

S A E
AERONAUTICAL INFORMATION
REPORT
NO. 4A

OXYGEN EQUIPMENT FOR AIRCRAFT



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PREPARED BY

Committee A-9, Aircraft Air Conditioning Equipment

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SUPPLEMENTAL DATA SHEET

REFERENCE SECTION 4.1.6.

This portable system (system 6) is intended for supplying supplemental oxygen through a continuous flow regulator and mask. It differs in principle from the system described in Section 4.1.5 (system 5) which supplies all of the oxygen being used by the wearer, through its non-diluter demand regulator and proper mask.

REFERENCE SECTION 4.1.7.

The system shown in Figure VI (system 7) does not have an automatic regulator but makes use of a sonic-velocity orifice in the outlet to limit flow to a continuous flow mask or pipe stem. Thus the flow varies only slightly with bottle pressure.

REFERENCE SECTIONS 6.1 AND 6.2.

Those cylinders listed in Section 6.1 are approved by the Interstate Commerce Commission, but those shown in Section 6.2 are not approved by the I.C.C. for the pressure of 400 psi.

The I.C.C. regulations, with respect to oxygen cylinders, apply only to those cylinders that are shipped as cargo or non-fixed equipment while containing oxygen under pressure. Bottles that are securely attached to the airframe as an item of its equipment are not required to comply with the I.C.C. regulations. Since the I.C.C. is concerned, in this regard, only with pressure containers being handled separately in the manner of cargo, its regulations include safety factors intended to provide safety even after a certain amount of handling damage. Fixed bottles, which are not subject to such damage, normally may make use of lower factors of safety.

REFERENCE CHART 3.

Typical Problem: Determine the oxygen supply required for 2 crew members and 7 passengers for a 2 hour flight at 15,000 feet.

$$Q_o = \frac{N \times F \times T \times 60}{.95 \times 28.32}$$

Q_o = Amount of oxygen required, in cubic feet.

N = Number of oxygen users.

F = Flow requirements for the conditions involved, in liters/minute.

T = Time of flight at altitude requiring oxygen, in hours (assumed to include climb and descent between the minimum altitude at which oxygen will be used and the cruise altitude.)

REFERENCE CHART 3. (Cont'd.)

Typical Problem: (Cont'd.)

60 = Minutes/Hour.

28.32 = Number of liters in a cubic foot.

.95 = Correction Factor for system efficiency.

Reading from Chart 3, for 15,000 feet:

F = 1.7 Liters/Minutes

$$Q_0 = \frac{(2 + 7) \times 1.7 \times 2 \times 60}{.95 \times 28.32} = 68.24 \text{ cubic feet (Standard Conditions at Sea Level.)}$$

To determine the number and type of oxygen bottles to be used, refer to Section 6.1. A single bottle of 73.0 cubic feet capacity, or two bottles of 38.4 cubic feet capacity each may be used.

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OXYGEN EQUIPMENT FOR AIRCRAFT

INTRODUCTION

This report has been prepared as a revision of the previous Aeronautical Information Report No. 4 dated May 1, 1944 in order to bring that report up to date by including the latest information available on the design and use of aircraft oxygen systems. It accordingly supersedes AIR 4 dated May 1, 1944.

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OXYGEN EQUIPMENT FOR AIRCRAFT

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Chart 1 - Equivalent Altitudes

Chart 2 - Oxygen Flow Recommended by USAF

Chart 3 - Requirements Set Forth in CAR

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OXYGEN EQUIPMENT FOR AIRCRAFT

1. PURPOSE: To present a resume of available information on the design and use of aircraft oxygen systems.
2. SCOPE: This information Report covers high and low pressure oxygen systems, both fixed and portable.
3. GENERAL:
 - 3.1 Physiological Requirements: Oxygen should be supplied in an increasing percentage of the total inhaled mixture as the partial pressure of the gas is decreased by increasing altitude. The resultant increasing availability of oxygen acts to counteract the decreasing pressure potential available for forcing the gas through the membranes of the lungs to a position where it may be picked up by the red corpuscles of the blood. The supplementation of free air by oxygen is considered to be advisable above 8,000 feet for active persons such as crew members, and 10,000 feet for inactive passengers. It is considered necessary above 8000 feet for active persons and above 10,000 feet for inactive passengers. Oxygen may be required at much lower altitudes for therapeutic use with various lung and heart disorders. It is necessary to supply undiluted oxygen at altitudes above 30,000 feet. The use of undiluted oxygen without supplemental pressure is considered acceptable only to 37,000 feet.
 - 3.2 Source of Supply consisting of some or all of the following items:
 - 3.2.1 Supply cylinders containing compressed oxygen carried on the aircraft. These are of two types:
 - 3.2.1.1 High Pressure cylinders (1800 psi).
 - 3.2.1.2 Low Pressure cylinders (400 psi).
 - 3.2.2 Check valves to isolate individual cylinders.
 - 3.2.3 Safety valves to prevent over pressure in cylinder from overcharging or heating.
 - 3.2.4 Warning signal to indicate dangerous depletion of supply.
 - 3.2.5 Pressure gage to indicate quantity of oxygen available.
 - 3.2.6 Manually operated shut-off valve to conserve supply when not in use and to permit replacement of individual cylinders.
 - 3.2.7 Valves for isolating portion of the system for crew or therapeutic use.
 - 3.2.8 Provisions for replenishing supply either by external filler or by removing and recharging the supply cylinders.

