Pressure Breathing

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THE INCREASING ALTITUDE performance of newer military aircraft has necessitated the development of a new type of oxygen system which gives aircrews at altitudes in excess of 35,000 feet greater protection against anoxia than can be obtained from the present demand system. The practical ceiling for the breathing of pure oxygen is approximately 42,000 feet for brief periods. The ceiling for continued operation can be increased several thousand feet by increasing the pressure of the oxygen in the lungs throughout the respiratory cycle by from 15 to 25 mm. Hg (or 8 to 12 inches of water pressure) above the ambient pressure.[3, 4] With such pressures a few minutes at 50,000 feet can be tolerated in an emergency.

Pressure breathing as now practiced will not completely prevent anoxia at altitudes above 43,000 feet. At 45,000 feet, using 20 mm. Hg pressure breathing, blood oxygen saturations approximate those found in subjects breathing air at 14,000 feet. Nearly two years of experience with the altitude chamber and aircraft indicate that normal subjects can maintain useful consciousness and carry out normal duties for one-half hour or more at 45,000 feet if pressure breathing is used. However, considering the increased incidence of "bends" and gas pains at these higher altitudes as well as the advisability of maintaining the highest possible blood oxygen saturation at all times, pressure breathing is not a substitute for cabin pressurization. Until cabin pressurization is perfected, pressure breathing will permit pilots to fly aircraft above 40,000 feet when military requirements or flight testing demand. Its usefulness should not end there. Pressure breathing should also be useful as emergency equipment in pressurized aircraft, which are in danger of loss of pressure through accident or enemy action. It is assumed that planes will not be pressurized to such a differential that oxygen can be dispensed with at extreme altitudes. Since the crew will be using an oxygen system at altitudes above 40,000 feet even in pressurized aircraft, it will be no problem to provide them with a pressure breathing system. Failure of the cabin pressure at altitudes between 42,000 and 50,000 feet would not involve as serious danger of sudden unconsciousness of the crew if the pressure breathing system were used as it would if the simple demand system were used. Crew members would simply turn up the pressure on the oxygen regulator and maintain useful consciousness at least until the aircraft could be brought to safer altitudes.

The most important immediate function of pressure breathing is the use of safety pressure between 35,000 and 40,000 feet. Blood oxygen saturation even with 100 per cent oxygen and a perfectly functioning demand system begins to fall off at approximately 37,000 feet. Because of imperfect fitting, continuous head movements of combat pilots, and other factors, mask leakage may bring this point to much lower altitudes. In order to initiate oxygen flow in the present demand system it is necessary to create a negative pressure in the mask. Where a mask leak exists, ambient air is drawn into the lungs, diluting the 100 per cent oxygen which is necessary for adequate saturation. The Germans long ago realized this danger and attempted to counteract it by equipping their demand regulators with an aneroid which automatically caused a metered continuous flow of oxygen into the mask, beginning at an altitude well below 30,000 feet.[9] This is uneconomical. The same purpose can be effected by a continuous mask pressure of from 1 to 2 inches of water. Since the system is still the demand type, this entails no increased use of oxygen unless a mask leak is present. Such safety pressure is a guarantee against inboard leakage and at worst results only in a small loss of oxygen.

Pilots using 2 to 4 inches of water pressure on combat missions at 30,000 feet and above return from long missions feeling far less fatigued than when using the demand system,[2] and aircrew members seem better able to carry out their duties, particularly when they entail considerable physical activity at altitudes of 35,000 feet and above.

Physiological Considerations

There are several methods of applying positive pressure, all of which have been used extensively in experiments and several of which have been used in combat. Although each of the methods has its advantages and limitations both physiological and practical, this discussion will be limited almost entirely to the method adopted by the AAF. In this system the intrapulmonary pressure is maintained at as constant a level as possible above the ambient pressure throughout the respiratory cycle. In actual practice expiratory pressure is somewhat higher than inspiratory.

During continuous pressure breathing, inhalation requires no effort, while a definite effort must be made to exhale against the pressure. Intermittent pressure breathing, in which the pressure falls off from the maximum during exhalation, was developed partly as an answer to this abnormal state. But intermittent positive pressure may cause hyperventilation,[10] and the subject may go into frank tetany, finally becoming unconscious, while maintaining a high blood oxygen saturation.

