.69	1.2499	1.1759	+ 0.0749	+ 5.9
14.7	2.90	2.1439	2.4473	- 0.3034	- 14.2
14.7	4.07	3.0070	3.0885	- 0.0815	- 2.17
14.7	4.36	3.2263	3.1094	+ 0.1169	+ 3.6
14.7	4.40	3.2545	3.2894	- 0.0349	- 1.1
14.7	5.96	4.4097	4.3914	+ 0.0183	+ 0.4
14.7	6.45	4.7716	4.2985	+ 0.4731	+ 9.9
14.7	8.15	6.0286	5.1877	+ 0.8409	+ 13.9

* NOTE: Reading error introduced by cabin in-leakage.

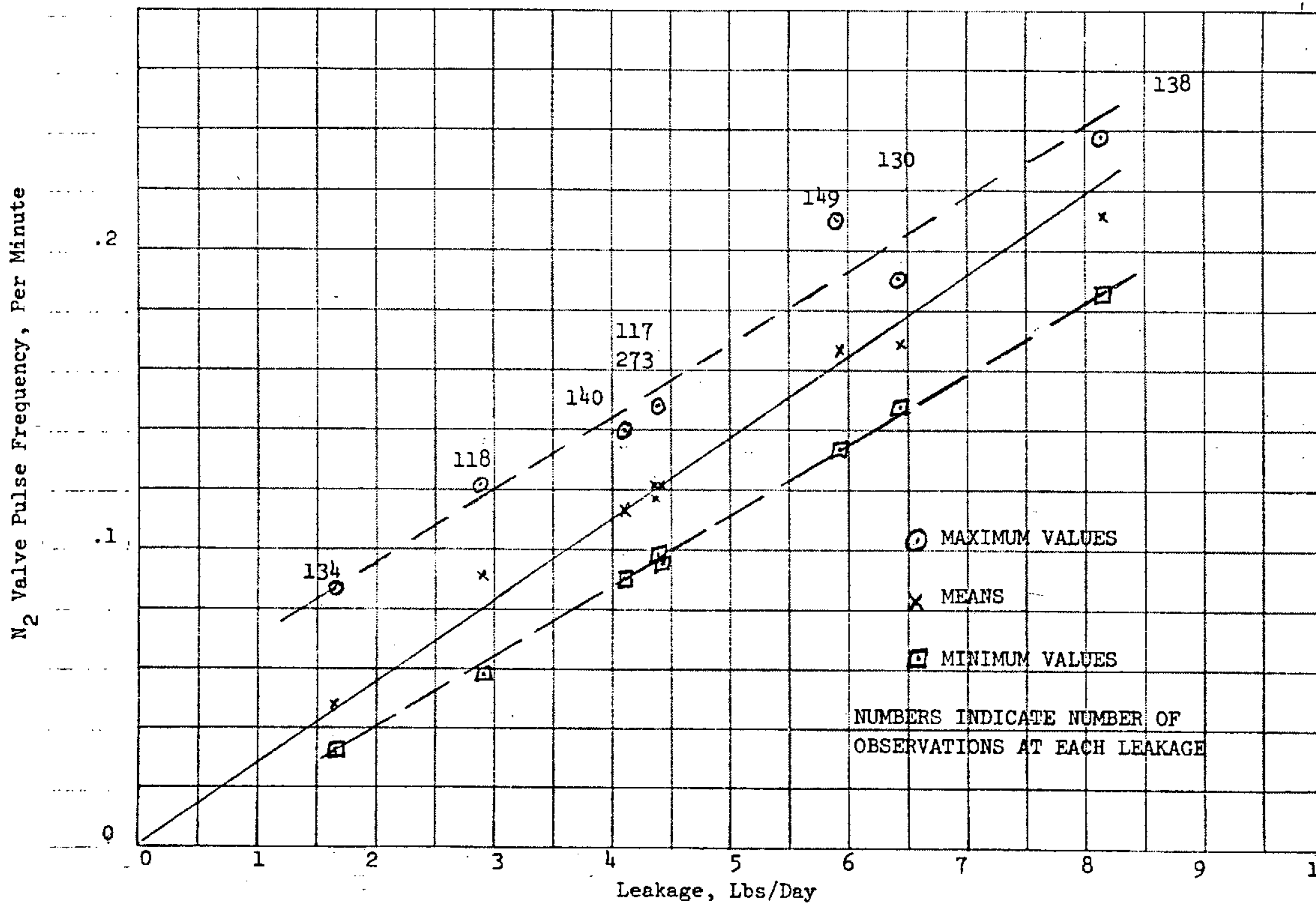
test. Further the metering valve was operated wide open. All these features tend to decrease the accuracy of the pulse size calibration. In spite of these difficulties, the overall average of flow measurement error was found to be 4.05 percent.

7.3.4 Leakage Measurement

Reference 2 has developed a method of measuring cabin leakage based either upon N_2 gas pulse frequency or upon N_2 integrator output pulses per 10 minute time period. This method was based upon an analytical model of control system operation. Data was collected during the endurance test to experimentally verify this leakage detection and measurement method and to provide actual performance data in order to improve the analytical model.

Actual operating times for the N_2 valve were recorded by the automatic data system. After initial transients had subsided, the valve operating periods were tabulated and statistically analyzed to determine the mean, standard deviation, and extreme values that were encountered at each leakage value. The reciprocals of these values, or pulse frequencies, are plotted in Figure 25. This curve can be compared with corresponding data from Figure 17 of Reference 2. At the design value of Shuttle Cabin Leakage (12 lb/day for orbiter; scaled to 5.25 lb/day during this test), it is found that the $\pm$ 2σ band (95% confidence) represents an actual flow variation of $\pm$ 1.20 lb/day of leakage ($\pm$ 2.74 lb/day simulated leakage). This compares with $\pm$ 1.9 lb/day of Orbiter cabin leakage predicted by the analytical model.

Examination of transient values of N_2 gas pulse period and N_2 partial pressures following step changes in cabin leakage show a tendency toward lower system damping than was predicted by the analytical model. The latter shows (Figure 7, Reference 2) a basically overdamped system which exponentially approaches the new value following a change in leakage. Data from the present test shows an underdamped system which tends to overshoot the final value, then return to it. This loss of stability is typical of a control system in which the loop gain is too high and there is an actual system dynamic lag which was not included in the analytical model.



N_2 VALVE FREQUENCY FOR MEASURING CABIN LEAKAGE

FIGURE 25

Previously presented calibration data show that both the N_2 integrator gain and the gas pulse size are slightly larger than design values. Reducing either or both of these would result in improved system stability and reduce the amount of overshoot, at some small expense in operating accuracy. It is believed that the dynamic lag which caused this destabilization is the mixing time required between introduction of a gas pulse and obtaining a mixed sample at the MSS inlet. Knowledge of this effect can enable improved analytical modelling which will result in a selection of the most favorable combination of design characteristics for accurate performance in pressure control and leakage measurement, and best system response.

