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IN-FLIGHT EVALUATION OF TWO MOLECULAR SIEVE OXYGEN CONCENTRATION SYSTEMS IN U.S. ARMY AIRCRAFT (JUH-1H AND JU-21G)

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20. ABSTRACT:

The logistical problems associated with using high pressure gaseous oxygen systems have encouraged the development of molecular sieve oxygen concentration systems for use on board aircraft. This report summarizes the in-flight static performance characteristics of two such oxygen concentrators installed in a JU-21G fixed-wing, twin-engine turbopropeller aircraft and a JUH-1H turbine-powered helicopter. Flight profiles consisting of five separate flights at altitudes of 1,524, 3,048, 4,572, 6,096, and 7,620 meters (5,000, 10,000, 15,000, 20,000, and 25,000 feet) were flown in the JU-21G and five separate flights at altitudes of 1,524, 3,048 and 4,572 meters were flown in the JUH-1H. Oxygen concentration at flows of 15, 25, 35, and 70 liters per minute were recorded at each altitude. These flows were chosen to represent normal breathing requirements for one- and two-man crews. In all cases, the concentrators met or exceeded the requirements of MIL-R-83178. The use of engine bleed air to drive the oxygen concentrators produced no noticeable effect on aircraft performance.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

In 1947, with the formation of the US Air Force as a separate branch of service, US Army aviation relinquished most of its high-altitude capabilities, requirements, and aircraft, resulting in a role of reduced importance for oxygen delivery systems in the Army aviation environment. Today, however, there are increased mission requirements, both training and operational, which dictate routine flights in certain aircraft to altitudes as high as 7,620 meters (25,000 feet) in an unpressurized cabin. As a result, oxygen systems are again a critical part of US Army aircraft life support systems. Currently, US Army aviation oxygen needs are satisfied only partially by continuous flow and diluter demand gaseous oxygen systems due to space, weight, and logistical limits. Additionally, the effectiveness of these systems is compromised by several factors. The amount of oxygen available during a given flight is limited by the number of high-pressure cylinders carried on board the aircraft. Carrying extra cylinders results in a weight and space penalty which reduces operational aircraft capability. Gaseous systems require frequent refilling which prolongs aircraft turnaround time. There also are high risk safety hazards associated with the storage, servicing, and use of high pressure gaseous oxygen systems; and logistical servicing facilities are not normally available at remote locations.

The logistical problems associated with using high pressure gaseous oxygen systems have encouraged the development of molecular sieve oxygen concentration systems for use on board aircraft. The US Army, Navy, and Air Force are studying the applicability of these systems for use on high performance jet aircraft, turbopropeller aircraft, and turbine-powered helicopters (Ernsting et al., 1980; Knox et al., 1981; Miller et al., 1980; and Pettyjohn et al., 1977).

A typical concentrator contains two cannisters or "beds" filled with a synthetic zeolite molecular sieve material of five Angstrom pore size. These two beds are pressurized alternately with bleed air diverted from the compressor stage of the turbine engine. During pressurization, oxygen in the bleed air is separated from nitrogen and then vented through the output port. Nitrogen is trapped in the zeolite molecular sieve material. The bed then is depressurized to the atmosphere as a nitrogen exhaust purge which completes the unit's "pressure swing cycle." During this phase of the cycle, some of the concentrated oxygen from the pressurized bed is bled in the reverse direction through the depressurized bed to assist in the nitrogen purge. Thus, when one bed is concentrating oxygen, the other is being purged of nitrogen. A rotary valve directs the flow of bleed air and also controls the flow of oxygen-enriched air and nitrogen purge. The valve is actuated by a 28-volt DC motor that is powered by the aircraft electrical system. A block diagram of this process is shown as Figure 1. This report summarizes the in-flight static performance characteristics of two such oxygen concentrators installed in a

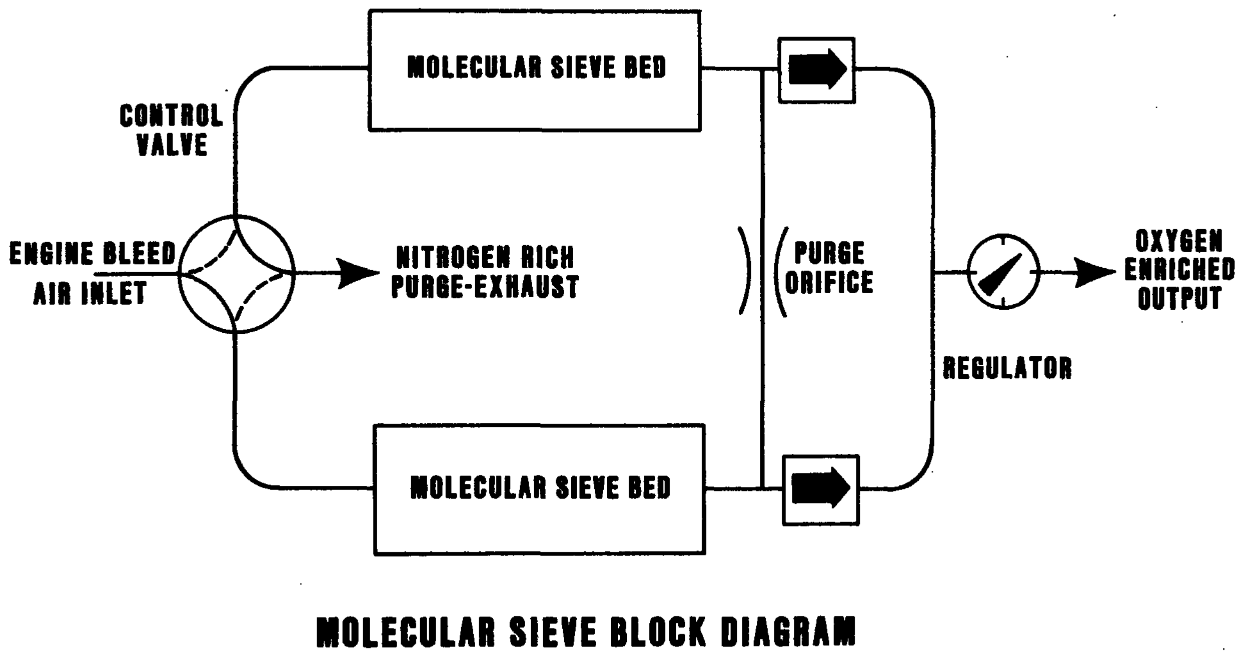

FIGURE 1. Molecular Sieve Block Diagram

JU-21G fixed-wing, twin-engine, turbopropeller aircraft (Figure 2) and a JUH-1H turbine-powered helicopter (Figure 3). Such an effort is a necessary first step for evaluation of candidate systems within the range of physiological requirements.

METHOD

APPARATUS

Two oxygen concentrators were tested, one manufactured by the Garrett Corporation* and the other by the Bendix Corporation* (Figure 4). Each unit occupies approximately one cubic foot and operates by basically the same method.

