National Aeronautics and Space Administration

Glenn Research Center
Cleveland, Ohio

Combustion Module-2 (STS–107)
Studying Fire in the Sky

Light a candle and it quickly forms the familiar teardrop shape, which is caused by hot air rising and cold air flowing in behind to keep the fire going. This airflow obscures many of the fundamental combustion processes we need to understand so that we can learn how to

- Burn fuels more efficiently
- Improve fire safety
- Reduce pollution

Conducting combustion experiments in the microgravity environment of orbit eliminates gravitational effects and slows many combustion processes so they become easier to study. Professor Gerard Faeth of the University of Michigan—the Laminar Soot Processes Principal Investigator—has said that gravity has impeded the development of combustion science much as the atmosphere has impeded astronomy.

We use a Combustion Module (CM), which is a state-of-the-art, complex laboratory, to study combustion in space. This reusable, modular combustion facility was first flown on the Microgravity Sciences Laboratory-1 and 1R (STS–83 and STS–94) in 1997. The forthcoming STS–107 shuttle mission will fly an updated version of the CM, known as CM–2. The three experiments that will be conducted are Laminar Soot Processes (LSP–2), Structure of Flame Balls at Low Lewis number (SOFBALL–2), and Water Mist Fire Suppression Experiment (Mist). CM–2 will complete the primary science plan for these investigations, and help set the stage for expanded, long-term experiments aboard the International Space Station.

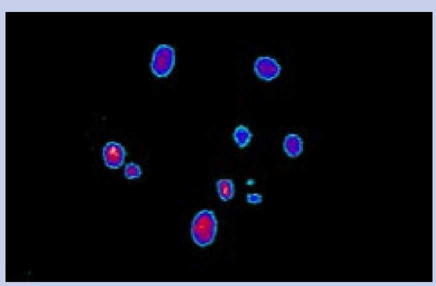
Members of the CM–2 team—a systems engineer and a software engineer—inspecting the CM–2.

LSP–2 Experiment

Objectives: Evaluate and predict flame shape and internal structures; determine the nature of the soot emission process; validate new universal equations for soot and temperature in a flame; and investigate the soot-bursting hypothesis. Results will improve our understanding of turbulent flames found in many combustion devices on Earth.

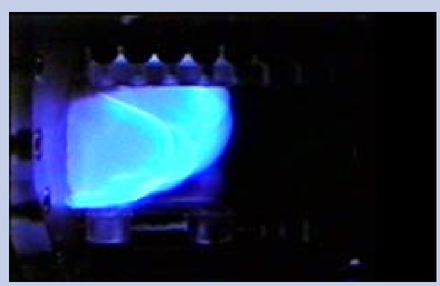
SOFBALL–2 Experiment

Objectives: Improve our understanding of the flame ball phenomenon and lean (low fuel) burning combustion; determine the conditions under which they can exist; test predictions of duration; and derive better data for critical model comparison. Results will lead to improvements in engine efficiency, reduced emissions, and fire safety.



Mist Experiment

Objectives: Measure the effectiveness of fine water mists to extinguish a flame propagating inside a tube to gain a better understanding of the water mist fire-suppression phenomenon. What is learned will help us design and build more effective mist fire-suppression systems for use on Earth, as well as in space.



