Development for Fire Safety Technology for NASA's Exploration Mission

2007 Annual Fire Conference
Gaithersburg, Maryland
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Development for Fire Safety Technology for NASA's Exploration Mission

Status of the
Fire Prevention, Detection, and Suppression (FPDS)
Technology Development Project

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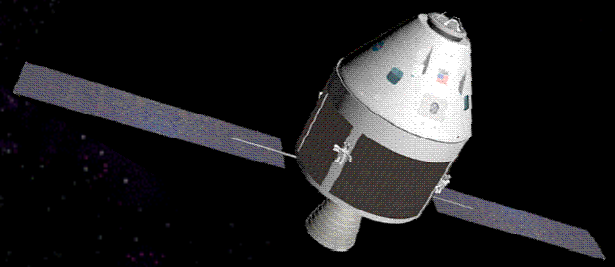
Background

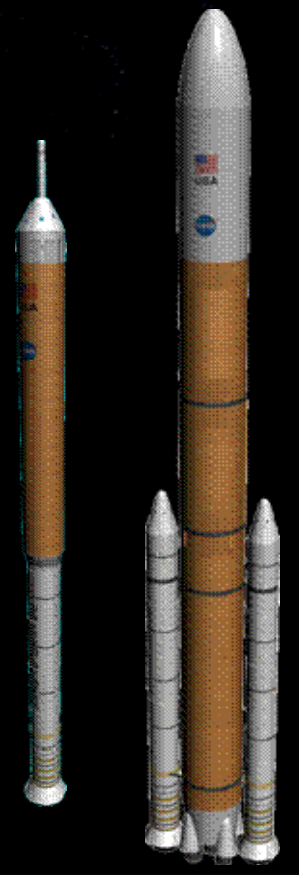
- ***Spacecraft fire safety was the justification for much of the microgravity combustion science program (20+ years)***
  - NRA-driven research selected by external peer-review
  - Entirely science-based research
- ***Bioastronautics Initiative (1999)***
  - Apply fundamental knowledge that had been created through ground and flight research
  - Continue structure of microgravity combustion science but fund applied technology development projects related to fire safety
- ***Vision for Space Exploration (2004)***
  - Focus of the entire program became technology development for exploration vehicles and habitats
  - Issues related to habitable atmosphere, size of vehicle, mission constraints
- ***Exploration Technology Development Program (2005 – present)***
  - Provide a unified structure for evaluation, development, and infusion of new technologies into the Constellation Program
  - Required technologies determined by the vehicle/mission

NASA's Exploration Vehicles

- Crew Exploration Vehicle
  - 5.5 meter diameter capsule scaled from Apollo
    - Separate Crew/Service Module configuration
  - Vehicle designed for Lunar missions with 4 crew
    - Can accommodate up to 6 crew for Mars and Space Station missions
  - Habitable volume atmosphere: 30% O_2, 10.2 psia



- Lunar Lander and Ascent Stage
  - 4 crew to and from the surface
  - Seven days on the surface
  - Lunar outpost crew rotation
  - Habitable volume atmosphere: 32% O_2, 8 psia



- Mars Transit Vehicle
  - Multiple launches of Cargo Launch Vehicle to assemble Mars Transfer Vehicle
  - CEV shuttles crew to Mars Transfer Vehicle

Product Lines and Deliverables

Fire Prevention and Material Flammability

1. Definition of a normal gravity material flammability test(s) to evaluate reduced gravity flammability
2. Assessments of material flammability in relevant cabin atmospheres and gravity levels for exploration transit vehicles and habitats

Fire Signatures and Detection

3. Advanced detection system for gaseous and particulate pre-fire and fire signatures
4. Verified models of the transport of contaminants, smoke, and combustion gases throughout the habitable volume of a spacecraft or habitat

Fire Suppression and Response

5. Design rules for suppressant system including effectiveness of suppressants, required concentrations, and dispersion methods

What does NASA do to avoid fires?