In the JU-21G, instrumentation for in-flight testing and data collection was installed in a specially-built test stand (Figure 5). Bleed air from the right engine at 15 to 55 pounds per square inch gauge (psig) was fed into the test stand through a 15.78mm (5/8-inch) internal diameter (ID) oxygen line. A 4.5-liter plenum chamber was installed to facilitate instrumentation and dampen pressure fluctuations caused by the pressure swing of the molecular sieve concentrator. Inlet bleed air pressure was measured by a Validyne differential pressure transducer* and a Harris sight gauge.* Temperature was measured with a Cole-Palmer digital thermometer* before the air was directed from the plenum chamber through the oxygen concentrator. The oxygen-enriched air (product gas) exited the concentrator and passed into a second 4.5-liter plenum chamber where the outlet pressure and temperature again were monitored and recorded using another Validyne differential pressure transducer, Harris sight gauge, and Cole-Palmer digital thermometer. Upon exiting the outlet plenum, the product gas was fed through a 9.5mm (3/8-inch) ID oxygen line to a Technology, Incorporated mass flow meter.* A shutoff valve, in conjunction with a Fischer-Porter rotameter*, was used to set various flows. Oxygen concentration was measured using a fast response Beckman OM-14 oxygen analyzer* equipped with an altitude sensor. A Wallace and Tiernan barometer* was used to measure ambient barometric pressures. Standard aircraft instrumentation was used for torque, engine temperature, airspeed, and altitude measurements. Calibration of instrumentation was maintained on a flight-by-flight basis at both ground level and at the various sampling altitudes.

The same instrumentation package was used for testing in the JUH-1H with the only difference being a slight modification of the test stand to allow for proper securing of the stand to the helicopter's cargo attachment points.

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*Indicates product manufacturer listed in Appendix A.

FIGURE 2. JU-21G Research Aircraft.

FIGURE 3. JUH-1H Research Aircraft.

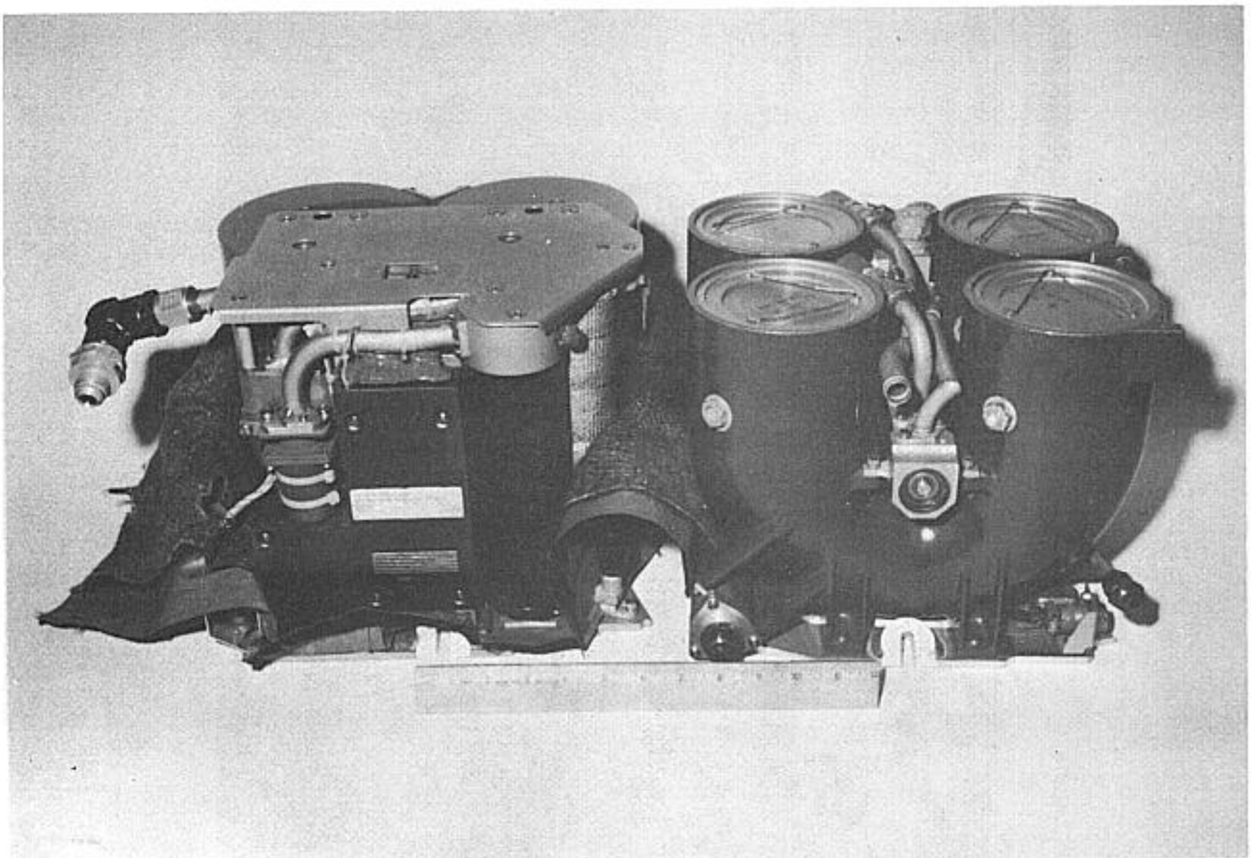

FIGURE 4. Oxygen Concentrators--Bendix Unit (Left), Garrett Unit (Right).

