Buoyant Effects on the Flammability of Silicone Samples Planned for the Spacecraft Fire Experiment (Saffire)

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and

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*USRA, Cleveland, OH*

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Outline

• Motivation
• Saffire Project
• Silicone Samples
• Facilities
• Results
• Residue Analysis
• Discussion and Model
• Summary and Conclusions
Research Motivation

• Fire can be a catastrophic hazard for the manned space flight program
  • ISS and S&MA community recently counted 516 discrete flammable items
  • Increase of 40% over 3 years
  • Bungees, plastic Ziplocos, paper, and packaging

• For NASA material testing, the assumption has been that materials will burn more readily in 1-g compared to microgravity

• However, flame spread behavior in low-gravity is substantially different than in 1-g

• Low-speed air flow has a major influence on material flammability
• Upward flame spread test
• Failed test if sample material is consumed past 15 cm
• 1-g upward flame spread is assumed to be worst case for flammability
• Some materials have shown downward flame spread to be worse
• Other figures of merit: MOC; ULOI
Saffire Project

- Spacecraft Fire Experiment
- Study microgravity flame spread
- Saffire I and III will study large sample
- Saffire II will study 9 small samples
Saffire Operations Concept
Silicone Samples

- 4 of 9 small samples on Saffire II will be Silicone
  - Polydimethylsiloxane (PDMS)
  - C\textsubscript{2}H\textsubscript{6}OSi
- Practical applications on ISS
  - Grips for spacesuit gloves
  - Microprocessor covers
- Flammability limits near expected test atmosphere
- Obtained different burn lengths for different thicknesses

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>MOC</th>
<th>ULOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>22</td>
<td>23.4</td>
</tr>
<tr>
<td>0.61</td>
<td>20</td>
<td>22.8</td>
</tr>
<tr>
<td>0.36</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>0.25</td>
<td>18</td>
<td>19.7</td>
</tr>
<tr>
<td>0.10</td>
<td>17</td>
<td>17.5</td>
</tr>
</tbody>
</table>

The maximum oxygen concentration and upward limiting oxygen index (in percent O\textsubscript{2}) for five thicknesses of silicone fuel [from Hirsch et al.] The chemical igniter provided 3000 J in 25 ± 5 s.
Test Facilities: Large Enclosure

- Most tests conducted in material flammability test chamber
- Unsealed enclosure ~ 1 m³ in size attached to room exhaust
- Hot wire igniter
  - 29 AWG Kanthal™
  - 3.8 amps for 8 seconds (92 W)
Test Facilities: Forced Flow Addition

• 5 lateral 7.5-cm diameter muffin fans
• Flow straightened by 1.5-cm thick honeycomb mesh
• Up to 2 m/s flow
Test Facilities: Sealed Chamber

- Used to vary oxygen concentration
- Gas flow (from pressurized bottles) between 0 and 30 cm/s achievable
- Chamber: 20-cm inner diameter
- Samples were 10-cm tall by 5-cm wide
Results: Upward Spreading Buoyant Flow

- 3 of the 4 thicknesses ignited
- Every thickness that ignited has at least 1 sample that self-extinguished

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Burn Length* (cm)</th>
<th>Burn Time* (s)</th>
<th>Spread Rate* (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>27.5</td>
<td>52.7</td>
<td>5.2</td>
</tr>
<tr>
<td>0.36</td>
<td>14.8</td>
<td>51.0</td>
<td>2.9</td>
</tr>
<tr>
<td>0.61</td>
<td>7.6</td>
<td>60.8</td>
<td>1.2</td>
</tr>
<tr>
<td>1.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

* Values represent the average of 6 tests for each thickness
# Results: Downward Spreading Buoyant Flow

- 2 of the 4 thicknesses tested ignited
- Every sample that was ignited burned the full length
- Significantly slower than upward flame spread

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Burn Length* (cm)</th>
<th>Burn Time* (s)</th>
<th>Spread Rate* (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>30.0</td>
<td>295.7</td>
<td>1.0</td>
</tr>
<tr>
<td>0.36</td>
<td>30.0</td>
<td>539.4</td>
<td>0.6</td>
</tr>
<tr>
<td>0.61</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

* Values represent the average of 6 tests for each thickness
Results: Angled Spreading Buoyant Flow

- Horizontal flame spread burned similar to downward flame spread
- Some angles for the 0.36-mm samples allowed complete burning

