Design Criteria for a Manned Space-Laboratory Environmental-Control System

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The history and philosophy of manned space-laboratory environmental-control systems is discussed, and suggestions for achieving a more equitable balance between environmental requirements and environmental control system costs are made. Available data on environmental factors are reviewed and various control recommendations made: continuous rms noise level should not exceed 89 db; effects of weightlessness on subsequent tolerance levels for accelerations must be considered; space station rotation rate should not exceed 4 rpm but should provide at least 0.2 apparent *g*, and Coriolis acceleration due to walking should be limited to 0.2 apparent *g*; in flexible space station assemblies, vibrations due to crew movement must be considered; low frequency vibrations should be limited to maximum rms acceleration of 1*g*; and ultrasonic vibrations should not exceed 0.1–0.2 kw power intensity. Available acute radiation dose data are reviewed. Cabin pressure and atmospheric compositions are discussed. Special hazards of meteoroid penetration (including decompression) and toxicity are noted. The magnitude of the resupply problem for a semi-closed life-support system makes development of components to approach closed operation very important; greatest gains will come from waste water conversion, CO_2 removal, and recovery of O_2 from CO_2. Some areas are suggested wherein ingenious vehicle design and integration techniques could lead to greater reliability with reduced weight and cost.

Introduction

THERE is little disagreement that the maintenance of an adequate environment for the spaceflight crew is a prime requirement for any manned space laboratory. On the other hand, there is a significant difference of opinion as to what constitutes an adequate environment.

Maximum returns per unit cost in national prestige, technology, and knowledge would appear to be a reasonable standard of excellence for early space laboratories. If this were so, an adequate environment could be defined as one permitting the crew to function in a manner to maximize these gains against cost.

Unfortunately, precise quantitative values have not been agreed upon for units of new technology or new knowledge, much less national prestige. Other costs, such as the weight of structures, subsystems, and stored metabolites, can be much more accurately assessed. These discrepancies in our ability to weigh value vs cost have a tendency to cause us to pay greater attention to the easily measurable costs than to the less easily measurable values. What is the measure of a unit of crew performance? What is fatigue? By what means can a 10% change in crew performance be detected? On the other hand, great stress is often placed on a 10% change in structural weight or a 5% change in propulsive efficiency. Because over-all space laboratory utility is a product function of the performance of the crew times that of the space vehicle, it follows that careful consideration must be given to both in order to arrive at a balance between values and cost.

Since the difficulty of balancing value and cost is great, it is important to be alert for opportunities to utilize data from early experience in laboratory tests and early space flights to improve the quality of the compromises between environmental requirements and their associated costs. It may be even more important to search out and develop means of reducing the cost of achieving a more nearly optimum crew environment. If a determined effort is made to develop economical means of approaching the ideal environment, it may be possible to approximate closely an ideal environment and at the same time reduce the weight and cost of the spaceflight vehicles. For example, pressure-containing vehicle structures have been designed which can carry full normal atmospheric pressure, reduce leakage to negligible values, and at the same time show significant weight advantages over existing space vehicle structures. A well-designed sandwich structure carrying 15 psi pressure in bending across a 20- × 40-in. panel would weigh approximately 1 lb/ft^2; but a structure carrying the same pressure in tension over a similar projected area would weigh only about 0.1 lb/ft^2.

These rather startling gains are made by the utilization of three techniques:

1) Careful control of the vehicle configuration to provide maximum usable space per unit of structural area and to minimize those portions of the structure required to carry bending loads as against those carrying simple tensile loads.

2) Use of materials to perform multiple functions; e.g., heat exchangers and carbon dioxide absorbent trays can be configured to serve as seat couch and plenum chamber structure while they are performing their gas or energy exchange functions. Micrometeoroid protection materials can double as a structural material and insulation while providing radiation protection, and packaged foods can provide interior insulation, aesthetic interior treatment, and radiation shielding.

3) Seals utilizing well-demonstrated techniques can reduce the leakage of vital gases to negligible values; e.g., tin cans, tubeless tires, sealed light bulbs, and freon compressors with rotating shaft seals are used daily in large numbers. Each of the techniques employed is economical, simple, and highly effective in producing a seal with negligible leakage compared to that of present spacecraft cabins.

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Environmental Requirements

It is obviously not enough merely to devise improved techniques of meeting established environmental requirements. It is equally necessary to gather new data showing, with improved accuracy, the effects of changes in the various environmental parameters and to present these "tolerance" or "satisfactory performance" envelopes in a form easily usable by equipment and subsystem design engineers. Environmental control as applied to manned space systems encompasses not only control of the space cabin atmosphere but also protection from or control of such environmental parameters as noise, vibration, acceleration, weightlessness, and radiation, to mention only a few.