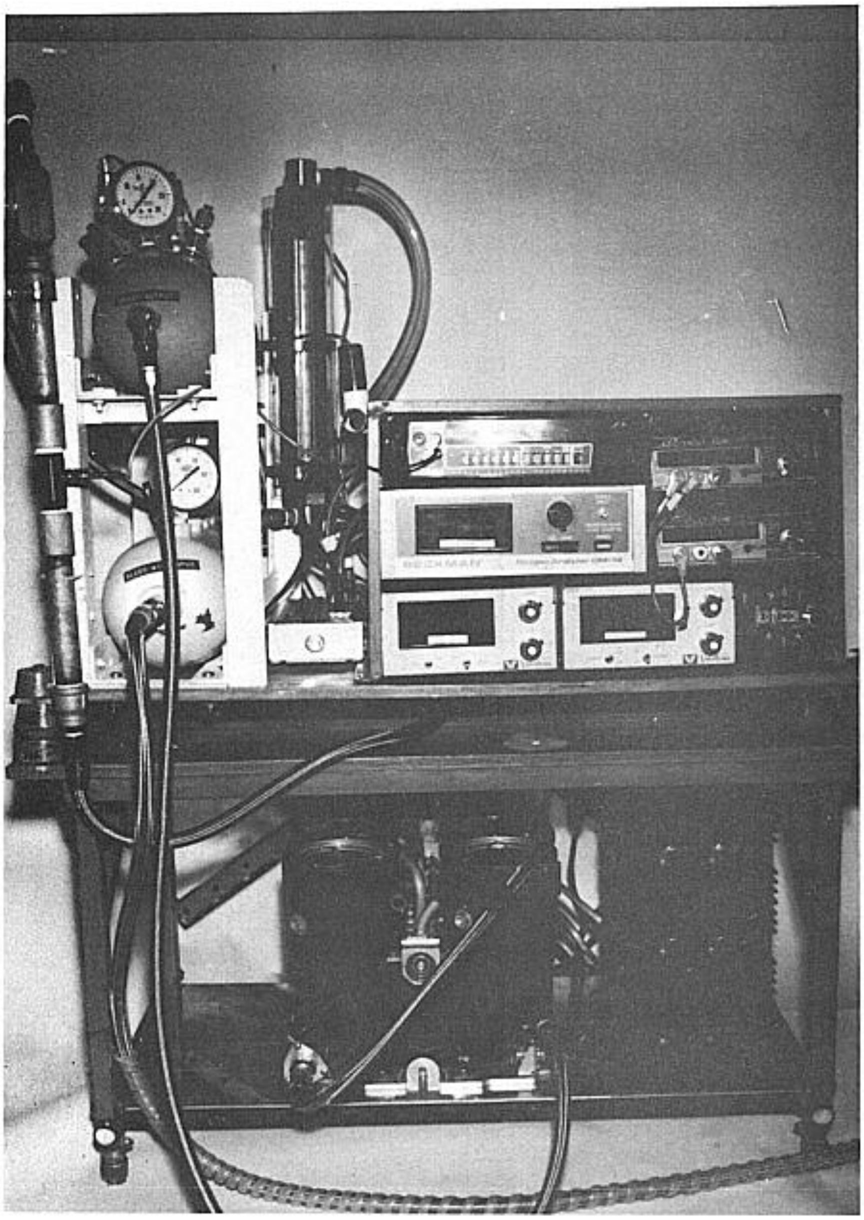

FIGURE 5. Test Stand.

PROCEDURE

In the JU-21G, five separate flights at altitudes of 1,524, 3,048, 4,572, 6,096, and 7,620 meters (5,000, 10,000 15,000, 20,000, and 25,000 feet) were conducted with each oxygen concentration unit. Four different flows of 15, 25, 35, and 70 liters per minute were chosen to represent normal breathing requirements for one- and two-man crews. Data were recorded for each flow at all altitudes and at both minimum and maximum engine power settings. Minimum power was defined as the power required to fly at 130 knots indicated airspeed (IAS) while maximum power was defined as 208 knots IAS with Interstage Turbine Temperature (ITT) not to exceed 705^{o}C. At these power settings, the inlet bleed air pressures at the oxygen concentrator were consistently in the range of 28 to 55 psig and oxygen-enriched air outlet pressure ranged from 22 to 28 psig, which is well within the limits of the low pressure oxygen regulators designed for use with molecular sieve oxygen concentration units. In the JUH-1H, five separate flights at altitudes of 1,524, 3,048, and 4,572 meters (5,000, 10,000, and 15,000 feet) were conducted with each oxygen concentration unit. Flow rates were the same as in the JU-21G, and the engine power setting was constant over the entire flight test period.

RESULTS

Oxygen concentrations and other system considerations for the JU-21G flights are shown for the Bendix unit in Table 1 and for the Garrett unit in Table 2. Oxygen concentration and system data for the JUH-1H flights are shown in Table 3 for the Bendix unit and in Table 4 for the Garrett unit. Generally, with both units, oxygen concentration decreased with increased flow and increased with higher altitude. In the JU-21G, oxygen concentration generally decreased with the higher engine power setting. However, with the Bendix unit, this condition was reversed in some instances. In all cases, as shown in Figures 6 through 11, oxygen concentration met or exceeded the requirements (indicated by the stippled area) of MIL-R-83178.

Data first recorded upon reaching a new altitude (low flows, Figures 6-9) often showed overlap where it was supposed there should be none. A careful review of data collection procedures revealed that it usually took 4 to 6 minutes for the system to stabilize and be repeatable. In order to test the working hypothesis that the initial readings in Figures 6 through 9 were taken prior to system equilibrium, data were recorded during three additional flights in the JU-21G at each altitude, allowing more time between flow changes and altitude changes for the system to stabilize. The data for the Garrett unit is presented in Table 5 and Figures 12 and 13 for these additional flights. Two low-altitude flights were made with the Bendix unit when the aircraft

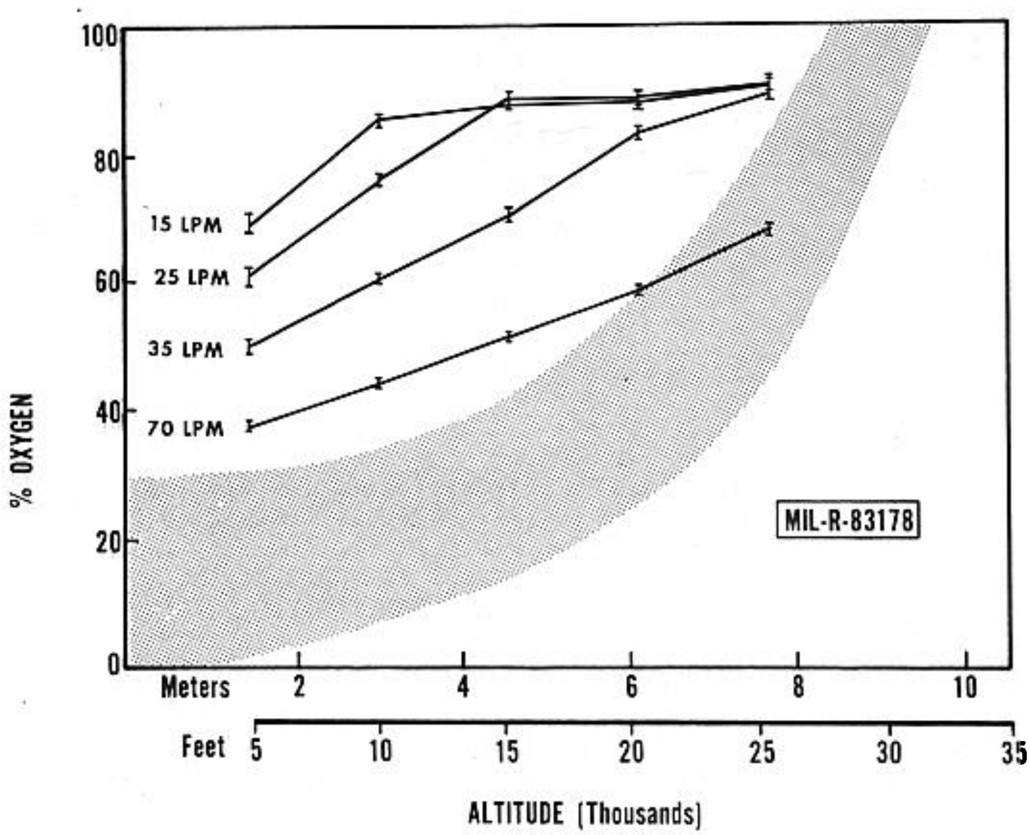

FIGURE 6. Oxygen concentration vs. altitude in JU-21G (Bendix unit, minimum power). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

