12 Oxygen (ATA 35)

12.1 Definition

Those units and components which store, regulate, and deliver oxygen to the passengers and crew, including bottles, relief valves, shut-off valves, outlets, regulators, masks, walk-around bottles, etc. (**ATA 100**)

12.2 Human Oxygen Requirements

The **human reaction to a lack of oxygen** depends on altitude. Normally, individuals living at sea level may become aware of the effects of altitude at about 3048 m (10000 ft). Above 10000 ft, piloting skills are degraded. Up to 4267 m (14000 ft), the body is more or less able to compensate for the diminishing partial oxygen pressure by a higher breathing frequency. Above 14000 ft, compensation is not possible anymore *hypoxia* symptoms (headache, etc.) become apparent. Above 6096 m (20000 ft) unconsciousness and death are only a function of time. If a person is exposed to an altitude of 9144 m (30000 ft), unconsciousness may well set in after 1 minute. At an altitude of 15240 m (50000 ft), unconsciousness may set in after 10 s.

In order to compensate these effects, the partial oxygen pressure can be increased by **breathing higher oxygen concentrations**. The partial oxygen pressure[1] p at sea level (SL) is

$$0.21\, p_{SL} = 0.21 \cdot 1013\,\text{hPa} = 212.7\,\text{hPa} \quad .$$

If this partial pressure is to be maintained with altitude h, the required oxygen concentration x is

$$x = \frac{212.7\,\text{hPa}}{p(h)} \quad .$$

As can be seen from Figure 12.1, 100% (pure) oxygen is required at an altitude of about 37000 ft. Beyond 37000 ft, it becomes necessary to increase the pressure of the oxygen delivered to the mask in order to provide a sea-level equivalent environment. The lungs are in effect supercharged by the differential pressure between the mask and the surrounding pressure in the (nonpressurized) cabin.

It is evident that cabin **decompression** at high altitudes requires immediate action by the crew. Passengers and crew have to be provided with oxygen, and an emergency descent has to be initiated. The lower the aircraft gets, the longer the survival time. Circumstances are eased

[1] Many special terms relevant to the oxygen system are defined in Section 2 (air conditioning).

by the fact that even a big hole in the structure does *not* instantly lead to ambient pressure in the cabin.

