Gaseous Environment Considerations and Evaluation Programs Leading to Spacecraft Atmosphere Selection

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THERE ARE MANY considerations in the selection of the gaseous environment for a manned spacecraft. Generally, these can be divided into two categories; engineering considerations and physiologic considerations. Ideally, the optimum spacecraft atmosphere, from a physiologic point of view, would be one which simulated normal or near normal sea level conditions. Since the present state-of-the-art has not advanced sufficiently to cope with the weight and volume penalty imposed by maintaining such an atmosphere, and since spacecraft decompressions cannot be precluded, compromises must be made which result in the selection of a spacecraft atmosphere that is not the optimum from all considerations, but which is adequate from practical considerations. The purpose of this paper is then: (1) to discuss the considerations involved in the selection of a spacecraft atmosphere, (2) to describe the required investigations to validate the selected atmosphere, (3) to discuss the implications derived from the results of these investigations with comments as to indicated areas of future study, and (4) to present the overall National Aeronautics and Space Administration (NASA) sponsored programs in this area.

ATMOSPHERE SELECTION CONSIDERATIONS

The prime design requirements in any spacecraft system are shown in Table I. From an engineering

TABLE I. LIFE SUPPORT DESIGN REQUIREMENTS

Minimum weight and volume
Minimum Power Usage
Reliability
Ease in maintenance
Environmental Compatability
Integration with other systems
Crew compatability

standpoint, necessary equipment must be provided in the minimum volume with a minimum of weight. Since power usage will affect both the volume and weight of a system, it must be maintained to a minimum. System reliability must be provided to meet the overall mission reliability factor. As the mission time increases, the system must allow the crewman to perform in-flight maintenance and repair. The systems must have the capability of withstanding both the naturally occurring and the induced environmental conditions of space flight; that is, vacuum, acceleration, heat, vibration, et cetera. Last, the system must integrate with other spacecraft systems to allow usage of common supplies and to serve more than one purpose.

In Project Mercury, a 100 per cent oxygen, 5-psia spacecraft atmosphere was selected. Although such physiological considerations as maintaining an adequate oxygen partial pressure and protection against decompression sickness were examined, the decision to use this atmosphere was based primarily on engineering considerations similar to those previously described.

A comparison of the advantages and disadvantages of a single gas, that is, 100 per cent oxygen atmosphere, with a two-gas atmosphere is shown in Table II. From

TABLE II. COMPARISON OF ARTIFICIAL ATMOSPHERES

	5 Psi O_2	3.5 Psi O_2; 3.5 Psi N_2
Engineering Considerations		
Weight	*	
Leakage Rates	*	
System Simplicity	*	
Reliability	*	
Fire Hazard		(*)
Evs Interface	*	
Physiological Considerations		
Dysbarism protection		*
Decompression protection	*	
Atelectasis protection		(*)

* = Advantageous.

an engineering standpoint, the single, gas 100 per cent oxygen at 5-psia, offers advantages in minimizing weight and leakage, in system simplicity and reliability, and in the extravehicular suit interface. From physiological considerations, it can be seen that the mixed gas atmosphere has advantages of offering protection against dysbarism and atelectasis, whereas the single gas atmosphere does afford greater decompression protection. Although ignition temperature as well as burning rates are improved by a multiple gas atmosphere, the hazard reduction is not considered operationally significant in currently planned spacecraft. Therefore, the asterisk denoting the advantage is enclosed in parentheses to indicate the questionability. A fire in any atmosphere within a spacecraft is a very serious matter, and it is for that reason that emphasis on fire prevention has become a primary consideration in design.

There are other considerations, both engineering and physiological, which have not been covered; however, only those considerations of major concern have been discussed.

