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ERRATA SHEET --- AIR 1069

p. 9 -- End of Abstract of Reference 1 should read as follows:

> "... subjects sometimes have a brief, mild impairment of consciousness, etc. ..."

p. 12 -- The chart labeled, "The Incidence of Hypoxia Following Rapid Decompression From 8,000 Feet in 1.5 Seconds," is Table I referred to in the Abstract of Reference 5.

p. 14 -- Second sentence of second paragraph should read:

> "... Severe anoxia in man from cardiac arrest if prolonged beyond 5 minutes almost always results in irreversible brain damage, etc. ..."

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LAND SEA AIR SPACE
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AEROSPACE INFORMATION REPORT

AIR 1069

Issued 10-1-68
Revised

CREW OXYGEN REQUIREMENTS UP TO A MAXIMUM ALTITUDE OF 45,000 FT.

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TABLE OF CONTENTS

1. PURPOSE

1.1 Determine the required minimum oxygen concentration to be breathed prior to, during, and after a loss of cabin pressurization, and

1.2 Determine recommended means necessary to provide the required oxygen concentrations.

2. CONCLUSIONS

2.1 To prevent impairment of consciousness caused by hypoxia after decompression oxygen must be used as follows:

A. Above 25,000 and up to 40,000 feet the system must provide, in accordance with Figure 1:

1) An increased minimum oxygen concentration prior to a decompression,
2) A schedule of increased oxygen concentration with increase in cabin altitude,
3) 100% oxygen at an altitude not higher than 24,000 feet, and
4) Safety pressure to begin simultaneously with delivery of 100% oxygen.

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B. Between 40, 000 and 45, 000 feet the system must provide, in addition to the above,

1) Delivery of 100% oxygen under positive pressure, increasing with altitude to maintain no less than the equivalent of 40, 000 feet.

C. When cabin altitude can not exceed 25, 000 feet

1) No change in present requirements.

3. RECOMMENDED MEANS TO ACCOMPLISH

3.1 Use of the oxygen regulator air mix (dilution) schedule controlled to Figure 1.

3.2 After the regulator goes to 100%, there should be not more than 2 seconds elapsed before 100% oxygen is delivered to the mask. The Reference 5 approach to the problem was to limit the volume of the part of the breathing system lying between the regulator air port and the mouth/nose to 150/milliliters. This in effect requires the use of a regulator mounted on the mask or Helmet. The use of 400 ml as specified by the British Air Ministry permits the regulator to be mounted on the body or seat which represents an engineering compromise and produces reduced effectiveness.

3.3 Since the inspired gas must contain an increased concentration of oxygen prior to decompression, it will be necessary for the pilot in control of the aircraft to wear and use his oxygen mask above some stipulated flight altitude.

4. A-10 COMMITTEE ACTION

4.1 Based on the results of the study, the following actions will be taken:

4.1.1 The crew oxygen regulator AS will include the oxygen concentration requirements of Figure 1 which increases the required minimum oxygen concentration below 19, 000 feet and requires 100% oxygen no higher than 24, 000 feet.

4.1.2 Since the results of the study indicate that remotely mounted regulators can not meet the minimum requirements for decompression to above 25, 000 feet, revise the AS 452 on crew oxygen masks to limit the altitude when used with a panel or remote mounted regulator to 25, 000 feet, and to permit use to altitudes of 40, 000 and 45, 000 feet when provisions are included to ensure that after the regulator goes to 100% no more than 2 seconds will elapse before 100% oxygen is delivered to the mask, and suitable positive pressure is provided above 40, 000 feet.

4.1.3 Revise AIR 825 to include the necessary pertinent information as shown in Appendix I to this report.

4.1.4 Civil and military regulatory requirements are out of the scope of Committee A-10 activities, except for recommendation of changes. Since many documents are affected (HIAD, MIL specs., AFR's, FAR's, etc.), it is not practical to do more than make this report available to the FAA and the military suggesting that appropriate action be taken.

4.1.5 Give consideration to adopting requirements or recommendations for requirements for provision of mask pressure relief valves as has been done in the British specifications References 8 and 9.

5. DISCUSSION

5.1 Oxygen Concentration - Data on the required minimum oxygen concentration are found in References 1 through 9, and 11 through 13. Reference 5 appears to be the basic published report and appears to document the requirements by test data for cabin altitudes up to 40, 000 feet. The Figure 1 Curve marked "38, 000 feet" shows the Reference 5 recommended oxygen concentrations vs. altitude, provided 100% oxygen is immediately available on decompression. It will be noted that prior to decompression the inspired gas should contain a minimum of 38 to 40% oxygen at cabin altitudes of sea level to 8, 000 feet whereas the "ideal" concentration for acrobatic, fighter, etc. aircraft is 50% when oxygen toxicity from long exposure and partial lung collapse from acceleration effects are considered.

