# Burning and Suppression of Solids (BASS)

The Burning and Suppression of Solids (BASS) investigation examines the burning and extinction characteristics of a wide variety of fuel samples in microgravity. The BASS experiment will guide strategies for extinguishing accidental fires in microgravity. BASS results contribute to the combustion computational models used in the design of fire detection and suppression systems in microgravity and on Earth

**Research Summary**

- Burning and Suppression of Solids (BASS) tests the hypothesis that materials in microgravity, with adequate ventilation, burn as well if not better than the same material in normal gravity with other conditions being identical (pressure, oxygen concentration, temperature, etc.).
- There are important differences in the suppression of fires in space compared to on Earth. On Earth it is understood that the best results are generally obtained when the extinguisher "attacks" the base of the flame, which is both the stabilization point and the point where fresh air first enters the flame.
- For a fire burning in microgravity, the best point of application of suppressant may not be immediately apparent, especially for a partially obstructed flame or a wake-stabilized flame. Depending on the geometry of the flame and the characteristics of the extinguisher (distance from flame, dispersion angle) it is possible that the suppressant stream will be ineffective or might actually make the flame worse through the entrainment of oxygen. Using nitrogen as a flame suppressant in microgravity provides a direct link to current and planned extinguishment techniques.

**Detailed Research Description**

Burning and Suppression of Solids (BASS) utilizes slightly modified Smoke Point In Co-flow Experiment (SPICE) hardware within the Microgravity Science Glovebox (MSG) for observations of burning solid materials on board the ISS.

BASS consists of 41 fuel samples. There are three categories of samples: flat, solid spheres, and candles within tubes. Thin flat samples (12 cm long by 1 and 2 cm wide) yield concurrent-flow spread rate and limiting flame length. The cotton-fiberglass fabric blend Solid Inflammability Boundary at Low-Speeds (SIBAL) fuel is our principal thin material, and it was specially developed just for this purpose. Other thin materials are burned including Nomex and Ultem. Thick flat samples (5 cm long by 1 cm wide by 1 and 2 mm thick) of Polymethylmethacrylate (PMMA) and wax-saturated fiberglass fabric yield thickness effects on flame spread and extinguishment. Solid spheres of PMMA (1 and 2 cm in diameter) have the advantage of an axisymmetric geometry and permit multiple tests as the flame is extinguished and reignited. Ignition of either the front or back portion of the spheres is achieved. Finally, candles within a thin ceramic tube (6 mm in diameter by 25 mm long) are examined. Two types of wax are used, common paraffin and "Japan wax", which has a very low soot point. For many of these tests, the nitrogen suppressant system is engaged at a gradually increasing level until extinction is reached.

The important experimental observations from BASS with respect to the burning process include flame shape and appearance as a function of flow speed, flame spread rate (how fast the flame develops), and flame dynamics (pulsations, oscillations, etc.). With respect to extinction, the critical observations and data are the time to extinction as a function of fuel geometry, the nitrogen flow rate, and the flame distance from the nozzle. The dynamics of the flame before extinction are also important for comparison to the modeling work.

The modeling effort includes:

- Modeling flame spread over flat samples: For flat samples, the steady spread characteristics can be examined using the three-dimensional model currently available. Alterations are the new tunnel and sample geometry and the upstream boundary condition. For the flame growing phase, a transient model is currently being developed.
- Suppression by nitrogen injection: This can also be modeled readily using the current model.
- Modeling burning and extinction of PMMA spheres: Similar problem on modeling two-dimensional circular PMMA cylinder in cross flow has been performed. Some changes are needed for the sphere and the duct flow.

Zero-g facility test burning 2-cm-diameter PMMA sphere in 30 cm/s airflow. Left: 1 g; Middle: 0 g, 1 s after drop; right: 0 g, 4 s after application of nitrogen extinguishing agent. PMMA Sphere

Drop tower results and modeling of a 2-cm-diameter PMMA sphere burning in 17% oxygen, 1 atm. pressure, at 2 cm/s forced convective flow. Experiment images are overlaid with computer simulations, which can capture the flame response as it transitions from 1-g to 0-g. Left-side contours show reaction rate (kgmol/m3/s); right side contours show temperature (K).