<table>
<thead>
<tr>
<th>Angle (deg)</th>
<th>Burn Length (cm) (0.36-mm thick)</th>
<th>Burn Length (cm) (0.61-mm thick)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>30.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60</td>
<td>30.0</td>
<td>9.5</td>
</tr>
<tr>
<td>75</td>
<td>30.0</td>
<td>9.9</td>
</tr>
<tr>
<td>80</td>
<td>15.8</td>
<td>9.4</td>
</tr>
<tr>
<td>90</td>
<td>14.8</td>
<td>7.6</td>
</tr>
</tbody>
</table>

* Values represent the average of 6 tests for each thickness
Results: Forced Flow

- Forced flow enhanced flame spread
- Samples could not ignite in the downward configuration under forced flow
- For samples ignited downward without flow, the flames were blown off almost immediately when forced flow was applied

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Burn Length (cm)</th>
<th>Burn Time (s)</th>
<th>Burn Velocity (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.36</td>
<td>30.0</td>
<td>88.6</td>
<td>3.4</td>
</tr>
<tr>
<td>0.61</td>
<td>30.0</td>
<td>198.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>

* Values represent the average of 6 tests for each thickness
Results: Upward, Downward and Forced Flow

- 1-mm thick sample did not ignite in air
- Forced flow increased burn length and upward spread rate for 0.61, 0.36 and 0.25-mm samples
- Samples in upward configuration that were burning under forced flow self extinguished after forced flow was shut off
Results: Maximum Oxygen Concentration

- Oxygen concentrations from 17% to 26% were examined

* Values represent the average of 3 tests for each thickness
Residue Analysis: TGA

- Thermo-Gravimetric Analysis
- 10° C increase per minute
- Post burn analysis of 0.61-mm sample
- Mass loss in 4 different areas
- Original fuel and undamaged silica covered fuel produced same mass loss curve
Residue Analysis: SEM and EDS

- Energy Dispersive X-ray Spectroscopy (EDS) performed on the deposit from an upward burning 0.36-mm sample post test
- Only silicon and oxygen detected leading to assumption the deposit was SiO$_2$ (silica)
- Scanning Electron Microscope (SEM) image of same sample post burn
- ~ 0.3 mm of silica deposit

SEM images. (a) SiO$_2$ layers formed on both sides of the originally 0.36-mm-thick silicone sample after an upward burn. (b) SiO$_2$ layer 286 μm thick was formed over the silicone sample.
Discussion and Model

- Flame spread model from Markstein and de Ris
- Critical heat flux needed to raise thermal inertia of half the thickness of a sample plus silica deposit
- Dashed line represents half 0.36-mm sample with 286 µm of silica deposit

\[
q'' = \left[ (\rho_s c_{p,s} \frac{\delta_s}{2}) + (\rho_{SiO_2} c_{p, SiO_2} \delta_{SiO_2}) \right] \frac{(T_{ign} - T_\infty)}{\tau}
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_s ) (kg/m³)</td>
<td>970</td>
</tr>
<tr>
<td>( C_{p,s} ) (J/kg-K)</td>
<td>1050</td>
</tr>
<tr>
<td>( \rho_{SiO_2} ) (kg/m³)</td>
<td>2600</td>
</tr>
<tr>
<td>( C_{p, SiO_2} ) (J/kg-K)</td>
<td>1591</td>
</tr>
<tr>
<td>( T_{ign} ) (K)</td>
<td>673</td>
</tr>
<tr>
<td>( T_\infty ) (K)</td>
<td>293</td>
</tr>
<tr>
<td>( \tau ) (s)</td>
<td>55</td>
</tr>
</tbody>
</table>

Legend:
- **0.25mm**
- **0.36mm**
- **0.61mm**
- **1 mm**
- **No Burn Limit**
Analysis Conclusions

• There is a critical heat flux needed to raise the temperature of silicone to the pyrolysis temperature and continue flame spread
• Silica deposits downstream onto silicone sample
• Flame uses energy to heat silica, has less energy for pyrolysis of sample
• Angled configuration and forced flow tests results support this hypothesis
• Other possible mechanisms for extinction:
  • Deposit layer could be acting as a physical barrier to mass transfer
  • Could affect flame stabilization zone or flame standoff distance
  • Emissivity of silica layer could be higher than silicone producing greater heat loss
• As silicone burns upward, silica deposits downstream