For efficient crew operation in a manned space laboratory, it is essential that the noise level be kept within reasonable limits, not only for ease of communications but also to reduce over-all fatigue. Onboard equipment in the Mercury capsule, for example, generated a background noise level of approximately 87 db. In a manned space laboratory, without the attenuation provided by helmet and earphones, such a level would exceed recommended maximum continuous rms limit values to preclude hearing damage (Fig. 1).[1–3] Either ear protection must be provided or the noise level controlled.

The question of weightlessness environment's effects on the crew of a manned space laboratory expected to operate for extended time periods is most critical to system design. There are preliminary indications that man's defined acceleration tolerances (Fig. 2)[4–6] may be significantly lowered after extended periods of zero gravity, which could affect re-entry techniques and vehicles. The long-term functionability of the cardiovascular system, the decrease in muscular tension and degree of possible compensation with specific exercises, and the possible decalcification within the bony structure are all potential problem areas from exposure to a long-term weightless environment.[2–9] If such potential problem areas are proved to be true problems in a zero-gravity manned space laboratory, artificial gravity may be the only practical solution to long-term manned occupancy.

Artificial gravity may be provided by the centrifugal force from rotation of the laboratory; however, new environmental problems arise. Tests by the Russians on animals in rockets and by the U. S. Air Force on man in aircraft flying controlled trajectories have established approximately $0.2g$ as the minimum required for efficient locomotion. Also, an upper-limit of approximately $1g$ is reasonable from an efficiency standpoint. The variables involved in achieving apparent gravity within these limits are the radius and rate of rotation of the system. A significant drawback to the rotation technique is the Coriolis acceleration that is generated every time motion is attempted perpendicular to the axis of rotation. This acceleration is the result of a fundamental law relating the time rate of change of a vector as measured by an observer in a reference inertial space to the time rate of change of the vector measured by an observer in a space rotating with respect to the reference space. This relationship is expressed mathematically by the vector equation

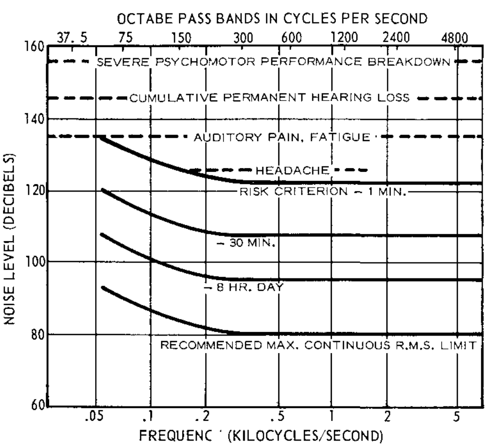

Fig. 1 Auditory vibrations—recommended limits for space crews. Ear protections required at risk criterion levels; pure tons lower limits by 10 db.[1–3]

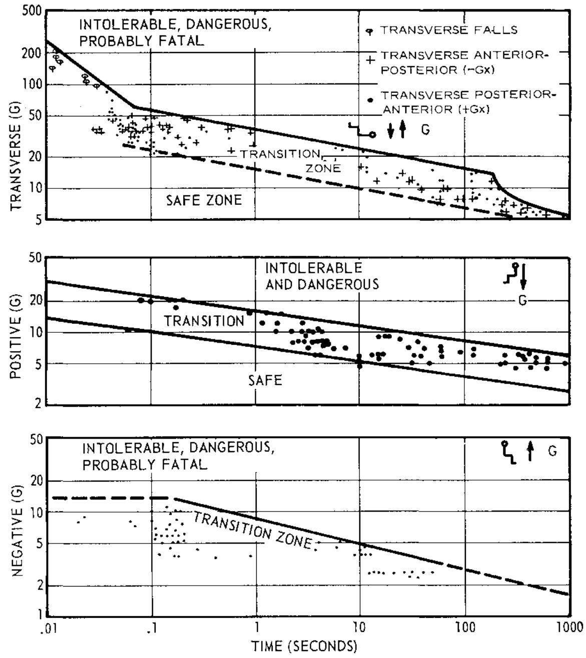

Fig. 2 Man's acceleration tolerance in earth g's.[4–6]

$$\left(\frac{d\mathbf{V}}{dt}\right)_r = \left(\frac{d\mathbf{V}}{dt}\right)_m + (\boldsymbol{\omega}_{rm} \times \bar{V})$$

where

$\left(\frac{d\mathbf{V}}{dt}\right)_r$ = Coriolis acceleration or change of velocity vector with respect to reference space

$\left(\frac{d\mathbf{V}}{dt}\right)_m$ = change of velocity vector with respect to moving space

$(\boldsymbol{\omega}_{rm} \times \mathbf{V})$ = change of velocity vector due to rotation of moving space

This acceleration manifests itself in two ways on the human in the rotating space: 1) it adds to the apparent weight of anyone moving in the direction of rotation and vice versa; and 2) when anyone moves toward the center of rotation, a force is exerted in the direction of rotation, and when he moves away from the center of rotation, the force is opposite to the direction of rotation. The second manifestation of the acceleration is the so-called "Coriolis effect" sensed by the semicircular canals of the ear and defined as "canal sickness." The limits on a rotating artificial gravity environment from these two effects are more critical or more severe than other criteria, such as difference in head-to-foot g, rim velocity of station, etc., and hence should define design criteria for radius and rate of rotation of the vehicle.

