

## CHAPTER 1

### OXYGEN EQUIPMENT AND ASSEMBLIES

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#### **Introduction**

1. The fundamental physiological requirement for any oxygen system is the delivery of the correct oxygen mixture at any particular altitude. In general, an oxygen system consists of three parts: a store of oxygen, a regulator, and a mask which covers the nose and mouth and provides a gas-tight seal on the face. The method of oxygen storage is not normally of physiological interest, but the regulator and mask design must be based on physiological considerations.

2. The flow characteristics of the system must be such that sufficient oxygen can be delivered to meet the requirements of each individual without noticeable resistance to breathing or other discomfort. It has been found that the ideal system must be able to provide up to 50 litres of oxygen a minute, but should also be capable of a peak flow rate as high as 125 litres a minute, if required. The system should be so designed that the maximum resistance to gas flow, due to the various components such as reducing valves,

regulator, pipes, hoses and so on, is tolerable. It has been shown that, if the resistance of any respiratory system is increased beyond a certain level, the breathing rhythm changes from slow and deep to rapid and shallow and that extremely disturbing symptoms, associated with signs of impending asphyxia, are experienced. There is little doubt that high back pressures can result in respiratory fatigue and in certain susceptible subjects to hyperventilation. A negative pressure not exceeding 50 mm of water is therefore specified.

3. In order for oxygen to be of a satisfactory standard, the following requirement must be met:

- a. Free from odour.
- b. Not less than 98.5% pure.
- c. Free from any toxic substance, such as degreasing agents.
- d. Contain not more than 0.002% of carbon monoxide.
- e. A sample of the oxygen drawn from a cylinder charged to between 1,600 and 2,000 psi shall not contain more than 0.02 grams of water per cubic meter (standard temperature and pressure) as measured by means of a high pressure hygrometer of approved type.

4. The earliest form of oxygen equipment gave a continuous flow of oxygen, through a "pipe stem" or simple mask. Such a system was both inefficient and uneconomical and two new systems came into being and are still in current use:

- a. The British Economizer system.
- b. The Pressure Demand system.

### BRITISH ECONOMIZER SYSTEM

#### General

5. The early direct flow oxygen system was very wasteful because oxygen flowed into the mask the whole time, whereas inspiration only occupied two-fifths of the breathing cycle. In order to overcome this problem a system was developed in which an economizer was incorporated in the oxygen line between the regulator and the man. The main components of the system are:

- a. *Oxygen Store.* The oxygen is stored at a pressure of 1,800 psi in steel cylinders wound with wire to prevent shattering. From these cylinders it is piped to a regulator, located within reach of the user.
- b. *Regulator.*
  - (1) The function of the regulator is to reduce the pressure of the oxygen and pass it on to the user at a suitable flow rate. The three regulators in current use with economizer systems are the Mk 10, Mk 11 and Mk 16.
  - (2) There are two flow indicators on the Mk 11 and Mk 16 regulators, but these only indicate flow as far as the regulator and not beyond, thus in the economizer system, it is essential for the user to feel puffs of oxygen coming into the mask, in order to be sure that the supply is reaching

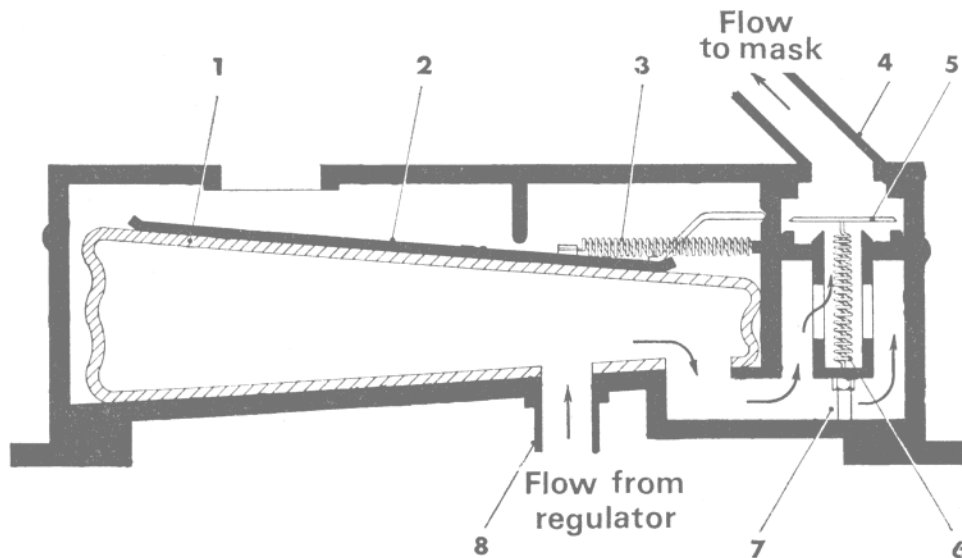


Fig 1 Principle of Oxygen Economizer

- |                         |                            |                                       |                         |
|-------------------------|----------------------------|---------------------------------------|-------------------------|
| 1. Flexible Storage Bag | 2. Moulded Breathing Plate | 3. Spring for Loading Breathing Plate | 4. Flexible Outlet Tube |
| 5. Mica Valve Disc      | 6. Valve Spring            | 7. Valve Chamber                      | 8. Inlet Pipe           |

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### OXYGEN EQUIPMENT AND ASSEMBLIES

him. A "puff-check" is best done, under ideal conditions, before starting up the engines and it is often easier to feel oxygen if the mask is held over the eyes.

c. *Economizer.* The economizer consists essentially of an inflatable bag into which oxygen flows from the regulator. The out-flow from the bag is guarded by a trip valve. During the expiratory phase of respiration the trip valve closes and the oxygen, which would otherwise flow to waste, inflates the bag. During inspiration the valve lifts and the bag deflates, discharging oxygen into the mask. When the bag is fully inflated, the valve lifts anyway and the oxygen is discharged into the mask. The economizer enables the endurance of a single oxygen cylinder to be doubled.

#### Flow Indicators

6. Flow indicators are fitted between the regulator and the economizer at all stations which are not within sight of a regulator. Each indicator shows whether or not oxygen is flowing, but gives no indication of the magnitude of the flow nor whether the oxygen is reaching the mask.

#### Cut-Off Valves

7. Where more than one economizer is supplied from a regulator, a cut-off valve is introduced to prevent wastage from the supply point when not in use. The valve is so designed that the action of stowing the end of the economizer tube in a clip, which is part of the valve, automatically cuts off the supply to the corresponding economizer. A small plastic plate with two luminous spots attached to the valve permits easy location in darkness.

#### Mark 10 Series Oxygen Regulators

8. Mk 10 series regulators are designed to supply aircraft carrying over eight and up to 50 men (Mk 10A and Mk 10B). They embody the following components:

- a. An ON/OFF valve.
- b. A pressure gauge graduated from FULL to EMPTY.
- c. A flow control knob which is adjustable, to vary oxygen pressure to the economizer or to L masks.
- d. A flow gauge, graduated in thousands of feet, which is, in fact, a pressure gauge.
- e. Several fixed orifices, which are not part of the regulator. One orifice is required to supply each station and it takes the form of a jet in a manifold. There may be several manifolds in each aircraft.

9. *Flow Testing.* To check the oxygen flow, open the master high pressure (HP) valve before turning on the regulator valve (when closing, turn off the regulator valve before closing the master HP valve). With two oxygen outlets open, turn the flow control knob fully ON and check that the pointer of the flow gauge moves steadily from about zero to the full EMERGENCY flow. Close the flow control knob and see that the pointer of the flow gauge returns smoothly to about zero.

10. *Use in Flight.* The following regulator settings should be used under the conditions listed below:

a. *In Level Flight.* The regulator should be set at the next multiple of 5,000 ft above the cabin altitude.

b. *At Low Rates of Climb.* When the cabin altitude is rising at less than 2,000 fpm the regulator should be set at 15,000 ft when the cabin altitude reaches 10,000 ft. It should then be set in stages to the next multiple of 5,000 ft above the cabin altitude.

c. *At High Rates of Climb.* When the cabin altitude is rising at more than 2,000 fpm the regulator should be set at 25,000 ft from ground level up to that height, and set at 40,000 ft at cabin altitudes above 25,000 ft.

d. *At High Speeds.* When flying at a TAS greater than 400 kt, the regulator should be set at 25,000 ft from ground level up to that cabin altitude and set at 40,000 ft at cabin altitudes above 25,000 ft.

e. *At Night.* When oxygen is used at night, the regulator should be set at 25,000 ft from ground level. When level flight is attained, or when cabin altitude rises above 25,000 ft, the appropriate settings defined above for climbing, high speed, or level flight should be made. Bear in mind the need for oxygen from 4,000 ft upwards, because of the effect of **anoxia** on night vision. *HYPoxIA* AL.3

f. *At 35,000 Ft and Above.* As a precaution against sudden loss of cabin pressure, the regulator should be set at 40,000 ft when the aircraft indicated altitude is above 35,000 ft, irrespective of the altitude indicated by the cabin altimeter. This regulator has no pressure breathing facility and should not be used above 40,000 ft.

g. *In Emergency.* The regulator can be set to give a high flow at any height by selecting EMERGENCY flow, the delivery dial then indicating in the sector marked EMER-

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GENCY. This is for use only if a restriction of the oxygen supply is suspected or to combat fumes.

h. *When Carrying Passengers in Transport Aircraft.* When the cabin altitude reaches 12,000 ft and is rising, the regulator should be set to the next multiple of 5,000 ft above the cabin altitude and to the cabin altitude on attaining level flight. The altitude limitation of the passenger mask Type L (Fig 2) is 30,000 ft cabin altitude, and its low temperature limitation is  $-5^{\circ}\text{C}$ .

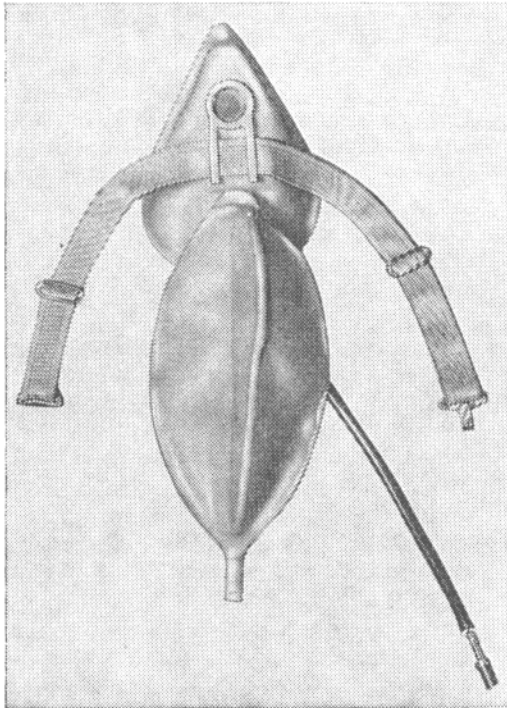


Fig 2 Passenger Mask Type L

### Mark 11 Series Oxygen Regulators

11. Mk 11 series regulators are designed to supply either one man (Mk 11C) or two men (Mks 11D and 11E). They eliminate the re-adjustment for each change of height of 5,000 ft which is required by the Mk 10 series. Mk 11 series regulators embody the following components:

- a. An ON/OFF valve.
- b. A contents gauge.
- c. A reducing valve giving constant reduced pressure.
- d. A flow change switch which has two positions, NORMAL up to 25,000 ft and

HIGH above 25,000 ft. In the NORMAL position, oxygen is allowed to flow through one fixed jet and in the HIGH position through two fixed jets.

e. A flow indicator, comprising two perspex tubes with a float in each. When there is no oxygen flow, the floats rest at the bottom of the tubes and are out of sight. When the oxygen flow is at NORMAL, one float is visible in the right-hand tube. When the flow is at HIGH, both floats are visible.