Contrary to prevalent belief, it is possible to breathe continuously against moderately high exhalation pressures. Exhalation resistance up to 4 inches of water pressure is easily tolerated; 8 inches is marginal;[7] and 12 inches requires a considerable muscular effort. Human subjects under pentothal surgical anesthesia continue to breathe against continuous pressures as high as 12 inches of water.[1] The exhalation effort of pressure breathing is greatly reduced at high altitude, where the

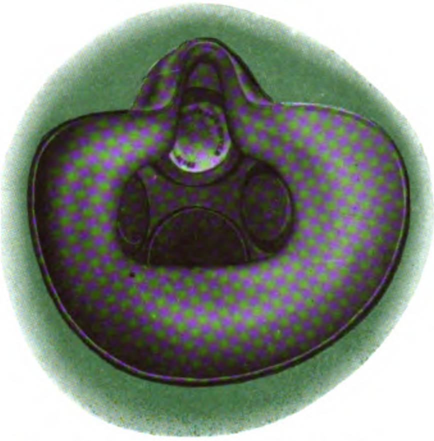

Fig. 1—*Facial view of A-15 Pressure Demand Oxygen Mask. The A-13 mask is standardized for limited procurement. The A-15, an experimental mask, will be standardized soon.*

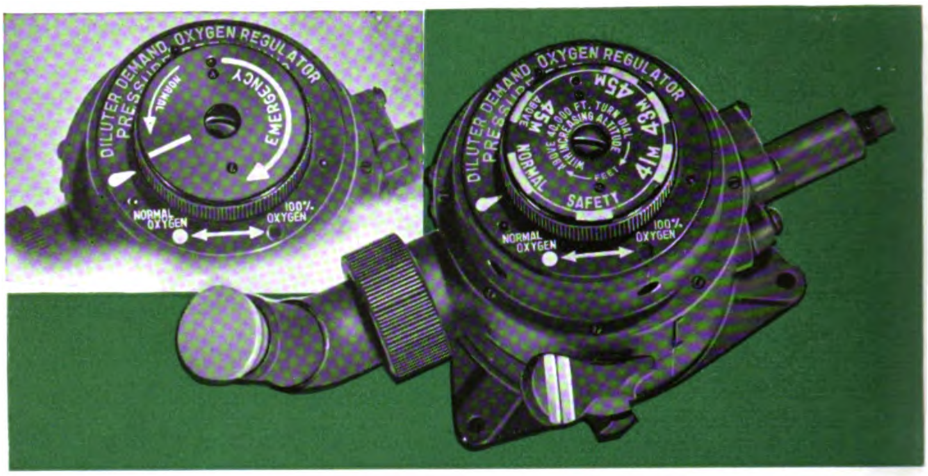

Fig. 2—The A-14 Diluter Demand Pressure Breathing Regulator with dial face used for pressure breathing. Insert shows reverse face of dial for use as a simple diluter demand regulator. Dial disk can be quickly reversed by removing two small screws.

density of the inhaled oxygen is much less than at sea level. For this reason one can get a true impression of pressure breathing only in flight or in the altitude chamber above 35,000 feet. The difficulties of breathing against safety pressure (1 to 2 inches of water) are negligible and this discussion is applicable only to the limited use of pressure breathing at extreme altitudes.

The value of positive pressure breathing at altitudes above 40,000 feet lies in the increase in partial pressure of oxygen in the lungs and in the consequent rise in oxygen saturation of arterial blood. This is particularly important in the range of 40,000 to 50,000 feet, where the limiting partial pressures necessary for maintenance of life with 100 per cent oxygen are approached, and where a change in partial pressure corresponding to those used in pressure breathing represents a considerable increase in effective altitude.

Experience in actual flight and in the altitude chamber indicates that the water pressures optimum for comfort and efficiency at altitudes above 38,000 feet[5] are as shown in table 1. Table 3 shows equivalent altitudes for air, demand oxygen, and pressure breathing, with blood oxygen saturations from both calculated and experimental data.

