U.S. Air Force Manned Orbiting Laboratory Cabin Atmosphere Research Involving Helium

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The U.S. Air Force (USAF) Manned Orbiting Laboratory (MOL) program was under development from 1963–1969 with the goal of placing two USAF astronauts into Earth orbit onboard a spacecraft for covert reconnaissance. A human research program was established at Brooks Air Force Base, San Antonio, TX, to resolve the medical and life support issues of spaceflights longer than the current NASA missions of 2 wk. The program was canceled on June 10, 1969, as unmanned reconnaissance technology had rapidly developed, rendering the manned mission obsolete. However, many research papers were published by scientists and physicians during the MOL program and still constitute a valuable resource. Considerable effort was directed at developing an acceptable cabin breathing gas mixture for the MOL spacecraft. The goal was to reduce nitrogen (N_2) in the MOL cabin atmosphere to prevent decompression sickness (DCS) during the frequent extravehicular activity that was being proposed. The early research was centered on determining if helium (He) could replace N_2 in the astronauts' cabin atmosphere while in orbit. Research in the early 1960s that was carried out as a part of the Mercury, Gemini, and Apollo programs favored low-pressure (5 psi) 100% oxygen (O_2) as the atmosphere of choice to prevent DCS, and it also allowed for extremely lightweight spacecraft cabin structures (the Apollo program could not have succeeded using the heavier spacecraft that would have been necessary to accommodate a higher-pressure cabin atmosphere). The tragic Apollo 1 fire in January 1967 was followed by a similar fire in a USAF research chamber a few weeks later, leading to the elimination of further designs incorporating 100% O_2 (at this late point, the Apollo program could not be redesigned). The Skylab cabin atmosphere was 70% O_2 and 30% N_2 at 5 psi. The Orion manned spacecraft under development has a cabin atmosphere the same as the International Space Station: 21% O_2 and 79% N_2 at 10.2–14.7 psi. The MOL cabin atmosphere research in the late 1960s continued to be focused on using a mixture of O_2 and He. The results of their work clarified and defined the effects of replacing N_2 with He in the cabin atmosphere to reduce DCS risk.

Although a three-gas cabin atmosphere mixture would have been further investigated during the MOL research, it could not be considered because the technology to make a three-gas mixture was not yet available. Early MOL research found that, during decompression, He was removed from human tissue in half the time compared to N_2 due to its much lower solubility in oil-water,[7,22] promoting the prevention of DCS. Additional physical and physiological properties of the other inert gases reinforced the decision to use an O_2-He breathing gas mixture in lieu of other possible inert gases for the MOL.

The oil-water solubility ratio of He is much less than that of N_2 or argon (see **Table I**), which indicates the relative propensity of those gases to dissolve in human tissue and therefore have a higher potential to produce gas bubbles during decompression.[1–3] Therefore, the heavier inert gases received much less research effort (despite some research showing better flammability suppression) than He as an O_2 diluent (to decrease flammability and O_2 toxicity issues) in the MOL breathing mixture.

The increase in molecular weight of the heavier inert gases would also result in an increase in weight, which means a greater cost for transportation to orbit or any end destination, as well as to maintaining life support while there (see Table I). Helium was selected as the inert diluent gas for the MOL primarily because of substantial weight-saving over N_2-O_2 or 100% O_2 atmospheres.[16,23] A trimix (three-gas) atmosphere was not feasible during the 1960s MOL research due to inadequate control systems, lack of necessary technology, and maintenance requirements. However, N_2 and He could be stored as a 50:50 mixture, and only two types of breathing gas storage containers would therefore be needed for a trimix atmosphere of O_2, N_2, and He. On future long-duration space flights, using a trimix of O_2, N_2, and He could result in a weight savings of 48%.

56-d Exposure Study

Extensive medical and physiological research on the use of He in a breathing mixture and how it affects human physiology performance and safety was conducted during a 56-d hypobaric research chamber study with four male subjects at Brooks Air Force Base, TX, in 1967.[15] The researchers

*Posthumously. This feature is coordinated and edited by Mark Campbell, M.D. It is not peer-reviewed. The AsMA History and Archives Committee sponsors the Focus as a forum to introduce and discuss a variety of topics involving all aspects of aerospace medicine history. Please send your submissions and comments via email to: mcamp@1starnet.com.