- 3.3 Distribution System - comprising one or more lines of metal tubing with suitable fittings and outlets to distribute the oxygen to various stations. Pressure in these lines may be that of the supply cylinder or it may be reduced by a reducing valve to some uniform low pressure. Those lines passing through a potential fire zone should be of stainless steel.
- 3.4 Regulators, comprising mechanical means for proportioning the amount of oxygen required by each individual. They may be permanently installed at individual stations, they may be portable, or they may be at one master station. Portable regulators may be attached to low pressure outlets or they may be attached to portable cylinders.
- 3.4.1 Regulators may be of the following types:
- 3.4.1.1 Continuous flow type with or without automatic or manual means for increasing the flow with altitude. With this regulator the flow is fixed for any given adjustment and does not vary automatically to suit work or rest conditions.
- 3.4.1.2 Demand type which allows oxygen to flow only when a suction is applied as by inhaling through a mask or tube. This regulator may feed only pure oxygen or may have automatic means for mixing air with oxygen to maintain the partial pressure of oxygen in the lungs at approximately sea level conditions up to some predetermined high altitude. An emergency valve for full continuous flow of oxygen is provided.
- 3.4.1.3 A rebreather type, in which air is continuously rebreathed and the oxygen consumed is replenished. Chemicals are provided to absorb water and carbon dioxide.
- 3.4.1.4 A pressure breathing demand regulator, which, when used with the proper mask imposes a pressure of from 6 to 8 inches of water upon the lungs, thus raising the safety ceiling to as high as 43,000 feet and the emergency ceiling to 47,000 feet. Below 30,000 feet the regulator functions as an ordinary dilute demand regulator.
- 3.4.2 Flow indicators can be usefully employed with demand regulators to insure the operator that he is actually getting the oxygen. These devices should operate by a means responsive to the flow of oxygen only.
- 3.4.3 Flow indicators should be used with all oxygen systems to insure proper oxygen supply. They may be in the form of pressure gages calibrated to the altitude, or in the form of flow meters.
- 3.4.4 Regulators are responsive to the ambient pressure and therefore are satisfactory for use in either pressurized or unpressurized airplanes.
- 3.4.5 Emergency overrides should be provided on all automatic regulators to permit administration of pure oxygen for therapeutic purposes at any altitude.
- 3.5 Means for Inhaling Oxygen:
- 3.5.1 At altitudes above 16,000 feet a mask or hood is essential to prevent excessive dilution of oxygen with air. Below 16,000 feet, a simple mouth-piece can be used or even a direct application of oxygen into the mouth through a pipe stem, although such a system is inefficient. Masks are commonly employed at all elevations where oxygen is required, as they are more efficient.

3.5.2 The characteristics desired in a mask are:

3.5.2.1 It should be leak-proof and comfortable.

3.5.2.2 It should be equipped with expiratory valves protected against freezing and capable of building up approximately one quarter of an inch water pressure in the system on exhaling.

3.5.2.3 It should be equipped with a rebreather bag used with a continuous flow regulator.

3.5.2.4 When possible, it should be individually fitted to the wearer. This is essential for sustained flight above 25,000 feet.

3.5.2.5 It must be easily cleaned by normal cleaning methods.

4. OXYGEN SYSTEMS IN USE IN UNITED STATES:

4.1 Characteristics of Various Systems:

4.1.1 System 1.- (See Figure 1) This system involves a tank of high pressure (1800 - 2000 psi) oxygen onto which is directly attached a manually operated continuous flow regulator. This regulator discharges into a manifold line to which several outlets are connected. A quick-coupling connection at the outlet connects to a tube leading to a mask and bag.

4.1.1.1 The regulator is supplied with a pressure reducer, a cylinder pressure gauge and may have a differential pressure gauge graduated in altitude by which the operator manually sets the pressure needed across built-in orifices at the outlets to supply the amount of oxygen suitable for the altitude. With this type, care should be taken that the oxygen outlet or hose is not closed off, as such would cause an erroneous indication of flow.

4.1.1.2 One regulator will serve several oxygen outlets. The outlets are closed by built-in check valves when not in use.

4.1.1.3 This system is in wide use.

4.1.2 System 2.- (See Figure 1) This is the same principle as above, except that it operates on a low pressure system, about 400 psi. It is also in wide use.

4.1.3 System 3.- (See Figure II) This is an automatic continuous flow regulator designed to operate on tank pressure from 50 to 500 psi on some systems, and as high as 1800 psi on other systems.

