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S. B. Sells, Nurhan Findikyan, and Marcia J. Duke

Contract No. Nonr 3436(00)
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Which Account for Behavior Variance
Group Psychology Branch
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FOREWORD

As one task related to the understanding of environmental variables accounting for behavior variance, our staff has undertaken extensive study of a variety of literatures related under the general topic of stress. A series of working papers was prepared, summarizing these reviews of the literature. These have been edited and will be reproduced for the use of colleagues who may find the compilations of value. The Stress Reviews completed to date cover extremes of the physical environment, involving cold, heat, radiation, and atmospheric extremes.

S. B. Sells, Ph.D.
Principal Investigator

ATMOSPHERE

Man is dependent on the environment to which he is developmentally adapted for the most efficient satisfaction of his energy requirements. Thus, at sea level he obtains his critical supply of oxygen naturally and effortlessly by breathing air, which at this level is under sufficient pressure to provide the optimum amount of kinetic energy to transport the oxygen molecules to the body tissues.

PROBLEMS AT ALTITUDE

Atmospheric pressure decreases progressively with altitude at the rate of a reduction, every 53,000 feet, to ten per cent of the previous value. A physiological result of the pressure reduction with ascent is the proportionate reduction of kinetic energy of the oxygen molecules which becomes increasingly less adequate for oxygen delivery. At altitude the organism must compensate for the loss of external pressure in respiration by converting chemical energy into mechanical energy in the body. However, this conversion is inefficient and compensates for the loss of external pressure to a limited degree.

At 10,000 feet, pressure is reduced by 31 per cent from sea level and many robust individuals can compensate quite well. At 18,000 feet, the reduction is 51 per cent and this is about the limit at which acclimatized persons can function. At 23,000 feet, pressure reduction is 60 per cent and compensatory mechanisms are so limited that the individual can maintain consciousness for only a few minutes. Above 23,000 feet, physiological mechanisms are totally inadequate to sustain consciousness in the ambient atmosphere and they become asymptotic at 50,000 feet (89 per cent reduction of pressure) at which level physiological compensation is impossible and unconsciousness results in seconds, breathing this air. As a result, 50,000 feet is usually regarded as the physiological boundary of "space equivalent" altitude.

Oxygen accounts for approximately 21 per cent of the air, regardless of altitude. Most of the remaining volume is nitrogen (78 per cent), which enters the body with inhaled oxygen, but does not enter into chemical combination. It is either dissolved or trapped in the blood, tissue, fluids, and cellular substances of the body, which all contain nitrogen as well as oxygen and carbon dioxide. The body normally contains over 1000 ml. of nitrogen in a pressure equilibrium between internal and external partial pressure, as a result of the continuous gas exchange occasioned by respiration. In rapid ascent to altitude, however, the partial pressure of nitrogen in the body may greatly exceed that of the external air, resulting in gas expansion in the tissues and hollow spaces of the body with consequent discomfort, pain and more serious symptoms of dysbarism, such as bends, chokes, and even neurocirculatory collapse. Dysbarism is facilitated by cold, which leads to increased metabolic rate and is more apt to occur in older and obese persons.

Carbon dioxide accounts for only .03 per cent of the ambient air and plays a vital role in the natural process of oxygen generation by photosynthesis. Man inhales oxygen and exhales carbon dioxide and when respiration occurs in a confined space without adequate ventilation the gradual accumulation of CO_2 becomes a decisive factor for survival. The lowest permissable concentration of oxygen for safety, with unacclimatized personnel is 12 per cent and the highest permissable concentration of CO_2 for unacclimatized persons is not over one per cent for more than a few hours (Clamann, 1961a). Theoretically acclimatization to low oxygen and to high CO_2 are incompatible.

In addition to problems related to assurance of adequate oxygen supply and pressure at altitude control of nitrogen pressures and ventilation of exhaled carbon dioxide the atmosphere may contain contaminants and toxic agents at altitude, which present other problems. These include noxious gases, such as carbon monoxide, and irritating fumes from lubricants or an aircraft power plant, ozone and atomic or ionized oxygen and nitrogen, ionizing radiations, and meteorites. Furthermore, the increased metabolic function involved in respiration at altitude also raises body temperature, which may involve numerous other interactions. Temperature and pressure variations with altitude are extensive and require compensations that frequently exceed the physiological energy available, particularly above 18,000 feet. As a result flight above this level (indeed, above 10,000 feet) has depended on environmental engineering to supply the necessary energy for effective physiological function. Engineering difficulties as well as costs have increased with every advance in altitude and speed and solutions have often reflected compromises and sacrifices, rather than ideal decisions.