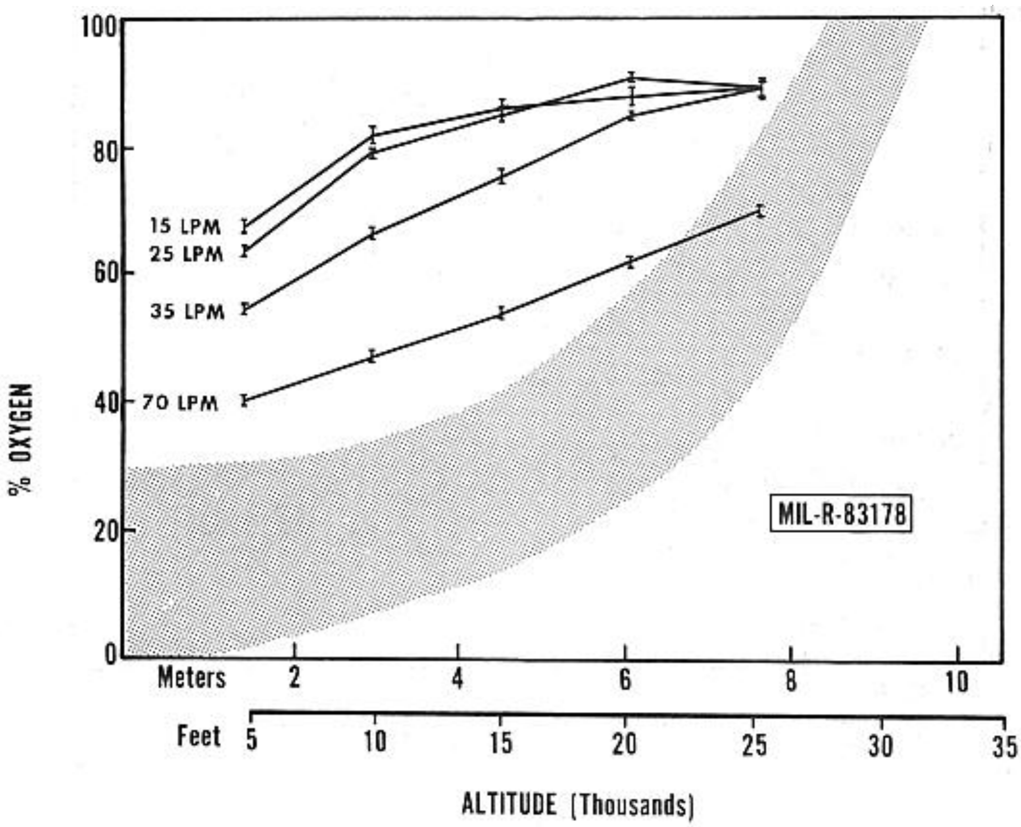

FIGURE 7. Oxygen concentration vs. altitude in JU-21G (Bendix unit, maximum power). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

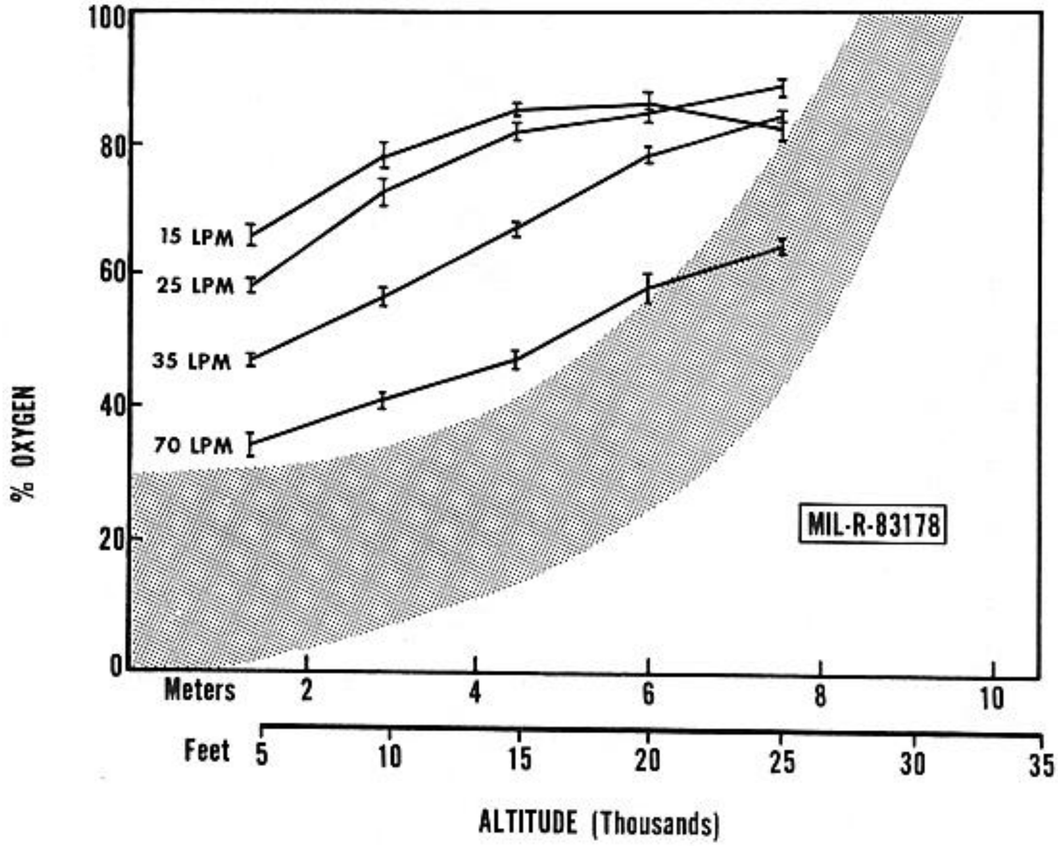

FIGURE 8. Oxygen concentration vs. altitude in JU-21G (Garrett unit, minimum power). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