- **Material Flammability**
  - NASA-STD-6001: Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion
    - Test 1: Upward Flame Spread Test
  - Materials that fail Test 1 must undergo additional testing and/or configuration control as defined by NASA Materials and Processes personnel
  - In case of fire, turn off power and ventilation flow

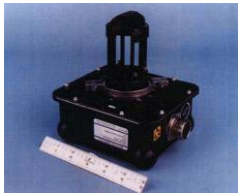
Sample failing NASA Test 1

- **Minimize ignition sources**
  - To the extent possible, designs attempt to minimize sources of ignition

FGB SD

- **Fire Detection**
  - On ISS, smoke detectors are positioned near air return vents
  - FGB and SM smoke detectors use different technology (ionization) than US smoke detector (photoelectric)

SM SD



US SD

- **ISS Fire Extinguishers**
  - US: Gaseous CO_2
  - RS: Water-based foam

US CO_2 fire extinguisher

Fire Prevention and Material Flammability

- Normal Gravity Material Flammability Test
  - Develop a test that, either by design or analysis, negates the effects of gravity
    - Equivalent Low-Stretch Scaling (Sandra Olson, NASA-GRC)
    - Sub-critical Rayleigh Number Scaling (Fletcher Miller, NCSER)
  - Develop a test that measures relevant material flammability characteristics and the uses these to predict low-g behavior
    - Forced Ignition and Spread Test (Carlos Fernandez-Pello, UCB)
- Understand the existing flammability test better
  - Evaluation of NASA-STD-6001 Test 1 and relate results to other types of flammability tests (Kashiwagi, NIST)
- How do we quantify flammability in partial gravity?
  - Pressure-Gravity Scaling (James T'ien, CWRU)
  - Partial Gravity Centrifuge (Paul Ferkul, NCSER)
- What is the impact of different habitable volume atmospheres on material use on exploration vehicles?

Recommendations for Constellation Habitable Atmosphere

- CEV (Block 1) limited to 10.2 psia, 30% O_2 (similar to STS and ISS)
- CEV (Block 2) and LSAM to 8 psia and 32 +/- 2% O_2 (equiv to 34% O_2)