When Coriolis forces are combined with the centrifugal force, a different apparent gravity vector exists in magnitude or both magnitude and direction. It is desirable to set limits on this force such that under normal translation velocities, the apparent gravity vector will not exceed the angle of sliding friction of leather on metal, which is approximately a 20° slope. Since normal translation velocity is 3 fps, it is recom-

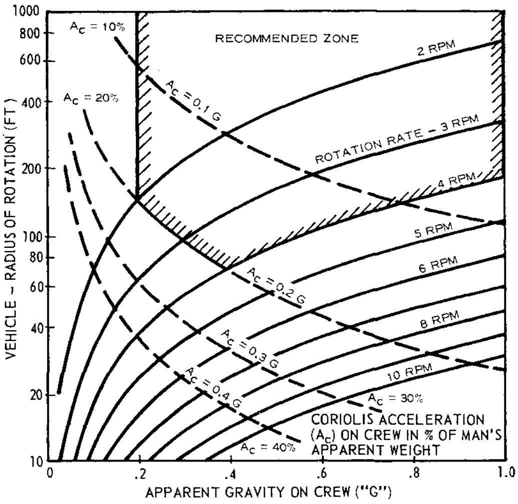

Fig. 3 Space vehicle artificial gravity due to rotation and Coriolis acceleration A_C in apparent g resulting from crew movement in vehicle at three fps.[9-11]

mended that the Coriolis force be limited to 20% of man's apparent weight in the rotating system when translating at this velocity. For a fast movement or walking at 5 fps, this allows a 35% Coriolis force, which under maximum conditions results in an apparent floor slope of 19.4°.

Based on tests in the slow rotation room at the U. S. Naval Air Missile Center, Pensacola, Florida, to define canal sickness limits, it appears that a reasonable design limit for rotation of the station is 4 rpm (Fig. 3).[9-11] Recent tests have indicated that selected crews could adapt up to 10 rpm; however, their over-all efficiency was lowered during any head movements out of the plane of rotation. Also, readaptation to a nonrotating environment was impossible to accomplish rapidly. This envelope is defined by Fig. 3.

If the space laboratory is rotated to obtain artificial gravity consistent with the prescribed envelope, opposite sides of the station may be connected by rigid or flexible structures. In a preliminary analysis of the flexible connections situation, it was assumed that two modules, each 18 ft in diameter, 40 ft long, and weighing 25,000 lb, were connected by a 6000-ft cable and rotated at 1 rpm to provide 1 earth g. By extreme crew movement, a plus or minus 4° perturbation could be induced in one module, which would damp and transfer the perturbation to the other module, as indicated on Fig. 4. These oscillations may be considered as a vibration environment to the crew and in this case would amount to 0.215 g at a frequency of $\frac{1}{4}$ cps. The degree of performance impairment from low-frequency vibration varies from a disagreeable and fatigue state to actual permanent physiological damage with no motor performance capability. In between these limits, the vibration may: 1) interfere with orientation and coordination (visual and tactile senses) and, consequently, the performance of skilled tasks; 2) induce psychosomatic or neuropsychiatric symptoms; and 3) induce discomfort, pain, and damage to tissues. To date the best vibration information is that defined for man in the seated or standing position subjected to longitudinal or vertical vibration. From the standpoint of mechanical impedance below about 2 cps, the body responds as a unit mass, whereas above this the various body organs and components exhibit resonance at discrete frequencies. Figure 5 has been based on all available data and defines the recommended limits for low-frequency vibration.[3, 12] The vibration of the 1-g space laboratory is well within the discomfort zone and certainly would result in decreased crew efficiency. A mutation-type wobble of a rigid rotating laboratory could result in similar vibration effects; hence the low-frequency vibration environment must be considered a parameter in over-all environment control.

Of somewhat lesser probability of occurrence, but nevertheless a possibility depending upon laboratory experimental setups, is the ultrasonic vibration environment. In the several hundred kc/sec range, vibration energy is propagated through body tissue in the form of compression waves. Tissue viscosity in this range results in increased energy absorption with increasing frequency, and also generates shear waves at the material boundaries in the medium (muscle to fat, etc.), at the boundaries of the energy beam, and at the boundaries of the medium. This is noticeable in the form of heat. Figure 6 gives the recommended maximum exposure limits to ultrasonic vibrations based on presently available data.[3, 12] The increased tolerance at the higher frequencies results from increased attenuation of the sound in body tissue with increasing frequency.