4.1.3.1 The regulator is connected to a supply tubing at tank pressure. A pressure reducer in the instrument reduces the pressure in the inlet chamber to a constant low absolute pressure. A second pressure reducer actuated by aneroid control admits oxygen to a manifold, provided with any number of outlet orifices up to 15, at a pressure increasing with altitude, so that one or all of the orifices will furnish the amount of oxygen suitable for the altitude.

- 4.1.3.2 Tubing with mask and storage bag may be connected to any of the outlets, which are closed by built-in check valves when not in use.
- 4.1.4 System 4.- (See Figure III) This regulator is a diluter demand regulator designed to be connected to a 400 psi supply system. A pressure reducer in the instrument reduces the cylinder pressure to a substantially constant low pressure. Inhalation suction operates a valve and causes a flow of oxygen.
- 4.1.4.1 An air inlet, which can be closed when oxygen only is wanted, admits air which mixes with oxygen in amounts decreasing with altitude. The mean of the tolerances calls for 15-35% added oxygen at 15,000 ft., 50-78% at 25,000 ft., and 70-100% at 30,000 ft. A check valve prevents escape of gas when exhaling.
- 4.1.4.2 An emergency valve by-passing the regulator permits a steady flow of oxygen to the mask if desired.
- 4.1.4.3 In addition to the instrument, a panel containing a cylinder pressure gauge, an oxygen flow indicator and a warning light to go on when the pressure is low, is used in some but not all installations.
- 4.1.4.4 A flexible tube, of convenient length runs from the outlet of the regulator to a snap type disconnect fitting with a clip for attaching to the clothing. A mask is provided with a plug-in fitting for the above disconnect. The mask has a check valve to allow air to escape on exhaling and to prevent it from entering on inhaling.
- 4.1.4.5 In normal quiet breathing, the pressures in the mask will be about 1/4" of water below atmospheric on inhaling and 1/4" above on exhaling. Great care must be taken to adjust the mask tightly as a considerable leak would dangerously dilute the oxygen at high altitudes.
- 4.1.4.6 One regulator must be provided for each person.
- 4.1.4.7 The system is economical, safe and easy to use, provided the instrument is reliable and the mask tight. It does not provide for bail-out or walking about the airplane nor is it well adapted for passenger use.
- 4.1.5 System 5.- (See Figure IV) This is a portable demand regulator used for walking about in the plane. It consists of a non-diluter demand regulator with a 400 psi oxygen bottle attached. It incorporates a pressure reducer for providing a lower constant working pressure to the demand valve, a clip for attaching the unit to the person, a quick disconnect filling plug equipped with a check valve for refilling from the supply line as needed, a cylinder pressure gauge, and a snap-in connection for the mask fitting. It has the following disadvantages: The low pressure bottle is bulky and its capacity depends upon the pressure available in the supply line. At best, the bottle has to be refilled every few minutes. When used with System 4, a charging connection for the portable cylinder is required in addition to the fixed position oxygen station.

4.1.6 System 6.- Same as System 5, except that an 1800 psi oxygen bottle is provided with a continuous flow regulator. This system, however, cannot be refilled in flight.

4.1.7 System 7.- (See Figure VI) This is a complete unit for "bail-out". It comprises a bottle, pressure gauge, release valve and "pipe-stem" mouthpiece. It automatically delivers the required amount of oxygen.

4.2 Oxygen Supply Pressur:

4.2.1 Except for some 1800 psi systems used with System 1, 3 and 6, a 400 psi system is used. The oxygen cylinders are permanently installed in the plane. Provision is made for refilling them from outside the plane. Check valves are often provided so failure of one cylinder will not affect the others. A relief valve can be used if desired to prevent overfilling. One or more lines run to permanent stations to which the regulators and their accessories are connected.

4.3 Airline Oxygen Systems:

4.3.1 Two types of oxygen systems are in general use by commercial airlines in the United States today. These vary with different companies, but in general are as follows:

4.3.1.1 A high pressure system basically the same as system 1 (paragraph 4.1.1), consisting of a high pressure tank, a gage, and a manual pressure reducer located in the pilot's compartment or adjacent to it. Low pressure lines with orifice outlets at the passengers' seats carry oxygen from the reducer. A member of the crew sets the oxygen pressure necessary for the altitude being flown. The passengers and crew obtain oxygen through mouth-pieces, lorgnettes, or masks. This system is simple and effective for the purpose and for the low altitudes encountered, but when mouth pieces or lorgnettes are used, is wasteful of oxygen as flow of oxygen during exhaling is lost.

4.3.1.2 A low pressure system, basically the same as system 2, making use of low pressure oxygen cylinders as a source of supply and being substantially the same as the system described in paragraph 4.3.1.1 in all other aspects.