• If the silicone is ignited in the downward configuration, it burns the entire length of the sample

• Burning upward at an angle increases the burn length in some cases possibly due to less silica deposition

• Forced flow in the upward burning case increases flammability, likely due to an increase in convective flow preventing silica from depositing

• Samples in upward configuration burning under forced flow self extinguish after forced flow is removed
Questions


Results: Angled Spreading Buoyant Flow

- Horizontal flame spread burned similar to downward flame spread
- Some angles for the 0.36 mm aloud the sample to burn to completion

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Thickness (mm)</th>
<th>Burn Length (cm)</th>
<th>Burn Time (s)</th>
<th>Burn Velocity (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>0.25</td>
<td>30.00</td>
<td>287.34</td>
<td>1.04</td>
</tr>
<tr>
<td>Horizontal</td>
<td>0.36</td>
<td>30.00</td>
<td>530.87</td>
<td>0.57</td>
</tr>
<tr>
<td>Horizontal</td>
<td>0.61</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>60 degree upward</td>
<td>0.36</td>
<td>30.00</td>
<td>141.89</td>
<td>2.11</td>
</tr>
<tr>
<td>60 degree upward</td>
<td>0.61</td>
<td>9.53</td>
<td>93.23</td>
<td>1.02</td>
</tr>
<tr>
<td>75 degree upward</td>
<td>0.36</td>
<td>30.00</td>
<td>103.00</td>
<td>2.91</td>
</tr>
<tr>
<td>75 degree upward</td>
<td>0.61</td>
<td>9.86</td>
<td>83.00</td>
<td>1.19</td>
</tr>
<tr>
<td>80 degree upward</td>
<td>0.36</td>
<td>15.80</td>
<td>55.00</td>
<td>2.87</td>
</tr>
<tr>
<td>80 degree upward</td>
<td>0.61</td>
<td>9.43</td>
<td>72.94</td>
<td>1.29</td>
</tr>
</tbody>
</table>
Residue Analysis: TGA

- Thermogravimetric Analysis
- Post burn analysis of 0.61 mm sample
- Mass loss in 4 different areas
- Original fuel and undamaged silica covered fuel produced same mass loss curve
- 10 degrees a minute
Residue Analysis: TGA

- Thermogravimetric Analysis
- Post burn analysis of 0.61 mm sample
- Mass loss in 4 different areas
- Original fuel and undamaged silica covered fuel produced same mass loss curve
- 10 degrees a minute
Conduct stakeholder review of the objectives and mission concept
- March 2015

Evaluate design concepts to define science requirements
- Interim Concept Review in November 2015

Develop breadboards and final design
- December 2015 – September 2016 (re-use of Saffire-I, II, III)

Manufacturing
- October 2016 – May 2017

Assembly and Test
- June 2017 – May 2018 (staggered test of IV, V, and VI)

Launches
- Saffire-IV: September 2018
- Saffire-V: March 2019
- Saffire-VI: September 2019

Plans will be submitted in PPBE17
# Prioritization of Objectives

<table>
<thead>
<tr>
<th>Objective</th>
<th>Est Priority</th>
<th>Comment</th>
<th>Stakeholder Priority?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Post-fire monitoring</strong></td>
<td>1</td>
<td>Demo of prototype flight hardware; specified in Program Resource Guidance</td>
<td>5</td>
</tr>
<tr>
<td>Fire behavior/modeling</td>
<td>2</td>
<td>Require to validate model development</td>
<td>1</td>
</tr>
<tr>
<td>Fire behavior/modeling</td>
<td>2</td>
<td>Required for model development</td>
<td>1</td>
</tr>
<tr>
<td>Fire growth/dynamics</td>
<td>3</td>
<td>More realistic configurations</td>
<td>2</td>
</tr>
<tr>
<td>Fire growth/dynamics</td>
<td>4</td>
<td>Elevated O₂, lower P; compare with Saffire-I, II, III; supplement small-scale tests in CIR</td>
<td>3</td>
</tr>
<tr>
<td>Fire growth/dynamics</td>
<td>5</td>
<td>Continue Saffire-I and III</td>
<td>4</td>
</tr>
<tr>
<td>Fire detection</td>
<td>6</td>
<td>Required for model development</td>
<td>5</td>
</tr>
<tr>
<td>Fire detection</td>
<td>6</td>
<td>Reject nuisance alarms</td>
<td>5</td>
</tr>
<tr>
<td>Fire detection</td>
<td>6</td>
<td>Combustion product detection by prototype CPM</td>
<td>5</td>
</tr>
<tr>
<td>Post-fire monitoring</td>
<td>6</td>
<td>Required for model development; get with Objective 9 but only natural decay</td>
<td>5</td>
</tr>
<tr>
<td>Post-fire cleanup</td>
<td>7</td>
<td>Demo of prototype flight hardware</td>
<td>6</td>
</tr>
<tr>
<td>Fire suppression</td>
<td>8</td>
<td>Effectiveness of fire ports</td>
<td>7</td>
</tr>
</tbody>
</table>
Advanced Exploration Systems
WBS 067463 - Spacecraft Fire Safety Demonstration