For altitudes from 40, 000 to 45, 000 feet, Reference 5 states with regard to the oxygen concentration inspired prior to decompression that all decompressions to altitudes in excess of 40, 000 feet may be considered as decompressions terminating at this pressure-altitude since the prevention of hypoxia in the steady state at these heights demands that the absolute pressure within the respiratory tract should not fall below that equivalent to 40, 000 feet, i.e., oxygen must be delivered under positive pressure above 40, 000 feet. However for civil, as opposed to military use, there is no assurance that this will occur (mask "on" and tightly secured) even though required by regulations and this has been considered in the preparation of Figure 3 from Figure 29 of Reference 11. This Figure (also shown in References 12 and 13) shows an estimate prior to confirmation by test at altitudes above 40, 000 feet of the oxygen enrichment of the breathing mixture vs. final altitude in a cabin pressurized to 8, 000 feet needed to prevent a critical fall in alveolar oxygen during decompressions to various altitudes. The critical level selected is an alveolar p02 of 33 mm Hg, below which transient mental deterioration would occur. It is assumed that 100% oxygen (under positive pressure above 40, 000 feet) would be supplied immediately. These predecompression mixtures would be necessary to prevent a critically low alveolar

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p02 during the event, that is before the first breath is taken, and under these conditions, the estimated oxygen concentration required for a final altitude of 45,000 feet is 60%.

The means used to achieve the required oxygen enrichment would appear to include the use of crew regu lators with dilution characteristics based on the relationships of Figure 1. This Figure shows a family of curves developed from Figure 3 for varying maximum altitudes. Further wide range decompressions to altitudes greater than 40,000 feet are needed to test the prediction that no degradation will occur if the alveolar oxygen tension reached during the transient fall of oxygen tension produced by a rapid decompression is not lower than 30 mm Hg. It should be noted that the criterion of 33 mm Hg p02 alveolar tension used in Figure 3 assumes that in civil use oxygen masks will not be secured tightly to the face to prevent leakage whereas Reference 5 assumes no leakage since the investigation is dealing with controlled military equipment and personnel. Slightly modified recommendations by the Subcommittee could result from receipt and review of test results not now available covering the higher altitudes.

Since the final recommendation will be an increased oxygen concentration over ambient, the pilot in control will be required to wear and use his mask. This in turn would require a change in regulations.

5.2 British Air Ministry Specifications - The British specifications for miniaturized crew oxygen system, References 2 through 4 have been reviewed and compared with Reference 5 in Figure 2. It was anticipated that Ernsting's recommendations in Reference 5 would be reflected in References 6, 8 and 9. However, Figure 2 shows that neither Reference 6 nor 8 requires increased oxygen concentration in the sea level to 19,000 feet cabin altitude range while the Reference 9 approaches but is slightly below the Reference 5 minimum. The explanation of the differences is as follows:

The oxygen requirements in Specifications 316/1, /2, and /3 are based on the referenced data. Specification RO316/1, which is now obsolete, was written in relation to one specific aircraft, and in fact no regulator has been developed to it. Specification 316/2 was written to define the oxygen equipment required in RAF and RN interceptor aircraft. Since all these aircraft have relatively low differential cabins (a maximum of the order of 4 lb/sq in) the cabin altitude will be greater than 15,000 feet when the aircraft altitude exceeds 30,000 feet. The very small differences in the concentration of oxygen required to prevent hypoxia following rapid decompression to an altitude above 30,000 feet (eg, 43% at a cabin altitude of 15,000 feet by these criteria) and that required to provide a sea level equivalent mixture (eg, 39% at 15,000 feet) in these circumstances was ignored in defining the minimum acceptable oxygen concentration in Specification 316/2. Furthermore, the primary object in relation to these aircraft was to keep the inspired oxygen concentration as low as possible in order to reduce the incidence of lung collapse during positive maneuvers.

It is Specification 316/3 which applies to aircraft with high differential pressure cabins such as those which carry passengers. The oxygen requirements in this Specification embody the results of the referenced experiments. The discrepancy between the shape of the minimum concentration curve in Reference 5 and that in Specification 316/3 is related to the schedule of pressurization of the military transport and bomber aircraft. In these, the cabin altitude is of the order of 5,000 to 6,000 feet when the aircraft altitude exceeds 30,000 feet. Hence it is only above a cabin altitude of 5,000 feet that is only above a cabin altitude of 5,000 feet that the oxygen system is required to give the higher concentration of oxygen. The airmix schedule below 5,000 feet would theoretically allow some economy in the use of oxygen, but in practice it is not believed that any manufacturer would attempt to follow the shape of curve given in 316/3.

5.3 Rapid vs. Slow Decompressions - Most of these tests reported have involved rapid decompressions, generally 1.5 - 2.0 seconds. However, when the duration of decompression was lengthened to 20 seconds by Ernsting in Reference 5 and 26 - 30 seconds by Ohio State University in Reference 11 or to 9 seconds as in Figure 4 and in Reference 3 essentially identical results were obtained.