12. On Mk 11C regulators (Fig 3) an EMERGENCY flow control valve is fitted. This valve, when operated by the lever on the regulator, permits a much increased flow of oxygen to pass through the reducing valve to the user.

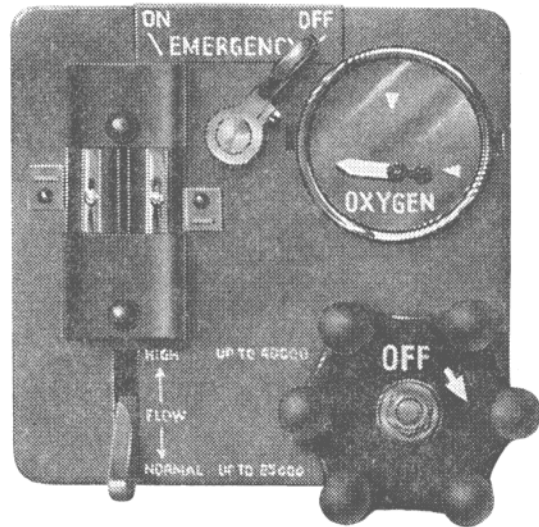


Fig 3 Oxygen Regulator of the Mk 11 Series

13. The Mk 11D regulator is used in conjunction with the Mk 11E to supply two men. The Mk 11D is fitted with an EMERGENCY control valve and is similar to the Mk 11C, except that it supplies oxygen through the Mk 11E for use by a second crew member. (The Mk 11E has no contents gauge, reducing valve or stop valve.)

14. **Flow Testing.** To check the oxygen flow ensure that the float in the right-hand tube of the flow indicator has risen with the flow change switch at NORMAL and that the float rises and falls in the left-hand tube when the switch is operated. Close the regulator ON/OFF valve and ensure that:

- a. The pointer of the contents gauge returns to zero.
- b. Both floats in the flow indicator drop out of sight.

15. **Use in Flight.** The following settings should be used under the conditions shown below:

- a. In unpressurized aircraft, the regulator should be locked at HIGH flow for all flights.
- b. In pressurized aircraft, HIGH flow should be selected by the pilot before take-off on all flights to be carried out above 25,000 ft cabin altitude. On multi-seat aircraft, however, only the pilot should select HIGH flow at ground level. The remaining crew members should use their regulators in accordance with sub-para 18a to 18e, except that for 30,000 ft read 25,000 ft in all applicable sub-para.
- c. As a precaution against a sudden loss of cabin pressure, the regulators should be set at HIGH flow when the aircraft altitude is above 40,000 ft, or at any altitude when under combat conditions.

**Mark 16 Series Oxygen Regulators**

16. Mk 16 series regulators are basically oxygen regulators of the Mk 11 series with the addition of an aneroid mechanism which automatically increases the oxygen flow from NORMAL to HIGH on reaching about 30,000 ft cabin altitude. On descending below this altitude, the aneroid mechanism must be reset manually to reduce the oxygen flow to the correct value. The manual control can also be used to override the aneroid mechanism to give HIGH flow when necessary at altitude below 30,000 ft. As, however, the cabin altitude in pressure-cabin aircraft should not normally exceed 30,000 ft, HIGH flow is usually only required in an emergency. In comparison with Mk 11 series regulators, the NORMAL oxygen flow of Mk 16 series regulators is slightly increased owing to the increase in the change-over altitude from 25,000 ft to 30,000 ft. Mks 16A, B and C regulators, corresponding to Mks 11C, D and E respectively, supersede the Mk 11 series regulators.

17. **Flow Testing.** To check the oxygen flow see that the flow change switch trips smoothly into the HIGH position when the latch on the underside of the lever is depressed. Ensure that the float in the right-hand tube of the flow indicator has risen when the flow change switch is at NORMAL and that the float in the left-hand tubes rises and falls as the switch is operated. Close the regulator ON/OFF valve and ensure

that the pointer of the contents gauge returns to zero and that both floats in the flow indicator drop out of sight.

*Note:* As the increased flow above 30,000 ft is automatic it is necessary only to select HIGH for test purposes and in certain emergencies, eg toxic fumes in the cockpit.

18. **Use in Flight.** The following settings should be used under the conditions shown below:

- a. *In Level Flight.* The regulator should be set at NORMAL up to 30,000 ft cabin altitude.
- b. *At Low Rates of Climb.* When the cabin altitude is rising at less than 2,000 fpm the regulator should be set to NORMAL at 10,000 ft.
- c. *At High Rates of Climb.* When the cabin altitude is rising at more than 2,000 fpm the regulator should be set to NORMAL from ground level.
- d. *At High Speeds.* When the aircraft is flying at a true air speed greater than 400 kt, the regulator should be set to NORMAL from ground level up to 30,000 ft cabin altitude.
- e. *At Night.* When oxygen is used at night, the regulator should be set to NORMAL from ground level up to 30,000 ft cabin altitude. Bear in mind the need for oxygen from 4,000 ft upwards, because of the effect of *anoxia* on night vision. HYPOxia AL 3
- f. *At Heights Above 30,000 Ft.* If cabin pressure is lost, the regulator automatically changes to HIGH flow when the cabin altitude reaches 30,000 ft.
- g. *Resetting.* After the regulator has automatically changed to HIGH, as a result of a fall in cabin pressure, it should be reset by hand to NORMAL when below 30,000 ft.

**Automatic Line Valve Mark 1**

19. The Automatic Line Valve Mark 1 shown in Fig 4, is designed primarily for use in fighter-type and training aircraft using oxygen regulators of the Mk 11 and Mk 16 series and ensures that the oxygen supply is always on when the aircraft is flying at altitudes where oxygen is required.

20. The valve is fitted into the HP oxygen supply line of the Mk 11 or Mk 16 Series regulators and the regulators must have their ON/OFF valve wired in the ON position.

21. The pilot switches on his oxygen by means of the ON/OFF switch on the cover of the line valve but should he not do so, an aneroid

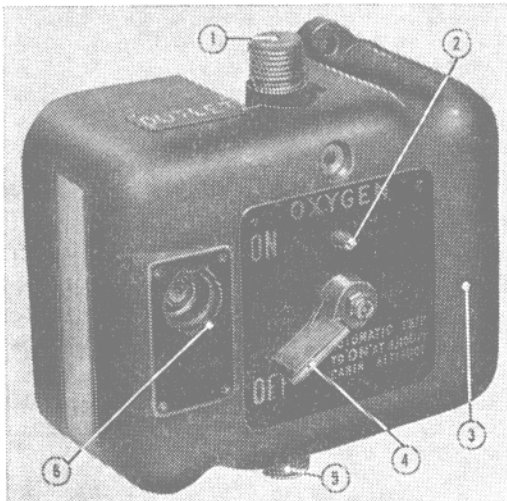


Fig 4 Automatic Line Valve Mk I

- 1. Outlet Connection
- 2. Handle Stop
- 3. Cover
- 4. Operating Handle
- 5. Inlet Connection
- 6. Cover Plate/Test Point Connection

capsule incorporated in the valve will automatically switch on the oxygen supply when the aircraft reaches 8,000 ft. The manual control lever on the automatic line valve must be turned to the OFF position on completion of each flight in order to avoid wastage of oxygen and exhaustion of the aircraft oxygen supply. Above 8,000 ft it is not possible to turn the switch on the line valve cover to the OFF position.

### Oxygen Mask Type H

22. The H type oxygen mask is currently used with the economizer system. The mask incorporates a microphone, twin expiratory valves and an inlet, or check valve. The check valve, which is a lightly spring-loaded inlet valve, permits controlled air dilution of oxygen to take place when the low rate of flow is being used. During inspiration, the first part of the breath consists of oxygen from the economizer. When the economizer is deflated, continued inspiration lowers the pressure within the mask which opens

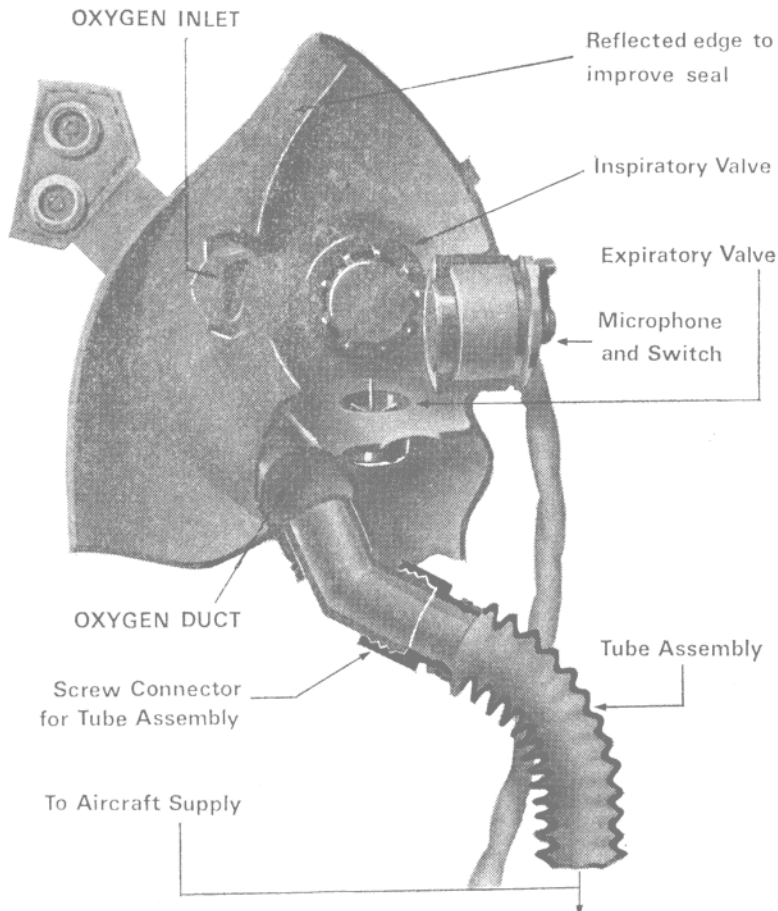


Fig 5 Oxygen Mask Type H

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the check valve and allows air to be breathed in with some oxygen straight through the economizer. When HIGH flow is selected on the regulator, the economizer never fully deflates and the check valve does not open, so there is no air dilution of the oxygen. The H type mask must *not* be used with any pressure demand system *nor* with pressure breathing equipment.