GRC Project Manager: MX/Gary A. Ruff
GRC Chief Engineer: LA/Lynn Capadona
GRC Chief Safety Officer: QER/Bill Schoren
GRC Lead System Engineer: LSB/Karen Weiland
GRC Resource Integration: MX/Thomas Acquaviva

Project Mission Statement:
Develop and conduct a large-scale fire safety experiment on an International Space Station resupply vehicle after it leaves the ISS and before it re-enters the Earth’s atmosphere.

GRC Scope:
• Project leadership
• Design, fabricate, and operate the large-scale low-gravity fire safety experiment

Project Life Cycle Schedule

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Continuation Review</th>
<th>ATP</th>
<th>MCR/SRR (Unit 1,2,3)</th>
<th>PTR-1 (Unit 1,2,3)</th>
<th>Safety $\phi$ I / II (Unit 1,2,3)</th>
<th>Continuation Review</th>
<th>PTR-2 (Unit 1,2,3)</th>
<th>Continuation Review</th>
<th>Safety $\phi$ III (Unit 1)</th>
<th>SAR (Unit 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milestones</td>
<td>Continuation Review</td>
<td>ORR (Unit 1)</td>
<td>Launch (Unit 1)</td>
<td>Safety $\phi$ III (Unit 2)</td>
<td>ORR (Unit 2)</td>
<td>Launch (Unit 2)</td>
<td>Safety $\phi$ III (Unit 3)</td>
<td>ORR (Unit 3)</td>
<td>Continuation Review</td>
<td>Launch (Unit 3)</td>
</tr>
</tbody>
</table>

FY15 Budget ($K): $7,308
FY15 FTEs/WYE: 32.3/14.0
Phase: D (System AI&T, Launch, and Check-out)
Project start/end: 10/1/2011 – 9/30/2017
Combustion

- Our primary energy source (85%)
- A catastrophic hazard for the manned space flight program
- The reality is that substantial improvements in the quality of life in space or here on earth will require improvements in our ability to predict and control combustion.
- High-efficiency, low-emission flames can be near limit, which are unstable, where kinetics are important
- Demonstration that flame spread behavior in low-gravity is substantially different from 1-g
- Invalidation of the prevalent assumption that 1-g is always a worse case than low-g
- Demonstration of the significance of low speed air flows on material flammability.

- **Materials Combustion**
  - Burning and Suppression of Solids (BASS), 2012, MSG
  - Flammability Assessment of Materials for Exploration (FLAME), CIR
Ignition at the middle of the sample:

• Flame spreads upstream, however, in the shape of a fan.
• With an increase in the incoming air flow velocity, the fan angle increases due to an increase in oxygen supply rate.
• This is completely contrary to normal gravity
• An unpredicted and presently unexplained smoldering pattern was observed in thin cellulose.
The Burning and Suppression of Solids Experiment (BASS) – 2012
in process now

Recent Results:
With BASS we can measure material flammability in microgravity to compare with normal gravity flammability. NASA-STD-6001 Test # 1. Results to date indicate that Test 1 is not conservative, and materials can burn at lower oxygen levels in microgravity than on Earth.
BASS also assesses the effectiveness of $N_2$ inert extinguishing agent in putting out flames over different materials, geometries, and flow. Results to date indicate that local application of suppressant is not adequate to fully extinguish the flames. The local jet entrains air and sustains the flame even when the ambient air flow is turned off.