DOI: https://doi.org/10.3357/AMHP.6225.2023

Table I. Physical Properties of Gases.[6,17,23]

GAS	ATOMIC NO.	MOLECULAR WEIGHT	WEIGHT kg/m^3	SOLUBILITY IN WATER	SOLUBILITY IN OLIVE OIL	OIL-WATER SOLUBILITY RATIO
Helium	2	4.00	0.454	0.0086	0.015	1.7
Nitrogen	7	28.01	1.251	0.013	0.061; 0.062	5.1; 4.7
Oxygen	8	31.99	1.429	0.003	0.116	?
Neon	10	20.18	1.835	0.0097	0.019	2.1
Argon	18	39.95	1.650	0.026	0.14	5.3

evaluated several physiological parameters during the exposures to 5.0 psi with 70% O_2 and 30% He. No significant medical abnormalities developed that could be directly attributed to the O_2-He mixture at 5.0 psi.[5,25]

Enteric microbial flora remained normal while subsisting on an experimental diet, although the enterococci showed a decrease. The change was not considered of clinical significance and was attributed to the diet and not the gas breathing mixture.[11] Renal function did not change during the study, with the conclusion that the breathing gas mixture and pressure had no adverse effect.[14] Respiration was found to be easier at lower atmospheric pressures, and the ability of respiration to remove He from body tissues during low-to-moderate decompressions was faster than for N_2 or neon.[21] That factor was deemed beneficial, continuing the preference of He as the inert component for the breathing mixture in the cabin atmosphere.[24]

Communication

The addition of He to a cabin atmosphere is well known to degrade verbal communication, and there was concern that this would limit its operational use.

An atmosphere of 56% He and 44% O_2 at 7.2 psi was tested, finding a need for further research because of the higher level of He.[4] Similar issues were found with a 50:50 mixture of O_2 and He.[9] Further studies showed that an O_2 and He environment does not produce a significant impairment in communication.[10] Again, the concentration of He in this research was even higher than the proposed 30%.

It was found that there was a reduction in the relative power of vocal output from breathing air at 7.2 psi. The intelligibility of speech in 30% He at 7.2 psi was found to be about the same as in air, minus a 5-dB speech-to-noise ratio:[18,19,20]

- Word intelligibility in the proposed cabin atmosphere would not, in an operational situation, be significantly different from that in air.
- Most talkers in a cabin atmosphere with an He concentration of 30% would quickly adapt, and fundamental pitch would generally remain relatively unaffected by the gas mixture.
- A mean velocity ratio of 1.16 and a mean second formant ratio of 1.109 were obtained for the 30% He mixture as compared to air in a 14.7-psi atmosphere.
- The effect He on speech is seen to persist after removal from the He environment.
- Talkers in He environments are capable of some adaptation and compensation, but the resultant speech quality will depend on the duration of the exposure and the percent of He in the cabin atmosphere. Speech quality was judged to deteriorate with an increased duration of exposure to the 30% He mixture.

During the 56-d exposure to 70% O_2 and 30% He at 5.0 psi, it was found that speech quality deteriorated with increased duration of exposure. This finding indicated a need for further research on the longer term effects of He exposure at the higher pressure of 7.2 psi.

Flammability and Heat Transfer

Unlike O_2, He is inert and does not contribute to the flammability of breathing mixtures. Its dilution of O_2 aids in the overall suppression of flammability. Research showed that He exhibited the greatest inhibition of burning at any given weight (concentration) of O_2 per unit time.[8] This factor was very important in making He the inert gas of choice for the MOL.

Helium will also transfer heat from areas of higher temperature to areas of lower temperature at a faster rate than N_2 or O_2. However, the effect on thermal equilibrium by replacement of N_2 with He at a pressure of 7.2 psi was found to be small. It was found that increased convective heat loss and subjective chilling occurred in an environment containing He, resulting in the reduction of evaporative water loss.[12,13] This property is beneficial, as He could convectively move heat from overheated electronics, reducing the likelihood of fire. It was verified that He was compatible with the crew, electrical equipment, and safety requirements.[16]

Conclusion

Based on the considerable published data emanating from the MOL atmosphere research, using He in a spacecraft cabin atmosphere would not be a significant problem and would have significant benefits. The National Reconnaissance Office published a summary of the MOL research efforts, which spanned over 5 yr and cost $1.56 billion. Although no MOL-related craft left the Earth during the program, this was not a failure. The multitude of research publications by the hundreds of scientists, physicians, and technicians have provided extensive information on the potential of inert gas atmospheres during space travel and in extraterrestrial habitats of the future.

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