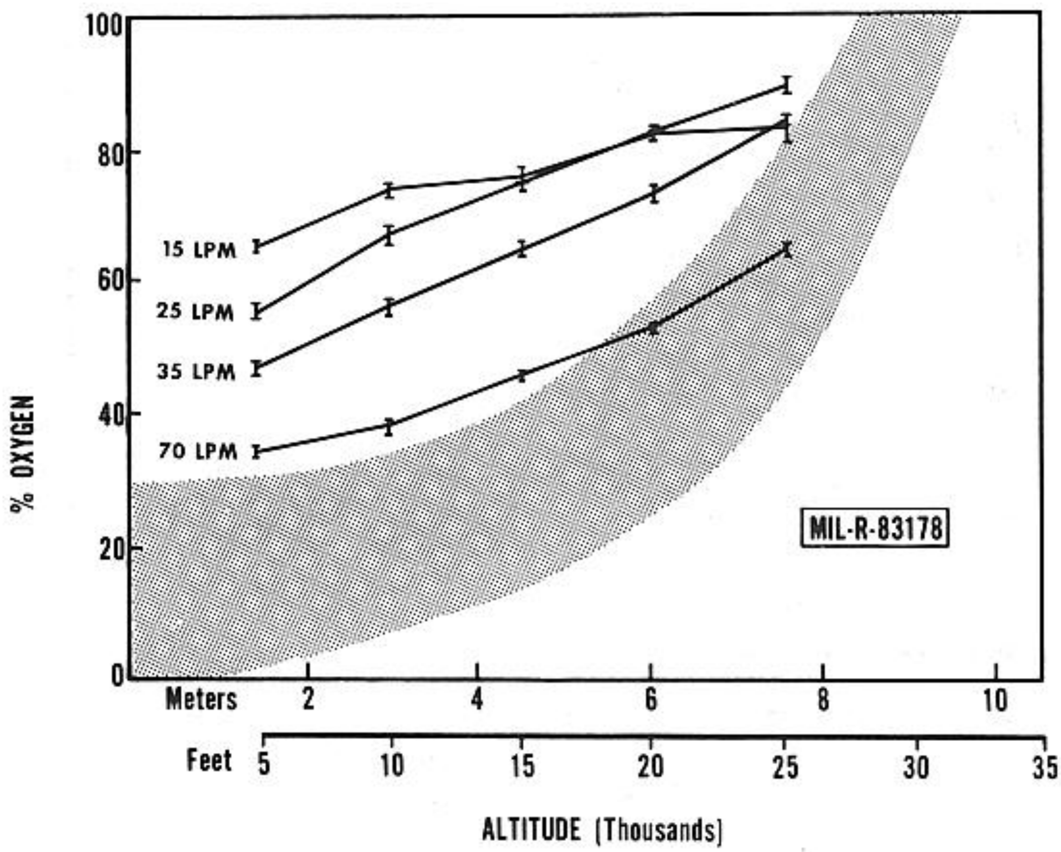

FIGURE 9. Oxygen concentration vs. altitude in JU-21G (Garrett unit, maximum power). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

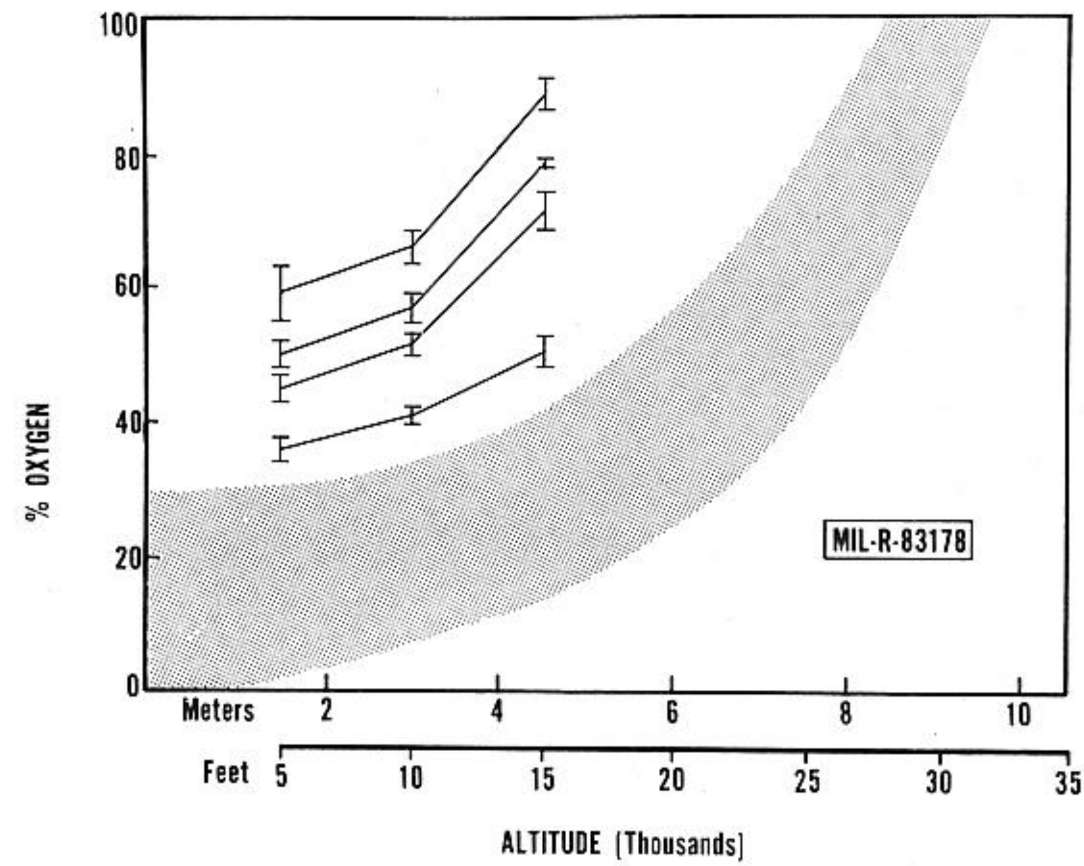

FIGURE 10. Oxygen concentration vs. altitude in JUH-1H (Bendix unit). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

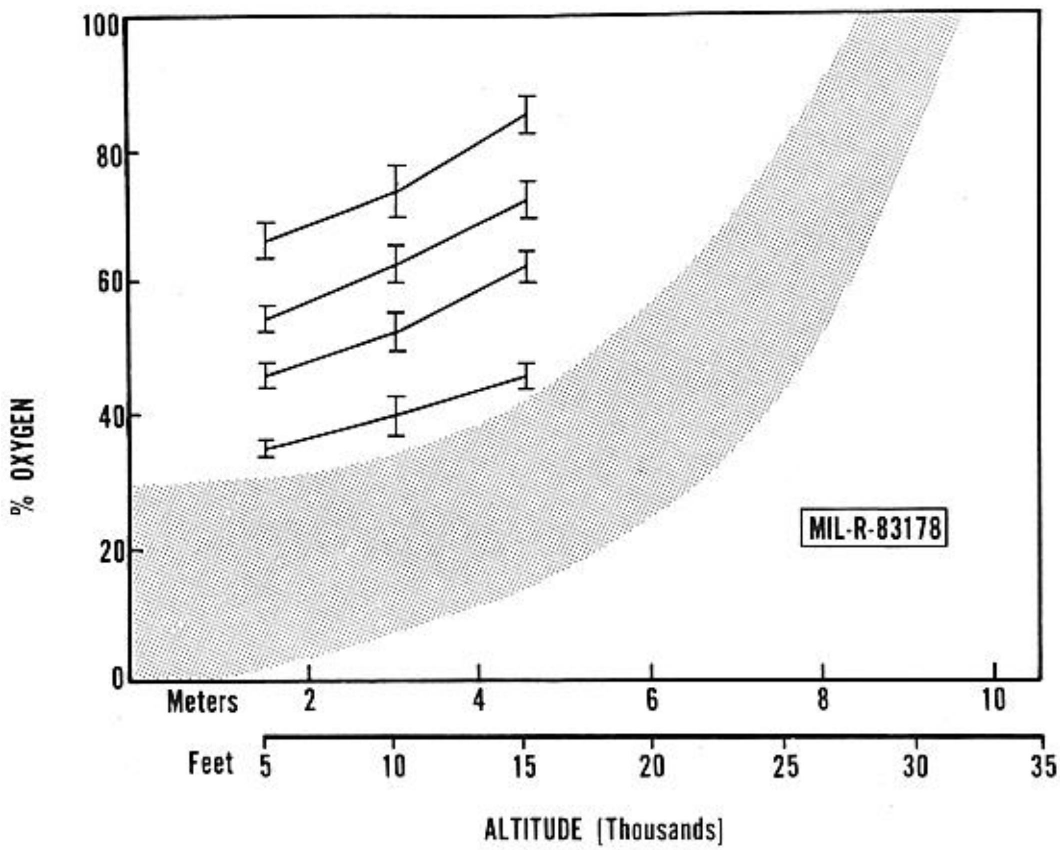

FIGURE 11. Oxygen concentration vs. altitude in JUH-1H (Garrett unit). Stippled area indicates oxygen requirements of MIL-R-83178. Bars indicate standard deviation at each data point.