Relevance/Impact:
Spacecraft fires are a significant risk factor for human exploration. Understanding material flammability and suppression in actual spacecraft environments relative to 1g materials screening is needed to mitigate this risk. The PMMA material burned in BASS is being considered for MPCV windows. JSC was surprised that this thick sample ignited easily and burned well in air. Ground-based drop tower testing provides some data, but long-duration microgravity data is needed to study flammability limits for all but the thinnest films.
Flammability Assessment of Materials for Exploration (FLAME)

**Objective:**
- To study and characterize ignition and flammability of solid spacecraft materials in practical geometries and realistic atmospheric conditions

**Relevance/Impact:**
- Improve EVA suit design
- Determine safer selection of cabin materials and validate NASA materials flammability selection 1-g test protocols for low-gravity fires
- Improve understanding of early fire growth behavior
- Validate material flammability numerical models
- Determine optimal suppression techniques for burning materials by diluents, flow reduction, and venting

**Development Approach:**
- Develop FLAME facility (CIR insert and avionics) to support multiple solid-material combustion and fire suppression studies
- Utilize Combustion Integrated Rack (CIR)
- Support multiple investigations using common infrastructure:
  - Common interfaces and flow control
  - Removable test sections and sample holders
  - Removable ignition system

**ISS Resource Requirements**

<table>
<thead>
<tr>
<th>Accommodation (carrier)</th>
<th>CIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upmass (kg)</td>
<td>250 kg</td>
</tr>
<tr>
<td>(w/o packing factor)</td>
<td></td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>0.50 m³</td>
</tr>
<tr>
<td>(w/o packing factor)</td>
<td></td>
</tr>
<tr>
<td>Power (kW)</td>
<td>0.75 kW</td>
</tr>
<tr>
<td>(peak)</td>
<td></td>
</tr>
<tr>
<td>Crew Time (hrs)</td>
<td>8 hrs</td>
</tr>
<tr>
<td>Crew Time (hrs)</td>
<td>8 hrs</td>
</tr>
<tr>
<td>- Initial configuration of CIR Rack</td>
<td></td>
</tr>
<tr>
<td>- Change-outs during experiment</td>
<td></td>
</tr>
<tr>
<td>Autonomous Ops (hrs)</td>
<td>200 hrs</td>
</tr>
<tr>
<td>Launch/Increment</td>
<td>Inc. 55</td>
</tr>
</tbody>
</table>

**Project Life Cycle Schedule**

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Kickoff</th>
<th>SCR</th>
<th>RDR</th>
<th>PDR</th>
<th>CDR</th>
<th>VRR</th>
<th>Safety</th>
<th>SAR</th>
<th>Ship</th>
<th>Launch</th>
<th>Ops</th>
<th>Ops End</th>
<th>Report</th>
</tr>
</thead>
</table>

**FLAME PI's:**
- Subrata Bhattacharjee, San Diego State University
- Sandra Olson, NASA Glenn Research Center
- James T’ien, Case Western Reserve University
- Carlos Fernandez-Pello, University of California, Berkeley
- Fletcher Miller, San Diego State University

**PS:** Paul Ferkul, NCSER

**PM:** Mark Hickman, GRC

**Engineering Team:** GRC in-house team

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Revision Date: 3/27/12
Most U.S. agencies responsible for large transportation systems conduct full-scale fire tests to address gaps in fire safety knowledge and prove equipment and protocols.

Objective:

- Advance spacecraft fire safety technologies identified as gaps by the Constellation Program and in the Exploration Technology Roadmaps
- Demonstrate their performance in a large-scale, low-gravity spacecraft fire safety test aboard an unmanned re-entry vehicle
  - Demonstration of the operational concept could allow future experiments to investigate fire detection and suppression equipment and protocols.

Relevance to Human Space Flight:
The material flammability questions to be addressed in this experiment were identified during the design of the ECLS system for Orion, Altair, and Lunar Surface Systems
- Addresses knowledge gaps that must be resolved for assured protection of a spacecraft from fire hazards

Cut-away of the Automated Transport Vehicle (ATV). The large-scale experiment could be conducted in one of the standard payload racks.
Saffire Overview

Needs:

- Low-g flammability limits for spacecraft materials
- Definition of realistic fires for exploration vehicles
  - Fate of a large-scale spacecraft fire

Objectives:

- **Saffire-I**: Assess flame spread of large-scale microgravity fire (spread rate, mass consumption, heat release)
- **Saffire-II**: Verify oxygen flammability limits in low gravity
- **Saffire-III**: Same as Saffire-I but at different flow conditions.