#### Limitations of the Economizer System

23. The economizer system is simple, reliable, safe and comfortable to use, but it has three disadvantages:

- a. It does not cater for changes in breathing rate.
- b. It gives no indication of function to the user other than that oxygen is flowing through the regulator at the normal or high rate.
- c. It cannot conveniently fit in with pressure breathing equipment or pressure suits.

24. The economizer system, therefore, reached the limit of its performance when aircraft began to operate above 40,000 ft. The economizer system was adapted for pressure breathing, but the adaptation had limited value and was only used as an interim measure, subsequently replaced by positive pressure breathing based on the demand system.

#### Adaptation of Economizer System for Pressure Breathing

25. As unpressurized aircraft began to operate above 40,000 ft, it was essential to modify the standard economizer system to afford the aircrew some protection. This arrangement also permitted crews in pressurized aircraft to operate at higher altitude with adequate safeguards in case of pressurization failure. The facility only protected the aircrew for an extra few thousand feet, however, and was not capable of keeping pace with aircraft performance.

26. In order to achieve this improved performance, positive pressure breathing had to be provided in a system where the regulator was simply a pressure reducing valve. Since there was no pressure forthcoming on the input side of the system, it was achieved by restricting the outlet by means of a spring-loaded expiratory valve in the oxygen mask. Thus the wearer had to overcome this resistance in the expiratory valve by building up pressure in the mask before being able to breathe out. This pressure, which depended upon the particular spring setting, was transmitted to the lung spaces thereby raising the

partial pressure of oxygen which facilitated its transfer into the blood stream. Clearly this depended upon a well-fitting mask or leaks would prevent the rise in pressure. Since the economizer bellows was not designed to cope with any back pressure, the economizer was by-passed and oxygen flowed direct from the regulator to the user. In place of the economizer, however, the subject wore a pressure breathing waistcoat, which, like the economizer, acted as a reservoir for oxygen, from which the user breathed. In addition, the waistcoat provided counter-pressure to the chest wall, making breathing easier as the pressure in the lungs increased.

27. The mask used with this assembly was the Type M Mk 2 oxygen mask. A Type N was also introduced for smaller face sizes.

28. The limit of operational flying using the economizer system and its pressure breathing adaptation has long been reached and all modern high performance aircraft are now fitted with the pressure demand oxygen system.

### PRESSURE DEMAND OXYGEN SYSTEM

#### General

29. In 1948 the Royal Air Force decided to adopt the pressure demand system for high altitude aircraft. Since that date, the pressure demand regulator has undergone much development and has been adopted for use with the RAF pressure jerkin system. This latter system permits pressure breathing in excess of 30 mm Hg—the limit of pressure breathing with the mask alone—and will be described separately.

30. The principle feature of the pressure demand system is that it delivers gas to the user only when he breathes in and the amount of gas delivered is automatically matched to the demand.

31. In common with all oxygen systems, the pressure demand system has three main components: the oxygen storage, the regulator and the mask.

#### 32. Aircraft Oxygen Storage.

- a. With certain exceptions, all current RAF aircraft oxygen is stored under high pressure in wire-wound cylinders of varying capacities. The pressure in these bottles, when full, is 1800 psi. The oxygen is piped through the

pressure cabin wall to the demand regulator in the cockpit *via* pressure reducing valves which bring the pressure down to 250-350 psi, which is the working inlet pressure of the panel-mounted demand oxygen regulators. There is a pressure gauge in the centre of the regulator, but since it is reading reduced pressure it will not show any decrease in oxygen delivery pressure until the oxygen system is nearly empty. This is the reason for the separate high pressure contents gauge which is fitted in all RAF aircraft to measure directly the pressure in the oxygen storage bottles.

b. Certain new aircraft are equipped with liquid oxygen systems. The liquid oxygen, which is stored in vacuum flasks, is allowed to evaporate, by means of a heat exchanger, until the pressure of gas builds up to the working level of about 110-150 psi, when this gaseous oxygen is fed directly to the demand regulator.

33. **Pressure Demand Regulators.** The pressure demand regulator is essentially a sensitive valve which, when connected to the oxygen mask by a wide-bore tube, allows oxygen to flow only when the user breathes in. In practice, a number of refinements are added to this basic principle to improve the performance in various ways and these will now be described:

a. *Air-Mix.* At altitudes below 30,000 ft, 100% oxygen is not usually required so the basic demand principle is modified so that air can be mixed with the oxygen in proportions according to the cabin altitude. Air/oxygen mixtures are supplied from ground level up to 30,000 ft, by which time the air-mix orifice has been completely sealed off by an expanding barometric capsule and so 100% oxygen is supplied above this height. The air-mix mechanism possesses two other features: it contains a non-return valve to prevent loss of oxygen, and it can be shut off manually by means of a lever should 100% oxygen be required below 30,000 ft as, for example, in the presence of fumes in the cockpit.

b. *Safety Pressure.* In a simple demand valve, a reduction in the mask pressure, below that of the surrounding atmosphere, is necessary before oxygen will flow from the regulator, so there is a risk of an inboard leak with an ill-fitting mask and the danger of <sup>Hypoxia</sup> ~~anoxia~~. In British demand regulators, this is prevented by the use of safety pressure at altitudes greater than 10,000 ft (cabin altitude). This safety pressure (2mm Hg) is produced by adding a spring loading to the diaphragm which opens the demand valve, thereby altering

the datum for pressure changes in the mask during breathing from ambient pressure, as in the simple demand valve, to 2 mm Hg pressure above ambient. In other words, to prevent flow from the regulator the pressure in the mask must be greater than ambient plus 2 mm Hg. When inspiration begins, the pressure drops below ambient plus 2 mm Hg and oxygen begins to flow while the pressure in the mask is still above ambient. This does not affect comfort but ensures that any leak which occurs will be outward unless breathing is very rapid. There are two small penalties to be paid for this safeguard: firstly, if the mask fit is not good there will be some waste of oxygen and secondly, oxygen will be wasted if a crew position is vacated in flight with the regulator switched on, due to the continuous flow of oxygen when safety pressure is operating.

c. *Indication of Oxygen Delivery.* When the regulator is in use, each delivery of oxygen is signalled by the blinker or doll's eye—depending on the particular series of regulator. In either case the indicator shows white at each breath (in contrast to the black colour of the regulator) thus indicating to the user that he is receiving oxygen from the regulator. The doll's eye is the later type of indicator and will be referred to exclusively in the text. Even if the oxygen supply is exhausted or turned off, it is possible to breathe through the regulator without much difficulty up to 25,000 ft or 30,000 ft, if the air inlet is open (lever set at NORMAL OXYGEN), but the doll's eye will *not* operate however, without oxygen flowing. If the doll's eye remains either white or black continuously, in spite of the user breathing, then there is some fault in the oxygen system. The doll's eye is electrically-operated.

d. *Pressure Breathing.* At altitudes above 40,000ft, oxygen must be delivered to the user at a positive pressure in order to prevent serious <sup>Hypoxia</sup> ~~anoxia~~. The mechanism by which this is carried out is similar to that which produces safety pressure. A barometric capsule acting through a series of levers applies a force to the breathing diaphragm which tends to open the demand valve. In this way, the pressure in the mask is raised, quite automatically, above ambient pressure by increasing amounts as the altitude increases. AL. 3

#### Regulators in Use with Demand Systems

34. The three types of demand oxygen regulator in use in the Royal Air Force differ principally in the relationship between the breathing pressure (that is, the amount of positive pressure

relative to ambient) and altitude. In each case, the breathing pressure increases proportionally with altitude above 40,000 ft, but at any particular altitude above 40,000 ft they each give different pressures:

- a. *Mark 17*—this is used with a pressure demand oxygen mask alone and is designed to give a maximum mask pressure of 30 mm Hg, which it delivers at 50,000 ft.
- b. *Mark 21*—this is used with the pressure breathing mask, pressure jerkin and anti-g suit assembly. It delivers a breathing pressure of nearly 70 mm Hg at 56,000 ft and 30 mm Hg at 45,000 ft. Although this regulator continues to deliver increasing breathing pressures with altitude, its current limit of safe operation is 56,000 ft.
- c. *Mark 20*—this is used with the pressure helmet, pressure jerkin and anti-g suit assembly and delivers a pressure of 100 mm Hg at 66,000 ft. It supplies a breathing pressure of 30 mm Hg at 43,000 ft.

As can be seen, the limiting breathing pressure for the mask alone, of 30 mm Hg is reached at progressively lower altitudes with the three different regulators.

35. On RAF regulators, safety pressure and a fixed breathing pressure may be obtained manually. The required pressures are produced by applying spring loads to the demand valve lever systems. Safety pressure can be selected manually if required at cabin altitudes below 10,000 ft, *eg* in conditions of cockpit contamination (the air-mix lever must be selected to 100% to prevent entry of fumes through air-mix orifice). The ability to select pressure breathing manually is provided for cockpit checks of the oxygen system. With the Mk 17 regulator, the pressure supplied is adequate to test the connector and mask. With the Mk 20 and Mk 21 regulators the pressure obtained is adequate to test the function of the pressure clothing assembly as well. Primarily these tests are used to check for leaks at the mask in all three cases as this is the likeliest cause of this defect.

36. On present RAF regulators, the manual safety pressure position is labelled EMERGENCY. This nomenclature is somewhat misleading in that the operation of the regulator to provide safety pressure and pressure breathing above 10,000 ft is entirely automatic and no manual operation is required.

#### Mark 17 Regulators

37. There are several types of Mk 17 regulator

which differ only in minor detail. The original Mk 17 is of British manufacture whereas the Mk 17B is American made and modified to the same standard as the Mk 17. The Mk 17C is similar to the Mk 17 but is fitted with a remote blinker additional to its normal blinker (four radial slots in the central dial of the regulator which are operated mechanically). The 17D differs from the Mk 17C in that it has the electrically-operated doll's eye situated in the upper left-hand corner of the regulator panel instead of the mechanical blinker slots. Since the Mk 17D is typical of current regulators from the point of view of appearance, it will be used as a basis for a general description of the mark and methods of handling.