Of all the space environmental hazards, probably the most acute to living organisms is the ionizing radiation of cosmic and/or solar origin. At best, the data available on biological effects of this radiation are "soft." Exposure tolerance limits cannot be exactly defined since the dose is closely tied to the ionization characteristics of the particular particles. Ionizing radiation has different effects on the body, depending upon the total dose (amount absorbed), the rate of absorption (chronic or acute), and the region and extent of the body irradiated (variations in sensitivity to radiation of different parts of the body). Very limited data exist as to the spectrum (composition and intensities) of cosmic radiation, particularly at the lower-energy levels. As the limited data that are available have (to a large degree) been measured in roentgens, because most measurements have not been carried out with tissue-equivalent ion chambers, there is a large margin of uncertainty in its effects on man.

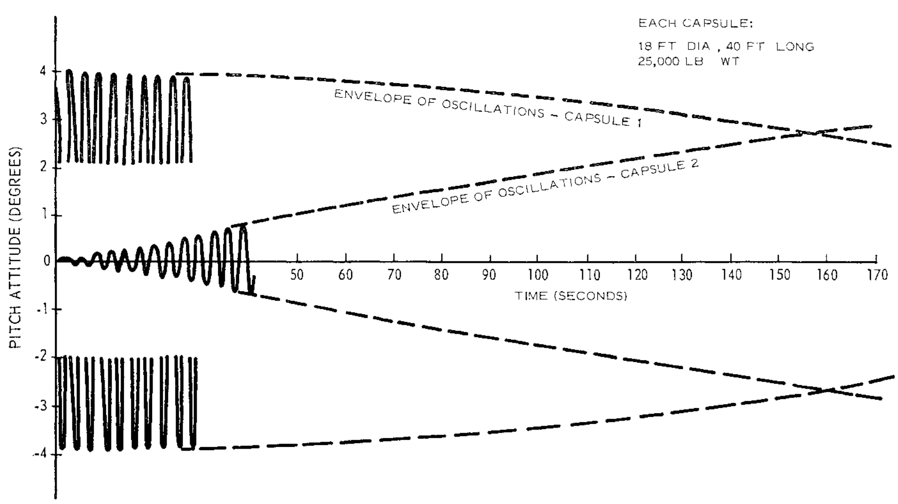

Fig. 4 Pitch attitude vs time for a two-capsule, 6000-ft cable, space station rotating at 1 rpm with a 4° perturbation in pitch due to rapid crew movement.

Table 1 Currently accepted relative biological effectiveness (RBE) factors for converting roentgens to radiation equivalent man (REM)

Type of radiation	RBE (whole body)	RBE (skin, eye, and gonad)
X, gamma, beta, electron	1	1
Proton	1.3	10
Alpha	1	15
C to Fe nuclei	indeterminate	indeterminate

Currently accepted Relative Biological Effectiveness (RBE) factors for converting roentgens (r) to Radiation Equivalent Man (REM) are given in Table 1.

Radiation exposure to the crew of a manned space laboratory may be acute or chronic and may generate cumulative genetic effects. Probable early effects in humans of acute exposure to ionizing radiation are given in Table 2.

If exposure to the radiation is not acute but prolonged, some of the tissues will undergo repair; and the degree of biological damage depends, among other things, upon the balance established between the repair process and the continuing exposure. For doses accumulated over a one-to-two-day period, the repair process is relatively ineffective; but on or after the third day, particularly at low-dose rates, very significant differences are evident in biological effectiveness. For example, a five-day dose may be attenuated by as much as 20%. Acute dose limits, based on the premise that the crew will run no risk of nonrecoverable exposure, are given on Fig. 7.[13–15] The solar flare radiation environment requires either extensive crew shielding during major flares or temporary abandonment of the laboratory.

During long-term occupancy of a large space laboratory, the meteoroid environment could become a hazard requiring special consideration; however, the construction that provides radiation protection usually could provide normal meteoroid protection with little or no additional weight. If a small meteoroid does penetrate the pressurized volume of the laboratory, it is likely that one or more of the following will occur: 1) decompression, unless the atmosphere is replaced at a rate in excess of the leakage rate; 2) a brilliant flash of the vaporous wall material and meteoroid which could produce temporary blindness and delay damage control; 3) local burns if a crew member is in close proximity to the point of penetration; 4) local puncture wounds from spalled wall material; and 5) depending on the amount of oxidizable material available in the cabin and the ratio of atmospheric oxygen, a flash of the entire cabin atmosphere could result.

This brings up the crew requirements as to internal atmospheric environment. The selection of a suitable atmosphere is a compromise which appears to best satisfy the diverse limitations set by the occurrence of "bends," hypoxia, fire hazard, cabin weight, toxicity, pressure, temperature, and humidity.