SUBMARINE PROBLEMS

As one descends below the surface of the sea, air compression increases at the rate of 1 atmosphere (from sea level atmosphere of 760 mm. Hg) approximately every thirty-two feet. The effects of increased pressure are very poorly tolerated by man beyond 1 atmosphere. Behnke (1962) noted that deep sea divers who had difficulty in assimilating facts and making quick decisions, and who sometimes experienced emotional disturbance and loss of consciousness at 9 to 10 atmospheres, were once regarded as psychologically unstable. However, undersea swimmers have experienced convulsive seizures at 33 feet, and in a compression chamber at 4 atmospheres decreased ability to work, mood changes, euphòria, varying degrees of stupefaction, and fixation of ideas have been reported. In this situation memory and concentration are difficult, and impairment of arithmatic calculation, recording of data, and motor performance are common.

These effects have been attributed to nitrogen narcosis and oxygen toxicity in the high-pressure atmosphere and have been overcome in submarines by the use of sealed cabins conditioned to normal sea level atmospheric parameters. In the confined submarine environment, long before space cabins were even envisioned, the problems of ventilation of CO_2, CO, and other contaminants, as well as control of noxious odors, were faced. Modern deep-diving, long-range submarines, without the weight restrictions of space craft, are adequately stressed to withstand the tremendous undersea pressures and employ advanced revitalization systems to maintain a safe environment in the cabin.

COMPONENTS OF THE ATMOSPHERE

OXYGEN

Oxygen comprises approximately 21 per cent of the air by volume and its partial pressure at sea level, obtained by multiplying the total pressure of 760 mm Hg. by .2094, is 169. The average man requires two pounds of oxygen per day and suffers disabling symptoms when the supply is inadequate (hypoxia) or over-abundant (hyperoxia). Hypoxia may occur as a result of low pressure of the ambient air at altitude or dilution of mixtures in confined spaces or obtained from stores. The effects of hypoxia are well known and have recently been reviewed extensively by Pugh (1962). It is particularly important to note that hypoxic effects may set in at altitudes as low as 7000 feet, where visual impairment may occur, and that when it occurs at high altitudes, as a result of equipment failure or explosive decompression, the resulting euphoria, overconfidence, loss of judgment, and impairment of performance are insidious. The importance of indoctrination of personnel and of the use of monitoring and warning devices to supplement other measures discussed hear for the maintenance of reliable performance cannot be overestimated.

Oxygen toxicity (Dubois, 1962, Behnke, 1962, Stein, 1962) occurs by inhalation of high oxygen concentration in an airtight system, resulting in the rapid absorption of gases from the closed spaces in the body. Atelectasis, accompanied by engorgement of the lungs and other symptoms may ensue. Other effects include impairment of behavior, loss of consciousness, and convulsive seizures. Severe effects may occur, breathing ambient air in a compression chamber, within three hours, and breathing 100 per cent oxygen at sea level, in four hours.

Denitrogenation, by breathing 100 per cent oxygen prior to flight, has been a standard procedure for high altitude flight, in order to avoid dysbarism in the event of sudden decompression and research has been conducted on the tolerance of high concentrations of oxygen related to this procedure. High concentrations of oxygen are known to "wash" nitrogen out of the lungs and circulate blood rapidly, but the replacement occurs more slowly in the tissue fluid and connective tissues. The question is, how long can high concentrations of oxygen be tolerated without toxic symptons? Hale et al. (1964) found significant hyperoxia-induced adrenocortical and sympathoadrenal depression in healthy subjects breathing 100 per cent oxygen by mask in four hours; since Pugh (1962) has recommended that denitrogenation for high altitude flight be of at least three hours duration with100 per cent oxygen at sea level, the limit is fairly well established.