**Brief Research Operations**

- The crewmember unstows and assembles the BASS hardware on the base plate within the MSG working volume and connects electrical and data harnesses.
- Before each test point, the crew installs and positions fuel samples and igniters. Tunnel flow speed, nitrogen flow rate, and flame ignition are controlled.
- After ignition and some period of burning, the crew turns on the nitrogen suppressant at an increasing level until the flame goes out.
- The crew controls video and still camera functions. Some photos are downlinked for near-real time coordination with the investigator. The crewmember uninstalls experiment from the MSG and stows the hardware once BASS is completed.

**Operational Requirements:**

BASS is conducted inside the sealed MSG work volume. The crewmember is involved throughout the experiment to load fuel samples, initiate tests, ignite the fuel, adjust suppression, monitor and record data, exchange fuel samples, and replace the igniter. Forty-one test samples will be burned in a variety of flow conditions for a total of 89 test points.

Data is downlinked via video during or immediately after each flame test. Digital photos are downlinked after selected flame tests for ground confirmation before proceeding. BASS testing session must be conducted during periods when no major reboost or docking procedures are underway on the International Space Station (ISS).

**Operational Protocols:**

The crewmember installs the BASS hardware in the MSG work volume. The BASS hardware consists of a small flow duct with an igniter and a small nozzle along with exchangeable fuel samples. During BASS operations a fan produces a co-flow of air through the duct. An anemometer is used to measure the actual flow rate. The crewmember adjusts the airflow from 5 to 50 cm/s. The flame is ignited and allowed to burn for about a minute. A nitrogen suppressant is then supplied via a mass flow controller, from 0 to 500 cc/min. A radiometer measures flame output. The crewmember conducts each test. They install the correct fuel assembly and set the air flow rate through the duct before igniting the flame. When the flame is ignited, the crewmember allows some time for the flame to stabilize then adjusts the flow of nitrogen suppressant through the nozzle until the flame goes out. After the test, the crewmember turns off the nitrogen flow and prepares for the next test. The science team on the ground monitors the video downlink to assist the crewmember in determining any peculiar flame behaviors and reviews the sensor data overlaid on the video image. Upon completion of the tests the crewmember stows the hardware, and the stored images and data are returned to Earth for analysis.

**Space Applications:**

The current NASA spacecraft materials selection is based on a standard test method (NASA–STD–6001 Test 1) that segregates material based on 1-g behavior without consideration of low gravity effects. A critical element of this understanding is the radiative heat emission from the flame. These results are used in first order models and predictions of heat release in spacecraft fires and to extend heat release data from tests like the NASA cone calorimeter test (NASA–STD–6001 Test 2) to a performance-based material selection process. Using nitrogen as a flame suppressant in microgravity provides a direct link to current and planned extinguishment techniques.

**Earth Applications:**

BASS results provide essential guidance to ground-based microgravity combustion research efforts. Detailed combustion models are validated using the simpler flow environment afforded by tests in microgravity. Once validated, they can be used to build more complex combustion models needed to capture the important details of flames burning in normal gravity. These models have wide applicability to the general understanding of many terrestrial combustion problems.

**Related Publications**


- Armstrong JB, Olson SL, T'ien JS. Transient Model and Experimental Validation of Low Stretch

Solid--Fuel Flame Extinction and Stabilization in Response to a Step Change in Gravity. Combustion and Flame. Vol. 147. pp. 262--277 (2006).