PHYSIOLOGIC VALIDATION OF ATMOSPHERES

Table II shows that from a physiological standpoint the greatest unknown associated with the selection of a

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mixed gas, 50 per cent oxygen-50 per cent nitrogen, 7-psia atmosphere was that of determining the potential decompression hazard which exists in the event of an inadvertent decompression. Accordingly, a NASA contract was awarded the U. S. Air Crew Equipment Laboratory (ACEL), Philadelphia, Pennsylvania, for the investigation of this potential decompression hazard associated in utilizing this mixed gas atmosphere. Tests were conducted to determine the required time of preoxygenation at sea level to provide adequate protection against bends in the event of an early mission decompression and whether protection against bends can be achieved following a decompression after equilibration to the subject 50 per cent oxygen-50 per cent nitrogen, 7-psia atmosphere. The results of this investigation[1] indicated:

1. That 3 hours of preoxygenation at sea level can provide adequate protection against the onset of bends following a decompression in 40 seconds from sea level to an altitude of 35,000 feet.
2. That without any preoxygenation, 18 hours exposure to the 7-psia, 50 per cent oxygen-50 per cent nitrogen atmosphere is adequate to afford protection against bends following a decompression from this subject atmosphere to an altitude of 35,000 feet in 1 minute.
3. That some screening as to individual susceptibility to bends be incorporated into the astronaut selection program.

The greatest physiological unknown associated with the 100 per cent oxygen, 5-psia atmosphere was that of the potential hazard of atelectasis. It has been generally accepted that pure oxygen at low pressures (190-160 mm. Hg) would present no pulmonary oxygen toxicity problem; however, investigations were required to determine the need of an inert gas in any artificial atmosphere. Accordingly, a comprehensive atmosphere validation program was developed by the NASA Manned Spacecraft Center in cooperation with the National Academy of Sciences Working Group on Gaseous Environment. Both industrial and Department of Defense laboratories were utilized in the program.

TABLE III. ATMOSPHERE PHYSIOLOGIC VALIDATION PROGRAM

Activity	Test Conditions	No. of Subjects
SAM	100% O_2, 5 PSIA 14 Days	6 (3 Test)
	1. Control (sea level) 14 days	6
	2. 100% O_2, 5 PSIA 14 days	6
Republic	3. 100% O_2, 7.4 PSIA 14 days	6
Aviation	4. 100% O_2, 3.8 PSIA 14 days	6
ACEL-AMAL	Launch "G" 100% O_2, 5 PSIA 14 Days Reentry "G"	6

Table III summarizes the entire program. As can be seen, the USAF School of Aerospace Medicine (SAM) carried out three investigations with the 100 per cent oxygen, 5-psia atmosphere in which six subjects were tested.[2,3] Republic Aviation Corporation was awarded a contract to study four groups of six subjects each exposed to 7.4-psia, 5-psia, and 3.8-psia pure oxygen atmospheres, as well as a control test at sea level conditions.[4] In addition, a joint project involving the U. S. Navy Air Crew Equipment Laboratory (ACEL) and the U. S. Navy Aviation Medical Acceleration Laboratory (AMAL) was established to study the combined effects on test subjects of acceleration and a 14-day exposure to a 100 per cent oxygen atmosphere at 5 psia.[5]

In the three investigations conducted under this program, similar experimental protocol, instrumentations, and methods were utilized. In these experiments, emphasis was placed on: (1) determining whether atelectasis occurs in man during continuous exposure to pure oxygen at decreased pressure, and (2) if atelectasis does occur, to determine to what degree, its rates of development and recovery, and whether the condition can be reversed by predetermined respiratory maneuvers. Physiologic assessments of any physical alveolar collapse was obtained primarily through measurement of arterial pO_2 and pCO_2, pulmonary function testing, and chest X-ray examination. In addition to the studies just described, cardiopulmonary studies, measurements relative to renal function, microbiological studies, performance studies, visual studies, and many others were performed in most, if not all, of the investigations.

These investigations are complete and the results are presented in the papers which follow; therefore, no attempt will be made to discuss the results in detail. Briefly, however, the results of these investigations did indicate that, in general, the 100 per cent oxygen, 5-psia atmosphere was well tolerated by all subjects for a 14-day period. Transient, minor difficulties similar to those expected from oxygen toxicity were evidenced in all investigations. These symptoms were restricted to eye irritation, coughing, substernal distress, and aural atelectasis. In addition, in the study made by the Republic Aviation Corporation, some unexpected urinary and hematological findings were encountered and are detailed in reference 4. In the ACEL-AMAL investigation, alterations in the subjects' peripheral vision were evidenced during night adaptation after they were returned to sea level atmospheres from the test atmosphere. The interpretation of significance of all these physiologic alterations has not been fully determined.