Michel et al. (1959) exposed six volunteers at 10,000 feet in an altitude chamber of 168 hours, breathing 80 per cent oxygen. There were no marked effects on general appearance, activity, or physical well-being, but signs of pulmonary irritation suggested that tolerable human limitations for prolonged exposure to a higher than normal concentration of oxygen may have been approached. Apparently, oxygen toxicity declines with altitude. Hale (1961) has stated that it does not occur above 15,000 feet and a study by Norgan, Cutler, and Shaw (1963) tends to support him. They found that four subjects tolerated well a simulated altitude of 27,000 feet (258 mm.Hg) with pO_2 of 243 mm. Hg for 14 days (336 hours).

Damato et al. (1963) investigated the hazard of rapid decompression following exposure to a proposed space capsule atmosphere. They reported that exposure to a mixture of 50 per cent oxygen and 50 per cent nitrogen for a minimum of 18 hours at 18,000 feet or to 100 per cent oxygen for three hours at sea level provides adequate protection against the decompression hazard of "bends" without toxic reaction to the oxygen in either mixture. Clamann (1961a) has pointed out that total decompression time increases with decreasing outside pressure, theoretically becoming infinite at the vacuum of space. Acute hypoxia, with vaporization bubbles in the body fluids is the principal danger above 63,000 feet. Since bailout in orbit is useless, transfer to another habitable spacecraft will be necessary, and protection during the critical post-decompression period is urgent. Dawes (1963) has emphasized the importance of an adequate cerebral circulation to prolong survival in anoxia. Ernsting (1963a, 1963b, 1963c) and Ernsting et al. (1961, 1960) have emphasized the importance of breathing an oxygen-enriched mixture prior to decompression, but have also cautioned about the dangers of oxygen toxicity on prolonged exposure at low altitudes (8,000 feet in their experiments).

The importance of extending altitude tolerance of space crews by selection and acclimatization is best understood in terms of the increased margin of safety gained by ability to operate at a lower pressure differential and to tolerate more marginal conditions. Pugh (1962) has reported that between 1922 and 1952, no less than 9 mountaineers ascended safely to 28,000 feet without oxygen equipment. This number is greater today. According to Pugh, experience at altitude (physiological adaptation and accustomization) and motivation are major factors in altitude tolerance: "men continue to show judgment and adaptability in activities in which they are specially trained and experienced (at high altitudes), whereas in other matters they may make serious mistakes."

In a study of respiratory response to hypoxia and hypercapnia after acclimatization at 19,000 feet, Michel and Milledge (1963) found that the parameters related to hypoxia were little affected by several months at that altitude, while those related to hypercapnia were conspicuously changed. Astrand and Astrand (1958) found that cardiac output and oxygen transport supply seemed to approach a relatively low ceiling at high work rates in two subjects acclimatized to 14,250 feet for four weeks, but an increase in oxygen during heavy work promptly increased the heart rate.

Phillips et al. (1963) investigated cognitive changes with five subjects at 12,470 feet for three days and with seven subjects at 14,250 feet for two days. No changes in immediate-memory tasks were found; one problem solving task was significantly impaired and one improved. Improvement was significantly correlated with changes in temperature and pulse rate, but impairment was not correlated with these measures. They concluded that performance under hypoxic conditions may depend on a interaction among several factors, including the degree of practice, complexity of the psychological functions, and the subject's ability to respond to awareness of his own physiological deficits by increased effort. Lansburg (1959-60) demonstrated impairment of performance of experienced pilots on stereophonic discrimination tests, with and without oxygen, at 20,000 feet.

Burgess (1958) reported that although there were individual differences, low oxygen partial pressures caused centrifuge subjects to show decreased tolerance to acceleration stress. He emphasized the hazard to a pilot who fails to use supplemental oxygen under conditions producing a mild hypoxic state. Hale (1961) mentioned heat as another factor that reduces acceleration tolerance. And Ernsting (1963a) has indicted high inspired oxygen concentration, which, he stated, increases the magnitude of lung collapse induced by exposure to accelerative forces. Lim and Luft (1962) noted that hypoxia and thermal stress (heat) have a synergistic action on total ventilation and heart rate. Clamann (1961b) emphasized the importance of odor control, in that noxious odors induce shallow breathing and hence hypoxia.