- Ferkul PV, T'ien JS. A Model of Low--Speed Concurrent Flow Flame Spread over a Thin Fuel.
  Combustion Science and Technology. Vol. 99. pp. 345--370 (1994).
- Ferkul P, Kleinhenz J, Shih H--Y, Pettegrew R, Sacksteder K, T'ien J. Solid Combustion Experiments Using a Continuous Fuel Dispenser for Use in Microgravity. Microgravity Science and Technology. Vol. XV/2 (2004).
- Foutch DW. Size and Shape of Solid Fuel Diffusion Flames in Very Low Speed Flows. NASA CR--
  179576 (1987).
- Friedman R. Fire Safety in the Low--Gravity Spacecraft Environment. NASA TM--209285 (1999).
- Goldmeer JS. Extinguishment of a Diffusion Flame Over a PMMA Cylinder by Depressurization in
  Reduced--Gravity. NASA CR--198550 (CWRU PhD Dissertation) (1996).
- Hsu S--Y. Flame Spread and Extinction over Solids in
  Buoyant and Forced Concurrent Flows:
  Model Computations and Comparisons with Experiments. Ph.D. Dissertation, CWRU (2009).
- Ivanov AV, Balashov YV, Andreeva TV, Melikhov AS. Experimental Verification of Material Flammability in Space. NASA CR--209405 (1999).
- Jiang C--B. A Model of Flame Spread Over a Thin Solid in Concurrent Flow with Flame Radiation.
  Ph.D. Dissertation. CWRU (1995).
- Kimzey JH. Skylab Experiment M479 Zero Gravity Flammability. Skylab Results, Proceedings of the Third Space Processing Symposium. Vol. 1. pp. 115--130 (1974) and NASA TMX--70252 (1974).
- Olson SL, Ferkul PV, T'ien JS. Near--Limit Flame Spread Over a Thin Solid Fuel in Microgravity.
  Twenty--Second Symposium (International)
  on Combustion. The Combustion Institute. pp. 1213--1222 (1998).
- Olson SL, T'ien JS. Buoyant Low Stretch Diffusion Flames Beneath Cylindrical PMMA Samples.
  Combustion and Flame. Vol. 121. pp. 439--452 (2000).
- Shih H--Y, T'ien JS. A Three--Dimensional Model of Steady Flame Spread over a Thin Solid in Low--
  Speed Concurrent Flows. Combustion Theory and Modeling. Vol. 7 (2003).

- Takahashi F, Linteris G, Katta VR. Extinguishment Mechanisms of Co--flow Diffusion Flames in a
  Cup--Burner Apparatus. Proceedings of The Combustion Institute. Vol. 31 (2007).
- Takahashi F, Linteris G, Katta VR. Extinguishment of Methane Diffusion Flames by Carbon Dioxide in Co--flow Air and Oxygen-
  Enriched Microgravity Environments. Combustion and Flame. Vol. 155, pp. 37--53 (2008).
- Tseng Y--T. Ignition and Flame Growth in Concurrent Forced Flow Over Thick Solids. M.S. Thesis, CWRU (2007).


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## Burning and Suppression of Solids – II (BASS-II)


Burning and Suppression of Solids – II (BASS-II) utilizes slightly modified Smoke Point In Co-flow Experiment (SPICE) hardware within the Microgravity Science Glovebox (MSG) for observations of burning solid materials on board the ISS.

BASS-II consists of 100 fuel samples and associated igniter wires. There are three categories of samples: flat samples, rod samples, and a section of a large solid sphere. Thin flat samples (10 cm long by 1 and 2 cm wide) yield concurrent or opposed-flow spread rates, limiting flame lengths, and extinction limits. The flat sample materials will include acrylic films and sheets of different thicknesses, and a cotton-fiberglass fabric blend Solid Inflammability Boundary at Low-Speeds (SIBAL) fuel which was previously tested in BASS. The rod samples are made of black or clear acrylic and will provide solid fuel regression rates and extinction limits for both opposed and concurrent flow. The large solid spherical section, also made of acrylic, will be used to study ignition of thick materials and flame growth over the thick material.

The important experimental observations from BASS-II with respect to the burning process include flame shape and appearance as a function of ambient oxygen concentration, flow speed, flame spread rate (how fast the flame develops), and flame dynamics (pulsations, oscillations, etc.). With respect to extinction, the critical observations and data are the time to extinction as a function of fuel geometry, flow, and ambient oxygen concentration. The dynamics of the flame before extinction are also important for comparison to the modeling work.

The modeling effort includes:

- Modeling flame spread over flat samples: For flat samples, the steady spread characteristics can be examined using the three-dimensional model currently available. Alterations are the new tunnel and sample geometry and the upstream boundary condition. For the flame growing phase, a transient model is currently being developed.
- Modeling burning and extinction of PMMA spheres: Similar problem on modeling two-dimensional circular PMMA cylinder in cross flow has been performed. Some changes are needed for the sphere and the duct flow.