One factor which may limit the use of pressure breathing is its effect on circulation. Continuously maintained increase in intrathoracic pressure should theoretically impede venous return to the right side of the heart,[8] but it has been found that levels of pressure adequate to maintain operational aircrews at 45,000 feet do not cause marked circulatory impairment,[10] The effect of the increased pressure is partially counteracted by a compensatory rise in venous pressure. Although stroke volume may be reduced, cardiac output is maintained at near normal levels by a rise in pulse rate.[10] Increased peripheral vasoconstriction also tends to maintain circulating blood volume and arterial pressure in the face of potentially reduced cardiac output.

A positive pressure of 8 inches of water can be tolerated by nearly all normal and trained individuals. Above 8 inches positive pressure the frequency of individuals suffering circulatory failure, although small, may increase. Subjects susceptible to circulatory failure are rare, especially among combat personnel who are a highly selected group both physically and mentally. Circulatory collapse during pressure breathing can be induced by pain, especially that caused by gaseous distention of the stomach and by bends. Fear also contributes to collapse during pressure breathing. In such cases release of pressure and lowered altitudes will usually bring immediate relief. On the other hand, confidence, experience, and practice with pressure breathing are good insurance against circulatory collapse, especially within the pressure limits previously outlined (table 1).

Mechanical aids in pressure breathing, though helpful, are limited by practical considerations. Covering the thoracic cage with an elastic corset or pneumatic vest may ease respiratory effort, but it will not alter the circulatory effects of increased intrathoracic pressure.[10] To improve venous

TABLE 1

OPTIMUM WATER PRESSURE FOR PRESSURE BREATHING OF PURE OXYGEN ABOVE 38,000 FEET

Altitude in feet	Pressure for Breathing
39,000	2 inches of water
41,000	4 inches of water
43,000	6 inches of water
45,000	8 inches of water
50,000	12 inches of water

TABLE 2

OXYGEN PRESSURE DELIVERED BY A-14 REGULATOR

Dial Setting	Altitude Range in thousands of feet	Delivery mm. Hg	Pressure in. H_2O
Normal	10—30	0	0
Safety	30—40	2	1
41 M	40—41	8	4
43 M	41—43	11	6
45 M	43—45	15	8
Above 45 M	45—48	23	12

return appreciably, the compensatory pressure must be applied over the abdomen and possibly the thighs. The disadvantages in the way of bulk, complexity of equipment, loss of evaporative cooling of skin surfaces, and difficulties of fitting outweigh the advantages of better venous return and higher potential pressures that may be gained with present protective garments. For continuous positive pressure breathing without respiratory aids, practice and experience minimize the possible danger from hyperventilation.

In the altitude range of 35,000 to 50,000 feet, where pressure breathing may be utilized, one of the important tactical factors that limits operations is the incidence of aeroembolism, or bends. Another is abdominal distention which occurs with greater frequency at these higher altitudes.

Positive pressure breathing up to 12 inches of water is not sufficient to cause any discomfort from distention of the tympanic membranes. Its effect on the auditory threshold is believed to be negligible. During descent from altitude, use of positive pressure breathing has been found by some to have a favorable effect on aeration of the middle ear and maintenance of the patency of the eustachian tube.

TABLE 3

ALTITUDES FOR EQUIVALENT ARTERIAL OXYGEN SATURATION WHEN BREATHING AIR, OXYGEN, AND OXYGEN UNDER PRESSURE*

Arterial O_2 Saturation	Breathing Air	Breathing O_2 (10% mask leak)**	Breathing O_2 (no leak)	Pressure Breathing O_2	Pressure (inches water)
95%	3,000 ft.	33,000 ft.	35,000 ft.	38,000 ft.	2
90%	10,000 ft.	37,500 ft.	40,000 ft.	42,000 ft.	4
85%	13,000 ft.	39,000 ft.	41,500 ft.	44,500 ft.	8
80%	15,000 ft.	40,000 ft.	42,500 ft.	45,500 ft.	8
75%	17,000 ft.	41,000 ft.	43,500 ft.	46,000 ft.	8
70%	18,000 ft.	41,500 ft.	44,000 ft.	49,000 ft.	12

* The figures in this table are combined from calculated and observed data.[6]

** Assuming that leaks up to 10% are to be expected with the simple demand system, the use of pressure breathing raises the ceiling from 4-5000 feet before serious anoxia begins to set in. In producing this result, the elimination of the effects of mask leakage is at least as important as the increase in alveolar O_2 tension.