NITROGEN

Nitrogen is the largest component of atmospheric air, comprising 78 per cent by volume and its partial pressure at sea level is 593mm.

Hg. It enters the body with inspired air and is diffused through the body fluids, air spaces, and tissues. As long as the difference between the partial pressure of nitrogen in the body does not differ from that of the surrounding atmosphere by more than 1 atmosphere, bubbles of nitrogen are not liberated within the body unless the supersaturation corresponds to more than a decompression from a total pressure of two atmospheres (Clamann, 1961a). Decompression symptoms (dysbarism) can be avoided by maintaining a rate of ascent, from sea level to altitude or from undersea depths to the surface, slow enough that the saturation of nitrogen in any tissue of the body will never reach double its normal value at any prevailing altitude pressure. A procedure approximating this principle was once used in deep sea diving, but the slowness of ascent made it impractical. It is, of course, impossible in flight. In both flight and submarine activity the dangers of rapid decompression have required special provisions for personnel protection.

Nitrogen narcosis has been a problem in deep sea diving and submarine medicine, similar to alcoholic intoxication and anoxia (Behnke, 1962). It occurs at raised pressures of air (40 to 50 psi), but the stupefying effects are alleviated by breathing a mixture of helium and oxygen, making depths exceeding 20 atmospheres possible. Taylor (1962) pointed out that most investigators doubt that "nitrogen narcosis" is the sole result of nitrogen effects. Linaweaver (1961) tested helium-oxygen mixtures for oxygen toxicity in an experimental diving unit and found no evidence of oxygen toxicity even when the presently accepted depth-time O_2 exposure limits were greatly exceeded.

CARBON DIOXIDE

Carbon dioxide can be tolerated in normal atmosphere at sea level as long as the concentration does not exceed two to three per cent. Clamann (1961b) stated that one per cent is more desirable for prolonged exposure. In conventional, pressurized aircraft CO_2 and other contaminants are easily ventilated, but high levels of CO_2 are a constant problem in sealed cabins of spacecraft and submarines. The effects of partial pressures of CO_2 above 15 to 20 mm. Hg are (1) a noticeable increase in breathing rate, and at high levels, incidence of hyperventilation, (2) distension of the air sacs of the lungs, and (3) impairment of normal gas exchange in the lungs. Partial pressures above 35 mm. Hg can be endured for only a few minutes (Life Support Systems Lab, 1961). At 38 mm. pCO_2 at sea level, the effects include heavy panting and respiratory distress, fatigue, stupefaction, narcosis, unconsciousness, and eventual death.

Cutler et al. (1963) hypothesized that CO_2 tolerance might be different, possibly greater, in 100 per cent-oxygen, low-pressure atmospheres than in normal air at sea level pressure. They exposed healthy young USAF pilots to 23 mm. Hg of CO_2 for three days in atmospheres of 700 mm. Hg and of 200 mm. Hg. The greater increase in alveolar CO_2 in the near-sea level atmosphere supported the hypothesis. Pierce et al. (1962) observed that hyperventilation during the breathing of 100 per cent oxygen elevates pO_2 of alveolar gas by the same amount that it lowers its pCO_2. Since the development of arterial hypocapnia causes cerebral vasoconstriction, brain oxygenation is drastically decreased even while arterial oxygenation is improved by hyperventilation. Administration of 30 per cent CO_2 with O_2 at an ambient pressure equivalent to an altitude of 39,000 feet prevented alkemia and, in spite of hyperventilation, restored cerebral venous oxygenation to a level at least equivalent to that found when pure oxygen was breathed at rest at the same altitude. The respiratory minute volume during administration of CO_2 with O_2 was greater than when O_2 alone was breathed at reduced ambient pressure. Since neither arterial pO_2 nor cerebral venous pCO_2 values differed in the two experimental situations, the respiratory stimulation was believed to represent the quantitative demonstration in man of a respiratory effect of CO_2 mediated by arterial chemoreceptor activation and unrelated change in the level of central chemical stimulus.