**Science Objectives**

The Burning and Suppression of Solids –II (BASS-II) investigation examines the burning and extinction characteristics of a wide variety of fuel samples in microgravity. The BASS-II experiment will guide strategies for materials flammability screening for use in spacecraft as well as provide valuable data on solid fuel burning behavior in microgravity. BASS-II results contribute to the combustion computational models used in the design of fire detection and suppression systems in microgravity and on Earth.

**Science Results**

BASS-II tests produced data on how ambient oxygen, ventilation, and fuel affect combustion and burning. Theoretical formulas and data on flame spread do not always match in normal gravity. With data from microgravity, scientists determined thin and thick fuel spread rates and a formula for transition from thin to thick fuels. Models predict higher spread rates than observed, so need improvement. Data also allowed calculation of combustion completeness, heat release rates, and fuel-to-oxygen global equivalence ratios and supported theoretical models for quenching boundaries. Results will guide choice of materials for future spacecraft and advance fire detection and suppression in space and on Earth.

**Research Overview**

- Burning and Suppression of Solids – II (BASS-II) tests the hypothesis that materials in microgravity, with adequate ventilation, burn as well if not better than the same material in normal gravity with other conditions being identical (pressure, oxygen concentration, temperature, etc.).NASA tests materials for flammability using an upward burning test, which is considered to be the worst-case geometry for flammability of the material on Earth. One objective of the BASS-II tests is to identify what is the worst case for material flammability in spacecraft environments, and how does that compare to the terrestrial upward burning used to screen the materials for safe use aboard spacecraft.
- The main variables to be tested are the effects of ambient oxygen concentration, ventilation flow velocity, and fuel type, thickness, and geometry. Many of the tests will focus on finding a minimum oxygen concentration or flow velocity where a material will burn in space, to compare with Earth-based limits. Flame growth rates are also of interest, to determine how quickly a fire in space can grow and if the flames reach a finite size or continue to grow. This has implications for firefighting strategies in spacecraft.

- Detailed combustion models can be validated by data obtained in the simpler flow environment in microgravity. Once validated, they can be used to build more complex combustion models needed to capture the important details of flames burning in normal gravity. These models have wide applicability to the general understanding of many terrestrial combustion problems.

**Space Applications**

A primary goal of BASS-II is improved spacecraft fire safety, improved understanding of combustion in space and how to avoid it. If you're on a mission far from Earth, a fire can be catastrophic. BASS-II helps engineers select the safest materials and improve firefighting methods on future space missions.

**Earth Applications**

In outer space, fuels burn as oval balls rather than with an upward pointed cone flame as they do on Earth. This simpler combustion process enables researchers to evaluate computer models of fuel burning. These models can then be used to more accurately study flames on Earth, such as in wildfires, building fires, energy recapture from waste recycling, and other combustion problems.

**Operational Requirements and Protocols**

BASS-II is conducted inside the sealed MSG work volume. The crewmember is involved throughout the experiment to load fuel samples, adjust nitrogen gas (GN2) concentration in the working volume vitiation of the working volume, initiate tests, ignite the fuel, monitor and record data, exchange fuel samples, and replace the igniter. Forty-one test samples will be burned in a variety of flow conditions for a total of 89 test points. Data is downlinked via video during or immediately after each flame test. Digital photos are downlinked after selected flame tests for ground confirmation before proceeding. BASS-II testing session must be conducted during periods when no major reboost or docking procedures are underway on the International Space Station (ISS).

The crewmember installs the BASS-II hardware in the MSG work volume. The BASS-II hardware consists of a small flow duct with an igniter and a small nozzle along with exchangeable fuel samples. During BASS-II operations a fan produces a co-flow of air through the duct. An anemometer is used to measure the actual flow rate. The crewmember adjusts the airflow from 5 to 50 cm/s. Nitrogen vitiation of the working volume is then initiated using station GN2 at a flow rate of up to 500 cc/min for a prescribed time. The flame is ignited and allowed to burn for about a minute. A radiometer measures flame output. The crewmember conducts each test. They install the correct fuel assembly and set the air flow rate through the duct before igniting the flame. When the flame is ignited, the crewmember allows some time for the flame to stabilize then adjusts the flow of nitrogen suppressant through the nozzle until the flame goes out. After the test, the crewmember turns off the nitrogen flow and prepares for the next test. The science team on the ground monitors the video downlink to assist the crewmember in determining any peculiar flame behaviors and reviews the sensor data overlaid on the video image. Upon completion of the tests the crewmember stows the hardware, and the stored images and data are returned to Earth for analysis.

