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# ATMOSPHERE SENSING AND MAINTENANCE SYSTEM

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# FOREWORD

This report was prepared by the Missile and Space Division of the General Electric Company, Philadelphia, Pennsylvania, under Contract AF33(615)-3612. The research was initiated by the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, under Project No. 6373, "Equipment for Life Support in Aerospace," Task No. 637305, Analysis and Integration of Life Support Systems." Mr. J. Arthur Brown, Biotechnology Branch, Life Support Division, Biomedical Laboratory, served as Contract Monitor for the Aerospace Medical Research Laboratories.

The research and development work reported herein was performed for the General Electric Company by Mr. David J. Withey, Supervising Engineer, and Mr. Edward J. Glanfield, Engineer. Mr. Joseph Boyd of the General Electric Company participated in the technical evaluation leading to the selection of the oxygen sensor. Work under the contract was initiated in May 1966 and was completed in April 1967.

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This technical report has been reviewed and is approved.

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ABSTRACT

This program encompasses the analysis, design, fabrication and testing of an Atmosphere Sensing and Maintenance System (ASMS) to be used in conjunction with the Aerospace Medical Research Laboratories (AMRL) Life Support System Evaluator (LSSE) chamber or similar space cabin simulators. The ASMS is a two-gas control system capable of monitoring and controlling the total pressure and the oxygen partial pressure of the atmosphere within the LSSE. Oxygen partial pressure is controlled to $\pm$ 2.5 mm Hg over the range to 100 to 250 mm of Hg and total pressure is controlled to + 7.5, - 2.5 mm of Hg over the range of 150 to 800 mm of Hg. Monitoring of the oxygen partial pressure and the total pressure of the LSSE atmosphere is possible from either the control panel or the monitor's panel of the ASMS. Control of the LSSE atmosphere is possible only from the control panel. The panels are designed to be interchangeable, to provide control capability either inside or outside of the LSSE with a minimum of effort.

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# SECTION I

# SYSTEM DESCRIPTION AND INSTALLATION

## A. BACKGROUND

The Atmosphere Sensing and Maintenance System (ASMS) is designed to be used in conjunction with the existing Life Support Systems Evaluator (LSSE) (Reference 1) and can be adapted for use with the Space Vehicle Environment Simulator (SVES) chamber. Both facilities are currently available at the Life Support Systems Division of the Aerospace Medical Research Laboratories (AMRL). These facilities serve as research tools for determining the technical feasibility of techniques and principles involved in the operation and design of life support equipment through integrated evaluation studies. These studies are planned to develop optimal life support systems, including respiratory equipment, nutritional support, and waste management. The broad spectrum of work involved in biologistics and bioastronautics can also be studied. These facilities are normally monitored utilizing consoles (Reference 2) having special purpose gas analysis equipment, total pressure sensors, temperature and humidity sensors, each complete with visual display and recorder printout. These consoles, as described, also include the necessary communications and closed circuit television for simultaneously monitoring the well-being of human subjects confined to either, or both, of these facilities.

## B. GENERAL

The ASMS is a two-gas control system designed to sense the oxygen partial pressure and the total pressure of the atmosphere within the LSSE and to maintain the atmosphere within the LSSE at a desired level. The atmosphere is maintained by the addition of oxygen to the LSSE chamber if the oxygen partial pressure decreases to a level lower than desired, or by the addition of a diluent (nitrogen or helium) if the total pressure decreases to a level lower than desired.

The performance characteristics of the ASMS are listed in Table I and the gas supply requirements are listed in Table II.

The system is composed of the following:

1. Control Panel (Figure 1 A, Dwg. No. 253E569)
2. Monitor Panel (Figure 1 B, Dwg. No. 253E568)
3. Aft Crew Cabin Alarm Panel (Figure 1 C)
4. Oxygen Analyzer Subsystem (Figure 3) containing:
    a. Analyzer Measuring Unit (Figure 2 A)
    b. Analyzer Electronic Unit (Figure 2 B)

Table I.

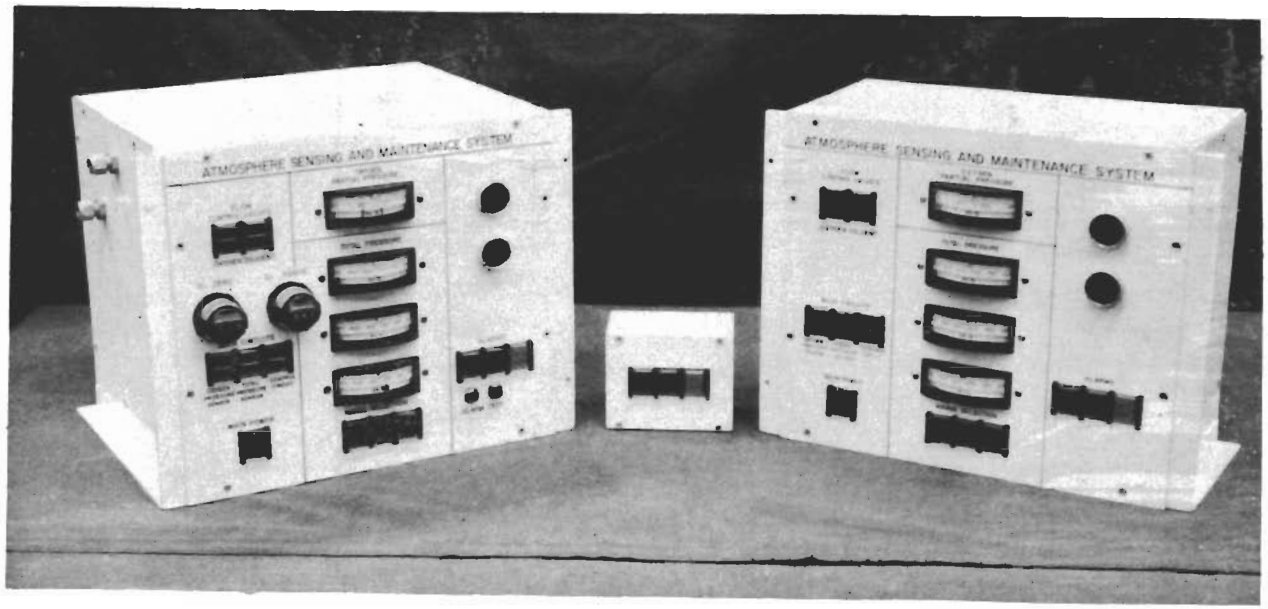
ASMS Control Performance

| Parameter | Two-Gas Atmosphere | Single-Gas Atmosphere |
|---|---|---|
| **Total Pressure Control** | | |
| Range | +7.5, -2.5 mm Hg from any set point between 200 and 790 mm Hg | ±2.5 mm Hg from any set point between 155 and 795 mm Hg |
| Control Dead Band | 5 mm Hg | 5 mm Hg |
| Alarm | Alarm point is adjustable to any pressure below 2.5 mm Hg of the set point | Alarm point is adjustable to any pressure below 2.5 mm Hg of the set point |
| Maximum Rate of Pressure Rise during gas addition | 10 mm Hg/min | 5 mm Hg/min |
| **$pO_2$ Control** | | |
| Range | ±2.5 mm Hg from any set point between 105 and 245 mm Hg | ±2.5 mm Hg from any set point between 105 and 245 mm Hg |
| Control Dead Band | 5 mm Hg | 5 mm Hg |
| Alarm | Alarm point is adjustable to any pressure below 2.5 mm Hg of the set point | Alarm point is adjustable to any pressure below 2.5 mm Hg of the set point |

Table II.

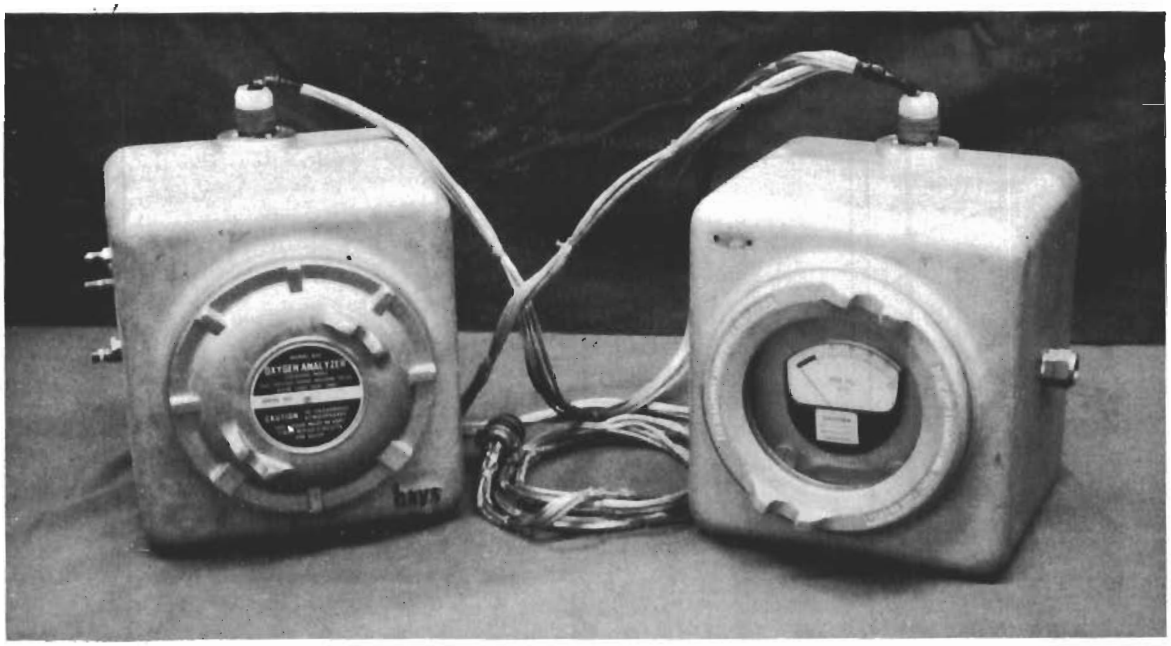
ASMS Gas Supply Requirements

| | |
|---|---|
| **Oxygen** | |
| Metabolic: | 2.2 lb/day min<br>8.8 lb/day max |
| Simulated Outboard Leakage: | 0 min<br>27 lb/day max. (40 $ft^3$/hr @ 5 psia, 100% $O_2$ atm) |
| $O_2$ Supply Pressure: | |
| High Inlet | 20 to 40 psig |
| Low Inlet | 15 to 45 mm Hg $\Delta$ P |
| **Diluent** | |
| Simulated Outboard Leakage: | 0 min<br>760 $ft^3$ (STP)/day max<br>(40 $ft^3$/hr @14.7 psia,<br>21% $O_2$ 79% diluent atm) |
| Diluent Supply Pressure: | 20 to 40 psig |




(A) (C) (B)

Figure 1. Atmosphere Sensing and Maintenance System Control Panel (A), Monitor Panel (B), and Aft Crew Cabin Alarm Panel (C)




(A) (B)

Figure 2. Paramagnetic Oxygen Analyzer

(A) Measuring Unit

(B) Electronic Unit

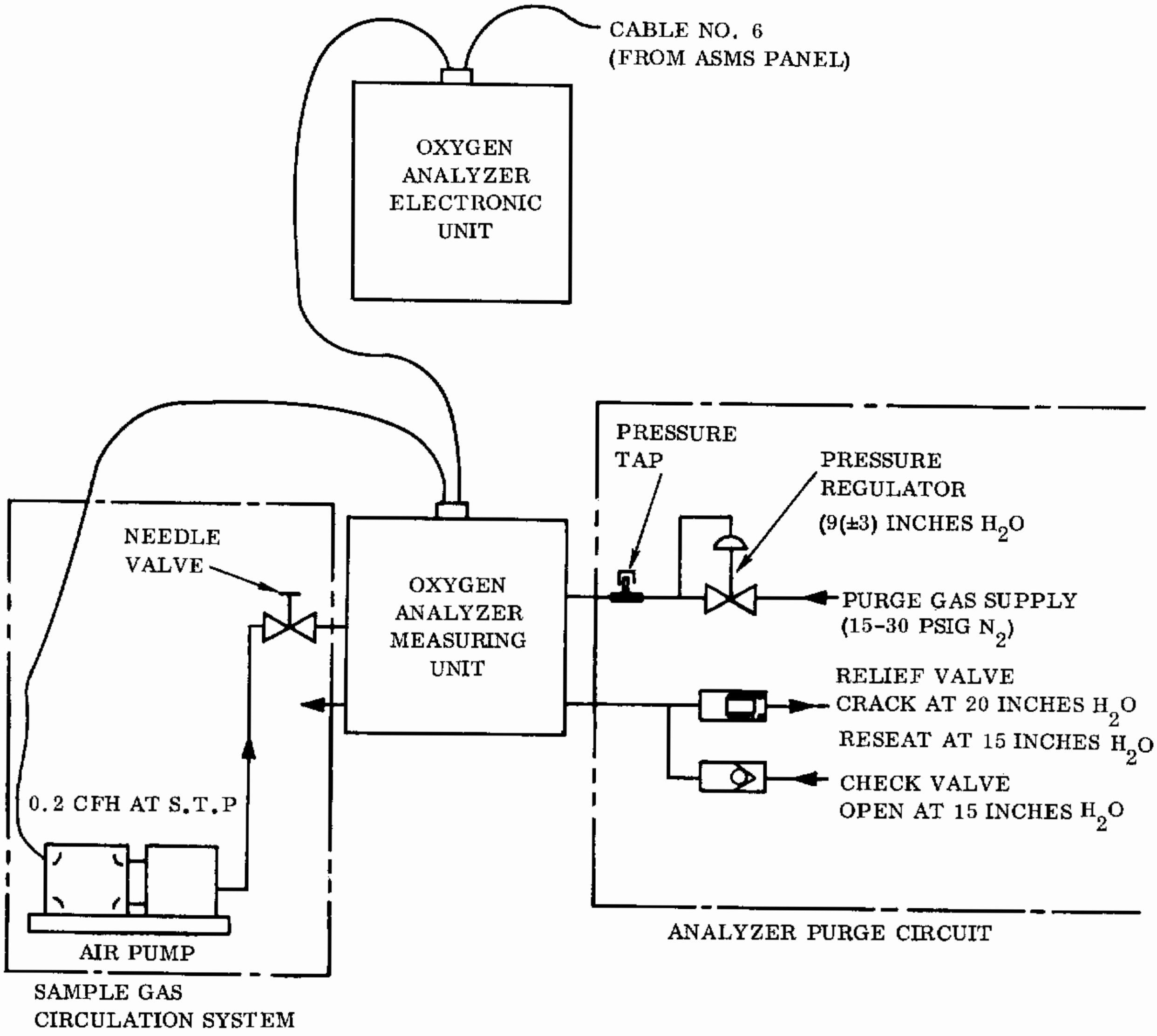



**Figure 3. Oxygen Analyzer Subsystem Schematic**

The control panel provides the monitoring and control capability of the ASMS through the use of the ASMS gas supply circuits (Figure 4), the oxygen partial pressure monitoring circuit (Figure 5), total pressure monitoring circuit (Figure 6), the control circuit (Figure 7), and the control circuit alarm system (Figure 8). All of the components of these circuits are located within the control panel, with the exception of the oxygen analyzer subsystem and the oxygen and total pressure meters. The oxygen analyzer is located outside of the control panel, due to its size. The oxygen and total pressure meters, which duplicate the readings of the oxygen and total pressure control meters, are located on the monitor panel.