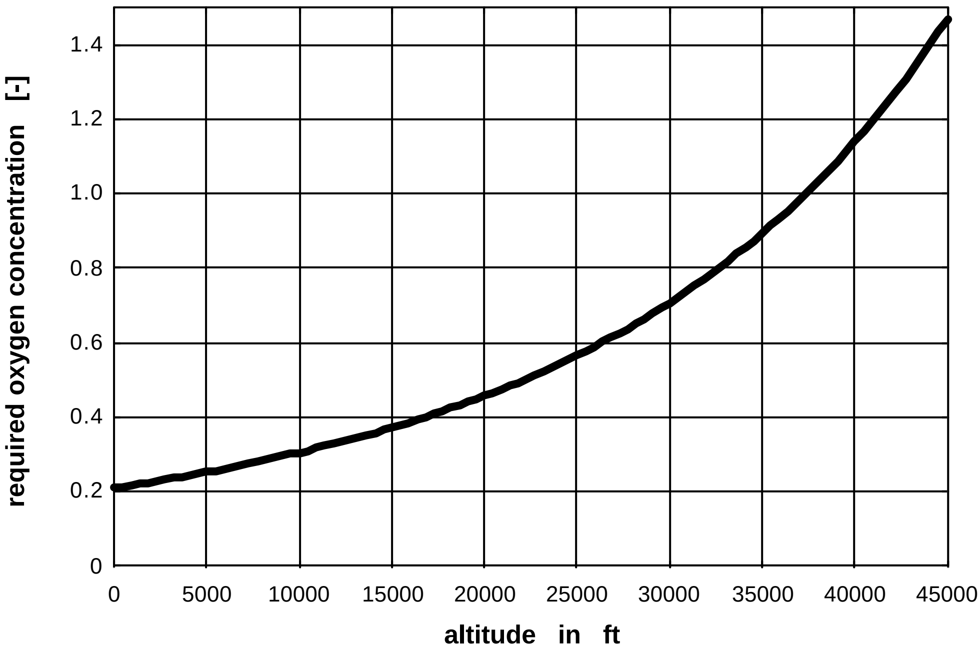

Figure 12.1 Required oxygen concentration with altitude

Certification requirements for transport category aircraft (with pressurized cabins) state, e.g., "If certification for operation above 30000 ft is requested, dispensing units providing the required oxygen flow must be automatically presented to the occupants ... before the cabin altitude exceeds 15000 ft" (**JAR-25**, section 1447).

12.3 System Classification

A classification of oxygen systems may take various aspects into account. We will look at classifications based on:

- various reasons for oxygen supply
- fixed versus portable oxygen equipment
- oxygen regulator types
- oxygen mask types
- different oxygen sources
- the type of person supplied with oxygen:
    - *passenger* oxygen system
    - *crew* oxygen system.

An **oxygen supply** may be necessary **for various reasons**. During high-altitude flights in nonpressurized cabins, *normal oxygen* supply is part of the normal flight procedures. In case of a failure of the normal supply, *emergency oxygen* is needed. In pressurized cabins emergency oxygen is supplied to all passengers and crew in case of cabin decompression. Provisions may have to be made for the supply of *sustenance oxygen* to a limited number of passengers after an emergency descent. Provisions also have to be made to supply *first-aid oxygen* to individual passengers for medical reasons. " '*Supplemental oxygen*' means the additional oxygen required to protect each occupant against the adverse effects of excessive cabin altitude and to maintain acceptable physiological conditions" (**JAR-1**) .

Oxygen equipment may be grouped into fixed and portable equipment. *Fixed equipment* is provided in those aircraft in which oxygen is frequently required or many passengers are involved. Additional *portable equipment* is used to allow the crew to move in the aircraft cabin under varying conditions. This could include the use of portable equipment when fighting small cabin fires. Portable equipment is also used for first-aid oxygen supplies to individual passengers. Small aircraft with nonpressurized cabins may not have a fixed oxygen system installed, so portable equipment is taken aboard whenever the situation arises due to planned high-altitude flights.

Oxygen taken from a bottle that provides a continuous flow via a supply hose directly into the mouth would technically be the easiest way to inhale. Although this was historically the first method applied, it has several disadvantages. The most apparent ones are:

1. Oxygen would will be wasted during exhalation.
2. There is no need to inhale 100% oxygen at low altitudes.
3. There will be a need to hold the hose.
4. Communication will be hampered.
5. In a toxic environment (smoke) a face protection will be missing.

In order to overcome disadvantages 1 and 2, different **types of oxygen systems based on the regulator design** (see 12.4) have evolved: the *continuous flow system*, the *demand system*, the *pressure-demand system*, the *diluter-demand system*, and the *pressure-demand system with dilution at low altitudes*. The most common systems in transport aircraft are: the continuous flow system for passengers and the diluter-demand system for members of the flight crew.

Problems 3, 4, and 5 are addressed with the specific design of the **oxygen masks** (see 12.5).

12.4 Regulators

A **continuous-flow system** provides – as the name indicates – a continuous flow of oxygen to the mask. In order not to waste the volume of oxygen flowing towards the mask during exhalation, a flexible *plastic or rubber reservoir* is incorporated between the mask and the supply hose. The reservoir that is used to collect the oxygen has typically a volume of 0.5 to 1.0 l. During inspiration the stored oxygen can be used together with the oxygen currently flowing. Three valves are built into a continuous-flow mask: an exhalation valve and a non-return valve to the reservoir and a dilution valve. The *exhalation valve* opens the mask to ambient air during exhalation. At the same time, the *non-return valve* to the reservoir closes to prevent used air to enter the oxygen reservoir. When the reservoir has been emptied during the first part of the inhalation phase, the *dilution valve* opens and allows ambient air to dilute the already inhaled oxygen from the reservoir during the second part of the inhalation phase. The primary disadvantage of the constant-flow system is its inability to adjust itself automatically to various levels of physical activity. A regulator could, however, be provided for manual adjustment of flow to the reservoir. A *constant-flow regulator* provides automatic control of the flow depending on altitude. This capability evidently depends on the ability of the oxygen source to allow for varying flows. Varying the flow of oxygen is not always possible: the chemical oxygen generators commonly used in aircraft cabins do not allow flow control.