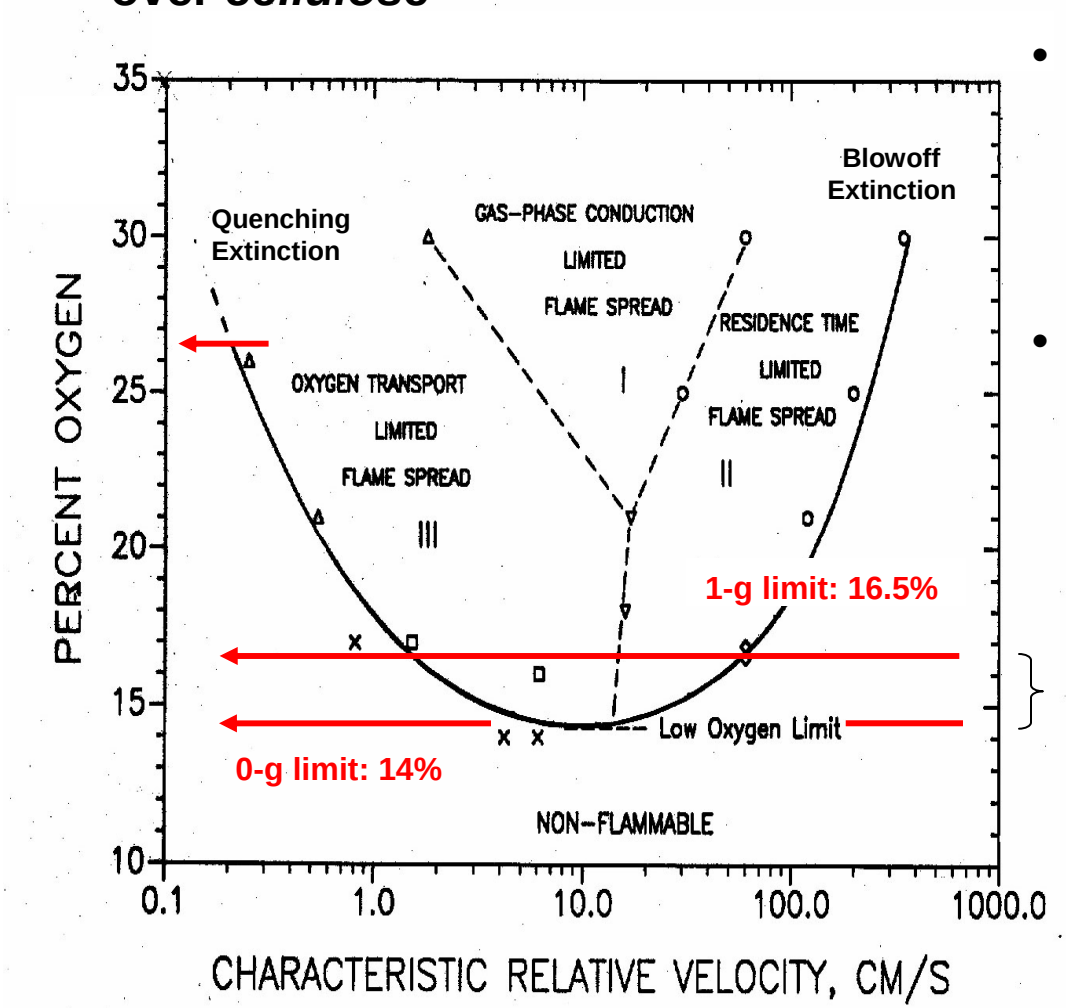
- There was concern by NASA Materials and Processes and Lockheed-Martin that materials used on Shuttle and ISS that would not be allowed on CEV if oxygen mole fraction was 34%

- Test plan was developed to investigate material flammability for CEV
  - NASA WSTF: Obtain maximum oxygen concentration (MOC) at which material passes NASA-STD-6001 Test 1 rather than "point testing" at 34% oxygen
    - Initially look at about 50 common spacecraft materials
  - NASA GRC: Low-gravity tests conducted in a 5.2-sec drop tower at GRC to assess the effect of gravity on the flame spread threshold

➢ Conducting tests to determine the MOC is a new approach for NASA because it quantifies the safety margin, not just a "pass/fail" result

Low and Partial Gravity Flammability Limits

- **Experimentally-based flammability map for *opposed flow* flame spread over *cellulose***



- **With no air flow, the margin of safety can be fairly large**
  - Depends on the material and location
- **With a moderate air flow (5 – 10 cm/s), a flame can be sustained to a lower oxygen concentration than in normal gravity**

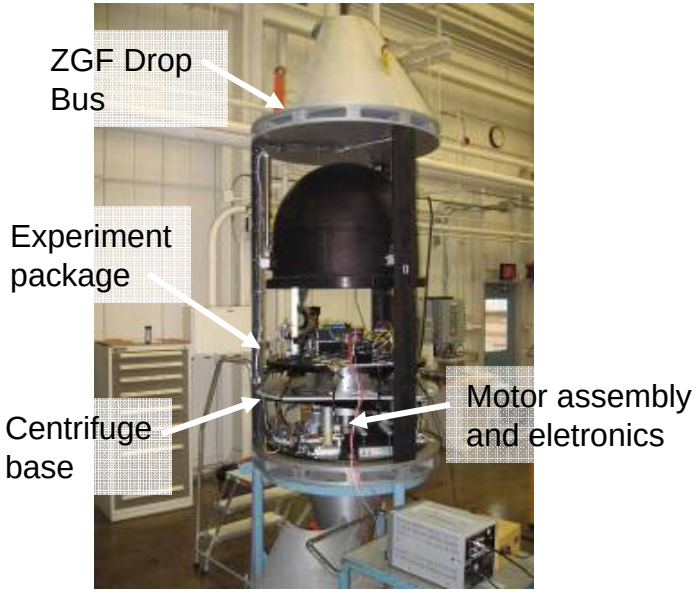
How large is this difference for practical materials?

