POTASSIUM SUPEROXIDE ATMOSPHERE CONTROL UNIT

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FOREWORD

This program was initiated by the Biotechnology Division, Biomedical Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. The effort was conducted by the MSA Research Corporation, Callery, Pennsylvania, under Contract No. AF 33(615)-1518, in support of Project 6373, "Equipment for Life Support in Aerospace," Task 637302, "Respiratory Support Equipment." The effort sponsored by this contract started in March 1964 and was completed in December 1964. Mr. D. A. Keating of the Respiratory Equipment Branch, Aerospace Medical Research Laboratories, was the contract monitor.

This technical report has been reviewed and is approved.

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ABSTRACT

Superoxides have been used in a new approach to atmosphere control systems for aerospace flight. This approach offered the control of dynamic systems and the low power requirement of passive systems. This technique can be adapted to unusual geometries with low weight and volume requirements. Potassium superoxide discs comprise the bulk of this new unit serving as a structural self-support and yet offering adequate carbon dioxide absorption and oxygen evolution. The discs are 3.77 in. in diameter x 3/16 in. thick and have a 7/8 in. diameter center hole. They are placed in a cylindrical aluminum housing with a 0.080 in. clearance between the shell and discs. The discs are separated from each other by integrally molded 1/16 in. protrusions. A one-man version of the unit for 24 hour service weighs 12 pounds, requires 17 watts power continuously, is 32 in. long x 4 in. in diameter and contains 110 discs. The disc configuration permits both radial and axial circulation at a throughput of 9 cfm and 1.6 in. of water ΔP. Tests with a one-man simulator in a 130 cu ft compartment showed adequate oxygen delivery and control at less than 1% carbon dioxide.

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INTRODUCTION

Solid oxygen sources are attractive as high integrity units having nearly unlimited shelf storage life and simplicity of operation. Application to space flight would appear to be a natural extension of the wide use of breathing units using these materials for oxygen supply and carbon dioxide removal. However, this has not been the case, perhaps because of the wealth of experience that has been developed with gaseous and cryogenic supplies for general atmosphere maintenance.

An attractive possibility for chemical oxygen supply application is that for an emergency unit. It was on this basis that a study and design has been made for a prototype superoxide atmosphere control unit for one man for 24 hours.

Chemical oxygen supplies have historically been utilized as granules of various sizes packed into beds of varying geometries. The primary approaches had been forced circulation with flow directed through the granular bed to promote the reaction of water vapor to release oxygen and the consequent absorption of carbon dioxide by the hydroxide which had been formed. A penalty both in power and volume was exacted by the requirement for circulation through a packed bed. Another approach was to expose thin trays of granules to the atmosphere and permit atmosphere control by natural circulation around the beds. This technique has been termed as passive atmosphere control since no power is required. The aim in the current work was to investigate how the best features of the two approaches could be combined: the low (no) power requirement of the passive system and the more positive control afforded by the dynamic system.

It was obvious that some radical departures were necessary in terms of geometry and flow patterns throughout such a compromise device. Advances in the formulation of various forms of both potassium and sodium superoxides promised the possibility of reduction of water sensitivity and a break from traditional granular beds. This work then began with a study of passive atmosphere control and led into dynamic methods of control. Both granular and non-granular forms of the superoxides were used in this work at various densities and with various additives. The goal was to attempt to develop the maximum self-sustaining geometry of non-granular superoxide form, thereby minimizing weight of the containment structure.

The program was divided into two phases: a design phase and a fabrication phase. Six air regeneration units were supplied that represented a marked advancement in superoxide life support systems. Unit weight was 12 lb, power was 17 watts. Volume was reduced ~15% over the same unit designed with granules.

Section II

EXPERIMENTAL

The following guidelines were used to establish experimental and design criteria for the application of passive-dynamic concepts using potassium superoxide or sodium superoxide for atmosphere control of aerospace enclosures.

Type of System	Back up life support atmosphere control system for aerospace flight emergency use
Number of Occupants	One Man
Mission Time	24 hr
Oxygen Consumption	0.1 lb m/hr or 1.12 SCFH
Carbon Dioxide Production	0.11 lb m/hr or 0.896 SCFH
Water Production	0.1 lb m/hr
Respiratory Quotient (RQ)	0.8
Chamber Conditions	
Temperature	70-80°F
Relative Humidity	30-60%
Electrical Requirements	120-208 volts ac 400 cycle
Other	
Dusting	Minimum
Acceleration, vibration, weightlessness	System must operate under those experienced during manned space flights

Besides meeting these requirements, other factors influencing the development of an acceptable design were to establish and justify:

1) Minimum weight, volume, and power requirements.

2) The best method of supplying metabolic O_2 requirements and CO_2 removal.

3) Methods of eliminating dusting that will occur when superoxides experience the acceleration, vibration, and weightlessness of space associated with space flight.

4) Evaluation of denser forms of superoxides and advantages offered by KO_2 and NaO_2.

5) Compatibility of materials of construction with superoxides.

6) Optimization of chemical bed design and best approach to lessen pressure drop should forced air circulation be required to supply and remove respiratory gases.

Prototype atmosphere control units were tested in a sealed 130 cu ft space chamber with an associated MSAR Metabolog^R (man simulator). A schematic of the test equipment is shown in Figure 1. The simulator uses a fuel, (acetylene) that is catalytically combusted to produce an RQ of 0.8. (RQ = vol CO_2/vol O_2). The catalytic combustion of acetylene does not generate the total water production requirement and water was added as required. This simulator consumed O_2 at the specified constant rate of 1.12 SCFH and produced CO_2 at the constant rate of 0.896 SCFH. A cooler inside the space chamber controlled the humidity. Gases from the simulator, enriched with moisture by fuel consumption and water makeup, were cooled by brine circulation through the cooler tubes.

The conditions in the space chamber were monitored by instruments recording O_2, CO_2, and humidity. These were a Beckman O_2 meter, an MSA CO_2 Lira system, and a Serdex relative humidity meter. The O_2 and CO_2 instruments were calibrated and checked regularly during the testing program with known gases to assure accurate readings.

Electrical power leads to fans and thermocouples were introduced into the space chamber through hermetically sealed

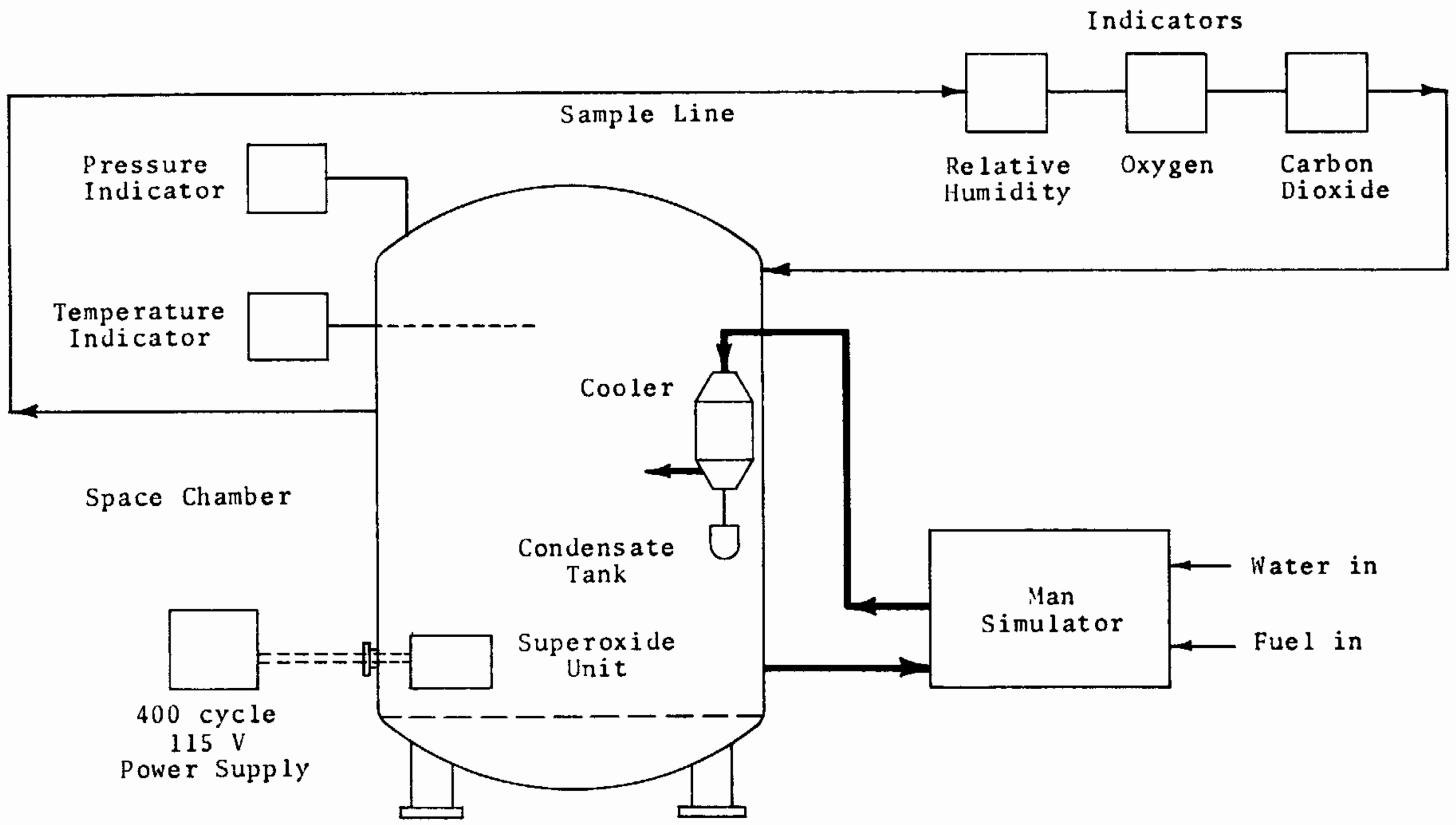


FIG. 1 - FLOW SCHEMATIC FOR PASSIVE SUPEROXIDE TESTS

plugs. A 100-watt, 115-volt, 400-cycle inverter was used to supply power for operation of fans. The space chamber was checked for leaks and was sealed tight by a screw-type door closure before beginning the tests. All tests were conducted at sea level and pressure changes in the chamber were sensed by a water manometer.

An investigation was made of factors that affect O_2 generation from superoxides employing passive techniques. Breadboard model atmosphere control units were equipped with fans to permit operation at passive-dynamic flow conditions as well as passive flow conditions (no forced circulation). The superoxides (KO_2 and NaO_2) were tested in both solid granular and solid non-granular forms. The experimental approach was to perform tests with various configurations using little or no power, and to establish the limitations and advantages of each design.

Dusting and compatibility of materials of construction with superoxides were evaluated. Containment of dust and practical ways of reducing dusting by methods which did not affect performance were considered. Aluminum offers substantial weight savings over materials such as stainless steel, copper, and titanium; however, aluminum is corroded by caustic generated by the superoxides. Therefore, protective methods applicable to aluminum were investigated.

Section III

DESIGN PHASE

The design phase yielded design criteria and approaches by testing various breadboard models. Complementary testing with regard to dusting and materials compatibility was also performed.

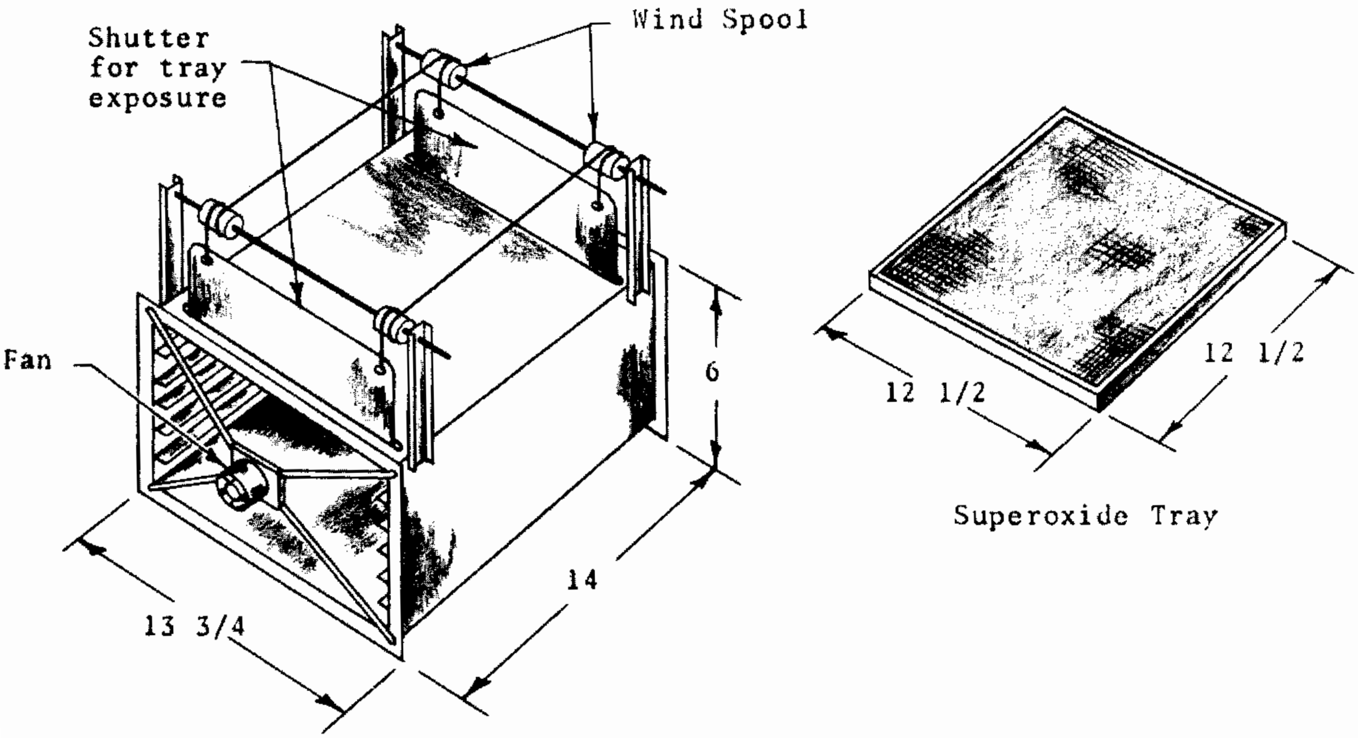
Tests were conducted with five breadboard models. Provisions for activating a fan were provided in each model to assist O_2 generation and CO_2 absorption when conditions within the test environment dropped below tolerable levels. Models 1, 2, and 3 were models for passive control of the atmosphere. Tests with models 4 and 5 were performed with passive-dynamic techniques when it was indicated that atmosphere control could be achieved better by continuous air circulation.