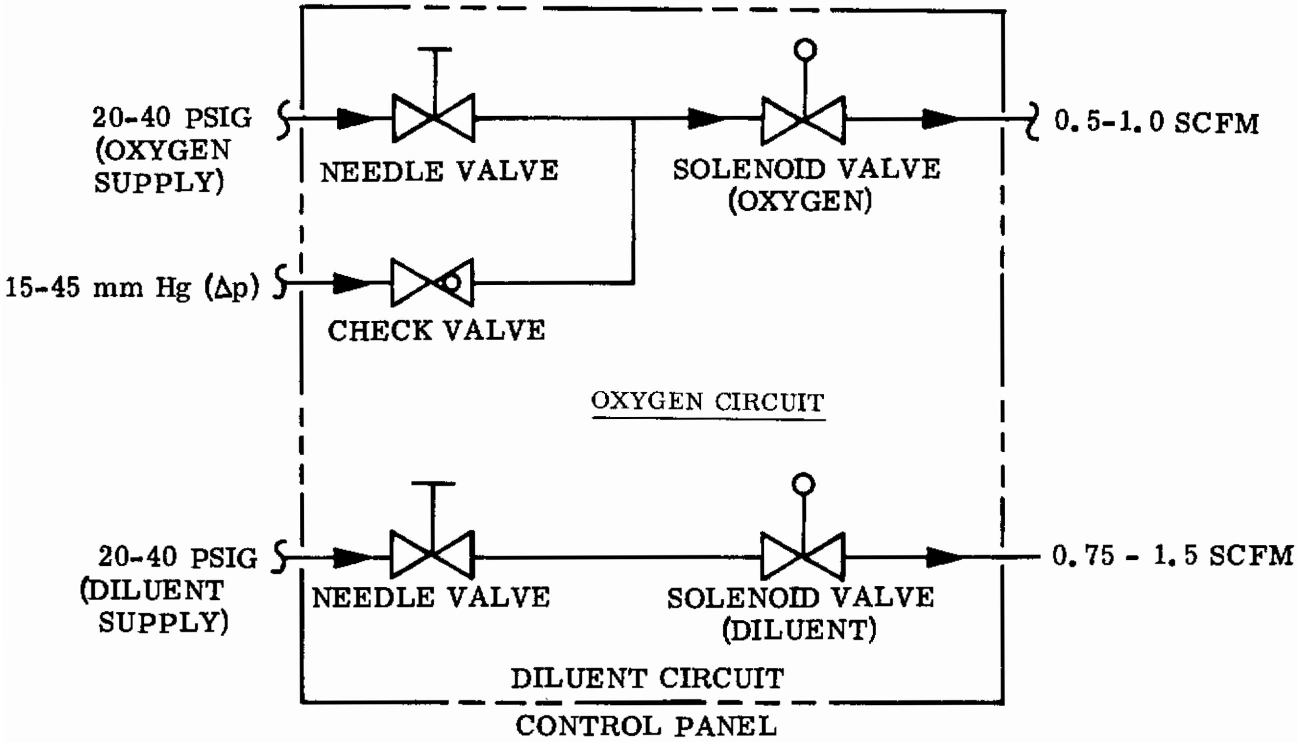



**Figure 4. ASMS Gas Supply Circuits**

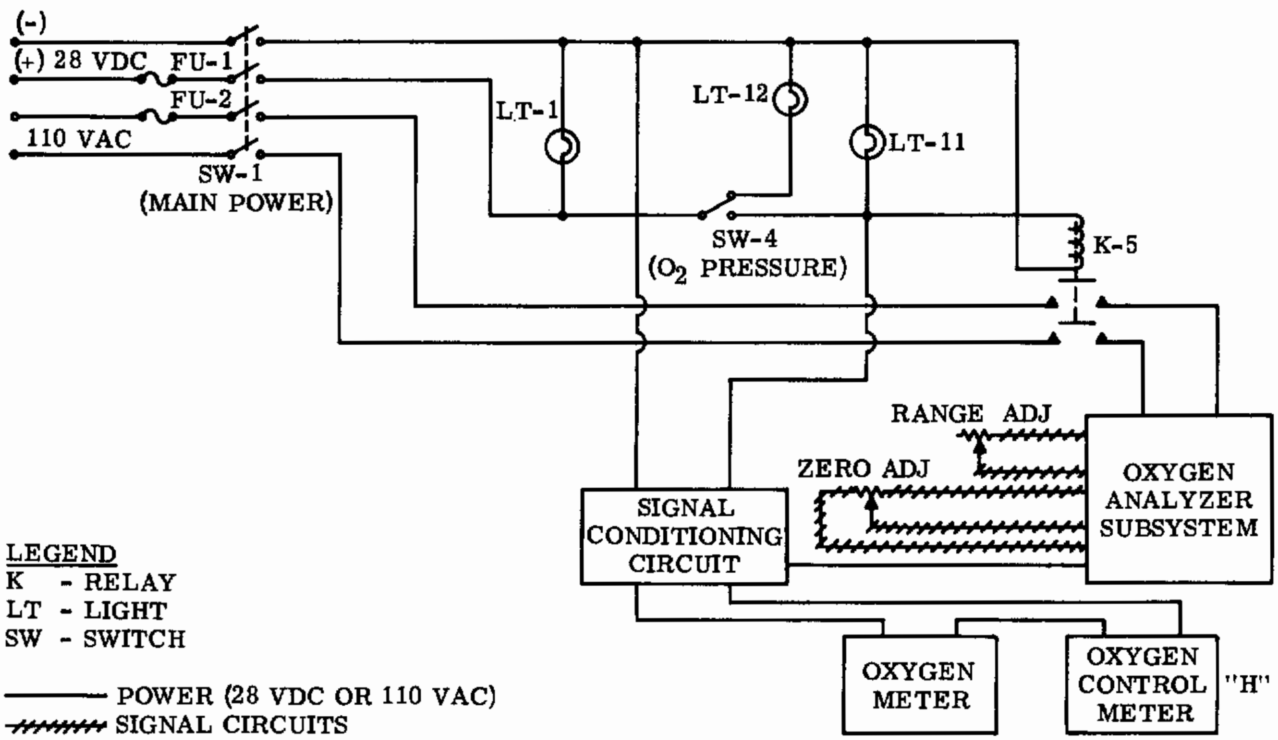



**Figure 5. Oxygen Partial Pressure Monitoring Circuit**

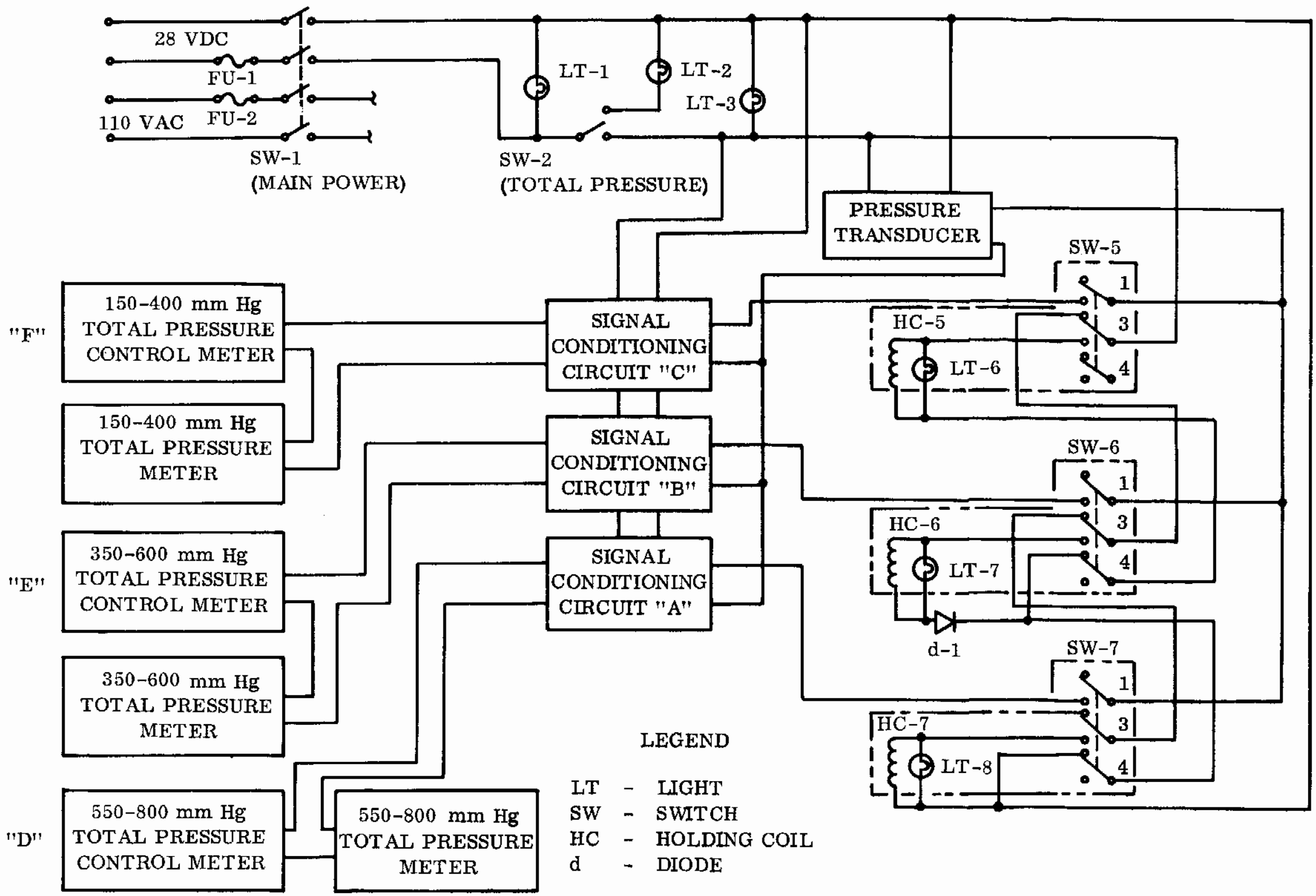
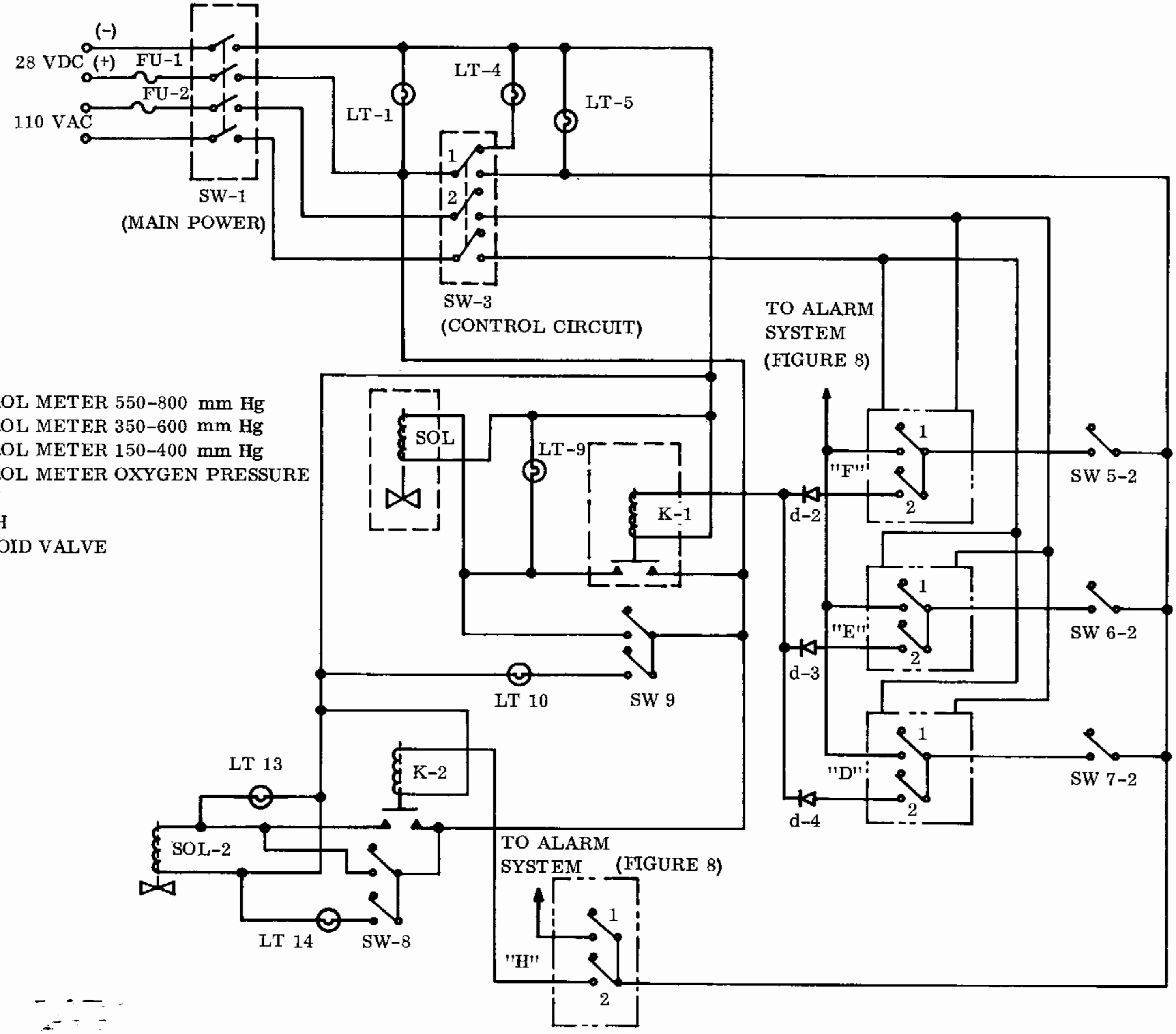
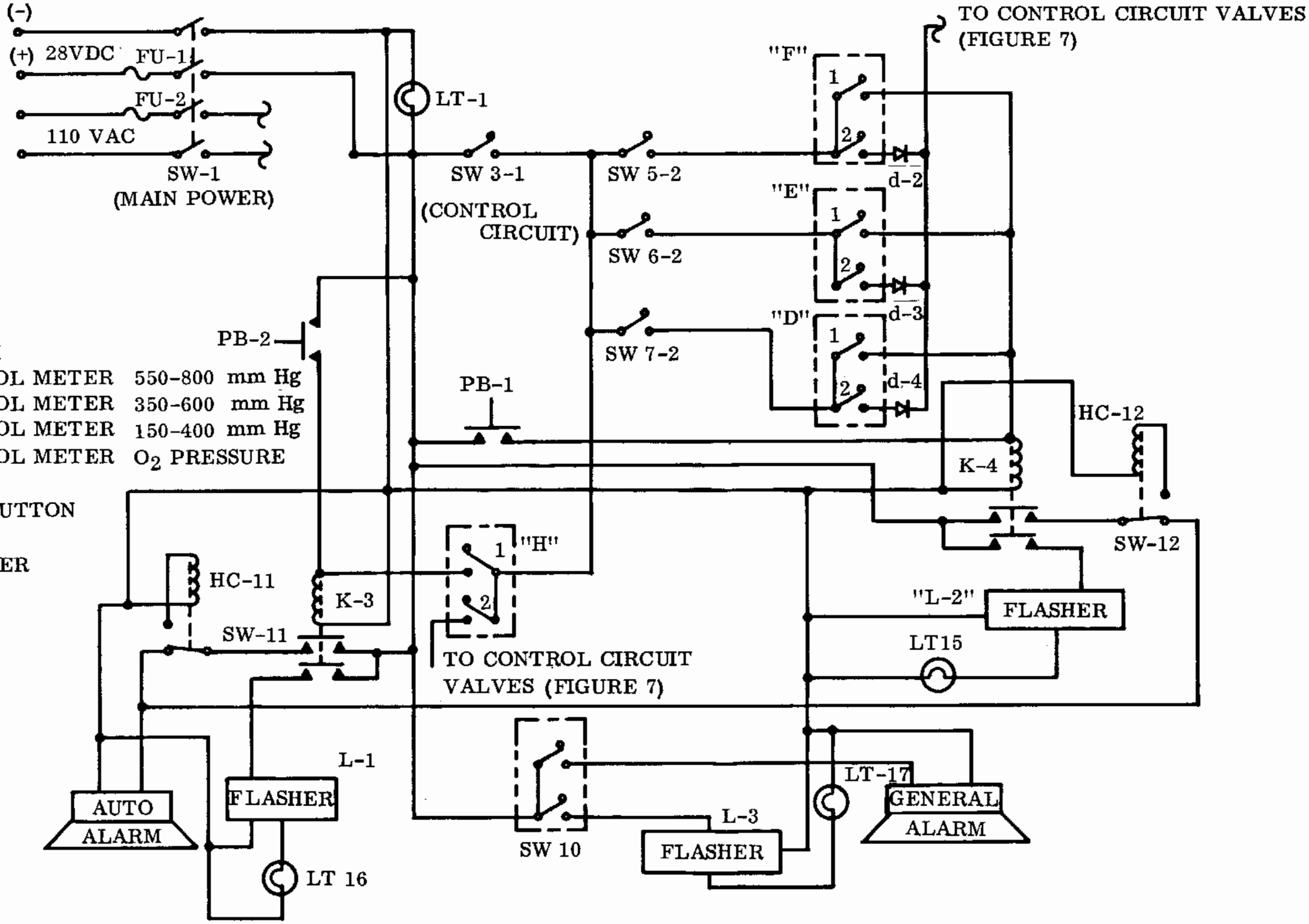