4.3.2 Oxygen systems for use with pressurized aircraft are designed basically for use as emergency systems in case of complete depressurization or for use for therapeutic purposes. The systems employed by the airlines are basically the same as for unpressurized aircraft.

4.3.3 The crew supply source should be separable from the passenger distribution system so that passengers cannot exhaust the crew supply.

4.3.4 Emergency Oxygen System: Emergency Oxygen Systems for protection against noxious gases should provide a flow of oxygen direct from the source of supply to the crew members without admixture of air. A non-dilutor demand system rest fills these requirements, or a dilutor-demand system set for 100% oxygen flow (see System 4). A full face oxygen mask should be used to provide protection for the wearer's eyes as well as respiratory system.

5. AVAILABLE SPECIFICATIONS - A partial list of available specifications covering Oxygen Equipment for Aircraft now in use is given below:
- 5.1 Adapters - Low Pressure System Filler Air Corps Dwg. No. 40A8475
- 5.2 Coupling, Automatic Air Corps Dwg. No. AN3009
- 5.3 Cylinders - High Pressure Army Spec. 94-40302, 40246, 40247, 40248, 40251, 40373
- 5.4 Cylinders - Low Pressure Army Spec. 94-40376, 40355, 40330, 40356, 40321, 40407
- 5.5 Indicator Lamps Air Corps Dwg. No. 42B3593-2
- 5.6 Indicator, Flow, Oxygen Army Spec. 40389 - 40427.
Army-Navy Aero. Spec. AN-1-12
Army-Navy Dwg. AN-6029
- 5.7 Installation Army Spec. 40362, 40363
- 5.8 Mask Army Spec. 3166, 94-3107
Army-Navy Aero. Spec AN-M-3
- 5.9 Oxygen: Aviator's Breathing (Gas) Army-Navy Aero. Spec. AN-O-1A
Army Specification 2198
Navy Specification M-243
- 5.10 Portable Apparatus Air Corps Dwg. No. 42D5357
- 5.11 Portable Rechargers Air Corps Dwg. No. 42D7261
- 5.12 Regulators, Oxygen (A-9A) Army Specification 94-40319
- 5.13 Regulators, Oxygen (A-12) Army Specification 40370
- 5.14 Regulators, Oxygen (A-N) Army-Navy Aeronautical Spec.
AN-R-5
- 5.15 Regulators, Oxygen (A-N) Army-Navy Dwg. AN-6004
Navy Spec. M-436b
- 5.16 Signal Assy., Oxygen Pressure Army Specification 32376
- 5.17 Signal, Oxygen Warning (High Pressure System) Army-Navy Aero. Spec. AN-S-21
Army-Navy Dwg. AN-6019
- 5.18 Tube Assembly, Oxygen Mask Regulator Army Specification 40387
- 5.19 Tubing, Copper Federal Spec. WW-T-799
- 5.20 Tubing, Aluminum Alloy Army Specification 55-187-3
- 5.21 Valve, Check Army Specification 40325
- 5.22 Valve, Filler Army Specification 40326
- 5.23 Valve, Oxygen Line Army Specification 40386
- 5.24 Valve, Relief, Oxygen Army Specification 40392

6. STANDARD CYLINDER SIZES

6.1 High Pressure - 1800 psi

WATER CAPACITY CUBIC IN.	FREE O ₂ AT 70°F & ATMOSPHERIC PRESSURE		APPRX. WEIGHT WITH VALVE & O ₂	CYLINDER SIZE WITHOUT VALVE	
	Cu. Ft.	Liters		Length	Diameter
57	4.25	120	3 lbs. 12 oz.	9-1/8 + 1/4"	3-9/16 + 1/16"
96	7.15	203	4 lbs. 8 oz.	13-1/4"	3-9/16"
147	11.0	312	6 lbs. 13 oz.	18-3/4"	3-9/16"
205	15.2	430	9 lbs. 4 oz.	13-3/4"	5-7/32"
295	22.0	623	12 lbs. 3 oz.	18-1/4"	5-7/32"
386	28.8	815	15 lbs. 15 oz.	15-1/8"	6-25/32"
514	38.4	1087	20 lbs. 1 oz.	19"	6-25/32"
646	48.3	1368	25 lbs. 6 oz.	23-1/4"	6-13/16"
853	63.7	1804	32 lbs. 6 oz.	26-7/16"	7-15/64"
978	73.0	2067	36 lbs. 11 oz.	29-3/4"	7-15/64"
1220	91.0	2577	47 lbs. 11 oz.	25-1/2"	8-31/32"
1430	107.0	3030	54 lbs. 10 oz.	29-5/8"	8-31/32"
2040	152.0	4305	74 lbs. 6 oz.	40-1/4"	8-31/32"
E-290	22.9	648	18 lbs. 14 oz.	25-3/4"	4-5/16"
M-1361	107.3	3040	65 lbs. 14 oz.	43"	7"

All light weight cylinders are made in accordance with I.C.C. 3-A, 1800 specifications and are filled to 1800 lbs.