7.3.5 Transient Performance Data

Data was collected showing the speed of approach to a new set point in partial pressure. At initial startup of the test, the chamber pressure was pumped down to 73.0 torr, with PPN_2 = 57.7 torr and PPO_2 = 16.2 torr as indicated by the MSS. The control was then initiated, at 0900, and the transient in O_2 and N_2 partial pressures recorded. The results for the first two hours are shown in Figures 26 and 27 respectively. The oxygen partial pressure only increased 2 torr during this time; an increase of 170 torr was required to reach the set point. It was realized that the O_2 flow capability of the system was inadequate to correct such a large error - most of the 6 day test period would have been required just to reach the set point. Procedures were therefore initiated to provide additional oxygen from bottled storage to bring this partial pressure up to requirements.

The N_2 partial pressure (Figure 27) had nearly reached the set point at the end of the 2 hour period and showed the exponential approach characteristic of proportional systems.

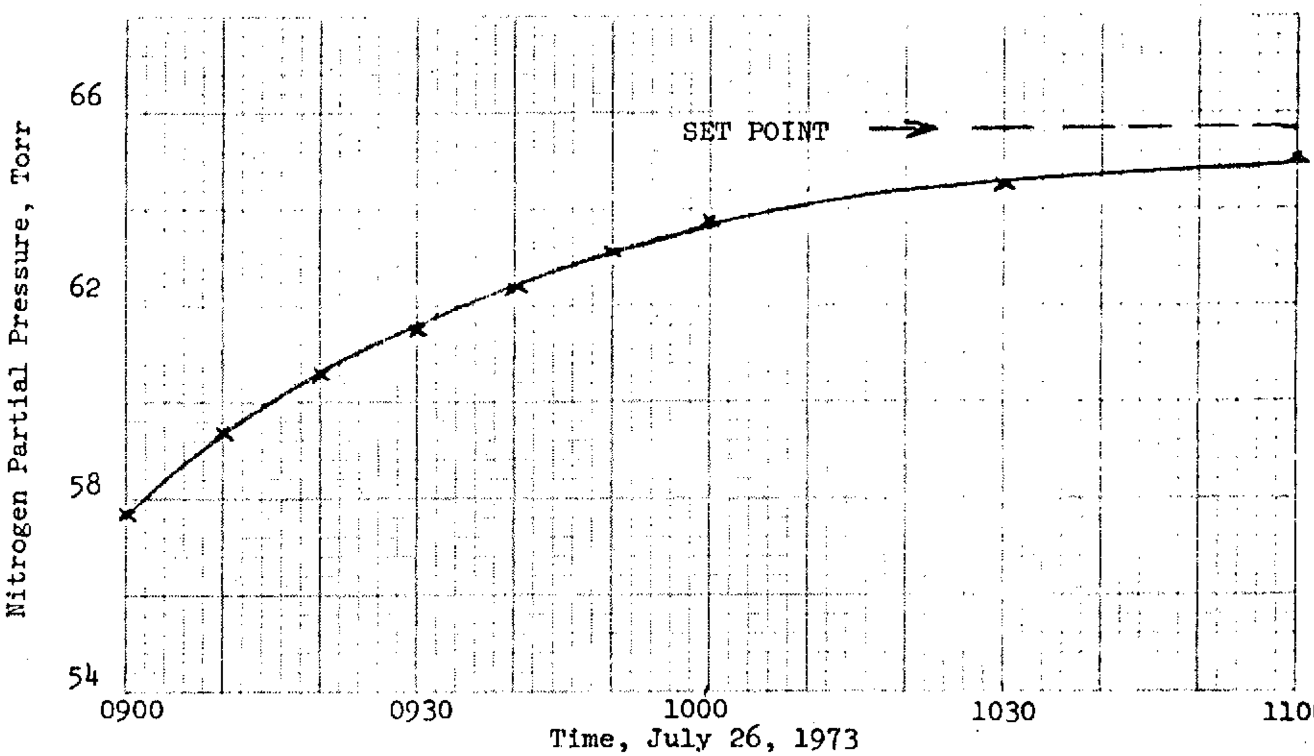


FIGURE 27 NITROGEN PARTIAL PRESSURE TRANSIENT

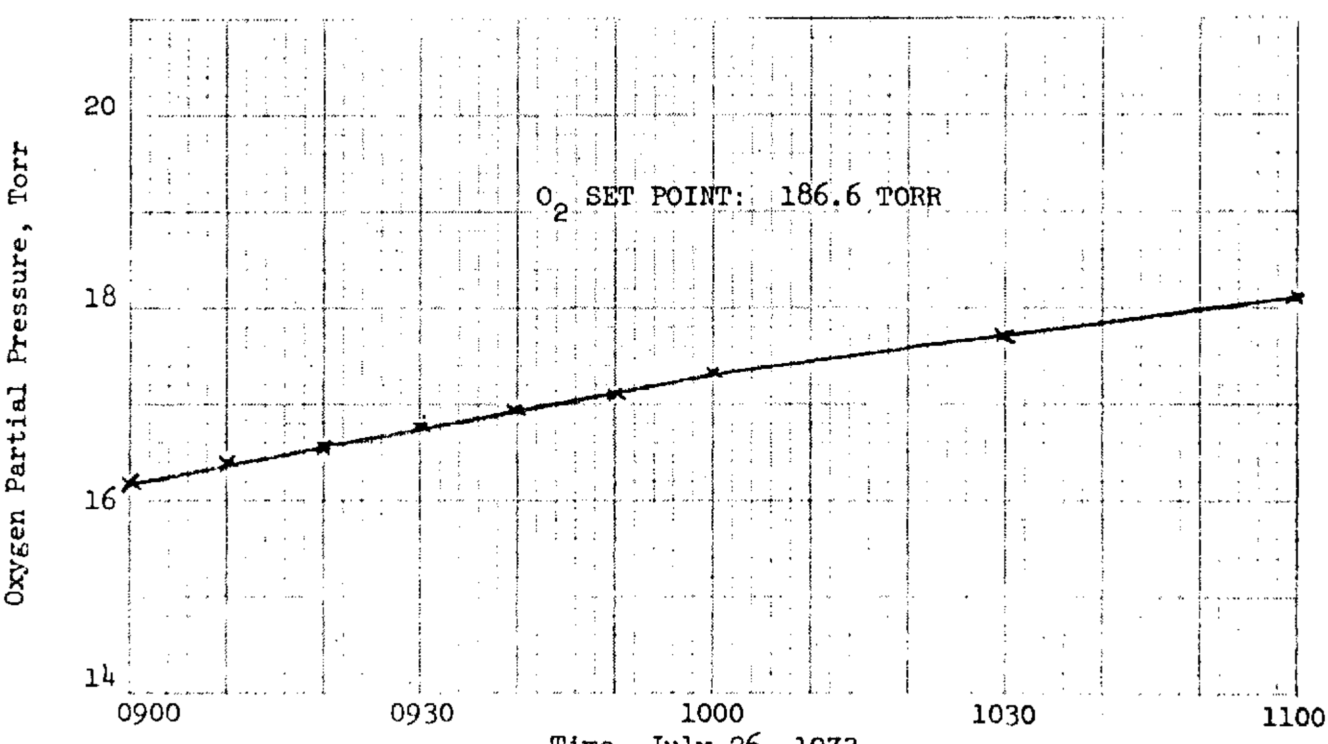
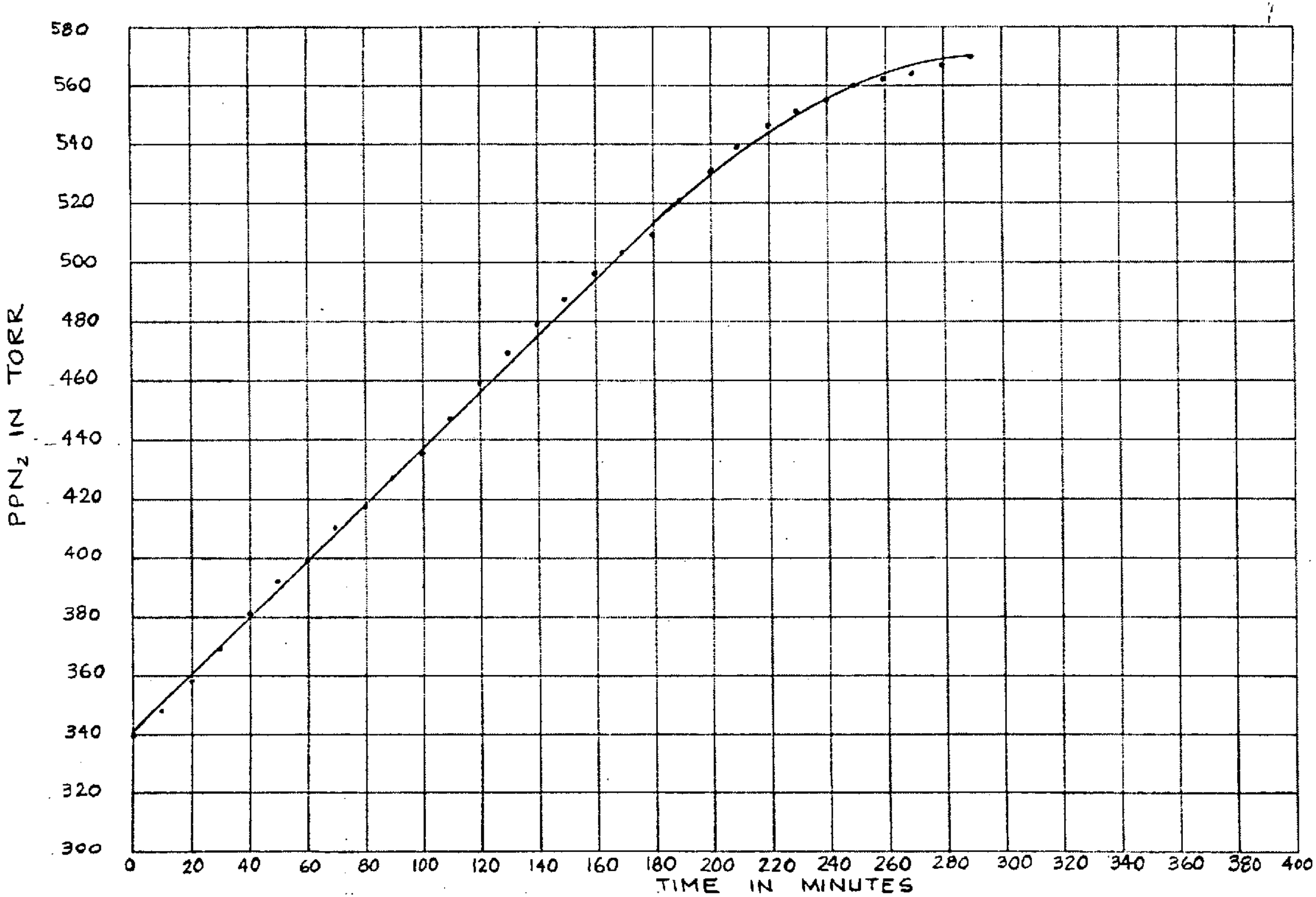


FIGURE 26 OXYGEN PARTIAL PRESSURE TRANSIENT