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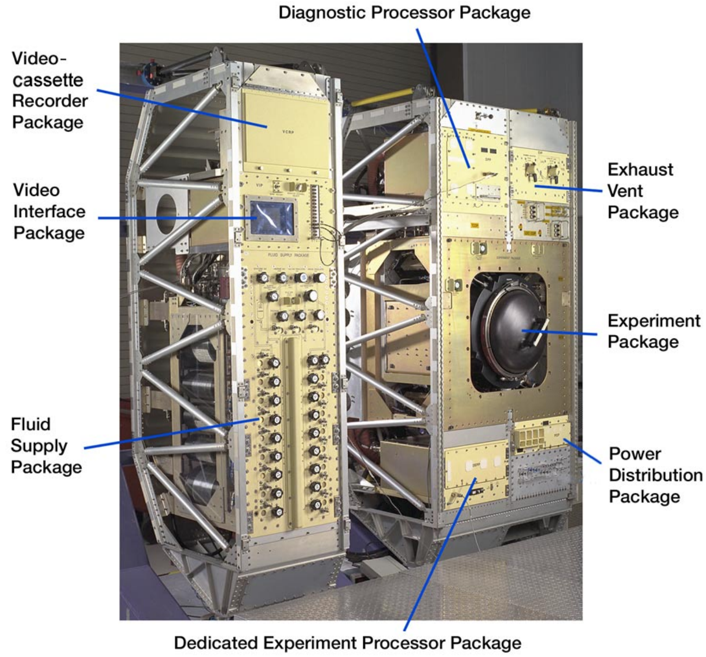
CM–2 Subsystems

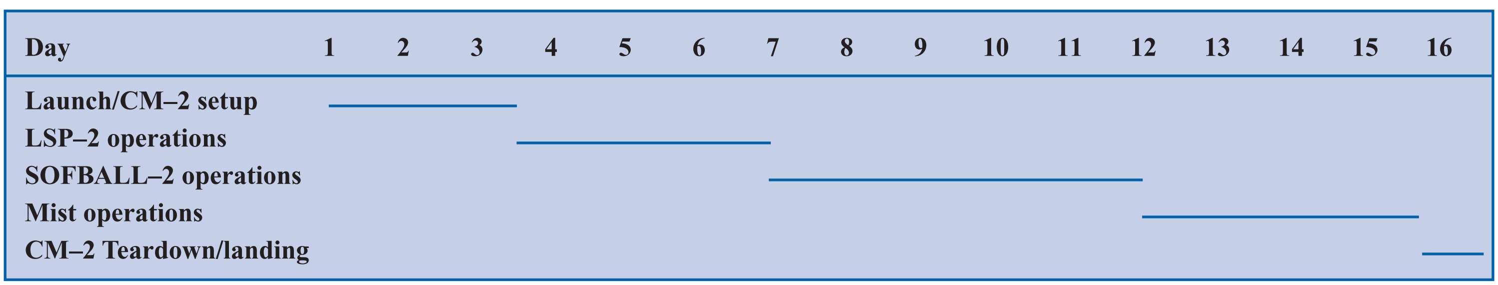
The *Experiment Package* is a 90-liter combustion chamber with six ports for three intensified near-infrared cameras, one color camera, and three black and white cameras; a gas chromatograph; crew switches; and thermistors. The *Fluid Supply Package* is a complex gas control and distribution system containing 20 composite, over-wrapped bottles. The *Videocassette Recorder Package* consists of four Hi-8 video recorders. The *Exhaust Vent Package* includes a blower, canister, and other fluid components for cleanup and evacuation of chamber gases. The *Dedicated Experiment Processor Package* is the main processor for experiment command and control, and connects to the crew laptop (the CM–2 human interface). The *Video Interface Package* is the primary video interface for switching, routing, and display. The *Diagnostic Processor Package* is the video frame grabber and storage system for digital data. The *Power Distribution Package* controls and conditions the power from the Shuttle/SPACEHAB for all CM–2 packages. Finally, the *Experiment Mounting Structures* (EMS) are experiment-unique chamber inserts. Each contains an ignition system and special sensors; the Mist EMS also contains test gases, a water mist generator, and a canister to remove water and carbon monoxide after each test.



CM–2 and its eight major components.