A **demand system** provides – as the name indicates – a flow of oxygen only on demand, i.e., during the inhalation phase, conserving oxygen during exhalation. A demand system requires a *demand oxygen regulator* for each user. The regulator may be panel-mounted, man-mounted, or seat-mounted. The regulator includes an outlet control valve that responds to minute changes in pressure. The slight negative pressure (compared to ambient cabin pressure) created within the mask at the onset of inhalation opens the valve and permits a flow of oxygen into the mask. At the end of the inhalation phase, the pressure has become slightly positive and the valve shuts off the flow. Masks for demand systems have to fit tightly. If the breather drew too much ambient air around the mask, the mask could not hold negative pressure and hence the regulator could not function properly.

A **pressure-demand system** is a demand system that has the ability also to supply oxygen under positive pressure (compared to ambient cabin pressure) to the mask. The principal components of the system are a mask that has the ability to hold positive pressure and an *oxygen pressure regulator*. A pressure-demand system is necessary for operation at altitudes above 10668 m (35000 ft) to maintain safe partial pressure for the user (compare with Figure 12.1).

The **diluter-demand system** is a demand system that has the ability to control the air-oxygen ratio automatically depending on altitude. The purpose of air dilution is to conserve the aircraft oxygen supply further and still maintain a safe partial pressure. For safe operating conditions, dilution occurs up to 9754 m (32000 ft). At this altitude the dilution port in the *diluter-demand oxygen regulator*, which is automatically controlled, is shut off and the regulator delivers 100% oxygen. Besides an on-off-type *supply lever*, these regulators have an *oxygen-selection lever* to obtain 100% oxygen delivery throughout the whole altitude range.

Some models are also provided with an *emergency lever* which, when actuated, will deliver a limited amount of positive pressure (safety pressure) for emergency toxic atmosphere protection (Figure 12.2).

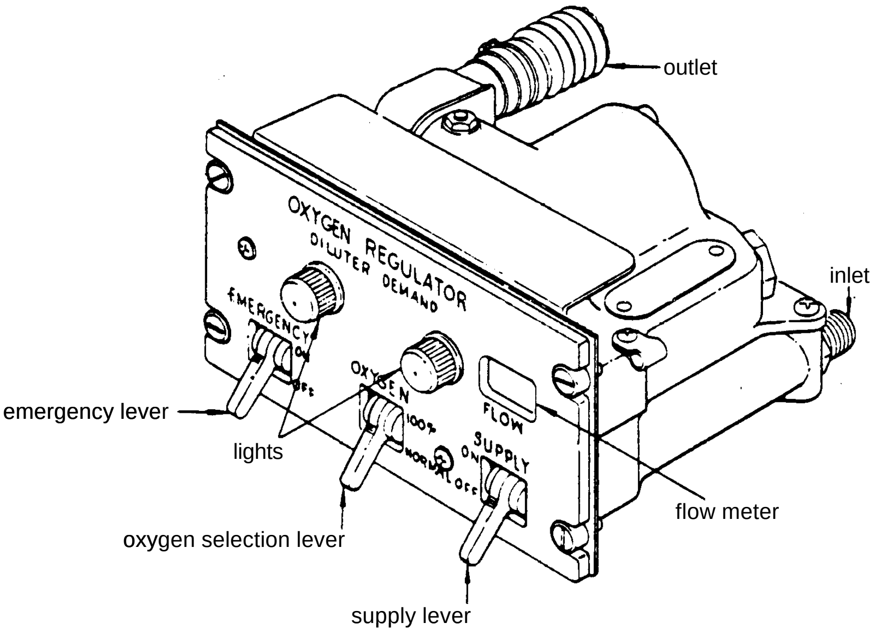

Figure 12.2 Basic panel-mounted diluter-demand oxygen regulator (VFW 614)

12.5 Masks

Different oxygen masks exist. Apart from the differences resulting from the type of oxygen system for which they are used (see 12.4), we may differentiate various types.