INITIAL START UP, 60 DAY TEST, 5 PSIA SET POINT

The transition from 10 psia to 14.7 psia required only a change in N_2 partial pressure from approximately 340 torr to 583 torr. Although such a transition probably would not be done automatically in an operational system (an auxiliary repressurization valve would be used), it was felt that useful data would be obtained if it were done during this test. Accordingly, the set point was changed at 1200 on August 7. The subsequent transient was recorded. Figure 28 shows the resultant change in nitrogen partial pressure. The rate of increase was nearly constant, with virtually continuous pulsing of the control, until about 540 torr was reached in 210 minutes. The effect of the proportional band then caused the characteristic asymptotic approach to the set point. The transient was terminated at 570 torr after 290 minutes due to the accidental opening of the chamber relief valve, previously discussed.

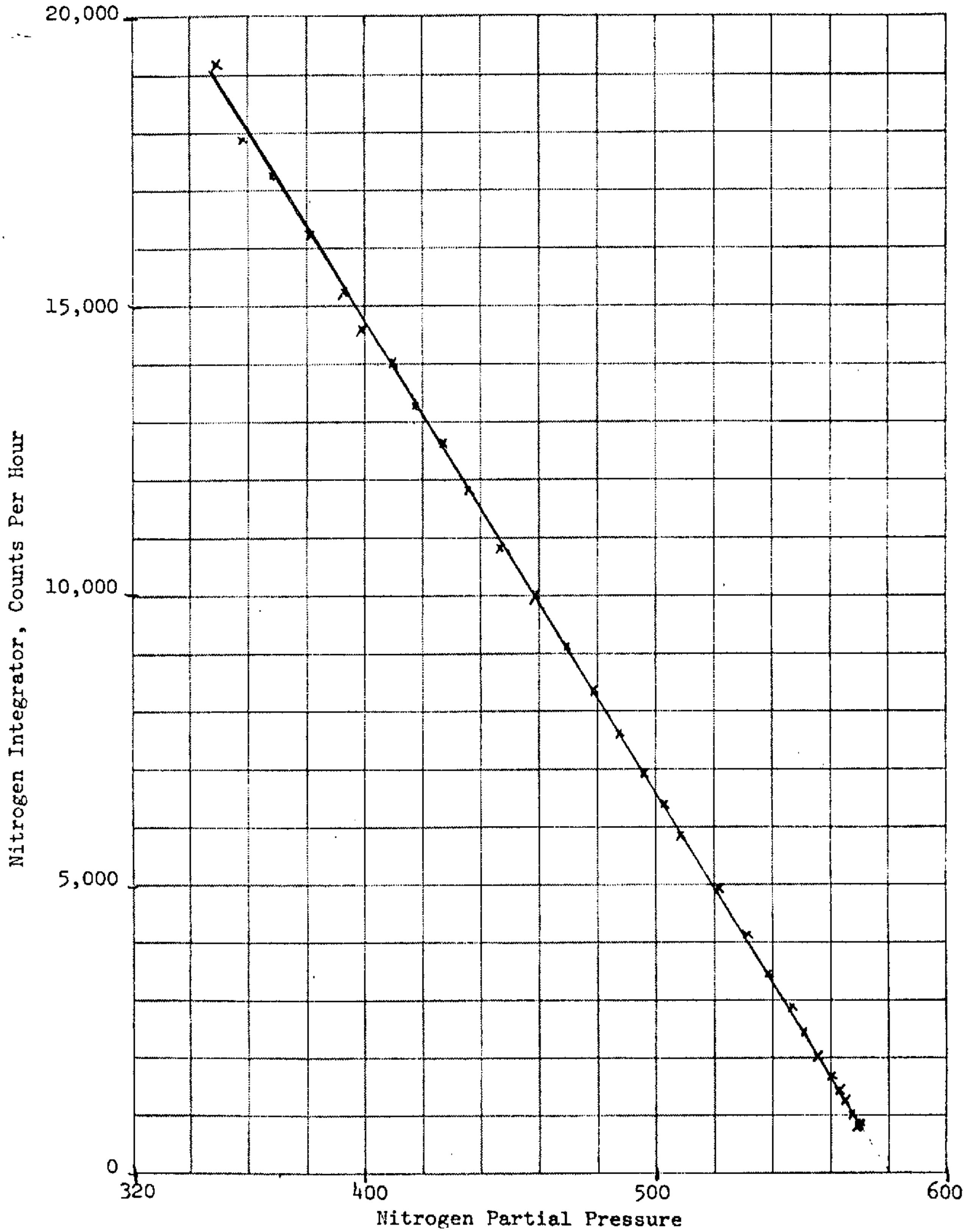
The corresponding variation of integrator pulse frequency as a function of N_2 partial pressure is shown for this transient on Figure 29. This compares with pretest data previously shown on Figure 9. The value of integrator gain is 11,050 pulses per hour per volt, compared with 11,400 pulses per hour per volt during the pretest measurement.