Pressure Breathing Oxygen Equipment

Pressure breathing equipment must be integrated with the present AAF demand oxygen system. Like the present demand system, it must be integrated with present AAF flying clothing, helmets and goggles; it must operate under conditions of extreme cold; and finally, it must be simple in construction, reliable in operation, and easy to use. The equipment consists essentially of two items, the A-13 (cover photo) or A-15 pressure demand mask and the A-14 pressure demand regulator.

A-13 and A-15 Masks.* These masks have all the features of a good demand mask and, in addition, seal comfortably on the average face for positive pressures up to 8 to 12 inches. The requirement for both a suction and pressure seal has made necessary two new design features: (a) a complete rolled inside flap (fig. 1), and (b) a rigid front shell.

As in all demand-type masks, to avoid failure due to freezing, re-breathing must not occur through any part of the inspiratory passages to the mask bowl and the expiratory passage must be as short and direct to the outside as possible. To meet this condition there has been developed a special exhalation valve (fig. 3) which loads with an exhalation resistance slightly higher than the supply pressure from the regulator. On the oxygen inlets to the mask are two cheek check valves which close during exhalation when the mask pressure is higher than the supply pressure.

One final factor involved in the use of the pressure demand type oxygen mask is the tension of the mask on the face. It should never be held on the face tighter than necessary to hold the pressure in use. If this procedure is followed, maximum comfort will be attained; otherwise the mask grips the face harder than the pressure requires and causes unnecessary discomfort.

A-14 Regulator. The A-14 Diluter-Demand Pressure Breathing Regulator (fig. 2) combines the standard features of a diluter-demand regulator with a dial-operated mechanism for manually adjusting spring-pressure applied to the valve diaphragm (fig. 4). When pressure is so applied, an equivalent delivery pressure of oxygen must be built up in order that the demand valve may close and the user may exhale. When the dial is in the "Normal" position, there are no torsion forces acting on the spring, and the regulator functions as a conventional demand regulator merely by responding to the changes in pressure during normal respiration, supplying oxygen or an oxygen-air mixture, at ambient pressure. Sufficient oxygen is delivered to the flyer at altitudes as high as 37,000 ±2,000 feet. By turning the dial to "Safety" between the altitudes of 30,000 and 40,000 feet, an additional margin of safety is gained because oxygen will be delivered to the user under one inch of water pressure, thus eliminating any danger of inboard leakage. Above these altitudes oxygen must be delivered under higher positive pressure. This is effected by turning the dial up, consequently applying a torsion force on the spring and thus loading the diaphragm by a proportional amount. For practicability, the dial is calibrated in terms of altitude so that if the dial setting compares with the altimeter reading, or exceeds it, oxygen delivery pressure will be sufficient. The actual oxygen pressures in terms of inches of water at dial settings between "Normal" and "Above 45M" and their effective ranges are as shown in table 2.

*The A-13 mask is an original development by Captain F. E. Randall, AC, Aero Medical Laboratory, Wright Field, Dayton, Ohio. The original models were made from plaster molds and were latex-dipped at Wright Field. Samples of this mask were then submitted to the Mine Safety Appliances Corporation for development as a production item.

