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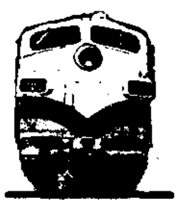

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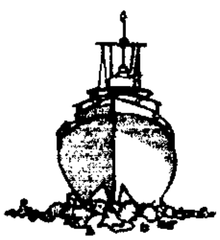

SPECIAL STUDY

CHEMICALLY GENERATED SUPPLEMENTAL OXYGEN SYSTEMS IN DC-10 AND L-1011 AIRCRAFT

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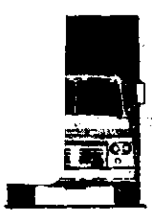

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16. Abstract

This study examines the problems encountered in four recent decompression incidents with respect to the presentation, understanding, and use of chemically generated supplemental oxygen systems installed in DC-10 and L-1011 aircraft. These problems include: Lack of oxygen flow indications; headband adjustment difficulties; lack of mask stowage methods; unreliability of oxygen compartment doors; method of oxygen mask presentation; flight attendant training; and passenger briefings. The study finds that there is a need for design guidance from the FAA in the design of supplemental oxygen systems as well as a need for proving these systems by actual demonstration. The Safety Board has made nine safety recommendations to the FAA regarding improvements in training, briefings, use, and design of the supplemental oxygen supplies.

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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D. C. 20594

SPECIAL STUDY

Adopted: March 3, 1976

CHEMICALLY GENERATED SUPPLEMENTAL OXYGEN SYSTEMS IN DC-10 AND L-1011 AIRCRAFT

INTRODUCTION

The Douglas DC-10 and the Lockheed 1011 aircraft have similar components in their chemically generated, supplemental oxygen systems. Both aircraft are equipped with the same oxygen mask assemblies and the same solid-state chemical generator. However, the installation, packing, and actuation of the systems differ between the aircraft.

In the DC-10, the mask and generator are packaged in passenger seatbacks and in lavatory and lower galley ceiling compartments. When cabin altitude reaches about 14,000 feet, doors open automatically and the oxygen masks are exposed. Passengers must pull the masks toward them to actuate the oxygen generator.

In the L-1011, masks drop from ceiling compartments and oxygen flow is initiated by electrical signal without passenger action. In both aircraft, the passenger must adjust the oxygen mask to fit over his nose and mouth tightly.

The National Transportation Safety Board's recent investigative experience has disclosed problems in the presentation, use, and understanding of these chemically generated, supplemental oxygen systems.

As a result of these problems, the Board studied selected incidents and accidents to determine what effect these problems have on air safety. From the available data, case histories were chosen which clearly demonstrate recurring problems both from the user's standpoint and from a design standpoint.

Although no serious injuries have resulted from the misuse or nonuse of supplemental oxygen, the potential for serious injuries and fatalities is great, and the Safety Board believes that adequate preventive measures must be taken to minimize these hazards.

As a result of this study, the Safety Board has made nine recommendations to the Federal Aviation Administration (FAA).

PROBLEMS OF DECOMPRESSIONS AND CHEMICAL OXYGEN SYSTEMS

In order to obtain an estimate of the number of decompressions which occur annually, the Safety Board reviewed the decompression statistics for the total U. S. turbojet fleet. Next, data were examined which related specifically to the DC-10 and L-1011 which use chemically generated, supplemental oxygen systems.

The Safety Board found that data on decompression incidents in U. S. air carrier operations are incomplete. McFarland (1) suggests that 40 to 50 incidents occur each year and that 20 percent of these involve emergency descents and deployments of oxygen masks. Incident data collected by FAA's Flight Standards Service, however, suggest a much higher incidence of decompressions. Over a 26-month period from May 1968 through June 1970, 253 incidents from all causes were reported to the FAA; oxygen masks were deployed 22 times.

The Safety Board reviewed its accident and incident files as well as the FAA's for 1973 through September 1975. These records were reviewed for those instances in which air carrier turbojet aircraft had lost pressurization, both rapidly and explosively, or in which a pressurization system had failed to maintain cabin pressure. The incidents in which cabin pressure exceeded 14,000 feet and in which the oxygen masks were deployed automatically or manually or failed to deploy in either mode of operation were identified. (See Appendix C.) Based on the foregoing data, the Safety Board estimates that as many as 10 severe decompressions occur each year in U. S. air carrier operations.

To bring the problem of aircraft decompression into perspective, it must be pointed out that the statistical incidence of decompression is relatively small. For instance, during 1973, there were over 5 million departures of certificated route air carriers in the U.S.; a total of 27 incidents were reported that year, of which the Safety Board identified 13 as potential or actual rapid or explosive decompressions. During 1974, with 4 and 3/4 million departures, 34 such incidents were reported, of which the Board identified 14 incidents as potential or actual rapid or explosive decompressions. (See Appendix C.) Nevertheless, with as many as 10 possible severe decompressions each year, 1,500 to 2,000 passengers may be exposed to the dangers of decompression.

With respect to specific problems in the DC-10 and the L-1011, a review of the mechanical reliability reports and the service difficulty reports for 1973 through September 1975 revealed that during 1974, a generator on a L-1011 activated and oxygen compartment doors failed to open during a ground check of the system. Also in 1974, there were 11 reports in which oxygen compartment doors failed to open during ground checks of DC-10 aircraft. During these 11 instances, 183 doors failed to open and several latches operated intermittently.

During 1975, 10 oxygen compartment doors failed to open in an L-1011 aircraft during a ground test. Also during 1975, 183 door failures were reported by two airlines operating DC-10 aircraft. On two reports, a notation was made that "20 to 30 percent of the doors failed to open during the test."

In addition, the Safety Board identified nine incidents involving five DC-10 and four L-1011 aircraft. (See Appendix C.) Based on its investigative experience, the Safety Board believes that any decompression is potentially severe. For example, a DC-10, allowing for furnishings and occupants, has a volume of about 25,500 cubic feet. If an aircraft is cruising at 39,000 feet and an 288-square-inch opening is created in the hull, the cabin theoretically will decompress to flight altitude in about 34 seconds. Other variables which affect the final cabin altitude and the time required to decompress completely are the ram effect of boundary layer airflow along the fuselage and the relationship between fuselage opening size and air inflow from the pressurization system. (2)

In any event, aircraft occupants have little time available to take protective measures before the physiological effects of reduced barometric pressure are felt. (See Appendix A.) Since this study is limited to the DC-10 and L-1011 aircraft, cases were reviewed to identify instances in which aircraft occupants experienced difficulties in the use and operation of the supplemental oxygen system in those aircraft. To illustrate these problems, four case histories were chosen which demonstrated recurring problems, both from a user's standpoint and from a design standpoint. A total of 562 passengers and 49 crewmembers were involved in these 4 mishaps.

Case History No. 1

A DC-10 was near Brownsville, Texas, on October 3, 1974, with 53 passengers and a crew of 12 aboard. The aircraft was descending from 35,000 feet to approach Mexico City, when a pressurization malfunction caused the cabin altitude to ascend to 25,000 feet. Oxygen masks deployed automatically at 14,000 feet cabin altitude. The senior flight attendant instructed passengers to don their oxygen masks.

Only 2 of the 53 passengers correctly removed the stowed oxygen masks to activate the oxygen generators and donned their masks. The remaining 51 passengers either did not react or merely leaned forward and attempted to breathe without fully removing the masks from their stowed positions. Flight attendants circulated among the passengers to activate oxygen generators and to reinstruct passengers. Passengers and flight attendants were concerned that oxygen was not being delivered to masks because the reservoir bags attached to the masks did not inflate. They interpreted this condition to mean that their units were not providing an oxygen flow.

Two flight attendants, one of whom was not qualified in the DC-10, were in the lower lobe galley when the cabin decompressed and were not aware of the mishap initially. Neither visual nor aural warning systems are located in the galley to warn of a pressure loss. The attendants could not actuate the ceiling-mounted oxygen generator, and shortly thereafter one attendant became hypoxic. The attendants went to the cabin via the personnel lift; after returning to the cabin one attendant convulsed and lost consciousness.

Case History No. 2

A DC-10 departed LaGuardia, New York, on May 1, 1975, with 182 passengers and a crew of 12 aboard. While at 33,000 feet, the crew noticed that the cabin altitude was 15,000 feet and increasing. Oxygen masks had deployed, and the cabin altitude reached 18,000 feet. The lack of pressurization was traced to an avionics compartment access door which was never fully closed and which prevented the aircraft from pressurizing after takeoff. The door-warning circuit malfunctioned and the crew could not detect the door's abnormal position. The altitude aural and visual warning devices failed to alert the crew at the 10,000-foot level because a plastic cap had been left on the cabin vent port of the cabin aneroid switch. The flightcrew remained unaware that the cabin failed to pressurize and that the passenger oxygen masks had deployed when cabin altitude reached 14,000 feet. The crew was alerted by a flight attendant that the masks had dropped, that passengers were feeling dizzy, and that the cabin was hot. An emergency descent to 10,000 feet was made.

Only two passengers properly actuated their oxygen generators and donned their oxygen masks. The remaining 180 passengers were assisted by flight attendants.

Case History No. 3

On November 3, 1973, a DC-10 was cruising at 39,000 feet southwest of Albuquerque, New Mexico, with 115 passengers and a crew of 12 aboard. Fragments from a disintegrating No. 3 engine fan assembly penetrated the fuselage and the No. 1 engine. The damaged fuselage caused the cabin to decompress immediately. A passenger was ejected through a broken cabin window after it was struck by a fragment of the engine's fan assembly. Damaged electrical systems caused some oxygen compartment doors to fail, and an emergency descent was made. The aircraft landed 19 minutes later. The cabin altitude reached 34,000 feet about 26 seconds after the window was broken.

Because the No. 1 AC electrical bus had failed, about 3 minutes elapsed before oxygen masks deployed in the first-class cabin, in the lower lobe galley, and in the center service area. Oxygen masks deployed correctly throughout the remainder of the cabin, except for those in the left rear cabin which were affected by failure of the No. 3 AC electrical bus. Several flight attendants and passengers forced open seatback oxygen compartment doors to obtain oxygen in these sections. Flight attendants were not aware of the manual releases on oxygen compartment doors.

When oxygen masks were presented, some passengers did not know how to use them. Others removed their masks from compartment doors and leaned forward into the mask, which prevented the lanyard pins from releasing; consequently, the oxygen generators were not activated. Other passengers discontinued using their masks because the attached reservoir bags did not inflate. The passengers concluded that the equipment was defective because the bags did not inflate.

At three seat installations, the oxygen generators were pulled from their mountings and the hot generators burned and scorched seat upholstery. Flight attendants were not aware that when the generators are activated the containers are heated to as much as 547°F. One attendant burned her fingers when she tried to remove a generator from a seat cushion.

Two flight attendants were in the lower lobe galley when the cabin decompressed. After they noticed that the oxygen masks had not dropped, they attempted to reach portable oxygen units stored elsewhere in the galley; they lost consciousness before reaching these units. In addition, three passengers, who were standing in the main cabin when it decompressed, lost consciousness. Aircraft occupants were exposed to altitudes above 30,000 feet for 1 minute and to altitudes above 25,000 feet for more than 2 minutes.