**Figure 6. Total Pressure Monitoring Circuit**




"D" - CONTROL METER 550-800 mm Hg
"E" - CONTROL METER 350-600 mm Hg
"F" - CONTROL METER 150-400 mm Hg
"H" - CONTROL METER OXYGEN PRESSURE
K - RELAY
SW - SWITCH
SOL - SOLENOID VALVE
d - DIODE

**Figure 7. Control Circuit**




| | | |
|---|---|---|
| SW - | SWITCH | |
| "D" - | CONTROL METER | 550-800 mm Hg |
| "E" - | CONTROL METER | 350-600 mm Hg |
| "F" - | CONTROL METER | 150-400 mm Hg |
| "H" - | CONTROL METER | $O_2$ PRESSURE |
| K - | RELAY | |
| PB - | BUSH BUTTON | |
| d - | DIODE | |
| L - | FLASHER | |

**Figure 8. Control Circuit Alarm System**

The control panel provides visual indication of the oxygen partial pressure and the total pressure of the LSSE and the status of the control panel circuits and gas flow control solenoid valves.

The monitor panel provides a visual indication of the oxygen partial pressure and the total pressure of the LSSE atmosphere and the status of the control panel circuits and components through the use of a cable connecting the components in each of the panels together. The monitor panel does not have any control capability.

The aft crew station alarm panel provides a visual indication of the presence of an alarm condition being sensed by the ASMS.

The oxygen analyzer subsystem is used to sense the partial pressure of oxygen in the LSSE. The oxygen analyzer is a paramagnetic-type sensor manufactured by the Hays Corporation (model 632C). The instrument is divided into two units; a measuring unit (Figure 2A) which contains the sensing element (Figure 9), and an electronic unit (Figure 2B) which amplifies the signal from the measuring unit and provides output to the remote meters on the control and monitor panels. The analyzer is contained in explosion-proof housings. This was done originally to minimize any hazard that might exist due to operation of the instrument in 100% oxygen atmospheres. Testing indicated that this type of operation presented no problem. The housing later proved useful due to the requirement to purge the measuring unit housing when diluents other than nitrogen are used. The measuring unit is equipped with a heater and thermostat. Manufacturer's instructions state that the temperature of the gas sample must not exceed 120° F.

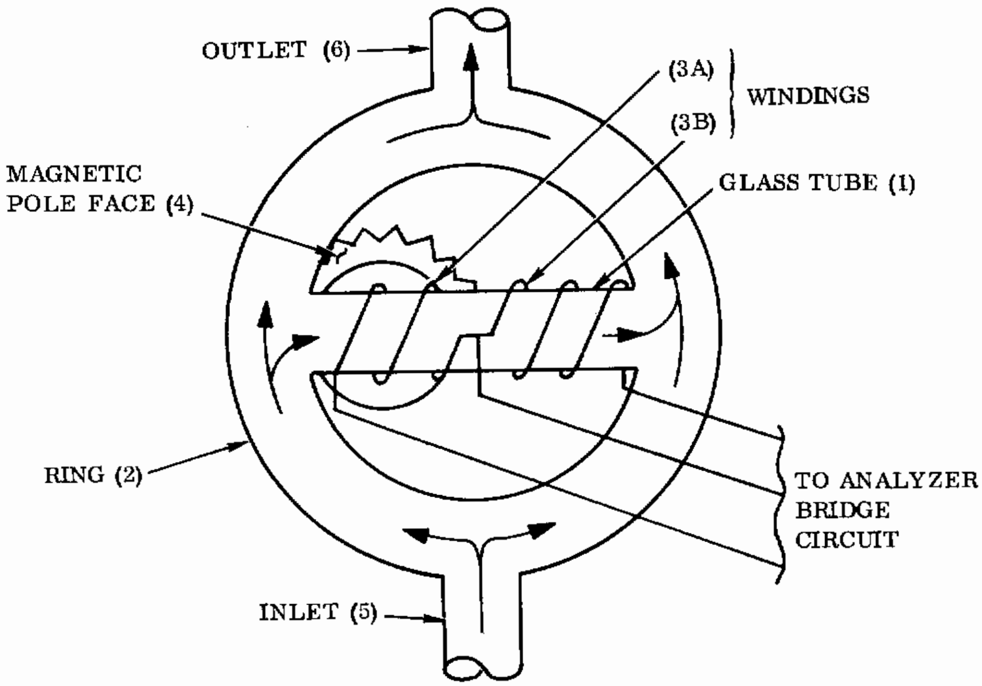



Figure 9. Hays Oxygen Analyzer Sensing Element Schematic

The analyzer utilizes the paramagnetic properties of oxygen and the sensitivity of these properties to increasing temperature to provide information on the partial pressure of oxygen in the atmosphere being sampled. The principle component of the analyzer is the sensing element (Figure 9) located in the measuring unit.

Operation of the analyzer is as follows (ref. 3): In Figure 9, the gas sample enters the analyzer and is carried through tubes to the sensing element inlet (5) where it is divided to flow around the toroidal ring (2). As the gas approaches the magnetic pole face (4), oxygen is, due to its magnetic properties, drawn into the glass tube (1) by the force of the magnet. The windings 3A and 3B are very hot and the movement of relatively cold oxygen through the glass tube causes the temperature of winding 3A to decrease thereby changing its resistance and unbalancing the analyzer bridge circuit. In addition, the heat transferred to the oxygen from the windings causes the paramagnetic qualities of oxygen to decrease. Cold oxygen entering the analyzer therefore has more affinity for the magnet than the warm gas and it forces the warm oxygen through windings 3B and then back into the ring where it mixes with the gas moving through the ring and ultimately moves out of the analyzer through the outlet (6). The flow of oxygen resulting from the paramagnetic qualities of the gas is sometimes referred to as a "magnetic wind."

The imbalance in the bridge circuit is sensed by the electronic unit and converted into a signal which is then imposed upon the meters and control meters in the ASMS.

The analyzer is sensitive to changes in diluent gas, total pressure and sample gas circulation rate. To compensate for the effects of different diluent gases, three range cards were provided with the analyzer, one for oxygen-nitrogen mixtures, one for oxygen-helium mixtures, and one for operation of the unit in a 100 percent oxygen environment. The range card is basically a voltage divider network, adjusted to provide for the effects of varying the diluent gas. The proper range card is installed in the analyzer electronic unit prior to starting any test. Zero and Range Adjustments have been provided on the control panel to compensate for the effects of total pressure changes and sample gas circulation mass flow rate changes resulting from the total pressure changes. Figures 15 and 16 illustrate the set points for various operating conditions that may occur within the LSSE.

Also included in the oxygen analyzer subsystem is a sample gas circulation system and an analyzer purge circuit (Figure 3).

The analyzer purge circuit is used to maintain stable thermal conditions within the measuring unit housing when helium is used as the diluent gas by providing a nitrogen purge to the analyzer measuring unit. This is necessary because the operation of the analyzer sensing element windings are affected by the difference in thermal conductivity between nitrogen and helium.

The sample gas circulation system provides quicker response of the analyzer to changes in the composition of the atmosphere by providing a controlled sample gas flow rate through the measuring unit which is necessary for proper analyzer operation. The circulation system is adjusted to provide a flow rate of 0.2 SCFH of air at ambient conditions.

C. INTERNAL CONTROL

The ASMS has been designed to permit the installation of the control panel either inside or outside of the LSSE. This was done to permit control of the chamber atmosphere from either location depending on whether the test being performed is with a manned or unmanned chamber. The control panel and the monitor panel are interchangeable and both are equipped with the same mounting provisions.

If the test to be performed is manned and it is desired to permit the test subjects to control the ASMS, then the Internal Control mode of operation must be used. In this mode, the ASMS components are located as shown in Figure 10; that is, the control panel is placed within the LSSE and the monitor panel is located outside the LSSE. The location of the aft crew cabin alarm panel and the oxygen analyzer subsystem shown in Figure 3, is the same for either mode of operation.

The oxygen and diluent gas supply lines are arranged to pass from the gas source located outside of the LSSE to the inside of the LSSE where they are connected to the rear of the ASMS control panel. Satisfactory ASMS response rates and conditions within the LSSE (Tables I and II) will be maintained when the gas supply to the ASMS is held at 20 to 40 psig (referenced to ambient pressure).

If the low pressure oxygen gas supply is to be used to supply oxygen, a line is installed from the low pressure source to the low pressure oxygen inlet on the rear of the control panel and the high pressure inlet is capped or closed off.

When a diluent gas other than nitrogen is being used, a nitrogen gas supply line passes from a source located outside the LSSE to the inside of the LSSE. This line is connected to the oxygen analyzer purge gas circuit as shown in Figure 3. The pressure in this line is maintained between 5 and 15 psig (referenced to ambient) to provide proper operation of the analyzer purge circuit. No connection is necessary for the total pressure transducer when the internal control mode is used.