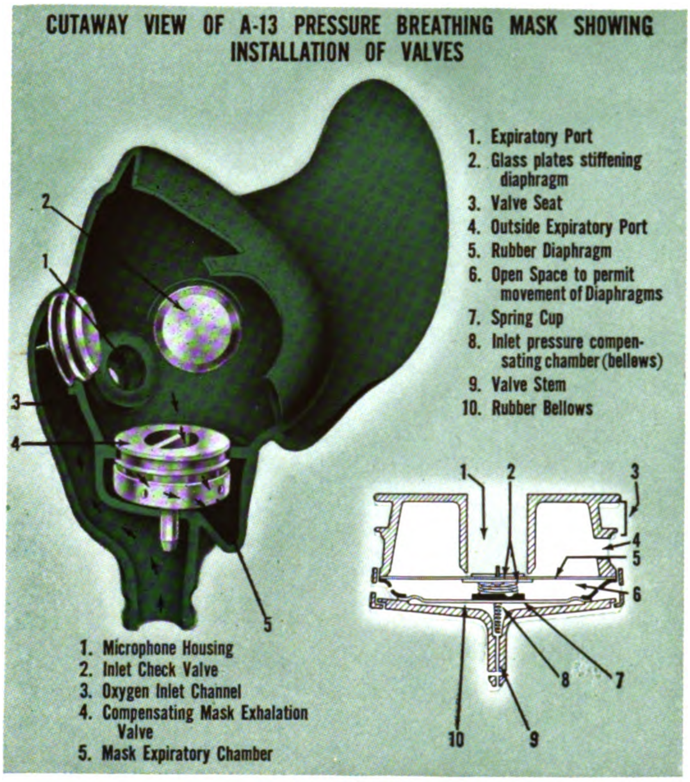

Fig. 3

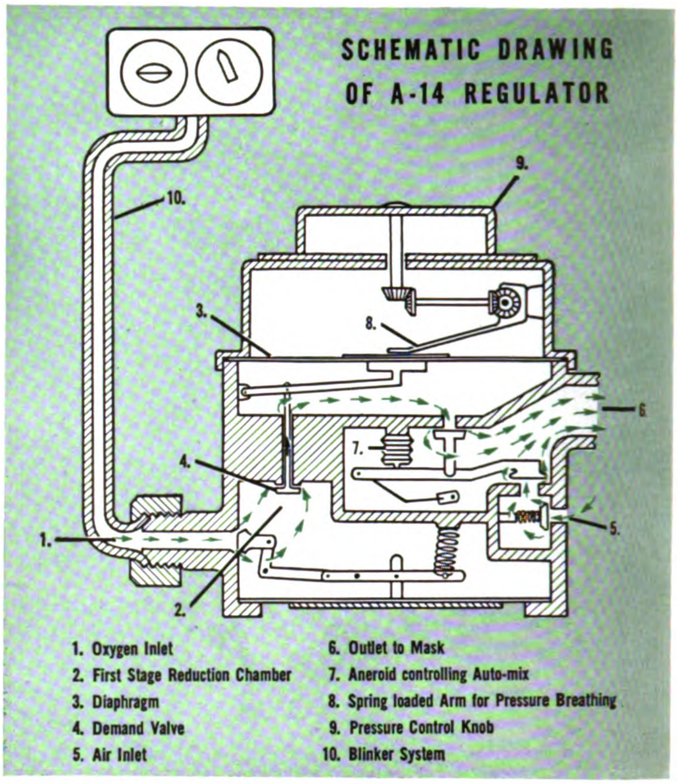

Fig. 4

The A-14 regulator is a station type (for permanent installation) and is designed to operate on an inlet pressure between 500 and 50 pounds per square inch. If positive pressure is not to be used and the dial is set at "Normal," the regulator may be used in conjunction with a standard demand oxygen mask. If pressure is to be used it is necessary that an A-13 or A-15 (pressure breathing) mask be used with it. Since these masks may also be used for demand, it is recommended that they be the only masks used with the A-14 regulator when the altitude calibrated dial is used.

An additional feature of the A-14 regulator is a reversible dial plate. One side of the dial plate is calibrated for pressure breathing. The reverse side renders the regulator practicable for use as a simple diluter-demand regulator (fig. 2). It is a simplified dial showing the "Normal" position and an arrow labelled "Emergency" showing the direction in which the dial must be turned to give an emergency flow of oxygen. It is recommended that this face of the dial be used when the conventional demand masks, A-10 and A-14, are used regularly.

This AAF pressure-demand oxygen equipment is now in limited production and is used by Photo Reconnaissance Squadrons in certain types of operations. There are other types of pressure breathing equipment in use by other air forces or under development by the AAF. Clinical applications of positive pressure also have been considered. These will be covered in subsequent issues of *The Bulletin.*

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