

Orion Emergency Mask Approach

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ABSTRACT

Human rated space vehicles must provide safe breathing air to the crew, in the event of fire or other upset that affects air quality. In very short missions, like those in Mercury, the crew could remain in their flight suit. As mission duration increased, some sort of emergency breathing apparatus was used to provide safe breathing air in emergency situations. The Orion vehicle has a unique set of emergency breathing apparatus design challenges: the vehicle is small compared to shuttle and station, the vehicle does not have a pressurized supply of breathing air, the vehicle has a 30% oxygen design limit, no airlocks or alternate habitable volumes, and during lunar missions the crew members need to remain in the vehicle for many hours after an emergency. A filtering respirator shows special promise to address the needs of Orion, but a filtering respirator for combustion products has never been built and qualified for space. This paper describes the emergency breathing apparatus needs for Orion and reports the results of some filtering respirator development tests.

INTRODUCTION

Fire on a space vehicle is a highly undesirable event and there are many precautions to

prevent fires. Avionic systems with fault detection and isolation controls, strict materials usage, and oxygen concentration limitations are used as safe guards to prevent fires from starting or propagating. Even with these strict controls, on rare occasions, fires do occur. Incidents such as an overheated wire bundle that pyrolyzes wire insulation before the fault detection and isolation system cuts off the current can create toxic byproducts that may containment the vehicle atmosphere. And when incidents do occur, the Fire Detection and Suppression (FDS) System is required to protect the crew and vehicle from catastrophic failure.

This protection function of the FDS System can be divided into four main functional areas: detection, suppression, post-fire cleanup, and Crew protection. These four functions are reflected by three main Constellation program level requirements:

- Orion shall provide fire detection and suppression for the Orion pressurized volume;
- Orion shall return the Orion pressurized volume to a habitable environment following the contamination of the cabin atmosphere following a fire, toxic release, and docking with

another vehicle that has suffered such an event;

- The system shall provide each member of the crew a contingency breathing apparatus, which provides breathable air that meets the quality specifications defined, etc.

These four functions are the backbone of the FDS System and are required to protect the crew and vehicle from fire emergencies. While this paper is focused on the emergency mask, or the contingency breathing apparatus function of the FDS, an understanding of how Orion is currently meeting the other requirements is important. The way a fire is suppressed or how cleanup is implemented has implications for how the contingency breathing apparatus functions are achieved. So before going into the details of the emergency masks, a quick survey of the rest of the current FDS system will be presented. All information presented will be based on the current configuration of the Orion vehicle before the Orion Preliminary Design Review (PDR).

FIRE DETECTION

Fire detection in microgravity is more challenging than its terrestrial counterpart. In microgravity, the absence of natural convection means that smoke particulates and gas by-products have less transport potential, and solely rely on expansion of hot gas and diffusion. Smoke does not “rise up” and as a result, an externally provided forced airflow is required for quick detection. Typically, having forced airflow is not an issue in any crewed part of the vehicle, as the same forced airflow for fire detection is also required to insure the cabin air is well mixed and pockets of carbon dioxide do not endanger the crew. This leads to the placement of a particulate smoke detector near the ventilation area of the crew cabin, ensuring that smoke from a cabin fire will be quickly detected.

Not all fire events produce a detectable amount of smoke, however; some materials, when pyrolyzed, instead produce a lot of carbon monoxide (CO). So having a CO sensor in conjunction with the particulate smoke detector increases the fire detection accuracy of the crew cabin.

In an area where forced airflow isn't necessary, such as the avionics bay, putting a particulate smoke detector is a hard decision. Forced airflow, while necessary for the crew and beneficial for fire detection, can also help sustain a fire that might otherwise put itself out in microgravity. A fire can quickly starve itself in microgravity without airflow supplying it with oxygen. As a result, the first step after the detection of a fire is to shut down forced airflow to prevent any feeding of the fire, allowing the fire to self-extinguish. As a result, it was decided that in the enclosed avionics bay with no forced airflow, no direct fire detection method was used. Instead, strict materials control will be used and avionic fault detection and isolation system will be the primary way to detect failures that may lead to a combustion event.