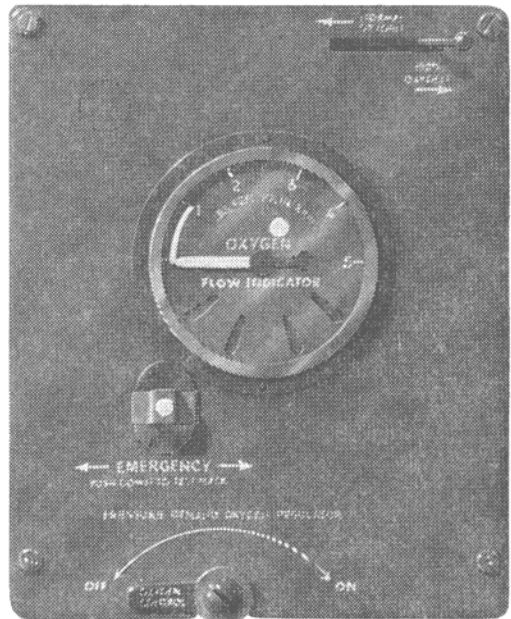


Fig 6 Pressure Demand Oxygen Regulator Mk 17 Series

38. A current type of Mk 17 regulator is shown in Fig 6 and the various features will now be described:

- a. *Manual Control—Normal Oxygen/100% Oxygen.* The manual control lever at the right-hand upper corner of the regulator panel allows the user to select air-mix or 100% oxygen. By selecting 100% oxygen, the addition of cockpit air to the oxygen is stopped. This is useful in the event of toxic fumes in the cockpit since it allows the user to isolate himself from contaminated cabin air.
- b. *Doll's Eye.* In the upper left-hand corner of the regulator panel there is an electrically-

operated doll's eye. This shows white at each breath, thereby indicating that the user is connected to the regulator and receiving oxygen. It should be noted that at cabin altitudes above 10,000 ft, where normal safety pressure is in operation, any outboard leak down-stream of the regulator will be indicated by a continuous white doll's eye.

c. *Pressure Gauge.* There is a pressure gauge in the centre of the regulator but this is of little practical use because it is designed for use in the low pressure American oxygen system. In the Royal Air Force high pressure installations there is a pressure reducing valve between the oxygen cylinders and the regulator which brings it down to an inlet working pressure of between 250-350 psi. Therefore the pressure gauge will not show more than this pressure nor will it indicate any fall in pressure until the cylinder pressure has fallen to less than a quarter. For this reason a high pressure contents gauge is used which measures the pressure in the storage bottles. The limitations of a pressure gauge as a true indication of contents should be appreciated. In a multi-cylinder storage system with some cylinders disconnected, a FULL contents indication is still given when only the connected bottles are fully charged. The presence of disconnected bottles will show up as an apparently high oxygen consumption rate, indicated by a rapidly falling contents reading.

d. *ON-OFF Cock.*

e. *Emergency Toggle Switch.* This is located just below the central pressure gauge. Moving the toggle switch either to the left or right permits the selection of a safety pressure of approximately 4 mm Hg. This has two uses: firstly, it enables the user to carry out a low pressure check of the oxygen mask seal (mask toggle up) to ensure that normal safety pressure (2 mm Hg) can be retained; secondly, it permits the selection of safety pressure below 10,000 ft and an increased safety pressure above 10,000 ft in the event of noxious fumes in the cockpit (in conjunction with 100% oxygen). Pushing the emergency toggle switch in as hard as possible provides a pressure of approximately 30 mm Hg. This also has two uses: firstly, it permits a high pressure check of mask seal (oxygen mask toggle down); secondly, the user can use this pressure in an attempt to blow debris off the mask inlet valve in the event of the valve not closing properly, indicated by difficulty in breathing out. This would be done with the mask off the face for a few seconds.

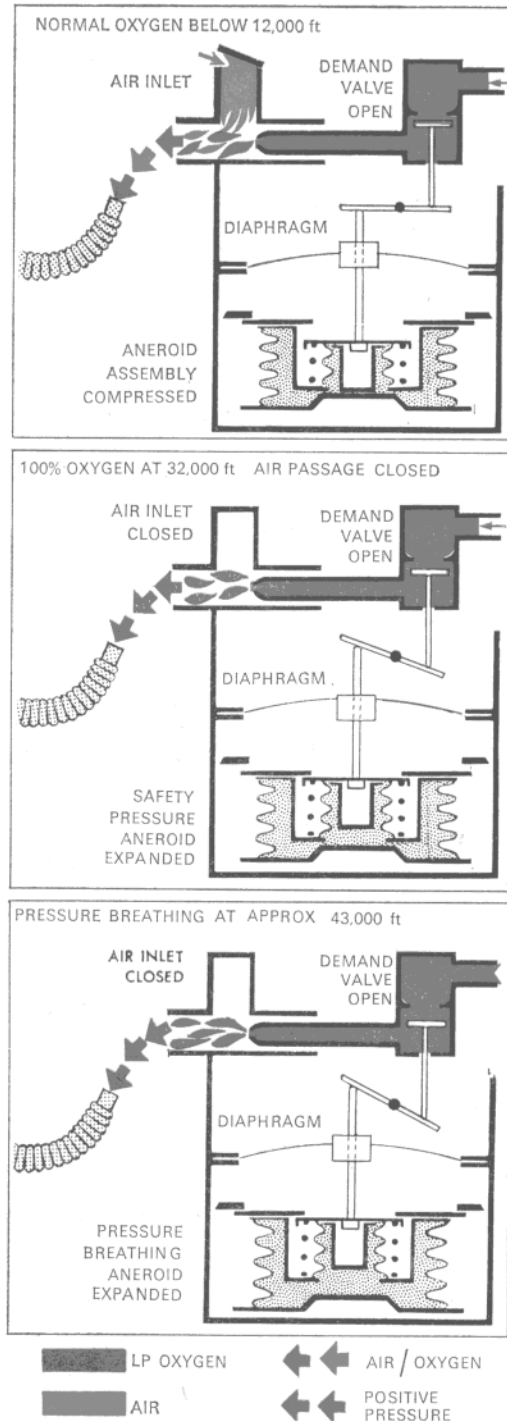


Fig 7 Operation of Mk 17 Regulator

39. One important feature of the system is the protection given if cabin pressure is lost between 40,000 and 50,000 ft. If this happens, the regulator will automatically deliver oxygen at a pressure dependent on the altitude and, if the mask seal is adequate, will help to maintain consciousness and enable a controlled descent from 50,000 ft to be made. During the descent the positive pressure decreases until at 40,000 ft only the safety pressure of 2 mm Hg remains. On loss of cabin pressure an immediate descent should be made at the maximum possible rate to 40,000 ft to prevent <sup>hypoxia</sup> ~~anoxia~~, and a further descent to 30,000 ft to prevent decompression sickness.

40. The personal equipment used with the Mk 17 series regulators and a summary of the protection provided by this aircrew equipment assembly is shown at para 56.

### Mark 21 Oxygen Regulator

41. The Mk 21 regulator (Fig 8) is similar in appearance to the Mk 17 series regulators which are equipped with doll's eyes instead of mechanical blinkers, except for the replacement of the emergency toggle switch by a four-position sweep lever. The following features of the Mk 21 regulator are therefore identical with those on the Mk 17 regulator and their description and function are as described at para 38:

- a. Manual control—Normal oxygen/100% oxygen.
- b. Doll's eyes.
- c. Pressure gauge.
- d. ON-OFF cock.

42. The toggle switch of the Mk 17 regulator, is however, replaced by a sweep-type lever which can be placed in four different positions:

- a. *Normal*. This is the position for routine use of the regulator. The regulator performs automatically giving the correct flow and pressure where necessary, according to the cabin altitude and the regulator performance.
- b. *Emergency*. This position provides a manual selection of a safety pressure of 4 mm Hg and is used in the same way as moving the emergency toggle of the Mk 17 regulator to the left or right, *ie* it is a means of carrying out a low pressure check of mask seal or selecting a 4 mm Hg safety pressure in the event of toxic fumes in the cockpit (100% oxygen is also selected).
- c. *Mask Test*. This, and the next position (*jerkin test*), can only be selected when the knob at the end of the selector lever is with-

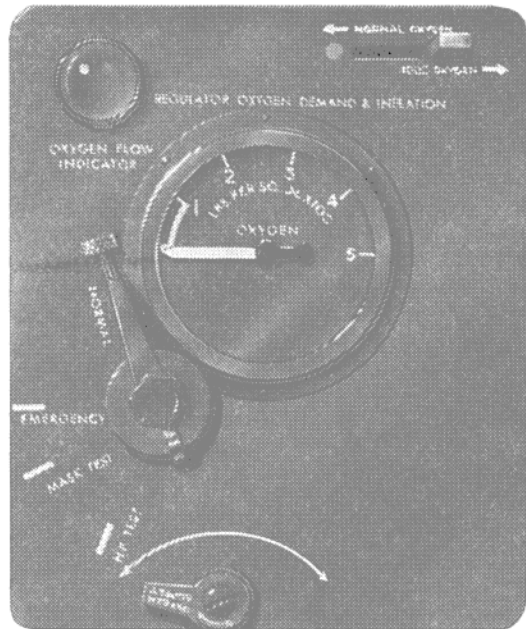


Fig 8 Oxygen Regulator Mk 21

drawn. The mask test position provides a breathing pressure of 30 mm Hg, and is used for the same purpose as when the emergency toggle of the Mk 17 regulator is pushed in hard. It is used as a high pressure test of mask seal when an oxygen mask is being used with a "low level" assembly (without the jerkin/anti-g suit) and as a means of clearing the inlet valve of the oxygen mask.

d. *Jerkin Test*. This provides a breathing pressure of approximately 60 mm Hg, for checking the high pressure face seal of the oxygen mask (mask toggle down) and assessing assembly leakage. *It must be stressed that this position may only be used when the pressure clothing is being worn and in the presence of another individual who could release the pressure if necessary. This position is NEVER used in the air.* The sweep lever is returned to the normal position when any pre-flight checks are completed.

43. Up to 40,000 ft the Mk 21 regulator has the same performance as those in the Mk 17 series. Above a cabin altitude of 40,000 ft, however, it delivers a higher pressure at any given height. At 56,000 ft the delivery pressure is approximately 70 mm Hg and it delivers a breathing pressure of 30 mm Hg at 45,000 ft. Although this regulator continues to deliver increasing breathing pres-

sure as cabin altitude exceeds 56,000 ft, this altitude is its currently accepted limit of safe operation. This is due to the shortfall in breathing pressure below the optimum required for protection above 56,000 ft with the partial pressure assembly currently used with this regulator.

44. The aircrew equipment assembly used with this regulator consists of the P or Q mask, pressure jerkin and anti-g suit. This gives protection from 56,000 ft, in the event of a rapid decompression, provided that only a half minute is spent at that altitude, and that a descent to 40,000 ft can be achieved in a further 1½ minutes. If flown with mask alone, the maximum cabin altitude which can be tolerated after rapid decompression is 45,000 ft, as at this altitude the regulator delivers the maximum acceptable pressure for mask alone (30 mm Hg).