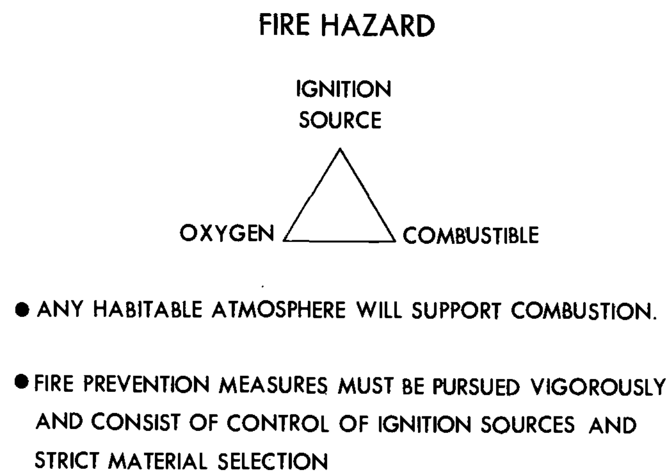
During the performance of this atmosphere validation program, two fires occurred: one at the SAM on the 13th day of a 14-day test, and one at the ACEL-AMAL test on the 17th day of a 20-day exposure test. The 20-day total duration of this investigation was a result of the six subjects entering the chamber on successive days. These fires demonstrated the expected hazard in using a pure oxygen atmosphere and the need for a careful screening of materials and electrical system designs and installations.

IMPLICATIONS DERIVED FROM THE RESULTS OF THE ATMOSPHERE VALIDATION PROGRAM

A 100 per cent oxygen, 5-psia atmosphere had been selected by the NASA for use in the Gemini and Apollo missions. The atmosphere validation program described was conducted for purposes of assessing the physiologic compatibility of this atmosphere for the anticipated mission of 14 days duration. The results of this program demonstrate that the subject atmosphere is generally well tolerated for a 14-day period. The unexpected and as yet unanswered abnormal urinary, hematological, and visual findings do not of themselves preclude the use of this atmosphere for the mission durations tested. The abnormal findings, however, may represent prohibiting factors in the use of the 100 per cent oxygen, 5-psia atmosphere in missions of longer duration.

As a result of the atmosphere selection studies to date, two areas of needed research demonstrate themselves. First, an investigation should be made of the 100 per cent oxygen, 5-psia atmosphere during exposure tests of longer duration (30 days) with special emphasis on those findings which appeared abnormal or questionable in the previous studies. Second, an investigation should be made of the use of other inert gases such as helium in a two-gas life support system.

The fires that occurred during the atmosphere validation program demonstrated the known hazard of a pure oxygen atmosphere; however, it should be pointed out that the inclusion of an inert gas in any spacecraft atmosphere does not eliminate the serious problem of potential spacecraft fires. In other words, any habitable atmosphere will support combustion. As shown in Figure 1 three factors are generally required to produce a



fire: an oxygen-containing atmosphere, a combustible material, and an ignition source. The answer to the fire hazard problem then appears to be one of diligent effort on the part of the spacecraft designers to be aware of the fire problems and to exercise strict control of both potential ignition sources and material selection.

Additional programs are currently being conducted to develop materials specifications which will provide testing procedures to determine potentially hazardous materials, to determine toxic products, and to permit a rigorous screening of materials for spacecraft applications. Exposure tests of longer than 14 days have been scheduled to artificial atmospheres. These exposure tests will extend the knowledge of the physiological effects of a 100 per cent oxygen environment as well as the comparative effects of several gas mixtures. Effects which appeared during the 14-day studies will be further elucidated and investigated during these exposure tests of longer duration.

. Finally, there has been conjecture in the past that two-gas atmospheres are somehow to be preferred over pure oxygen atmospheres in spacecraft. Factual knowledge is inadequate to allow a debate of this question. Within rather broad limits, either can be acceptable, but it has not been demonstrated that either is preferable. If, for long duration missions, a two-gas atmosphere were selected, it is still probable that pure oxygen would be the backup or emergency mode. This is the rationale for the continuing interest in pure oxygen atmospheres.

SUMMARY

The NASA Manned Spacecraft Center has been actively involved in the direction and support of programs leading to the selection and validations of the atmosphere for forthcoming Gemini and Apollo missions. This paper discusses the engineering and physiologic considerations involved and describes the investigations to validate spacecraft atmospheres. The implications derived from the results of these investigations are discussed together with indicated areas of future study.

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