These cylinders are made in accordance with I.C.C. 3-A, 2000 specifications, and are filled to 2000 lbs.

6.2 Low Pressure - 400 psi Working Pressure

ARMY TYPE	FREE O ₂ AT 70°F & ATMOSPHERIC PRESSURE		SIZE	
	VOLUME CUBIC IN.	WT. - LBS.	Length	Diameter
A-4	104	1.44	7-5/8	5-1/4
A-6	280	3.8	14-1/2	5-3/4
D-2	500	6.9	23-1/2	5-3/4
F-1	1000	13.8	17-1/2	10-1/8
F-2	1000	13.8	44-1/2	5-3/4
G-1	2100	33.1	24-1/2	12-9/16
J-1	18,000	247.6	49-1/2	24-1/2

7. PROPERTIES OF OXYGEN

7.1 Density:

DEGREES F.	GRAMS PER LITER	POUNDS PER CUBIC FEET	POUNDS PER CUBIC INCHES
-40	1.67	.105	.602 x 10 ⁻⁴
-20	1.60	.100	.576 x 10 ⁻⁴
0	1.53	.095	.552 x 10 ⁻⁴
20	1.47	.091	.530 x 10 ⁻⁴
40	1.40	.088	.507 x 10 ⁻⁴
60	1.35	.085	.487 x 10 ⁻⁴
80	1.30	.081	.470 x 10 ⁻⁴
100	1.26	.078	.453 x 10 ⁻⁴

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7.2 Weight of Oxygen in Supply Cylinders:

$W = P \times d \times \frac{V}{K}$ where P = gage pressure, atmosphere's
 W = weight of oxygen in pounds
 d = density of oxygen pound per cubic inch
 v = volume of cylinder, cubic inches
 k = compressibility factor (-see table)

<u>PRESSURE</u>	<u>PSI</u>	<u>ATMOSPHERE'S</u>	<u>K at 32° F.</u>	<u>K at 68° F</u>
	450	30.6	.973	.981
	900	61.3	.945	.962
	1800	122.5	.915 (approx.)	.938 (approx.)

7.3 Weight in Pounds per Hour of an Oxygen Flow of one liter per Minute at 32° F and Ambient Pressure:

ALTITUDE - Thousands of ft:-	0	10	20	25	30	35	40
OXYGEN - Pounds per Hour: -	.189	.130	.086	.070	.056	.044	.035

7.4 Oxygen From Tank Supply to Produce Required Mixtures of Oxygen and Air at Mask:

PER CENT OF OXYGEN AT MASK:-	21	30	40	50	60	70	80	90	100
PER CENT OF TOTAL VOLUME WHICH IS DRAWN FROM TANK:-	0	11	24	37	49	62	75	87	100
PER CENT OF TOTAL VOLUME WHICH IS DRAWN FROM AMBIENT:-	100	89	76	63	51	38	25	13	0

8. DESIGN CRITERIA

- 8.1 The Ventilating rate of average lungs is 30 cu. inches or 500 cc per respiration at a rate of 12 to 16 times per minute or 6 to 8 liters of air per minute. The peak respiration rate is 20 to 30 liters/min. at the midpoint of inhalation or exhalation. Provision should be made for a minimum flow of 15 liters per minute for an exercising person.
- 8.2 It is customary when figuring oxygen supply requirements in this way to allow a 5% leakage factor for masks and fittings. Chart #1 shows equivalent altitudes when using various concentrations of oxygen. Chart #2 shows oxygen flow recommended by the Army Air Forces. Chart #3 shows the requirements set forth in Civil Air Regulations, Part O4B issued May 19, 1947.

9. BIBLIOGRAPHY

- Manufacturers Catalogs, etc.
- Handbook of Respiratory Data in Aviation - Office of Scientific Research & Development.
- Your Body in Flight - T.C. 30-105-1 Army Air Forces.
- Use of Oxygen and Oxygen Equipment - T.O. 03-50-1 Army Air Forces