The resulting frequency of N_2 valve operation during this transient was interesting. The valve must stay open 10 seconds when energized. Initially the integrator pulse frequency was about 19,200 per hour, resulting in the integrator counter reaching 16 in about 3 seconds. The counter reset; the valve remained open until the 10 second time was up, then closed even though 3 resets of the counter had occurred. At the next reset - 12 seconds after the original opening - the valve received the next signal to open. As a result, the valve operating frequency was about 300 per hour. As the pressure increased, the integrator frequency decreased. At about 368 torr (N_2 partial pressure), the frequency had decreased to slightly less than 48 counts in 10 seconds, and the valve frequency increased from 270 per hour to 360 per hour, or essentially continuously open. Further pressure increase caused



PARTIAL PRESSURE N_2 vs. TIME (TRANSITION FROM 10 PSIA TO 14.7 PSIA)

FIGURE 28



NITROGEN INTEGRATOR PERFORMANCE DURING
TRANSIENT, 10 TO 14.7 PSIA SET POINT

FIGURE 29

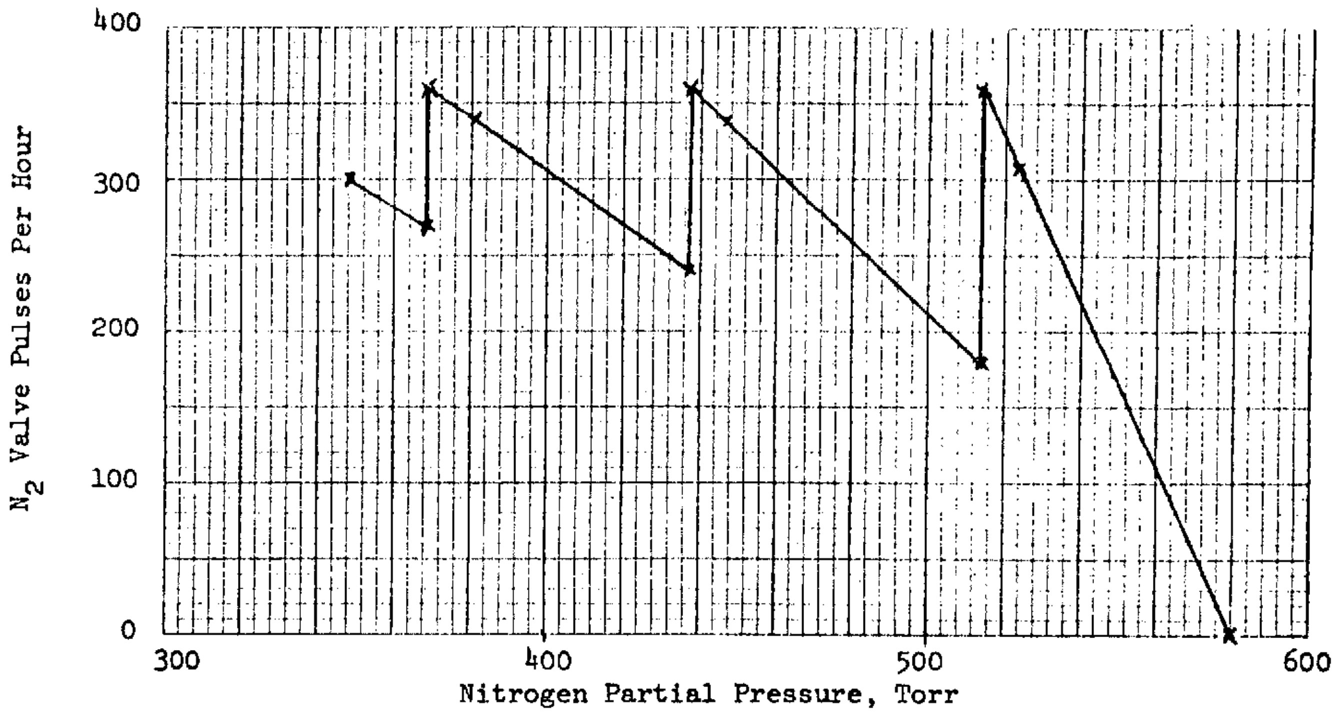


FIGURE 30 NITROGEN VALVE OPERATION DURING TRANSIENT FROM 10.0 TO 14.7 PSIA SET POINT

the valve frequency to decrease to 240 per hour at a partial pressure of 437 torr, at which point the integrator count was 32 in 10 seconds, or 11520 per hour, and the valve frequency returned to 360 pulses per hour. At 514 torr, the valve frequency had dropped to 180 per hour and the integrator frequency to 16 in 10 seconds. The valve frequency then went to 360 per hour again since the valve opening pulses were slightly more than 10 seconds apart. Further increase in partial pressure resulted in a corresponding, linear decrease in valve frequency until the transient was terminated. This valve operation is illustrated on Figure 30.

7.4 Mass Spectrometer Performance

Although evaluation of the mass spectrometer sensor was not part of the test objectives, some data was obtained and will be reported for future reference.

From a qualitative standpoint, the excellent stability, repeatability, and resolution of the MSS makes it an ideal sensor for use in the ACS. The ability to obtain consistent data on chamber leakage by N_2 gas pulse frequency is an indication of these characteristics, since this could not be done if resolution was poor or hysteresis was present. The response time to transients is also very good.

During the testing period there was no re-calibration of the instrument, and no failures. The MSS was received on November 1, 1972 and stored. On December 22, 28 vdc power was supplied to the ion pump to maintain internal vacuum. Although there had been no pumping for nearly two months, the unit was still evacuated and the pump started immediately. Power has been kept on the ion pump since that time, except for brief periods when the MSS was moved to the endurance test area, then returned to the laboratory. The unit was operated for about 62 days during the endurance test without problems.