In 1953, Faucett and Newman reported a Navy study in which 22 men were confined in a sealed submarine cabin for 60 days in order to measure the physiological and psychological effects of breathing atmosphere with well above normal amounts of CO_2 and other contaminants. Several physiological measures indicated that some adaptation did occur. The long exposure produced no adverse physiological effects, but the behavioral effects were extensive. They included impairment of manual dexterity, increased hand tremor (first week), decline in mechanical ability test scores, gradual decline in motivation, increased anxiety and tension, decline in alertness, and decline in quality of sleep until the third week, when there was an improvement that continued. More recently, Weybrew (1960) discussed the highly efficient and continually improving techniques of atmospheric revitalization during prolonged submarine submergence. No acutely harmful effects of specific atmospheric contaminants have been reported, although the effects of breathing higher than normal concentrations of CO_2, CO, and other contaminants for periods of 60 to 90 days are still matters of concern. At present, however, the principal research attention is being focused on altitude problems of the crews.

CARBON MONOXIDE

Schulte (1963) measured the effects on 49 healthy men between

25 and 55 years of age of exposures for varying duration to an atmosphere containing 100 parts per million of CO. Exposure produced levels of carboxyhemoglobin in the blood ranging from 0 to 20.4 per cent. Impairment of function due to exposure to CO occurred earliest in the higher centers of the brain controlling cognitive and psychomotor abilities. Impairment is detectable at levels of carboxyhemoglobin below five per cent and increases with concentration of carboxyhemoglobin in the blood.

A Russian study (Air Int. Div., 1961) reported the effects of air contamination by exhaled CC of smokers and non-smokers confined in groups of three in a testing chamber with an air volume of 24 cu. in. for three days. Smokers exhaled CO at an average rate of .038 mg/l while the rate for non-smokers was .016.

IONIZED AIR AND WATER DROPLETS.

Atomic or ionized oxygen and nitrogen appear in the atmosphere in significant concentrations only at high altitudes (Hale, 1961). Positive and negative air ions and condensation droplets have also been found in the atmosphere of fleet-type submarines and were observed to increase significantly during periods of submergence (Schaefer, 1959). Concern with ions reflects the belief that they may have adverse effects on physiological functions, such as respiration, and on certain aspects of performance. Davis (1962) concluded that the literature is suggestive of physiological and behavioral effects, but that sensitive tests are needed to assess effects.

Frey (1961) and Granda and Frey (1962) reviewed the literature on the effects of atmospheric ions on behavior. The earlier review reported a wide variety of different effects of positive and negative ions and hypothesized that they may reflect promotion of the release of free serotonin (positive ions) or release of its oxidation (negative ions). The later review mentioned the hypothesis that negative ions stimulate the secretion of glucocorticoids and positive ions either stimulate the secretion of mineralocorticoids or inhibit glucocorticoid secretion. Granda and Frey also reported research data that are difficult to relate to their hypothesis. Under non-stress they found, as predicted, that ionization had no effect on a visual threshold task and psychomotor task. Under stress, significant effects were found. These authors concluded that stress is a precondition for ion effects to occur. Granda and Savage (1962) found no significant effects of ions on two psychomotor tasks and concluded that, at least up to about 60,000 ions per cc, ions have no effects on psychomotor performance under either stress or non-stress conditions. This conclusion is supported by the work of Chiles et al. (1960) with university students exposed to extreme concentrations of ionized air for 3 to 4 hours, using a complex mental task, a vigilance task, and an attitude check list.

Knoll et al. (1961) developed an automatic electronic visual reaction time meter with which they tested the effect of light atmospheric ions on human reaction time. Individual differences among subjects were great and no systematic results were reported. Only one report has been found with clean-cut results. This is an abstract (translated) of a Russian study by Minkh (1963), who found significant improvement in male subjects exposed to negatively ionized air for 15 minutes daily over 25 days. Health, appetite, sleep, work capacity, reaction time, and metabolism were improved in men and also in women.

At this time the case for the hazard of ionization appears unsupported.