The **nasal mask** fits snugly around the nose and is intended for flights below 4877 m (16000 ft), where air intake through the mouth is acceptable. The **oronasal mask** fits completely over the mouth and nose. Provisions are made for the inclusion of a microphone for communication purposes. **Full-face masks** cover the mouth, nose, and eyes. These masks can meet protective breathing equipment requirements, but cannot be used in a pressure-demand system because the eyes should not be exposed to a positive pressure. **Goggles combined with an oronasal mask** can meet both protective breathing and pressure demand requirements.

If certification for transport category aircraft is sought for operation above 25000 ft, each flight crew member must be provided with a **quick-donning mask** (see Figure 12.4) that can be put on within 5 s (**JAR-25**, section 1447). Quick-donning masks are equipped with an inflatable harness. The crew member presses a side lever on the mask when passing the harness over the head. The *side lever* guides pressurized oxygen into the harness, causing the *harness* to stretch. When the side lever is released, the oxygen escapes from the harness and integrated straps pull the harness tightly to the head.

A *smoke hood*, a mask used to fight small cabin fires, protects the head and parts of the body and includes some type of oxygen supply.

12.6 Sources

Oxygen supply may be in form of *gaseous oxygen* supply, *liquid oxygen* (LOX) supply, *chemical oxygen* supply, and *On-Board Oxygen Generation* (OBOG).

Gaseous oxygen is stored in the aircraft in special oxygen cylinders. US oxygen cylinders are colored green. They are properly marked and must only be filled with aviators breathing oxygen. Charge pressure is 12.8 MPa (1850 psi). Oxygen cylinders are fitted with a combined flow-control and pressure-reducing valve as well as a pressure gauge. Two types of high-pressure cylinders exist: *standard weight cylinders* and *lightweight cylinders*. These cylinders are certified to Department of Defense (DOT) standards. They must regularly be checked and are life limited. Safety precautions have to be adhered to because of the general danger associated with such pressure vessels and the risk involved with handling oxygen. Crew oxygen systems on transport aircraft use gaseous oxygen.

Oxygen boils at sea-level pressure at -183 °C. The highest boiling point is -118 °C at 5.07 MPa. Hence, **liquid oxygen** has to be below that temperature. Liquid oxygen is stored in insulated tanks. Special equipment is required to convert liquid oxygen to gaseous oxygen on-board the aircraft. Liquid oxygen systems show weight and space savings compared to equivalent gaseous oxygen systems. Evaporation losses, however, can amount to 5% per 24 hours and need constant refilling in service. For these reasons, liquid oxygen systems are used on most combat aircraft but seem impractical for civil operation.

Chemical oxygen generation on aircraft is done with *sodium chlorate*. Sodium chlorate decomposes when heated to 478 °C into salt and oxygen:

$$2\,NaClO_3 + heat \rightarrow 2\,NaCl + 3\,O_2\,.$$

The heat is generated with some kind of "fuel", commonly iron. The chemical reaction is:

$$NaClO_3 + Fe \rightarrow NaCl + FeO + O_2 + heat\,.$$

The overall mass balance of both equations combined: 100% sodium chlorate yields 45% oxygen by weight, 38% of which is delivered and 7% of which is used in oxidizing of the iron. The chlorate core is located in the center of the generator and is insulated against the outside steel housing. Nevertheless, the outside of the generator reaches temperatures of up to 260 °C, so that adjacent aircraft components need to be protected against the generator. The oxygen cools quickly and has reached normal temperatures when it arrives at the mask. The chemical reaction is self-sustained and can be started mechanically (in most aircraft by pulling a lanyard) or electrically (Lockheed L-1011) with an adequate device on the generator. An outlet filter holds back particles and gaseous impurities. The reaction cannot be stopped once it is in progress. In case the outlet gets blocked, a pressure-relief valve averts an explosion of the generator. Figure 12.3 shows a cross-section of a chemical oxygen generator. Its diameter determines the flow rate and its length the duration of the supply. Generators are designed for a flow duration of about 15 minutes. The overall flow rate depends on the number of masks attached to the generator (1, 2, 3, or 4) and on certification requirements. The flow rate decreases over the duration of the supply. Most transport aircraft use chemical oxygen generation for the passenger oxygen system because of weight and maintenance savings compared with gaseous oxygen supply.