The MSS includes a total pressure transducer, and a gain adjusting circuit is designed to make the sum of partial pressures of H_2O, N_2, O_2 and CO_2 equal to the total pressure. During the endurance test a gradual shift was observed in this relationship. The difference between barometric pressure, read by a precision Wallace and Tiernan gage with a rated accuracy of 0.1 percent, and the average of summed partial pressures of the MSS, is shown on Figure 31. The indicated error started at about -0.7 percent and gradually increased to +2.0 percent by the end of the test. The unit is being returned to Perkin Elmer for examination to determine the cause of this shift.

The MSS was supplied with ambient air samples several times during the test period. The results of analysis of three such samples are shown on Table 28. This confirms the gradual drift previously discussed. Since the major variation appears to be in the summation of partial pressures and the relative percentages appear to remain close to that expected, it appears that the drift is probably due to the pressure transducer, rather than some other cause.

Another characteristic worth commenting upon was the high frequency noise observed on the MSS output signals at the start of the 14.7 psia segment of the test. This caused the data system to read pressure fluctuations that were obviously not occurring. The noise level was reduced by about 80 percent by placing 22 microfarad capacitors at the output of the Interface Buffer Assembly. The residual variation, especially in N_2 partial pressures, may well be due to this noise rather than to actual pressure variations. The magnitude was not significant however.

This input noise did not adversely affect the control action. The means, standard deviations, and extremes of N_2 valve pulse frequency data taken before and after the filters were inserted were virtually identical, showing that the input integrator was successfully smoothing this noise.