Twenty-four persons, including four flight attendants, were treated for smoke inhalation (caused by hydraulic fluid vapors which penetrated the air-conditioning system) barotrauma, hemorrhagic barotrauma, increased inner ear pressures and fluids, and minor abrasions sustained in the emergency evacuation.

Case History No. 4

On April 1, 1973, an L-1011 was inbound to New York, with 212 passengers and a crew of 13 aboard. The aircraft decompressed while descending from 29,000 feet, and an emergency descent was made to 10,000 feet; the aircraft was landed 37 minutes later. During the decompression, the cabin altitude rose to 20,000 feet. Most oxygen masks automatically deployed in the cabin from the overhead compartments, but 20 oxygen compartment doors failed to open. Additionally, one oxygen generator did not activate, one oxygen mask plastic tube was kinked and inoperable.

Passengers donned their masks immediately, but in doing so, some placed the masks over their mouths instead of over both their noses and mouths. A deadheading airline captain and the flight attendants reported that several masks failed to drop from the overhead compartments. Some flight attendants stated that some masks failed to operate and that oxygen was not being delivered to other masks; as a result, some passengers were directed to use masks at adjacent seats and some were moved to other seats.

A number of flight attendants were not aware immediately of the decompression; some recalled feeling ear discomfort and later noticed the oxygen masks drop. During the emergency descent, flight attendants assisted passengers who were hyperventilating and those who experienced ear blockage. One attendant sat on a seatback and instructed passengers in the use of their masks. None of the attendants became incapacitated, although most experienced ear discomfort. The flight attendants reported that it was difficult for them to instruct passengers while also breathing oxygen.

ANALYSIS OF PROBLEMS

After its review of case histories, the Safety Board concluded that problems involving supplemental chemical oxygen systems could be grouped into two areas: Hardware and design problems and problems incurred by users of the systems.

Hardware and Design Problems

Oxygen Flow Indications

In many cases, passengers and flight attendants concluded erroneously that oxygen was not being delivered to masks because the reservoir bag did not expand immediately or did not contract with each inhalation. Passengers became alarmed and had to be reseated by flight attendants to try a second or even a third oxygen mask. In some cases, the use of oxygen was discontinued either because of a lack of flow indication or because passengers felt no need for oxygen although they may have been hypoxic.

The cabin altitude affects the reservoir bag's behavior. At lower cabin altitudes the reservoir bag will demonstrate little or no noticeable action although the maximum flow of oxygen is being delivered. Conversely, as the cabin altitude increases and ambient pressure decreases, the oxygen flowing from the generator will expand before entering the reservoir bag. The expanded volume of oxygen, which is being stored in the reservoir bag during the expiration cycle, will induce more noticeable expansion of the reservoir bag as altitude increases. For example, a 3 liter-per-minute oxygen flow at 14,000 feet will expand and increase to a 19 to 20 liter-per-minute flow at 40,000 feet. This characteristic of the reservoir can lead users to assume that oxygen is not being delivered to the mask. Currently, there are no other means available in the DC-10 and L-1011 oxygen systems to indicate to passengers and to flight attendants that oxygen is being delivered to the mask. (See Appendix B for a detailed description of the supplemental oxygen system.)

Adjustment of Headband

An adjustable elastic headband is attached to the mask so that it will fit tightly around the nose and mouth. The wearer must pull a short adjustment strap on each side of the mask until the desired tightness is attained. Unfortunately, passengers have not always been able to tighten their masks or have donned them incorrectly and covered only their mouth. In addition, passengers often hold the mask against the face with one hand and attempt to adjust the headband with the other. If the passenger is hypoxic, he could become unconscious before the mask can be adjusted tightly or before the strap can be positioned over the head. Laboratory tests and actual decompressions have proven that persons have difficulty seeing the short adjustment ends of the headband, and, once seen, have difficulty actually finding and pulling the adjustments. (3)

When flight attendants demonstrate the use of masks, they often do not actually don and adjust the mask.

Reservoir Bag Service Life

Instances have been reported in which reservoir bags have failed to inflate because the bag's interior surfaces were stuck together. Recently, when a military aircraft decompressed at 21,000 feet, two passengers reported these difficulties. During air carrier scheduled inspections of oxygen systems, masks have been found with the interior surfaces of the bags stuck together.

Instances have also been reported in which the vinyl plastic bag itself was so inflexible that the bag could not inflate. When the vinyl plastic has been subjected to low temperatures for some time, the material becomes inflexible. When the bag fails to inflate, an insufficient amount of oxygen will be stored and the dilution valve will open early during the inhalation cycle. As a result, ambient air will enter the mask and the oxygen partial pressures will decrease.

As the vinyl plastic material ages, certain chemical changes occur that could cause the conditions described above. The manufacturer should establish a service life to prevent in-service occurrence of these conditions; however, such a service life is not required by the Technical Standard Order governing the manufacturing of the oxygen masks components.

The continuous Airworthiness Program delineated in 14 CFR 121, Subpart 6, should prevent the in-service difficulties of nonfunctioning reservoir bags as well as other difficulties (such as kinked supply hoses) found during the Board's investigations. However, preventive maintenance procedures apparently do not always cover these items satisfactorily and inspection intervals may vary with different air carriers. Establishment of a service life by the manufacturer could eliminate these problems because realistic inspection cycles and adequate inspection procedures could then be established in the Continuous Airworthiness Programs of air carriers.

Manual Compartment Release

Within the fleet of DC-10 aircraft, the seatback oxygen compartments may be manually opened using any one of five methods. This is possible because each air carrier chooses the manufacturer for the passenger seats and also specifies the manner for the manual release. However, there may be more than one manual release method on a single aircraft if that aircraft is equipped with seats supplied by more than one manufacturer. Air carriers want the manual release to be as unobtrusive as possible so that passengers will not intentionally or inadvertently open the oxygen compartments and tamper with the oxygen system components. During an emergency, however, these multiple opening methods place undue burden on flight attendants. On the L-1011 aircraft, a manual release has not been incorporated on the oxygen compartment doors. Instead, there is redundancy in the sequence timer which cycles twice to supply power to all compartments and generators. A manual switch in the cockpit bypasses the aneroid switches and supplies power to the sequence timer directly.

Stowage of DC-10 Masks for Emergency Landing

If an aircraft is damaged after decompression, an emergency landing might be necessary, or the captain could order the cabin prepared for an emergency landing as a precautionary measure. Consequently, the passengers would have to be protected from objects inside the opened seatback compartment. In order to close a seatback oxygen compartment door, a crewmember must repack the oxygen masks inside the compartment and reset the latching mechanism. In case history No. 3 passengers attempted to restow the oxygen masks into the compartments and to close the compartment doors. Several masks and reservoir bags were damaged and melted because they came into contact with the hot generators. The FAA does not require the manufacturer to demonstrate that the open compartments are not hazardous. Similarly, they are not required to show that the oxygen compartment door can be closed by passengers and that the door can be closed with the oxygen masks deployed and hanging down outside the compartment. In fact, because of the latch design, a passenger probably would not be able to close the compartment door without crew assistance.

Reliability of Oxygen Compartment Doors

Oxygen compartment doors have failed to open during decompressions, during ground tests, and during flight tests following decompression in both the DC-10 and L-1011 aircraft. The FAA issued several Airworthiness Directives specifying steps to be taken to ensure that remedial action would be taken to correct conditions responsible for recurring failures. Unfortunately, within the months following incorporation of design changes, such failures were still being reported on DC-10's. Similar, but fewer, problems also continue to be reported on L-1011 aircraft.

User Problems

Oxygen Mask Presentation

In current air carrier operations, passengers are expected to understand and to follow emergency procedures which are relatively complex and which are not always clearly explained in the emergency instructions given for the operation of the supplemental oxygen system. Usually, the oxygen mask's location, the facial position of the mask, and the instruction to breathe normally and to extinguish all smoking materials are given. The recognition of an emergency, the proper use of the mask, and adequate and efficient response are left to the passenger.

To minimize reliance on proper passenger behavior, automation was designed into the presentation of oxygen equipment. In earlier pressurized aircraft, the masks fell down automatically at a predetermined cabin altitude, oxygen flow began, and the passenger had only to reach for the mask and apply it to his face. Such is the system on the L-1011.

In the DC-10, however, the supplemental oxygen equipment is contained in the seatback in front of the passenger. Although the door opens automatically when the equipment is needed, the masks remain stowed and the equipment is not activated until the passenger removes the mask from the door and pulls it toward him.

The case histories clearly illustrate that this method of presentation is inadequate. Passengers apparently are reluctant to disturb a neatly packaged system, especially when they are not familiar with its function. Furthermore, presentation of the entire system, including the generator, the linkages, the piping and connections, tends to confuse and frighten passengers and, rather than experiment with it, they ignore it. Such passenger behavior was observed in several of the decompression incidents cited in this study. Therefore, the DC-10 presentation of supplemental oxygen requires excessive passenger involvement and response.

The confusion caused by the presentation of the oxygen system on DC-10 aircraft is potentially hazardous. A confused passenger may delay action for sufficient time to cause hypoxia. At 30,000 feet, time of useful consciousness is 35 to 60 seconds, and those times decrease rapidly as altitude increases. A study by Donaldson et al. (4) showed that masks may have to be donned and oxygen delivered within 15 seconds of decompression to 36,000 feet to avoid loss of useful consciousness.

Flight Attendant Training

A flight attendant can be assigned to an aircraft for the sole purpose of assisting in the preparation and distribution of meals and beverages. Technically, the attendant has no other duties; therefore, such attendants are not required to be qualified in that aircraft and, as a result, need not be knowledgeable in the location of the portable oxygen bottles. Case No. 1 illustrates that flight attendants are assigned as supplementary crewmembers to assist in the cabin service while not being fully knowledgeable of the location of all emergency equipment.

To familiarize attendants with their system's characteristics, Douglas Aircraft has published and distributed a booklet written for flight attendants which explains the operation of the chemically generated oxygen system. Unfortunately, the booklet has not been widely accepted by air carriers. The booklet includes the warning not to touch an oxygen generator after it has been activated because of its high operating temperature. An example of a lack of awareness of this warning occurred in Case No. 3 wherein a flight attendant was burned while attempting to pick up generators which fell from their compartments. This same case also illustrates that flight attendants were unaware of the manual method to release the oxygen compartments; the various methods for opening the compartments are illustrated in Douglas' booklet.

Passenger Briefings

Although recent improvements have been made in the illustration of safety information on passenger information cards, the flight attendant's briefing is the only occasion when a passenger will receive verbal instructions on the use of the oxygen system. Federal Aviation Regulations specify that such briefings be given and FAA regional offices approve the format and contents of these briefings. Air carriers develop the briefings for the required emergency situations and submit them for approval. However, because there are no standards, specifications, or universally accepted criteria by which to measure the adequacy of such briefings, there are diverse opinions among the FAA regional offices as to what constitutes an adequate briefing. Consequently, passenger briefings are not standardized.