OZONE

Ozone is formed by the absorption by oxygen of the shorter range of ultraviolet radiations (c. 2000 angstroms) in the range between 50,000 and 140,000 feet and is destroyed by absorption of ultraviolet radiations in the range of 2100 to 2900 angstroms. The latter process liberates heat. It is found in maximum concentration of about 8 parts per million by weight at around 75,000 feet.. Despite its low concentration,it is believed to have considerable physical and biological significance. The liberation of heat in the destruction of ozone is held responsible for the increase in temperature in the middle layer of the stratosphere (110,000 to 160,000 feet), which in turn leads to air turbulence and other meteorological phenomena. Armstrong (1961, p. 117) holds that the formation and destruction of ozone almost entirely blocks the biologically destructive ultraviolet radiation below 3000 angstroms, but that the atmospheric ozone is extremely toxic and might constitute a hazard to personnel in pressurized cabins at the maximum concentration level of 70,000 to 80,000 feet. Hanks (1961) has called attention to the need for reliable cabin-ozone measurements in the 50,000 to 90,000 foot range at different latitudes and seasons in order to assess the problem for up-coming generations of jet transports. He has reported cabin concentrations of only .075 ppm by volume of air, at the olfactory threshold, in flights at 40,000 to 50,000 feet, but regarded these measurements as unreliable. Trumbull (personal communication), however, cited measurements by Young et al. in a DC-8 aircraft on 325 flights between 29,000 and 39,000 feet which averaged 30 to 40 ppm by volume in the passenger cabin and slightly below 50 ppm in crew compartments. Studies by Juin and Pineau and by Lagerwerff, cited by Trumbull, point to the possible effects of ozone as follows: fatigue on long flights, decrease of visual acuity in the scotopic and mesopic ranges, significant and measurable increase in peripheral vision, and changes in muscle balance affecting all extra-ocular muscles except the superior and inferior recti.

ATMOSPHERIC CONTROL

SUPPORT AT ALTITUDE

Cabin pressurization has been a physiologically adequate means of controlling aircraft environments within the range in which compressors (and air breathing engines) function efficiently. The limiting factor, physiologically, is the danger of explosive decompression resulting from damage to the cabin walls by impact or failure of the structure to withstand the pressure differential on the walls resulting from pressurization. Although jet passenger aircraft have tolerated greater pressure differentials than military aircraft, for obvious reasons, they have accepted a lower operational ceiling in order to avoid cabin altitudes (over 8,000 feet) requiring routine supplementary oxygen. A jet liner at 40,000 feet (2.72 psi), pressurized at 5,000 feet (12.23 psi) has a pressure differential of 9.51 psi, which could not be greatly extended with safety unless heavier and costlier designs were used.

Military jet aircraft, which have operated well above 50,000 feet, have maintained a lower pressure differential of around 5 psi as a safety precaution against the greater danger of explosive decompression in combat aircraft. This has been accomplished by pressurizing to higher cabin altitudes, which then require supplementary crew support for oxygen and nitrogen pressures, temperature, and g-forces in very high performance flight. At 50,000 feet (1.69 psi), the cabin must be pressurized to at least 20,000 feet (6.75 psi), requiring the crew to breathe stored oxygen; this also gives added protection against dysbarism in the event of decompression at this altitude. At higher altitudes, further protection of crew members has been required. The partial pressure suit has enabled pilots to breathe oxygen at physiologically satisfactory pressures and to "get down" to lower altitudes safely in the event of explosive decompression. However, the partial pressure suit provides no protection against dysbarism per se, and denitrogenation, by breathing 100 per cent oxygen for a sufficient period prior to flight, has been adopted as a standard procedure. For high altitudes, Pugh (1962) and others have recommended that this period should be for three hours. Full pressure suits, which were greatly improved in the X-15 and Mercury programs, provide for both oxygen and nitrogen problems. Ventilation of expired CO_2, CO, fumes, and noxious odors has not been a particular problem in jet aircraft.

Both the air breathing engines and present compressors have a ceiling at 80,000 feet, where atmospheric pressure is only 3.5

per cent of sea level and power plant as well as personnel must depend on a transported oxygen supply. For operation above 80,000 feet, which has therefore been called the "edge of space," rocket-propelled vehicles with sealed cabins have been deveolped. The sealed cabin must provide an oxygen supply as well as means of ventilation to remove carbon dioxide, water vapor, carbon monoxide, and other noxious gases and odors. In the sealed cabin, confinement is a predominant environmental factor and time of occupancy for various missions has a profound influence on construction, furnishings, and life support equipment required.