Breadboard Models

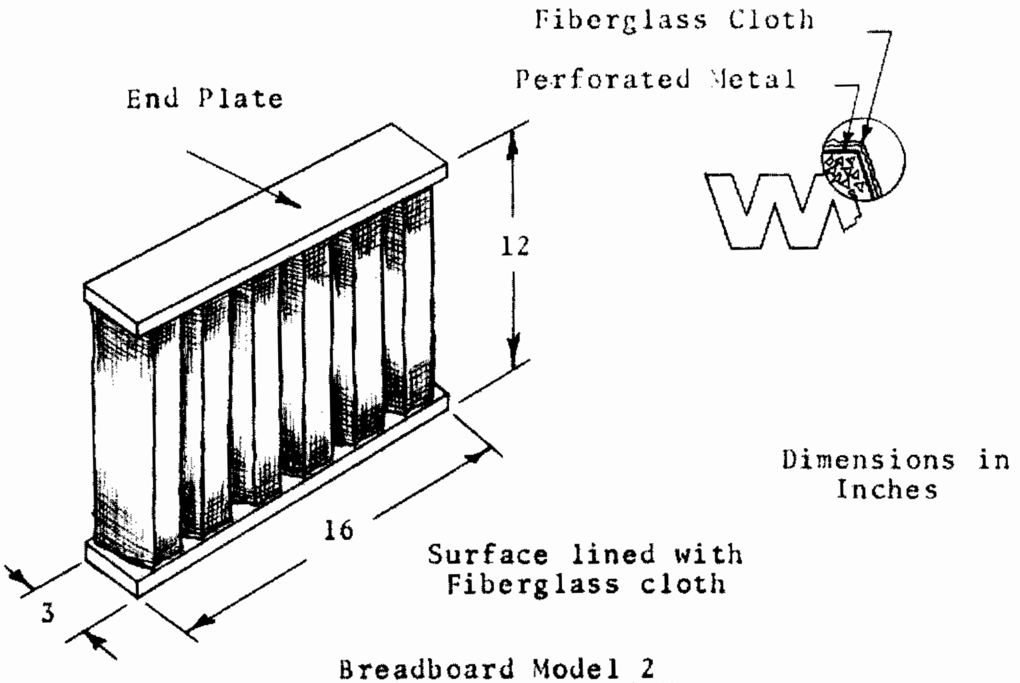
Model 1 (see Figure 2) was a five tray configuration within a housing open on two ends. A fan was attached to one end. Each end had an adjustable shutter which can be raised remotely to expose fresh trays. The trays were approximately 12-1/2 in. x 12-1/2 in. x 1/2 in. thick and the five trays provided a volume of 390 cu in. for superoxide. About 1-3/4 lb m could be packaged in this design. Spacing between trays was approximately 1/2 in. and the overall volume of the model was 1150 cu in. Each tray had a surface of 288 sq in. (144 sq in. each side) and surface area for five trays was 1440 sq in. Copper channel sides, 1/2 in. x 1/4 in., were covered with No. 12-mesh copper screen to form the trays.

Model 2 (see Figure 2) was a continuous bed made from perforated metal with 1/16 in. diameter holes in a zig-zag pattern. The area of this pattern was 1500 sq in. This model exhibited a free area less than that represented by the screen trays arrangement of Model 1. The free area was also occluded by a fiberglass cloth covering which acted as a barrier to contain dust.

The initial breadboard models shown in Figure 2 were sized by calculating the quantity of chemical necessary to sustain metabolic requirements of one man for 24 hr. Thus, the amount of KO_2 to supply 0.1 lb m/hr O_2 for 24 hr was estimated to be 8 lb m, assuming a 90% utilization of KO_2. The volume required for 8 lb m of granular KO_2 is about 350 cu in. Passive experiments conducted in previous projects were used to make an estimate of exposure surface. A surface area of 1350 sq in. was estimated



Breadboard Model 1



Breadboard Model 2

FIG. 2 - BREADBOARD MODEL OF THE SUPEROXIDE ATMOSPHERE CONTROL UNITS

to produce an O_2 flux of 0.12 cu ft O_2/hr sq ft at an average chamber specific humidity of 0.008 lb H_2O/lb air.

Breadboard Model 3 is shown in Figure 3. This was simply a rearrangement of trays used in Model 1 in that the trays were not housed in a shell and that diffusion of air to the trays was possible in three planes compared to only one plane as in Model 1. This model made it possible to space the trays farther apart to improve performance characteristics.

Breadboard Model 1, 2, and 3 were intended to demonstrate design effects on passive operation to sustain the O_2 supply and maintain the CO_2 concentration at suitable levels. Breadboard Model 3 achieved better CO_2 control than did Breadboard Model 1, but CO_2 concentrations approached undesirable levels. The fan was used to investigate the transition effects from passive to dynamic air circulation.

Nongranular forms of superoxides performed nearly as well in Model 1 as did granular forms. Methods of increasing surface areas of nongranular forms were sought, hence corrugated and non-corrugated rectangular configurations were tested. Model 4, shown in Figure 4, was a preliminary model of passive-dynamic design wherein solid corrugated configurations were packaged to give additional surfaces and at the same time provide passage ways for air flow. Two types of rectangular configurations were examined in this model.

Model 5 (see Figure 5) was a cylindrical model for passive-dynamic operation with discs with a central hole for air flow. To expose surfaces between adjacent discs, screens were introduced. Screens were also used between the discs and the housing. Models 4 and 5 were designed for 8 hr tests to develop design criteria for a 24-hr model.

Passive Runs

Runs 1 through 17 were primarily of the passive type and were conducted with intermittent fan operation in an effort to lower CO_2 concentration or increase O_2 supply. The results of these runs are listed in Table I. All runs were conducted at 1 atm.

Run 1 investigated passive O_2 and CO_2 control with Breadboard Model 1 with 4-8 mesh NaO_2 granules. Sealed chamber conditions for this run are given in Figure 6. Oxygen generation was effectively maintained, but CO_2 concentration was above 1% after 2 hours of operation. Run 2 was conducted with 4-6 mesh KO_2 granules in Model 2. This model was ineffective as a passive

TABLE I - PASSIVE RUNS WITH BREADBOARD MODELS

Subject simulation conditions for one man:
O_2 consumption - 0.1 lb m/hr - 1.12 cu ft/hr
CO_2 production - 0.11 lb m/hr - 0.897 cu ft/hr
RQ - 0.80
H_2O production - 0.1 lb m/hr

Volume of sealed chamber: 130 cu ft
Pressure in sealed chamber: 1 atmosphere

Run no.		1	2*	3	4	5*
Run time (hr)		24	13.6	24	24	24
Chemical						
Type		NaO_2	KO_2	KO_2	KO_2	NaO_2
Weight (gm)		3970.0	4160.0	4075.0	4005.0	4400.0
Mesh or shape		4-8	4-6	4-6	4-8	4-8
O_2 efficiency %		83.0	44.0	77.0	77.0	75.0
O_2 liberated	SCF	32.8	18.4	24.8	25.5	33.5
	(lb)	2.92	1.64	2.21	2.27	2.98
CO_2 absorbed	SCF	18.80	15.4	18.4	18.5	18.3
	(lb)	2.30	1.19	2.25	2.27	2.24
RQ		0.57	0.67	0.74	0.76	0.55
H_2O absorbed (gm)/chemical (gm)		0.129	0.061	0.113	0.069	0.116
Exposed apparent surface		1440.0	1500.0	1440.0	1440.0	1500.0
System						
Final O_2 conc. (%)		20.0	20.3	18.6	18.7	23.9
Final CO_2 conc. (%)		1.86	1.44	1.62	1.17	1.89
Initial H_2O conc. (%)		1.16	1.06	1.06	1.79	0.98
Final H_2O conc. (%)		1.27	1.70	1.19	0.98	1.72
System RQ		0.64	0.78	0.78	0.77	0.58

* Runs with Breadboard Model 2

TABLE I - PASSIVE RUNS WITH BREADBOARD MODELS (Cont.)

Run no.		6	7	8	9	10
Run time (hr)		24	24	18	24	24 1/4
Chemical						
Type		NaO_2	Cat. KO_2	Sint. KO_2	NaO_2/LiOH	KO_2
Weight (gm)		3831.0	3453.0	5025.0	3632/363	3894.0
Mesh or shape		Plates**	4-8	4-8	4-8	Plates**
O_2 efficiency	%	77.0	87.0	59.0	80.2	68.2
O_2 liberated	SCF	30.7	23.3	24.0	29.9	21.6
	(lb)	2.73	2.07	2.14	2.66	1.92
CO_2 absorbed	SCF	19.7	17.4	15.3	19.5	17.3
	(lb)	2.41	2.13	1.88	2.32	2.12
RQ		0.64	0.76	0.44	0.65	0.80
H_2O absorbed (gm)/chemical (gm)		0.048	0.148	0.094	0.071	0.092
Exposed apparent surface		1500.0	1500.0	1500.0	1440.0	1440.0
System						
Final O_2 conc. (%)		20.1	20.1	18.4	19.6	17.1
Final CO_2 conc. (%)		2.82	2.22	4.08	1.62	3.21
Initial H_2O conc. (%)		1.67	1.40	1.72	1.37	1.15
Final H_2O conc. (%)		1.13	1.06	0.91	0.98	0.95
System RQ		0.74	0.74	0.64	--	--

** Flat, rectangular plates

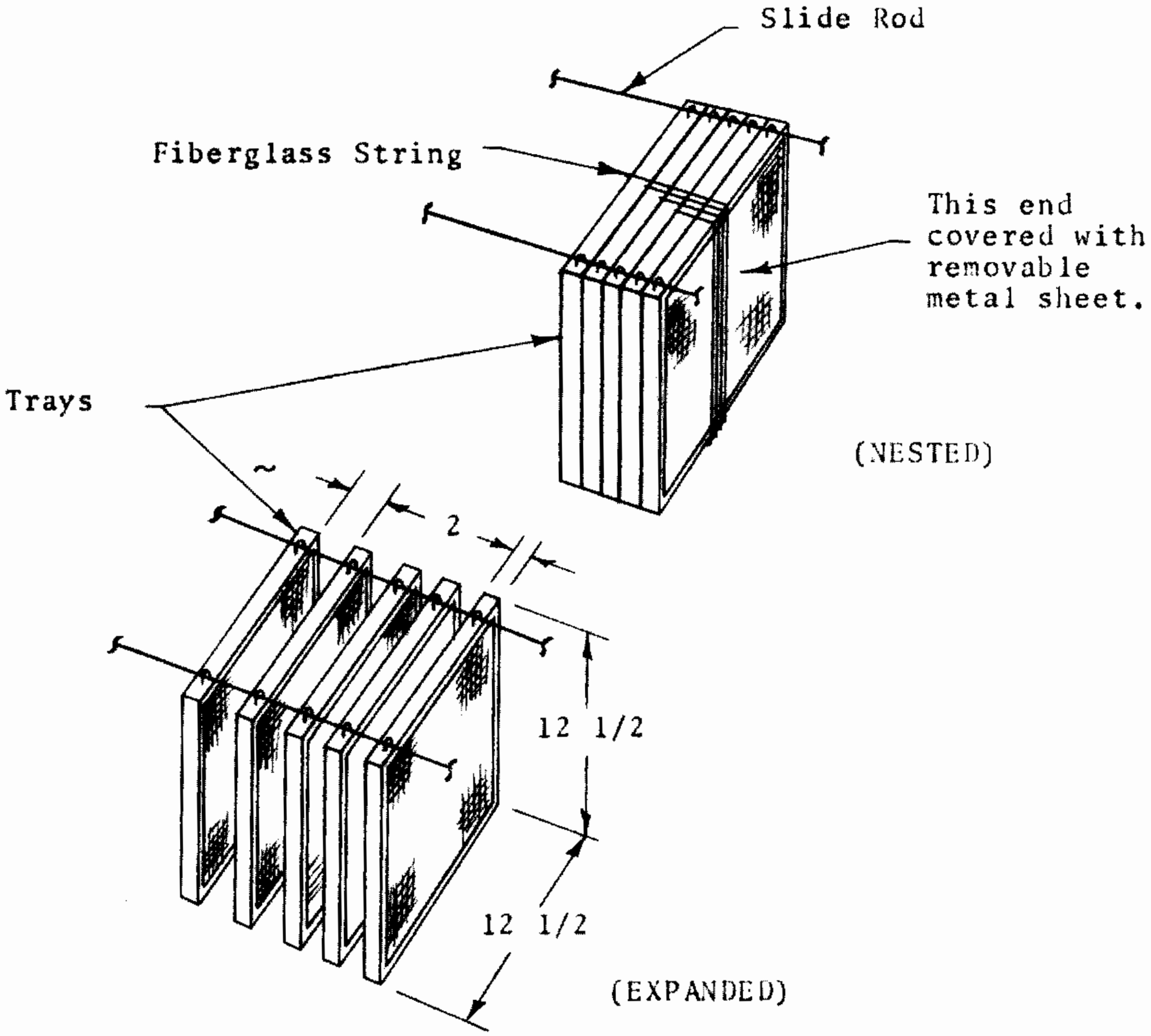
TABLE I - PASSIVE RUNS WITH BREADBOARD MODELS (Cont.)

Run no.	11***	12***	13***	14***
Run time (hr)	26 1/4	28 1/2	27	27 1/2
Chemical				
Type	KO_2	KO_2	KO_2	NaO_2
Weight (gm)	4064.0	4184.0	4199.0	4050.6
Mesh or shape	4-6	4-8	4-8 in Canister #3	4-8 Open tray
O_2 efficiency (%)	90.7	89.3	90.5	85.0
O_2 liberated (SCF)	29.2	29.6	30.1	34.0
(lb)	2.60	2.64	2.68	3.03
CO_2 absorbed (SCF)	22.9	24.6	25.0	23.65
(lb)	2.81	3.01	3.06	2.88
RQ	0.79	0.83	0.792	0.715
H_2O absorbed (gm)/chemical (gm)	0.113	0.038	0.0131	--
Exposed apparent surface	1440.0	1296.0	1440.0	1440.0
System				
Final O_2 conc. (%)	19.8	17.3	17.5	19.9
Final CO_2 conc. (%)	1.89	1.83	1.56	1.50
Initial H_2O conc. (%)	1.63	1.52	1.67	1.52
Final H_2O conc. (%)	0.98	0.95	1.37	1.03

*** Breadboard Model 3

TABLE I - PASSIVE RUNS WITH BREADBOARD MODEL 3 (Cont.)