5.4 Requirement for Use of 100% Oxygen Immediately on Decompression - The referenced data indicate that 100% oxygen must be inspired immediately on decompression. Delays of up to 8 seconds resulted in profound impairment of performance when breathing air before decompression to 38,000 feet, and when breathing 40% oxygen, the decrement in performance was moderated but reduced to a level which is unacceptable for the members of the crew of an aircraft. In decompressions to 30,000 feet breathing air with 100% oxygen immediately available, there was no decrement in performance; but with delays up to 8 seconds, performance was

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reduced to an unacceptable level. Possibly a higher percentage of oxygen in the inspired gas would permit an acceptable delay in terms of seconds for the inspiration of 100% oxygen and thus permit consideration to establish a relationship between percent oxygen in the inspired gas and mask-to-regulator hose length. However, until test data are available to support this it must be required that, in addition to supplying increased minimum oxygen concentrations at cabin altitudes of sea level to 8,000 feet, 100% oxygen be immediately available on decompression. Refer to Figure 4 for results of available test data on the effect of hose length. This appears to require the use of regulators mounted as close to the face as practicable, and to limit the use of panel or remote mounted regulators to an altitude less than 30,000 feet. The limiting altitude would be determined by mask-to-regulator hose length and final cabin altitude if different than the flight altitude. However, since a final decompression cabin altitude less than flight altitude cannot practically be assured (unless pressure suits are worn) and data on the effect of hose length, or delay in breathing 100% oxygen below 30,000 feet are not available, it is recommended that 25,000 feet be the upper limit.

5.5 Means to Deliver 100% Oxygen on Decompression - The means recommended by which 100% oxygen can be supplied immediately are:

(1) to keep to an absolute minimum the volume of the breathing system trapped between the regulator air port and the mask,
(2) to minimize the breathing equipment (mask) dead space,
(3) to close the air port as quickly as possible on decompression,
(4) reduce the altitude where 100% oxygen is delivered,
(5) require safety pressure simultaneously with delivery of 100% oxygen, and
(6) require that the pilot in control wear and use his mask.

On the subject of trapped volume References 8 and 9 require a maximum regulator to mouth volume of 400 ml (milliliters). The following breakdown shows how restrictive this is. The panel mounted regulator air port-to-outlet volume is estimated to be 1.5 cubic inches or 25 ml. The typical crew mask cavity provides an estimated 150 ml, and the conventional regulator-to-mask hose provides a volume of approximately 10 ml per inch of length. Restricting the total to 400 ml results in a hose length of 22.5 inches (regulator 25 + mask 150 = 175, or 225 ml remaining for hose length.) Ernsting in Reference 5 made no specific recommendation for maximum trapped volume but did recommend 150 ml max. for dead space of the breathing compartment.

It will be noted in Summary A that the maximum trapped volumes of Reference 8 and 9 systems are limited to 400 ml, and that the Reference 6 system does not list a specific number for the maximum volume but instead requires that "the composition and quantity of gas trapped between the regulator and mouth shall not cause impairment of consciousness after explosive decompression." Use of 400 ml in References 8 and 9 is based on a compromise established by the British Air Ministry and does permit the regulator to be man-or-seat-mounted, the permissible hose length in this case being approximately 22 inches. An additional indication of the value of the use of the small volume is that 400 ml at 8,000 feet becomes 1600 ml (or 1.6 liters) at 40,000 feet. This compares with 4 to 5 liters produced by use of the conventional 6 to 8 feet hose, the use of the smaller volume substantially reducing the trapped gas pressure relief problem, by reducing the time required for relief as well as reducing the maximum transient pressure level.

It is obviously desirable that the regulator air port be closed instantaneously but this is not possible in a barometrically (bellows) controlled mechanism, since there is an inherent lag in the sensing and closing operation. This probably can best be minimized if not overcome by initiating the closing action at the lowest practicable altitude. It will be noted in Table I that in Reference 8, the maximum altitude for dilution is 24,000 feet. This compares with approximately 32,000 feet for current regulators.

Requiring 100% oxygen at no higher than 24,000 feet provides no significant operational penalty since unpressurized emergency flight will normally be limited to 18,000 feet because of decompression sickness. Therefore, from a practical standpoint, the maximum altitude for dilution could be reduced below 24,000 feet. However, since an altitude range or tolerance of at least 2,000 feet is required, it is concluded that the 22,000 to 24,000 feet range of Reference 9 is acceptable. An additional advantage of supplying 100% oxygen at the recommended level is that when the decompression is relatively slow the crew member may well breathe in during the decompression and will receive 100% all the sooner.

An additional means of assuring delivery of 100% oxygen is to provide safety pressure (1-2 inches H_2O) to begin simultaneously with delivery of 100% oxygen. Since masks when worn will not be worn tightly secured to the face it is very likely that during an emergency decompression the mask would leak until properly adjusted. Thus inboard mask leakage is likely to occur without the presence of an effective safety pressure.