FIRE SUPPRESSION

Fire suppression on the Shuttle and ISS composes of pressurized gas system systems using either Halon or carbon dioxide (CO₂), respectively. Neither of the two options was selected for Orion for various reasons.

Halon reacts with the chemical reaction occurring in a fire, stopping the combustion through chemical inhibition. Because of this, Halon systems are extremely effective at fire suppression. However, Halon is also extremely difficult at being removed and has chemical capability issues with certain cabin air trace contaminant control systems. For that reason, ISS restricts Halon use. Every time the Shuttle docks to ISS, trace amounts of Halon are detected in the ISS that comes from the extremely well sealed Halon fire suppression bottles on the Shuttle. This isn't as big of an

issue with the Shuttle that visits Station in 2-week intervals, and only about 5 times a year. However, Orion is planning to be docked with ISS for up to 6 months at a time, which will lead to a lot more Halon leaking into the ISS.

The removal and compatibility issue with Halon is why ISS decided to use a carbon dioxide suppression system. Carbon dioxide is an effective way of suppressing a fire through a combination of chemical reduction and isolation of oxygen. However, for this to be effective, about 30% CO₂ concentration is required, which is above the toxicity level of CO₂ to the crew as well. On ISS, where there is a relative large volume and a method of isolating modules and equipment racks, the crew can move to unaffected modules and CO₂ can be used effectively and safely. In the small-pressurized area environment of Orion, CO₂ use will be extremely difficult from a crew protection perspective.

Just like fire detection, Orion approaches fire suppression differently in the crew cabin area and the enclosed avionics bays. In the enclosed avionics bays, a nitrogen (N₂) suppressant system is used. When discharged, the nitrogen reduces the oxygen level in the avionics bays to a point where a fire cannot be sustained. This, along with strict material control, provides an effective way to extinguish a fire without adversely affecting the crew. Nitrogen is also part of the normal pressure control system; as a result, no additional hardware is necessary in addition to the suppressant itself.

Because of the small crew cabin, a gas suppressant system is difficult to implement inside the crewed volume. Without donning a contingency breathing apparatus first, using a gas suppressant puts the crew in danger of suffocation. In this case, a directed fire suppressant reduces this risk. Generally, a water-based (water foam or water mist) suppressant is most effective as a local fire suppressant and needs to be directed onto the fire itself. A water-based fire suppressant

suppresses a fire through the reduction of heat. Due to the small size of the cabin and the low voltage of the power system, a water foam extinguisher has been chosen as the baseline for the cabin portable fire extinguisher. Water foam extinguisher was also used on Apollo and is currently used on the Russian modules on ISS.

POST FIRE CLEANUP

After a fire event, a cabin cleanup is required to remove any toxic gases generated by the fire allowing the crew to get back into a safe clean environment. Generally this involves a complete purge of the cabin air. This can be achieved either through a continuous purge, cleaning the air through dilution, or a one time complete cabin depressurization and repressurization. The Shuttle, which does not have the ability to vent the cabin complete to vacuum, utilizes a continuous cabin air purge. This is achieved by introducing clean air into the cabin while venting the cabin at the same time, allowing the crew to stay in a short-sleeved environment with a protective breathing mask. While effective, this dilution purging utilizes a lot of consumables, generally on the order of 3 times the cabin volume exchange. Orion, on the other hand, is designed to operate the cabin at complete vacuum, and therefore able to perform a one time complete cabin depressurization and repressurization. While this method utilizes only the amount of consumables necessary to repressurize the cabin, operationally it is more complex, requiring the crew to get into their pressurized space suit to allow for a complete depressurization of the cabin to vacuum.

CREW PROTECTION

Orion's small pressurized cabin volume and resource limitations are important factors in the consideration of the emergency breathing masks. Historically, emergency breathing masks utilize pressurized O₂ systems. Both Shuttle and ISS utilize this type of emergency-breathing mask. On Orion however, the use of