Run no.	15	16	17
Run time (hr)	30	28	8
Chemical			
Type	NaO_2	NaO_2	NaO_2
Weight (gm)	4062.8	4014.6	1534.7
Mesh or shape	4-8 Covered with fiber	4-8	4-6 & 4-8
O_2 efficiency (%)	90.0	87.5	58.0
O_2 liberated (SCF)	36.2	29.8	7.88
(lb)	3.32	2.66	0.701
CO_2 absorbed (SCF)	25.2	21.1	3.75
(lb)	3.08	2.58	0.46
RQ	0.75	0.752	0.75
H_2O absorbed (gm)/chemical (gm)	0.0246	0.1005	0.092
Exposed apparent surface	1440.0	1440.0	1440.0
System			
Final O_2 conc. (%)	21.3	19.8	20.1
Final CO_2 conc. (%)	1.50	1.50	1.89
Initial H_2O conc. (%)	1.52	1.42	0.8
Final H_2O conc. (%)	1.21	1.27	1.56

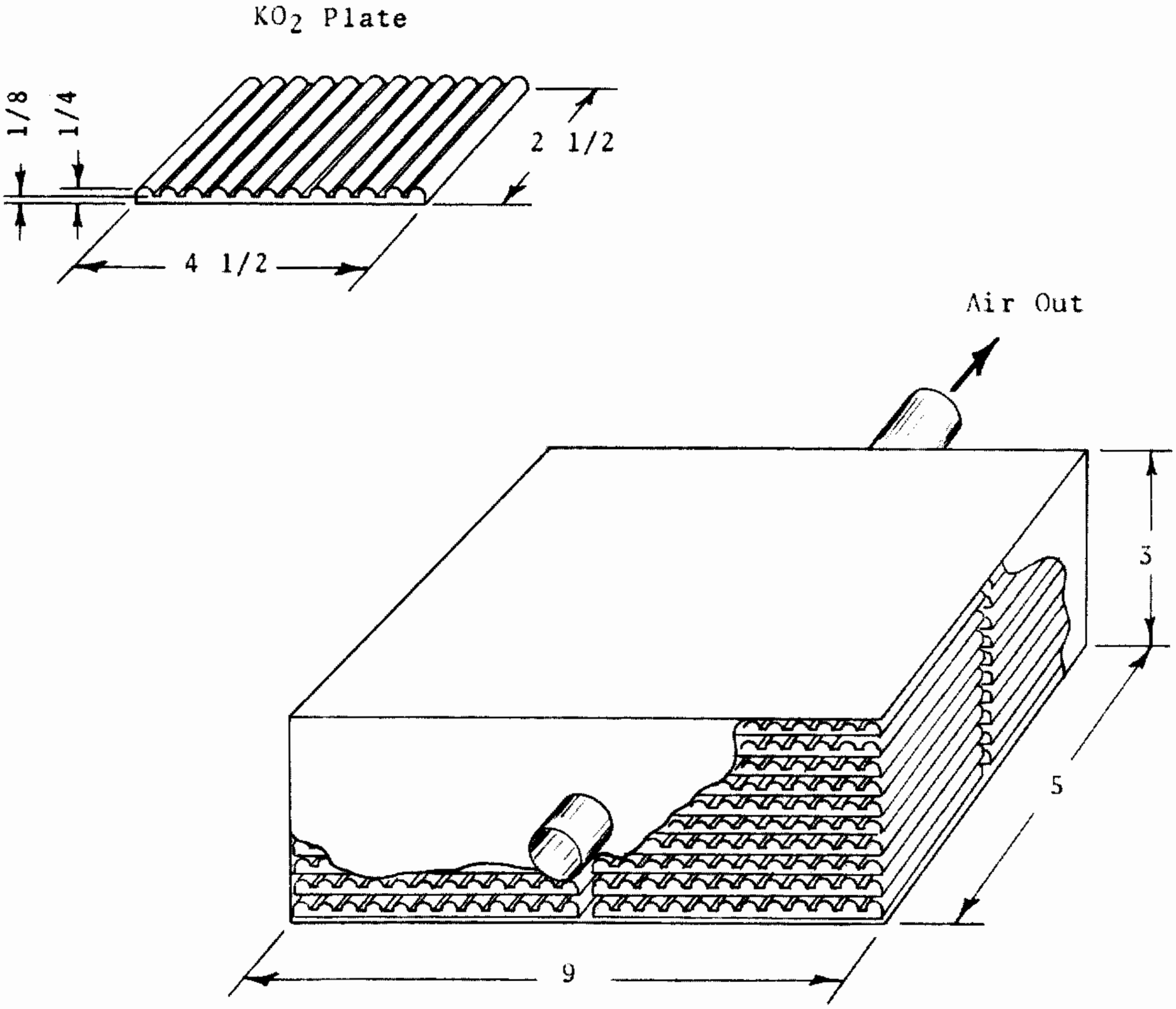


Dimensions in Inches

FIG. 3 - BREADBOARD MODEL 3 OF THE SUPEROXIDE ATMOSPHERE CONTROL UNIT

KO_2 Plate

Surface Area/Each Plate - 29.8 sq in.
Weight Each Plate - 0.077 lb
Density - 62 lb m/cu ft



Dimensions in Inches

FIG. 4 - FLAT, CORRUGATED KO_2 PLATES
BREADBOARD MODEL 4

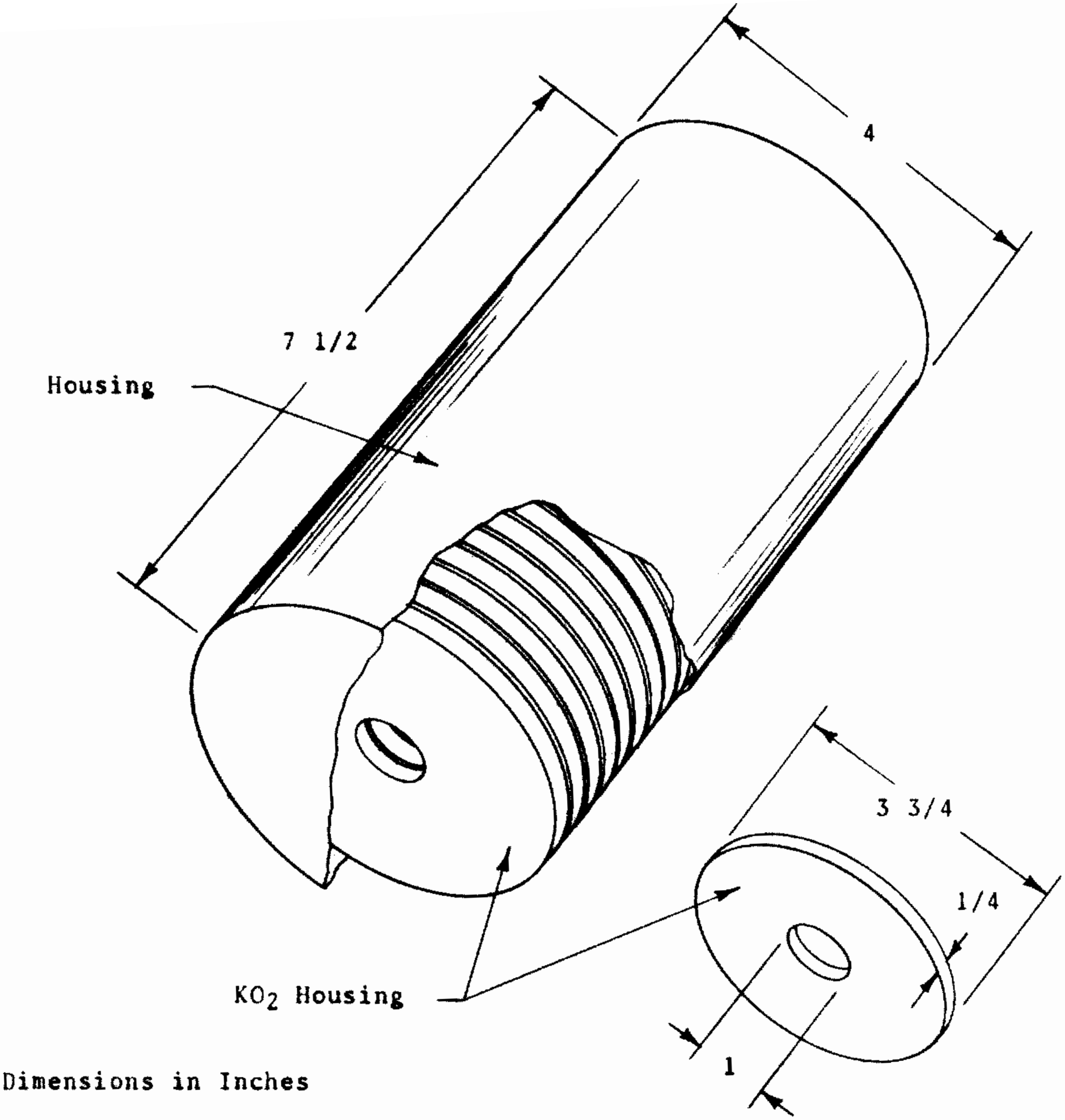
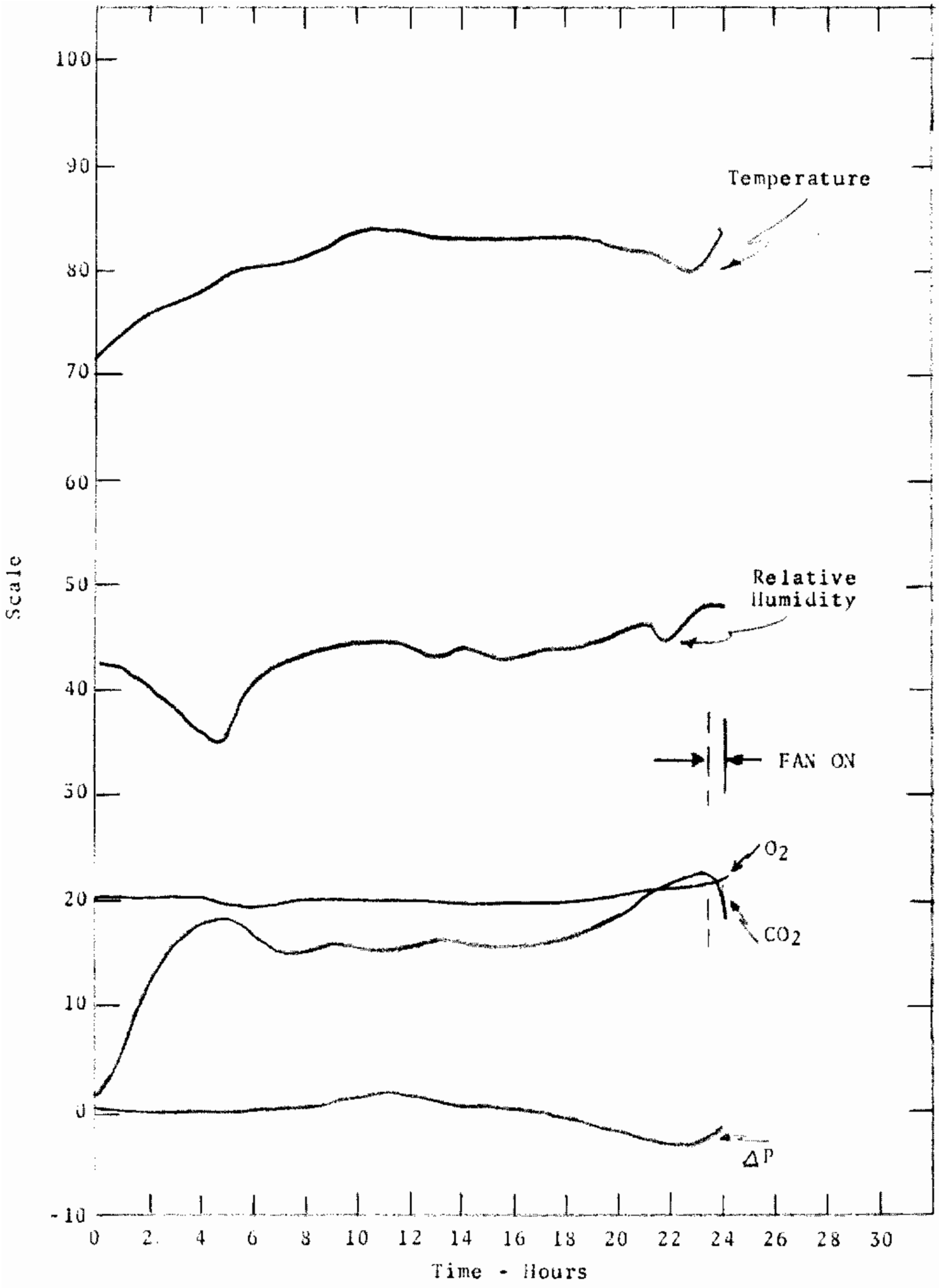


FIG. 5 - SUPEROXIDE DISCS



Scale

Temp. - °F of Sealed Environment
O_2 - % by Volume
CO_2 - % by Volume x 10^{-1}
ΔP - in. of Water (Chamber - Ambient)
Relative Humidity - %

Pressure at 1 Atmosphere
Specific Humidity at 0.008 lb water/lb air

FIG. 6 - PASSIVE RUN NO. 1 WITH BREADBOARD MODEL 1 AND 4-8 MESH NaO_2

design, and the run was terminated after 13-1/2 hr. Run 5 was conducted with Model 2 using NaO_2 granules, which did not substantially improve performance. Runs with Model 2 were abandoned and the investigation continued with Model 1. Run 3 was made with 4-6 mesh KO_2 granules, run 4 with 4-8 mesh KO_2 granules, run 7 with 4-8 mesh catalyzed KO_2 granules, and run 8 with sintered 4-8 mesh KO_2 granules. Chamber conditions that existed in run 4 are shown in Figure 7. No particular advantage was offered by varying mesh size, catalyzing, or sintering the granules.

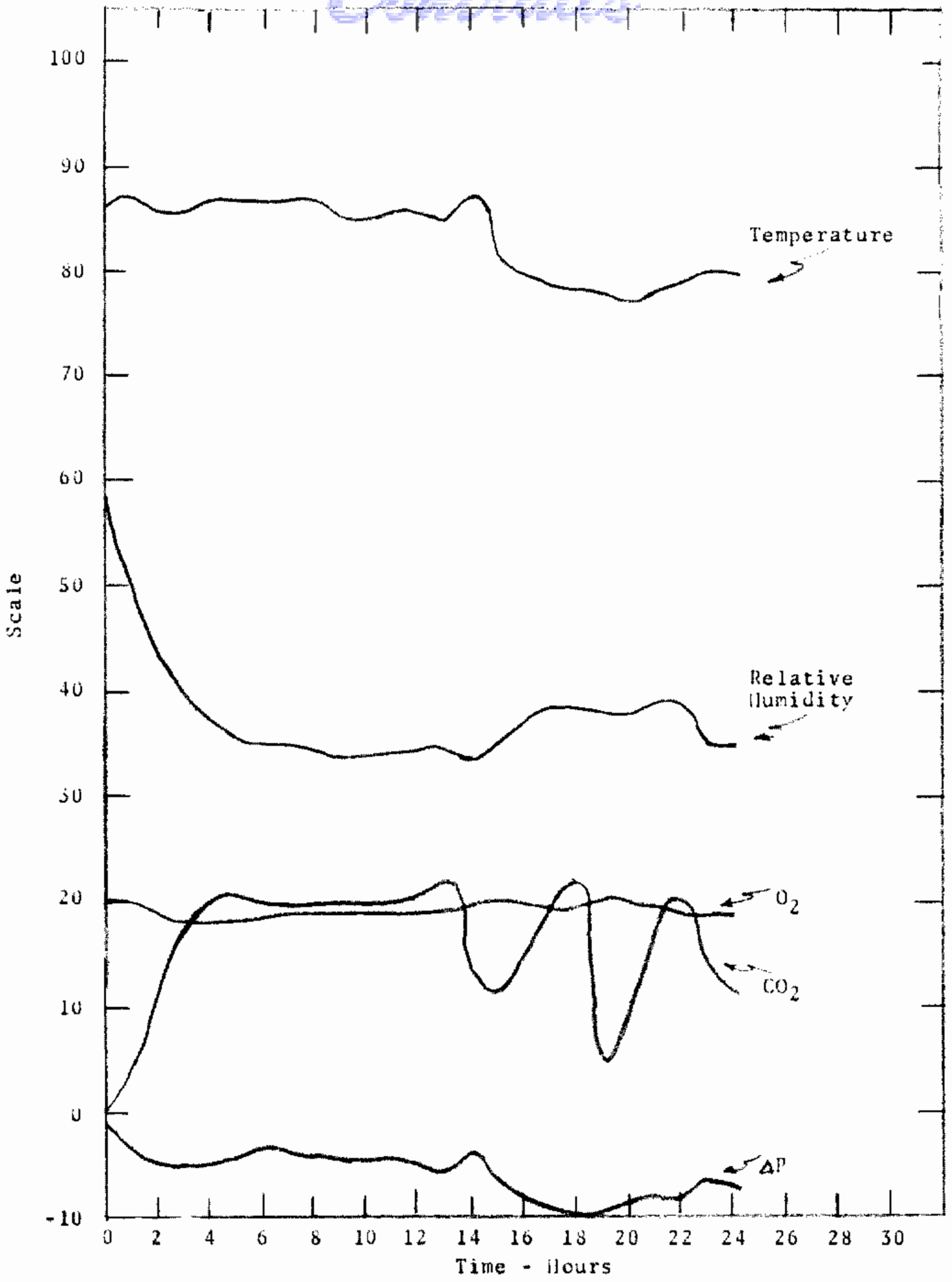
Runs 6 and 10 were conducted with NaO_2 and KO_2 cakes, respectively. These runs were of particular interest since reactions of the flat, rectangular plates were good, as observed by analyzing the penetration or reaction zones of the plates. Analyses of this spent superoxide revealed that a low residual of O_2 and a sizeable absorption of CO_2. Conditions existing in the sealed chamber during runs with the nongranular forms are shown in Figure 8 and 9. In both runs, the fan was activated to increase O_2 generation and CO_2 absorption. Fan operation had a noticeable effect.