As a result, some briefings on aircraft with chemically generated emergency oxygen equipment do not differ from those given on aircraft equipped with gaseous oxygen systems. While there are similarities between the two types of systems, insofar as expected passenger action is concerned, there are also marked fifferences between the two systems. For example in the DC-10, the passenger must remove the mask from its stowed location and pull it toward him to initiate the oxygen generator. A loud snap can be heard as the initiator fires, and the passenger should be prepared to expect the noise. On the other hand, in the L-1011, the oxygen generator is fired electrically by a sequence timer which also activates the overhead compartment doors. A lanyard attached to the door pulls the oxygen masks from the compartment at the instant the springloaded door opens; the oxygen masks fall down in front of the passengers, ready for use.

A second example, which was previously discussed, is the absence of oxygen flow indications. This, coupled with the lack of reservoir movement while a person is breathing and the possibility that it can take up to 15 seconds for full oxygen flow to develop emphasizes the need for a more thorough passenger briefing to prepare the passenger for a decompression. Other than the Federal Aviation Regulation, which requires passengers be briefed, there is no guidance as to what a passenger must be told in order to operate the oxygen system properly.

A problem arises following decompression when flight attendants must assist passengers who are not able to follow procedures, or who experience difficulty donning or adjusting their masks. There is available for the DC-10 and the L-1011, as a customer option, a tape recorded message of passenger instructions which is broadcast automatically over the cabin public address system when the cabin altitude exceeds 14,000 feet. The use of this tape, which can be heard above the cabin ambient noise, would free the attendants from having to make repeated announcements and individual instructions when they also would be in need of oxygen.

Finally, there are no standard criteria by which the FAA can determines the adequacy of instructions given to passengers on passenger information cards.

Summary

The Safety Board believes that supplemental oxygen equipment should be designed so that the passenger need only to don the mask and adjust it to fit. To avoid delay on the part of passengers, the mask should be presented for immediate use and should be delivering oxygen at that time. The case studies presented in this study clearly show that the behavioral response of passengers to the emergency situation of a decompression is predictable - such behavior had been predicted by studies on decompressions in altitude chambers (4), (5), (6), and (7).

Although we know of no fatalities or serious physiological consequences to crew or passengers because of lack of oxygen in modern turbine-powered transport/air carriers involved in noncatastrophic pressurization failures, the potential for serious injuries rises with the growth of aviation. Studies on the effects of high altitudes on humans always have been performed under closely controlled conditions with healthy, medically qualified subjects. However, the air carrier passenger population is unselected medically and the aged and those passengers with pulmonary and cardio-vascular diseases are more vulnerable to the effects of high altitude than the test subjects who initially established known hypoxia parameters. Thus, this passenger vulnerability makes imperative the best possible design of emergency supplemental oxygen equipment.

Many problems presented in this study result from the oxygen systems located in the seatbacks on DC-10 aircraft. While this particular location may appear to enhance passenger accessibility to the oxygen mask, it should be recognized that, historically, most passengers would expect that the masks be presented from the overhead. Consequently, the design of the DC-10 supplemental oxygen equipment and its presentation to the passenger caused most of the inadequate and faulty passenger responses presented in this study. These problems are a direct result of the absence of guidance for the designer of supplemental oxygen systems. An oxygen source and a means by which to deliver the oxygen to the user which does not consider fully the user-equipment interface can result in the misuse or nonuse of such equipment. Development of a Technical Standard Order (TSO) or other appropriate means of guidance for the designer of such equipment would result in better user-equipment compatability.

In addition, before a system is installed, it should be clearly demonstrated that the user will have minimal difficulty with it. The design of a system is so closely related to the safety of the passengers that it should be tested in a mockup demonstration in the early design stages to show that passengers can perform the actions required to initiate oxygen flow, to don a mask, and to adjust the mask in sufficient time to avoid unconsciousness. Such demonstrations would assist designers in making early design changes when problems are discovered. Therefore, the Safety Board believes that a demonstration test should be developed to show that passengers understand the operation of the supplemental oxygen system and respond adequately to it.

Finally, with regard to the problem of passengers' not being provided with adequate illustrative materials to instruct them on the proper use of supplemental oxygen systems, a recent study by the Douglas Aircraft Company (3) was initiated to evaluate illustrated instruction placards for the seatback-installed oxygen systems in the DC-10. The study showed that without the placard less than 25 percent of the test subjects performed the necessary tasks to obtain oxygen. Using three different instructional placards, 27 percent, 75 percent, and 94 percent, respectively, performed these tasks successfully. (The most successful of these placards is shown in Figure 7, Appendix B.)

CONCLUSIONS

1. As many as 10 severe decompression incidents may occur each year in U.S. air carrier operations in which supplemental oxygen systems may have to be used by aircraft occupants.

2. The characteristic behavior of the oxygen mask reservoir bag can lead users to assume that oxygen is not being delivered to the mask. In several instances, passengers and flight attendants have concluded erroneously that oxygen equipment malfunctioned because there are no indications, other than inflation of the reservior bag, to indicate that oxygen flow is taking place.

3. The ends of the elastic headband, which must be adjusted to tighten the oxygen mask against the wearer's face, are not easily seen and are difficult to locate by touch.

4. Because a service life for oxygen mask reservoir bags has not been established, preventive maintenance programs may have inadequate inspection methods and inspection intervals to detect malfunctioning reservoir bags.

5. There are as many as five methods of manually opening the oxygen compartment doors on different DC-10 aircraft seats. These multiple opening methods can cause unnecessary confusion among flight attendants during an emergency situation.

6. Open oxygen compartments in the seatbacks in DC-10 aircraft constitute serious potential for head injury during crash landings. Passengers are not able to close these compartments without crew assistance and attempts by passengers to close compartment doors have resulted in heat damage to masks, reservoir bags, and supply hoses.

7. Despite extensive redesign of oxygen compartment doors and latching mechanisms, instances are being reported of compartment doors failing to open on DC-10 and L-1011 aircraft.

8. The DC-10's presentation of oxygen masks inhibits passengers from timely initiation of oxygen flow and mask donning because the mask remains stowed and the equipment is not activated until the mask is removed and pulled forcefully toward the user.

9. In several cases examined, the training of flight attendants in the use and operation of chemically generated, supplemental oxygen systems was inadequate.

10. Unqualified flight attendants are assigned ancillary duties on aircraft. As a result, they may not know the location of all emergency equipment. In one case, this practice resulted in a severe hypoxic state of a flight attendant.

11. Although FAA approves the format and contents of passenger briefings on the operation and use of supplemental oxygen equipment, there are no specifications or commonly accepted guidelines by which the adequacy of such briefings can be measured.

12. The design-induced problems in the DC-10's supplemental oxygen system result from the absence of guidelines for design of such systems.

13. A passenger supplemental oxygen system should be tested by demonstration early in its development stage so that designers may make design changes when problems are discovered.

RECOMMENDATIONS

As a result of this Special Study, the National Transportation Safety Board issued the following recommendations to the Administrator, Federal Aviation Administration:

"1. Require, after a certain date, that passenger emergency supplemental oxygen systems have readily discernible means to indicate that oxygen is flowing.

"2. Amend 14 CFR 37.169 "Oxygen Mask Assembly, Continuous Flow, Passenger (for Air Carrier Aircraft) - TSO-C64," to require adjustment tabs on oxygen mask headbands, which can be easily recognized by distinctive shape and color.

"3. Issue an Airworthiness Directive, requiring installation of adjustment tabs on in-service and in-stock passengers' supplemental oxygen mask headbands.

"4. Establish service life and periodic inspection requirements for oxygen mask reservoir bags.

"5. Require that operators of aircraft having the chemically generated passenger supplemental oxygen systems include detailed information regarding the operational characteristics of these systems in the training programs for their cockpit and cabin crewmembers. Such information should include flow rates and the time and volume lag in the delivery of oxygen.

"6. Issue an Advisory Circular (AC) to all Part 121, 123, and 135.2 certificate holders to provide guidelines for improved passenger briefings and printed instructions for the use of chemical supplemental oxygen systems.

"7. Issue an Operations Bulletin for a review of oral briefings and passenger safety cards for each Part 121, 123, and 135.2 certificate holder to assure that briefings and printed instructions for the use of the passenger chemical supplemental oxygen system are factual and unambiguous and conform to the guidelines of the above AC.

"8. Develop standards for the use of accepted human factors engineering principles and system design concepts in the design of passenger supplemental oxygen systems.

"9. Develop standards for type certification demonstration tests of passenger supplemental oxygen systems."

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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March 3, 1976

APPENDIXES

APPENDIX A

Physiological Requirements for Supplemental Oxygen

The requirement for supplemental oxygen to sustain life at high altitude has been known for over 100 years. Oxygen was first used at high altitudes on April 15, 1895, in France, when three scientists ascended in a balloon to 28,000 feet. The oxygen was stored in goatskin bags and breathed through a small rubber tube held in the mouth. In an effort to conserve their supply, the three balloons occupants became severely hypoxic and lost consciousness; only one survived the ascent.

Paul Bert, a French physiologist who had previously researched the effects of barometric pressures, was the first to prove that hypoxic effects at high altitudes are caused by the reduced partial pressure of oxygen in the inspired air. (8)

Dry air is composed of approximately 21 percent oxygen, 78 percent nitrogen, and 1 percent of other gases (carbon dioxide, helium, argon, hydrogen, neon, krypton, and xenon). The pressure exerted by any of these gases, called the partial pressure of that gas, can be calculated for a given barometric pressure. (2)

The partial pressure of oxygen (PO_2) in the air sacs of the lung (alveoli) of normally healthy individuals determines the amount of oxygen that can be absorbed by the bloodstream. At sea level, the alveolar PO_2 is about 103 millimeters of mercury (mmHg) and the oxygen saturation of the blood at that pressure is about 98 percent. At 10,000 feet the alveolar PO_2 is 61 mmHg and blood saturation is reduced to about 90 percent. At 20,000 feet, these figures are about 33 mmHg and 70 percent, respectively. As altitude increases, the PO_2 decreases proportionally but the percentage of oxygen saturation of the blood decreases much more rapidly. The PO_2 values quoted are from actual measurements on human subjects. They differ from theoretical values due to the increasing hypoxic stimulus to respiration (hyperventilation) caused by the decrease in PO_2 with increasing altitude. (9)

The brain uses about 20 percent of the oxygen consumed by the body, and since there is no means whereby the brain can store oxygen, it depends on a continuous supply of oxygenated blood. Therefore, as alveolar PO_2 decreases, arterial oxygen tension falls and the central nervous system is impaired. This condition is known as hypoxia -- a lack of sufficient oxygen supply to the tissues.

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The onset of hypoxia varies with the cause. In a climb to higher altitudes, the onset is as gradual as the rate of climb. Below 10,000 feet, no appreciable effects are noted although vision is known to be affected at altitudes above 4,000 feet. Between 10,000 feet and 18,000 feet, recent memory, coordination, and judgment are impaired, but healthy individuals at rest rarely lose consciousness at these altitudes. Above 18,000 feet, the mental functions deteriorate rapidly and the time to unconsciousness is measured in minutes above 25,000 feet and in seconds above 30,000 feet. (10)

In cases of sudden exposure to low barometric pressures, such as during rapid or explosive decompressions, the length of time before consciousness is lost is determined primarily by the altitude to which the individual suddenly is exposed. Times to unconsciousness are much shorter in cases of sudden decompression because PO_2 in the lungs drops immediately rather than gradually.