CM–2 Flight Operations

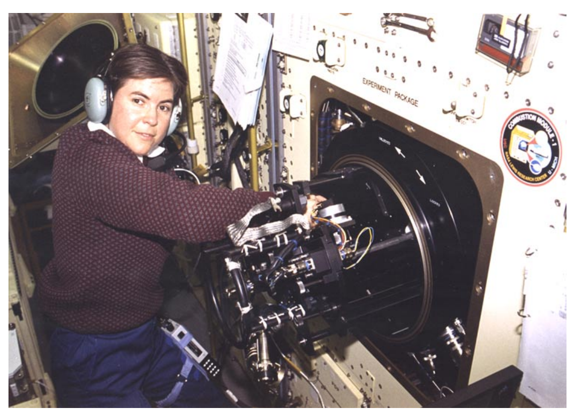
Although the flight crew is in the spotlight for shuttle missions, there is a team of engineers, scientists, and other support personnel who are on the ground making it all possible. The CM–2 Team, comprising almost 40 engineers and scientists, will work side-by-side with the Johnson Space Center Mission Control Team in Houston, Texas. For STS–107, 16 days of around-the-clock operations are conducted to ensure safety and mission success. The CM–2 experiments timeline spans the entire mission.



CM–2 experiments timeline.

CM–2 Statistics

Size:	Main racks—7 ft tall by 5 ft wide by 3 ft deep
Weight:	Main racks—1840 lb; Other CM–2 hardware—355 lb
Subsystems:	Eight rack-mounted components and three chamber inserts
Power Usage:	Average—419 W (dc); Peak—543 W (dc)
Chamber Size:	16 in. (40 cm) diameter by 30 in. (76 cm) long; 24 gallons empty
Cameras:	Seven—one color, three intensified near-infrared, three black and white
Lasers:	Two sets of low-power beams for LSP and Mist measurements
Sensors:	Dozens of pressure, temperature, and radiation sensors
Gas Analysis:	Gas chromatograph determines percent of each kind of gas
Gas Bottle Sizes:	Total of 21—three 10 liter, nine 3.8 liter, eight .7 liter, one .4 liter
Gas Bottle Usage:	Fourteen SOFBALL mixes, two air, two LSP fuel, three chromatograph
Software:	Three computers, ~35,000 lines of code, 25-MHz clock speed
Video:	Four VCR's, frame grabber, and two-channel downlink capability; 6-in. diagonal screen onboard
Data:	13.3 gigabytes storage (20 hard drives/flash memory cartridges)
Crew Time:	86 hours



Astronaut Janice Voss services the LSP EMS, partially withdrawn from the combustion chamber, during the MSL–1 mission in 1997.

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Laminar Soot Processes-2 (STS–107)
Studying Fire in the Sky

Soot: The Good, the Bad, and the Ugly

Soot is a scourge. It looks and smells bad, and it's a health hazard. It's also wasted energy, which is a paradox since soot forms in a flame's hottest regions, where you would expect complete combustion and no waste.

The causes of soot production are among the most important unresolved problems of combustion science. This is because gravity's effect on the combustion process has impeded the development of combustion science, much as the atmosphere has impeded the development of astronomy.

Areas Affected by the Study of Soot Processes

Transportation: Internal combustion engines on aircraft (jet and piston), rail, ships, trucks, and buses

Industry: Power and manufacturing plants that use combustion heating

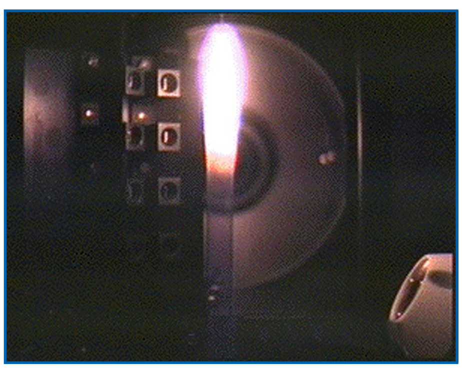
Consumer: Home heating and cooking and gas-fired heat pumps

The Laminar Soot Processes-2 (LSP–2) experiment will use the microgravity environment of space to eliminate buoyancy effects and thus slow the reactions inside a laminar jet diffusion flame so they can be more easily studied. These flames are similar to candle flames except that the fuel is supplied by a gas jet rather than by evaporation from a wick. The effect is similar to that of a butane lighter and the flames approximate the combustion that takes place in diesel engines, aircraft jet engines, furnaces, water heaters, and other devices.