➢ **If the difference is more than 1 - 2% O_2, the presumed safety margin doesn't exist**

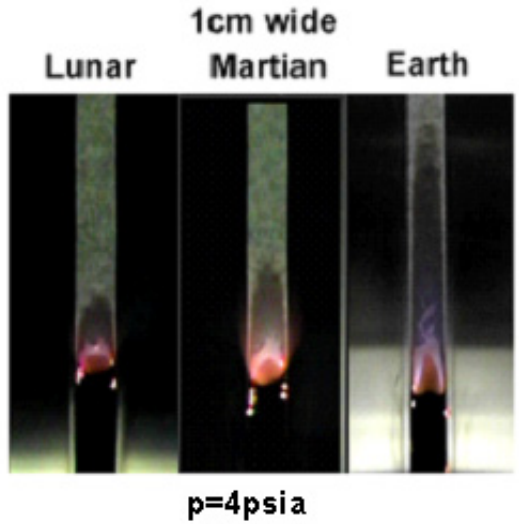
Olson, S. L. "Mechanism of Microgravity Flame Spread Over a Thin Solid Fuel: Oxygen and Opposed Flow Effects," Combust. Sci. and Tech., Vol. 76, 1991, pp. 233-249.

Material Flammability in Partial Gravity

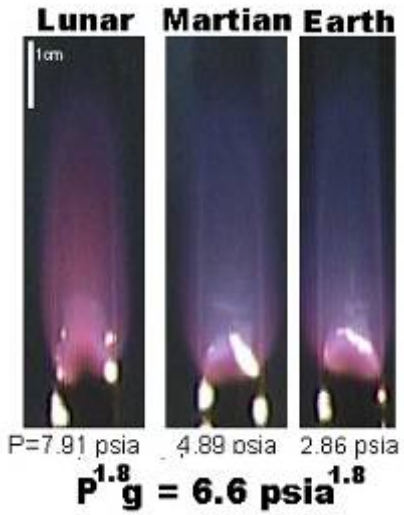
- Material flammability assessments for Lunar and Martian habitats were highlighted by the Exploration Systems Architecture Study as a needed technology for exploration
  - Partial-gravity simulation using a centrifuge in a drop tower
  - Scaling buoyancy effects using relationships between pressure and gravity (P^2-g scaling)



Centrifuge rig installed in Zero Gravity Facility drop bus. Black dome lowers onto centrifuge base



Partial gravity flames from KC-135 expts

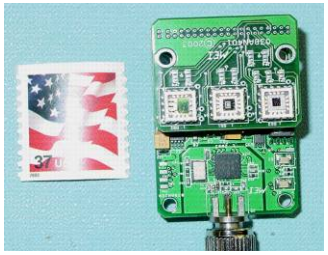


Scaled normal gravity flames

With appropriate scaling, behavior of partial gravity flames can be reproduced in normal gravity

Fire Signatures and Detection

- Do we have the right sensors to detect a fire?
  - Gas and particulate sensor development (Gary W. Hunter and Paul Greenberg, NASA-GRC)
    - Solid state (Schottky-diode and metal oxide sensors) for species-specific gas measurements
      - CO, CO_2, H_2, Total HC, and humidity
    - Scattering-based particulate sensor



Incorporate False Alarm Resistant Fire Detection System to CLV 'Lick and Stick" Architecture

- Do we know what signatures we are looking for?
  - Quantification of Fire Signatures (Randy VanderWal, NCSER)
    - Developed facility to quantify fire signatures from typical spacecraft materials
    - Preliminary evaluation of advanced fire detection technologies
    - Smoke and Aerosol Measurement Experiment to quantify low-g smoke" particulate size distribution
      - ISS Microgravity Glovebox experiment scheduled to be launched in Summer 2007
- Where do you put a smoke detector?