The changes in the central nervous system as a result of hypoxia render individuals unable to act rationally well before they become unconscious. Since subtleness of hypoxia is as dangerous as unconsciousness, "time of useful consciousness" has been determined. Time of useful consciousness is the time at a given barometric pressure during which any sort of purposeful activity can be performed. It represents the time between the exposure to reduced PO_2 and the onset of an individual's inability to take rational action. Figure 1 shows these times for rapid decompressions to various altitudes above 25,000 feet.

The obvious action to take after being exposed to reduced barometric pressures is to enrich the inspired air with oxygen. Alveolar PO_2 can be maintained at sea level values by breathing 100 percent oxygen up to an altitude of about 33,000 feet. Above this altitude oxygen must be supplied under pressure to maintain equivalent sea level alveolar PO_2. However, since the effects of hypoxia are negligible at an alveolar PO_2 value of 61 mmHg, breathing 100 percent oxygen up to altitudes of about 39,000 feet will prevent the effects of hypoxia in the average individual.

In the mid-1940's because of the possibility of decompression in commercial transport aircraft capable of flying at increasingly higher altitudes, passenger supplemental oxygen systems were developed to meet the physiological requirements for oxygen. The introduction of the turbojet transports in the early 1950's stimulated development of passenger oxygen systems which were capable of sustaining life up to aircraft cruising levels of 40,000 feet. These oxygen systems had to be capable of providing oxygen concentrations near 100 percent. As a result, new types of continuous flow reservoir oxygen masks and automatically actuated oxygen systems were designed. In these systems, gaseous oxygen is stored under pressure in cylinders and carried in the aircraft in sufficient quantity to meet the needs of occupants for a specified time and under the conditions set forth in 14 CFR 25.

With the advent of the wide-bodied aircraft, which can carry up to 450 passengers, new approaches to passenger supplemental oxygen supplies were sought because of the increasing weights and volumes required to stow oxygen supplies and the desire to decrease the fire hazards associated with high-pressure, gaseous oxygen systems. Because of the successful long-term use of chemical oxygen generators in submarines in the U.S. Navy, the Lockheed Aircraft Company and the McDonnell Douglas Aircraft Company pioneered the chemical supplemental oxygen systems for passenger emergency use in the L-1011 and DC-10 wide-bodied aircraft. The primary advantages of the chemical oxygen systems are their simplicity, reliability, ease of maintenance, lighter weight, and they reduce fire hazards.

DECOMPRESSION EVENTS AND UNCONSCIOUSNESS

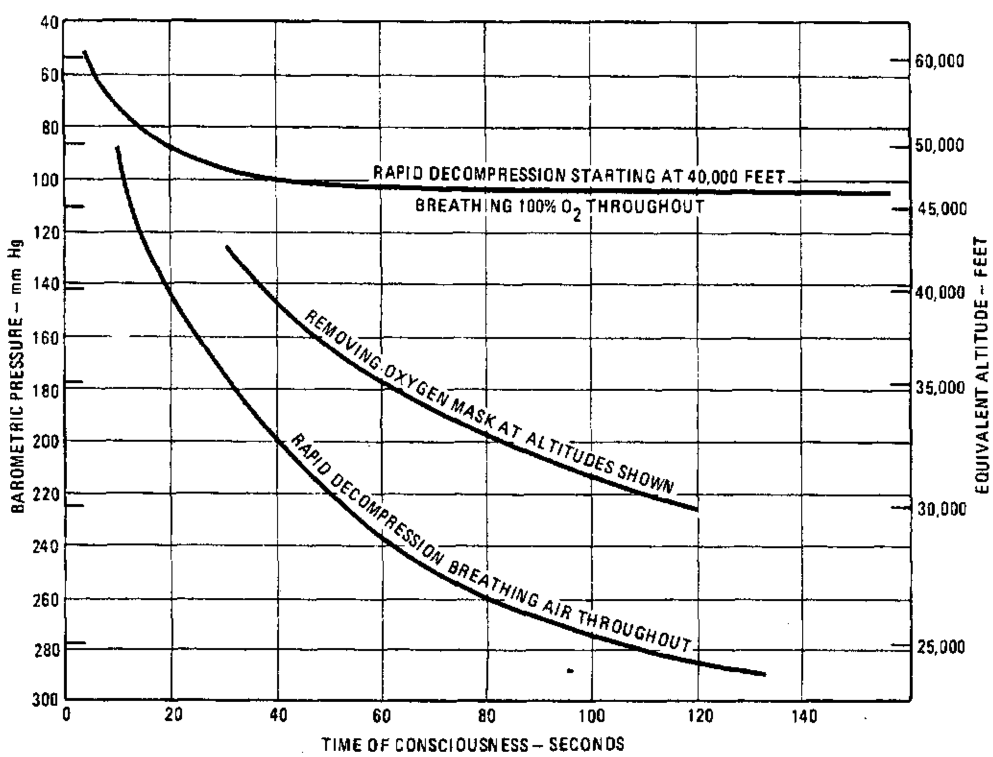

Figure 1

Two decompression conditions and the time of consciousness for each type as a function of barometric pressure at the end of decompression, and for comparison a third curve showing the effect of removing the oxygen mask at altitudes from 30,000 to 43,000 feet. The rapid decompressions shown for air breathing throughout start at 10,000 feet. (Adapted from AF Manual 160-5, 1954; and Blockley and Hanifan, final report on contract FA-955, Fed. Av. Agency, 1961.)

APPENDIX B

Chemically Generated, Supplemental Oxygen Systems

Oxygen Generator

During World War II, many countries developed the technology of using the thermal decomposition of alkali metal chlorates to produce oxygen for use in submarines. However, oxygen generated by this method was found to be of inadequate purity for use in aircraft. In the 1960's work was renewed to develop a highly efficient, light weight oxygen generation system which could meet the high standards of purity necessary for aircraft applications.

To generate oxygen, sodium chlorate, $NaClO_3$, is mixed with iron powder and additives and then molded into a solid cylindrical tapered block. The taper assures that the oxygen flow is highest following activation and the flow is thereafter proportional to the aircraft's descent profile. The $NaClO_3$ chemical core is surrounded by a metal cylindrical protective canister. A layer of insulating material, located between the core and the cylinder, retains heat necessary for decomposition of the $NaClO_3$ and insures a suitable external temperature of the canister. A filter inside the canister removes gaseous and impure particles. A manifold delivers the oxygen to one or more oxygen masks. One end of the cylinder contains the initiation device which can be either a pin-actuated percussion cap or an electrically powered igniter. (See Figure 2.) The thermo-chemical reaction takes place when the initiation device produces heat and the sodium chlorate core begins to burn and thermally decomposes into sodium chloride and oxygen. Thus:

$$Fe + NaClO_3 \xrightarrow{\text{heat}} FeO + NaCl + O2$$

Byproducts of the process include chlorine, carbon monoxide, carbon dioxide, and water vapor, which are filtered out. Iron oxide and sodium chloride remain inside the steel canister as solid residues. In addition to meeting the requirements of MIL-STD-810: Environmental Test Methods, Military Standard - for environmental testing, and, MIL-O-27210: Type 1 Oxygen, Aviators Breathing Liquid and (Gas, Military Specification - for oxygen purity, the oxygen generator must further comply with the following:

Chlorine	0.05 ppm
Carbon monoxide	8 ppm
Carbon dioxide	trace
Water vapor	10 mg/liter
Solid particles	100 microns
Maximum fibers	600 microns length 40 microns diameter
Maximum total solids	0.05 mg/liter

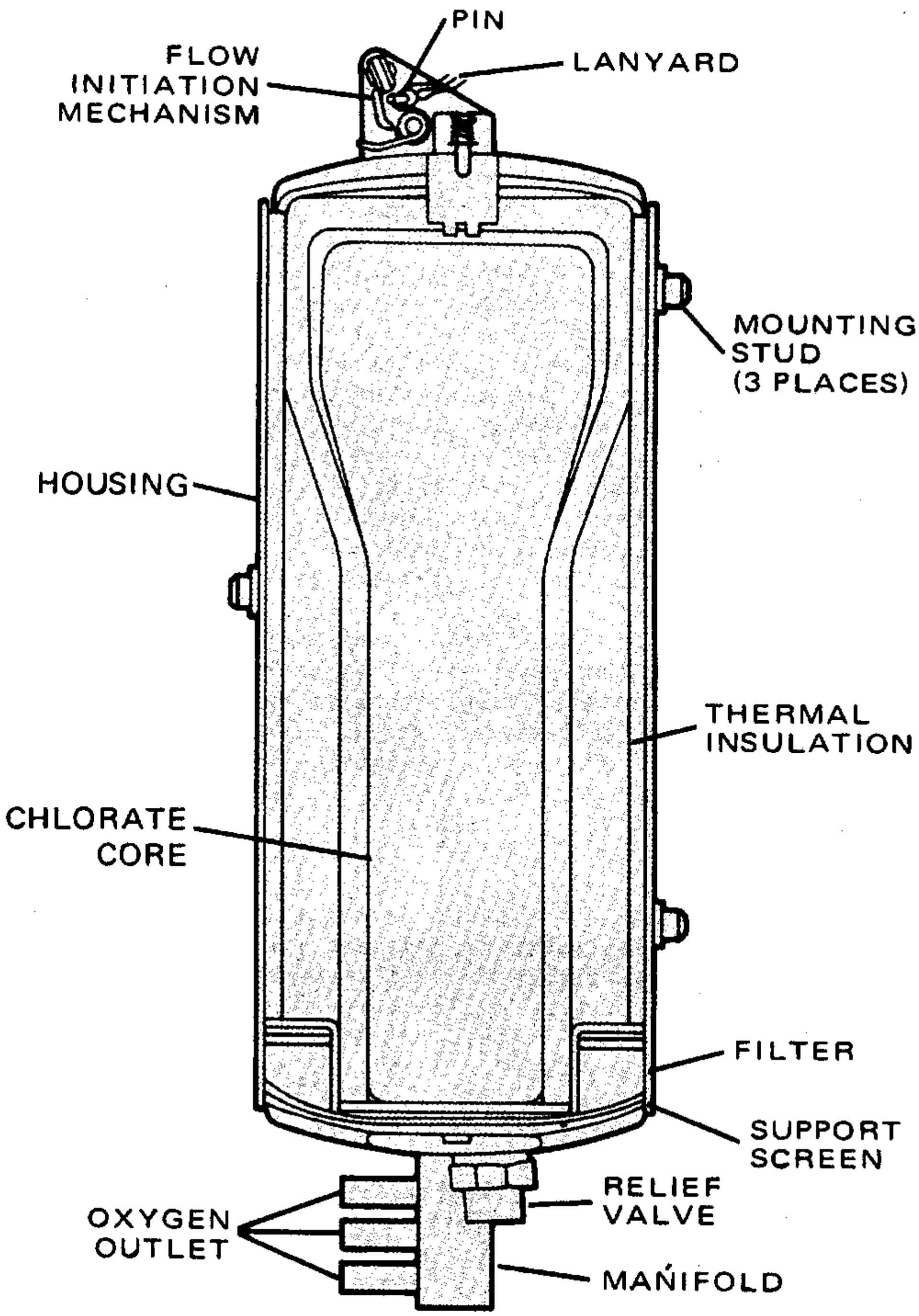

Figure 2

OXYGEN GENERATOR - CUT-AWAY VIEW

Reprinted with permission of Douglas-Aircraft Company Long Beach, California

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A detailed description of the chemical reactions of the oxygen generator core is shown in Table 1. Table 2 delineates typical specifications for commercial oxygen generators.