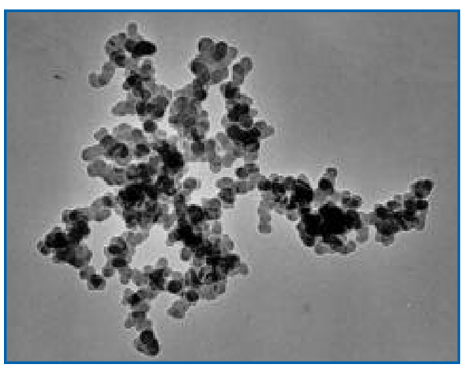
LSP–2 will explore the provocative results of Laminar Soot Processes (LSP–1), which was flown in 1997. The data suggest the existence of universal state relationships—called the "soot paradigm"—that, if proven, will be used to model and develop more efficient combustion systems on Earth.

Science Objectives

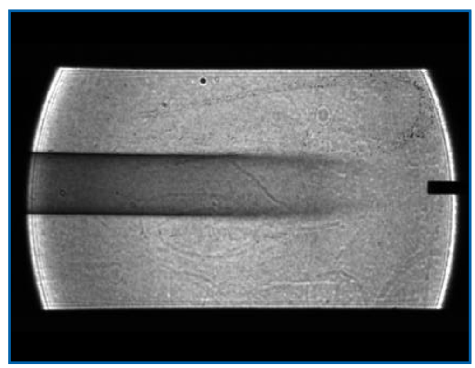
The primary objectives of LSP–2 are to evaluate flame shape predictions, determine the nature of the soot emission process, assess the soot-state relationship concept, investigate the soot bursting hypothesis, and develop methods for flame structure predictions.



LSP uses a small jet burner—similar to a butane lighter—that produces flames up to 60 mm (2.3 in) long.



Individual soot particles from MSL–1 experiments are 10 to 60 nanometers wide; aggregates are 1000 nm (1 micron) wide.



This laser image shows the soot produced by an LSP flame.

LSP–1 Results

LSP–1, which flew in 1997, yielded a number of surprises. A new mechanism of flame extinction caused by radiation from soot was discovered. The mechanism is unusual because the flame quenches near its tip, unlike a buoyant flame which quenches near its base. The LSP–1 team also made the first observations of steady, soot-containing nonbuoyant flames (with and without soot emissions).

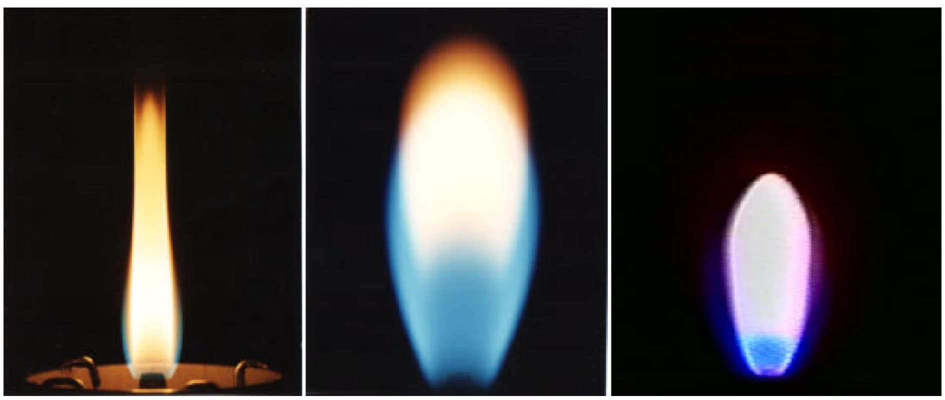
LSP–2 Hardware

LSP–2 experiments will be conducted inside the Combustion Module-2 (CM–2) facility. CM–2 consists of a rack that holds the Fluid Supply Package and video support equipment and a double rack that includes the Experiment Package, computer, and mechanical support equipment.