The minimum alveolar oxygen pressure (P_{O_2}) that precludes any symptoms of hypoxia is 61 mm of mercury. This

Table 2 Probable early effects in humans of acute exposure to ionizing radiation

Acute dose (REM)	Probable effect
0–25	No obvious injury
25–50	No serious injury—possible blood changes
50–100	Blood cell changes; some injury; fatigue; no serious disability
100–200	Injury; possible disability; no deaths anticipated
200–400	Injury and disability certain; death possible to approximately 25%
400–500	Fatal to 50% within one month
600–more	Fatal up to 100%

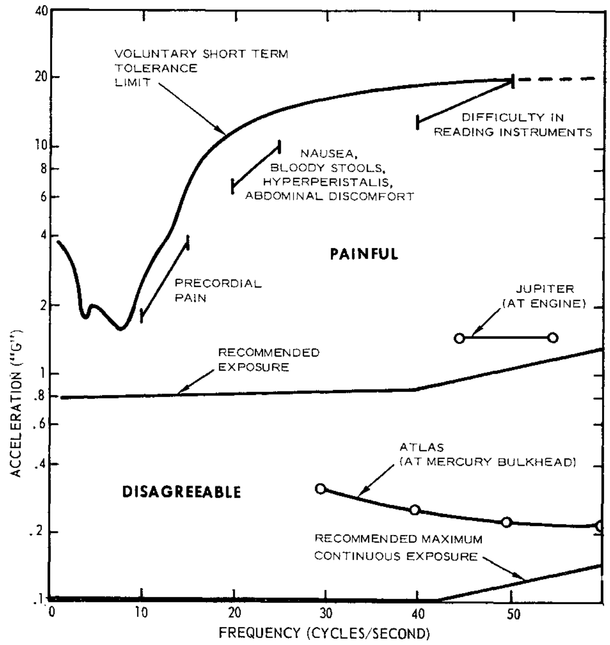

Fig. 5 Low-frequency vibration—recommended limits for space crews.[3, 12]

is equivalent to 100% oxygen at a total pressure of 144-mm Hg, or a pressure altitude of 39,500 ft, which in turn is equivalent to the alveolar P_{O_2} when breathing natural air at 10,000 ft. The occurrence of "bends," however, is a limiting factor in the selection of cabin atmosphere. It may occur without extensive oxygen prebreathing at 25,000–30,000-ft alt, depending on the amount of physical exertion. Also, a cabin pressure of 18,000 ft presents a hazard in case of rapid decompression. An emergency pressure suit will provide approximately 180-mm Hg pressure (equivalent to 35,000 ft). Submarine practice establishes a maximum

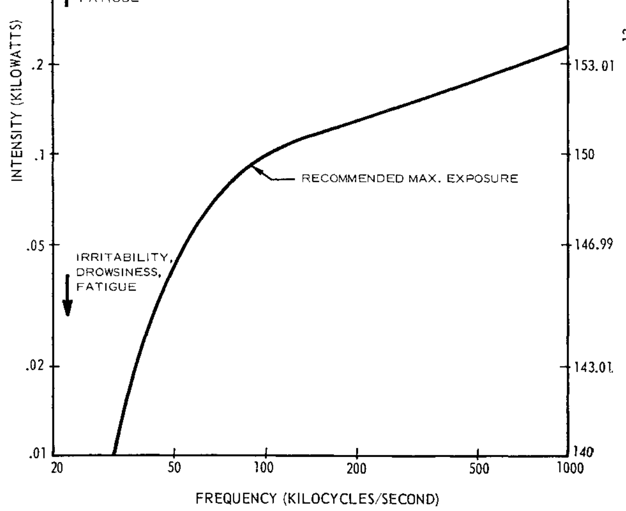

Fig. 6 Ultrasonic vibration—recommended limits for space crews.[3, 12]

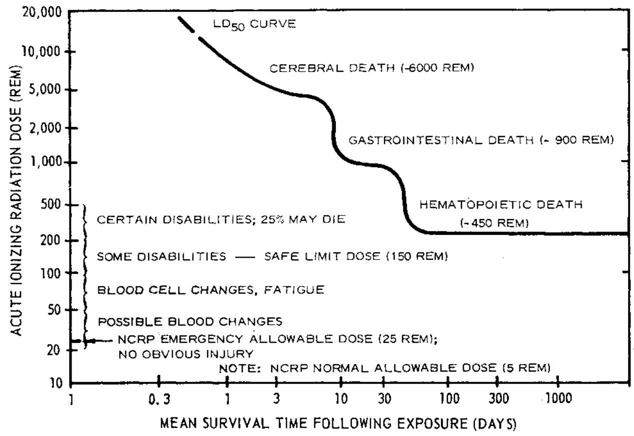

Fig. 7 Effects of acute human radiation dose and survival time relationship for fatal doses.[13,15]

pressure change ratio of 2:1 without danger of bends. This criterion permits cabin pressurization to a maximum of 360-mm Hg (approximately 18,000 ft) since the 360–180-mm Hg) pressure could be used if the pressure in the emergency system were sufficiently reliable, as in the case of commercial airliners, or if the emergency suit pressure were increased to one-half atmosphere. The Russian Vostoks use this latter approach.[16]