TABLE 1

OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (BENDIX/JU-21G)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O_2 Conc (%) $\bar{X}$	S_x
1524 (Min)*	15	41.0	20.1	34.2	30.4	69.3	8.8
	25	41.6	20.6	33.8	30.3	60.8	5.8
	35	41.3	21.9	34.0	30.0	49.7	4.4
	70	42.7	21.6	34.0	28.2	38.3	1.5
1524 (Max)*	15	47.0	23.1	55.2	34.9	67.9	5.2
	25	47.9	23.1	55.2	35.0	63.5	2.9
	35	48.5	23.4	55.0	34.8	54.7	2.4
	70	50.2	23.9	54.2	33.6	40.9	1.7
3048 (Min)	15	47.3	26.1	32.0	28.9	83.6	2.9
	25	46.6	26.5	32.5	28.7	76.5	3.6
	35	45.8	26.6	31.7	28.6	60.3	1.5
	70	45.1	27.1	32.5	27.6	44.6	2.0
3048 (Max)	15	49.4	27.3	49.5	33.8	82.0	7.2
	25	50.4	27.6	49.7	33.6	79.0	3.5
	35	51.2	27.9	50.0	33.4	66.1	2.3
	70	51.7	28.1	49.3	32.5	47.8	1.9
4572 (min)	15	46.7	27.1	30.3	27.8	88.2	6.0
	25	45.3	27.1	30.2	27.5	89.1	5.1
	35	44.4	27.2	30.7	27.6	71.1	4.6
	70	43.9	27.6	30.8	27.5	50.9	3.4
4572 (Max)	15	45.8	27.7	41.5	31.1	86.7	5.4
	25	47.1	27.7	41.8	30.9	85.7	5.5
	35	47.8	27.9	41.8	31.0	75.7	3.9
	70	48.4	28.4	42.0	30.0	53.5	2.7

TABLE 1 (Cont.)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O_2 Conc (%) $\bar{X}$	S_x
6096 (Min)	15	45.4	25.4	29.4	28.8	88.2	5.1
	25	43.8	25.9	28.8	27.7	88.5	4.9
	35	42.9	26.5	30.2	27.6	83.5	4.4
	70	42.1	26.9	30.1	27.7	58.7	2.5
6096 (Max)	15	43.2	25.9	35.0	30.5	86.8	6.1
	25	43.5	26.0	34.8	30.1	90.1	3.6
	35	43.5	26.2	34.8	29.9	85.6	1.9
	70	43.7	26.4	35.0	29.5	61.9	1.7
7620 (Min/Max)**	15	42.3	27.2	29.4	27.8	89.7	5.5
	25	41.9	26.9	29.8	27.5	89.8	5.8
	35	41.6	26.8	29.6	27.4	88.8	5.8
	70	41.5	26.8	29.2	27.2	69.2	2.8

*Minimum power defined as 130 knots IAS. Maximum power defined as 208 knots IAS with ITT not to exceed 705°C.

**At 7620 meters, minimum and maximum power setting is the same.

TABLE 2

OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (GARRETT/JU-21G)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O_2 Conc (%) $\bar{X}$	S_x
1524 (Min)*	15	35.9	20.8	34.2	27.6	64.5	6.0
	25	38.0	20.5	34.8	27.1	57.7	1.9
	35	39.0	20.5	35.0	26.7	46.3	2.3
	70	40.1	20.5	35.6	26.7	33.7	1.9
1524 (Max)*	15	43.6	21.4	54.2	33.9	64.7	2.0
	25	44.6	21.0	54.5	33.9	55.7	5.9
	35	45.4	21.1	54.5	33.7	46.0	4.1
	70	46.1	21.5	54.2	33.0	34.0	2.7
3048 (Min)	15	43.7	22.1	34.0	27.2	78.1	8.4
	25	43.0	22.3	33.4	27.2	72.6	7.9
	35	42.5	22.5	32.6	26.3	55.9	5.9
	70	42.1	22.6	32.2	25.5	40.3	3.2
3048 (Max)	15	45.9	23.3	53.0	27.4	73.5	4.2
	25	47.0	23.4	52.6	26.8	67.4	6.6
	35	47.8	23.3	53.2	26.0	55.7	4.9
	70	48.3	23.5	50.2	26.0	38.6	4.1
4572 (Min)	15	41.5	25.0	30.0	25.5	84.6	2.2
	25	40.4	24.8	30.8	25.2	80.9	4.7
	35	39.5	24.5	31.2	25.1	67.5	3.6
	70	38.8	26.0	30.8	24.8	47.2	3.9
4572 (Max)	15	38.7	23.6	45.4	24.3	75.7	3.8
	25	40.1	23.1	44.8	24.2	75.1	4.0
	35	41.4	22.8	44.6	24.2	64.0	4.0
	70	42.4	22.9	44.0	23.5	46.0	2.2

TABLE 2 (Cont.)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O_2 Conc (%) $\bar{X}$	S_x
6096 (Min)	15	41.3	23.8	29.2	26.8	86.0	5.8
	25	40.3	24.2	29.2	24.7	84.4	5.4
	35	39.5	24.7	28.8	24.4	78.7	5.2
	70	38.9	24.9	28.8	25.0	57.2	9.4
6096 (Max)	15	39.2	25.8	41.0	25.5	81.2	3.7
	25	40.0	26.0	40.0	24.7	81.8	3.7
	35	40.6	26.2	40.0	24.1	73.5	4.2
	70	41.2	26.3	39.0	23.8	52.7	3.4
7620 (Min/Max)**	15	40.0	25.6	31.2	24.5	82.1	9.5
	25	39.5	25.3	31.6	24.4	88.7	4.6
	35	39.1	25.1	30.8	24.1	83.4	3.4
	70	38.9	24.7	31.4	24.6	63.8	3.3

*Minimum power defined as 130 knots IAS. Maximum power defined as 208 knots IAS with ITT not to exceed 705°C.