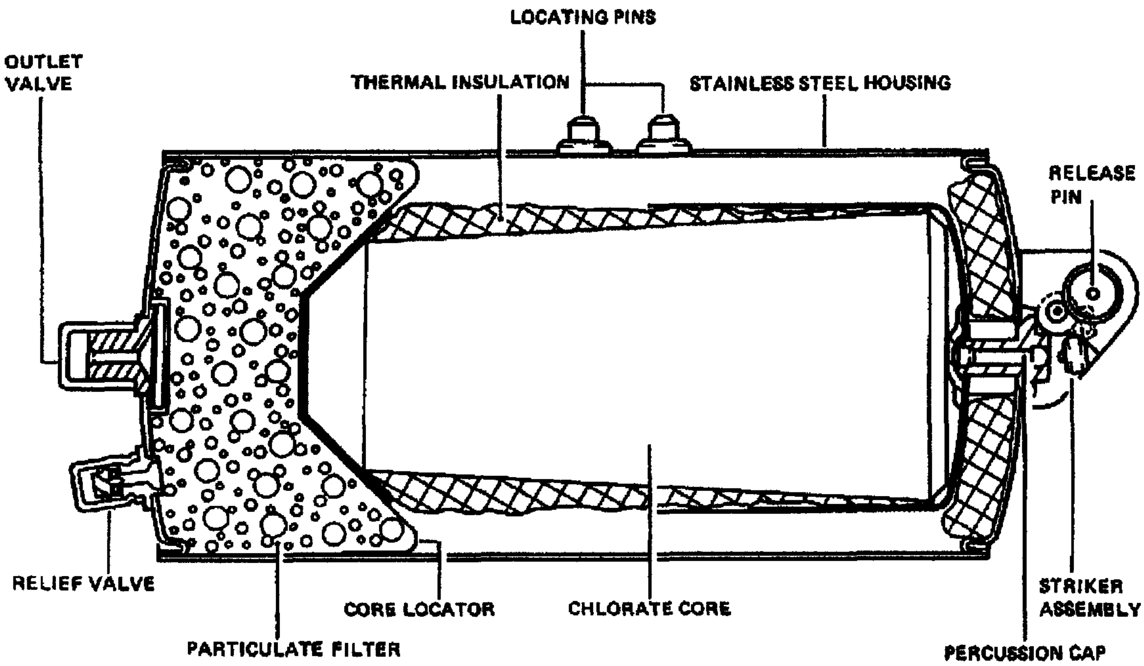

Figure 12.3 Chemical oxygen generator (Airbus A321)

On-Board Oxygen Generation Systems (OBOGS) apply electrical power and bleed air to produce breathable oxygen from ambient air. Various techniques exist. Air can be processed through molecular sieve beds to provide oxygen-enriched breathing gas.

12.7 Example: Airbus A321

The aircraft has three separate oxygen systems. A flight crew oxygen system, a passenger oxygen system, and a portable oxygen system.

The **flight crew oxygen system** (Figure 12.4) supplies oxygen to the flight crew if there is a sudden decrease in cabin pressurization. It also supplies oxygen if there is smoke or dangerous gases in the cockpit. Each crew station has a quick-donning mask with a demand regulator installed. The oxygen is supplied from a high-pressure oxygen cylinder to the masks through a pressure regulator/transmitter assembly and a distribution circuit.