Another dominant consideration is to provide adequate conditions for gas exchange in the lungs where the blood is charged up with oxygen and excess carbon dioxide is given off. Since gas exchange is accomplished by diffusion, it is dependent upon the partial pressures of oxygen and carbon dioxide in the inhaled gas. On entering the respiratory passages, the inspired gas is warmed up to approximately body temperature (98°F) and fully saturated by water vapor, the latter exerting a partial pressure of 47-mm Hg at all times. This has to be taken into account in consideration of the effective partial pressure of oxygen and carbon dioxide at altitude.

The partial pressure of each gas is determined by the total pressure and the dry volume fraction F of each constituent. Thus, the partial pressure of oxygen in the warm saturated inspired air is $P_{O_2} = 760 - 47) \times 0.2094 = 149$ mm.

At 5000-ft alt, with a barometric pressure of 632-mm Hg, the partial pressure of oxygen on entering the lungs is $P_{O_2} = (632 - 47) \times 0.2094 = 122$ mm.

In view of the fatiguing effects of hypoxia in extended operation, adequate partial pressure of oxygen of at least 122-mm Hg should be required Thus, if a total cabin pressure corresponding to 18,000 ft (7.35 psi or 379-mm Hg) is contemplated, a minimum dry volume fraction of oxygen of 37% is necessary to prevent hypoxia: $P_{O_2} = (379 - 47) \times 0.37 = 122$-mm Hg.

Another parameter to be considered is the relative hazard of fire as the oxygen in the atmosphere is increased and the total pressure is reduced. Figure 8 shows the human tolerance envelope of oxygen to total pressure and the relative fire hazard (based on propane minimum ignition energy) between that at sea level pressure (760-mm Hg), 21% oxygen, and 5 psia (258-mm Hg), 100% oxygen. For example, at 18,000-ft-cabin altitude (379-mm Hg) when the oxygen partial pressure is maintained at sea level equivalent, the relative fire hazard increases approximately one-third the difference between that at standard sea level conditions and that at 5 psia, 100% oxygen. It is desirable to maintain as near a standard atmosphere and composition as practicable to minimize the fire hazard. However, from a minimum weight standpoint, it is desirable to go to as low a pressure as practicable and use only oxygen.

Much experimental work has been carried out over several years to define the human comfort zones as to temperature and humidity as shown by the psychrometric chart (Fig. 9a) for sea level conditions.[17] Of importance in maintaining comfort is the effective temperature; i.e., the temperature of saturated air, which at a velocity of 15–25 fpm induces a sensation of warmth or cold as that of the condition being compared. At sea level, the comfort zone effective temperature ranges from a low of 63°F to a high 75°F. Based on the limited experimental data to date from the Mercury program (i.e., Glenn's and Carpenter's flights), the comfort zone for 5 psia, 100% oxygen, has been defined (Fig. 9b). Of interest is the drop in both effective temperature and humidity for comfort. Effective temperatures for comfort range from 55°–64°F, and the humidity lies between 20 and 60%. Much more experimental work is required in this area for long-term space station operations.

As to the partial pressure of carbon dioxide allowable in the atmosphere, the lower the better. Under no circumstances should it exceed 15-mm Hg, which corresponds to a volume fraction of 2% at sea level of $4\frac{1}{2}$% at 18,000-ft-cabin altitude.

For the inert gas of the cabin, it is probably better to use nitrogen than any other inert gas. It has been found that voice pitch changes appreciably if the enrichment of the atmosphere with helium gets as high as 50%.

As far as toxic substances are concerned, there are factors in orbital extra-atmospheric flight which must be kept in mind, since they modify the earth-based notions of toxicity; i.e.,

1) Physical removal from the harmful region is not possible.

2) Data for industrial plants do not apply because exposures are not 40 hr/week or 8 hr/day, but 168 and 24, respectively.

3) Ventilation for air removal and dilution with safe air is not possible, except to a severely limited extent.

4) Pressure of a reduced atmosphere increases evaporation of volatile substances.

5) Rare and unexpected events such as overheating, fire, or explosion convert harmless material to harmful.