#### Mark 20 Regulator

45. The Mk 20 regulator is exactly the same in appearance as the Mk 21. The two regulators can be identified by reference to the mark number which is stamped on the top centre of the regulator panel.

46. Up to 40,000 ft the regulator performance is the same as the Mk 17 and Mk 21. Above this altitude the Mk 20 delivers a higher pressure, at all heights, than either the Mk 17 or 21 and is capable of maintaining a pressure equivalent to 40,000 ft (141 mm Hg) to all altitudes.

47. The Mk 20 regulator is to be used primarily with the partial pressure helmet/pressure jerkin/anti-g suit assembly, giving protection up to 66,000 ft provided that a rate of descent of 10,000 fpm is initiated within one minute and continued through 40,000 ft. A partial pressure helmet with ear pressurization worn with a combined partial pressure assembly and anti-g suit increases the ceiling of protection to 75,000 ft, with the same limits on time and rate of descent. The pressurization applied to the outside of the ear drum helps to equalize any pressure differential across the drum, caused by the high breathing pressure gaining access to the middle ear. When the Mk 20 regulator is used with the P or Q mask and no pressure clothing, it must be remembered that the maximum breathing pressure without counter-pressure, of 30 mm Hg, is reached at 43,000 ft.

48. **Pressure Demand Mask.** Since the demand oxygen regulator is designed to deliver oxygen under pressure to the mask under certain conditions, the mask must be capable of holding that

pressure. There are, therefore, two features of the demand mask of special interest, namely the mask seal and the special form of compensated expiratory valve.

a. *Mask Seal.* In order to ensure a good seal between the mask and the face, a reflected edge is used, *ie* as the rubber of the mask approaches the face it doubles back under itself in a gentle curve, for a short way. Thus the same surface which is the outside of the mask is also the surface in apposition with the skin. As the pressure builds up on the inside of the mask, it not only forces the front of the mask outwards, but also presses the reflected edge more firmly on to the face.

b. *Compensated Expiratory Valve.*

(1) The special feature of this type of expiratory valve is that the pressure in the inlet tube from the regulator to the mask is applied to the under-surface of the expiratory valve by way of a compensating tube. Therefore, as the regulator delivers oxygen under increased pressure, creating force in the mask which tends to open the expiratory valve, an equal force is applied to the under-surface of the valve (by way of the compensating tube) so that it remains closed and the pressure in the mask is able to rise. If there were no other valves, however, the wearer would be unable to breathe out and so there is an inlet non-return valve provided at the point where the oxygen enters the mask. The increase in mask pressure created by the beginning of expiration is no longer able to be transmitted back down the inlet tube and along the compensating tube to the under-surface of the expiratory valve. There is now more pressure on the upper surface of the expiratory valve, which opens and allows the wearer to breathe out. Only a small leak back past the inlet non-return valve is necessary to make breathing out either very difficult or impossible, so that the state of this valve and its ability to function correctly are essential. This simple type of compensated expiratory valve, so far described, has a serious defect in circumstances where the pressure in the inlet tube between the regulator and the mask drops below ambient, since this negative pressure would be transmitted to the under-side of the valve and open it. This could occur for example, if the corrugated mask tube were stretched during head movements. So long as the pressure in the inlet tube

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 remained below ambient, the wearer would breathe in and out through this open expiratory valve, with the serious risk of anoxia. In order to overcome this, the modern compensated expiratory valve has two plates, one of which is the actual plate of the expiratory valve and the other is the plate to which the pressure in the mask inlet tube is applied via the compensating tube. These two plates are connected by a spring and a decrease in pressure below ambient in the mask will not open this type of expiratory port.

(2) Basically there are two series of masks for use with the pressure demand system: the original A13A series which was a British adaptation of an American mask and the modern P or Q series masks.

(3) The A13A series of masks is designed to hold a maximum of about 30 mm Hg breathing pressure, but it is very difficult to achieve a seal as good as this and many individuals find them uncomfortable to wear. There is no difference in the face-piece or valves of the various A13A variants; the only difference being in outer components such as harness and mask tube.

(4) The P and Q masks were developed to replace the A13A series and pressures as high as 100 mm Hg have been held in these masks. In practice however, a mask pressure of 70 mm Hg is the highest that can be tolerated by most individuals. The only difference between these two masks is that the Q mask has a smaller face-piece and microphone. However, the smaller microphone is now being fitted to P masks, so this is no longer a reliable distinguishing feature.

(5) The various masks in the current P and Q series only vary in their respective mask hose assemblies, with the exception of those whose reference has the suffix MED, denoting that the face-piece in this particular variant has been made of a special anti-dermatitic mixture for an individual whose skin has become sensitive to the rubber of the ordinary mask.

#### Use of Emergency Oxygen Equipment with the Pressure Breathing Mask

49. A supply of emergency oxygen is available to each crew member should the main supply fail or ejection become necessary at high altitude. It is contained in an emergency oxygen cylinder which is normally of 55 litres capacity, or 70

litres when a miniature emergency regulator is installed. The location of the cylinder differs with crew position and aircraft type and is operated either manually, or automatically during ejection. The method of operation of the emergency oxygen set depends upon associated equipment and it is convenient, therefore, to consider this in respect of an inlet warning connector, the inward relief valve (RV51) and a miniature emergency regulator.

a. *Inlet Warning Connector.* P1A and Q1A masks have an inlet warning connector on their inlet tubes. In use, this provides a ready indication of disconnection from the oxygen supply by an immediate increase in resistance to breathing in. The emergency oxygen tube is connected to the inlet warning connector and, when operated, the oxygen feeds in up-stream of the inlet non-return valve. An excess pressure relief valve is therefore required to prevent a build-up of pressure should the continuous flow of emergency oxygen exceed the user's respiratory demands. The excess pressure relief valve is situated in the inlet warning connector and pressure relief can be obtained only when the connector is separated from the main oxygen hose. Thus, when the emergency oxygen is operated, the inlet warning connector must be disconnected. When the flow of emergency oxygen becomes less than the inspiratory demands of the individual, a "top up" of air is provided through the main port of the inlet warning connector if, of course, it has been disconnected from the main line.

*Note:* P2A and Q2A masks differ from the P1A/Q1A series in having a simple bayonet attachment instead of the inlet warning connector, so there is no need to disconnect the mask tube when operating the emergency oxygen set in this case.

b. *Inward Relief and Excessive Pressure Valve (RV 51).* The RV 51 is a device which modifies the continuous flow of oxygen from the emergency oxygen bottle in order to meet the needs following ejection or failure of the main regulator. Since this is a continuous flow system from a small (55 litre) bottle, the initial supply will be in excess of breathing requirements, and excess pressure is allowed to escape. As the bottle becomes exhausted, so there must be inward relief to supply additional air. In addition, the RV 51 is designed to give pressure breathing above 40,000 ft and a safety pressure of 8-12 mm Hg below 40,000 ft. The unit has four valves:

(1) *The Oxygen Inlet Valve.* This is a

spring-loaded self-sealing valve which is automatically opened when the emergency oxygen supply pipe is connected to the valve by a bayonet-type coupling.

(2) *The Outlet Valve.* This is a non-return valve which prevents the flow of oxygen back from the main oxygen supply in the Personal Equipment Connector (PEC).

(3) *The Excess Pressure Valve.* This is a disc valve held closed by a spring which has a loading pressure of 8-12 mm Hg. Below 40,000 ft, this maintains a safety pressure which is twice emergency pressure. Mounted within this spring is a barometric capsule which presses against the back of the valve. Above 40,000 ft, the expansion of this capsule puts an increasing load on the back of the valve with increasing altitude. The capsule is so made that it never allows the pressure within the breathing system to fall below 141 mm Hg and therefore, as barometric pressure falls with altitude, increasing pressure breathing is experienced.

(4) *The Inward Relief Valve.* This is a spring-loaded valve which will not open until a suction of about 16-20 mm Hg is applied. Thus, when the emergency oxygen bottle is becoming exhausted and the flow from it does not meet the requirements of the user, inward relief of ambient air is obtained, albeit with some inspiratory effort. This effort also gives warning of failure or exhaustion of the main oxygen supply.

c. *Miniature Emergency Regulator.* This assembly consists of a 70 litre emergency oxygen bottle and a miniature demand oxygen regulator in place of the RV 51. The emergency bottle has a contents gauge and the oxygen flows through a pressure reducing head to a miniature regulator which has the characteristics of a Mk 20 regulator. When fitted to an ejection seat the emergency oxygen enters the seat portion of the personal equipment connector and so to the user. In the case of a rear crew member the oxygen flows directly from the side-mounted regulator directly into the main oxygen hose assembly.

#### **Demand Oxygen System Failures and the Appropriate Corrective Action**

50. These failures can best be understood by dividing them into different categories, according to their mode of presentation.

a. *Difficulty in Breathing IN.* This denotes that the supply of oxygen to the subject has

become interrupted; possible causes are:

- (1) Exhaustion of the aircraft oxygen contents.
- (2) Regulator or reducing valve failure causing interruption of the flow of oxygen.
- (3) Inadvertent disconnection of the mask tube assembly when using an inlet warning connector.
- (4) Kinking of mask tube assembly.

The degree of difficulty of breathing in, when the supply of oxygen is reduced or exhausted (confirm on the high pressure contents gauge) will obviously depend upon whether the air-mix aperture is open or closed. If there is any doubt or it is open, then close it and if breathing is difficult act immediately as described. In aircraft fitted with an RV 51, air could still get in, but only with much inspiratory effort, so the action to be taken is unaffected.

b. The actions to be taken in event of difficulty in breathing in, are:

- (1) Ensure that oxygen connections are properly made and that hoses are not kinked.
- (2) If connections are secure, check aircraft oxygen contents (high pressure contents gauge). If the contents gauge indicates in the red, operate emergency oxygen and initiate descent to below 10,000 ft.
- (3) In the event of an adequate aircraft oxygen supply, it is advisable to change to a spare regulator, if available. If this is not possible, or if this action fails, operate the emergency oxygen supply and descend to 10,000 ft.