5.6 Review of Decompression Incidents - Having come to the conclusion above based on altitude chamber tests, a review of decompression incidents in Reference 13, compiled from FAA records, seems in order. In the

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SUMMARY A

ITEM	(1) REFERENCE 6	(1) REFERENCE 8	REFERENCE 9
Aircraft	Transport	Aerobatic	Transport
Max Alt (FT)	40,000	50,000	50,000
Air Mix - Min Alt	26,000	27,000	22,000
Air Mix - Max Alt	28,000	32,000	24,000
Min % Air Mix			
Sea Level	21	21	21
5,000	25	26	26
8,000	29	29	39.5
Safety Press - Alt			
100% Oxygen	S.L. & up	S.L. & up	S.L. & up
Air Mix	15,000 & up	15,000 & up	15,000 & up
Safety Pressure (In. H_2O)			
Nominal Up to 39,000	1.0 (up to 40,000)	1.2	1.5
39,000 and up	---	1.5	1.9
Regulator Mounting	Man	Man or Ejector Seat	Man
Require Emergency Standby Regulator	No	Yes, or Manual Bypass Constant Flow	No
Max Press Limited by Mask Relief Valve (PSIG)	0.5	0.8	0.8
Regulator to Mouth Max Volume (Liters)	(2)	1.0 (25,000 ft Cabin Alt) 0.4 (8,000 ft Cabin Alt)	Same as Reference 8

(1) Included here for academic interest only - see notes in Appendix II abstracts of References.

(2) No volume specified. However, it is required that the composition and quantity of gas trapped between the regulator and mouth shall not cause impairment of consciousness after explosive decompression.

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period April 1956 through July 1964, there were 18 reported incidents occurring between 30,000 and 41,000 feet altitude. Of these seven were voluntary and pressure controlled to prevent excessive cabin altitude. Of the eleven involuntary decompressions, the records indicate that the maximum cabin altitude:

1. has been reached relatively slowly
2. has been relatively low, physiologically, and
3. duration has been a minimum consistent with emergency descent procedures.

In short, it appears that the large volume of the transport aircraft pressurized cabins and the nature of the failures (producing a small orifice) have so far not duplicated the altitude chamber conditions in regard to time of decompression, rate of decompression, or maximum cabin altitude reached with one exception. On May 5, 1966 one incident was reported where a charter flight carrying military personnel lost cabin pressure at 39,000 feet but no official report was made of the maximum cabin altitude reached. However, this was unofficially reported as 33,000 to 34,000 feet. At least three persons lost consciousness. Of particular importance is the maximum cabin altitude reached since it is generally agreed that rapid and slow decompressions have similar effects. Therefore, it would appear that the requirements established in the previous sections could be waived if it can be shown that the cabin altitude will never exceed 25,000 feet.

5.7 Additional Safety Requirements - Beyond the scope of the immediate problems but in the interest of increased safety, consideration should be given to adopting some of the new requirements of the British Specifications References 6, 8, and 9, especially to include the requirements for mask pressure relief valves. The relief valve will prevent a dangerous rise in mask and hence lung pressure in the event of failure of the regulator (demand valve remaining open) as well as relieve pressure of trapped gases in a rapid decompression.

5.8 Comparison of Features of References 6, 8 and 9 - Selected items of general interest have been excerpted from the British Specifications and are listed in Summary A.

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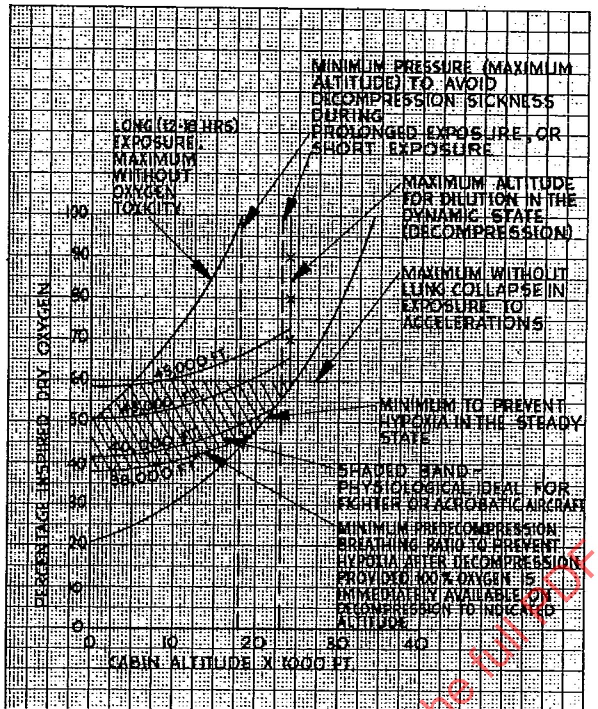

