Evaluation of Spacecraft Materials Flammability for the Constellation Program

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We must accurately predict spacecraft materials flammability because of the potentially steep penalties for incorrect assumptions. Correlation of ground 1g materials flammability test data with real-life spacecraft conditions rely on many assumptions. As we look to the future of long-duration space missions, those assumptions are challenged. On long space missions such as for the Constellation Program, fire safety design must take into account unexpected events and changes in environment conditions.

Some emergency events may result in pressure loss and ensuing oxygen enrichment. Examples include depressurization of the crew module (CM) caused by micrometeoroid impact, failed hatch or valve seal, or unforeseen leaks; nitrogen loss due to impact damage or leakage; emergency procedures to enable rescue of a distressed extravehicular activity; and venting the environment to control a spacecraft fire. Many other unexpected circumstances could challenge the space system fire safety design boundaries, such as Environmental Control and Life Support System malfunction or human error when using flammable materials.

A realistic evaluation of fire safety factors for space travel could be possible if rigorous correlations are established between 1g materials flammability qualification tests and data obtained in the ventilated microgravity environments of space systems. Most flammability testing, however, occurs on the ground. One disadvantage of ground testing, even in the anticipated "worst-case" environment per *Upward Flame Propagation Test Document* (NASA-STD-6001 Test 1), is that the qualitative nature of the pass/fail data does not correlate with microgravity data. However, evaluation of extinction boundaries does allow correlation with real-life spacecraft conditions.

NASA White Sands Test Facility (WSTF) proposed materials selection is based on extinction boundary, and is the focus of recent testing.

The Orion system design anticipates situations of varying pressures and oxygen concentrations. The present Orion Crew Exploration Vehicle CM plan is to operate in an atmosphere containing a maximum of 24.1% oxygen at 14.7 psia for missions to the International Space Station, and up to 30% oxygen at 10.2 psia for lunar missions. When the Orion CM returns to Earth, a snorkel device will be activated after splashdown to provide outside air to the crew; however, it is desirable to maximize the time the crew is able to breathe cabin air before the snorkel device is activated. To do so, scientists proposed to raise the oxygen concentration in the CM immediately before re-entry while maintaining the cabin pressure at 14.7 psia. Therefore, NASA needed to determine the oxygen concentration at 14.7 psia where the materials, found acceptable from a flammability point of view in 30% oxygen at 10.2 psia, would still be nonflammable.

WSTF established total pressure-oxygen concentration extinguishment limits to determine safe oxygen concentration levels at increased pressures that will result in extinguishment, even for materials that marginally pass the NASA Standard Test 1 certification requirements. Test results show that the effect of pressure on the oxygen concentration flammability threshold is strongly material dependent (figure 1). In the range of 7 to 17.3 psia, the

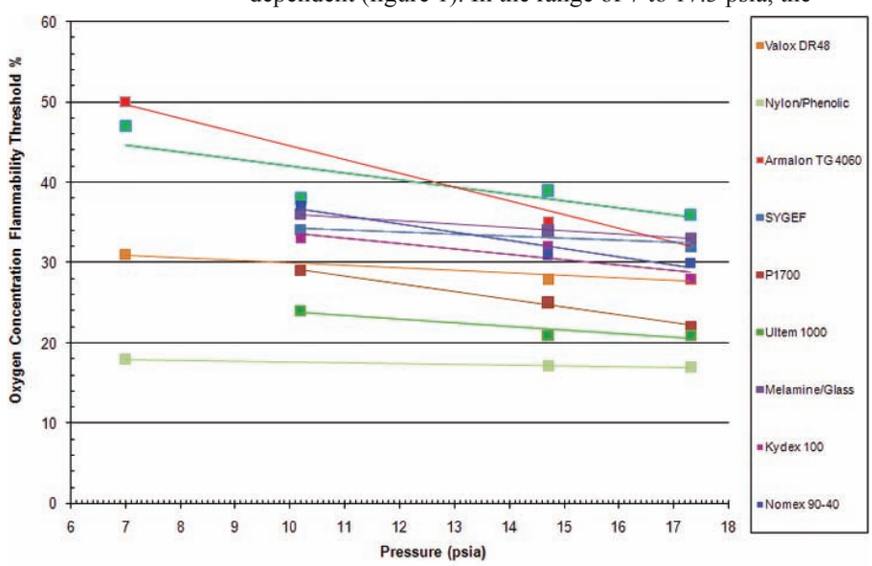

Fig. 1. *Maximum oxygen concentration flammability limits of materials at various total pressures.*

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oxygen concentration flammability threshold shows a near-linear dependence on total pressure, a finding that confirms previous data. Test results indicate that the oxygen concentration for the Orion CM at 14.7 psia cannot be set higher than 25.6% without invalidating the materials flammability certification for some materials established by NASA Standard Test 1. Data also indicate that materials certified in 30% oxygen at 10.2 psia would still be self-extinguishing in ambient air at 17.3 psia, the pressure intended to leak-check the CM.

To minimize the uncertainty of evaluating pressure-related effects on the oxygen concentration flammability threshold, we recommend that flammability threshold testing for Constellation materials be conducted at 14.7 psia, the highest operational space systems pressure. To determine the confidence intervals for the data, a study characterizing the precision of the proposed method would be advantageous.

WSTF's extinction boundary approach was followed by the NASA Glenn Research Center for tests performed in ventilated microgravity environments. Preliminary results on thermally thin fuels indicate that in certain ventilated environments, the fuels burned in microgravity at lower oxygen concentrations than they did using the NASA Standard Test 1 protocol. Further studies will be conducted to determine proper flammability safety factors for adequate selection of aerospace materials. Included on the horizon are plans at WSTF to conduct more studies of flammability thresholds at various pressures and in microgravity, lunar, and martian reduced-gravity environments under both stagnant and flowing conditions.

Evaluating the flammability threshold allows the option of selecting better, or best, aerospace materials as opposed to just "acceptable" aerospace materials from a flammability point of view. The net result will be an increase in space systems fire safety.

For more information and a fully referenced paper on this subject, see "Some Aspects Related to the Assessment of Space Systems Materials Flammability" by Hirsch et al., in *Proceedings of the 3nd IAASS Conference "Space Safety in a Global World,"* Rome, Italy, October 2008.

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