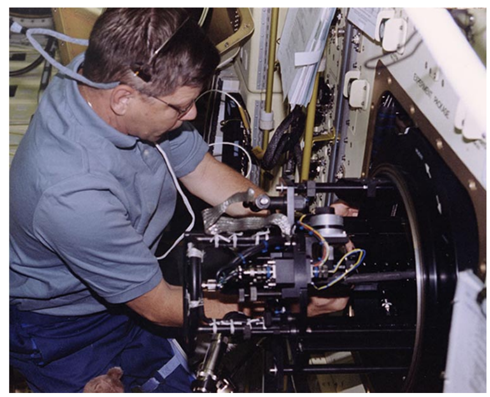
The Experiment Package is a forged aluminum combustion chamber (40 cm in diameter and 76 cm long) and diagnostic equipment. Six windows let external diagnostic instruments view and measure events inside the chamber. Diagnostics include a color camera, a soot volume fraction system (which measures soot by shining a laser through the flame), and a soot temperature measurement system.

The LSP–2 Experiment Mounting Structure (EMS)—which consists of experiment-specific equipment—has a large central volume in which the laminar flames will be formed. A series of soot samplers snap through the flame to capture particles for post-flight analysis.

A NASA engineer inspecting the CM–2, which consists of the fluids supply rack (left) and the experiment rack (right).



In buoyant flames (left), soot mainly nucleates at the outer boundary of the soot production region, moving inward before approaching the flame sheet near the flame tip. In nonbuoyant, or microgravity, flames (center and right), soot mainly nucleates near the inner boundary of the soot production region, and is then drawn toward the flame sheet.



Dr. Roger Crouch, a payload specialist on 1997's MSL–1 mission, inserting the LSP–1 EMS into Combustion Module-1 during flight.

Operations in Space

LSP–2 is operated by the flight crew by means of a laptop computer connected to CM–2. During flight, the crew will install the EMS, fill the chamber with fresh air, ignite the flame, adjust the fuel flow rate to get the right smoke height, adjust the camera exposure time to get the best possible images, end the test run, and vent the chamber for the next test.

Benefits of Studying Soot

Better burner design and operation will
- Reduce soot production in combustion processes
- Reduce radiative heat transfer from soot that damages engines and furnaces
- Improve combustion models for designing new, optimized systems and retrofitting existing systems

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Structure Of Flame Balls At Low Lewis-number-2 (STS–107) Studying Fire in the Sky

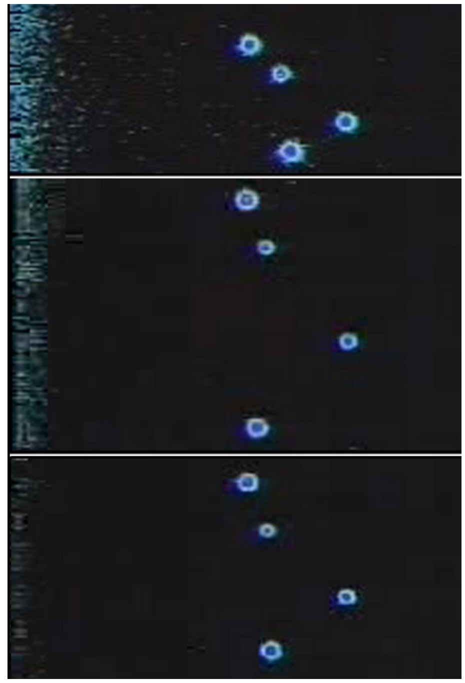
Great Balls of Fire!

For years, scientists have been conducting experiments on flames at low gravity—a condition called "microgravity"—by using drop towers and aircraft flying parabolic trajectories. These experiments have demonstrated a variety of new combustion phenomena that are hidden by the effects of gravity.