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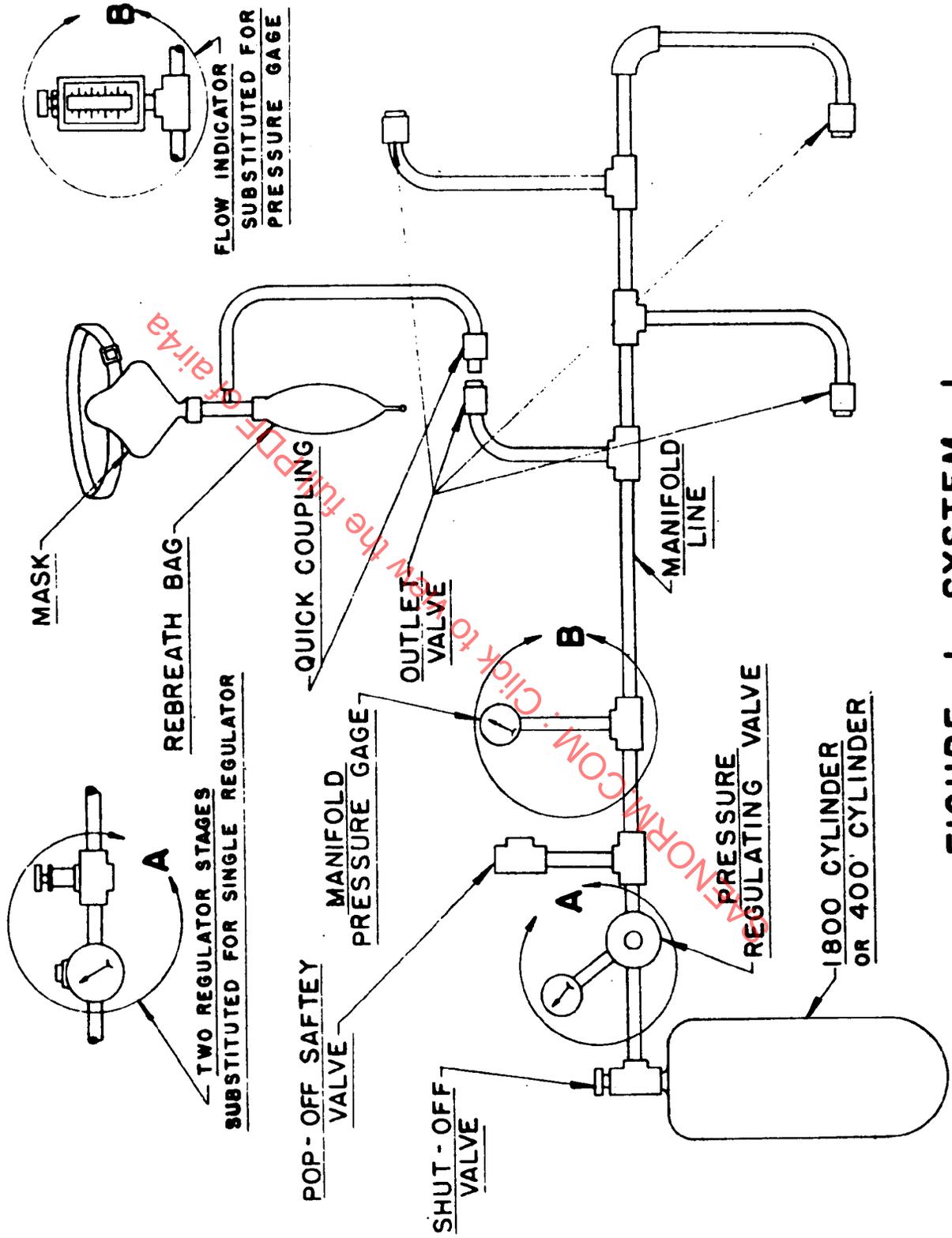