*Note:* there is no point in changing the regulator if the contents gauge indicates in the red. When using an inlet warning connector, this must be disconnected from the main supply when the emergency oxygen system has been operated. Difficulty in breathing in may not be detected when air-mix is selected and there has been a failure of contents or regulator below 30,000 ft.

c. *Difficulty in Breathing OUT.* This is almost certainly caused by failure of the inlet non-return valve to close completely due to debris on the valve seating. In this event, some exhaled air escapes through the partially open inlet valve and is conducted along the compensating tube to the bottom of the expiratory valve. Breathing pressure will be felt on both sides of the expiratory valve and this results in

the expiratory valve remaining closed; it is therefore difficult or impossible to breathe out.

d. The actions to correct this fault are:

- (1) Ease the mask off the face.
- (2) Push in hard the emergency toggle on the Mk 17 regulator or select "Mask Test" on the Mk 21 and 20 regulators, as the case may be. The flow of high pressure gas (30 mm Hg) over the valve seating should be sufficient to clear away any debris. In the event of failure of repeated attempts to clear debris in this way, breathing out can be effected round the edge of the mask seal by easing the mask from the face. In such conditions, it is desirable to select the EMERGENCY position to prevent inboard leaks, bearing in mind the additional oxygen consumption. This should be considered only as a temporary measure and action should be taken to change the mask if possible or descend to below oxygen height.

e. *Continuous White Doll's Eye.* This indicates a continuous flow of oxygen and hence a leak must be present in the system. This leak will almost certainly be from around the edge of the oxygen mask, which should be tightened before checking for such things as the integrity of the oxygen hose and connections. It is worthwhile tapping the doll's eye in case it is stuck and giving a false indication.

f. *Continuous Black Doll's Eye.* A black doll's eye indicates a no-flow condition such as may occur with a hose disconnect below the cabin altitude which provides safety measure; otherwise, the commonest cause is an electrical failure of the doll's eye itself. It is essential however to be able to differentiate between a doll's eye failure and a genuine failure of the oxygen supply. The following drill should be followed:

- (1) Switch regulator to 100% to close air-mix orifice. If still able to breathe in quite comfortably the oxygen supply is intact.
- (2) Watch the needle on the regulator centre gauge. This should fluctuate in time with your breathing and is as good as a second doll's eye.

g. *Low Reading on High Pressure Contents Gauge.* If the reading of the high pressure contents gauge is unexpectedly low, a check for leaks should be instituted at once and appropriate corrective action taken. The gauge should continue to be monitored closely and plans prepared for a possible alteration of

flight plan. As contents become exhausted, difficulty in breathing will be experienced and at high altitude the emergency oxygen set should be operated and an emergency descent undertaken at once.

51. A summary of the common oxygen system failures and appropriate corrective actions is given in the table overleaf.

**Pressure Breathing Assemblies**

52. The limit of pressure breathing wearing a mask alone has already been defined and is 30 mm Hg, which in terms of altitude will depend upon the particular regulator which is delivering the oxygen. Furthermore, certain regulators have upper limits of performance dictated by the maximum pressure they can deliver. This data is tabulated in the following table.

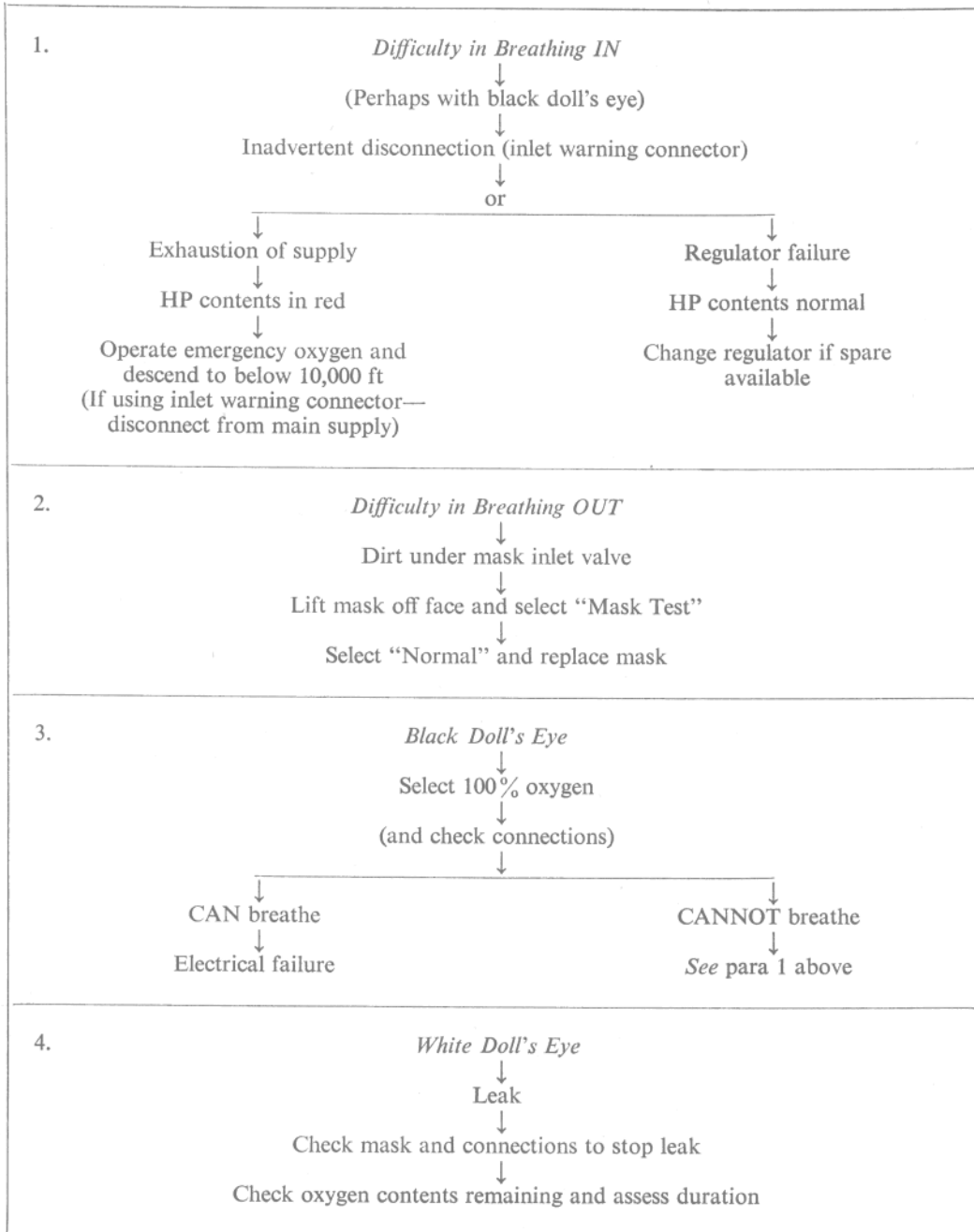
**PERFORMANCE LIMITS OF CERTAIN OXYGEN REGULATORS**

Regulator	Equivalent Altitude Breathing Pressure of 30 mm Hg	Altitude Limit of Regulator
Mk 17	50,000 ft	50,000 ft
Mk 21	45,000 ft	56,000 ft
Mk 20	43,000 ft	100,000 + ft

53. The Mk 20 regulator is the most efficient of the three and is capable of supplying the correct breathing pressure to altitudes in excess of 100,000 ft at which height the atmospheric pressure is only 8 mm Hg. This apparent anomaly of the more efficient regulators seemingly giving less protection, when worn with the mask alone, is due to the fact that the more efficient the regulator, the sooner one reaches the altitude at which it produces 30 mm Hg—the limiting breathing pressure for mask alone. The full value of the more efficient regulators is only achieved when used in conjunction with pressure clothing.

54. Of the three regulators currently in use, only the Mk 20 is capable of supplying the correct pressure, at any altitude, to maintain a lung equivalent altitude of 40,000 ft. At 50,000 ft, the Mk 17 regulator gives only 30 mm Hg instead of the physiological requirement of 54 mm Hg, and so the lung altitude is equivalent

COMMON OXYGEN SYSTEM FAILURES  
AND APPROPRIATE CORRECTIVE ACTIONS



to about 44,000 ft. The Mk 21 regulator is about 10 mm Hg short of the required pressure at 56,000 ft thereby giving an equivalent lung altitude of about 42,000 ft at that height. This degree of anoxia associated with the Mk 17 and

Mk 21 regulators at their maximum permissible altitude is considered acceptable for the short time of exposure in the emergency situation when cabin pressure is lost.

AL. 3

*hypoxia*

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 55. Pressure breathing assemblies are for use in an emergency when cabin pressurization is lost. Under these circumstances, their function is to protect the wearer from <sup>HYPOXIA</sup> ~~anoxia~~ whilst a descent is made through 40,000 ft. The limitations of the various assemblies are given in the table at para 56. There are a number of general considerations which govern the performance of the assemblies and unless these requirements are fulfilled, there is likely to be a serious decline in performance with dangerous consequences at the higher altitudes.

- a. The various items of the particular personal assemblies must be properly fitted to the individual.
- b. The user must understand thoroughly how to use the equipment, be practised in its use, and aware of its limitations.
- c. The equipment must receive regular care and maintenance by trained personnel.
- d. The user of this equipment should undergo refresher training in the use of his own equipment at regular intervals.

56. The following table is a display of the maximum performance of these assemblies irrespective of aircraft type. Certain aircraft have added restrictions imposed upon them, *eg* a reduced ceiling because of an inability to descend from maximum altitude within the time-scale of the equipment.

57. It will be noted that the time at altitude with the last two assemblies is greater, due to the fact that the Mk 20 regulator gives an ideal lung equivalent altitude, namely 40,000 ft. The increased operating altitude of the last assembly is due to the increased coverage of the body surface provided, which gives better support to the circulation, thereby prolonging the time at which these high breathing pressures can be tolerated.

58. Physiologically, the optimum assembly would be a full pressure suit providing an absolute pressure of 280 mm Hg, equivalent to 25,000 ft. This would have no theoretical limitations since the loss of the aircraft pressure cabin would be replaced by a personal pressure cabin in the form of a suit.

**PERSONAL OXYGEN EQUIPMENT AND PRESSURE CLOTHING**

**General**

59. The personal assemblies used to provide an adequate amount of oxygen for all circumstances vary from a simple oxygen mask and helmet to the more complex arrangements of pressure clothing. The current pressure clothing consists of various partial pressure assemblies which provide a "get-you-down" facility in the event of loss of cabin pressure above 40,000 ft. The various assemblies listed in para 56 are now described.

**SUMMARY OF PROTECTION AFFORDED BY VARIOUS PARTIAL PRESSURE ASSEMBLIES**

Assembly	Official Maximum Altitude (ft)	Maximum Time at that Altitude on Loss of Cabin Pressure	Minimum Descent Rate to 40,000 ft
P or Q Mask/Mk 17 Regulator ...	50,000	30 secs	10,000 fpm
P or Q Mask/Jerkin/Anti-g Suit/Mk 21 Regulator ... ..	56,000	30 secs	10,000 fpm
Pressure Helmet/Anti-g Suit/Mk 20 Regulator ... ..	66,000	1 min	10,000 fpm
Partial Pressure Helmet with Ear Pressurization/Combined Partial Pressure Assembly/Anti-g Suit/Mk 20 Regulator ... ..	75,000	1 min	10,000 fpm

**P/Q Mask—G Helmet**

60. The P and Q masks are identical in performance and differ only in that they are provided for different size faces. The differences between the various P and Q masks in the respective series are limited to the types of connectors fitted for different assemblies.