D. EXTERNAL CONTROL

If the test to be performed is unmanned or it is desired to control the LSSE atmosphere from outside the chamber, the ASMS components are arranged as shown in Figure 11; that is, the control panel is located outside of the LSSE and the monitor panel is placed within the LSSE. The location of the aft crew cabin alarm panel and the oxygen analyzer subsystem shown in Figure 11 is the same as when internal control is used.

The oxygen and diluent gas supply lines are then arranged to pass from the gas source to the control panel connections and then into the LSSE. Satisfactory ASMS response rates and conditions within the LSSE (Tables I and II) will be maintained when the gas supply pressure is 20 to 40 psig (referenced to ambient pressure). In addition, a line is connected to the pressure transducer port on the control panel from the interior of the LSSE to permit sensing of the LSSE total pressure.

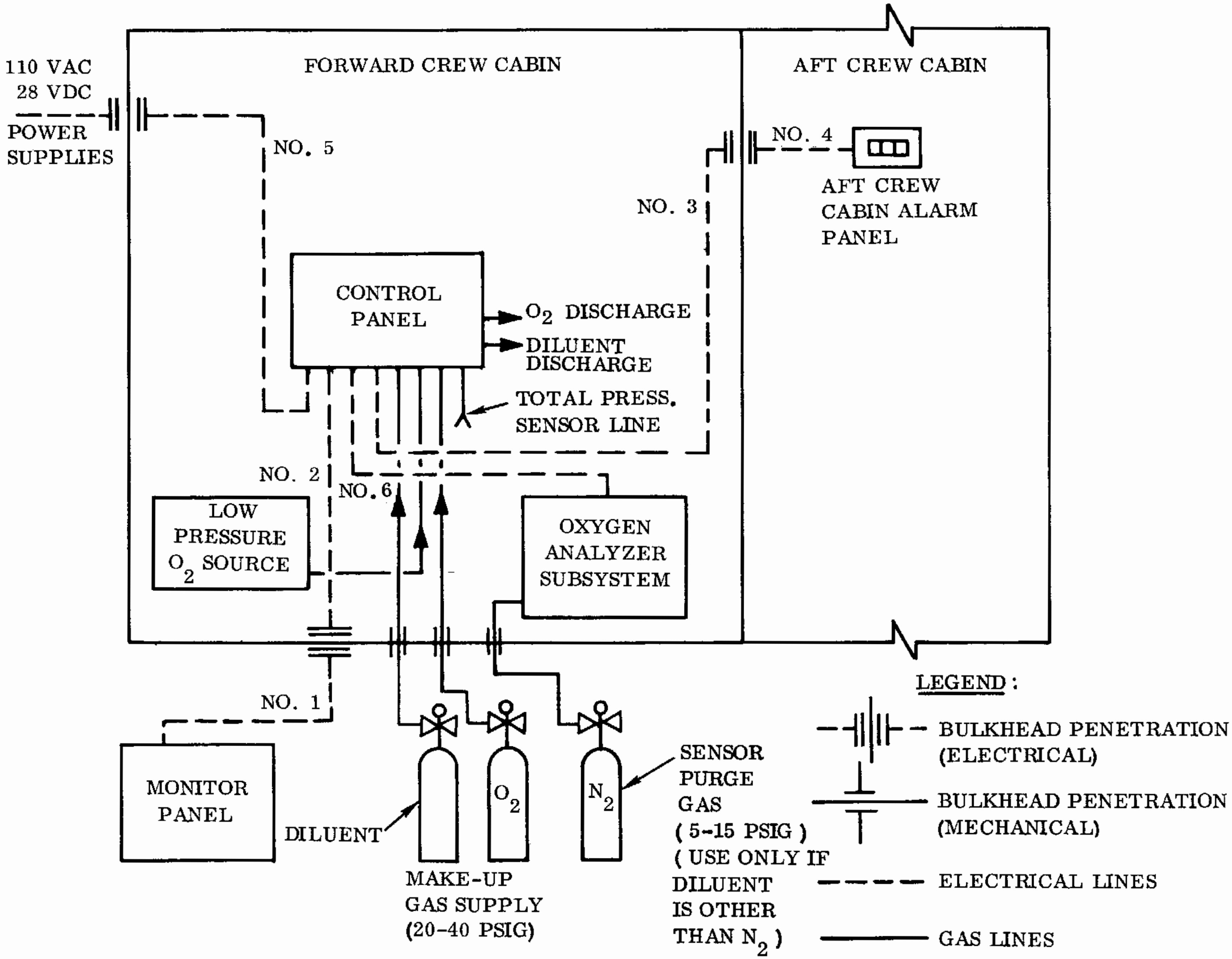



Figure 10. ASMS Connections - Internal Control

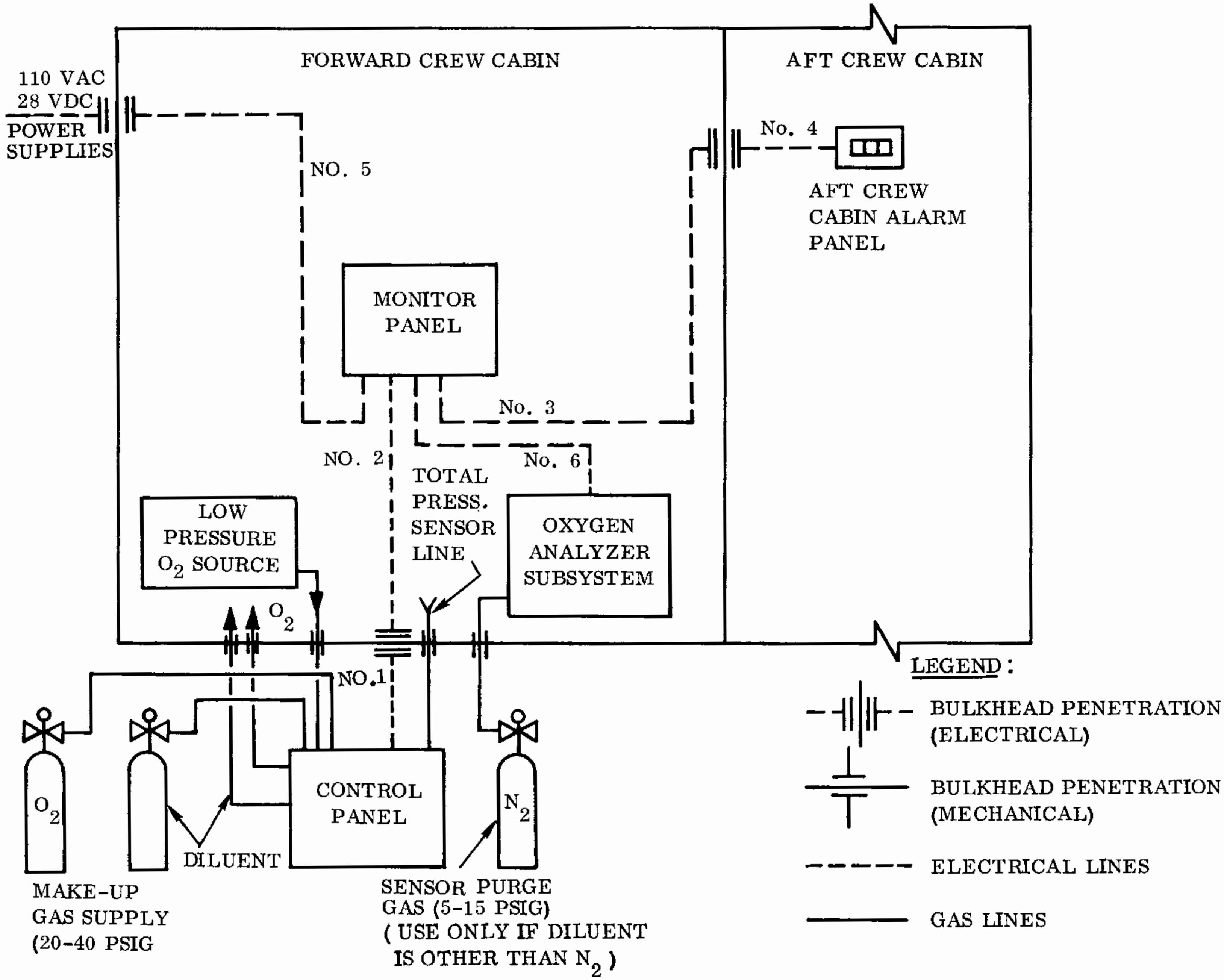



**Figure 11. ASMS Connections - External Control**

When a diluent other than nitrogen is being used, a nitrogen gas supply line passes from a source outside the LSSE to the inside of the LSSE where it is connected to the oxygen analyzer purge gas circuit as shown in Figure 3. The pressure in this line is maintained between 5 and 15 psig (referenced to ambient) to provide proper operation of the analyzer purge circuit.

Electrical power for the system is carried through cable 5 to the monitor panel and from there to the control panel through cables 1 and 2. Cables 3 and 4 distribute power and electrical signals to the crew station alarm panel and cable 6 is used to power the oxygen partial pressure sensor and carry the signals from it.

## E. MOUNTING PROVISIONS

The mounting provisions for the control and monitor panels are in the form of aluminum angles located on both sides of the front of the panels and similar angles located on both sides of the bottom of the panels. An adapter is provided with the panels to permit mounting to a standard electrical relay rack. As an alternate, the panels can be placed on any flat surface. The crew station alarm is designed to be placed on a shelf. If desired, the housing can be easily adapted for wall mounting.

The Hays Oxygen Analyzer Electronic Unit can be mounted on a shelf or to a wall. The latter method should utilize four tapped mounting holes located in bosses on the explosion proof housing. If the unit is placed on a flat surface some provision must be made to prevent the unit from rocking since the housing is not flat on the bottom.

The Measuring Unit must be mounted firmly since the sensing element within the unit must be level to ± 1 degree at all times. The only mounting provisions made on the unit are in the form of four tapped mounting holes located in bosses on the rear of the unit. An adjustment for accurately leveling the sensor element is located within the housing and will be discussed later.

# SECTION II

# SYSTEM OPERATION

## A. GENERAL

The ASMS is designed to control the atmosphere of either the LSSE forward cabin (292 $ft^3$), or the entire LSSE (1,131 $ft^3$) to the limits specified in Table I when subject to the requirements of Table II. See reference 4 for complete operating and calibration procedures.

The system provides automatic control and monitoring of the atmosphere composition within the LSSE. In addition, provisions have been made for monitoring the atmosphere at a remote location and an alarm system has been provided to indicate variations in the pressure and oxygen partial pressure below pre-established limits.

The ASMS is composed of three main circuits; an oxygen partial pressure monitoring circuit (Figure 5), a total pressure monitoring circuit (Figure 6) and a control circuit (Figures 7 and 8).

NOTE: Figures 5, 6, 7, and 8 do not indicate the presence of indicating lights or alarms on the monitor panel. They have been omitted to maintain the clarity of the figures; however, it should be realized that each light and/or alarm unit on the control panel has a counterpart, in electrical parallel with it, located on the monitor panel and in the case of the alarm lights (15, 16, and 17) a third light is located in the aft crew cabin alarm panel. The lights are joined electrically through the cables connecting the panels.

Each circuit is controlled by a separate, lighted ON-OFF indicator switch (see Figure 12). The oxygen partial pressure monitoring circuit is composed principally of a Hays Instrument Company oxygen partial pressure sensor and an API Instruments Company Control Meter. The total pressure monitoring circuit is composed of a Consolidated Controls Corporation absolute pressure transducer and three API Instrument Company Control Meters (one for each of the pressure ranges 150-400, 350-600 and 550-800 mm of Hg). The control circuit utilizes a contactless switching capability of the control meters to operate the gas feed solenoid valves and maintain the pressure within the evaluator within a +7.5, -2.5 mm Hg pressure range and the oxygen partial pressure within ±2.5 mm of Hg of the desired oxygen partial pressure and to operate an alarm system (Figure 8) in the event the pressures being sensed fall below a preset limit. In the following discussion, reference should be made to Figure 12 for the location of switches, meters, and adjust knobs.

## B. OXYGEN PARTIAL PRESSURE MONITORING CIRCUIT (Figure 5)

The Oxygen Partial Pressure Monitoring Circuit is placed in operation by depressing the main-power switch (SW-1). This will cause lights Lt-1 (main-power "ON") and Lt-12 (Oxygen Pressure Sensor "OFF") to light. Depressing SW-4 de-energizes Lt-12 and energizes Lt-11 (Oxygen Pressure Sensor "ON") and relay K-5 which permits 110 Vac