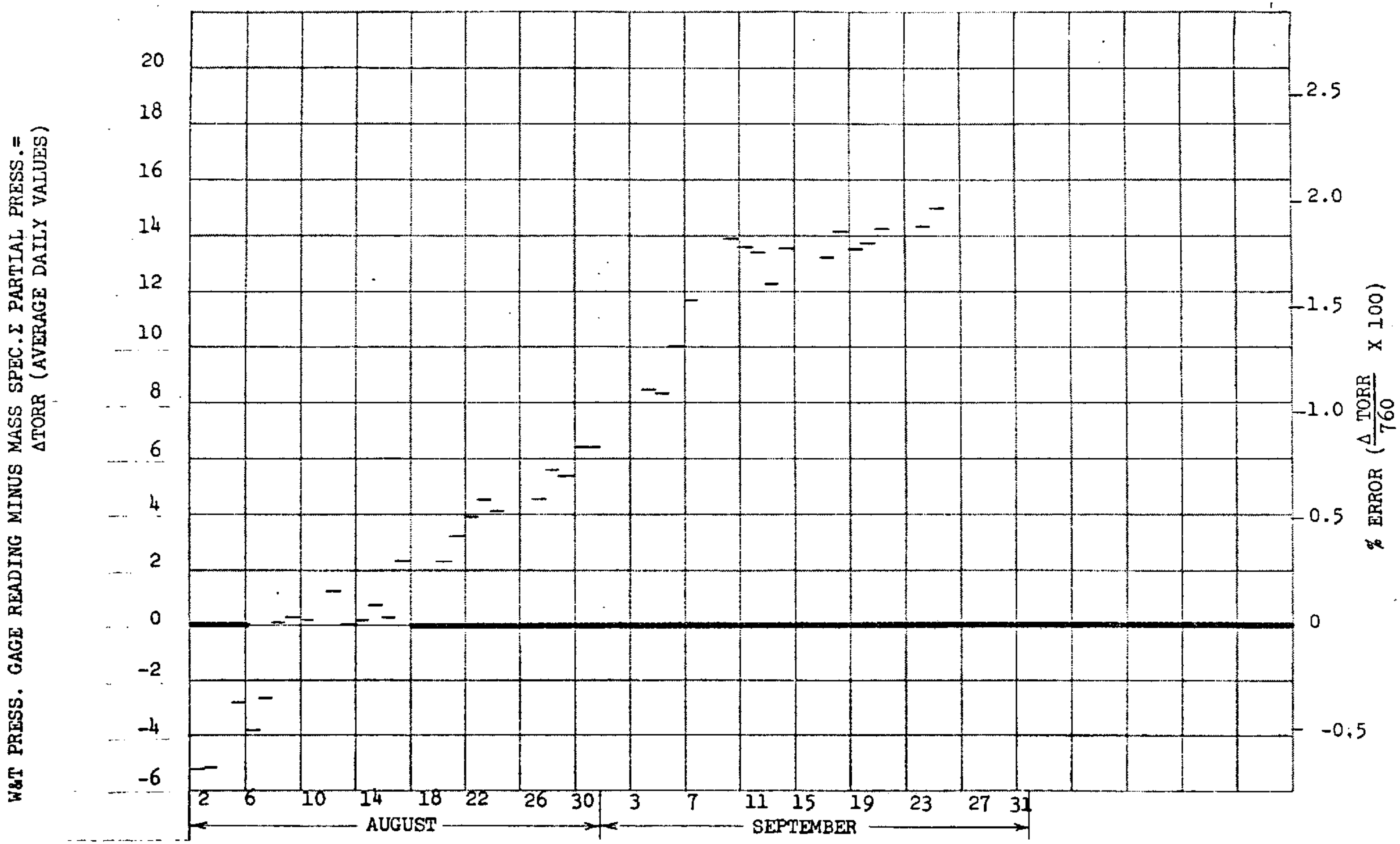


FIGURE 31 CALIBRATION OF THE MASS SPECTROMETER SENSOR

Table 28

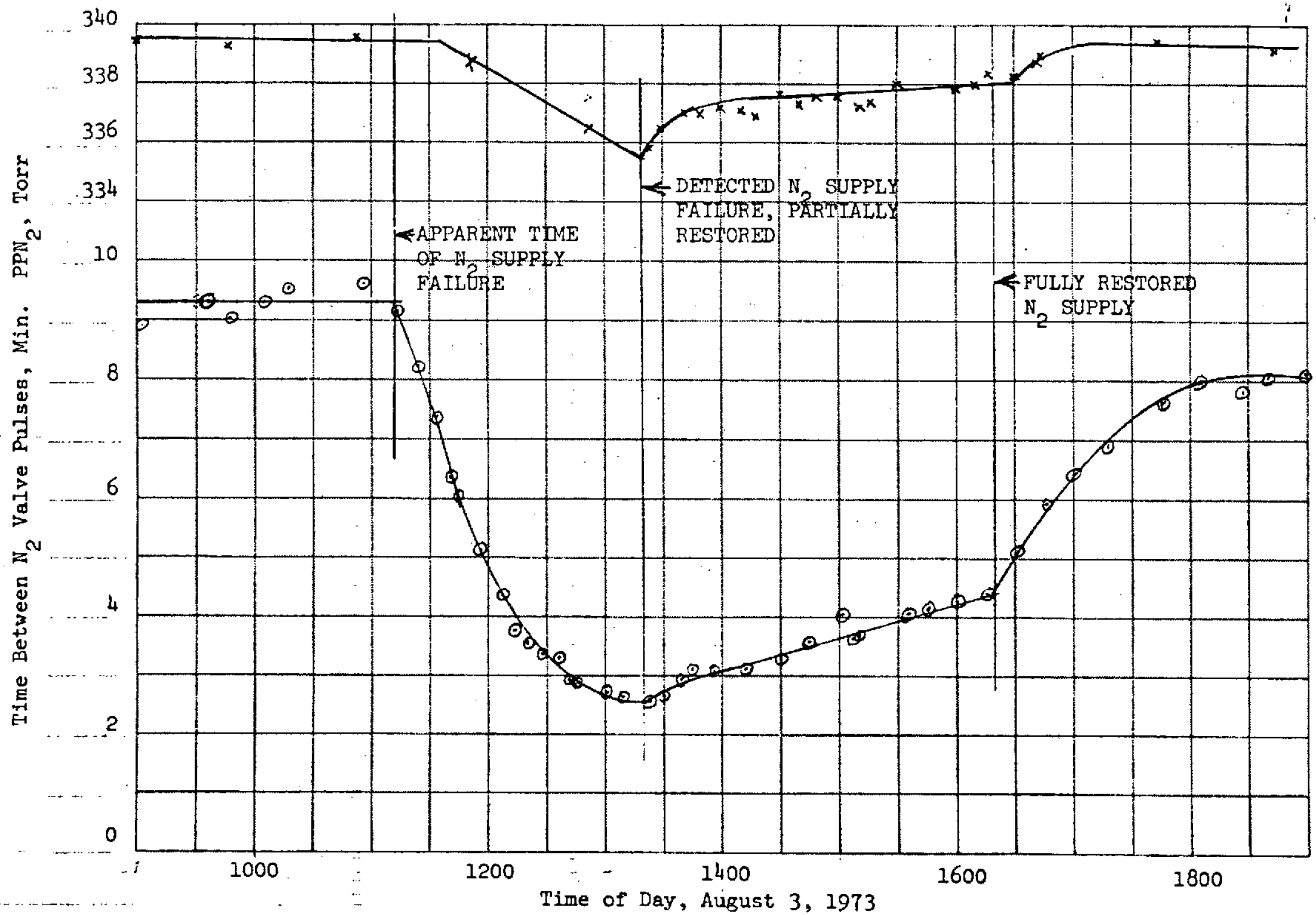
ANALYSIS OF AMBIENT AIR SAMPLES BY MASS SPECTROMETER

	July 26, 1973		August 1, 1973		September 26, 1973	
	Torr	Percent (Volume)	Torr	Percent (Volume)	Torr	Percent (Volume)
Nitrogen	594.79	0.7663	597.43	0.7690	585.29	0.7817
Oxygen	161.11	0.2076	161.83	0.2083	158.33	0.2115
Water Vapor	19.31	0.0249	16.70	0.0215	4.62	0.0062
Carbon Dioxide	0.93	0.0012	0.87	0.0011	0.46	0.0006
Total	776.14	1.0000	776.83	0.9999	748.70	1.0000
Barometric Pressure	760.0		760.0		760.0	
Error (percent)	- 2.12		- 2.21		+ 1.49	

7.5 Failure Data

There were no failures, either of the ECA or the MSS, during the testing reported herein. A significant event did happen when the gaseous nitrogen supply to the PCP failed. At about 1320 on August 3 it was found that the N_2 bottle had been replaced and the supply valve had not been turned on. This failure was detected by noting that the N_2 valve pulse period had decreased from an earlier value of about 9.5 minutes (before lunch) to about 2.5 minutes (after lunch). The valve was opened, but by about 1600 the period had only increased to about 4.5 minutes. A recheck showed that the regulator setting at the gas bottle was low. After returning this to the original setting, the pulse period increased to over 8 minutes.

The time sequence of N_2 pulse period and corresponding data on N_2 partial pressure is shown on Figure 32. The rapid decrease in period following the apparent loss of N_2 supply is dramatic. The decrease of N_2 partial pressure is less than 4 torr in the meantime. If valve operating period had been adequately monitored, the loss of N_2 supply could have been detected within about 30 minutes of its occurrence. This graphically points out the advantage of monitoring N_2 valve frequency as a failure indicating device.



USE OF 2-GAS CONTROL TO DETECT N_2 SUPPLY FAILURE
10 PSIA PORTION OF ENDURANCE TEST

FIGURE 32

Section 8

DISCUSSION

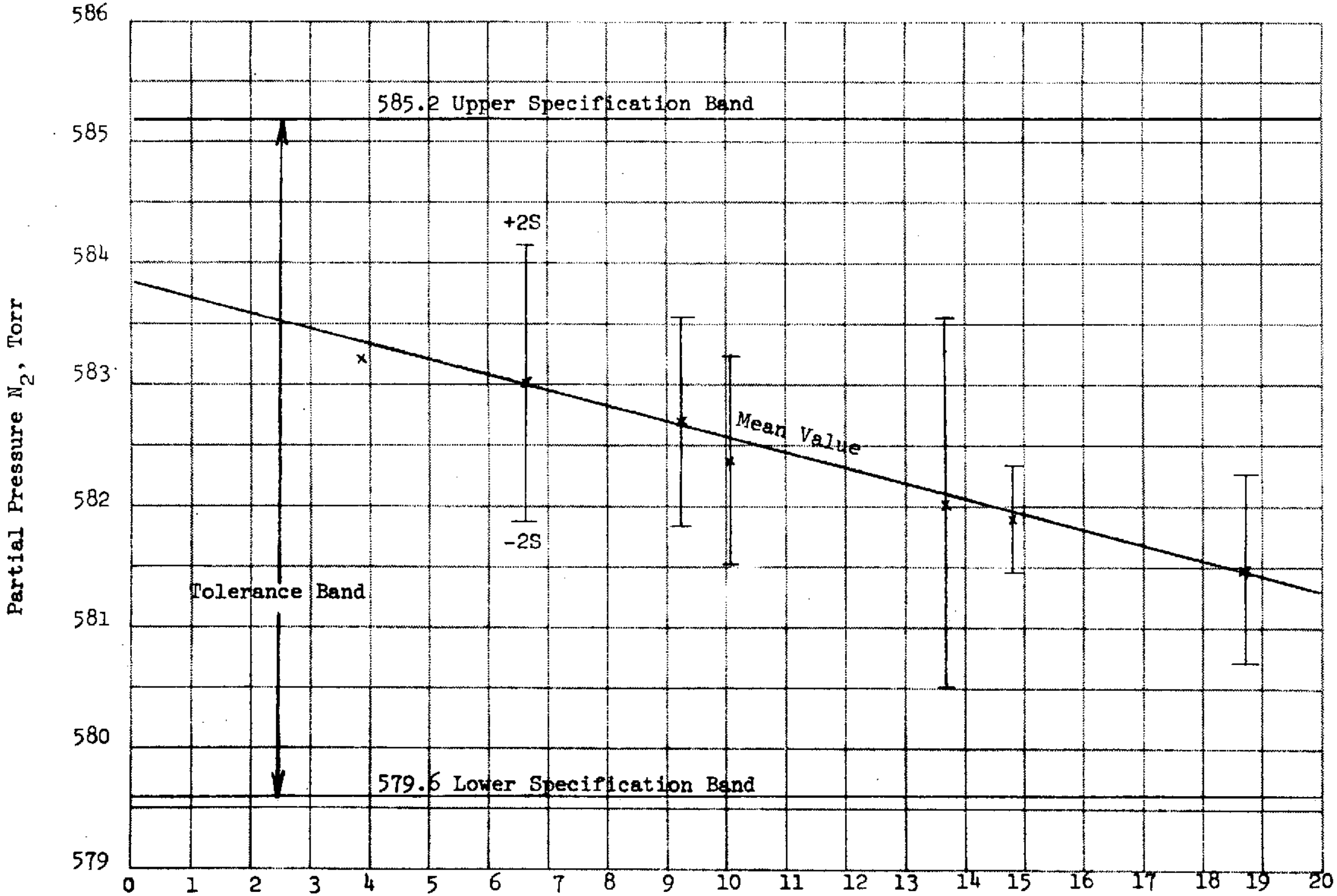
The following interpretation and comments on the test results presented in the previous section are appropriate:

8.1 CONTROL ACCURACY

The primary objective of the development of the Atmosphere Control Subsystem was to design and build a flight qualifiable prototype and demonstrate its ability to achieve accurate control over N_2 and O_2 partial pressures. Figure 33 shows the results of data taken on the N_2 channel at the 14.7 psia set point, indicating the means and 95 percent confidence bands at each level of leakage that was tested. Some of the indicated variation in pressure is due to noise on the MSS output signal rather than actual pressure fluctuation. Even so, all data falls between 580.5 and 584.15 torr, compared with the allowable range of 579.6 to 585.2 torr. This corresponds to $\pm$ 0.31 percent accuracy.

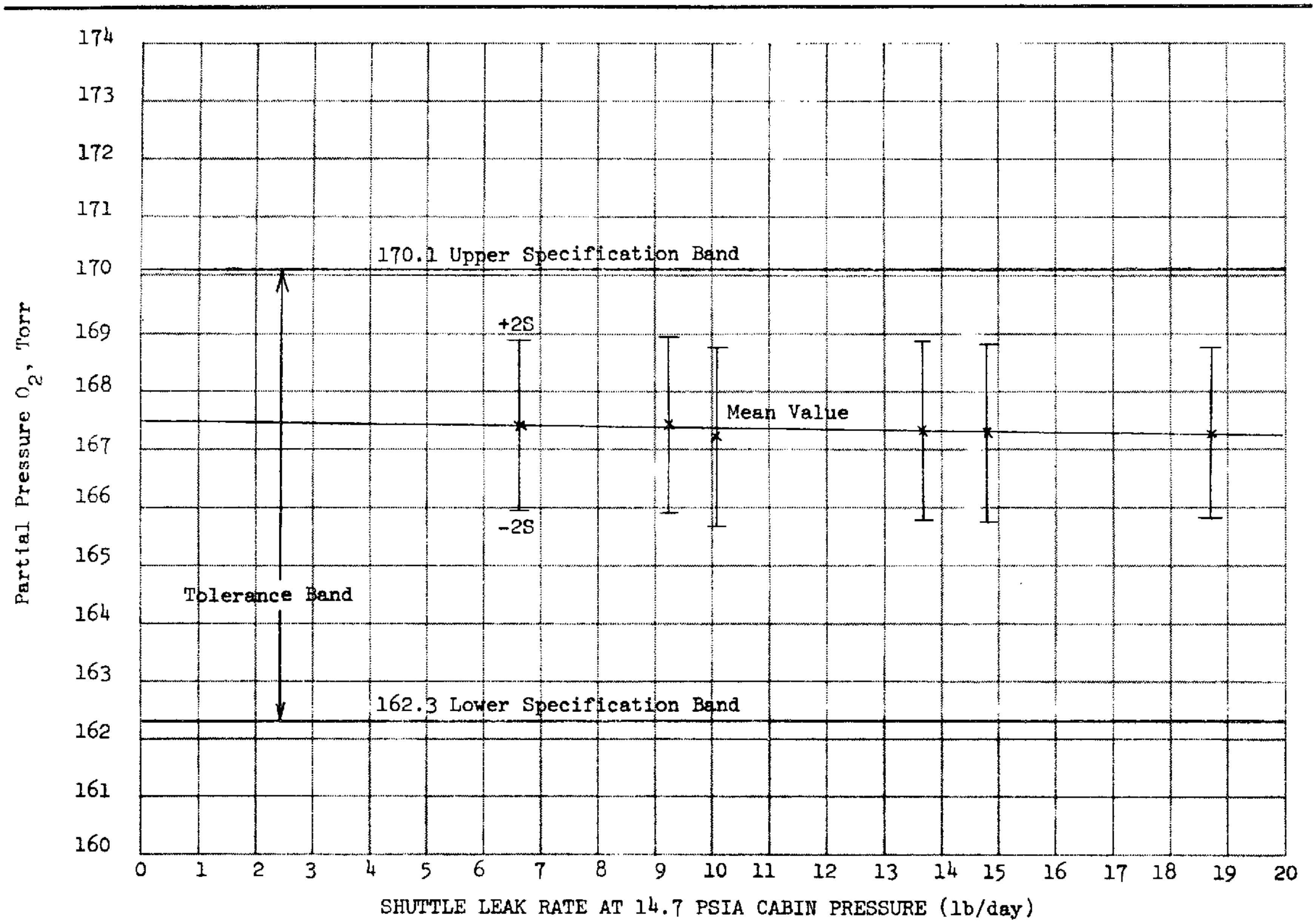
The O_2 channel data is on Figure 34. Here the effect of the O_2 dead band and the lack of sensitivity to cabin leakage is apparent. All values of O_2 partial pressure lie between 165.7 torr (3.20 psia) and 169.0 torr (3.27 psia), compared with the specified band of 162.3 torr to 170.1 torr.

The total pressure data is shown on Figure 35. The total pressure operating band is lower than nominal since the partial pressures of H_2O and CO_2 were much lower in the test chamber than they would have been in the manned cabin. All values lie between 748.0 torr (14.47 psia) and 755.5 torr (14.62 psia) for an accuracy of $\pm$ 0.5 percent.