FIGURE 1 - RECOMMENDED OXYGEN CONCENTRATION VS. ALTITUDE

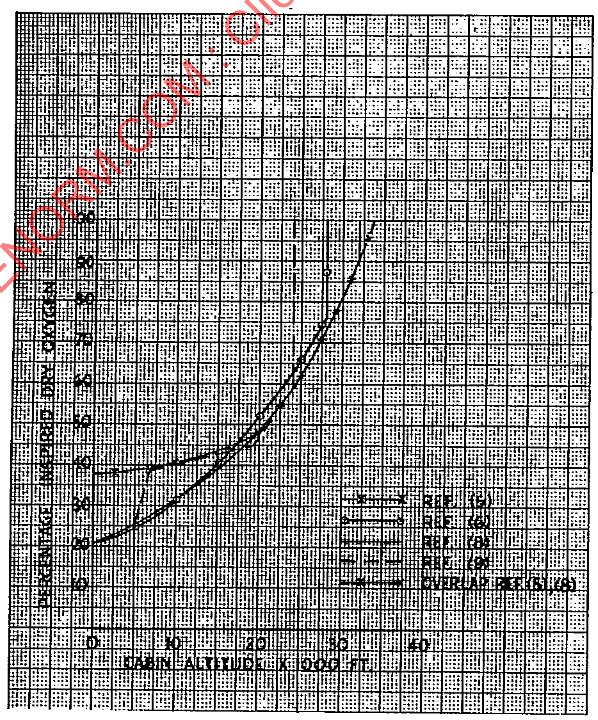

FIGURE 2 - COMPARISON OF OXYGEN CONCENTRATION VS. ALTITUDE

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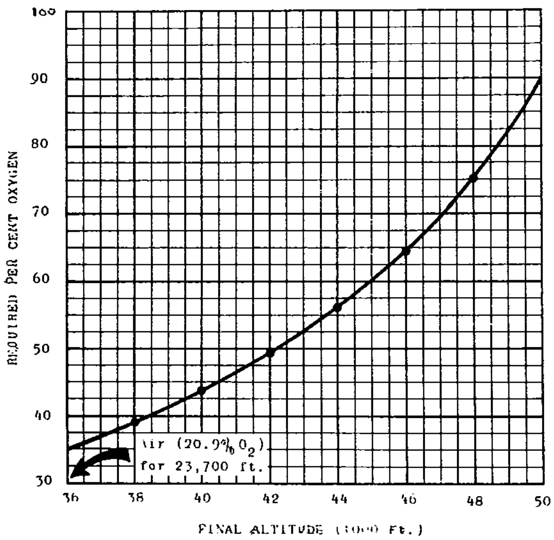

FIGURE 3 - BREATHING MIXTURES BEFORE DECOMPRESSION

The estimated oxygen enrichment of the normal breathing mixture (at cabin altitudes below 8,000 feet) which would be needed to prevent a critical fall in alveolar oxygen during decompressions to various altitudes. The critical level was taken to be an alveolar pO_2 if 33 mm Hg, below which transient mental deterioration is expected to occur. It is assumed that 100% oxygen (under positive pressure above 40,000 feet) would be supplied immediately. The predecompression mixtures would be necessary to prevent a critically low alveolar pO_2 during the event; that is, before the first breath is taken. (From Blockley and Hanifan, final report on contract FA-955, Fed. Av. Agency, 1961.)

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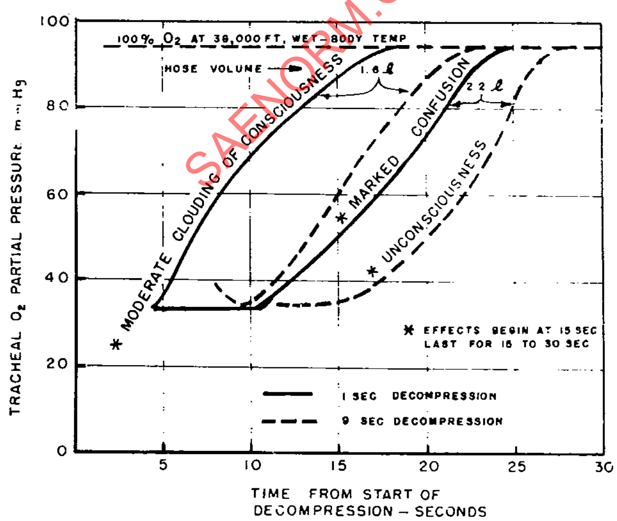

FIGURE 4 - OXYGEN HOSE VOLUME AND DECOMPRESSION

The influence of the volume of oxygen hose leading to the mask on the condition of the subject during decompression from 8,000 to 40,000 feet. A diluter-demand regulator delivered 38% O_2 at 8,000 feet, and pure O_2 at 40,000 feet. Oxygen is delayed in reaching the mask because of the dilution of incoming oxygen by the air-oxygen mixture still in the hose. (Data of Ernsting, R.A.F. Inst. of Av. Med. 1961.)

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REFERENCES

1. Bryan and Leach: Physiologic Effects of Cabin Pressure Failure in High Altitude Passenger Aircraft. Aerospace Medicine 267-275, April 1960.

2. Ernsting, Gedye and McHardy: Anoxia Subsequent to Rapid Decompression. Flying Personnel Research Committee FPRC/1141, September 1960.

3. J. Ernsting: The Relation Between the Capacity of the Regulator-Mask Hose and the Incidence of Anoxia Following Rapid Decompression. I.A.M. Report No. 183, June 1961.