SAME (Smoke Aerosol Measurement Experiment)

PI: D. L. Urban **PS**: G. A. Ruff
Co-Is: George Mulholland (U of Maryland), Zeng-guang Yuan (NCSER), Jiann Yang (NIST), Thomas Cleary (NIST)
PM: W. Sheredy **Engineering Team**: G. Funk, Project Lead

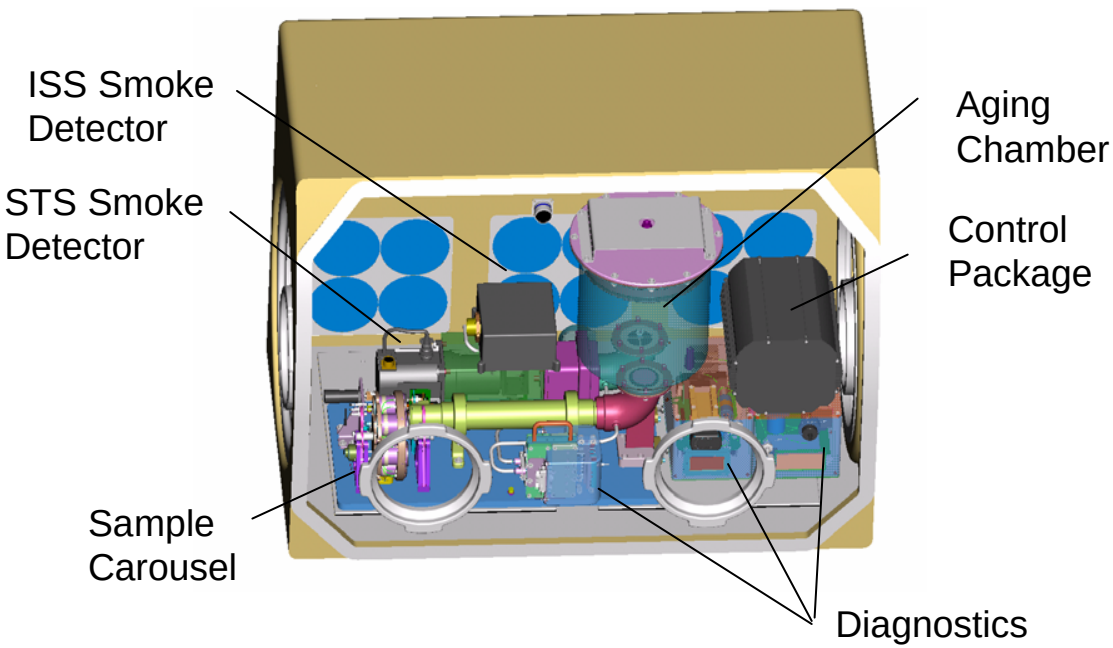
Goals

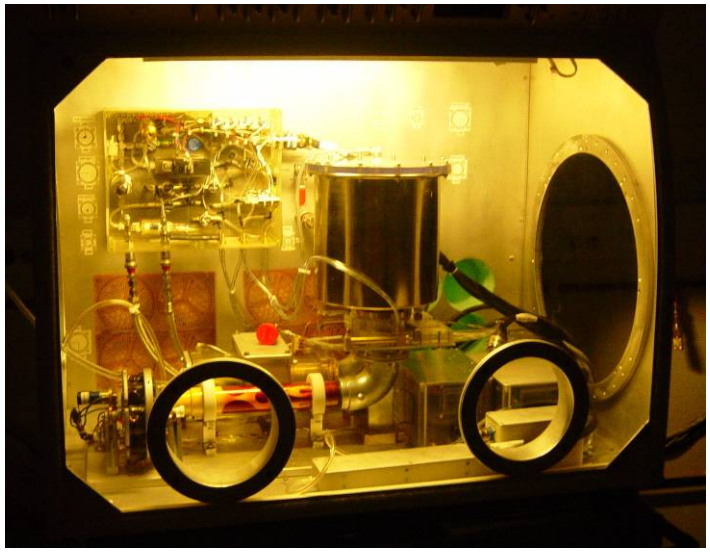
- Perform in-situ measurements of smoke particle size distributions for spacecraft materials in low-gravity
- Consider different materials and smoke generation conditions
  - Teflon, Kapton, silicone rubber, cotton
- Traditional instruments are too large or crew intensive.
- Several commercial diagnostics will be used to measure moments of the aerosol size distribution using features of aerosol particle size distributions
  - TSI PTrak®, DustTrak™, calibrated ionization detector
  - Thermophoretic sampling
  - Shuttle and ISS smoke detectors