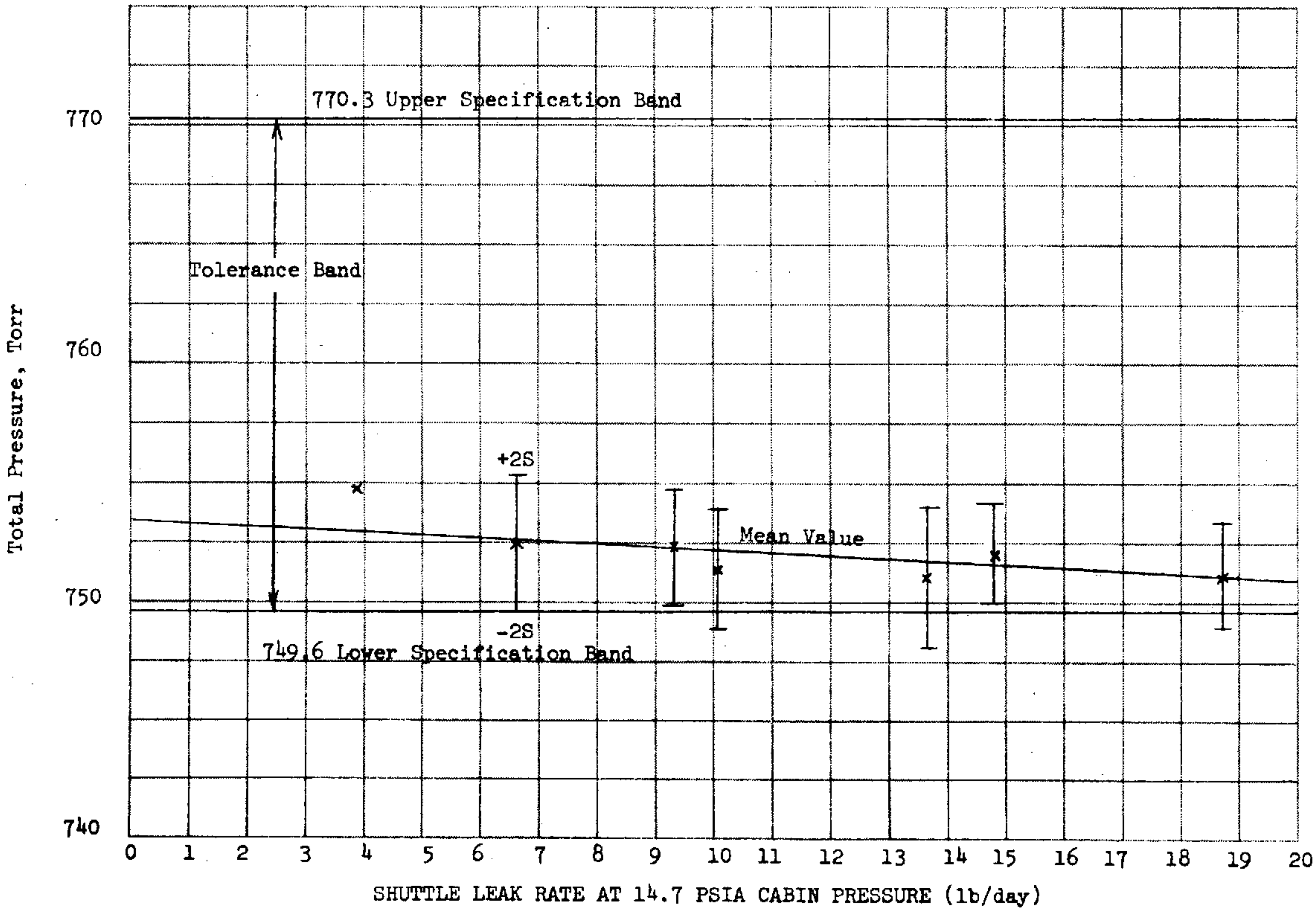
SHUTTLE LEAK RATE AT 14.7 PSIA CABIN PRESSURE (lb/day)
SUMMARY OF PARTIAL PRESSURE N_2 DATA

FIGURE 33



SUMMARY OF PARTIAL PRESSURE O_2 DATA

FIGURE 34



SUMMARY OF TOTAL PRESSURE DATA

FIGURE 35

8.2 SET POINT ADJUSTMENT

The design approach of predetermining the control set point by selection of an internal resistor network did not prove to be practical. However it was possible to adjust the N_2 set points for 10 and 14.7 psia operation to fall within the desired band by use of external resistors. At the 14.7 psia set point the required resistor was found to be 1100 ohms per torr of desired decrease. This portion of the endurance test was performed with a 4700 ohm resistor. In future applications a selector switch or potentiometer should be provided to enable trimming the set points to the desired value.

8.3 FLOW MEASUREMENT BY COUNTING PULSES

Data was taken which related N_2 valve pulses to N_2 gas usage. An accuracy of $\pm$ 14 percent was obtained for averages over several days of operation. It was felt that most of this inaccuracy was due to poor design of the N_2 gas circuit. Tubing sizes were not large enough for the flow rate, line lengths, and low operating pressures used, so that pressure drop occurred in lines rather than the metering valve. Some effort is in order to develop better design criteria for this installation, which includes a pressure regulator, solenoid valve, metering orifice and interconnecting plumbing. It is felt that there is an excellent potential for improving the accuracy of this circuit.

8.4 LEAKAGE MEASUREMENT

Test data shows that cabin leakage can be measured by timing the interval between successive N_2 gas pulses (3 to 30 minutes over the range tested) with an accuracy of $\pm$ 2.75 lb/day of Shuttle equivalent flow at a 95 percent confidence level. This compares with an analytical prediction of $\pm$ 1.9 lb/day. The difference appears to be due to a slight oscillatory characteristics in the test data that was not present in the analytical model. It is believed that this is caused by a delay in MSS output following addition of a gas pulse due to mixing in the chamber and transporting a mixed sample to the MSS. The system analysis should be modified to include this effect and further studied to determine the optimum combination of design variables to obtain best system accuracy when leakage measurement is a system requirement.

8.5 FAULT DETECTION

The measurement of time interval between gas pulses is a rapid indicator of system failures such as gas supply loss or valve failure. This was demonstrated by an incident in which N_2 supply failed during the test. With continuous monitoring, the failure could have been detected within 1/2 hour of occurrence. It was actually found by the engineering monitor about 2 hours after occurrence. At that time the N_2 pulse period had dropped from approximately 9 minutes to 2.5 minutes. The associated decrease in N_2 partial pressure was only 4 torr.

8.6 OTHER CONTROL MODES

Although the ECA was tested using the MSS as sensor for the O_2 and N_2 partial pressures, it is adaptable for use with other sensors and control modes. Typical of these are the Beckman polarographic or General Electric fuel cell sensors for O_2 partial pressure, and various total pressure sensors which are also required for cabin pressure monitoring.

Section 9

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be made as a result of the Atmosphere Control Subsystem program reported herein:

Accuracy of control operation on the pulse modulated proportional control channel for pp N_2 was $\pm$ 0.31 percent; well within specification requirements.

Accuracy of the dead-band type of control on the pp O_2 channel was excellent. At the 14.7 psia set point all recorded values of pp O_2 were within a 3.3 torr (0.065 psi) band width. There was indication that a narrower dead band would have produced equally acceptable operation.

The design approach of determining the set points by pre-selection of input circuit resistance values was inadequate. A method was found for inserting external resistance into the circuit which allowed correction of operating errors and achieved the desired set points. Some method is required in operational use for accomplishing this fine trim of the set points. This may be done by a fine selector switch or potentiometer.

Flow measurement by counting gas pulses was found to give an overall accuracy of 4 percent, with shorter periods, of several days in length, having errors as high as $\pm$ 14 percent. Improvements can be made by proper design of the pneumatic components (pressure regulator, solenoid valve, metering orifice, and interconnecting plumbing). Further investigation of the required design criteria is recommended.

Leakage measurement data by relating gas inflow rate to chamber leakage showed an accuracy of $\pm$ 2.75 lb/day of Shuttle equivalent flow, compared with analytical prediction of 1.90 lb/day. It was believed that some inaccuracy may have been introduced by delays of mixing of cabin atmosphere. This points out the importance of obtaining the atmosphere sample from a well-mixed area and providing sample transport lines of minimum length to the MSS. Further analytical and experimental studies are recommended to improve the correlation between predicted and actual performance of this leakage measurement method.

The ability to perform fault detection by monitoring the time interval between N_2 gas pulses was graphically illustrated by an occurrence in which the failure of the high pressure N_2 supply could have been detected within 1/2 hour after occurrence.

Section 10

REFERENCES

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