4. J. Ernsting: Some Effects of Profound Anoxia Upon the Central Nervous System. Selective Vulnerability of the Brain in Hypoxaemia. Oxford, McMenemy and Schade, 1963.

5. J. Ernsting: The Ideal Relationship Between Inspired Oxygen Concentration and Cabin Altitude. Aerospace Medicine 991-997, November 1963.

6. British Ministry of Aviation Specification No. R. O. 316/1, Specification of Requirements for Miniaturized Controlling System for Oxygen for Crew in Static Seats in Non-Aerobatic Aircraft at Altitudes Up to 40,000 Feet, December 1963.

7. J. Ernsting: The Physiological Effects of Failure of the Pressure Cabins of Passenger Aircraft Flying at Altitudes Between 35,000 Feet and 65,000 Feet. I.A.M. Report No. 313, February 1965.

8. British Ministry of Aviation Specification No. R. O. 316/2, Specification of Requirements for Miniaturized Oxygen Systems for Aircrew in Ejector Seats in Aerobatic Aircraft Up to Maximum Cabin Altitudes of 50,000 Feet, March 1965.

9. British Ministry of Aviation Specification No. R. O. 316/3, Specification of Requirements for Miniaturized Oxygen Systems for Aircrew in Static Seats in Non-Aerobatic Aircraft Up to Maximum Cabin Altitudes of 50,000 Feet, March 1965.

10. USAF SAM TDR 63-56, Continuous Functional Testing of Oxygen Breathing Equipment.

11. Blockley and Hanifan Report for FAA, February 1961, Final Report on Contract FA-955, An Analysis of the Oxygen Protection Problem at Flight Altitudes Between 40,000 and 50,000 Feet.

12. NASA Life Sciences Data Book, First Edition, June 1962, Pages 57-70.

13. Bioastronautics Data Book NASA SP-3006, 1964 Edition, Sections 1 and 6.

14. Summary of Cabin Pressure Loss Incidents, April 1956 through July 1964, Attachment to John Meldrum SAE Letter dated November 13, 1964 to Committees A-10 and AC-9.

Note: See Appendix II for abstracts or condensations of References 1 through 9.

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APPENDIX I

PROPOSED REVISION TO AIR 825

Add to end of paragraph 1.15 - "Above 25,000 feet to assure the pilot's continued control uninterrupted by possible impairment or loss of consciousness, it is essential that 100% oxygen be instantly available in the mask on decompression and that the predecompression breathing mixture provide an oxygen concentration in accordance with Graph 5 dependent on the maximum approved flight altitude of the aircraft."

Add after paragraph 4.3.1.2:

"4.3.1.3 Limitations and Recommendations - If there is a probability that cabin pressurization will be lost and result in cabin altitudes of 25,000 feet and above protection of crew members from hypoxia resulting in impairment of consciousness must be provided by supplying 100% oxygen immediately on decompression and by assuring that the minimum predecompression breathing mixture provides an oxygen concentration of not less than that required on Graph 5, in Section VI. This can be accomplished by use of mask mounted regulators or regulators mounted sufficiently close to the users head that the volume of that part of the breathing system lying between the regulator air port and the mouth/nose is limited so that 100% oxygen is delivered to the mask in not less than 2 seconds after the regulator goes to 100%. The panel or remote mounted regulators requiring a length of relatively large diameter (approx. 7/8 in.) low pressure breathing hose to connect to the mask are limited to a maximum altitude of 25,000 feet. This requirement can be waived above 25,000 feet where the crew member wears and uses his mask with regulator set on 100% oxygen.

For regulator requirements SAE has proposed a Minimum Standard for Regulator, Crew Oxygen Breathing.

Add to Section VI -- Charts, Tables and Systems Schematics - "Graph 5, on page 39, (to be based on chart I.D. 8 of Ref. 12 expanded to include requirement for 100% oxygen to be supplied at 24,000 feet maximum altitude or use of Figure 1 of this report, or probably both)."

APPENDIX II

ABSTRACTS OF REFERENCES 1-9

ABSTRACT OF REFERENCE 1

Physiologic Effects of Cabin Pressure Failure in High Altitude Passenger Aircraft. Flight Lieutenant Charles A. Bryan and Squadron Leader Wilson G. Leach, RCAF.

Presented on April 28, 1959 at the 30th Annual Meeting of the Aero Medical Association, Los Angeles, California. Printed in Aerospace Medicine April 1960.