One of the more remarkable findings of these experiments was the discovery of "flame balls," which are tiny, stable, stationary, spherically symmetric flames that occur in combustible gas mixtures having low Lewis-numbers, and only in microgravity. Dr. Paul Ronney, a scientist at the University of Southern California, made the discovery in 1984 during a drop tower experiment.

To further study this phenomenom, an experiment called Structure Of Flame Balls At Low Lewis-number (SOFBALL) was performed on two shuttle missions in 1997. It will fly again onboard STS–107.

The Lewis-number part of SOFBALL is a measure of the rate of diffusion of fuel into the flame ball relative to rate of diffusion of heat away from the flame ball. Hydrogen and methane are the only fuels that provide low enough Lewis-numbers to produce stable flame balls, and even then only for very weak, barely flammable mixtures. Nevertheless, these flame balls give scientists the chance to test combustion models in an ideal environment.



Flame balls seem to shine bright as stars, but only because they are observed in the dark by cameras with image intensifiers. Under normal lighting in a space module, the flame balls would be invisible—to the eye and to fire detectors—and, consequently, potentially hazardous.

Science Objectives

The goals of the SOFBALL–2 experiment are to

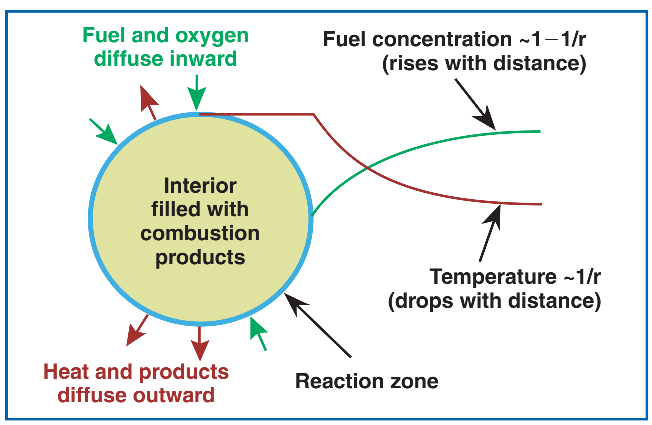
- Improve our understanding of the flame balls phenomenon
- Determine the conditions under which flame balls can exist
- Test predictions of flame ball lifetimes
- Acquire more precise data for critical model comparison

Application of SOFBALL Results

- Improved design of lean-burning car engines
- Improved detection of fire and explosion hazards in mine shafts, oil refineries, and chemical plants
- Improved safety aboard spacecraft from the hazards presented by long-lived flame balls

SOFBALL–2 Science

SOFBALL burns extremely lean fuel-air mixtures that are near the lower limit of combustion. The mixtures are ignited by an electrical spark. Because the mixture is lean and has a low Lewis-number, the flame does not spread across the mixture. Instead, the flame forms a spherical shell filled with combustion products and supported by fuel and oxygen diffusing inward while heat and combustion products diffuse outwards. This diffusion-controlled combustion process provides the weakest known flames and provides a means to study the limits of lean combustion. This is possible only in a microgravity environment, where buoyant flow is absent.



All the combustion in a flame ball takes place in a razor-thin reaction zone that depends on diffusion to keep the ball alive. Such a fragile balance is impossible on Earth.

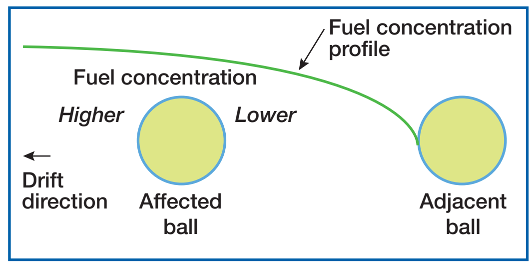
SOFBALL–2 Hardware

SOFBALL–2 experiments will be conducted inside the Combustion Module-2 (CM–2). CM–2 includes one rack that holds the Fluid Supply Package and video support equipment and a double rack that holds the Experiment Package, computer, and mechanical support equipment.

