Greider HR, Barton JR. ***Criteria for design of the mercury environmental control system, method of operation and results of manned system operation.*** **Aerosp Med 1961; 32:839–43.**

In this classic paper, engineers from the McDonnell Aircraft Corporation presented a detailed description of the Mercury capsule's life support system before the first U.S. manned spaceflights. Fundamental design considerations included simplicity, redundancy, low weight, and critical delivery time requirements. For this reason, a decision was made early in the design process to use a low-pressure 100% O_2 atmosphere. This was considered necessary as it was less complex than a mixed gas cabin atmosphere, avoided high structural weight, and greatly decreased the cabin leakage rate. The disadvantage was that it made heat removal more difficult. It was also noted that the fire hazard greatly increased with the increase in the O_2 concentration. The physiological pO_2 cabin pressure limits at 100% O_2 were considered to be between 16,000 ft (412 mmHg) and 38,000 ft (155 mmHg). The final cabin atmosphere chosen was 27,000 ft (258 mmHg or 5.0 psi) as this would provide adequate oxygenation and enough barometric pressure to avoid decompression sickness.

The key initial determination was the astronaut metabolic rate, as this drove the requirement for O_2 supply, CO_2 removal, heat removal, food, and water. The design reference mission was for 28 h of orbital flight. From past experiences of crewmembers in pressurized suits on simulated flights, a metabolic rate of 100 cal-kg/h was selected. The O_2 supply was calculated to be 345 cc/min at STP based upon the metabolic rate, a leakage rate of 300 cc/h, and a margin of 155 cc/min. This was provided by two supply tanks with 4 lb of O_2. The CO_2 production was calculated to be 283 cc/min based upon the metabolic rate and a respiratory quotient of 0.82. The lithium hydroxide canister which was used for CO_2 removal was designed to handle 400 cc/min. Charcoal was used to remove trace organics and the cabin humidity was removed by passage through a sponge system that routed the water to a tank. Heat removal was by evaporating water by exposure to vacuum, but that meant there would be no effective heat removal during launch and re-entry when the capsule was below 100,000 ft altitude or after landing. During preparation for blastoff, heat removal and atmospheric control were accomplished through umbilicals to systems on the launch pad.

The solo Mercury astronaut entered the capsule 2 h before launch; first the suit and then the cabin were purged with 100% O_2 at 14.7 psi. Cabin pressure followed ambient pressure until the cabin pressure relief valve closed during launch when passing through 25,000 ft altitude. It opened when passing back through this altitude during re-entry. Biomedical data consisted of two EKG leads, respiratory rate, and core body temperature, but voice communication with the astronaut was considered to be the most important method of determining his physiological well being. Cabin sensors transmitted total pressure and O_2 partial pressure. The electrical supply depended entirely on batteries. The system was designed to operate at multiple G levels: on the ground, during launch, in weightlessness, and during high-G re-entry. All systems were redundant so that catastrophic failure could not result from the failure of a single component.

More than 100 h of manned testing of the life support system were conducted using five test subjects, including a 28-h test at a cabin pressure of 5 psi, during which pCO_2 was maintained below 1 mmHg and the FiO_2 varied from 92–95%. One test simulated an astronaut confined to the capsule for 12 h post-landing with external ambient conditions of 85°F and 85% relative humidity. The test subject's condition remained acceptable, although his heart rate increased to 110 and his core body temperature to 101°F.

Background and Commentary

Although the engineers recognized that there was an increased fire hazard with the high oxygen concentration even at 5.0 psi, they failed to identify the extremely high fire hazard during the oxygen purge at 14.7 psi. A previous study (4) in 1958 had shown greatly increased combustion rates for 100% O_2 even at low pressure and concluded that the safe upper limit for a sealed cabin atmosphere was probably 50% O_2. A subsequent NASA study noted, "Hazard reduction (using a mixed gas atmosphere) is not considered operationally significant in currently planned spacecraft. A fire in any atmosphere within a spacecraft is a very serious matter, so emphasis on fire prevention has become a primary consideration in design" (3). However, another study at about the same time concluded, "Significant oxygen enrichment (greater than 30%) may be achieved safely only by the introduction of a physiologically safe gas that is more dense than nitrogen (such as argon)" (1).

Previous studies had delineated the basic requirements for a sealed cabin (2,5). This represented the first actual U.S. design for a spacecraft life support system and was remarkable in its simplicity. It proved to be extremely reliable and successful. In retrospect, the choice of a low-pressure 100% O_2 cabin atmosphere was unfortunate as this was more dangerous than realized at the time and set the conditions for the later Apollo 1 fire on the launch pad. However, the Mercury capsule probably could not have been designed for a higher pressure as that would have required much greater structural weight. The use of manned testing with a spacecraft prototype was also quite remarkable and resulted in greater design confidence.

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