Mask	Suspension Harness	Connector
P1A	Chain toggle Mk 4	Inlet warning (quick release)
P2A	Chain toggle Mk 4	Mk 7 bayonet union plug
Q1A	Chain toggle Mk 5	Inlet warning (quick release)
Q2A	Chain toggle Mk 5	Mk 7 bayonet union plug

a. The P/Q mask consists of a fibreglass exoskeleton containing a soft rubber moulded face-piece with a reflected edge which provides a self-sealing property since it is pressed harder onto the face as the pressure builds up in the mask. Without this type of edge, the seal would quickly break away from the surface of the face. Moulded into the nose-bridge is a strip of soft metal which can be shaped to improve the fit around the wearer's nose.

b. Mounted in the face-piece are the inlet valve, a compensated outlet valve and a microphone.

c. When the mask is worn under normal conditions, the toggle is said to be "up", namely wide-ribbed extension uppermost, with the two chains bearing on the arms of the bow. When the regulator delivers oxygen at pressures higher than those normally experienced in the air (eg if a cabin decompression occurs at an altitude above 40,000 ft) the wearer rotates the mask toggle downwards. This clamps the mask tighter against the face, providing a more adequate face/mask seal. At present, the P and Q masks are used only with the fabric type G flying helmet or an integral protective helmet.

61. **Fitting the G Helmet and P/Q Mask.** It is important that the correct size of helmet is selected. The helmet should fit snugly; the ear buns must be correctly aligned and the neck strap adjusted accordingly. In cases where, on initial fitting of the mask, the adjustment of the turn-buckles has been fully taken up, it will be found that the ear buns of the helmet have moved too far forward. The webbing neck strap should then be adjusted to re-align the buns over the ears and the turn-buckles of the harness

once more adjusted to improve the fit and mask suspension.

62. Wearing the G helmet with the chin-strap fastened, the mask is tried on both upper and lower studs of the helmet. It may occasionally be necessary to attach the mask to the studs in a skew fashion; rarely, an additional pair of studs "super-upper" may need to be fitted to the helmet by a competent safety equipment worker. When the most efficient stud selection has been found which provides comfort and mask seal, the retaining screws must be secured through each mounting plate.

63. **Serviceability Checks of P/Q Series Masks.** The serviceability checks for the P/Q series masks are:

a. All parts secure and clean; note ice guard for position, face seal for lack of distortion and chain for acceptable degree of wear.

b. Concertina/stretch test to prove the inlet valve, oxygen hose and exclusion of any inboard leak through the expiratory valve.

c. An expiratory valve outboard leak is excluded by a satisfactory high pressure test using the regulator (see para 64).

64. **Pre-Flight Checks and In-Flight Use of the Mask.** The pre-flight checks and in-flight use of the P/Q series masks are shown in the table opposite.

**Partial Pressure Helmet**

65. The partial pressure helmet Type E is in service in certain high performance aircraft in the Royal Air Force. It enables the wearer to breathe a higher pressure than is possible with a standard oxygen mask (with the appropriate counter-pressure). It is always used in conjunction with partial pressure clothing and a Mk 20 pressure demand regulator.

66. In normal flight, the helmet provides the usual services and limited head protection. The back of the head is not covered by the protective shell. It has an opening vizor which closes automatically on loss of cabin pressure above 40,000 ft, but which can also be operated manually. There is an adjustable anti-glare sun vizor. The wearer has access to the mouth by means of a manually-operated spring door. A later version of the partial pressure helmet includes ear pressurization.

67. **Description and Function.**

a. *Helmet Shell.* This is made of Durestos

PRE-FLIGHT CHECKS AND IN-FLIGHT USE OF THE MASK

Regulator Pressure		Pre-Flight Checks	In-Flight Use
"Manual Safety Pressure"	4 mm Hg	To check the sealing property of the mask with its toggle UP. (Ability to seal safety pressure.)	If toxic fumes are suspected, ensure "100% oxygen" on the regulator and roll mask toggle DOWN.
"Mask Test"	30 mm Hg	To check the sealing property of the mask with its toggle DOWN. (High pressure check—mask alone.)	In the event of difficulty in breathing OUT, ease mask from face whilst selecting "Mask Test" in order to clear debris from inlet valve seating.
*"Jerkin Test"	60 mm Hg	To check the sealing property of the mask when the pressure jerkin is worn and connected. Toggle DOWN . . . and only under supervision. (This will also test the integrity of the pressure garments.)	Never to be selected manually in the air.

*Note:*

1. Safety pressure (2 mm Hg) is delivered automatically above a cabin altitude of about 10,000 ft to ensure that any leaks are outboard.
2. In the event of a decompression above 40,000 ft, the oxygen regulator automatically delivers oxygen under pressure. This pressure varies according to residual cabin altitude.
- \*3. Precautions to be taken when using "Jerkin Test", as previously discussed at para 42d, must be observed.
4. Check R/T circuits.

with additional laminates of terylene to give protection against impact. It has a window aperture and carries the hinges for the transparent pressure vizor.

b. *The Pressure Bladder.* This has two compartments, the oxygen mask and the head-enclosing bladder. The vizor seal is also an integral part of the pressure retaining bladder. A later modification permits ear pressurization.

c. *The Lining.* The bladder is lined with a detachable layer of pure silk which greatly adds to its comfort and hygiene. It is important that the lining is washed frequently using soap flakes and not detergent.

d. *The Pressure Vizor.* This consists of two layers of curved perspex with an intervening air space which prevents misting, for a short time, on exposure to a very cold environment. Demisting is assisted by wiping the inside of the vizor with a special demisting fluid before donning the helmet. The pressure vizor is held open by a pair of spring-loaded plungers. It

may be shut manually by pulling down the black bar and locked under the force of a spring attached to either end of the vizor mounting. When pressure breathing is required, the pressure in the oxygen mask is transmitted up a tube to a small rubber bladder which, when distended, causes the catch holding the vizor open to be released. The pressure vizor then springs shut automatically. Failure of the vizor to lock down is made obvious to the wearer by the presence of the black bar in his line of sight. Should any leak occur through the hair or past the vizor seal, the balance of pressure between the helmet and mask is maintained by a balancer valve attached to the small rubber bladder.

e. *The Anti-Glare Vizor.* This consists of a dark perspex transparency fitted to the shell by nylon brackets. It is mounted externally to the pressure vizor. Its position is set manually and held by friction discs in the mounting and is independent of the position of the pressure vizor.

f. *The Mouth Opening.* This is closed by a spring-loaded hinged door which opens upwards. It is held shut by a catch which can be released by squeezing a pair of finger grips on either side of the door.

g. *Oxygen Mask.* This is an integral part of the pressure bladder moulding. It is a separate compartment from the head-enclosing bladder, being separated on each side by a thin rubber membrane that crosses each cheek. It allows unpressurized oxygen breathing under normal conditions with the vizor open.

h. *The Inlet/Outlet Valve.* This allows inspiration and expiration through one valve. Resistance to breathing is minimal and the outlet portion is compensated so that pressure breathing may be obtained.

j. *The Earphones and Microphone.* These fit into pockets within the pressure bladder moulding. The earphones fit into recesses in the polyurethane pads lining the shell and as these pads enclose most of the head, the noise exclusion properties of the helmet are very good. The microphone switch is situated to the left of the mouth door and is upside down when compared with the microphone of the standard oxygen mask.

#### 68. Pre-Flight Inspection.

a. The correct functioning of the helmet is vital, particularly in its use as an oxygen mask and for communication. It is important, therefore, that the routine examinations and checks are made conscientiously. The following checks and examinations should be made before each flight:

##### b. Check for Cleanliness.

- (1) Oxygen compartment.
- (2) Silk lining. Each helmet has two spares to allow for frequent laundering.
- (3) Pressure vizor, which should be removed for treatment with demisting fluid.

##### c. Check for Condition and Fasteners.

- (1) Zip fastener tapes and stitching.
- (2) Zip fastener quick release at bottom.
- (3) Zip fastener press stud at top.
- (4) Adjustable straps.
- (5) Bladder rubber, lining and crown pads.

##### d. Examine Moving Parts.

- (1) Pressure vizor.
- (2) Hinges — general condition — vizor hinge crank pins screwed home.

(3) Open and close vizor a few times by operating the vizor bar and make sure that it functions correctly and locks properly in the open and closed positions.

(4) Examine the seal of the vizor.

(5) Mouth door fixing and the operation of the door and catch, also the seal.

##### e. Examine R/T. Telephones and microphones snug in sound exclusion pads.

69. **Pre-Flight Checks.** These are carried out on a Godfrey test cabinet with the assistance of a safety equipment worker. The pre-flight checks for the partial pressure helmet differ only slightly from those enumerated in para 64 for the oxygen mask. When using "Jerkin Test" the pressure vizor should be lowered (in lieu of rotating the mask toggle). The nitrogen dilution test should be carried out weekly, a visual indication and record can be taken by ducting normal breathing. An inspiration reading of less than 5% dilution should be obtained if the mask is fitting properly. Check the R/T circuits.

*Note: These tests must be made on the head of the person to whom the helmet belongs.*

#### 70. After-Flight Action.

- a. Remove the lining for laundering.
- b. Wipe the rubber bladder inside where it has been in contact with the face, with a clean damp cloth.
- c. Dry off the bladder and apply a small amount of french chalk or talcum powder.
- d. Replace clean silk lining, making sure that the press-studs are correctly located.

71. **Packing.** At all times, when not in use, the helmet should be kept in its transit case. When packing and unpacking great care should be taken to ensure that the main oxygen connector pipe is carefully folded and not kinked.

72. **Oil Hazard.** On no account must grease or oil (even hair oil) be allowed to enter the interior of the helmet, touch the inside of the vizor or the vicinity of the oxygen tubes.

#### The Partial Pressure Jerkin and Anti-g Suit

73. The physiological effects of pressure breathing are described in Sect 1, Chap 2. The need for counter-pressure on the outside of the chest wall at breathing pressures in excess of 30 mm Hg is met by the partial pressure jerkin or, in some cases, for the lower limbs and abdomen by an anti-g suit. These two pieces of equipment are described fully in the next chapter.

### Walk-Around Oxygen Set

74. There are three types of walk-around oxygen sets in service. These are:

a. *Mark 1B (Fig 9a)*. This consists of a small high pressure cylinder with a regulator screwed into the neck. The mask tube is connected to the regulator by an adaptor tube. The regulator has an ON/OFF valve, a reducing valve and a fixed metering jet. The flow cannot be regulated, the valve being either open or shut. The endurance of a full cylinder is 10 minutes, and the available supply is shown on a gauge graduated in minutes. As the set does not incorporate a breathing bag or economizer it should not be used at cabin altitudes above 25,000 ft. Above 37,000 ft physical movement should be restricted to a minimum and no attempt made to move between crew stations.

b. *Mark 3 (Fig 9b)*. This set has a longer endurance and is for use in transport aircraft below 30,000 ft. It comprises a 150 litre cylinder, a regulator, breathing bag, an outlet connection, a charging connection and a light metal case. The flow is adjustable for height and exertion and the set has an endurance of about 55 minutes at 20,000 ft. With this type the mask tube is plugged directly into the outlet socket in the metal case, no adapter being necessary. Arrangement may be made for the set to be recharged in flight from the main oxygen supply.

c. *Mark 4 (Fig 10)*. The walk-around oxygen set Mk 4 is designed for pressure demand masks (P and Q). A filler point is provided on the set for recharging in flight from a special charging connection in the aircraft supply.