FIGURE 1 SYSTEM I

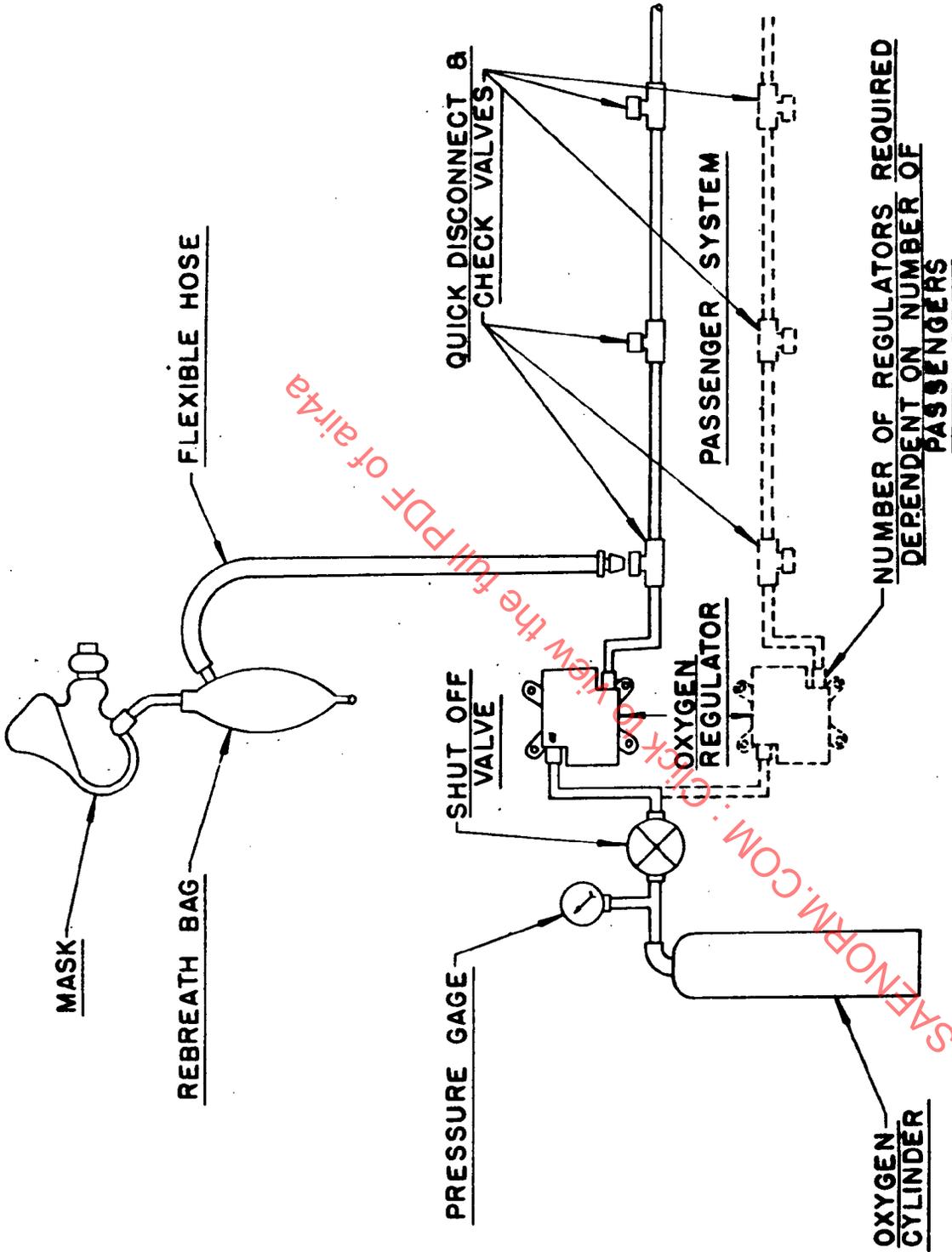


FIGURE 11 SYSTEM 3

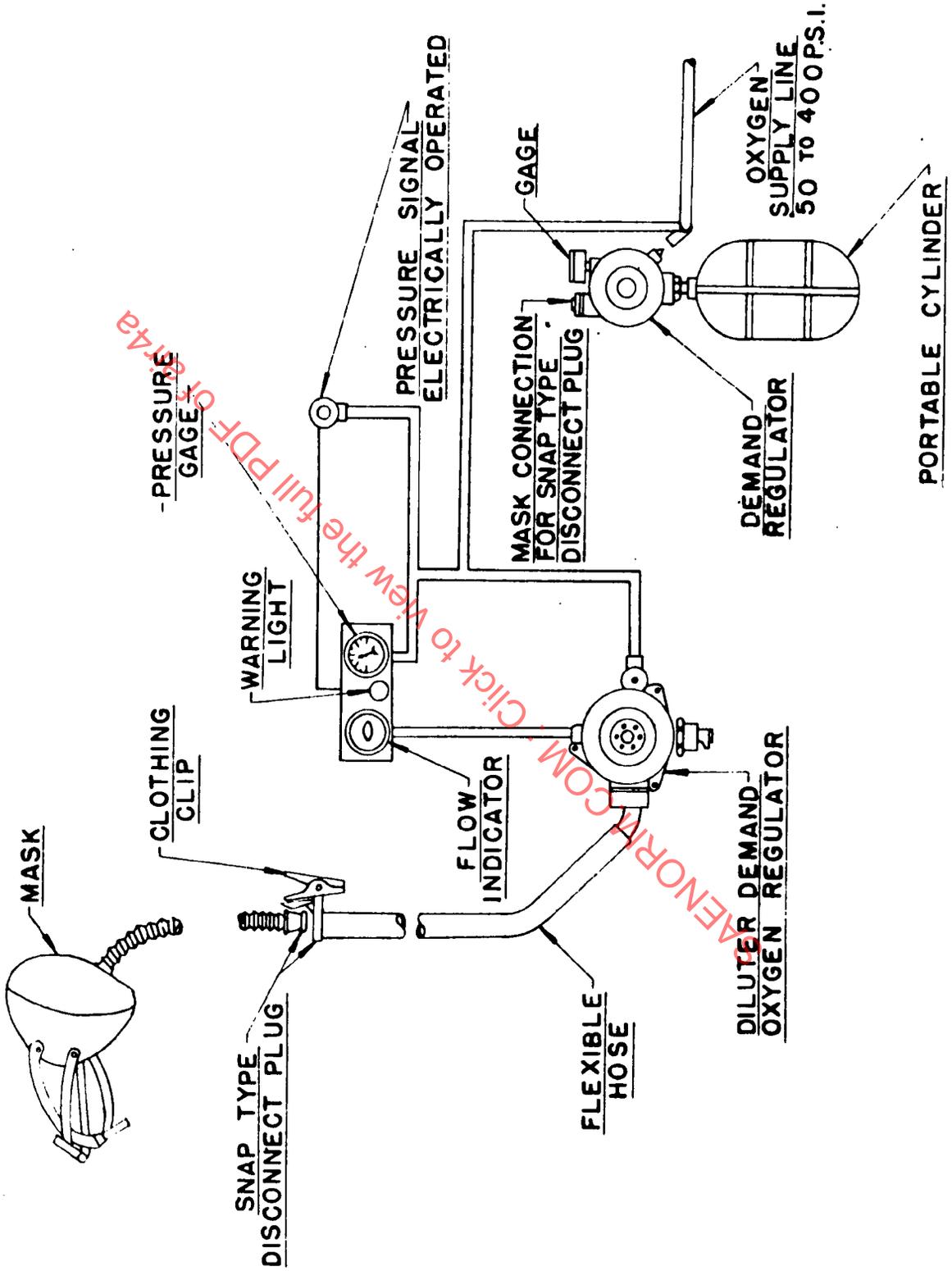