The physiologic hazards of cabin pressure loss in high altitude passenger aircraft are reviewed. Cabin decompression from 8,000 to 40,000 feet in 2.5 seconds was simulated in the altitude chamber using eight healthy male subjects aged 22 to 38 years in eight rapid decompression tests. Four channel EEG, one lead ECG, and respiration rate by chest excursion measured by a mercury in rubber strain gauge were recorded. Performance was followed by the ability to cancel rhythmic alternating light signals by two spatially unrelated buttons. Various commercial passenger oxygen masks were used for resuscitation. The average time of useful consciousness was found to be 18 seconds. The passenger masks were inefficient for maintaining consciousness or reviving subjects at 40,000 feet, mainly due to poor face seal, and because they were dropped by the subject when hypoxic. To preserve continuous consciousness, the oxygen has to be given in under 7 seconds. However, determining the minimum time for oxygen administration is almost impossible with a passenger oxygen system. Even using a fitted type A-13A mask and a demand regulator set at "Normal" (Auto-Mix on) throughout the decompression, subjects sometimes have a brief, mile impairment of consciousness, as the regulator cannot immediately compensate for the sudden drop in alveolar oxygen pressure. There have been no serious consequences from the rapid pressure change itself.

ABSTRACT OF REFERENCE 2

IAM Report FPRC/1141, Anoxia Subsequent to Rapid Decompression, September 1960.

This report details three series of tests designed to determine physiological and psychological effects of delivering oxygen at various times before and after 1.5 second decompressions from 8,000 - 38,000 feet. Six subjects, aged 22 - 38 were exposed to a total of 140 decompressions.

Series 1 - determined respiratory responses under four conditions:

a. Air breathed throughout test.
b. Air breathed before decompression. Oxygen provided 2 seconds after.
c. Air breathed before decompression. Oxygen provided 8 seconds after.
d. Oxygen breathed 5 minutes before and throughout test.

Series 2 - measured instantaneous expired nitrogen concentrations and arterial oxygen saturation by earlobe oximeter.

Series 3 - determined central nervous system reactions to the last three of the above four conditions by

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means of four channel EEG and performance of a sequential motor task.

RESULTS

(All times referred to start of decompression.)

Series 1

Alveolar Carbon Dioxide Concentration - All four conditions - dropped to 8 mm Hg. Rose to 25 mm at 15 seconds and to 30 mm at 45 seconds.

Alveolar Oxygen Concentration

1) Conditions a, b, c - dropped to 14 mm Hg.
2) Condition a - rose rapidly to 20 mm and stayed there for as long as process could be followed (13 seconds maximum because of consciousness impairment). Condition b - rose to 60 mm at 25 seconds and about 63 mm at 45 seconds.
   (a) Concentration below 40 mm for about 8 seconds. Even after 45 seconds concentration remained below that in condition d because of residual nitrogen concentration.
3) Condition c - rose to 50 mm at 25 seconds and about 63 mm at 45 seconds.
   (a) Concentration below 40 mm for about 17 seconds. After 45 seconds same as for condition a.
4) Condition d - dropped to 100 mm at decompression. Dropped progressively to 77 mm at 15 seconds. This fall mirrored rise of CO_2 in same period.

Series 2

Typical case - oxygen delivered at 6.5 seconds

A. Expired Nitrogen Concentration - Dropped below inspired nitrogen even before oxygen breathed. Fall in nitrogen accentuated by 100% oxygen. Dropped to 15% at 32 seconds. Earlier oxygen delivery caused very rapid drop in expired nitrogen concentration.

B. Arterial Oxygen Saturation - 90% saturation at 8,000 feet before decompression. Maintained 90% for 5 seconds. Fell to about 55% at 7 seconds. Rose slowly to about 62% at 13 seconds, to 73% at 15 seconds. Rose slowly to about 62% at 13 seconds, to 73% at 15 seconds. Reached 90% at 34 seconds. Increase in arterial saturation approximately mirrored fall in expired nitrogen.

Series 3

Task Performance - Measured by time to complete correct sequence of 8 digital operations scoring every 5 seconds except when gross disturbances occurred and the time to complete exceeded this interval.

Condition b. Very significant impairment of performance commencing at 12-15 seconds, persisting until 25-30 seconds.

Condition c. Very gross confusion, one case unconsciousness. Started at 12 seconds persisted to about 62 seconds.

Condition d. No impairment of performance.

EEG

Condition b. Significant changes in EEG, either appearance of 8-13 cps activity or accentuation to such activity already present. Changes commenced suddenly at 15-16 seconds and persisted to 23-25 seconds. After 25 seconds reverted to pattern similar to predecompression.

Condition c. EEG changes more marked. 8-13 cps activity at 15 seconds in every case. Frequently followed by high voltage 2-4 cps activity. All abnormal activity disappeared by 25 seconds.

Condition d. No significant EEG changes occurred.

These experiments were designed so that the problem of donning a mask was excluded from consideration. The subject wore a mask throughout each experiment and no action was required of him in order that he should breathe 100% oxygen. The time which elapsed between the delivery of oxygen to mask and the subject taking his first breath of oxygen varied considerably. The longest time which elapsed was 4.2 seconds, the mean delay being 1.0 second. It is important to realize that the time at which a mask is donned is not necessarily synonymous with the time at which oxygen first reaches the lungs.

This series of experiments has demonstrated that unacceptable impairment of mental faculties will occur even if the first breath after the decompression consists of 100% oxygen, and that an oxygen enriched mixture must be breathed before decompression occurs.