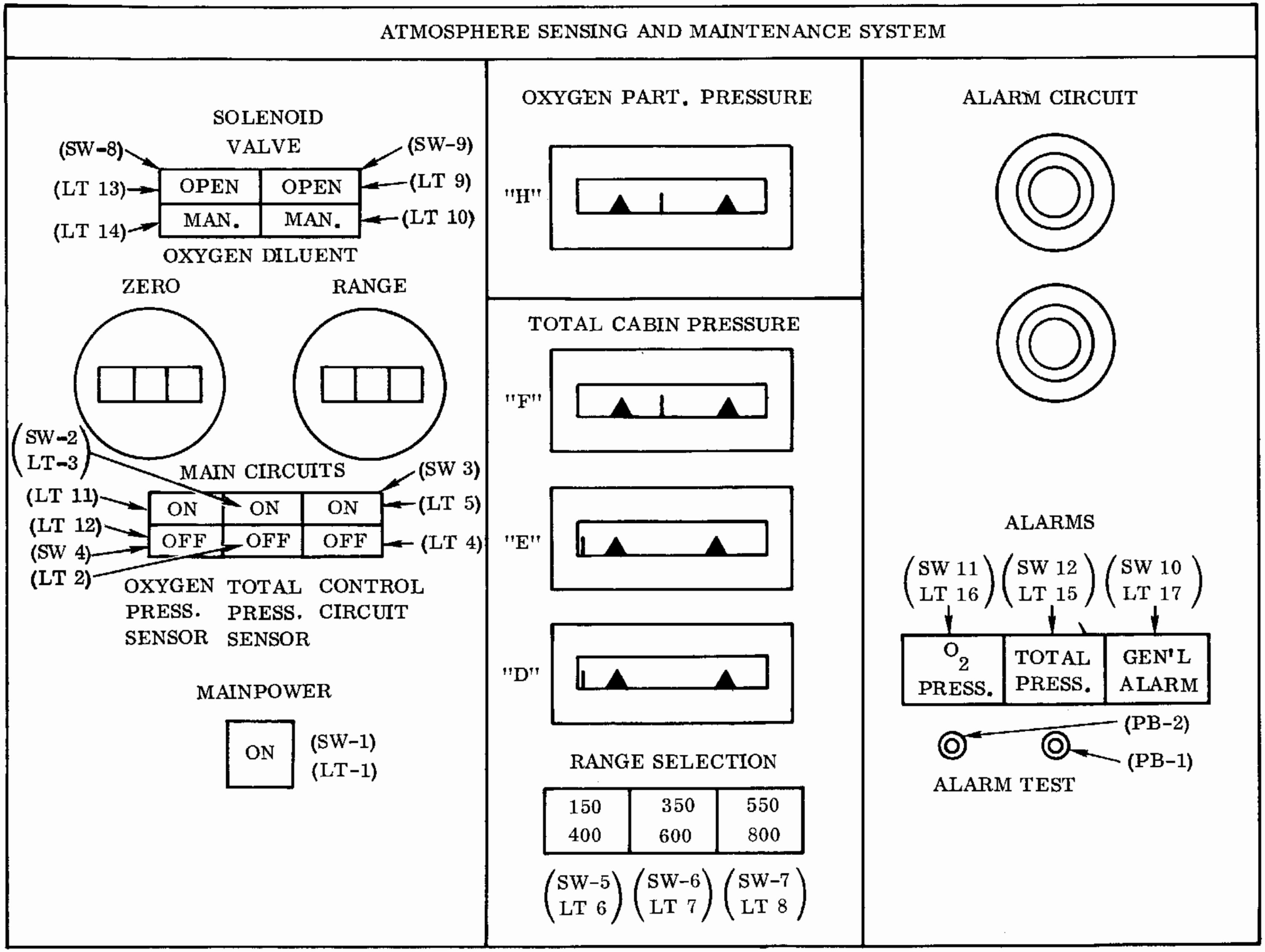



Figure 12. Control Panel

current to pass to the oxygen sensor subsystem. The Oxygen Partial Pressure Circuit contains a control meter ("H") on the control panel for monitoring and controlling the oxygen partial pressure within the LSSE. The meter is designed to indicate oxygen partial pressure and is equipped with two adjustable set points, the higher of which is set at the oxygen partial pressure to be maintained within the LSSE and the other point at the minimum oxygen pressure or alarm point. The function of these set points is explained in the Control Circuit and the Alarm Circuit portions of this section. A separate black indicating pointer on the meter indicates the actual oxygen partial pressure in mm of Hg. When the circuit is thus energized, the output signal from the oxygen analyzer is imposed on the control meter which indicates the oxygen partial pressure within the LSSE. The range and zero adjust knobs located on the control panel must be set to conform to the total pressure at which the system will be operating. A curve for determining the proper set points is given in the calibration section of this report (Figures 15 and 16).

Indicating meters and lights on the monitor panel indicate the status of the control panel at all times.

The signal conditioning circuit shown in Figure 5 is located on an electronic circuit board mounted immediately behind the audible alarms on the control panel. The circuit is used to modify the signal from the oxygen analyzer electronic unit (1-5ma) to a level acceptable for operation of the indicating meters (0-1ma).

C. TOTAL PRESSURE MONITORING CIRCUIT (Figure 6)

The Total Pressure Monitoring Circuit is placed in operation by depressing the main-power switch (SW-1) located on the control panel. This will cause lights Lt-1 (main-power "ON") and Lt-2 (Total Pressure Sensor "OFF") to light. Depressing SW-2 de-energizes Lt-2 and energizes Lt-3 (Total Pressure Sensor "ON") and the Total Pressure Circuit by supplying 28 Vdc power to the pressure transducer sensing the total pressure in the LSSE. The Total Pressure Circuit contains three control meters ("D", "E", and "F") on the control panel for monitoring and controlling LSSE total pressure. Each of the three meters is designed to indicate pressure over a set range when used in conjunction with signal conditioning circuits "A", "B", and "C". The control meters are equipped with two adjustable set points, the higher of which is set at the total pressure to be maintained within the LSSE and the other point at the minimum pressure or alarm point. The function of these set points is explained in the Control Circuit and Alarm Circuit portions of this section. A separate black indicating pointer on the meter indicates the actual total pressure in mm Hg.

When the proper LSSE operating pressure range has been determined, the appropriate range selection switch (SW-5, SW-6 or SW-7) should be depressed, causing Lt-6, 7 or 8 to be energized and imposing the output signal of the pressure transducer on the total pressure meter corresponding to the proper operating range. The meter will indicate the internal pressure of the LSSE in mm of Hg. The Range Selection Switches utilize a holding coil used in conjunction with a "bailing circuit" to provide for cancellation of a selection simply by depressing another range selection switch. The diode (d-1) has been placed between contacts 3 N.O. and 4 N.C. on SW6 to prevent a back flow of current through HC-6 and LT 7 and LT7A (not shown) to ground if SW7 is depressed while SW6 is in the actuated condition.

LT7A is located on the monitor panel and is connected in parallel with LT7 and HC6 through the cable joining the two panels. (The cable has not been shown in Figure 6).

The Signal Conditioning Circuits are designed to prevent damage to the meters if the wrong range selector switch is inadvertently depressed. If it becomes necessary to cancel the range selections entirely, the Total Pressure Sensor Main Circuit Switch (SW-2) should be depressed shutting the circuit "OFF".

Indicating meters and lights on the monitor panel indicate the status of the control panel at all times.

The signal conditioning circuits, shown in Figure 6, are located on an electronic circuit board mounted immediately behind the audible alarms on the control panel. The circuits are used to modify the signal from the absolute pressure transducer (0-5 volts) to a level acceptable to total pressure indicating meters (0-50 microamperes).

D. CONTROL CIRCUIT (Figures 7 and 8)

The Control Circuit is divided into three main sections; the Total Pressure Control Circuit and the Oxygen Partial Pressure Control Circuit and the Alarm Circuit. The Control Circuit is energized by depressing the main-power switch (SW-1). This will cause lights Lt-1 (main-power "ON") and Lt-4 (Control Circuit "OFF") to light. Depressing SW-3 de-energizes Lt-4 and energizes Lt-5 (Control Circuit "ON") and causes 110 Vac to pass to the Control Meters (D, E, F) and 28 VDC current to pass to the total pressure circuit range selection switches SW-5, 6, 7, and to the oxygen partial pressure control meter "H".

NOTE: The control meters contain a meter relay which is actuated by optical system within the meter. The optical system and the meter relay are actuated by the 110 Vac power supplied to meters when SW-1 and SW-3 are closed, causing contacts 1 and 2 in D, E, F, and H to close. When the total pressure range selection switch SW5, 6 or 7 is depressed, the signal from the total pressure transducer is fed into the meter and power is applied to the contacts of the meter indicating the proper pressure range. Diodes are placed in the line between contact 2 of the meters and relay K-1 to prevent current from passing back through the contacts of the meters not in use and thereby actuating the Alarm Circuit. It should be noted that the contacts in the meters not in use will be closed when SW3 is depressed.

It now becomes necessary to energize the Total Pressure and the Oxygen Partial Pressure Monitoring Circuits in order to place the Control Circuit in complete operation. As mentioned in the Total Pressure and Oxygen Partial Pressure Monitoring Circuit description, the control meters each contain two set points which are shown in Figures 7 and 8 as contacts 1 and 2 in "D", "E", "F", and "H".

1. Total Pressure Control Circuit

When the Total Pressure Monitoring Circuit and the Control Circuit have been energized the total pressure in the LSSE will be maintained at the nominal total pressure +7.5, -2.5 mm of Hg through the switching action of contact 2 in control meter "D", "E", or "F", whichever is appropriate for the operating pressure range. (The tolerance levels are due to the possibility of oxygen being required immediately after the diluent gas has been added.) The total pressure control meter switch contacts are designed to close whenever the total pressure in the LSSE falls below the nominal setpoint by more than 2.5 mm of Hg. When the contact closes relay K-1 is energized opening solenoid valve SOL 1, thereby admitting diluent gas and lighting Lt-9 (diluent solenoid open). The solenoid valve will remain open until the total pressure in the LSSE increases by 5 mm of Hg or 2.5 mm of Hg above the nominal level at which time the valve will close.

The diluent gas supply circuit is designed to control the gas flow rate at between 0.5 and 1.8 SCFM (at 70°F). These rates define the minimum flow required to overcome the maximum leakage rate of the LSSE and the gas flow rate required to meet the maximum rate of total pressure increase (5mm Hg/min) when a test is being performed in the forward cabin only.

In the event the total pressure continues to decrease past the lower nominal level, the second setpoint on the control meter ("D", "E", or "F") will actuate the alarm circuit which will be explained under the section on the Alarm Circuit operation.

2. Oxygen Partial Pressure Control Circuit

When the Oxygen Partial Pressure Monitoring Circuit and the Control Circuit have been energized the oxygen partial pressure in the LSSE will be maintained at the nominal oxygen pressure level ±2.5 mm of Hg through the switching action of contact 2 in control meter "H". The control meter switch contact is designed to close when the oxygen partial pressure falls below the nominal setpoint by more than 2.5 mm of Hg. When the switch contact closes, relay K-2 is energized opening solenoid valve SOL-2 thereby admitting oxygen to the LSSE and lighting Lt-13 (oxygen solenoid open). The solenoid valve will remain open until the oxygen partial pressure in the LSSE increases to 2.5 mm of Hg above the nominal level, at which time the valve will close. The oxygen gas supply circuit is designed to control the gas flow rate at between 0.28 and 1.8 SCFM (at 70°F). These rates define the minimum oxygen flow required to pressurize the LSSE if the only oxygen required is that required to supply one man (2.2 pounds/day), and the flow rate required to meet the maximum rate of total pressure increase (5 mm Hg/min) when a test is being performed in the forward cabin only. In the event the oxygen partial pressure continues to decrease past the lower nominal level, the second setpoint in control meter "H" will activate the alarm circuit which will be explained under the section on the Alarm Circuit operation.

NOTE: The maximum gas flow rates supplied by the total pressure control circuit and the oxygen partial pressure circuit were determined to prevent physiological effects on the crew when both gas supply solenoids are open at the same time.

3. Alarm Circuit (Figure 8)

The Alarm Circuit is divided into three main sections; the total pressure alarm section, the oxygen partial pressure alarm section and the general alarm section. Each of these sections provides an audible and/or visual indication at the crew stations as described previously in the System Description.

The Alarm Circuit is energized in the same manner as the Control Circuit, that is, by depressing the main-power switch SW-1 and the control circuit switch SW-3. Performing these two operations permits 28 VDC current to pass to the control meter switches and to the contacts in relays K-3 and K-4.

When an alarm condition occurs, contact 1 in the control meter sensing the condition will close and energize relay K-3, if the alarm is due to low oxygen partial pressure, or relay K-4 if it is due to low total pressure. When the appropriate relay is energized and its contacts close, the audible alarm will sound and the alarm light and flasher will be energized. Switches SW-11 and SW-12 have been provided to permit shutting the audible portion of the alarm off by depressing the switch. Due to a holding coil incorporated in the switch, the audible circuit will automatically reset when the alarm condition has been corrected.

In addition to the automatic alarm circuit just described, a general alarm circuit is also provided. This alarm provides the same alarm indications as the automatic system, that is, a flashing light and an audible signal with the exception that the audible signal is a different tone. The general alarm is energized by depressing switch 10 and is cancelled by depressing this same switch a second time. It is not necessary to energize the control circuit to sound the general alarm. All that is necessary is that main-power be "ON" and the general alarm switch be depressed.

Test switches PB-1 and PB-2 have been provided to test the automatic alarm circuit. These switches also only require that main-power be "ON" to energize the alarms.

4. Manual Operation

In addition to the automatic control circuits just described, the ASMS also provides the capability of manual override of the gas control solenoid valves SOL-1 and SOL-2. This manual control can be utilized whenever the main-power switch SW-1 is "ON" and can be accomplished by depressing switch SW-9 (diluent manual override) or SW-8 (oxygen manual override).

Diluent gas can be added to the LSSE by depressing SW-9, thereby opening solenoid valve SOL-1 and lighting Lt-9 and Lt-10 to indicate manual opening of the solenoid valve. Depressing SW-9 a second time will cause SOL-1 to close.

Oxygen can be added to the LSSE by depressing SW-8, thereby opening solenoid valve SOL-2 and lighting Lt-13 and Lt-14 to indicate manual opening of the solenoid valve. Depressing SW-8 a second time will cause SOL-2 to close.

