Long-term Testing of Oxygen Compressors

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Since the inception of human space flight, NASA has dealt with the dilemma of pressurized oxygen systems aboard space vehicles. Oxygen is essential as an atmospheric gas for the crew and, by itself, is relatively benign. Unfortunately, it is also an effective oxidizer capable of rendering most materials flammable. Furthermore, as pressure and temperatures increase (a common occurrence on spacecraft), the flammability of materials in oxygen-enriched atmospheres increases.

To their credit, since Apollo 204, NASA personnel have successfully completed thousands of hours of human space flights without a fatal oxygen fire. Much of this can be attributed to the expensive lessons learned from Apollo 204, Apollo 13, and extravehicular mobility unit (EMU) fires and the resulting investigations. Figure 1 highlights some of this human space flight history including the Apollo launch, the Apollo 204 capsule and crew, an astronaut in an EMU, a fire-damaged EMU, the damaged Apollo 13 service module, and a shuttle launch. Through the investigation process, several test methodologies, reams of data, and methods for applying that data have been developed. NASA White Sands Test Facility (WSTF) personnel continue to add new information to yesterday's data to determine how to safely fly today and how to design safe spacecraft for tomorrow.

As NASA considers options for production and storage of oxygen for current and future spacecraft, it is apparent that the agency must develop a means to safely pressurize oxygen. Pressurized oxygen can be stored in smaller containers, reducing the weight and volume so critical in spacecraft. But, pressurizing oxygen increases the flammability of the materials involved and adds heat energy – a potential source of ignition. However, some of the concepts under consideration for future systems would pressurize the oxygen at a relatively slow rate, minimizing the rate of heating into the system and maximizing the system's ability to dissipate the heat generated. This approach, originally constrained by the rate of the oxygen production systems considered, could allow NASA to pressurize oxygen safely using less power – an added benefit on any spacecraft.

To determine the feasibility of this concept, WSTF personnel performed market research to determine whether commercial off-the-shelf units are available for the pressures and flow rates required to pressurize the airlock tanks on the International Space Station. Two units were acquired that met the operational envelope requirements; these were analyzed for suitability in oxygen systems. Our analysis determined that the materials and design were

Fig. 1. *Highlights of human space flight history.*

suitable, but we could not determine the service life or potential for failure. Furthermore, industry information indicates that when oxygen compressors fail mechanically, there is a good chance an oxygen fire will result.

Since either a mechanical failure or an oxygen fire would be unacceptable in space, WSTF personnel developed a test replicating what would be required on an extended mission by operating the compressors continuously in oxygen until failure (figure 2). The manufacturer's anticipated life is up to 5,000 hours, so the test was automated to prevent personnel having to staff a test console for 208 or more consecutive days.

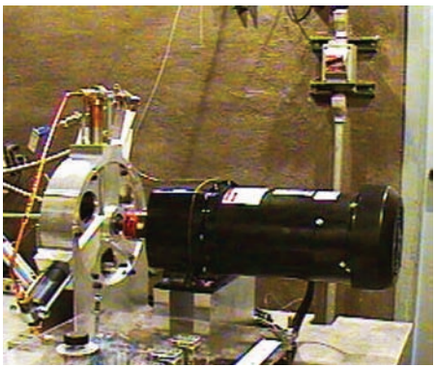

Fig. 2. *Oxygen compressor in test.*

Although automated testing is not new, testing an oxygen component to the point of failure or fire is usually performed with test personnel present. This allows these personnel to use the means necessary to limit the fire damage to the test article and protect the test facility. WSTF personnel determined it is possible to accomplish these goals through appropriate application of the oxygen system design tools that have been developed.

Most of the state-of-the-art oxygen system design tools are contained in *Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operation, and Maintenance* (previously *NASA Safety Standard for Oxygen and Oxygen Systems*, NSS 1740.15), a document maintained for NASA and the American Society for Testing and Materials by WSTF personnel. In the section "Design to Manage Fires," nine guidelines are offered to protect personnel and equipment in case of a fire. Table 1 lists the guidelines and how they applied to the design of this automated test system.

Since the inception of testing, both the test articles and test system have operated safely, continuously, and autonomously for over 1,600 hours. If and when an oxygen compressor fails during testing, WSTF personnel will review the data obtained from the test and use them to guide NASA in safely implementing oxygen compressors in current and future vehicles.

Guideline	System Design
1. Provide for accessible or remote shutoff	Four points of isolation (two valves, two regulators) are controlled from the remote test console. Manual valve is external to test cell.
2. Design for automatic source isolation	Data Acquisition and Control System (DACS) monitors: inlet and outlet pressure and flow, system temperatures, and pump motor current. In the event of an anomaly, the DACS isolates the oxygen source, vents the oxygen in the system, and alerts the test conductor.
3. Ensure easy escape for personnel	See item 4 – no personnel present.
4. Reduce personnel exposure	Test system contained within a concrete test cell; access to cell prohibited during operation.
5. Use remote operation for first use	Remote operation for all operations.
6. Design for fire containment	Concrete cell provides overall containment. Flexible hoses, used to connect test articles to the system, provide fire breaks between the two.
7. Ensure fire extinguishers are available	Remote operation fire deluge system in cell.
8. Minimize flammables near system	Test articles mounted on metal table in concrete cell.
9. Separate bulk storage from the system	Oxygen supplied to test cell via a distribution system with several points of isolation between the source and the test cell.

Table 1. *"Design to Manage Fires" guidelines and design applications.*

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