Run 9 had LiOH mixed with the NaO_2 present in the ratio of one to ten. The LiOH was added as an auxiliary CO_2 absorber, however, the run disclosed that CO_2 absorbtion was not enhanced and no advantage was gained.

Runs 11 through 17 were performed with Model 3. These runs showed that better CO_2 control could be achieved by a wider spacing of trays. The runs also showed that exposure of the trays to air flow from three available planes rather than one plane, as was the case in Model 1, contributed to better CO_2 control.

Oxygen yield and CO_2 concentration were improved in run 11 in comparison to run 3 which also used 4-6 mesh KO_2 granules. At corresponding time intervals, CO_2 concentration was lower with Model 3 than with Model 1. See Figure 10 and 11 for chamber conditions during runs 11 and 12. The fan was employed in run 11 to determine the effects of air flow. These runs with Model 3 pointed out that a better mode of passive operation is to expose trays in all 3 available planes.

In summarizing the results of passive runs (runs 1-17), CO_2 concentrations below 1% at 1 atm. were not attained without increasing surface area or continuous operation of a fan. In the former case, additional surface exposure would add to the weight of the air regeneration unit and evidently be accompanied by an unfavorable overproduction of oxygen. Results of dusting test,



Scale

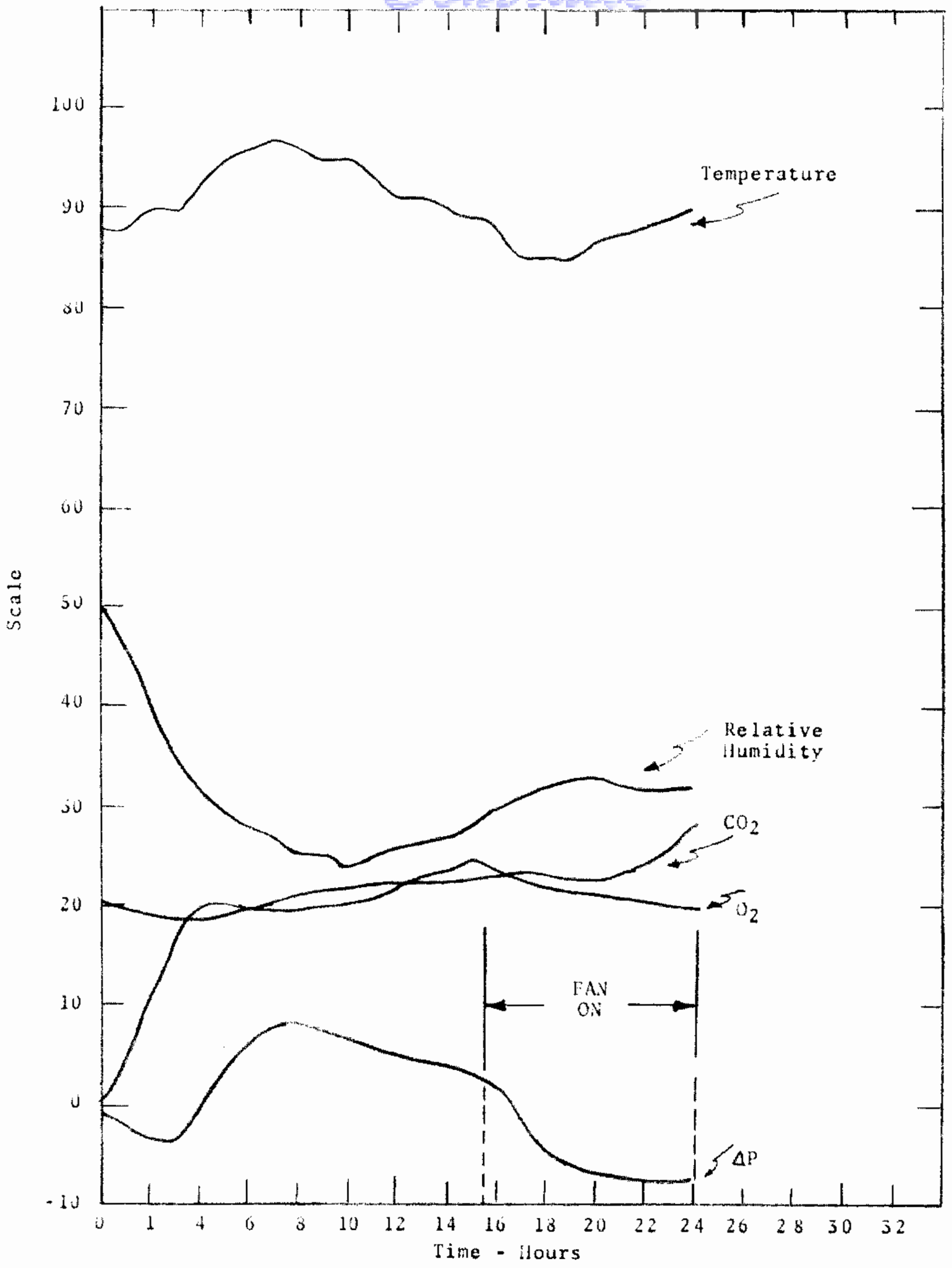
Temp. - °F of Sealed Environment
O_2 - % by Volume
CO_2 - % by Volume x 10^{-1}
ΔP - in. of Water (Chamber - Ambient)
Relative Humidity - %

Pressure at 1 Atmosphere
Specific Humidity at 0.008 lb water/lb air

Fan On

13.5 hr to 14.5 hr
18.0 hr to 19.0 hr
29.5 hr to 23.5 hr

FIG. 7 - PASSIVE RUN NO. 4 WITH BREADBOARD MODEL I AND 4-8 MESH KO_2

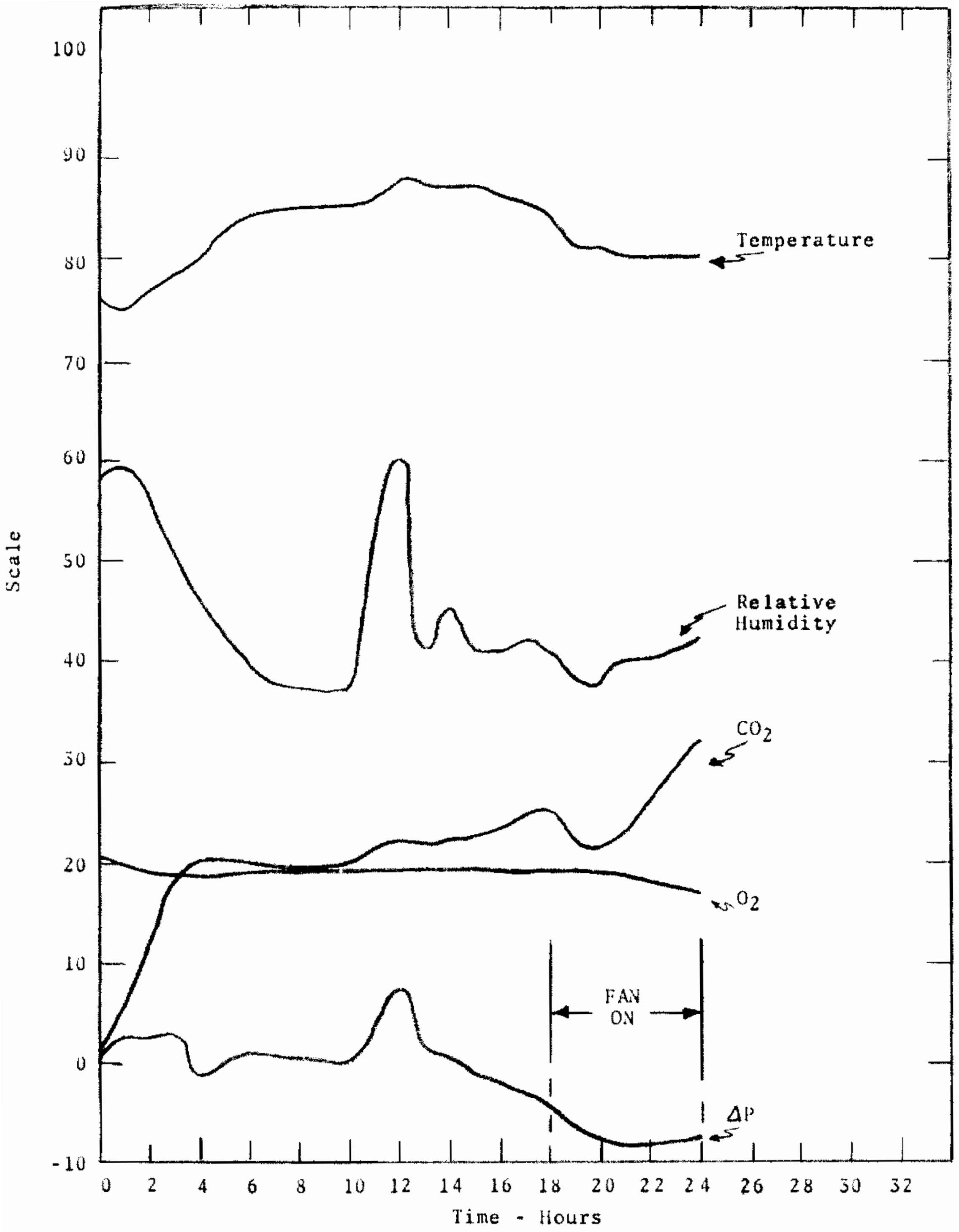


Scale

Temp.-°F of Sealed Chamber
O_2 - % by Volume
CO_2 % by Volume x 10^{-1}
ΔP - in. of Water (Chamber-Ambient)
Relative Humidity - %

Pressure 1 Atmosphere

FIG. 8 - PASSIVE RUN NO. 6 WITH BREADBOARD MODEL 1 AND NaO_2 FLAT, RECTANGULAR PLATES

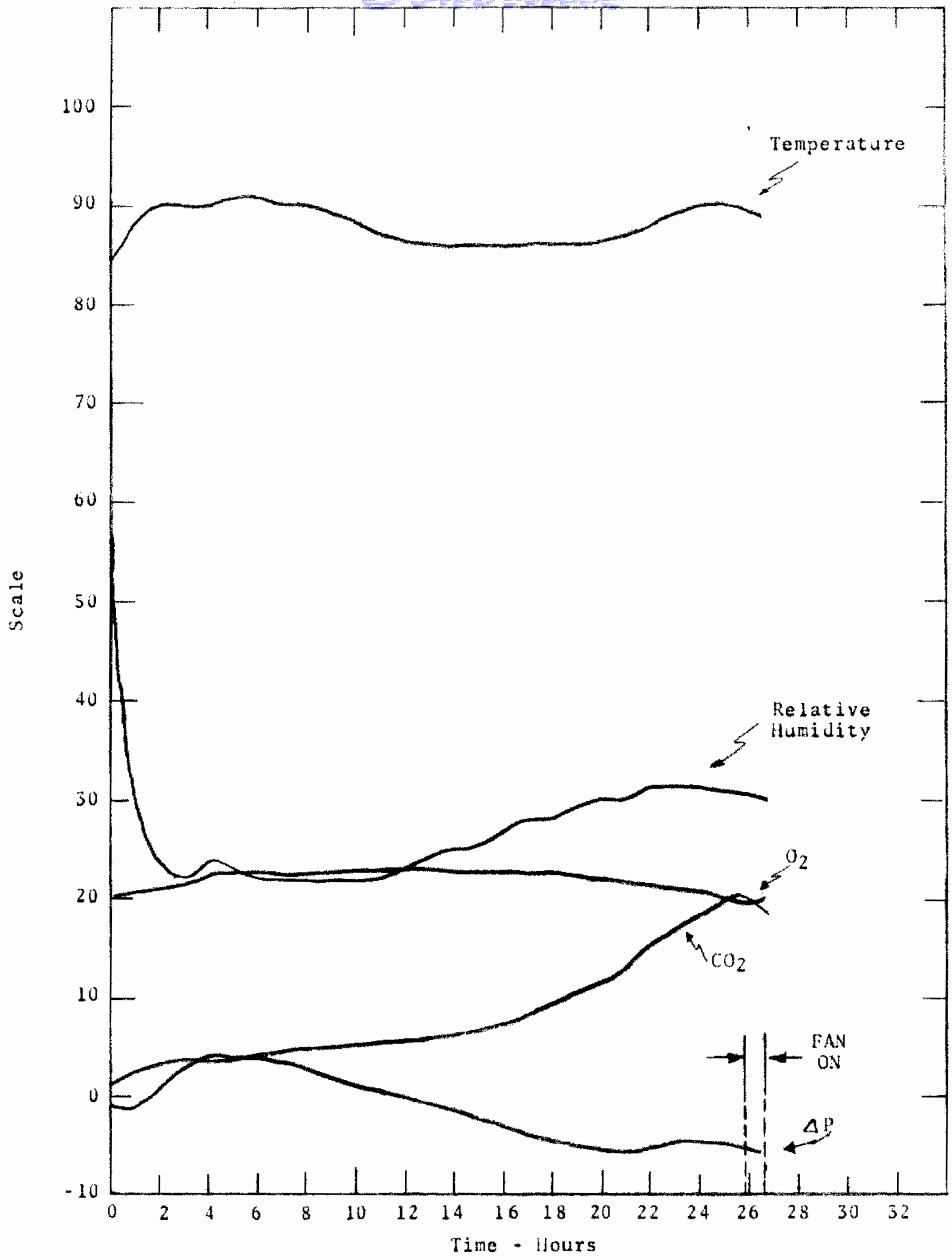


Scale

Temp. - °F of Sealed Environment
O_2 - % by Volume
CO_2 - % by Volume x 10^{-1}
ΔP - in. of Water (Chamber - Ambient)
Relative Humidity - %