NOTE: For results of two further conditions using the procedures of Reference 2 see Reference 4.

ABSTRACT OF REFERENCE 3

IAM Report No. 183 - The Relation Between the Capacity of the Regulator-Mask Hose and the Incidence of Anoxia Following Rapid Decompression, June 1961. Squadron Leader J. Ernsting.

The report details twelve tests in which three subjects were decompressed from 8,000 feet to 40,000 feet in either 1 or 9 seconds while breathing an enriched air mixture containing 35-50% oxygen. A relief valve in the mask hose set at 10 cm of water protected subjects against excessive transpulmonary pressure. The influence of various regulator hose capacities upon the subsequent hypoxia was determined.

The report summarized previously unpublished tests of 1.5 second decompressions from 8,000 feet to 38,000 feet. Appendix B covers a single test decompressing from 8,000 feet to 54,000 feet a subject wearing a Mk 3 jerkin and B.W.T. helmet to confirm calculated effects on hypoxia of a pressure jerkin.

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Conclusions:

1. If breathing mixture prior to a decompression to altitudes above 38,000 feet contains less than 40% oxygen, detectable impairment of performance will occur about 15 seconds after decompression and will persist for at least 15 to 20 seconds.
2. If 100% oxygen is not inspired until 8 seconds have elapsed from the beginning of the decompression, very severe mental confusion and occasionally unconsciousness will occur.
3. The total air volume between the regulator outlet chamber and the mouth must be purged before 100% oxygen can be inspired. The greater this volume and the shallower the breathing pattern, the longer will be the period following decompression before 100% oxygen is inspired and the greater the resulting hypoxia.
4. Mask hose volume of 1.0 liter produced a slight but definite clouding of consciousness. A capacity of 1.6 liters induced unconsciousness in one subject and a capacity of 2.2 liters caused unconsciousness and very severe hypoxia in two subjects. Calculations indicate a volume of 1.4 liters may occasionally result in unconsciousness.
5. The jerkin test produced very severe clouding of consciousness commencing at 15 seconds after start of decompression and persisted for 20 seconds further. Consciousness was not fully regained until 50 seconds had elapsed.

ABSTRACT OF REFERENCE 4

Some Effects of Brief Profound Anoxia Upon the Central Nervous System, J. Ernsting in McMenemy, W. H. and Schade, J. P.: Selective Vulnerability of the Brain in Hypoxaemia, 1963.

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This presentation describes again the results of FPRC/1141 and includes results of the same procedures under two further conditions:

e. 29 percent oxygen in nitrogen breathed at 8,000 feet followed by 100% oxygen immediately after decompression.

f. 40 percent oxygen in nitrogen breathed at 8,000 feet followed by 100% oxygen immediately after decompression.

Results:

The oxygen saturation and pH of brachial arterial blood were measured continuously in many of the experiments. The arterial oxygen tension remained at the predecompression level for 4-5 seconds and then fell very suddenly. The lower the oxygen concentration in the inspired gas at 8,000 feet, the lower was the minimal arterial oxygen tension immediately after the decompression. The effects of decompression upon the alveolar carbon dioxide tension and arterial pH were found to be similar in all the tests. Thus the various experimental conditions produced a graded series of brief exposures to arterial hypoxaemia, each of which was accompanied by a brief but severe degree of hypocapnia.

The effects upon the central nervous system were investigated in three ways:

1. Noting the changes reported by the subjects
2. Recording performance on the sequential motor task
3. EEG

1. Subjective Reports

Condition d. No significant disturbance of consciousness.

Condition b. All subjects reported some mental confusion arising at about 15 seconds and persisting for 15-20. On half the occasions the subject also reported either general dimming of vision or loss or peripheral vision.

Condition c. Subject grossly confused on every occasion and vision frequently lost completely. Several cases lost consciousness. Symptoms commenced about 15 seconds and frequently persisted for 30-45 seconds.

Condition e. About 2/3 of cases had a slight but definite clouding of consciousness. Remainder had no subjective disturbances.

Condition f. Only half experienced mild and transient subjective disturbances.

2. Motor Task Performance

Conditions e and f. No significant impairment of performance.

3. EEG

Condition e. 8-13 cps activity appeared in all EEGs at 15.5 seconds and persisted until 24 seconds.

Condition f. No significant change occured in the EEG.

ABSTRACT OF REFERENCE 5

The Ideal Relationship Between Inspired Oxygen Concentration and Cabin Altitude. J. Ernsting: Aviation Medicine 991-997, November 1963.

Hypoxia - No impairment of performance is apparent if alveolar oxygen tension is greater than 80 mm Hg. 80 mm (which is produced by breathing air at 4,000 feet) is associated with a significant reduction of the range of night vision. About 55 mm or 10,000-12,000 feet a significant impairment of general intellectual function occurs in a relatively short time. 8,000 feet generally accepted for crew and passengers. However, evidence suggests that such higher intellectual functions as complex decision making may be impaired above 5,000 feet or 75 mm. This is minimum desirable for

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