**At 7620 meters, minimum and maximum power setting is the same.

TABLE 3

OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (BENDIX/JUH-1H)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O_2 Conc (%) $\bar{X}$	S_X
	15	42.7	23.3	53.0	26.8	58.7	4.0
1524	25	41.9	23.3	53.0	26.5	50.0	2.1
	35	42.1	23.6	52.8	26.3	44.4	2.1
	70	43.2	25.2	52.8	25.1	35.9	1.6
	15	42.5	24.1	47.0	25.7	65.3	2.7
3048	25	42.5	24.1	46.6	25.4	56.6	2.0
	35	42.6	24.2	46.8	25.2	51.3	1.5
	70	43.6	25.6	46.6	24.4	40.8	1.2
	15	44.5	21.6	43.1	26.3	89.1	2.8
4572	25	44.1	19.3	42.9	25.9	79.0	0.6
	35	43.2	17.5	42.7	25.8	71.3	2.7
	70	43.2	16.8	42.4	25.3	50.6	1.8

TABLE 4

OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (GARRETT/JUH-1H)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O_2 Conc (%) $\bar{X}$	S_x
	15	44.4	24.1	52.8	22.2	66.2	2.6
1524	25	45.1	23.8	52.2	22.1	54.3	2.0
	35	45.6	23.8	52.6	22.0	45.3	1.7
	70	46.7	24.6	52.6	21.3	34.8	1.8
	15	46.3	24.1	47.4	22.0	74.0	4.3
3048	25	46.4	23.7	47.6	22.1	62.4	2.4
	35	46.4	23.3	47.6	22.2	53.2	2.7
	70	47.0	23.7	47.2	21.5	39.7	2.2
	15	47.8	19.9	43.7	21.8	85.5	3.1
4572	25	46.6	18.7	43.1	21.7	72.9	3.0
	35	46.0	17.9	43.0	21.4	62.1	2.3
	70	46.0	17.7	42.7	20.9	45.7	2.0

TABLE 5

OXYGEN CONCENTRATION AND SYSTEM CONDITION UNDER STATIC FLOW (GARRETT/JU-21G)
SUPPLEMENTAL DATA

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O_2 Conc (%) $\bar{X}$	S_X
1524 (Min)	15	46.9	26.8	36.1	22.3	77.6	1.4
	25	45.9	26.0	37.0	22.1	59.4	2.9
	35	48.6	25.5	36.8	22.2	49.6	1.0
	70	49.0	25.9	36.4	21.3	36.6	0.3
1524 (Max)	15	50.4	25.2	61.4	23.1	72.8	2.0
	25	52.7	24.9	61.1	23.0	54.4	1.3
	35	53.3	24.7	61.0	22.7	46.0	0.4
	70	57.1	25.5	60.3	21.8	35.2	0.6
3048 (Min)	15	50.5	24.5	34.8	23.1	85.8	4.9
	25	48.3	24.1	34.7	23.0	70.2	6.9
	35	47.8	24.4	34.6	23.1	56.2	1.6
	70	48.2	25.1	30.6	22.5	40.6	1.8
3048 (Max)	15	49.6	25.1	53.6	22.7	75.3	0.8
	25	50.8	25.2	53.6	22.5	60.4	1.4
	35	51.6	25.8	53.2	22.3	51.0	1.2
	70	52.3	26.9	53.0	21.5	37.6	0.4
4572 (Min)	15	49.4	26.1	30.4	22.5	84.4	2.4
	25	48.5	26.1	30.8	22.7	71.4	1.3
	35	48.1	26.1	30.8	22.7	59.1	1.4
	70	48.1	26.8	30.1	21.9	41.4	0.4

TABLE 5 (Cont.)

Altitude (Meters)	Flow (LPM)	Inlet Temp (°C)	Outlet Temp (°C)	Inlet Press (psig)	Outlet Press (psig)	O_2 Conc (%) $\bar{X}$	S_x
4572 (Max)	15	50.8	26.3	46.3	22.4	76.0	4.5
	25	51.2	26.2	46.4	22.8	64.2	2.7
	35	51.4	26.2	46.4	22.4	55.9	1.1
	70	51.6	27.0	46.2	22.0	39.7	0.7
6096 (Min)	15	51.2	24.9	33.7	23.1	92.1	3.0
	25	47.5	24.0	35.3	22.9	83.2	3.1
	35	47.6	23.5	35.0	22.7	72.3	3.7
	70	48.5	23.5	34.5	22.7	50.4	1.9
6096 (Max)	15	52.5	23.6	40.3	22.7	88.7	4.0
	25	53.3	22.8	40.4	22.6	78.0	3.1
	35	54.1	22.8	40.1	22.4	67.8	2.7
	70	54.7	23.1	40.1	21.9	50.1	2.6
7620 (Min/Max)	15	46.6	21.5	34.0	23.2	90.5	3.7
	25	44.8	20.7	33.9	23.0	88.7	1.7
	35	44.3	20.2	33.9	23.0	78.7	2.8
	70	44.1	20.1	31.9	22.9	56.0	1.3

suffered a lightning strike. The aircraft main electrical inverters malfunctioned and the motor in the Bendix On-Board Oxygen Generating System (OBOGS) unit would not operate in the laboratory after the flight. The unit is being repaired. No additional data for the Bendix unit is reported.

Other aircraft flight parameters which were recorded, but not included in this report were engine torque and ITT or exhaust gas temperature. There was no noticeable difference in the instrumentation readings nor could the pilots "feel" when the concentrators were being driven by bleed air.

DISCUSSION

Static testing of the molecular sieve concept of onboard oxygen concentration systems for the Army aircraft is a necessary first step to insure their physiological adequacy. Although each unit met or exceeded the requirements of MIL-R-83178, the results obtained in the JUH-1H helicopter differed from those obtained in the JU-21G fixed-wing aircraft. A comparison of these results shows that the Garrett unit performed similarly in both aircraft when the JU-21G was at maximum power. The Bendix unit, however, in some instances, produced a lower oxygen concentration in the JUH-1H than in the JU-21G. A comparison of these data with the data in Table 1 of Ernsting et al. (1980) reveals that operation of these units in flight produces oxygen concentrations slightly higher with the Garrett unit and slightly lower with the Bendix unit than the respective values obtained during tests in the hypobaric chamber.

The oxygen concentration process of the molecular sieve depends on many factors including flow, inlet temperature, inlet pressure, and the pressure differential across the molecular sieve bed. Additionally, although the cause has not been definitely determined, the resistance of the nitrogen exhaust purge hose seems to be a factor and attention should be directed to the design of an exhaust port to maximize oxygen concentration. The differences in oxygen concentration reported here and those reported by Ernsting are probably a result of differences in all of these factors. One notable difference in test procedures was our use of heated engine bleed air instead of unheated laboratory instrument air as used in Ernsting's hypobaric chamber tests. Both units have internal pressure regulators which limit the inlet pressure to between 25 and 28 psig. This effectively eliminates the effect of bleed air pressure changes that might result from differing engine power settings since even minimum engine power settings produce bleed air pressure in excess of 25 psig.

The use of engine bleed air to drive the oxygen concentrators produced no noticeable effect on aircraft performance.

During the upcoming toxicology phase of this project, in which tests will be conducted to determine whether or not any harmful substances from bleed air exhaust are passed through the molecular sieve, the noted variables will be studied more closely and an attempt will be made to optimize them for maximum oxygen production.

The results in Table 5 and Figures 12 and 13 confirm the hypothesis that some early readings were taken prior to system equilibrium. This means that the first set of data is slightly more conservative in stating oxygen output at low flows and at the lower altitudes.

The primary objective of the study was to assess the physiological adequacy of these molecular sieve oxygen concentration units in order to qualify hem for human use so that dynamic-human interface can be studied in flight. The results obtained indicate that both units generate enough oxygen to support two human subjects in a dynamic breathing study. There is a possibility that two aviators under high workload conditions (e.g. Night NOE with NVG) would require minute volumes greater than these systems can produce.