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## Burning and Suppression of Solids-Milliken (BASS-M)

The Burning and Suppression of Solids-Milliken (BASS-M) investigation utilizes slightly modified Smoke Point In Co-flow Experiment (SPICE) hardware within the Microgravity Science Glovebox (MSG) for observations of burning solid materials on board the International Space Station (ISS).

BASS-M consists of 44 textile samples with integrated igniter wires. There are four samples of each textile type, of which there are eleven. A set of control samples are included which provide untreated textile samples. The other ten sets of textile samples share a similar configuration. Each has a small piece untreated textile which is ignited by an integrated hot wire igniter. The flame from the untreated textile impinges on the treated textile which is immediately adjacent to the untreated sample.

The important experimental observations from BASS-M, with respect to the burning process, include flame shape and appearance as a function of flow speed, flame spread rate (how fast the flame develops), and flame dynamics (pulsations, oscillations, etc.). With respect to extinction, the critical observations and data to be collected are the time to extinction as a function of textile material and air flow. The dynamics of the flame before extinction are also important for comparison to the modeling work.

**Research Overview**

- The Burning and Suppression of Solids-Milliken (BASS-M) investigation tests the hypothesis that materials in microgravity, with adequate ventilation, burn as well, if not better than, the same material in normal gravity with other conditions being identical (pressure, oxygen concentration, temperature, etc.).

- BASS-M tests ten different treated textiles at various air flow rates found in forced convection in microgravity environments, or in a free fall environment. Each textile's ability to self-extinguish is evaluated and compared against normal terrestrial behavior.
- NASA tests materials for flammability using an upward burning test, which is considered to be the worst-case geometry for flammability of the material on Earth. One objective of the BASS-M tests is to compare the microgravity results to the terrestrial upward burning used to screen the materials for safe use.

**Space Applications**

NASA selects materials for use in space based on ground tests of their flammability. But these tests do not consider the effects of microgravity, which changes how materials burn. This investigation conducts space-based burning and flame extinguishment tests on cotton textiles that have been treated with flame retardants. Results provide new knowledge of how low gravity affects a material's flame-retardant behavior, improving procedures for testing new materials.

**Earth Applications**

Flame-retardant materials are designed to stop flames from spreading and consuming more material. This investigation provides new information on how low gravity affects a material's flame-retardant material behavior, which benefits materials science research on Earth.

**Operational Requirements and Protocols**

BASS-M is conducted inside the sealed MSG work volume. The crew member is involved throughout the experiment to load flame retardant textile samples, initiate tests, ignite the untreated textile sample, monitor and record data, exchange textile samples, and replace the memory card in the still camera. Forty-four test samples are burned in a variety of flow conditions for a total of 44 test points.

Data is downlinked via video during, or immediately after, each flame test. Digital photos are downlinked after selected flame tests for ground confirmation before proceeding. BASS-M testing session must be conducted during periods when no major re-boost or docking procedures are underway on the International Space Station.

The crew member installs the SPICE and BASS hardware in the MSG work volume. The SPICE and BASS hardware consists of a small flow duct with an igniter and a small nozzle, along with exchangeable textile samples. During BASS operations, a fan produces a co-flow of air through the duct. An anemometer is used to measure the actual flow rate. The crew member adjusts the airflow from 5 to 50 cm/s. The untreated textile is ignited and allowed to impinge on the treated textile until both extinguish, which takes about a minute. A radiometer measures flame output. The crew member conducts each test by installing the correct textile assembly and setting the correct air flow rate through the duct before igniting the flame. After the test, the crew member prepares for the next test. The science team on the ground monitors the video downlink to assist the crew member in determining any peculiar flame behaviors and reviews the sensor data overlaid on the video image. Upon completion of the tests, the crew member stows the hardware, and the stored images and data are returned to Earth for analysis.