Pressure 1 Atmosphere

FIG. 9 - PASSIVE RUN NO. 10 WITH BREADBOARD MODEL 1 AND KO_2 FLAT, RECTANGULAR PLATES

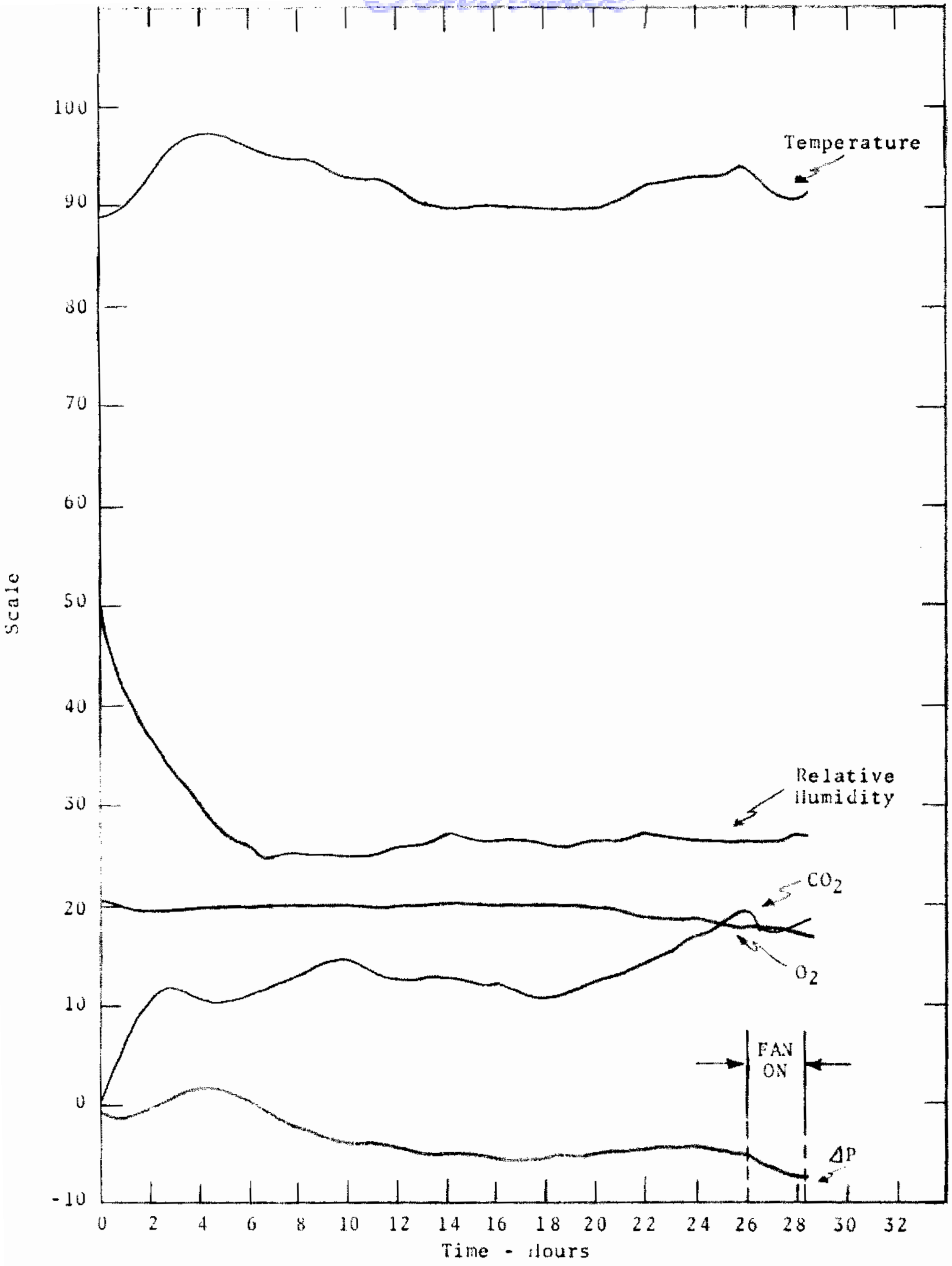


Scale

Temp. - °F of Sealed Chamber
O_2 - % by Volume
CO_2 - % by Volume x 10^{-1}
ΔP - in. of Water (Chamber-Ambient)
Relative Humidity - %

Pressure 1 Atmosphere

FIG. 10 - PASSIVE RUN NO. 11 WITH BREADBOARD MODEL 3 AND 4-6 MESH KO_2 GRANULES



Scale

Temp. - °F of Sealed Environment
O_2 - % by Volume
CO_2 - % by Volume x 10^{-1}
ΔP - in. of Water (Chamber - Ambient)
Relative Humidity - %

Pressure at 1 Atmosphere

FIG. 11 - PASSIVE RUN NO. 12 WITH BREADBOARD MODEL 3 AND 4-8 MESH KO_2 GRANULES

discussed below, and the obvious need to provide air movement to maintain a suitable CO_2 concentration suggested that a system designed around solid KO_2 discs would best reduce weight and volume, however, at the expense of expending power. All succeeding tests were consequently aimed at combining solid superoxide configurations with continuous fan operation but with models having low pressure drop characteristics to conserve power.

Dusting Tests

Superoxide granules can release dust which is irritating to the mucous membranes and skin. Concurrently with passive testing, an investigation was made to determine the dusting properties of various forms of the superoxides. Granules were packaged in screens of various mesh sizes and enclosed in plastic bags. These specimens were vibrated for one-half hour periods in a Rototap machine at 150 vibrations per minute. The dust collecting in the plastic bags was dissolved in water and titrated.

Results are given in Table II, with quantity of dust generated as shown. Dusting is seen to continue with each vibration period. Sodium superoxide granules dust more than potassium superoxide. Pressed discs produce less dust than granules of either high or low density.

No further work was performed with granules since pressed discs were to be used in the final units. Compounding with other materials or conditioning the surface by partial reaction may reduce dusting. The tests made were not intended to duplicate flight conditions, but were consistent for comparison purposes.

Passive-Dynamic Runs

Runs conducted with the fan operating continuously were designated as passive-dynamic runs. Runs 18-22 were conducted with Breadboard Models 4 and 5 which were sized for 8 hr operation (Table III). Performance of these units in regard to average O_2 generation and CO_2 absorption was correlated with surface area of the chemical (Figure 12). The rates of O_2 generation and CO_2 absorption were lower than the specified 1.12 SCFH O_2 and 0.896 SCFH CO_2 in runs 18-22. Extrapolation of the average O_2 generation rate and CO_2 absorption rates (Figure 12) to intersect the specified rates can be used to determine the surface required for 1.12 SCFH O_2 and 0.896 SCFH CO_2. Approximately 1250 sq in. was indicated, requiring 50 discs, which represented about

TABLE II - DUSTING TESTS WITH SUPEROXIDES

Weight of Each Sample - Approx. 75 gm

Superoxide and Forms	Vibration Period*	Superoxide Dust (gm)			
			Container Materials		
		#8 Mesh SS Screens	#12 Mesh Copper Screens	#12 Mesh Steel Screens	Fiberglass Cloth
KO_2: 2-4 Mesh	(1)	0.095	0.043	0.355	0.010
	(2)	0.095	0.132		0.083
	(3)	0.129	0.144		
KO_2: 4-6 Mesh	(1)	0.105	0.046	0.172	0.009
	(2)	0.063	0.072		0.091
	(3)	0.501	0.927		
KO_2: 4-8 Mesh	(1)		0.647	0.344	0.063
	(2)			1.965	
	(3)				
KO_2: 4-8 Mesh (high density)	(1)		0.143	0.100	0.0955
	(2)				
	(3)				
KO_2: Disc	(1)		0.0815	0.020	0
	(2)				
	(3)				
NaO_2: 4-8 Mesh	(1)	0.313	1.310	0.219	0.018
	(2)				
NaO_2: Disc	(1)		0.215	0.154	
	(2)				

* Vibration Period: (1) First half hour in Rototap.
(2) Second half hour in Rototap.
(3) Third half hour in Rototap.

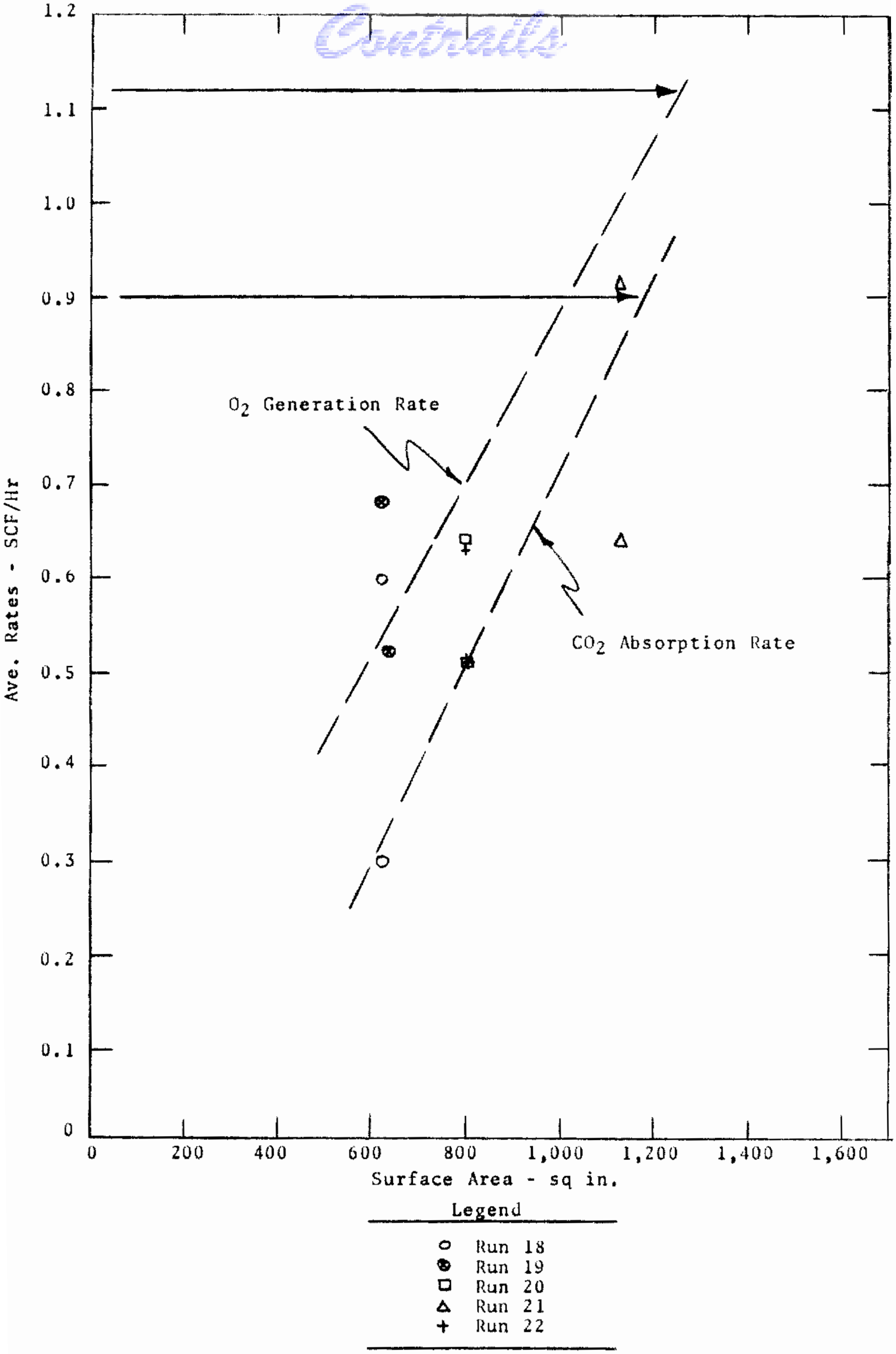
TABLE III - PASSIVE-DYNAMIC RUNS WITH BREADBOARD MODELS

Subject simulation conditions for one man:	O_2 consumption - 0.1 lb m/hr - 1.12 cu ft/hr CO_2 production - 0.11 lb m/hr - 0.897 cu ft/hr RQ - 0.80 H_2O production - 0.1 lb m/hr
Volume of sealed chamber:	130 cu ft
Pressure in sealed chamber:	1 atmosphere

Run no.	18①	19①	20	21	22
Run time (hr)	4	8	8	8	8
Chemical					
Type	KO_2	KO_2	KO_2	KO_2	KO_2
Weight (gms)	1176.0	1167.0	960.0	1300.0	955.0
Mesh or shape	Discs	Discs	Plates②	Plates②	Plates②
O_2 efficiency (%)	18.8	52.0	73.4	76.5	--
O_2 liberated SCF	1.75	4.46	5.59	7.88	--
(lb)	0.16	0.40	0.498	0.702	--
CO_2 Absorbed SCF	1.32	5.68	3.41	6.35	--
(lb)	0.16	0.70	0.412	0.777	--
RQ	0.76	0.79	0.61	0.672	--
H_2O absorbed (gm)/chemical (gm)	0	-	-	0.099	0.191
Exposed apparent surface	620.0	620.0	795.0	1130.0	795.0
System					
Final O_2 Conc. (%)	18.8	17.6	17.5	18.9	17.4
Final CO_2 Conc. (%)	1.95	2.49	2.46	1.69	2.55
Initial H_2O Conc. (%)	1.27	0.86	1.29	1.52	1.04
Final H_2O Conc. (%)	1.50	1.41	1.27	1.32	1.62

① Runs with Breadboard Model 5
Other runs with Breadboard Model 4

② 2 1/2 in. x 4 1/2 in.



Pressure at 1 Atmosphere
S.H. - 0.010 lb H_2O/lb Air
Air Flow - 3 CFM

FIG. 12 - O_2 GENERATION AND CO_2 ABSORPTION RATES FOR PASSIVE-DYNAMIC OPERATING SUPEROXIDE DISCS

1750 g KO_2; theoretically enough for almost 13 hr. A total of 3250 g KO_2 is the theoretical amount for a 24 hr mission. Although runs 18-22 showed 20 to 70% utilization of O_2, more efficient utilization of O_2 from the KO_2 was expected for longer runs. Run 23 was planned on this basis.