Oxygen generators are required by 14 CFR 25.1443 and 14 CFR 121.329(c) and .333(e) to provide a specified flow. These requirements have been developed from human physiological needs as a function of cabin altitude following a failure of the aircraft's pressurization system. Pressurization system failures can be correctable as in the case of a malfunctioning outflow valve, or failures can be noncorrectable as in the case of the loss of a cabin window. Specifications are based on a worst-case failure of the pressurization system. A chart is developed of the profile of the rate of rise in cabin altitude, the aircraft's emergency descent rate, and other factors which may influence the duration of the aircraft's descent. For example, if a noncorrectable failure were to occur over mountains, the altitude to which the aircraft could safely descend would be limited by the height of the mountains. The aircraft would then maintain the lowest safe altitude for terrain clearance until clear of that terrain. A second descent to 10,000 feet would be made when clear of the mountains. This would permit cessation of the oxygen requirements. Figure 3 shows a typical descent profile.

The anticipated storage life for oxygen generators is 10 years. Oxygen generators must be inspected visually for evidence of activation. In the DC-10, the generator's striker mechanism will rest on the percussion cap if the generator has been activated. In the L-1011, the generators have a heat sensitive paint stripe which will change color when the generator has been activated.

Oxygen Mask Assembly

The mask assembly is a soft, pliable, cone-shaped facepiece, with an adjustable head strap, a reservoir bag, and tubing which connects the reservoir bag to the oxygen generator. In the mask's facepiece spring-loaded check valves allow oxygen to flow into the mask upon inspiration, allow ambient (cabin) air to flow into the mask during the latter period of inspiration, and allow expirated air to flow out of the mask.

The continuous flow oxygen from the supply tube is collected in the reservoir bag during the respiratory pause and exhalation. The flow continues at the same rate during inspiration. During inspiration, a sensitive check valve opens which allows 100-percent oxygen to be delivered to the mask until the bag is emptied. At that time, a second valve opens and allows ambient air to enter the mask to provide sufficient volume for the remainder of the inspiratory cycle; 100-percent oxygen is delivered at the beginning of the inspiratory cycle. For example, if a person's tidal volume (the volume of gas taken in or out at each respiration) is 650cc and the reservoir contains only 500cc at the beginning of

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TABLE 1

COMMONLY ACCEPTED CHEMICAL REACTIONS

1. Primary reaction:

$$2\ Na\ Cl\ O_3 \longrightarrow 2\ Na\ Cl + 3\ O_2$$

2. Intermediate reactions:

(a) $Na\ Cl\ O_2 + (M\text{-}C) \longrightarrow (M\text{-}C) + (O) + Na\ Cl\ O_2$ — (M-C) Metallic Catalyst

$$(M\text{-}C)\ (O) + Na\ Cl\ O_2 \longrightarrow Na\ Cl + (M\text{-}C) + 3/2\ O_2$$

(b) $Na\ Cl\ O_3 + (M\text{-}C) \longrightarrow (M\text{-}C) + (O_2) + Na\ Cl\ O$

$$Na\ Cl\ O + (M\text{-}C)\ O_2 \longrightarrow (M\text{-}C) + O_2 + Na\ Cl + O$$

(Overall reaction: $2\ Na\ Cl\ O_3 \longrightarrow 2\ Na\ Cl + 3\ O_2$)

3. Side reactions:

Chlorine control:

$$2\ Na\ Cl\ O_3 \longrightarrow Na_2\ O + Cl_2 + 2\ 1/2\ O_2$$

$$Ba\ O_2 + Cl_2 \longrightarrow Ba\ Cl_2 + O_2$$

If water is present,

$$Na\ Cl\ O_3 \xrightarrow{H_2O} Na\ Cl\ O + O_2$$

4. Heat of oxidation from Fe:

$$2\ Fe + O_2 \longrightarrow 2\ Fe\ O$$

also, $Fe_3\ O_4$ and $Fe_2\ O_3$

The actual composition of the chemical generator, core is proprietary.

However, a typical composition used by the Navy is:

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TABLE 1 (CONTINUED)

COMMONLY ACCEPTED CHEMICAL REACTIONS

			Percent by Weight
Sodium Chlorate	$Na\ Cl\ O_3$		88
Iron Powder	Fe	Fuel	4
Steel Fiber	Fe	Binder	4
Barium Dioxide	$Ba\ O_2$	Chlorine Removal	4

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TABLE 2 - TYPICAL SPECIFICATIONS

COMMERCIAL PASSENGER OXYGEN GENERATORS

	Type Unit		
	1 MAN	2 MAN	3 MAN
Overall length (electrical activation), in.	7.78	8.03	8.14
Overall length (percussion activation), in.	8.66	8.91	9.02
Diameter, in.	1-7/8	2-1/4	2-3/4
Diameter with shield, in.	2-1/8	2-5/8	3-1/8
Weight - no shield (lb)	0.74	1.04	1.45
Weight with shield (lb)	0.78	1.08	1.50
Total oxygen weight (lb)	0.12	0.22	0.33
Max. operating pressure, psi	50		
Relief valve setting, psi	50-75		
Container seal	Check Valve		
Max. surface temperature, F	550		
Max. surface temperature shield, F	400		
Lanyard pull force (percussion ignition), lb max	4		
Igniter current, amp min	0.5		
Guaranteed shelf life, yr	10		
AQL, %	1		

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TABLE 2 - TYPICAL SPECIFICATIONS (CONTINUED)

COMMERCIAL PASSENGER OXYGEN GENERATORS

Qualification Data

Max. storage temperature, F	+160
Min. storage temperature, F	- 65
Max. operating environmental temperature, F	115
Min. operating environmental temperature, F	0
Vibration - endurance	5g per MIL-STD 810
Vibration - operating	3g per MIL-STD 810
Acceleration - operating	6.2g for 1 min.
Humidity	MIL-STD 810 proc I
Salt fog	MIL-STD 810 proc I
Explosion	MIL-STD 810 proc II

DC-10 PASSENGER OXYGEN GENERATOR DESIGN CONDITIONS

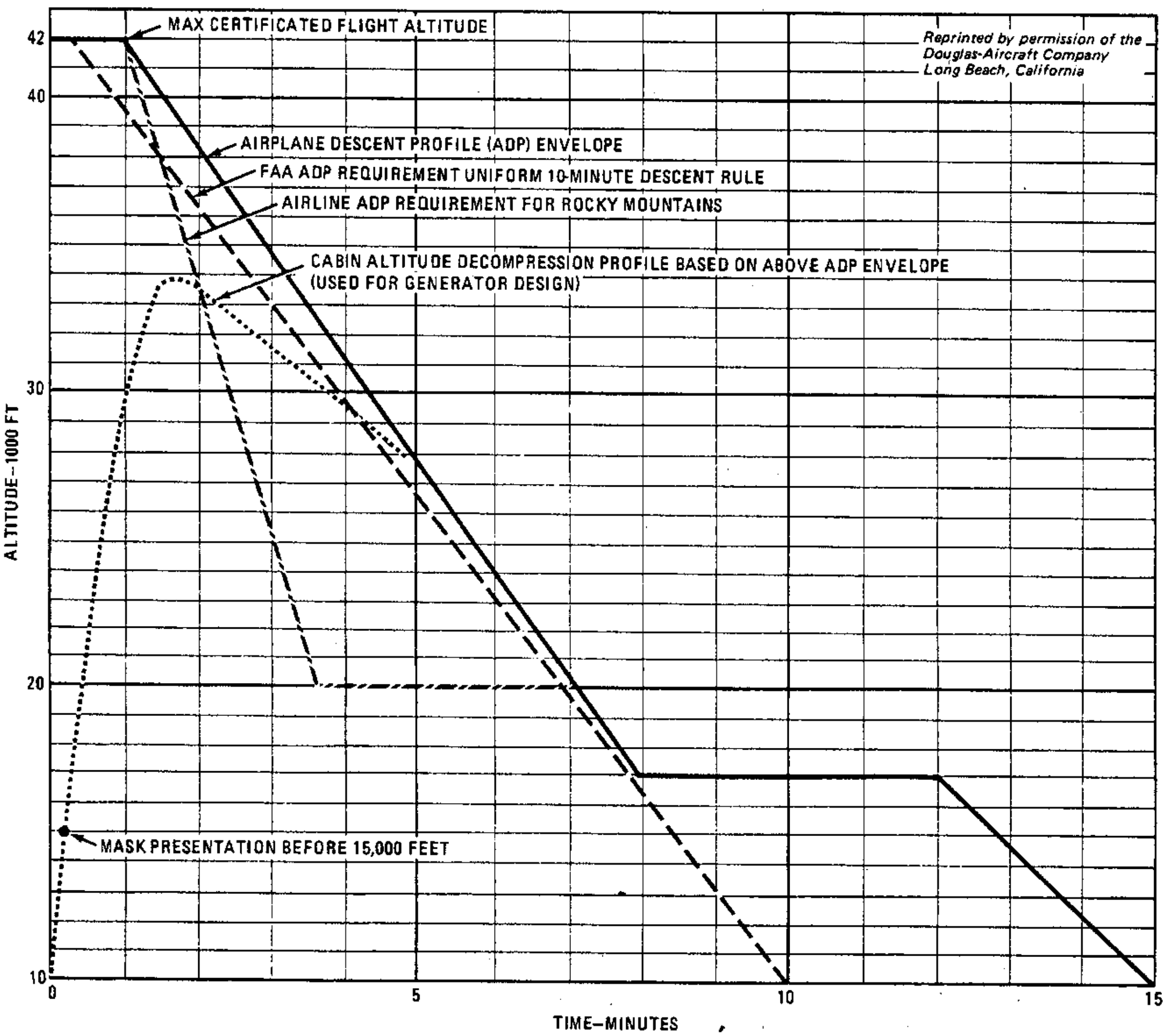

Figure 3

the inspiration, the 500cc of 100-percent oxygen will be inspired first and delivered to the lungs. The anbient air valve will then open and deliver 150cc of ambient air which will enter the mouth, trachea, and other "dead" or inactive spaces of the respiratory system. On expiration, this air is the first to exit through the exhalation valve. This process is repeated with each respiratory cycle. Usually, reservoir bags contain a maximum of 1,100cc which provides for increased tidal and minute volumes (the volume of inspired air per minute). (11) The functional characteristics of the phase diluter mask are shown in Figure 4.

The efficiency of the continuous flow phase dilution mask depends largely on the proper functioning of the reservoir bag. The expansion and contraction of the reservoir bag, is a function of:

1. The elapsed time from generator activation to full volume performance;

2. the expansion of the oxygen gas as a function of cabin altitude;

3. the user's tidal volume as a function of breathing rate;

4. the oxygen flow rate as a function of altitude;

5. the balance of the breakout forces of the inhalation and diluter valves; and

6. the pliancy of the bag's material.