Also of prime importance in the requirements for a manned laboratory environment is the amount of time it takes to

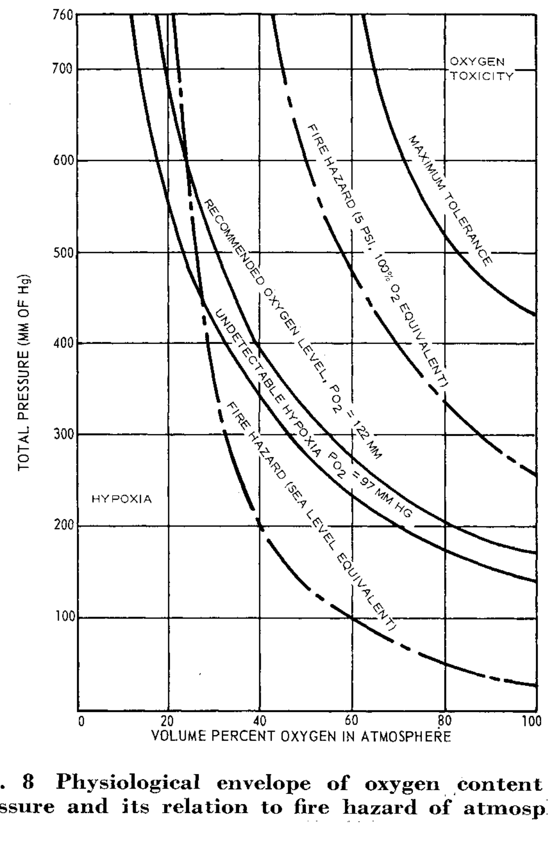

Fig. 8 Physiological envelope of oxygen content and pressure and its relation to fire hazard of atmosphere.

decompress to a pressure requiring a pressure suit as a function of the variables of hole size and initial pressure and volume. Figure 10 is a nomograph for determining decompression time for any size of laboratory with any given pressure, hole size, etc.

Environmental Control Design Considerations

The implementing of the necessary environmental systems can be carried out in a manner contributing to high reliability and reduced cost. Technology for semiclosed-type systems, where no waste material recycling is attempted, is available from current programs. The permanent space station, however, requires a more sophisticated system. This type of vehicle will allow man to live in space for long periods of time and is the first manned space mission in which a closed life-support system is desirable. Provision of this closed life-support system to reprocess waste material and convert these wastes into reusable products requires new and unique concepts in life-support system components and integration methods.

Since an earth orbital space station can be resupplied from earth on a periodic basis, the development of a closed life-support system is not mandatory for mission accomplishment. From the logistics standpoint, however, it is desirable to close as many loops in the life cycle as is possible. This is readily seen by considering resupply requirements for a semiclosed (Apollo-type) environmental control system, which requires approximately 21-lb/man-day. A 10-man crew would require 6300 lb on a 30-day resupply cycle, or 21,000 lb on a 100-day cycle. Such large requirements would impose a continual drain on our national economy by requiring additional boosters, launch complexes, and crews, just to keep the flow of supplies moving.

Figure 11 shows the reduction in these resupply requirements which is obtained for various degrees of closure in the system. Complete conversion of wastes has been assumed to obtain the results shown. This somewhat simplifies the

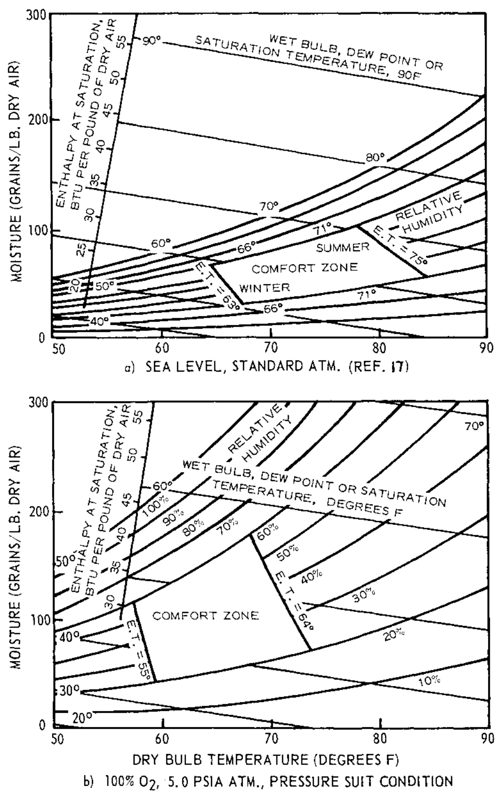

Fig. 9 Psychrometric charts showing human comfort zones; constructed from data resulting from Glenn's and Carpenter's orbital flights.