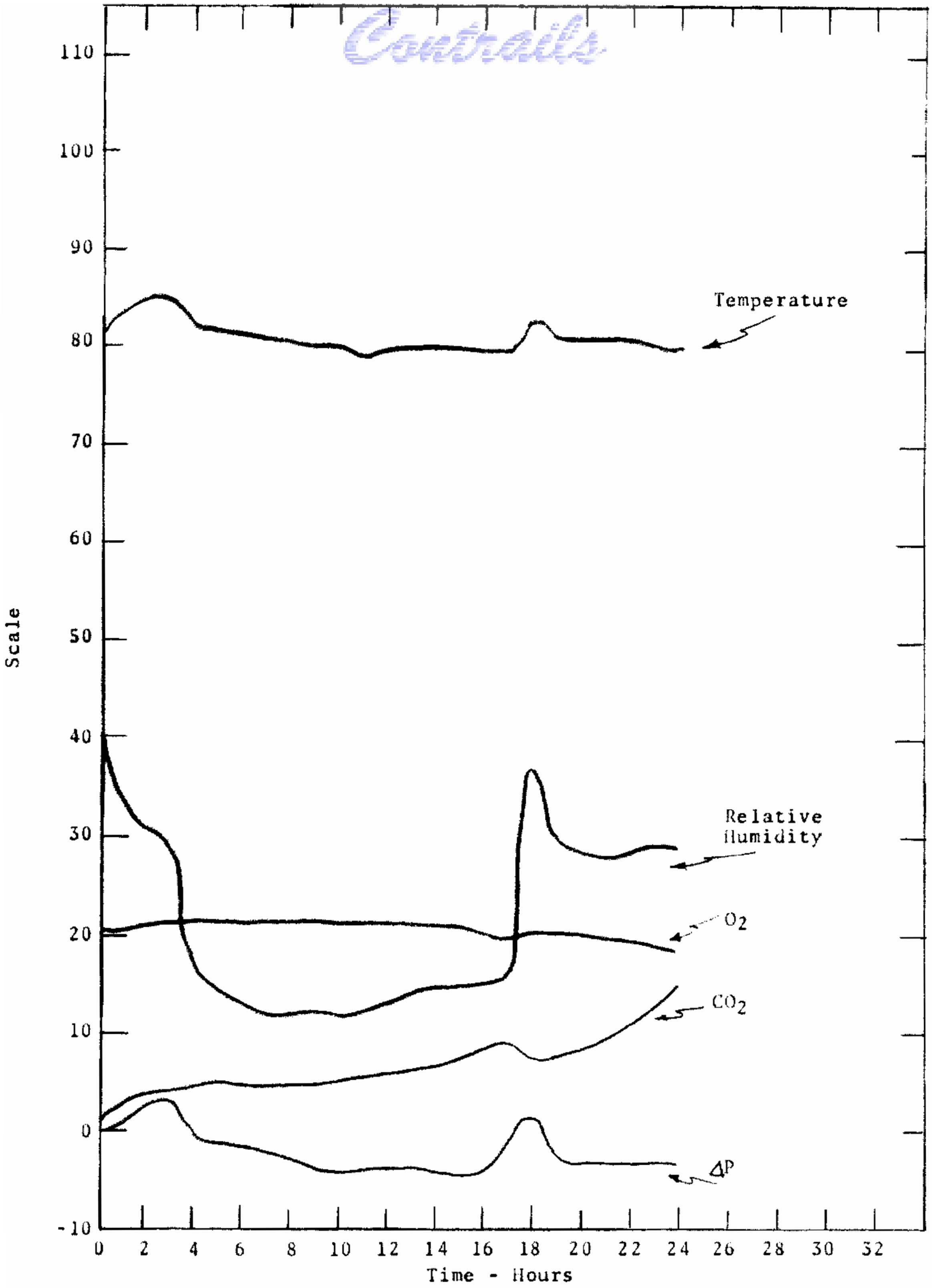
In run 23, a total of 101 discs of the design shown in Figure 5, having a total surface of 2400 sq in., were used. The discs were 3/16 in. thick and stacked to an overall bed length of 25 in. Chamber conditions during run 23 are shown in Figure 13. Utilization of available O_2 was 85% and CO_2 concentration was maintained at the lowest level of any previous runs of 24 hr duration. Run 24 was conducted to duplicate run 23.

Run 25, similar to runs 23 and 24, investigated whether an additive such as potassium permanganate would enhance performance. Upon normalizing the data on the basis of CO_2 absorbed per gram of superoxide, it was concluded that adding 2.5% $KMnO_4$ offered no particular advantage and did impose a weight penalty. Results of these runs are given in Table IV. Run 25 was the termination of the Design Phase.

Material Compatibility Tests

Aluminum as a construction material provided a substantial weight savings over materials such as stainless steel, copper or titanium. Aluminum, however, is subjected to corrosion when exposed to the caustic generated by superoxide during operation. Stainless steel and titanium were not affected by exposure to superoxide whereas copper did show some attack from the caustic. These exposure tests were exaggerated in that caustic concentrations were created in considerably higher concentration by exposing the corrosion specimens to superoxide in the open atmosphere, causing the superoxide to accumulate considerable amounts of water resulting in "mushing up" of the chemical. These high caustic concentrations are not encountered in tests with atmosphere-controlled chambers but an extreme corrosive situation best showed resistant behavior.

Aluminum was examined extensively in corrosion tests. Anodizing the aluminum did not provide protection but epoxy coatings did offer some resistance. One commercial epoxy coating offered more protection than others. Plating aluminum with a 0.0005 in. thick chrome-nickel surface proved to be the best measure in preventing corrosion.



Scale
Temp. - °F of Sealed Chamber
O_2 - % by Volume
CO_2 - % by wolume x 10^{-1}
ΔP - in. of Water (Chamber-Ambient)
Relative Humidity - %
Pressure at 1 Atmosphere

FIG. 13 - PASSIVE-DYNAMIC RUN NO. 23 WITH PROTOTYPE ATMOSPHERE CONTROL UNIT AND KO_2 DISCS

TABLE IV - PASSIVE-DYNAMIC RUNS WITH PROTOTYPE ATMOSPHERE CONTROL UNIT

Subject simulation conditions for one man:	O_2 consumption - 0.1 lb m/hr - 1.12 cu ft/hr CO_2 production - 0.11 lb m/hr - 0.897 cu ft/hr RQ - 0.80 H_2O production - 0.1 lb m/hr
Volume of sealed chamber:	130 cu ft
Pressure in sealed chamber:	1 atmosphere

Run no.		23	24	25
Run time (hr)		24	24	24
Chemical				
Type		KO_2	KO_2	KO_2*
Weight (gms)		3561.0	3633.0	3340.0
Mesh or shape		Discs	Discs	Discs
O_2 efficiency %		80.0	88.0	90.0
O_2 liberated	SCF	23.7	24.9	25.7
	(lb)	2.11	2.22	2.29
CO_2 absorbed	SCF	18.2	19.0	17.3
	(lb)	2.23	2.33	2.11
RQ		0.77	0.76	0.67
H_2O absorbed (gm)/chemical (gm)		0.121	--	0.086
Exposed apparent surface		2450.0	2450.0	2450.0
System				
Final O_2 conc. (%)		18.6	17.3	17.4
Final CO_2 conc. (%)		1.50	1.77	2.46
Initial H_2O conc. (%)		0.98	1.19	0.88
Final H_2O conc. (%)		0.88	1.75	2.46

* Contained 80 grams $KMnO_4$ in addition to 3340 grams KO_2.

Section IV

FABRICATION PHASE

Based upon performance of runs 23-25, the selection of the design for the atmosphere control unit was made.

Additional experimentation was conducted to further define design parameters and equipment requirements for the atmosphere control unit.

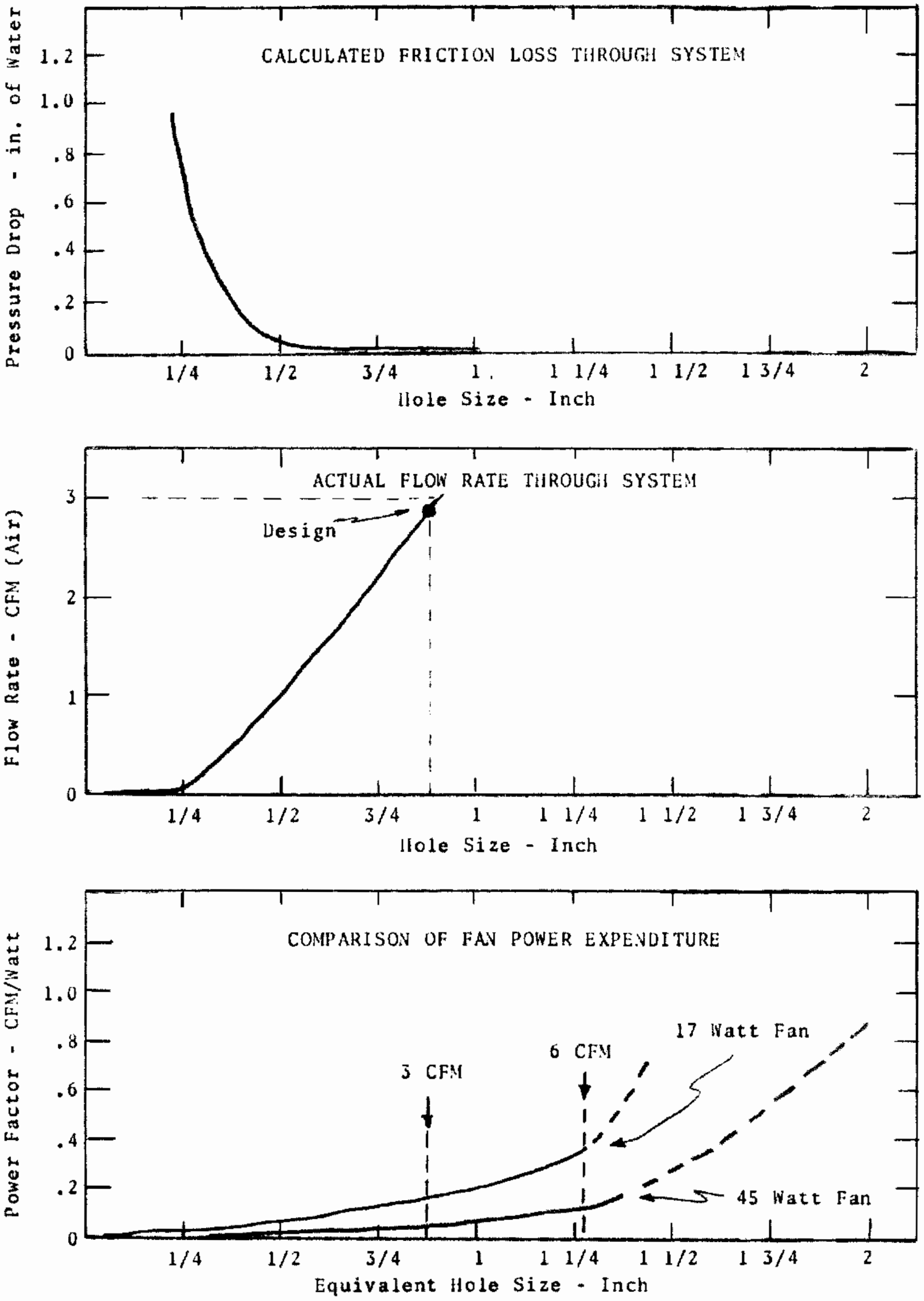
A minimum flow of 3 CFM or 180 CFH was estimated to be required to maintain 1% CO_2 concentration at 1 atm. in the chamber with effluent concentration (y) of 1/2% at 1 atm. from the atmosphere control unit. The equation

$$G = \frac{0.9\ (1-y)}{(0.01-y)} \quad \text{in} \quad (\text{CFH})$$

was used to establish this flow requirement. Pressure losses were determined experimentally with a simulated chemical bed made from transite discs. With an overall length of the array of 28 in., central holes of 1/4, 1/2 in. and 7/8 in. produced the data shown in Figure 14. This includes expansion and contraction losses. Pressure losses are shown to be at a minimum with holes 3/4 in. or larger at 3 CFM. Calculation on 1/4, 1/2 and 1 in. gave the pressure drops shown in Figure 14 (top). A 7/8 in. diameter hole was selected for the cakes to obtain a minimum flow of 3 CFM and therefore requiring a fan of low power consumption.

Two fans of low power consumption were evaluated in a prototype assembly of the atmosphere control unit. Performance data on these fans are:

	Fan 1	Fan 2
Power (watts)	17	45
Free air flow (CFM)	22	64
Head at no flow (in. of H_2O)	1.5	2.2
Head, max. (in. of H_2O)	1.7	2.3
Flow at max. heat (CFM)	12	44
Weight (gm)	117	142



Fluid - Air
Pressure - At 1 Atmosphere
Temperature - 75°F
Tube Length of 28 in.

FIG. 14 - SUPEROXIDE UNIT PERFORMANCE CRITERIA

Both fans have met environmental specifications and operate from 115 volt, 400 cycle, 1 phase electrical power supply. In Figure 14, the 17 watt fan (Fan 1) is shown to have the higher rating or flow factor (CFM/watt) at equivalent flow rates. The 17 watt fan was chosen since this fan performed as well as the 45 watt fan (Fan 2) when the system pressure drop is within 1.7 in. water (max. head developed by Fan 1), consumed less power, was lighter in weight, and had equivalent reliability since it met environmental MIL Specifications.

Additional passive-dynamic runs were conducted during the Fabrication Phase (Table V). The need to provide flow between the edge of the disc array and the shell was illustrated in runs 23 and 26. In run 23 a nominal clearance of 100 mills between the edge of the disc array and the shell was present. In run 26 there was no clearance for air flow. Absorption of CO_2 was adversely affected as shown by CO_2 concentration at 2.97% at 1 atm. in run 26 whereas in run 23 the CO_2 concentration was 0.96% at 1 atm. after 21 hours.

Discs for use in the atmosphere control units were manufactured with protrusions which permitted flow between adjacent discs. A disc having circumferential protrusions had a strength factor of three over a disc with radial protrusions. The performance of the circumferential pattern disc was examined in run 27; and compared to run 23 had the same CO_2 concentration of 0.96% CO_2 at 1 atm. after 21 hours.

A preliminary prototype model of an atmosphere control unit was fabricated. This model provided for a clearance of 0.060 in. between the shell and the discs. Run 28 disclosed that this clearance may have been inadequate. For instance, CO_2 concentration reached 1.11% at 1 atm. in run 28 whereas it was 0.96% at 1 atm. in run 23 after 21 hours.

Six air regeneration units were assembled with radial clearance increased to 0.080 in. by reducing the disc diameter to 3.770 in. (nominal 3 3/4 in.). Four 0.065 in. thick x 0.250 in. wide aluminum strips were equally spaced on the inside periphery of the shell. The shell was welded 4 in. x 0.035 in. wall aluminum tubing (alloy 6061-T6); the inside surface being protected by a 0.0005 in. chrome-nickel plating. A removable fan housing was designed from aluminum to further conserve weight. The fans, with adjoining capacitor and electrical connectors, were operated for 24 hours to check out reliability. A dust filter was designed for filtering air leaving the unit. The filter was also removable to permit servicing of the atmosphere control unit. Further description of these units is given in the following section of this report.