CONCLUSIONS

Oxygen production by each of the molecular sieve oxygen concentrators studied met or exceeded the requirements of MIL-R-83178 at all flows and altitudes. Both units have shown themselves capable of producing the oxygen required at normal minute volumes for a one- or two-man crew on the JUH-1H and JU-21G aircraft. However, in cases where no air mix is allowed and the aviators are under high stress, it would be possible for two aviators to attempt to over breathe the system. Prior to initial human interface studies, however, it will be necessary to complete product gas toxicology tests to insure that contaminants from aircraft engine bleed air are not passed through the concentrators in harmful amounts.

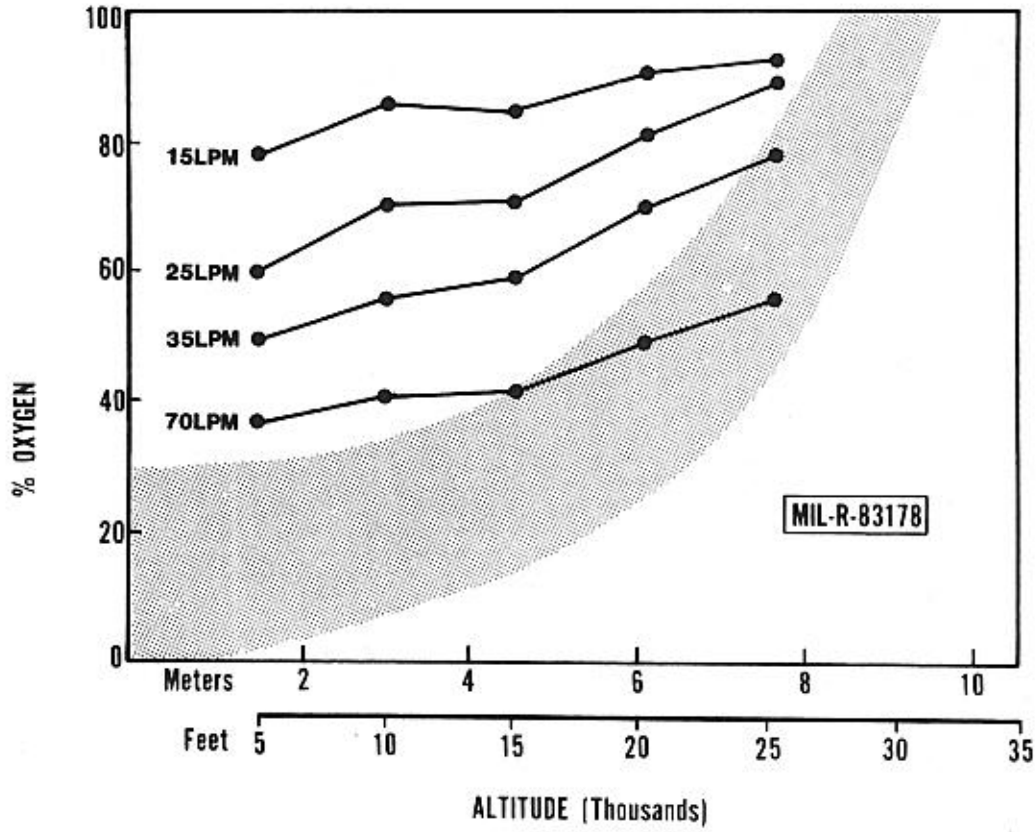

FIGURE 12. Garrett Minimum Power - JU-21G. (Supplemental Data)

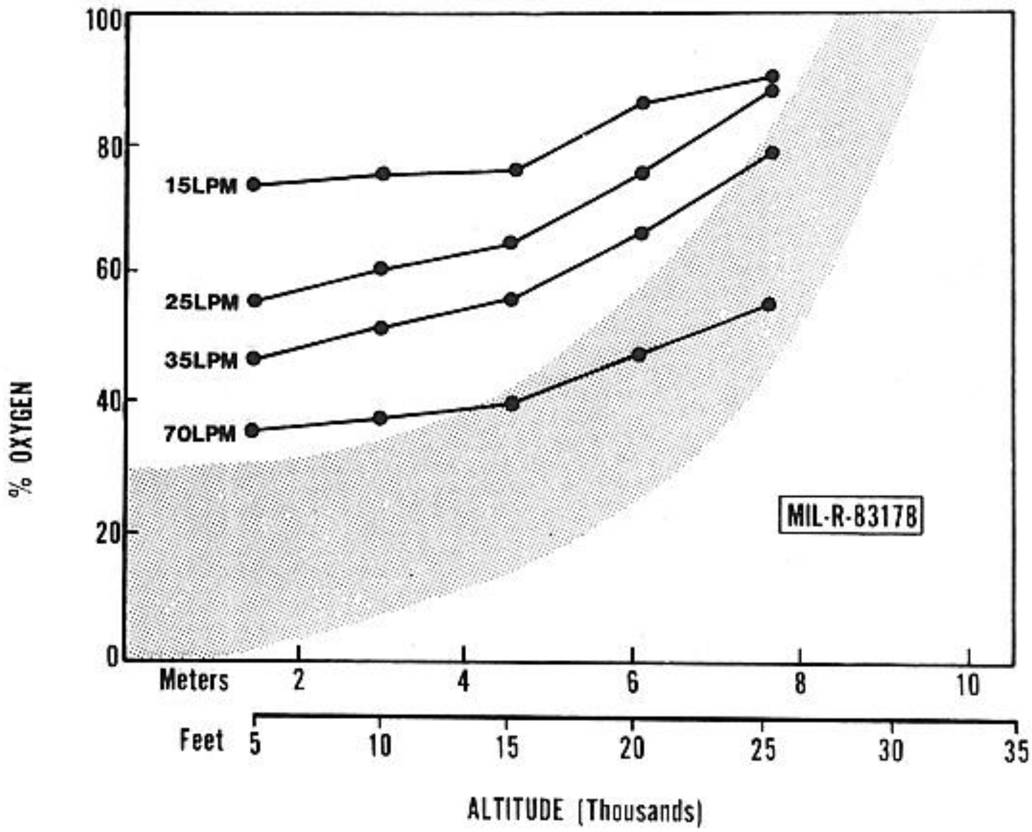

FIGURE 13. Garrett Maximum Power - JU-21G. (Supplemental Data)

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APPENDIX A

EQUIPMENT AND MANUFACTURER LIST

EQUIPMENT AND MANUFACTURER LIST

Molecular Sieve Oxygen Generator
Model 2202490-1-1
Serial #49-R1
AiResearch Mfg Co. of California
Garrett Corporation

Validyne Differential Pressure
Transducer
1914 Londelius Street
Northridge, California 91324

Technology Incorporated, Mass
Flow Meter
Dayton, Ohio 45431

Harris Pressure Gauge
Melbourne, Florida 32901

Wallace and Tiernan Barometer
Belleville, New Jersey 07109

Molecular Sieve Oxygen Concentrator
Model 99251-3261009-0105
Serial #90801 5E
*Bendix Instruments and Life Support
Division
Davenport, Iowa 52802

Beckman OM-14 Oxygen Analyzer
2500 Harbor Boulevard
Fullerton, California 92634

Cole-Palmer Digital Thermometer
Chicago, Illinois 60648

Fischer-Porter Rotameter
Warminister, Pennsylvania 18974

*Now known as Clifton Precision