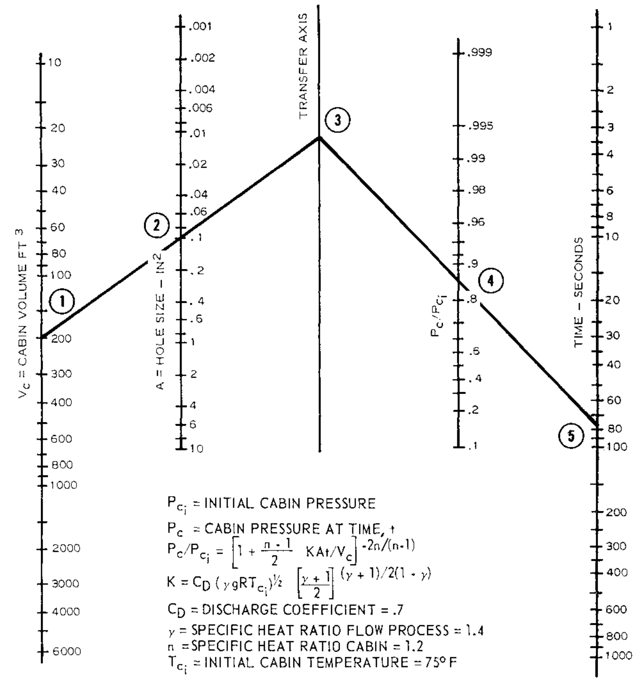

Fig. 10 Nomograph for cabin decompression problems (polytropic decompression).

problem, since 100% efficiency in waste conversion to required supplies is difficult to imagine. The plot does, however, serve to single out the more important areas for closed subsystem development. These areas in the order of their importance are: water supply, CO_2 removal, O_2 supply, food supply, leakage, odor removal, and spares.

Table 3 lists, for each of these areas, concepts that have, or are receiving, development effort.[18–20] In addition, Table 3 indicates the relative status of these concept development efforts. From this table it becomes evident that considerably more component development effort is required in order to achieve the desired degree of waste reconversion in permanent space-station environmental-control systems.

Although development of suitable c'osed-type subsystems can reduce resupply to a negligible problem, this alone does not solve all the problems. The fixed weight and size of the system must also be reduced in order to achieve the maximum gains in space station payload capability. In this area, an item, which is often overlooked, is the dividends available through ingenious installation designs. In Mercury, the mechanical and electrical installation hardware (i.e., brackets, clips, cables, ducts, etc.) represents 26% of the

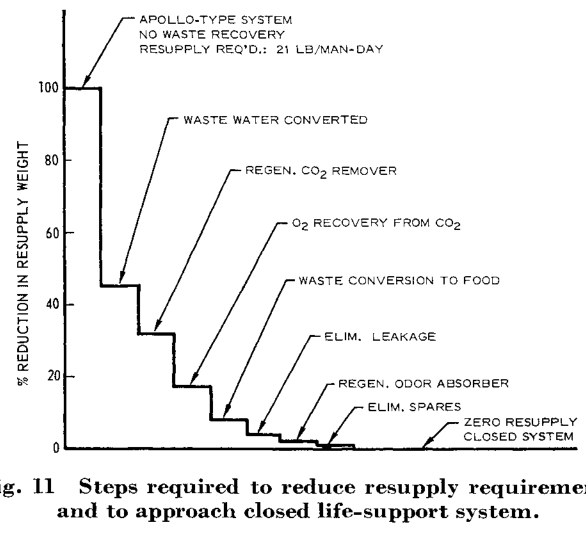

Fig. 11 Steps required to reduce resupply requirement and to approach closed life-support system.

Table 3 Possible methods of providing closure of life-support functions (Refs. 18–20)

Life-support function	Possible subsystem	Development status
Waste water reclamation	Vacuum distillation	Medium
	Compression distillation	Medium
	Filtration and chemicals	Medium
	New developments	Low
CO_2 separation	Molecular sieves	High
	Freeze-out	Low
	Permeable membranes	Low
	Regenerative chemical processes	Medium Medium
	Photosynthesis	Low
Oxygen recovery	Sabatier reaction	
	without H_2 recovery	Medium
	with H_2 recovery	Low
	Direct hydrogenation	Low
	Catalytic decomposition	Low
	Direct electrolysis	Low
	Fischer-Tropsch reaction	Low
	Photosynthesis	Low
Waste reconversion to food supplies	Photosynthesis	Low
Leakage reduction	New techniques	Low
Odor removal	New techniques	Low
Spares reduction	New techniques to achieve longer mean time to failure	Low

total system weight. No single subsystem represents as large a percentage of total system weight. It appears, then, that installation and integration problems should receive extensive development effort in order to define the best over-all space station environmental control system.

One of the more obvious ways to achieve lower-weight installation is to obtain maximum integration of environmental control equipment with other equipment within the space station. For example, couches, seats, structural bulkheads, and tables are required in order for the crew to achieve the desired mission. By ingenious designs, these items can be built up from ECS ducts, heat exchangers, absorbers, etc. Achievement of such integration requires close cooperation between the ECS equipment manufacturers and the space station prime contractor. A design study of this type of integration is needed now in order to provide direction to equipment manufacturers in achieving the desired shapes and sizes of components during the various component development programs.

A philosophy stressing the value of environmental parameters vs costs coupled with improved system integration and excellence in subsystem implementation is important to the provision of simple, reliable, and economical environmental systems for manned space stations.

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