FIGURE III SYSTEM 4

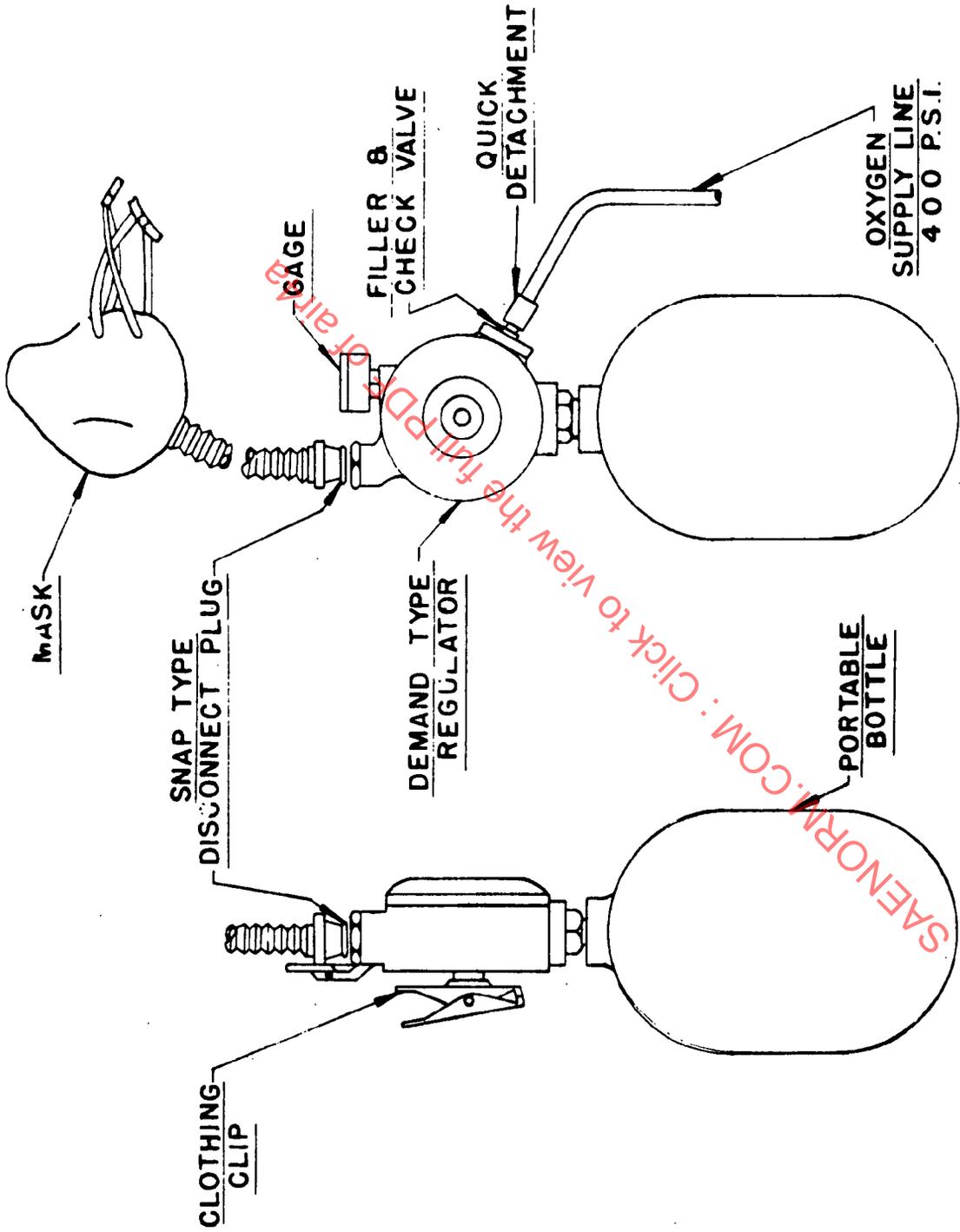


FIGURE IV SYSTEM 5