SAME (Smoke Aerosol Measurement Experiment)

Status

- Hardware has been completed and shipped to Kennedy Space Center
- Manifested on STS-118 scheduled to launch in July 2007
- Experiment operated on ISS during August and September





Smoke Aerosol Measurement Experiment (SAME) in MSG

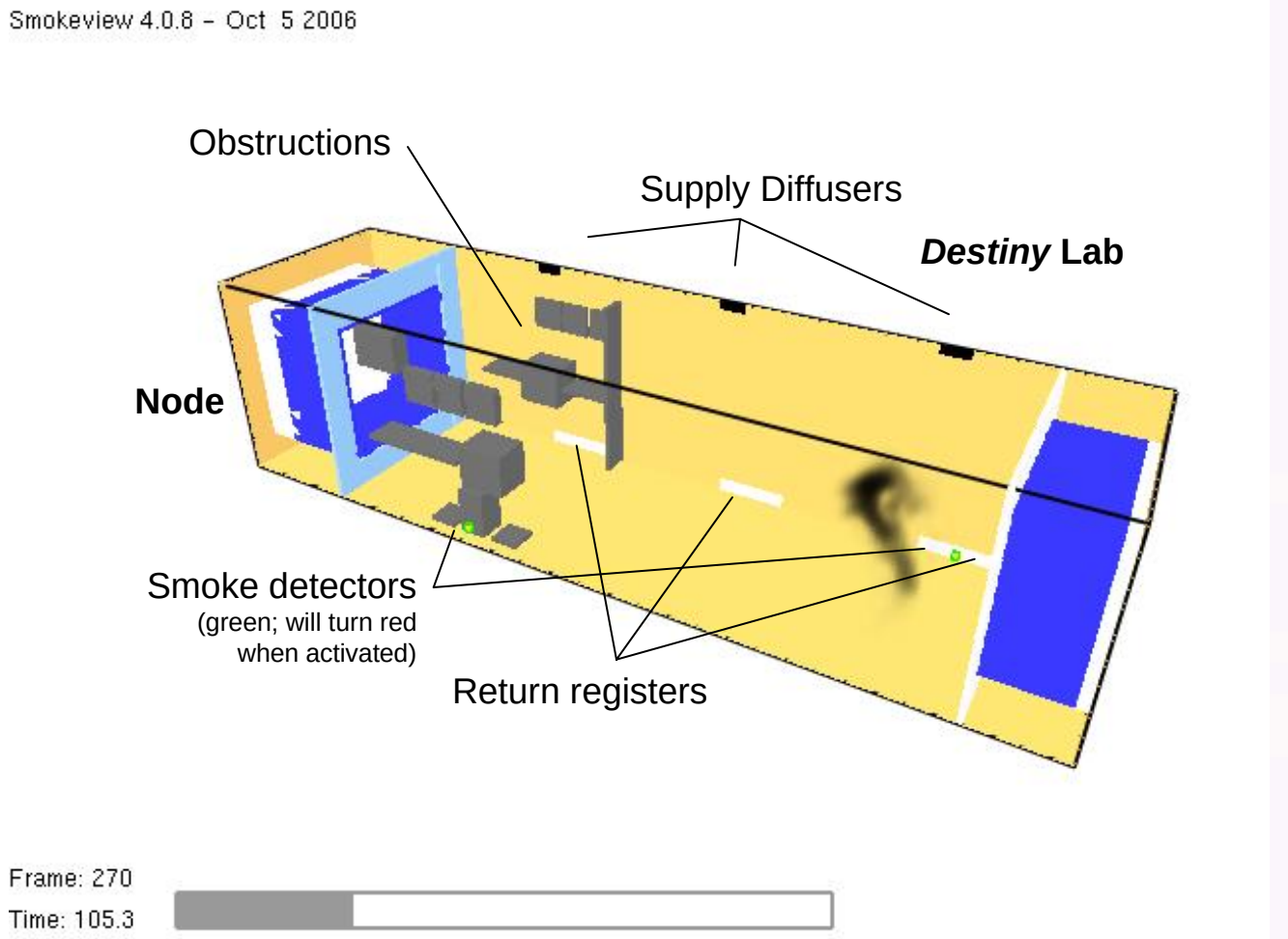
Where do you put a smoke detector?