TABLE V - PASSIVE-DYNAMIC RUNS WITH PROTOTYPE ATMOSPHERE CONTROL UNIT

Subject simulation conditions for one man:
O_2 consumption - 0.1 lb m/hr - 1.12 cu ft/hr
CO_2 production - 0.11 lb m/hr - 0.897 cu ft/hr
RQ - 0.80
H_2O production - 0.1 lb m/hr

Volume of sealed chamber: 130 cu ft
Pressure in sealed chamber: 1 atmosphere

Run no.	26	27	28
Run time (hr)	24	28	28
Chemical			
Type	KO_2	KO_2	KO_2
Weight (gms)	3747.0	3895.0	3845.0
Mesh or shape	Discs	Discs	Discs
O_2 efficiency %	84.0	93.0	93.0
O_2 liberated SCF	25.1	31.6	28.6
(lb)	2.23	2.81	2.55
CO_2 absorbed SCF	16.8	19.2	19.8
(lb)	2.05	2.35	2.43
RQ	0.67	0.61	0.69
H_2O absorbed (gm)/chemical (gm)	0.070	0.118	--
Exposed apparent surface	2620.0	2620.0	2620.0
System			
Final O_2 conc. (%)	17.7	17.5	18.8
Final CO_2 conc. (%)	3.33	2.49	2.73
Initial H_2O conc. (%)	1.33	1.19	0.83
Final H_2O conc. (%)	3.0	2.06	2.42

Section V

FINAL DESIGN OF THE ATMOSPHERE CONTROL UNIT

The design of the atmosphere control unit is shown in Figure 15. Major components of the units are the fan, the chemical bed of KO_2 superoxide cakes, the dust filter and the shell.

Fan

The fan is mounted within a chrome-nickel-plated aluminum fan housing. See Figure 16 for fan housing detail. The housing is removable from the unit. The fan is mounted to the bulkhead in the housing by three filister head screw clamps (Synclamps). A split phase capacitor and electrical power plug are also mounted to the bulkhead. A slot in the housing engages with a key affixed to the shell to prevent radial movement. A retaining ring holds the fan in the containment shell. Performance characteristics of the fan are given in Figure 17. The fan circulates approximately 9 CFM (air at 1 atm.) through the unit.

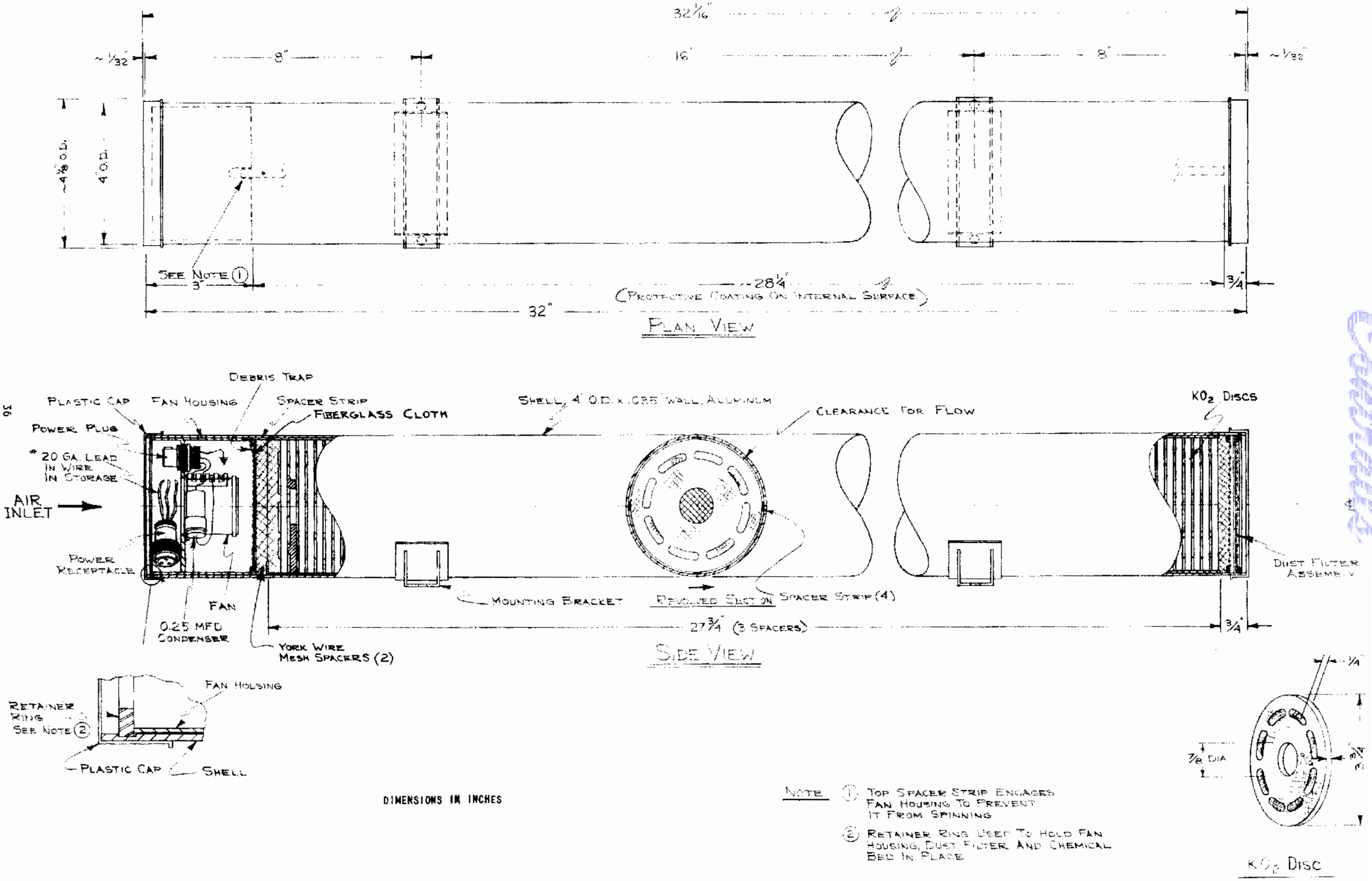
A debris trap, consisting of a screened ring and fiberglass cloth, prevents any dust or particles from contacting the fan, the split phase capacitor and internal wiring. The debris trap is situated on the downstream side of the fan housing and upstream from the chemical bed.

Dust Filter

The KO_2 discs initially produce some fine dust. To prevent dust escape from the unit, a dust filter is located at the outlet end of the shell. Detail of the filter is shown in Figure 18. The filter is held in against the York wire mesh spacers by a retaining ring. The dust filter and spacers press against the chemical bed to prevent movement of the chemical bed.

Shell

The outer housing is aluminum and has the dimensions of a hollow cylinder of 4 in. OD x 32 in. long x 0.035 in. thick. Grooves, 0.120 in. wide x 0.015 in. deep, are located at both ends of the shell to accommodate the retaining rings. Four aluminum longitudinal spacers are spot welded to the inside of the shell. The spacers prevent the discs from touching the inside of the shell, and gives clearance for flow between the discs and the shell. The top spacer also serves as a key to lock the fan housing. The other three spacers are bent over about 1/2 in.



DIMENSIONS IN INCHES

NOTE ① Top Spacer Strip Engages Fan Housing To Prevent It From Spinning

② Retainer Ring Used To Hold Fan Housing, Dust Filter And Chemical Bed In Place

FIG. 15 - PASSIVE-DYNAMIC KO_2 ATMOSPHERE CONTROL UNIT

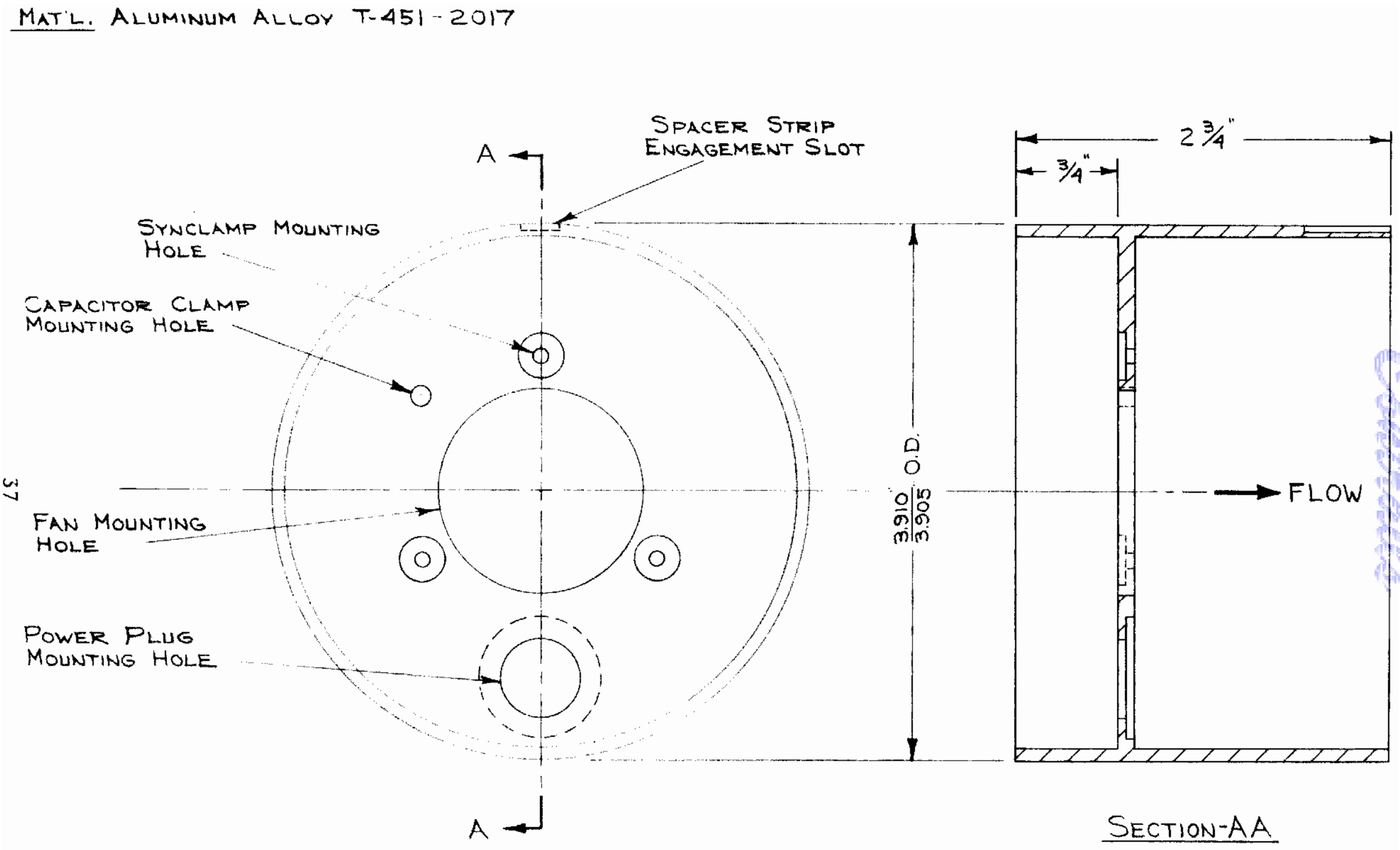
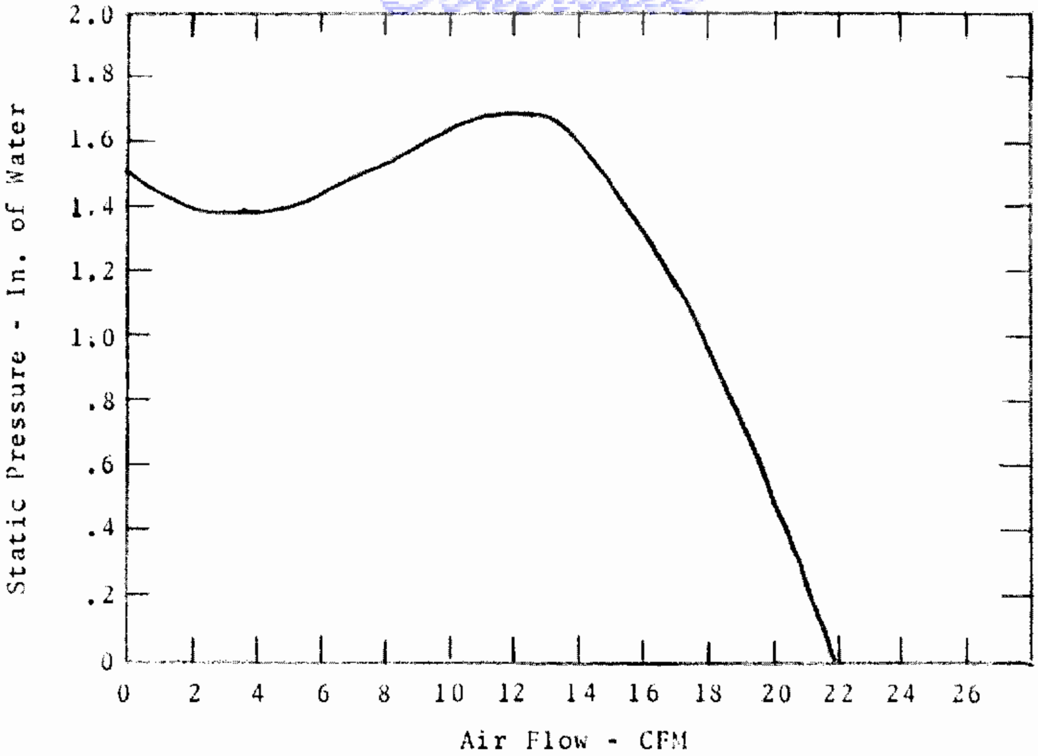
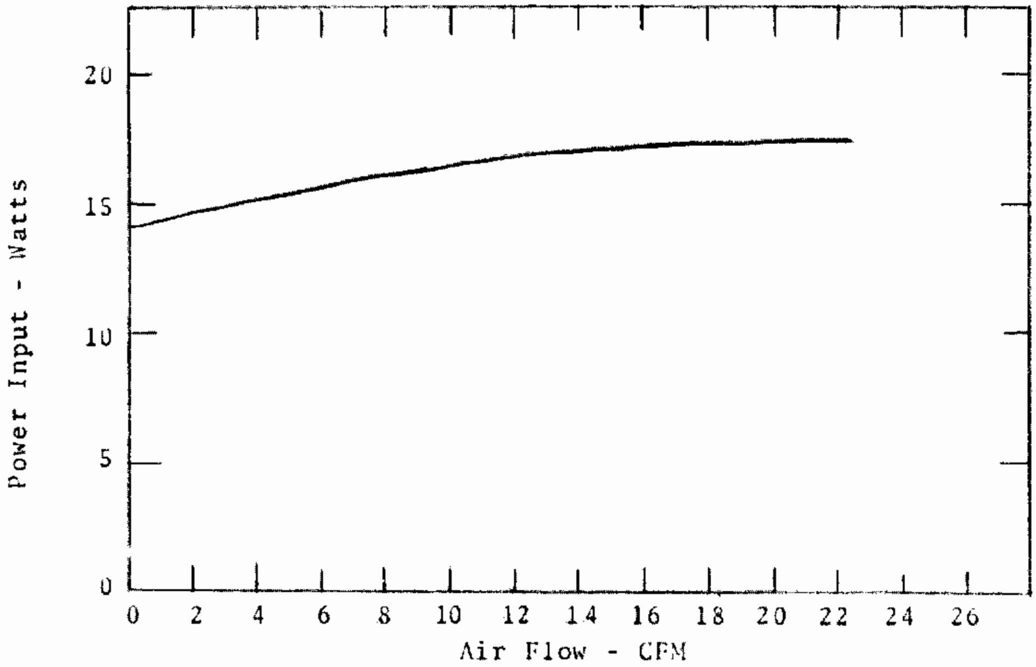