- Data obtained from the experiment will be used to validate modeling of spacecraft fire response scenarios
- Evaluate NASA’s normal-gravity material flammability screening test for low-gravity conditions.
Cygnus approaching ISS

Unpack cargo, reload with trash

Proposed location of the SFS Demo experiment (back of vehicle)

Check-out SFS Demo experiment
**Issues**

**Trash packing**

- Based on input from Orbital, we anticipated that Cygnus packing for re-entry would be similar to launch
  - Developed a Payload Integration Agreement to prevent stowage near the Saffire inlet and outlet
Issues
Trash packing

- Actual trash packing is not quite so organized
  - Impacts air mixing and oxygen availability for Saffire

- Project has discussed this with Orbital and begun discussions with our Payload Integration Manager with ISS
Silicone Samples

• 4 of 9 small samples on Saffire will be Silicone

  • Silicone is a very simple option for burning on the second flight of the Saffire project. It has practical application in space such as covering for camera microprocessors and for grips for space suit gloves. The silicone samples that are being proposed are readily available in various thicknesses which will make it easy to test thickness effects on flammability in microgravity. It has been studied extensively on the ground, with a thickness that is right on the border of passing NASA Standard 6001 Test 1 (self-extinguish before 6 inches)[1]. It is solid and non-porous, giving it great structural integrity. The MSDS and material properties are readily available and understood.

  • Silicone has been tested in a 1-G environment using the NASA STD-6001 Test #1 experiment. Five thicknesses have been testing and three thicknesses are close to the limit. The .04” thickness does not ignite, while the .024” and .014” on average pass Test 1. .01” and .004” thicknesses do not pass Test 1 in any of the trials. Figure 1 demonstrates an “S” curve, which gives the probability of a sample to pass Test 1 against a certain variable. Tables 1 through 4 show the specific results below.

  • If the Silicone, especially the .014” thickness, burns greater length in microgravity, it could prove that Test 1 is not a conservative test and needs to be re-evaluated. The MOC for the same thicknesses of silicon has been tested by Hirsch [2]. It would be interesting from a scientific point of view to see if the MOC changes once in microgravity. The .014” thick Silicone sample also burns downward without self-extinguishment, showing it could possibly be more flammable in microgravity than 1-G.

  • The purpose of the experiment will be to test silicone thicknesses that are near the limit of passing NASA STD-6001 Test 1 in air at 1-G. Then by picking a thickness above the flammability limit and below the flammability limit, the effect of 0-G on thickness of material can be determined. The length of the burn, and whether the material passes Test 1 can be compared for 1-G vs. 0-G, along with the burn rate. The proposal is to burn a sample of the .024”, .14” and .01” thicknesses of the silicone samples.
Silicone Samples

• 4 of 9 small samples on Saffire will be Silicone
  
  • An effort to determine the thinnest sample that can pass Test 1 has been complete and the data is shown below. Testing that thickness and others near the limit will help determine the conservatism of Test 1 in microgravity. The samples take approximately 1 minute to burn in 1-G so microgravity results using drop towers and parabolic flights would not be an option. MOC and ULOI data for these samples exist, which can be compared to the results obtained in microgravity.

  • The samples to be tested are thermally thin, meaning the thickness of the material determines its flammability. The silicone samples are simple in nature, making it easy to find their thermophysical properties, and the MSDS from the supplier is readily available.

  • The stakeholders for this experiment are the scientific community that researches combustion and flammability, along with the spacecraft engineers who determine which materials are safe for microgravity. This experiment can satisfy both types of stakeholders by comparing ground data to microgravity data, and by testing the conservatism of tests used to select spacecraft materials.

<table>
<thead>
<tr>
<th>Thickness</th>
<th>MOC</th>
<th>ULOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00 mm</td>
<td>22</td>
<td>23.4</td>
</tr>
<tr>
<td>0.61 mm</td>
<td>20</td>
<td>22.8</td>
</tr>
<tr>
<td>0.36 mm</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>0.25 mm</td>
<td>18</td>
<td>19.7</td>
</tr>
<tr>
<td>0.10 mm</td>
<td>17</td>
<td>17.5</td>
</tr>
</tbody>
</table>

The minimum oxygen concentration and upward limiting oxygen index in percent mole (balanced with nitrogen) for five thicknesses of silicone fuel, as studied by Hirsch et al. The chemical ignition provides approximately 3000 J for a duration of 25 ± 5 s.