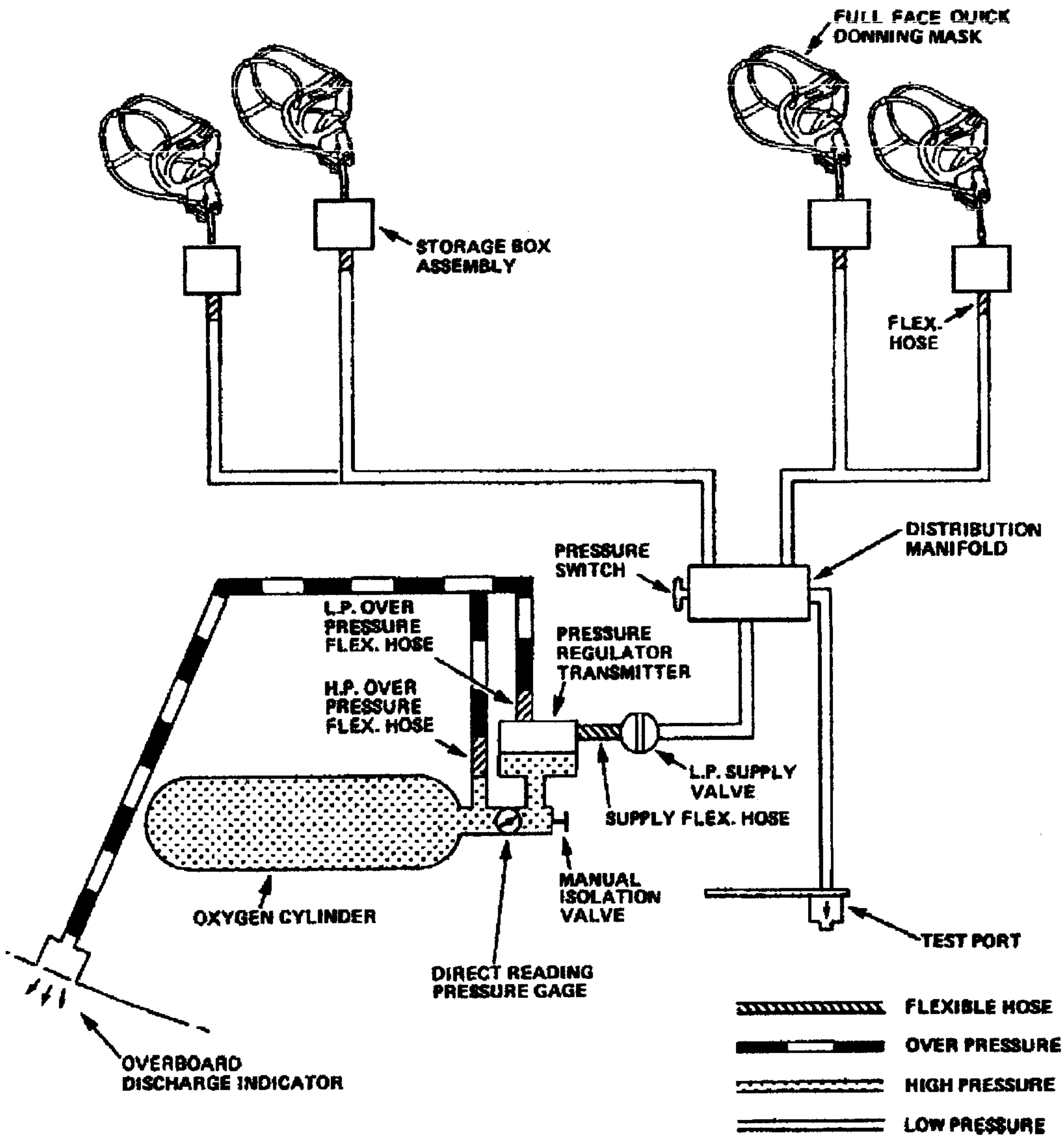

Figure 12.4 A321 crew oxygen system

The **passenger oxygen system** provides emergency oxygen for passengers and cabin attendants (Figure 12.5). Emergency oxygen containers are installed:

- above the passenger seats
- in the lavatories
- at the cabin attendant stations
- in the galley working areas.