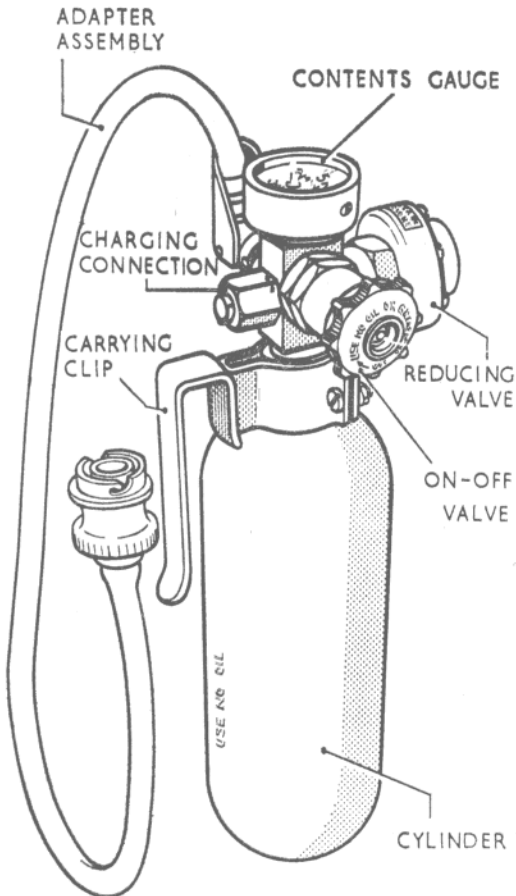


Fig 9a Walk-Around Oxygen Set Mk 1B



Fig 9b Walk-Around Oxygen Set Mk 3

This charging connection is located in the system down-stream of a reducing valve where the pressure is 450 psi. A non-return valve in the set prevents the escape of oxygen from the cylinder. Fig 10 is a general view of the set, showing the demand type regulator Mk 19 which, with a small (150 litre) Mk 13 oxygen cylinder, constitutes the Mk 4 walk-around oxygen set. A spring-loaded diaphragm in the regulator controls the pressure at which oxygen is delivered to the mask. The spring loading can be varied by setting the control, as stated on the selector, which causes a lever on the pressure breathing mechanism to exert the required force on the diaphragm. The selector is set as necessary according to the cabin altitude. It is left at NORMAL until the cabin is at 30,000 ft. In emergency, or in the event of physical exertion requiring it, the selector is set to the EMERGENCY position. To recharge the cylinder in flight the charging connector is connected to the appropriate

point in the aircraft supply. The recharging valve in the aircraft is then opened slowly. When the pointer of the contents gauge stops rising, the recharging valve is closed and the charging connector disconnected.

75. The walk-around oxygen set has been replaced in nearly all large aircraft by a long oxygen pipe enabling crew members to move around the flight deck when requiring oxygen at altitude.

#### Liquid Oxygen Systems

76. Aircraft oxygen cylinders have always been heavy and bulky and the growing oxygen requirements in modern aircraft have increased the weight and space penalties. This problem is being overcome by the introduction of liquid oxygen converters which store oxygen in aircraft as liquid under low pressure and convert the liquid to gaseous oxygen at normal temperatures when required for breathing. At atmospheric pressure liquid oxygen boils at  $-183^{\circ}\text{C}$ ; it must therefore be stored in very efficiently insulated vessels to prevent it from evaporating. Liquid oxygen converters are double-walled vessels with high vacuum between inner and outer shells, the inner shell containing the liquid oxygen. Heat losses through pipe connections and radiation are kept to a minimum. Although the best theoretical shape is a sphere, cylinders with reasonable ratios of length to diameter are nearly as efficient.

77. The converter operates at a constant pressure which can be altered by design to any value required. The converters in use in RAF aircraft will operate between 150 and 200 psi and thus gaseous oxygen can be led directly to the regulators without passing through pressure reducing valves. An evaporating coil and valve system allows the liquid to vaporize as and when required; the oxygen gas then passes through the pressure demand regulators to the masks of the aircrew automatically upon demand and at the right temperature.

78. Fig 11 shows a typical circuit for a liquid oxygen converter (1). The liquid is normally prevented from flowing out of the inner container by the liquid check valve (2). If the gas pressure in the converter drops below its design setting, the pressure closing valve (3) opens, allowing the gas pressure above and below the liquid to equalize. There is then an excess pressure due to the liquid head acting on the check valve which opens and allows some liquid to trickle through into the evaporating pipe (4).

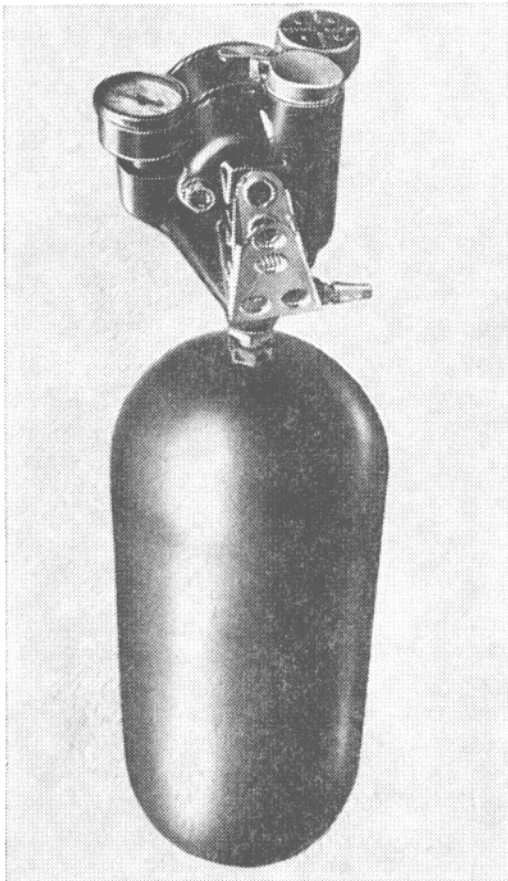


Fig 10 Walk-Around Oxygen Set Mk 4

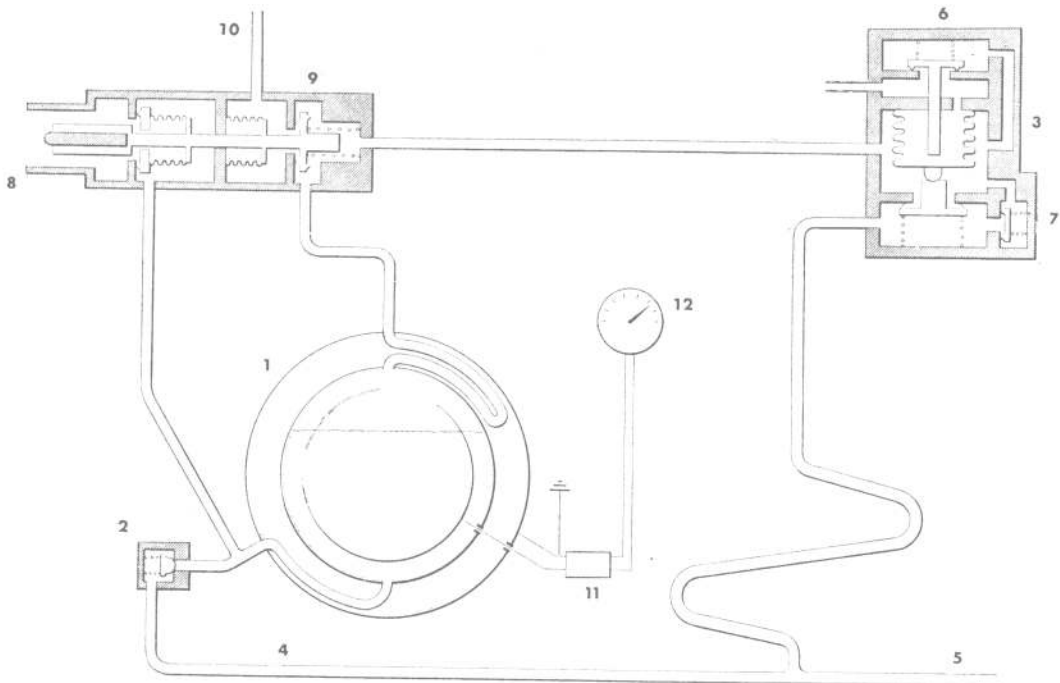


Fig 11 Circuit Diagram for a Liquid Oxygen System

Here the liquid is evaporated by atmospheric heat, and the gaseous oxygen passes through the circuit back into the top of the converter, thus raising the pressure. When the working pressure is reached, the pressure closing valve automatically shuts and prevents any further oxygen passing through into the gas space of the converter. Any further liquid evaporating in the pipe (4) shuts the liquid check valve by building up pressure between it and the pressure closing valve. This prevents any further outflow of liquid oxygen. Similarly, a demand for gaseous oxygen results in a reduction of pressure behind the liquid check valve which opens to allow liquid to trickle through into the evaporating pipe, vaporize and pass to the supply line (5). When demand ceases, increasing pressure again shuts the liquid check valve.

79. Excessive pressures in the gas or liquid phases of the converter are prevented by the relief valves (6 and 7).

80. The converter is filled through a filler valve (8) which forms a self-sealing coupling with a mating valve on the end of the filling hose on the liquid oxygen bowser. There is no danger of liquid oxygen in any quantity being spilled during filling. The filler valve is combined with a vent

and build-up valve (9) which automatically vents the gas phase of the converter to atmosphere (10) when the charging coupling is connected to the filler valve. It is therefore impossible to fill the converter while it is pressurized.

81. The inner vessel of the converter contains a spherical capacitance plate which measures the level of the liquid in the container. This measurement is converted by the gauging unit (11) to give a contents reading on the gauge (12). This gauge shows the pilot how much oxygen is in the converter and is a true contents gauge.

82. As far as the pilot is concerned there is no difference in using liquid oxygen as opposed to gaseous oxygen but the regulator gauge will show much lower pressures and the contents gauge is electrical. With liquid oxygen, sufficient time must be allowed for the pressure in the system to build up. The increase begins as soon as the replenishing trolley is disconnected and the working pressure should be reached during the normal turn-round time of the aircraft. However, pilots must make the normal oxygen checks of content and pressure before take-off. If the pressure gauge needle is positioned either below the zero or above the full content position it will indicate an electrical defect in the gauging system.



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