FIG. 16 - FAN HOUSING FOR ATMOSPHERE CONTROL UNIT



FAN STATIC HEAD VS FLOW RATE
Air at 1 Atmosphere



FAN POWER INPUT VS FLOW RATE
Air at 1 Atmosphere

Fan Power Supply		
Volts	-	115
Phase	-	1
CPS	-	400
Cap. Mfd.	-	0.25
RPM	-	22,500

FIG. 17 - CIRCULATION FAN PERFORMANCE CHARACTERISTIC

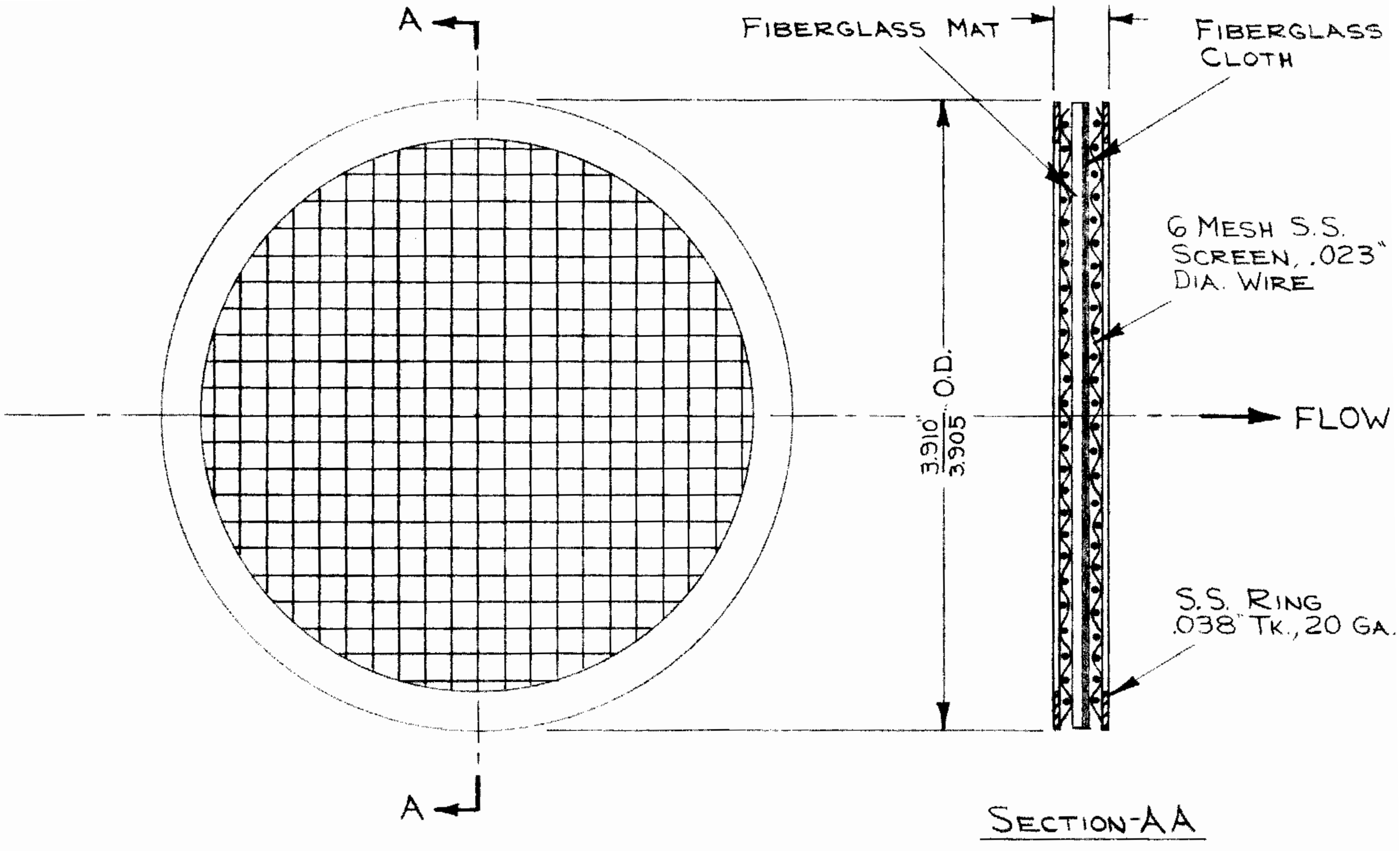


FIG. 18 - DUST FILTER FOR ATMOSPHERE CONTROL UNIT

extending towards the center of the shell. These extensions fix and position the superoxide discs in the shell and prevent lateral movement. Internal surface of the shell (and spacers) are chrome-nickel plated. The external surface of the shell is protected with a non-glare blue paint.

Chemical Bed

The chemical bed is a tandem array of 110 KO_2 discs which are structurally self supporting and permit both radial and axial air circulation. The overall length of the bed is 26-1/2 to 27-1/2 in. long. The discs have protrusions circumferentially located which provide spacing of approximately 1/16 in. between adjacent discs. The approximate dimensions of the discs are:

Outside diameter	3-3/4 in. (approx.)
Inside diameter	7/8 in.
Thickness	
Max. (at protursions)	1/4 in.
Min.	3/16 in.
Weight	0.079 lb (or 36 gm)
Volume (overall)	2.67 cu in.
Density (overall)	0.0296 lb/cu in. or 51 lb/cu ft
Density KO_2	0.044 lb /cu in. or 76 lb/cu ft

York wire mesh spacers are situated on both ends of the bed. They are slightly compressed to help hold the chemical bed in place. A retaining ring at one end of the shell and the bent-over ends of the spacers at the other end hold the total assembly in place.

Nominal dimensions of the shell and clearances of internal arrangement are:

Shell	
Length	32 in.

Diameter

Outside, OD	4.000 in.
Inside, ID	3.930 in.

Spacers

Thickness	0.064 in.
Diameter (inside)	3.802 in.
Disc Diameter	3.770 in.

Clearance between shell and disc

Diameter	0.160 in.
Radius	0.080 in.

The shell has two external base supports approximately 8 in. from both ends. Each support has two 1/4 in. holes for mounting the unit. These holes are on 3-3/8 in. centerlines.

The shell is the main body of the atmosphere control unit. The chemical bed of KO_2 discs must be sealed from the atmosphere to assure that reaction does not occur before operation is desired. Sealing of the chemical bed in the shell is achieved by plastic cover caps which are press fitted over the ends of the shell. Between the caps and the shell, strips of destructible vinyl tape were placed to act as a tamper seal and indicate that the units remain in a sealed condition.

Evolution of Unit

In summary, the prototype atmosphere control unit represented a sizeable reduction in volume compared to initial breadboard models. This was achieved by developing a unit which functioned with solid superoxide discs that were self supporting.

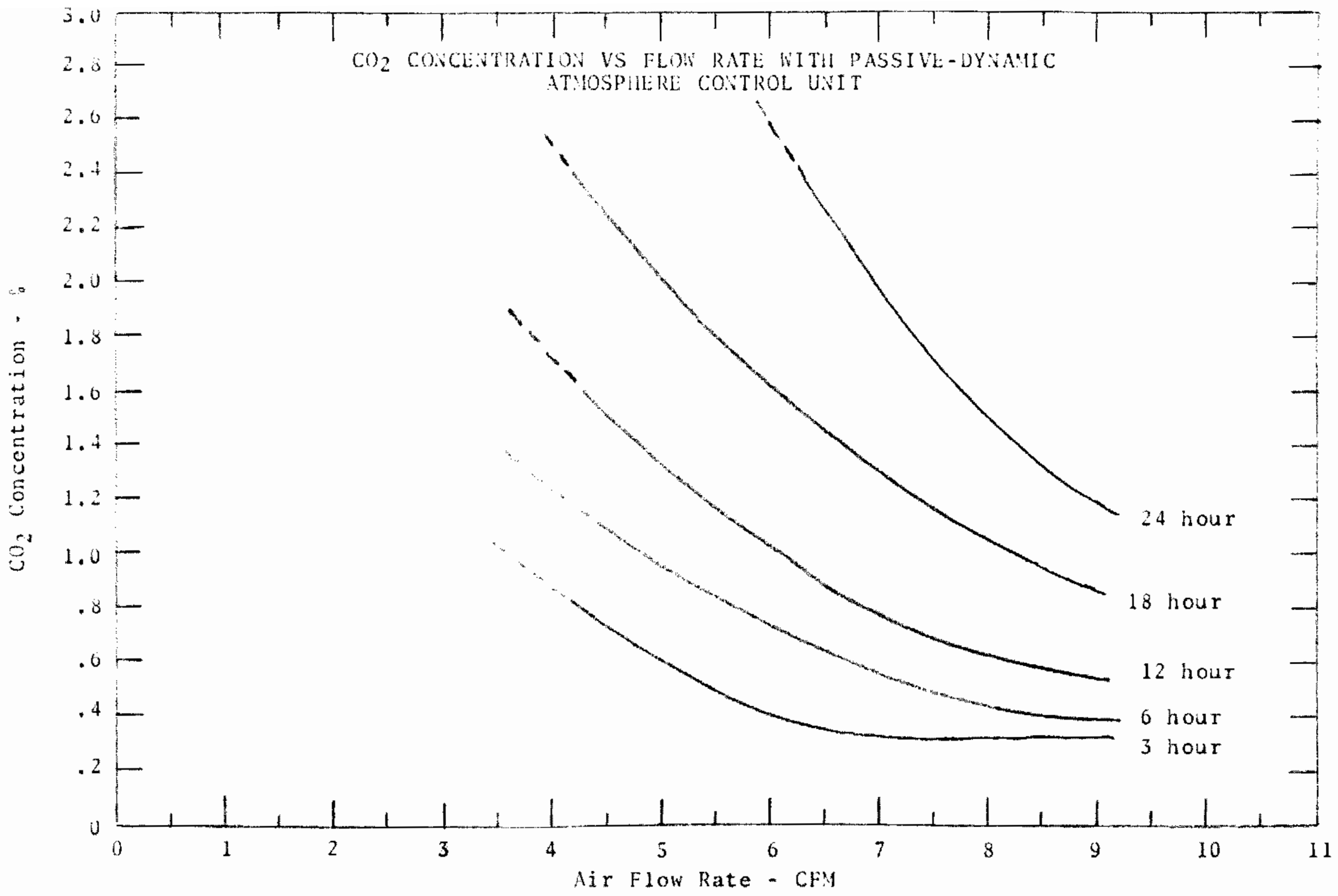
A comparison of Breadboard Models 1, 2 and 3 with the final atmosphere control unit which was developed is given below. The weight includes the superoxide charge and the fan.

Although the unit has not been flight tested it is believed to be capable of withstanding these conditions.

	Model 1	Model 2	Model 3	Atmosphere Control Unit
Volume (cu in.)	1150	595	475	400
(cu ft)	0.662	0.344	0.275	0.231
Weight (lb)	24.6	14.3	15.4	12.0
(gm)	11,180	6500	7000	5450

Performance of Unit

The unit is designed to operate in a sealed chamber and movement of the atmosphere through the unit by the fan at 9 CFM automatically generates O_2 and absorbs CO_2. The calculated 3 CFM was inadequate for CO_2 control but was sufficient for O_2 production. This is shown in Figure 19, where the need for air flow rates greater than 3 CFM for CO_2 control is clearly evident, and adequate performance is not obtained until about 9 CFM.



Chamber Volume - 130 cu ft
Pressure - 1 Atmosphere
Relative Humidity - 30-60%

FIG. 19 - EFFECT OF AIR FLOW RATE ON CO_2 CONCENTRATION IN SEALED CHAMBER

Section VI

CONCLUSIONS AND RECOMMENDATIONS

The following are conclusions on the work accomplished during this project.

1. Weight and volume have been reduced over prior superoxide dynamic systems.
2. Dusting is reduced by using disc forms as opposed to granular configurations.
3. Power requirement has been reduced compared to the usual dynamic system.
4. Water sensitivity has been reduced.
5. Active-inactive material weight ratio has been increased.
6. Carbon dioxide absorption can be more efficiently controlled for extended periods of time.

Recommendations for additional work have been considered and are as follows:

1. Additional study of sodium superoxide and combinations of the superoxides should be made in an effort to apply sodium superoxide to present and future uses.
2. The same techniques of packaging could be applied to a portable unit for space suits.
3. The same type of chemical compounding might be applied to other life support media, such as LiOH.
4. While water sensitivity was reduced in this work, further reduction may be possible.
5. Further study of geometry and solid forms could reduce volume and weight and evolve still more compact designs.

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1. ORIGINATING ACTIVITY *(Corporate author)* MSA Research Corporation Callery, Pennsylvania	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

POTASSIUM SUPEROXIDE ATMOSPHERE CONTROL UNIT

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final report, March 1964 - December 1964

5. AUTHOR(S) *(Last name, first name, initial)*

McGoff, M. J.

6. REPORT DATE September 1965	7a. TOTAL NO. OF PAGES 44	7b. NO. OF REFS None

8a. CONTRACT OR GRANT NO. AF 33(615)-1518	9a. ORIGINATOR'S REPORT NUMBER(S) MSAR Report No. 64-123
b. PROJECT NO 6373	
c. Task No. 637302	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
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13. ABSTRACT

Superoxides have been used in a new approach to atmosphere control systems for aerospace flight. This approach offered the control of dynamic systems and the low power requirement of passive systems. This technique can be adapted to unusual geometries with low weight and volume requirements. Potassium superoxide discs comprise the bulk of this new unit serving as a structural self-support and yet offering adequate carbon dioxide absorption and oxygen evolution. The discs are 3.77 in. in diameter x 3/16 in. thick and have a 7/8 in. diameter center hole. They are placed in a cylindrical aluminum housing with a 0.080 in. clearance between the shell and discs. The discs are separated from each other by integrally molded 1/16 in. protrusions. A one-man version of the unit for 24 hour service weighs 12 pounds, requires 17 watts power continuously, is 32 in. long x 4 in. in diameter and contains 110 discs. The disc configuration permits both radial and axial circulation at a throughput of 9 cfm and 1.6 in. of water ΔP. Tests with a one-man simulator in a 130 cu ft compartment showed adequate oxygen delivery and control at less than 1% carbon dioxide.

DD FORM 1 JAN 64 1473

AF-WP-B-AUG 64 400

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Carbon dioxide, control						
Alkali metals, potassium						
Life support, space flight						
Respiration, carbon dioxide						
Absorption						
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