# SECTION III

# CALCULATIONS AND TESTS

The ASMS has been designed to control two gas supply circuits, oxygen and a diluent, separately on demand from the controlling instruments, in order to maintain a desired atmospheric composition within the crew cabins of the LSSE chamber. The ASMS will provide control of the oxygen partial pressure and total pressure as shown on Figure 13. Note that the characteristics of the system are in accordance with the system requirements described in Table I

## A. DESIGN CALCULATIONS

The gas flow required to maintain the desired conditions and to meet the requirements of pressure increase rates in the LSSE was determined as follows:

### ASMS - GAS FLOW REQUIREMENTS

1. Cabin Volumes

   LSSE (both cabins) 1131 $ft^3$

   LSSE Forward Cabin Only 292 $ft^3$

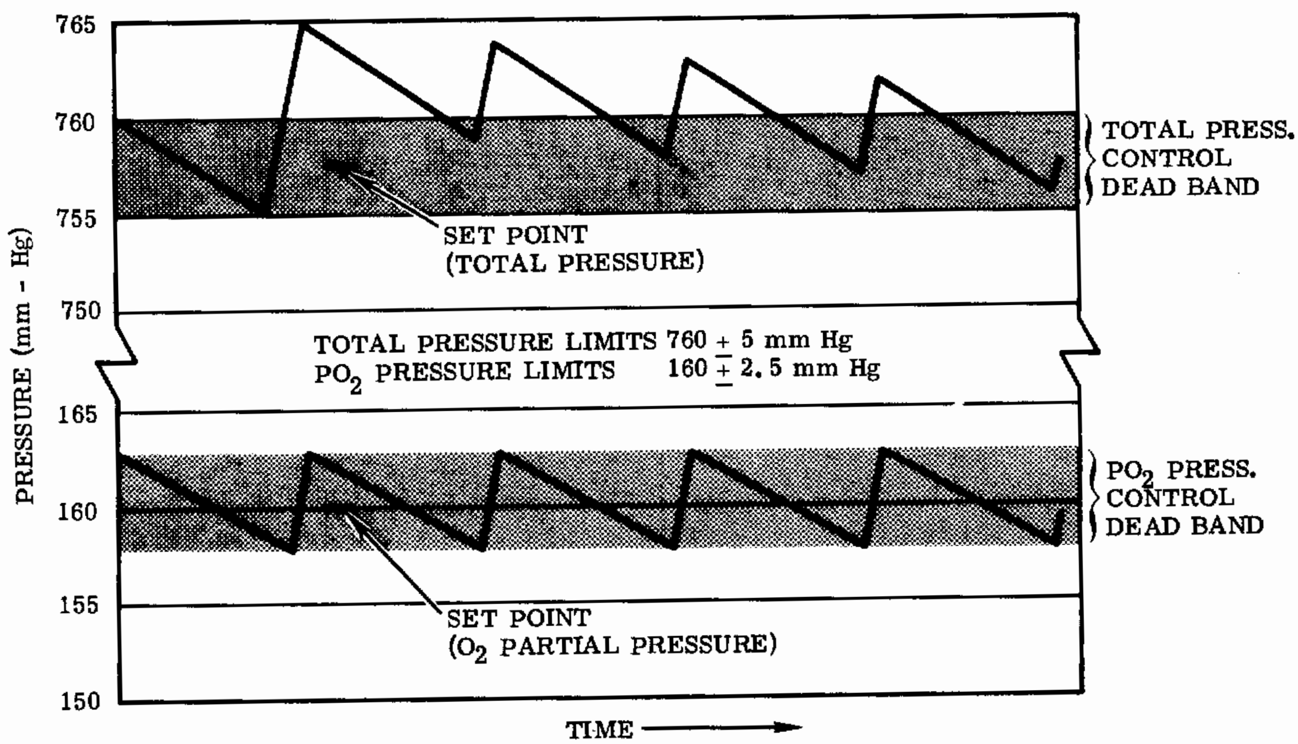



Figure 13. Two-Gas Control System Characteristics

2. Gas Consumption

Maximum 4 men @ 2.2 lb $O_2$/day = 8.8 lb $O_2$/day

Simulated Outboard Leakage = 40 $ft^3$/hr at LSSE pressure

3. Maximum $O_2$ Usage

Men - 8.8 lb/day

Leakage - assume LSSE at 5 psia 100% $O_2$

Now $\rho O_2 = \frac{PM}{RT}$ where $\rho$ = density, lb/$ft^3$

P = pressure, lb/$ft^2$

M = molecular weight

R = universal gas constant $\frac{ft/lb}{lb\text{-}^oR}$

T - temperature $^o$R

$$\rho O_2 = \frac{(5)\ (144)\ (32)}{(1544)\ (530)} = 0.0281 \text{ lb/ft}^3$$

Leakage = (40) (24) (0.0281) = 27 lb/day

Maximum total $O_2$ usage = 35.8 lb/day

Minimum total $O_2$ usage = 2.2 lb $O_2$/day (one man, no leakage)

4. Maximum $N_2$ Usage

Assume sea level atmosphere, 40 $ft^3$/hr leakage

$$\rho N_2 = \frac{PM}{RT}$$

$$\rho N_2 = \frac{(0.79)\ (14.7)\ (144)\ (28)}{(1544)\ (530)} = 0.0574 \text{ lb/ft}^3$$

Leakage = (40) (24) (0.0574) = 55 lb/day

Minimum $N_2$ usage = 0 lb/day

5. Control Parameters - $O_2$

Gas addition per 5 mm Hg increment $= \Delta\rho O_2 V = \dfrac{\Delta PO_2 VM}{RT}$

$$\frac{(5)\ (14.7)\ (144)\ (1131)\ (32)}{(760)\ (1544)\ (530)} = 0.617 \text{ pound for LSSE (both cabins)}$$

similarly,

$$\frac{(5)\ (14.7)\ (144)\ (292)\ (32)}{(760)\ (1544)\ (530)} = 0.159 \text{ pound for LSSE forward cabin only}$$

Time for $pO_2$ to drop 5 mm Hg (for 1131 $ft^3$ LSSE)

$$t = \frac{0.617}{35.8} = 0.0172 \text{ day} = 0.414 \text{ hour}$$

$$= 25 \text{ minutes, minimum}$$

$$= \frac{0.617}{2.2} = 0.28 \text{ day} = 6.73 \text{ hours}$$

$$= 6 \text{ hours and } 44 \text{ minutes, maximum}$$

Time for $pO_2$ to drop 5 mm Hg (for 292 $ft^3$ LSSE forward cabin)

$$t = \frac{0.159}{35.8} = 0.00445 \text{ day} = 0.107 \text{ hour}$$

$$= 6.4 \text{ minutes, minimum}$$

$$= \frac{0.159}{2.2} = 0.0723 \text{ day} = 1.735 \text{ hours}$$

$$= 1 \text{ hour and } 44 \text{ minutes, maximum}$$

Then, minimum $O_2$ flow rate = 0.159 lbs/6.4 minutes

= 0.617 lbs/25 minutes

$$= \frac{0.617}{(25)\ (0.089)} = 0.276 \text{ SCFM (minimum)}$$

Maximum $O_2$ flow limited by maximum rate of pressure rise of 5 mm Hg/minute, and is based on LSSE forward cabin.

$$\text{Maximum } O_2 \text{ flow rate } = \frac{0.159}{0.089} = 1.79 \text{ SCFM}$$

6. Control Parameters - $N_2$

$$\text{Gas addition per 5 mm Hg increment } = \Delta \rho \; N_2 V = \frac{\Delta \rho N_2 VM}{RT}$$

$$\frac{(5)\;(14.7)\;(144)\;(1131)\;(28)}{(760)\;(1544)\;(530)} = 0.54 \text{ pound for LSSE}$$

similarly,

$$\frac{(5)\;(14.7)\;(144)\;(292)\;(28)}{(760)\;(1544)\;(530)} = 0.139 \text{ pound for forward cabin}$$

Time for $pN_2$ to drop 5 mm Hg (for LSSE)

$$t = \frac{0.54}{55} = 0.0098 \text{ day} = 0.236 \text{ hours}$$

$$= 14 \text{ minutes, minimum}$$

Time for $pN_2$ to drop 5 mm Hg (for forward cabin)

$$t = \frac{0.139}{55} = 0.00253 \text{ days} = 0.0606 \text{ hours}$$

$$= 3.64 \text{ minutes, minimum}$$

$$\text{Then, minimum } N_2 \text{ flow rate } = \frac{0.54}{(14)\;(0.078)} = 0.495 \text{ SCFM, minimum}$$

Maximum $N_2$ flow rate =

$$\frac{0.139}{(0.078)} = 1.8 \text{ SCFM maximum (for 5 mm Hg/min for forward cabin)}$$

7. Summary

$O_2$ flow rate = 0.28 to 1.8 SCFM (at 70°F)

$N_2$ flow rate = 0.5 to 1.8 SCFM (at 70°F)

Minimum value will hold pressure at maximum usage rate.

Maximum value produces 10 mm Hg/min. pressure rise in forward cabin when used alone (5 mm Hg/min. $O_2$ + 5 mm Hg/min. $N_2$)

Gas addition times - LSSE (both cabins)

$O_2$ - every 25 minutes to every 6 hours, 44 minutes

$N_2$ - zero to every 14 minutes

Gas addition times - LSSE forward cabin only

$O_2$ - every 6.4 minutes to every 1 hour, 44 minutes

$N_2$ - zero to every 3.6 minutes

The above flow rate and gas addition times are independent of the diluent used, assuming a constant 40 $ft^3$/hr simulated outboard leak rate.

Based on these flow requirements the component specifications were determined. The diluent supply circuit was designed to permit a gas flow rate of 1.5 SCFM at 40 psig supply pressure or 0.75 SCFM at 20 psig supply pressure. The circuit is composed of a solenoid valve in series with a metering orifice (Figure 4). The solenoid valve is sized to cause approximately one-half of the system pressure drop and the adjustable metering orifice is provided to permit metering of the gas to the required flow rate. The solenoid valve is actuated by the switching of the total pressure control meters located on the control panel of the ASMS.

The oxygen supply circuit (Figure 4) consists of two supply lines, one designed for a gas supply pressure of 15-45 mm of Hg above the LSSE pressure and the other designed for a 20-40 psig oxygen supply.

A solenoid valve controls the gas flow. The valve is designed to permit an oxygen flow rate of 0.5 SCFM when placed in series with a check valve and supplied with oxygen at 15 mm Hg differential pressure. The check valve is used to prevent any damage to the low oxygen pressure source due to back pressure surges in the gas lines. The high pressure oxygen gas circuit contains a metering orifice of the same type as that used in the diluent supply circuit to provide the pressure drop necessary to attain a flow rate equal to that of the low pressure circuit. The solenoid valve is actuated by the control circuit of the oxygen partial pressure indicator controller located on the ASMS control panel.

In addition to the automatic functioning of the oxygen and diluent solenoid values, the ASMS control panel is provided with manual switches to open the solenoid valves, thereby overriding the automatic controls. The override switches contain an indicator light to signify that the valves have been operated by the override switch. Lights are provided on the monitor's panel and the pilot's panel to indicate that power is supplied to the solenoid valves by either the automatic or override modes of operation. The system is capable of supplying both cabins simultaneously in either automatic or manual operation.

## B. TEST PROGRAM

The test program of the ASMS was established to calibrate the system and provide information on the operating characteristics of the components. The ASMS Check-Out Test Plan had the following objectives:

1. Establish the proper adjustments of the gas supply metering valves.

2. Determine the operating characteristics of the control circuit over all ranges of operation.

3. Evaluate the alarm circuit operation.

4. Permit calibration of the system instrumentation including the oxygen analyzer, the control meters and the signal conditioning circuit.

Establishment of the gas supply metering valve adjustments and evaluation of the alarm circuit operation was found to be very simple and the operating characteristics of the control circuit were found to be satisfactory. Calibration of the total pressure sensor had been performed by the manufacturer. The instrument was checked for proper operation with the ASMS signal conditioning circuit and after several adjustments to the zero and range potentiometers located in the signal conditioning circuit the total pressure sensor was found to be satisfactory. Figure 14 is the calibration curve for the total pressure sensor.

Some difficulty was encountered during the evaluation and calibration of the Hays Oxygen Analyzer. The analyzer was found to be sensitivie to; the sample gas flow rate, changes in the total pressure of the atmosphere being sampled and also changes in the background or diluent gas of the atmosphere being sampled. Overcoming these problems required a greatly extended test effort and resulted in several modifications to the ASMS.

During the design phase of the program it was decided, based on discussions with the manufacturer, that the oxygen analyzer would not require a forced circulation system for the sample gas. It was indicated that the "magnetic wind" generated within the instrument and natural convection would be sufficient to provide an adequate response time (approximately one minute). (The "magnetic wind" is a flow of gas created by the paramagnetic quality of the oxygen molecules.)