The elapsed time to full oxygen volume generation can be up to 15 seconds, while noticeable bag expansion may take even longer. The user may hyperventilate because of anxiety or physical activity before sufficient oxygen has been attained by the generator. Consequently, the diluter valve may open unnecessarily. The valve may also open if the bag is not sufficiently pliant, and thereby reduce the balance inside the bag and cause insufficient storage capacity. If inhalation and diluter valve operation are not balanced, the partial pressure of the inspired oxygen will be lowered.

The L-1011 Supplemental Oxygen System

The L-1011 system consists of a controller unit in the flight engineer's panel, a sequence timer in the cabin, and oxygen generators and masks in the passenger service modules in the ceilings of the cabin, lavatories, and lower lobe galley. In accordance with Federal Aviation Regulations additional masks (at least 10 percent of the maximum number of cabin occupants) are provided for children-in-arms and for flight attendants who may be away from their stations.

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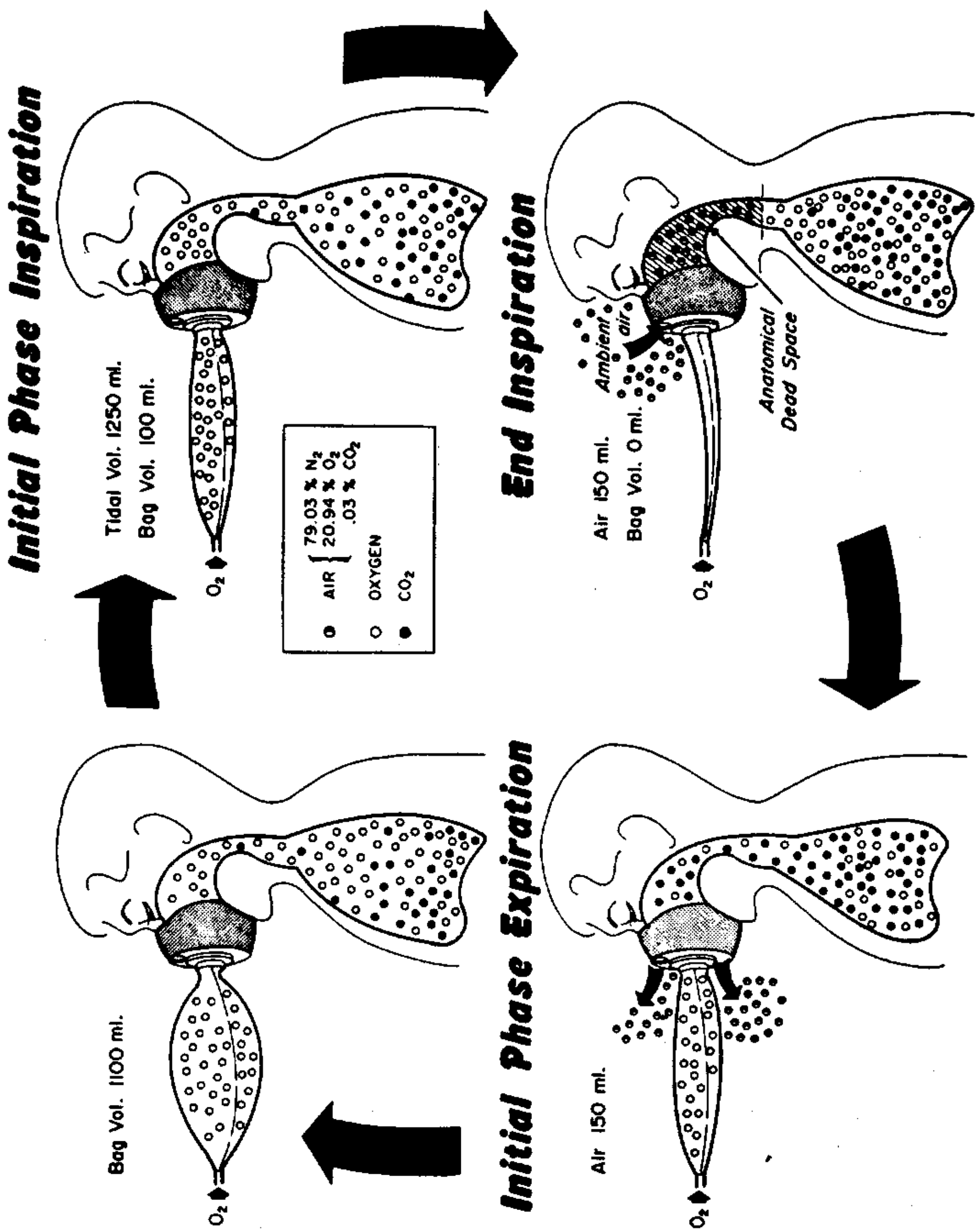

Functional characteristics of the NAS 1179 reservoir or phase dilution constant flow passenger oxygen mask. For clarity the diagram indicates flow stops at end of expiration. Actually some 1,000 cc of oxygen may be introduced into the reservoir bag at maximum jet transport flow rates during a 2 second inspiration.

From Federal Aviation Agency report AM 67-3, April 1967.

Figure 4

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The oxygen system is activated automatically by a pair of dual aneroid switches in the forward cabin. The electrical sequence, from initiation of the system to deployment of all masks to initiation of the oxygen generators, takes about 6 seconds.

When cabin altitude reaches 10,000 feet, a warning horn and warning lights are activated in the cockpit, and the no-smoking and fasten-seatbelts signs are illuminated in the cabin. If cabin altitude rises to 13,300 $\pm$ 600 feet, either pair of dual aneroid switches will close and will initiate the sequence timer. The timer distributes electrical power sequentially via two rotary-driven solenoid switches to passenger service modules (PSM) located in 15 cabin zones. Electrical power is applied sequentially to two channels to each cabin zone. One channel provides electrical signals to the pyrotechnic initiators at the oxygen generators and the second channel activates the coil of each PSM door - release mechanism. The sequencer cycles twice for redundancy. An "OXYGEN FLOW" advisory light illuminates on the flight engineer's control panel when the sequencer completes its first cycle. The light indicates that the oxygen generator in the 15th zone has received electrical power to fire the oxygen generator's initiator. Electrical power for the system is provided by the DC standby bus which is powered by the aircraft's electrical system and a nickel-cadmium battery.

Oxygen masks, encased in clear plastic containers, are installed in the PSM's. This design permits the masks to be installed as a prepackaged unit, thus facilitating replacement as well as providing protection from dust and other impurities during storage.

PSM doors are spring-loaded to open 180°. A ball-pin striker engages a magnetic latch to open the door, an electrical signal to the latch coil cancels the field of a permanent latch magnet. This releases a spring-loaded lever and plunger, and the ball-pin striker is disengaged. Springs in the door hinges rapidly open the door to a 180° position. A lanyard, fastened to the door and to one of the oxygen masks, pulls the cluster of masks from the container. Figure 5 presents a line drawing of this supplemental oxygen system.

Each of the 15 cabin zones is designed to be independent, thereby permitting the system to function normally if one of the zones fails.

If the cabin altitude rises to 11,500 feet, an altitude limit switch signal is used to automatically maintain cabin altitude to between 11,500 and 12,000 feet through control of the outflow valve. Higher cabin altitudes will be avoided if the pressurization loss is correctable, (such as with a malfunctioning environmental control system) and cabin pressure will be maintained below the level at which the supplemental oxygen system is activated. Unnecessary deployment of the oxygen masks thereby is avoided. The flight engineer also can override the sequencer manually

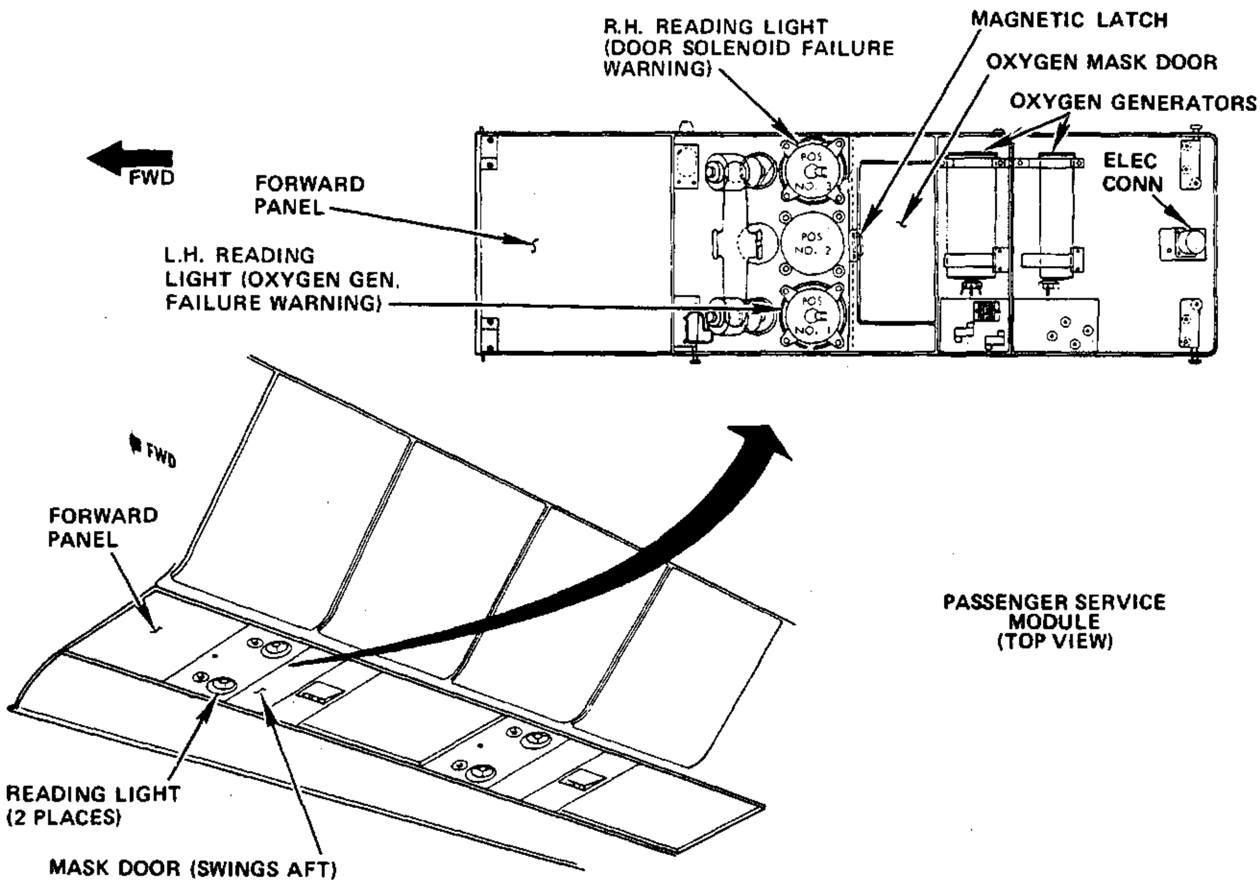

Figure 5

OUTBOARD OVERHEAD PASSENGER OXYGEN MODULE

Reprinted with permission of Lockheed - California Company Burbank, California and can, therefore, control cabin pressurization following a correctable system malfunction. If a pressurization failure is not correctable, the dual aneroid switches will close between 12,700 and 13,900 feet and the supplemental oxygen system will actuate automatically. When the "OXYGEN FLOW" light does not illuminate on the flight engineer's control panel under those conditions, a manual switch is provided for the flight engineer that bypasses the aneroid switches and provides power to the sequence timer to initate oxygen flow and mask deployment.