ISS013E17268

Modeling of Smoke and Contaminant Transport

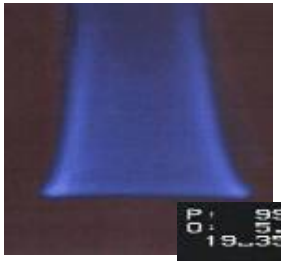
- **In the absence of a sufficiently detailed CEV design, develop and demonstrate capability using the ISS *Destiny* Lab Module**
  - Utilize the National Institute for Standards and Technology (NIST) Fire Dynamics Simulator (FDS) code

- Finite Difference, Large Eddy Simulation
- Smoke originates from a rack panel
- Transported to detectors via module air flow
- Calculate time-to-alarm under various flow configurations and fire locations
- Flow rates and conditions from Boeing ISS ECLSS personnel



Fire Suppression and Response

- How effective are suppression agents in low- and partial-g?
  - Continue to quantify suppressant effectiveness in reduced gravity
    - Cup-Burner
    - Opposed jet/Stagnation Point Diffusion Flame
    - Flame Extinction (FLEX) experiment on ISS
    - PMMA Cylinders
  - Trade study to collect and reconcile normal and low-g data
    - Various configurations, suppression agents, and gravity levels



Low-g cup burner flame

Low-g suppression tests on PMMA cylinder

- How do the agents behave when deployed?
  - Modeling of suppressant dispersion in CEV geometry
    - Tied to the modeling of smoke and contaminant transport
    - Requires details of CEV design

Water mist experiments on STS-107

- Evaluation of spacecraft fire suppression
  - Brings together material flammability, fire signatures, contaminant transport, and suppression effectiveness
  - Various groups are working on this task (Linteris, NIST; Brooker, NASA-GRC)

Summary

- **The FPDS project is NASA's only work in incorporating low-gravity effects into spacecraft fire safety protocol**
  - Effects of low and partial gravity on fire, smoke generation, and fire suppression are significant
  - Expertise gained through the Microgravity Combustion Science Program
- **FPDS deliverables are aligned with NASA's fire safety philosophy**
  - Spacecraft systems cannot be made completely fire-proof
  - Tasks address these deliverables with both short- and long-term applications
  - Each destination will present new constraints and challenges
    - So does each budget cycle!
- **FPDS personnel are involved in Constellation activities**
  - Developing requirements as well as influencing design options
- **Major objectives are:**
  - Continue the tasks described in this presentation
    - Make relevant to CEV and LSAM needs as the designs develop
  - Work with the NASA and contractor personnel on fire detection and suppression strategies and protocols
  - Infuse the FPDS technologies into Constellation vehicles