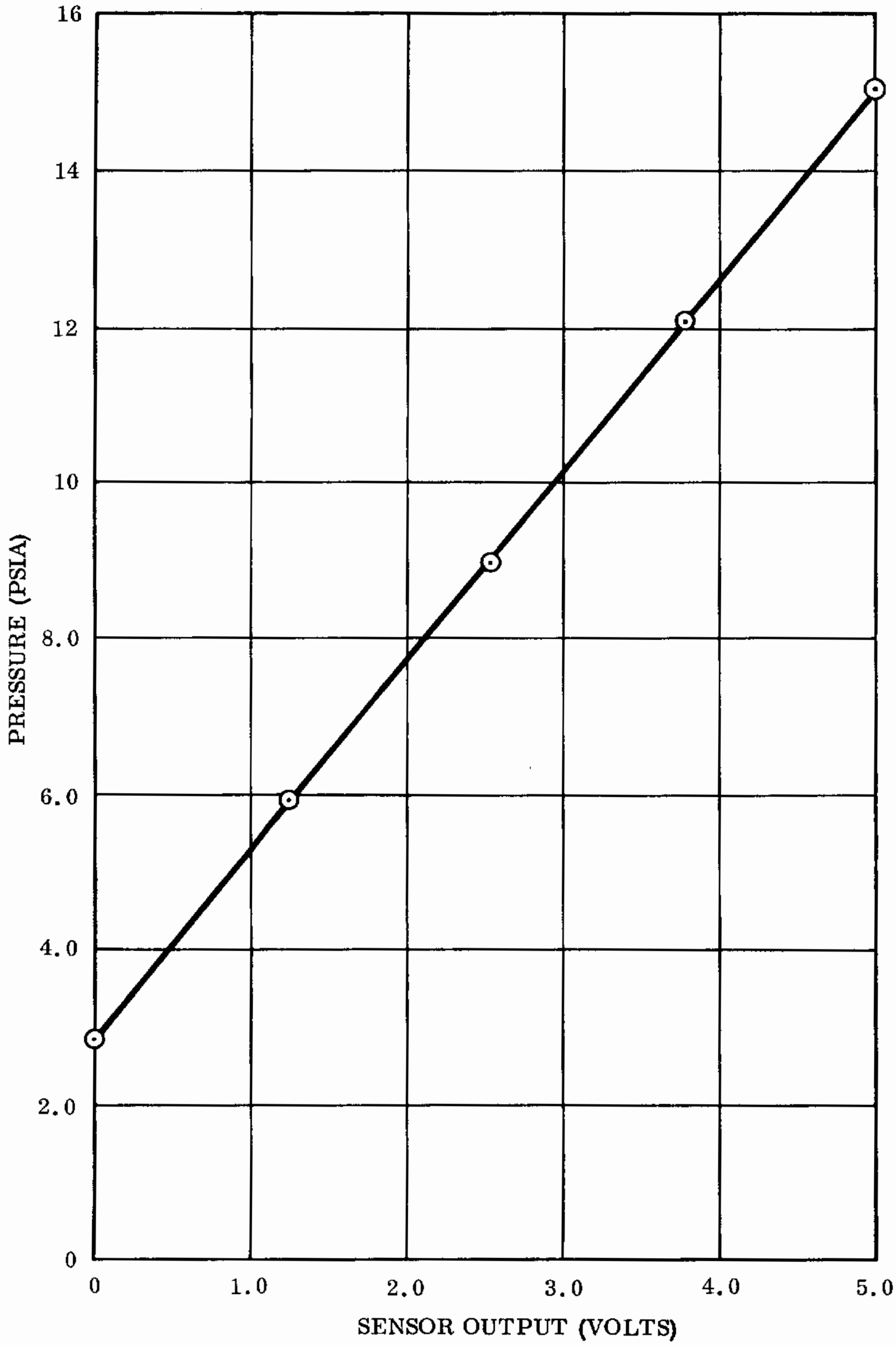



Figure 14. **Total Pressure Sensor Calibration**

The response time of the instrument during the test phase of the program was found to be approximately 45 minutes, which was considered too long for proper ASMS control and completely unsatisfactory from a safety standpoint (Figure 3). As a result of these findings the sample gas circulation system containing an oilless diaphram air pump was added to the system to provide forced circulation of the sample atmosphere. The sample gas flow rate was established at 0.2 SCFH at atmospheric conditions. An adjustable orifice was used to control the flow rate. As testing proceeded it was determined that large variations in sample gas flow rate resulted in changes in the analyzer output but no output change was observed for flow variations normally encountered.

Initial testing of the system was performed at ambient temperature and pressure, using nitrogen as a diluent and upon overcoming the inadequate response time, as previously described, the analyzer was placed in a bell jar for evaluation at pressures between 760 and 250 mm Hg.

NOTE: A vent was installed in the side of the explosion proof analyzer housings to vent the housings and thereby maintain the pressure inside the analyzer at the same level as the pressure of the surrounding atmosphere. This was necessary to prevent damage to the glass tube in the analyzer sensing element. The glass tube may be broken if subjected to pressure differentials across the glass walls of more than 50 inches of water. To maintain the integrity of the explosion proof housings in which the analyzer is mounted, flame arresters were used as vents.

A known gas mixture of oxygen and nitrogen was injected into the chamber and several unsuccessful attempts were made to obtain a correct readout of the oxygen partial pressure at varying total pressures. It became evident that the analyzer was sensitive to changes in total pressure.

The manufacturer was contacted and it was verified that the Hays Oxygen Analyzer was affected by changes in the total pressure of the sample gas. Through testing, it was determined that the zero and range adjustments on the analyzer could be used to compensate for the changes in total pressure. This solution was evaluated and found to be valid. Provisions were made to modify the analyzer by removing the oxygen zero and oxygen range adjustment from the analyzer housing and relocating both adjustments on the ASMS Control Panel.

Prior to completing this modification, however, a feasibility test was run to evaluate the full effects of the relocation of the zero and range adjustments. Potentiometers having a capacity similar to those supplied with the analyzer were substituted for those in the analyzer and were located outside the belljar to permit adjustment during the test. Tests indicated change was entirely feasible, but rather than stop testing to make the change, it was decided to proceed with the test program and evaluate the analyzer operation when a different atmosphere background gas was used.

Up to this time various nitrogen-oxygen mixtures were used and it was decided to inject helium-oxygen mixtures into the belljar. The analyzer was known to be sensitive to changes in background gases and when the instrument was purchased, three range cards, one for nitrogen oxygen, one for helium-oxygen, and the third for 100 percent oxygen atmospheres were provided to compensate for this sensitivity. The range card is a voltage divider circuit that plugs into the electronic unit of the analyzer. During tests with gas mixtures with a nitrogen background, a nitrogen range card was placed in the analyzer. Now, due to the change in background gas, the helium range card was installed in the unit.

Upon injecting the helium-oxygen mixtures into the belljar, the analyzer response became erratic, and it was not possible to obtain consistently accurate oxygen partial pressure readings. The zero and range potentiometers did not have sufficient adjustment to compensate for the effects of the change which resulted in extremely low output from the analyzer. A study was made of the electronic unit circuitry and it was determined that, by modifying the pre-amplifier slightly, the amplifier gain could be increased. This was done and it was then possible to adjust the zero and range potentiometers over a sufficiently wide range to provide maximum and minimum oxygen partial pressure readings. However, the output of the analyzer was found to be non-linear and erratic. Oxygen partial pressure readings could not be obtained over the operating range of the system. Further tests were run which indicated that the presence of high concentrations of helium in the measuring unit housing had a marked effect on the analyzer output. It was decided to seal the measuring unit housing and install a purge circuit to maintain a nitrogen atmosphere within the measuring unit at a slightly higher pressure than that maintained in the LSSE when diluents other than nitrogen are to be used.

The necessary modifications to incorporate analyzer purge circuit (Figure 3) were made. The explosion proof housing of the analyzer measuring unit was found to be porous in several areas and it was necessary to coat the inside of the housing with a silcone rubber sealant to prevent gas leakage from the housing. Once again, the system was operated using helium as a background gas. The analyzer response was good, and accurate indications of the oxygen partial pressure were obtained.

Upon obtaining satisfactory analyzer performance, the zero and range potentiometers were permanently located on the control panel, and cable harnesses were changed to compensate for this relocation. Ten turn knobs were placed on the potentiometers to permit accurate repositioning. Subsequent tests were performed to determine the correct zero and range potentiometer settings to compensate for changes in total pressure. The settings for nitrogen-oxygen mixtures were found to be slightly different than those for helium-oxygen mixtures (Figures 15 and 16). Figures 17 and 18 present the instrument reading vs the actual oxygen partial pressure for various total pressures of both oxygen-nitrogen and oxygen-helium mixtures.