The DC-10 Supplmental Oxygen System

The DC-10 supplemental oxygen system is similar to that in the L-1011 insofar as the 10,000-foot cabin altitude warning horn, warning lights in the cockpit, and the provisions for the flight engineer to manually control cabin altitude are concerned. Also, oxygen compartment doors open automatically at an altitude of 14,000 ± 350 feet cabin altitude.

In the DC-10, the automatic mode is activated by a dual aneroid switch located in the forward cabin. The aneroid powers a 5-second timer relay which in turn provides electrical power to activate the oxygen compartment door latches. When the doors open, passengers must remove the oxygen masks from the doors and pull a lanyard attached to the mask. When pulled to its full length, a pin at the end of the lanyard is released from the initiator of the oxygen generator allowing the percussion igniter to start the generator.

The oxygen generator is installed in the seatback cavity with three smooth mounting pins. Two pins align the generator to the mounting surface in the bottom of the oxygen compartment while the third pin at the top is held by a spring clip. A perforated heat shield prevents the passenger from contacting the hot generator and also dissipates the heat. Clips hold oxygen masks on the compartment door. Lanyards, which are attached to each mask, permit any one of the mask lanyards to activate the generator when a mask is pulled away from the door. (Figure 6.)

A more unitized packaging technique results in a more compact installation (Figure 7). The method was developed to reduce the possibility of passenger misuse of the system. Masks are located above the generator, this leaving the door free of protuberances except for the latching strike pin. A placard affixed to the door illustrates the sequential steps necessary to activate the system and to don and adjust the mask.

Oxygen compartments located in seatbacks can be opened manually for maintenance or if they fail to open automatically during a decompression Doors are spring-loaded to assist gravity free fall to a vertical position.

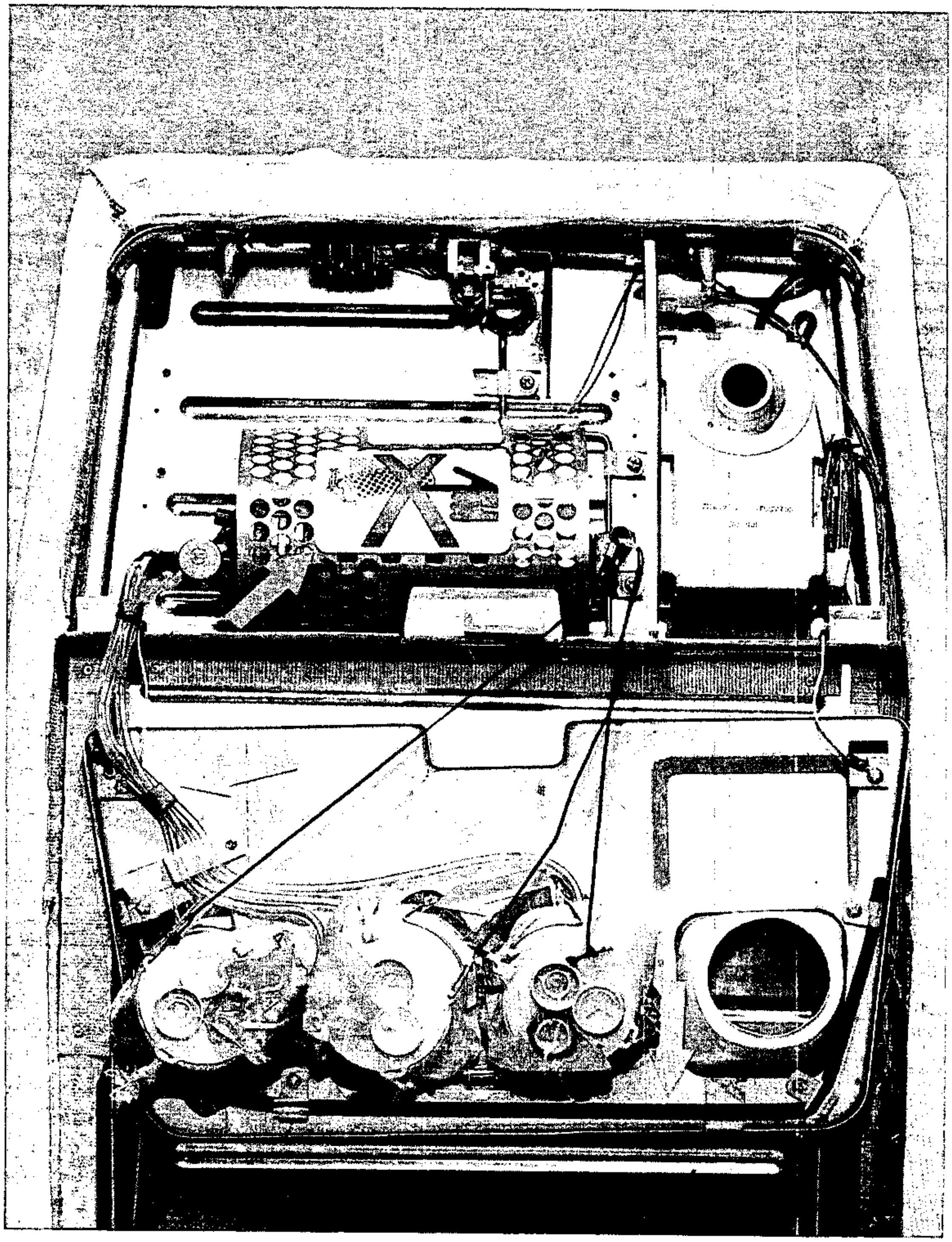

Figure 6. DC-10 supplemental oxygen system - "non unitized" packaging. Photograph reprinted with permission of Douglas-Aircraft Company, Long Beach, California.

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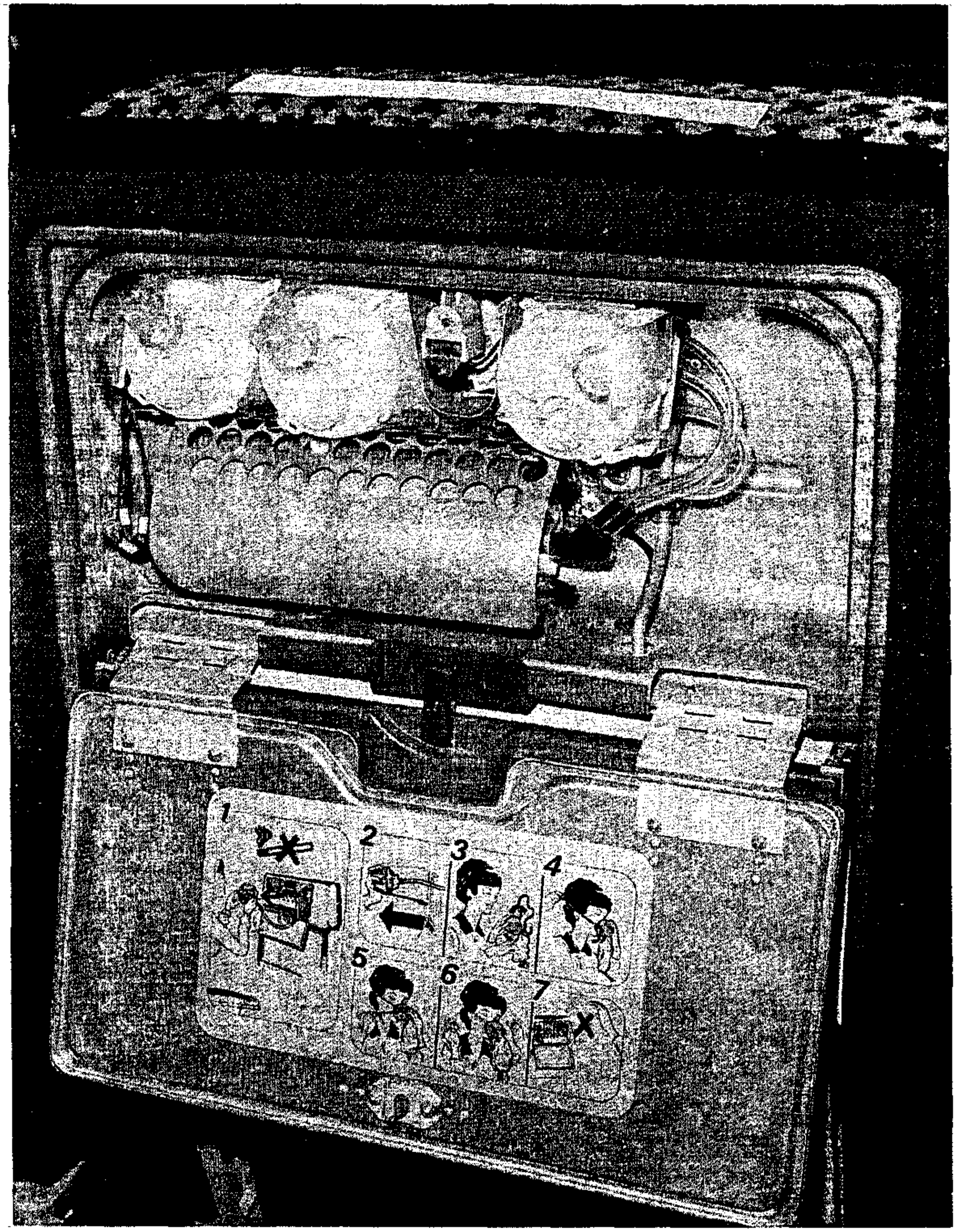

Figure 7. DC-10 supplemental oxygen system - "unitized" packaging Photograph reprinted with permission of Douglas-Aircraft Company, Long Beach, California.

Two types of door latch designs are used; one latch design uses a pin-shaped striker on the door which is held in place by a permanent magnet. An electrical signal reverses polarity of the magnet and allows the spring-loaded latch mechanism to free the strike from the latch. The second type of latch uses a roller-type striker on the door, held in place by a catch which is electromagnetically released by a spring and bail mechanism. Both types of latches can be found on some aircraft installations.

Depending upon the type of latch and the orientation of the manual release mechanisms, as many as five methods are used to open the doors manually. Two methods use finger pressure through an access hole located either in the headrest cushion or beneath the compartment on the rear of the seatback. The third and fourth methods require that the service tray be lowered to expose an access hole, in which either a small diameter rod must be inserted and pushed upward or a finger must be inserted to contact the door-latch release mechanism. The fifth method requires that the top of the seatback cushion be pulled free of the seat to expose a finger access hole in the seatback. In some cases, more than one method may be employed on the same aircraft, since the choice of passenger seats and the methods of manual door operation are left to the operator's discretion.