Physiologically, sea level atmospheric pressure and composition of gases is the most desirable cabin atmosphere in space ships, as well as submarines. However, from the engineering standpoint, this would require the space ship, in the vacuum of space, to endure a pressure differential of 14.7 psi, which is considered structurally unsafe. Therefore, a contrived atmosphere, with a smaller pressure differential and gaseous contents providing an optimal solution for all personnel and engineering requirements has been sought.

A major problem is control of carbon dioxide concentration. Since the respiratory ratio of volume of exhaled CO_2 to O_2 consumed results in about 15 per cent more O_2 absorbed from the surrounding atmosphere than is replaced by exhaled CO_2, a pressure drop is produced in a confined space by normal respiration, provided temperature and humidity remain constant. The effects can be illustrated by the example of one man at rest in a sealed cabin of 50 cu. ft., without an oxygen supply or means of absorbing CO_2 or water vapor. After four hours, cabin oxygen would drop to about 14 per cent (equivalent to atmosphere at 10,000 feet). CO_2 concentration would rise about six per cent, and humidity would reach 100 per cent in 15 minutes. Clamann (1961b) has suggested that the pressure changes, with temperature and humidity constant, could be used to monitor cabin oxygen.

This country has had an extensive research program on the design of an optimal space cabin atmosphere and the development of components of regenerative life support systems to permit extended operation of personnel in sealed cabins beyond the brief periods thus far achieved with stored supplies and waste removal equipment. Parker and Ekburg (1963) have taken into consideration pO_2, diluent gas, temperature, humidity, CO_2, and space suit problems and recommended an atmosphere for an orbiting space station, containing nitrogen as a diluent, pO_2 between 160 and 175 mm. Hg, total pressure between 350 and 380 mm. Hg (18,000 to 20,000 feet), pCO_2 range of 5 to 8 mm. Hg and pH_2O of 5 to 15 mm.

Hg, with a dry-bulb atmospheric temperature of 70° to 80°F. White and Smith (1963), with reference to Project Gemini, found no contraindications to a design involving a near 100 per cent O_2 at 5 psi (27,000 ft.), inlet temperature of 65°F, relative humidity control, pCO_2 below 2 mm. Hg, positive control of toxic materials, and positive circulation of gases.

The limiting factor in the extension of spaceflight for long periods of time, with respect to these factors, as well as food, water, and waste control, is the weight of supplies and equipment that must be carried for the requirements of each crew member. Clamann (1961a) has reviewed these requirements and the rationale of the regenerating life support systems that have since been under active research and development. When these reach the stage of practical feasibility, they will greatly extend the range of space operations.

In addition to the impressive environmental engineering accomplishments making the penetration of high altitude atmospheric and space flight a daily reality, other supporting measures must not be overlooked. Commercial airlines, the military air forces, and NASA have devoted tremendous effort to personnel selection, physiological indoctrination, acclimatization, accustomization in flight simulators of unbelievable realism, in-flight monitoring and warning, and training in safety and emergency procedures. A high level of research and development assures that the progress of knowledge will lead to eventual space flight on the same routine basis as present day jet travel.

PROTECTION IN SUBMARINES

One of the greatest advantages of the submarine over air and space craft is that weight is no problem with respect to design factors for environmental support. The cruising submarine may use a snorkel tube for fresh air near the surface, but at greater depths is a sealed cabin in many respects like that of the space ship. It differs from present space ships, however, in cabin size, crew size, space for physical movement, cabin atmosphere and ventilation requirements. The larger space provisions and jobs aboard submarines involve a higher level of physical work than may be required of space crews and, hence, large supplies of oxygen per man. There appears to be no need for a different gas mixture than in the normal sea level environment, and submarines can be maintained with essentially normal pressures and mixtures. Although ventilation of CO_2, CO, foul odors, and other contaminants is rather well provided for in the more recent submarines, the levels of these contaminants are carefully monitored and still regarded as a problem. However, as Weybrew (1960) has reported, present problems appear to be related more to crew attitudes and general adjustment to long periods of submergence than to the adequacy of the environmental habitability systems.

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The effects of atmospheric pressure on high and low altitudes on the human organism are reviewed. The behavioral and physiological effects of hypoxia, oxygen toxicity, carbon dioxide poisoning, decompression, nitrogen narcosis and ozone concentration are described. Supportive and protective measures for these stressors are mentioned.

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