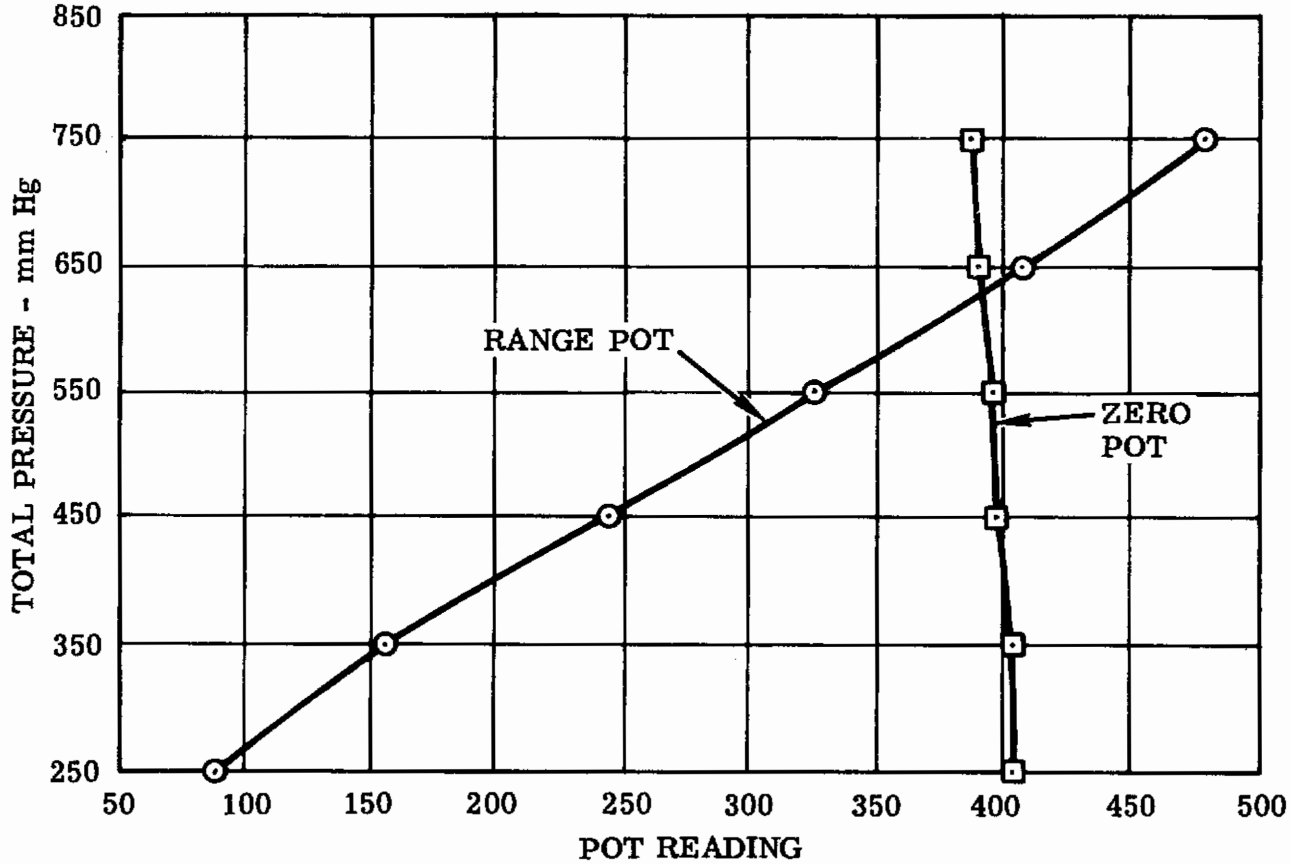



Figure 15. **ASMS $O_2$-$N_2$ Zero and Range Adjustment**

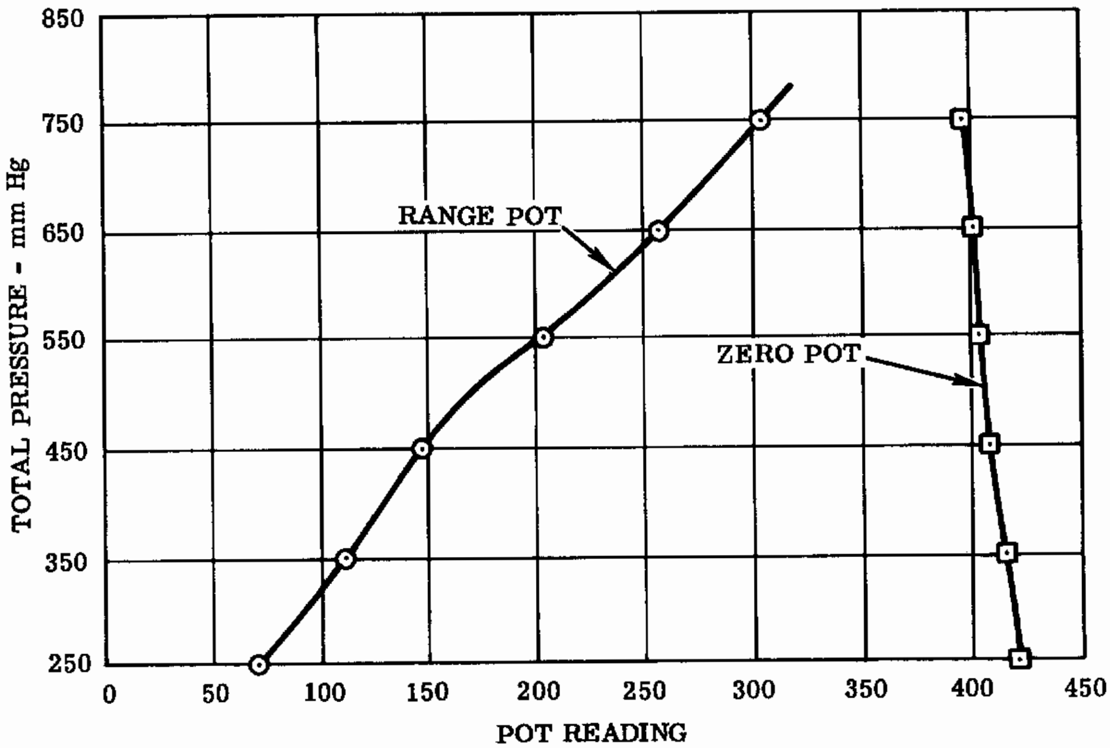



Figure 16. **ASMS $O_2$-He Zero and Range Adjustment**

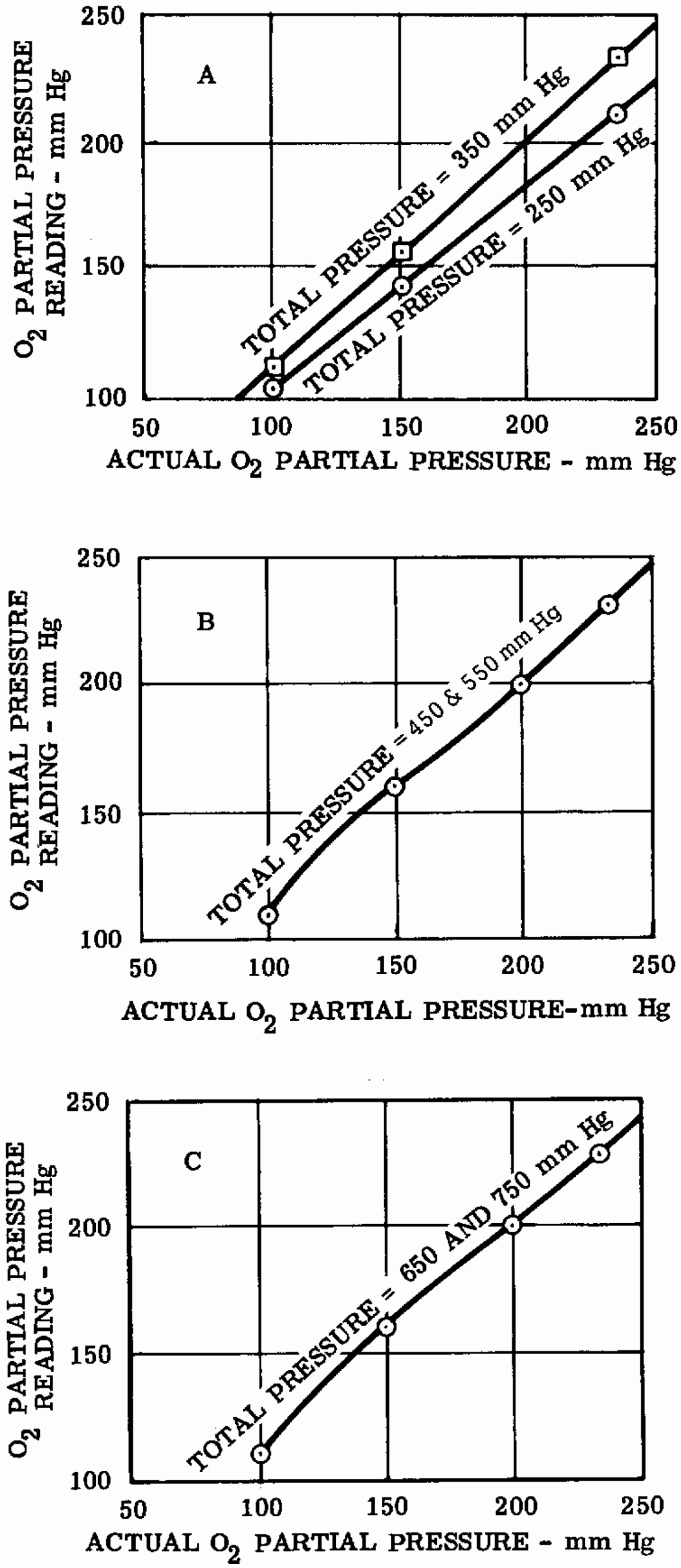



Figure 17. ASMS $O_2$-$N_2$ Mixture -$O_2$PP Actual Versus Indicated

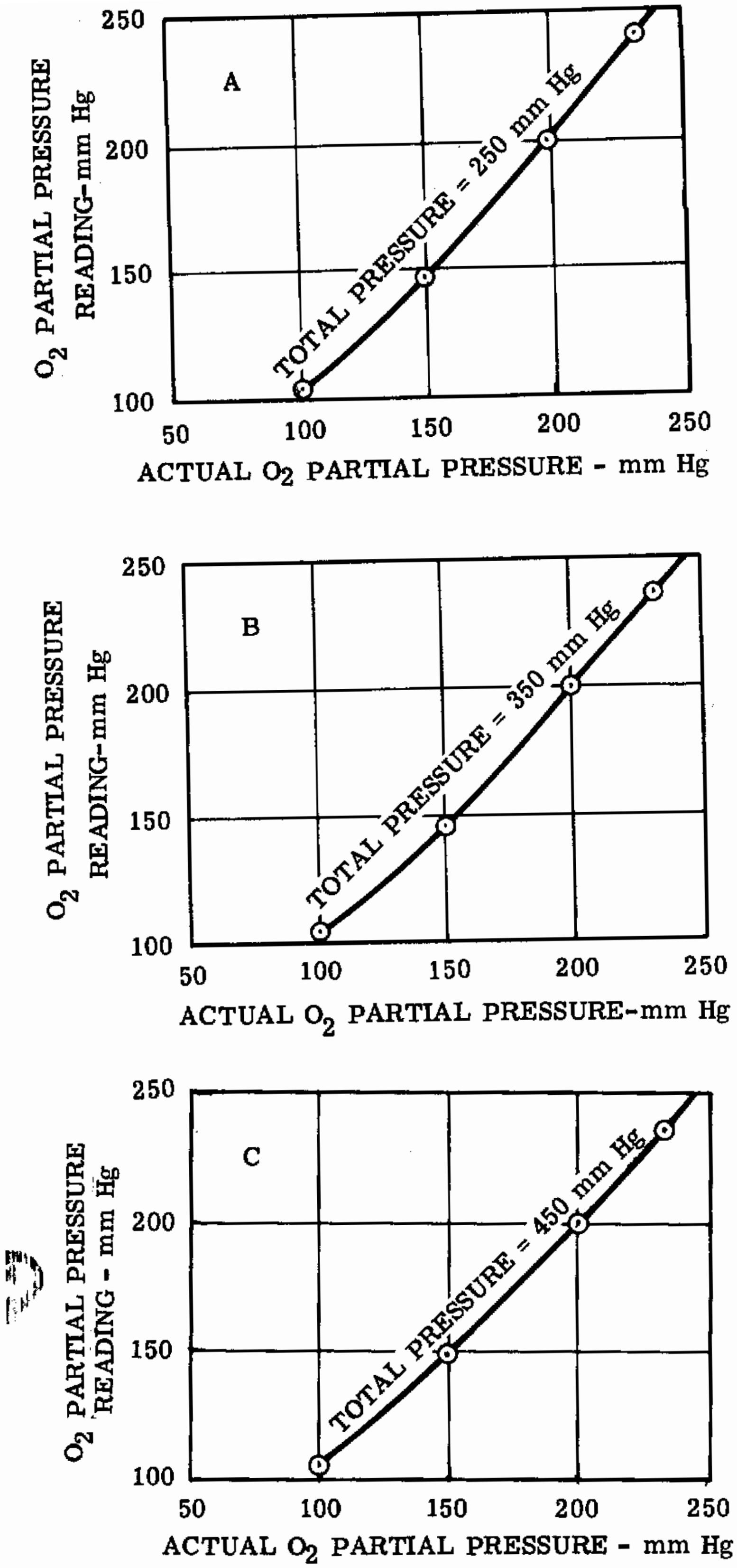
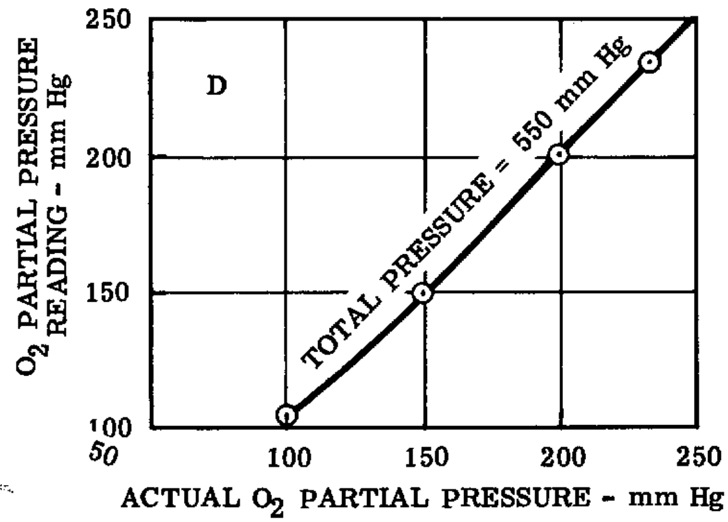
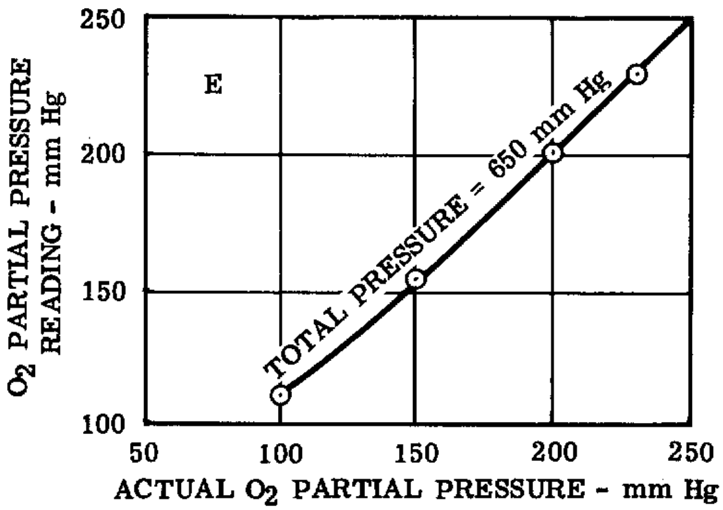



Figure 18. **ASMS $O_2$-He Mixture -$O_2$PP Actual Versus Indicated (Sheet 1 of 2)**



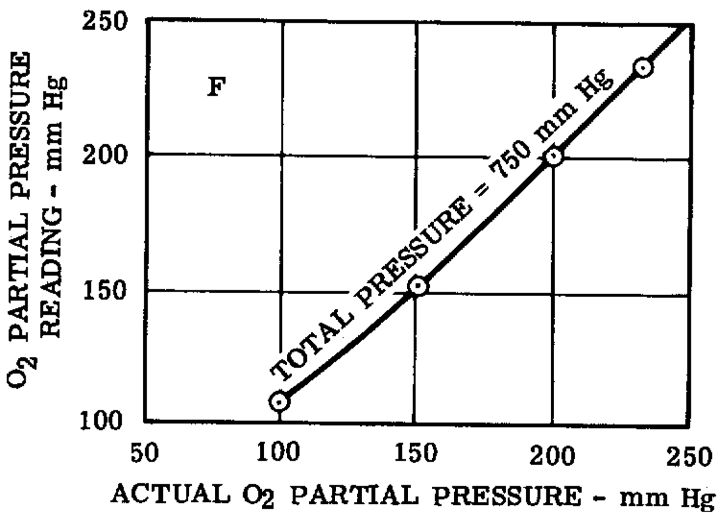




Figure 18. **ASMS $O_2$-He Mixture -$O_2$PP Actual Versus Indicated (Sheet 2 of 2)**

## SECTION IV

## CONCLUSIONS AND RECOMMENDATIONS

The ASMS two gas control system is capable of providing control of the oxygen partial pressure and the total pressure within the LSSE when either nitrogen or helium is used as the diluent gas. Oxygen partial pressure can be controlled to ±2.5 mm of Hg of a set point over the range 100 to 250 mm of Hg and the total pressure can be controlled to +7.5, -2.5 mm of Hg over the range of 150 to 800 mm of Hg.

The paramagnetic oxygen analyzer used in the ASMS was found to be affected by variations in total pressure, diluent gas and sample gas flow rate. Modifications to the system to compensate for the effects of these changes were designed to maintain the relative simplicity of operation of the system. The changes consisted of the addition of; an oxygen zero and oxygen range adjustment requirement to compensate for atmosphere total pressure changes, the addition of an analyzer purge circuit to compensate for changes in diluent gas and a sample gas circulation system to prevent variations in sample gas flow rate and provide a quicker response of the analyzer to changes occurring in the atmosphere being sensed.

The size and weight of the analyzer as presently designed, detract from its suitability as a light weight, zero gravity operable flight type unit. It is felt however, that through a concentrated effort an analyzer operating on the same principal as that provided with the ASMS but smaller and lighter in weight could be developed. This could be accomplished through consolidation of the electronic circuits within the analyzer and isolation of the sensing element windings from the atmosphere being sensed by the analyzer. Automatic devices to overcome the effects of varying total pressure on the analyzer have been developed but have not been incorporated with the particular model of Hays Analyzer used in the ASMS.

At the present time there is no light weight, low power, long life, reliable oxygen sensor available that can be considered flight qualified equipment. Several programs are in progress aimed at developing such a sensor, however.

Since the early sixties the General Electric Company has been developing (with both contract and in-house funding) a class of sensors based upon the electrochemical characteristics of fuel cells. To date the major efforts have been directed at the development of sensors to measure the partial pressures of either oxygen or hydrogen. The prototype sensors tested have clearly demonstrated their ability to selectively measure partial pressures, essentially independent of normal diluents and not affected by total pressures.

As noted above, the sensor operated according to the electrochemical characteristics of a hydrogen-oxygen fuel cell. The oxygen sensor operates as a current limited device with the current level positively controlled by a gas-diffusion barrier that has a fixed permeation constant for oxygen.

The prototype sensors under test store the fuel as a solid rather than as hydrogen gas used in earlier designs. Sensor outputs are on the order of 100 mv for 250 mm Hg oxygen pressure and are independent of diluent makeup. Signal conditioning circuits have been designed to boost this output to 5 v using a 28-volt amplifier. The total package is approximately 2 inches by 2 inches by 3 inches including electronics and suitably packaged to withstand typical flight environments.

Life testing is continuing but sensors to date have been operating for 40 days with a signal drift over that period of approximately 12 percent of full scale. Sensor accuracy in the prototypes tested are on the order of ± one percent of full scale.

The calculated life expectancy of the sensor is approximately one year.

It is recommended that, when flight qualified oxygen sensors reach an operational stage of development, the ASMS be retrofitted with this type of sensor, in order to more fully develope the ASMS as a flight prototype system.

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13. ABSTRACT

This program encompasses the analysis, design, fabrication and testing of an Atmosphere Sensing and Maintenance System (ASMS) to be used in conjunction with the Aerospace Medical Research Laboratories (AMRL) Life Support System Evaluator (LSSE) chamber or similar space cabin simulators. The ASMS is a two-gas control system capable of monitoring and controlling the total pressure and the oxygen partial pressure of the atmosphere within the LSSE. Oxygen partial pressure is controlled to ± 2.5 mm Hg over the range to 100 to 250 mm of Hg and total pressure is controlled to + 7.5, - 2.5 mm of Hg over the range of 150 to 800 mm of Hg. Monitoring of the oxygen partial pressure and the total pressure of the LSSE atmosphere is possible from either the control panel or the monitor's panel of the ASMS. Control of the LSSE atmosphere is possible only from the control panel. The panels are designed to be interchangeable, to provide control capability either inside or outside of the LSSE with a minimum of effort.

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