A Prototype Cryogenic Oxygen Storage and Delivery Subsystem for Advanced Spacesuits

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Future spacesuit systems for the exploration of Mars will need to be much lighter than current designs while, at the same time, reducing the consumption of water for crew cooling. One of the technology paths NASA has identified to achieve these objectives is the replacement of current high-pressure oxygen storage technology in extravehicular activity (EVA) systems with cryogenic technology that can simultaneously reduce the mass of tankage required for oxygen storage and enable the use of the stored oxygen as a means of cooling the EVA astronaut.

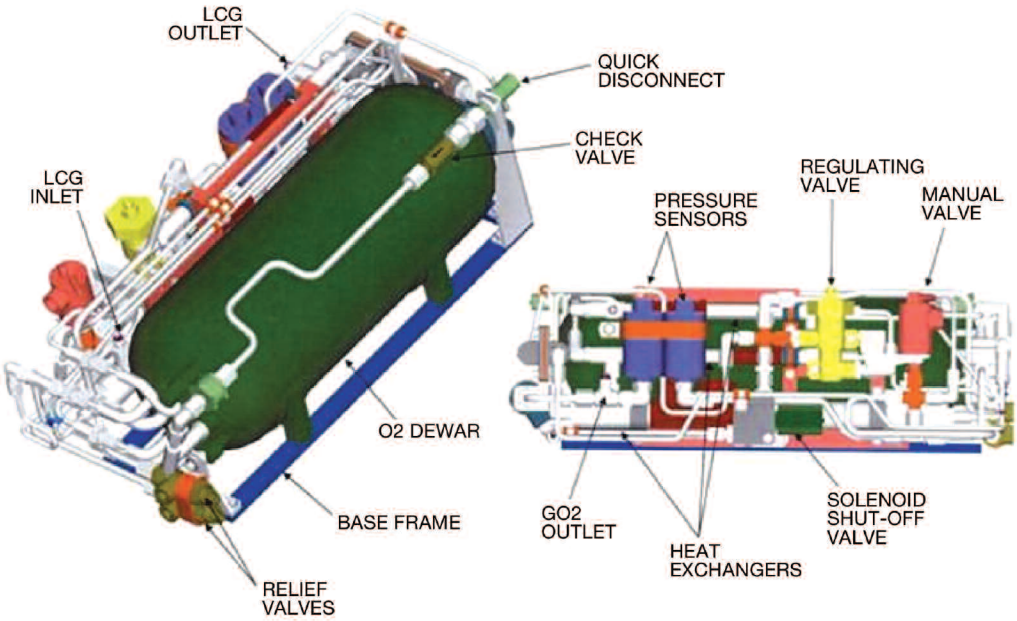

Fig. 1. The Advanced Spacesuit Oxygen Subsystem (ASOS) assembly provides a compact package.

Historic use of cryogenic fluids in human spaceflight systems makes it logical that cryogenic oxygen storage would be a strong candidate technology for advanced EVA system designs, especially for missions such as Mars exploration in which in-situ resource utilization is expected to result in cryogenic oxygen availability as a major element in the mission infrastructure. Interest in this technology option is further strengthened by the possible use of cryogenic oxygen as a heat sink to supplement the capabilities of nonexpendable heat rejection systems (e.g., radiators), eliminating EVA systems' historical reliance on water and the porous plate sublimator as an expendable heat sink. As a result, technology development for EVA cryogenic oxygen storage systems for both microgravity and planetary environments has been actively pursued by NASA's advanced technology experts and their contractors for many years.

The cryogenic oxygen storage and delivery system was developed to:

- Store more than 6.6 lbs of usable oxygen in a compact and lightweight storage vessel
- Deliver the oxygen at a controllable rate between zero and 5 lbs per hour
- Provide an interface pressure of approximately 100 psi over the full range of flow rates
- Evaporate and warm the delivered oxygen using waste heat from the spacesuit's liquid cooling garment
- Operate in any gravity field from microgravity to Earth gravity (1-g) and in any orientation with respect to the gravity vector
- Allow assisted operations using oxygen supplied from a rover or an airlock source

- Support charging from a cryogenic oxygen supply from a warm condition within 60 minutes and allow system recharge while operating
- Provide reliable monitoring capability for the quantity of oxygen available in the dewar throughout EVA missions
- Meet mission requirements after up to 2 hours for EVA preparations after filling with cryogen

In addition, the system was designed to support a representative EVA metabolic profile while maximizing the efficiency of cryogen use and to ensure system safety throughout the anticipated development test program. The metabolic load data were combined with anticipated thermal environments and other system heat loads to derive predicted demands for cryogen flow in addition to that needed for ejector operation and metabolic consumption. The system prototype produced in this study was not required to be human-rated or to support human testing.

A subsystem design implementing this principle of operation includes several major components:

1) A cryogenic dewar containing heat transfer coils.

2) External heat exchangers to thermally condition cryogenic oxygen using heat transferred from circulating liquid cooling garment water.

3) A pressure-regulating valve to control the fraction of delivered fluid passing through the dewar's internal heat transfer coils.

4) A flow restrictor to balance pressure drops between the heat transfer coils and heat exchangers and the bypass loop direct to the subsystem fluid delivery interface.

5) A thermal closing valve to prevent delivery of cryogen or excessively cold gas from the system in the event of a failure or malfunction.

Numerous other components support system fill and drain, provide fluid filtration and pressure relief, and protect against possible failure modes and abnormal operating conditions.

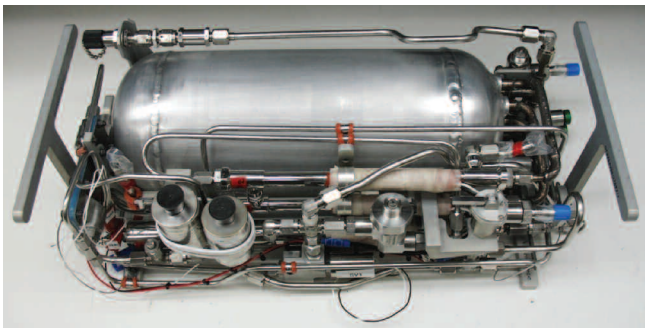

***Fig. 2.** The Advanced Spacesuit Oxygen Subsystem (ASOS) prototype fully assembled.*

Normal oxygen delivery from the system begins with the flow of cryogenic liquid or vapor out of the dewar's discharge port. The total flow passes through a heat exchanger where it is vaporized (as required) and warmed by metabolic waste heat transferred from the liquid cooling garment (LCG). The flow is then split between two flow paths. A portion passes through the flow restrictor and then directly through the system discharge valve and thermal closing valve to the oxygen delivery interface. The remainder flows through one of the heat transfer coils inside the dewar where it is chilled to near the dewar's internal temperature. From there it flows through a second external heat exchanger where it is again heated by the LCG coolant and returns through the dewar in the second internal coil. There it deposits additional heat in the dewar and chills again to near the dewar's internal temperature. The combined heat delivered in both internal heat transfer coils vaporizes sufficient oxygen in the dewar to compensate for the volume of the removed vapor and/or liquid and maintain dewar pressure. After leaving the coil, the oxygen is warmed by LCG coolant in the third external heat exchanger and flows through the pressure-regulating valve before recombining with the remainder of the delivered flow and passing through the system discharge and thermal closing valves.

The ASOS prototype is shown in detail in figure 1, and fully assembled in figure 2.