SOURCE: FAA FLIGHT STANDARD FILES

DEPRESSURIZATION INCIDENTS - 1973

DATE 1973	AIRCRAFT TYPE	OCCUPANTS PAX	F/A	CREW	AIRCRAFT 02 SYSTEM	PROBLEMS WITH 02 SYSTEM	AIRCRAFT ALTITUDE	CABIN ALTITUDE	MEDICAL PROBLEMS	REMARKS
2-27	B-707 (AA)	97	5	3	Unknown	None reported	37,000	Unknown	None reported	Unable to maintain 8.4 psi pressure differential. Unscheduled landing. Beverage can stuck in toilet valve.
3-9	DC-9 (TW)	57	3	2	Automatically deployed	None reported	25,000	Unknown	None reported	Unable to control pressure loss shortly after leaving 25,000 feet.
3-18	DC-9 (EA)	31	3	3	Masks did not drop	None reported	21,000+	9,000 climbing at 600 FPM	None reported	Unable to stop pressure loss.
4-1	L-1011 (EA)	212	10	3	Automatically deployed	See remarks	29,000	Unknown	Passenger with heart history given ECG & released	Rapid decompression. Emergency descent from 29,000 feet to 10,000 feet. Several oxygen compartment doors did not open. Flight test showed 20 doors did not open. Found one O_2 plastic tube kinked. Also found one canister did not operate. An additional drop test showed five doors failed to open; four doors (which did not fail before) failed to open. GENOT issued to drop test L-1011 O_2 systems.
5-20	B-737 (EA)	44	3	3	Masks dropped automatically at 12,000 feet	Premature drop. Passengers advised not to use masks	12,400	Unknown	None	Uncontrolled cabin pressure after takeoff. Continued climb to 10,000 feet when pressure ran away. Press stabilized. Manual mode selected by flight engineer and complete loss of pressure at 12,400 feet.

SOURCE: FAA FLIGHT STANDARD FILES

DEPRESSURIZATION INCIDENTS - 1973 (Continued)

DATE 1973	AIRCRAFT TYPE	OCCUPANTS PAX	F/A	CREW	AIRCRAFT O2 SYSTEM	PROBLEMS WITH O2 SYSTEM	AIRCRAFT ALTITUDE	CABIN ALTITUDE	MEDICAL PROBLEMS	REMARKS
5-27	DC-10 (AA)	54	6	3	Automatically deployed	None reported	35,000	Unknown	None	Rapid decompression at 35,000 feet. Emergency descent made to 10,000 feet. Pressure then became controllable and flight continued at 25,000 feet. Pressure became erratic again. Aft cargo compartment door seal malfunctioned.
7-2	B-707 (NW)	165	4	3	Automatically deployed	None reported	35,000	17,000	None	During descent from 35,000 feet, unable to control pressure. Flightcrew donned masks. Leveled aircraft at 17,000.
7-10	B-727 (DL)	70	3	3	Automatically deployed	None reported	25,000	14,000	Passenger complained of discomfort	Decompression at 25,000 feet. Emergency descent to 6,000 feet. Regained pressure at 6,000 feet.
7-25	DC-8 (DL)	48	5	3	Automatcally deployed	None reported	31,800	10,500	None	While climbing through 31,000 feet cabin, altitude rose at 6,000 FPM. Emergency descent.
8-27	CV-880 (DL)	57	3	3	Automatically deployed	None reported	Not reported	Not reported	Passenger complained of ear discomfort.	Descent to land.
9-4	DC-10 (NW)	189	8	3	Not reported	None reported	13,000	10,400	None reported	On climbout, unable to obtain cabin pressure. Manual mode selected; 1.3 psi at 13,000 MSL.

SOURCE: FAA FLIGHT STANDARD FILES

DECOMPRESSURIZATION INCIDENTS - 1973 (CONTINUED)

DATE 1973	AIRCRAFT TYPE	OCCUPANTS PAX	F/A	CREW	AIRCRAFT O2 SYSTEM	PROBLEMS WITH O2 SYSTEM	AIRCRAFT ALTITUDE	CABIN ALTITUDE	MEDICAL PROBLEMS	REMARKS
10-24	CV-880 (TW)	52	4	3	Automatically deployed	None reported	35,000	Not reported	None	Cruising at 35,000 feet. Lost Pressure.
11-3	DC-10	116	9	3	Masks dropped manually. Automatic mode was inoperative	Electrical problems. Generator problems	39,000	34,000	Baro-trauma problems. Five persons unconscious	Fuselage penetrated by engine fragments. Passenger lost out of window. Passengers unable to use oxygen system properly. Oxygen compartment door failures.

SOURCE: FAA FLIGHT STANDARD FILES

DEPRESSURIZATION INCIDENTS - 1974

DATE 1974	AIRCRAFT TYPE	OCCUPANTS PAX	F/A	CREW	AIRCRAFT O2 SYSTEM	PROBLEMS WITH O2 SYSTEM	AIRCRAFT ALTITUDE	CABIN ALTITUDE	MEDICAL PROBLEMS	REMARKS
1-16	DC-9 (AL)	71	2	2	Automatically deployed	All passengers donned masks. Some concerned that bag did not inflate	31,000	11,000	Passenger complained of light headedness	Cruising at 31,000 feet. Pressure could not be controlled. Rapid descent to 10,000 feet. Cabin pressure rose to 11,000 feet.
3-21	B-737 (OC)	77	3	2	Not reported	Not reported	Not reported	Not reported	Not reported	Aircraft lost pressure. Emergency descent to 10,000 MSL.
4-24	BAC 1-11 (AL)	47	2	2	Not reported	Not reported	Not reported	Not reported	Not reported	Cabin pressure malfunctioned. Descending to 10,000 MSL.
5-15	DC-9 (EA)	81	3	2	Automatically deployed	Not reported	33,000	19,000	Not reported	Cruising at 33,000 feet. Rapid decompression. Masks dropped. Emergency descent to 19,000. Cabin pressure stabilized at 19,000 feet using manual mode.
5-30	L-1011 (TW)	-	-	3	Not reported	Not reported	12,000	6,500	Not reported	Electrical malfunction.
6-24	DC-9	12	2	2	Automatically deployed	15 compartment doors did not open	27,500	11,000	Not reported	Climbout at 27,000 feet. Both air packs failed. Cabin altitude rose to 11,000 feet.
7-11	B-727 (DL)	93	5	3	Masks did not drop	None reported	23,000 in climb	Not reported Indicator pegged	Not reported	Climbing to 24,000 feet. Cabin pressure became uncontrollable. Emergency descent to 10,000 feet.
7-27	DC-9 (EA)	9	2	2	Automatically deployed	None reported	Not reported	Not reported	None reported	Cabin altitude followed aircraft altitude during climb. During descent masks dropped.

SOURCE: FAA FLIGHT STANDARD FILES

DEPRESSURIZATION INCIDENTS - 1974 (CONTINUED)

DATE 1974	AIRCRAFT TYPE	OCCUPANTS PAX	F/A	CREW	AIRCRAFT 02 SYSTEM	PROBLEMS WITH 02 SYSTEM	AIRCRAFT ALTITUDE	CABIN ALTITUDE	MEDICAL PROBLEMS	REMARKS
8-3	B-707 (TW)	84	4	3	Not reported	None reported	35,000	Not reported	None reported	Aircraft requested emergency descent to 10,000 feet.
8-8	DC-9 (TW)	48	3	2	Manually dropped at 10,000 cabin altitude	None reported	28,000	12,000	None reported	At 28,000 feet while climbing cabin altitude started to climb. Rapid descent to 10,000 feet. Cabin 10,000 feet warning light came on and masks manually deployed.
8-19	B-727 (CO)	68	4	3	Automatically deployed	"System operation normal"	31,000	Not reported	None reported	Descended from 31,000 feet to 10,000 feet.
8-25	DC-9	-	-	-	Automatically deployed	None reported	13,000	Not reported	None reported	While climbing through 13,000 feet cabin pressure low light on and masks deployed automatically.
9-19	DC-8 (UA)	53	4	3	Manually dropped	Precautionary drop of masks	Not reported	Not reported	None reported	In cruise flightcrew heard air leak. Manually dropped masks and made emergency descent.
10-3	DC-10 (AA)	53	9	3	Automatically deployed	25% of masks dropped. Of those that dropped flight attendants had problems activating pins	35,000	25,000	None reported	Descent from 35,000.

SOURCE: FAA FLIGHT STANDARD FILES

DEPRESSURIZATION INCIDENTS - TO SEPTEMBER 1975

DATE 1975	AIRCRAFT TYPE	OCCUPANTS PAX	F/A	CREW	AIRCRAFT 02 SYSTEM	PROBLEMS WITH 02 SYSTEM	AIRCRAFT ALTITUDE	CABIN ALTITUDE	MEDICAL PROBLEMS	REMARKS
2-24	B-707 (TW)	101	4	3	Manually dropped at 12,000 cabin altitude	None reported	Not reported	Not reported	None reported	During climb to 29,000, forward door seal blew out. Aircraft made rapid descent to 12,000 feet.
3-5	B-727 (EA)	Not Reported			Masks dropped	None reported	23,000	Not reported	None reported	Pressurization was uncontrollable in automatic and manual modes.
4-8	DC-9 (TW)	54	2	2/ 1 FAA	Masks dropped	None reported	21,000	Not reported	92 year old woman had difficulty breathing	Emergency descent to 10,000 feet after a rapid decompression. Outflow valves were fully open and manual controls would not hold pressurization.
5-1	DC-10 (AA)	182	9	3	Automatically deployed	None reported	18,000	18,000	None reported	Avionics compartment door was not closed before takeoff. Door open warning was inoperative. Cabin pressure aural warning and warning light failed to operate. This was due to cabin aneroid switch having a nonvented plug installed in the switch sensor. Aircraft failed to pressurize from takeoff.
5-22	L-1011 (DL)	61	10	3	Masks were deployed as a precaution but not used	None reported	35,000	Not reported but climbed at 15,000 FPM	None reported	Normal descent to 21,000 following pressure loss. Regained pressurization and climbed to 24,000 and continued to destination.

SOURCE: FAA FLIGHT STANDARD FILES

DEPRESSURIZATION INCIDENTS - 1975 (CONTINUED)

DATE 1975	AIRCRAFT TYPE	OCCUPANTS PAX	F/A	CREW	AIRCRAFT O2 SYSTEM	PROBLEMS WITH O2 SYSTEM	AIRCRAFT ALTITUDE	CABIN ALTITUDE	MEDICAL PROBLEMS	REMARKS
6-8	B-737 (FL)	6	0	2	Automatically deployed	None reported	31,000	About 15,000 at 4-5,000 fpm rate of climb	Company employee sustained a collapsed lung	Water leaking from capped galley water line, dropped onto outflow valve. Manual system used to control pressurization (Ferrying aircraft)
6-25	DC-9 (SO)	65	3	2	Automatically deployed	None reported	33,000	Not reported	One male passenger lost consciousness	Emergency descent from 33,000 to 12,000 cabin altitude. Continued to destination.
7-7	B-727 (DL)	104	3	3	Automatically deployed	None reported	Not reported	Not reported	None reported	Emergency descent. No cause found for depressurization.
7-23	DC-9 (OZ)	14	3	2	Automatically deployed	None reported	28,000	Not reported	None reported	Climbing through 28,000 pressurization became uncontrollable. Emergency descent to 10,000 feet.
9-2	L-1011 (EA)	232	10	3	Automatically deployed	None reported	17,000	17,000	28 passengers to hospitals for precautionary exams and hyperventilation.	After takeoff cabin continued to climb when aircraft failed to pressurize. Reached 17,000 and then descended to 9,000. No mechanical cause found for failure to pressurize.

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