Each container has a chemical oxygen generator and two or more continuous-flow oxygen masks, each with a flexible supply hose.

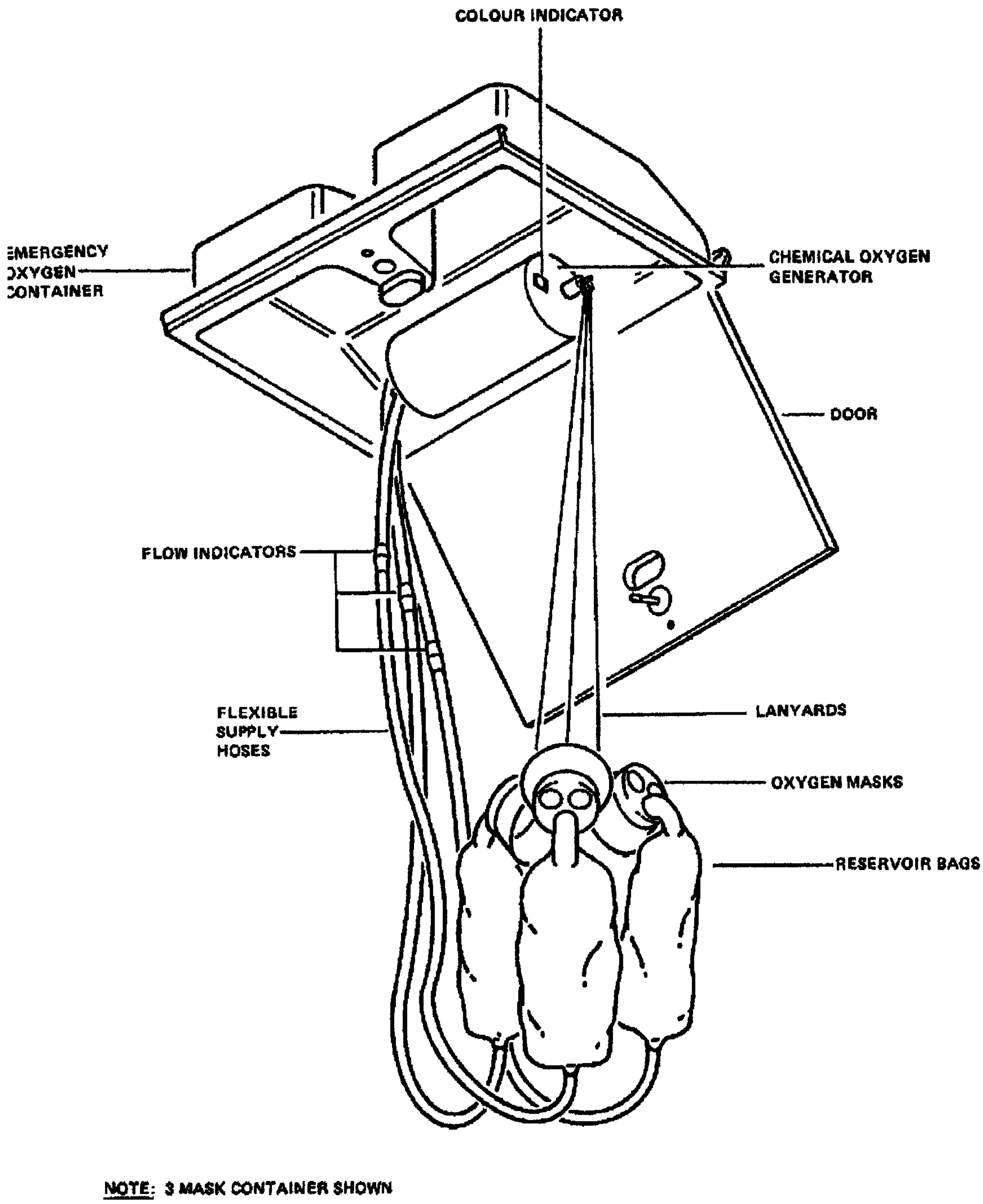

Figure 12.5 A321 emergency passenger oxygen container