The Experiment Package is an aluminum combustion chamber with diagnostic equipment. Six fused-silica windows let external diagnostic instruments view and measure events inside the chamber. Diagnostic instruments include color and image-intensified cameras, and a gas chromatograph to measure combustion product composition.

The SOFBALL–2 Experiment Mounting Structure (EMS)—which includes experiment-specific diagnostic equipment—is cylindrical and about 62 cm long and 40 cm in diameter (24.4 by 15.7 in.), and weighs approximately 39 kg (87 lb). The main components are the spark igniter; temperature sensors (arranged as a rake of six thin thermocouple wires); two pairs of radiometers; a mixing fan; and volume compensators to reduce the amount of gas needed for each experiment.

A NASA engineer inspecting the EMS in the CM–2.



Scientists learned during SOFBALL–1 that flame balls drift away from each other at a decreasing rate, indicating that they move into areas of greater fuel concentration.

Fields Affected by SOFBALL Results

Combustion physics: Study the simplest interaction of chemistry and transport.

Spacecraft design: Systems that handle hydrogen or biological products (food, waste, and lab animals) that produce hydrogen and other combustible gases.

Automotive engineering: Design of lean-burning engines using pure hydrogen or using hydrocarbon fuels in which hydrogen combustion is a significant component.

SOFBALL–2 Operations

The flight crew will load the EMS into the combustion chamber and activate it. They will run the first three tests through the CM–2 laptop computer. The SOFBALL–2 science team on Earth will adjust conditions from one burn to the next, but the flight crew will initiate combustion, determine whether flame balls exist, adjust and monitor instruments, terminate the experiment, and initiate a reburn if needed. The flight crew can replace the spark igniter tips or thermocouple rake or manually adjust the spark settings, if necessary. The crew will also replace VCR cassettes and computer hard disk drives.

Key science measurements include flame ball size, brightness, temperature, radiant emission, lifetime, and combustion products.

Dr. Janice Voss, a mission specialist on the MSL–1 mission, services an EMS.

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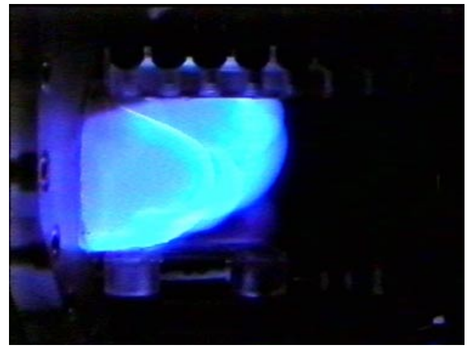
Water Mist Fire-Suppression Experiment (Mist)
Studying Fire in the Sky

Misting Fires Isn't a Foggy Idea

Water is used to put out common fires, but it can also damage computers, paper, and other valuables. However, water mist—like that of a fine fog—has become an important subject of study as a fire suppressant because traditional chemical agents (e.g., halons) are harmful to the ozone layer and have been banned by international agreement. Water mist has many advantages: it's nontoxic, inexpensive, and more efficient than current sprinkler systems.

Because of these advantages, it is important to do research to more fully understand the exact methods by which water mist extinguishes a flame. In addition, it is important to study this phenomenon in microgravity, where gravity-induced effects (such as flame buoyancy and droplet settling) are virtually eliminated, making it easier to understand and model the mechanisms at work.



A flame propagating from left to right, through the flame tube during a normal gravity testing of the Mist experiment at NASA Glenn Research Center.

The Mist project was developed by the Center for Commercial Applications of Combustion in Space (CCACS) at the Colorado School of Mines, in collaboration with the NASA Glenn Combustion Module-2 (CM–2) team. The Mist experiment will be flown on the STS–107 mission of the Space Shuttle.

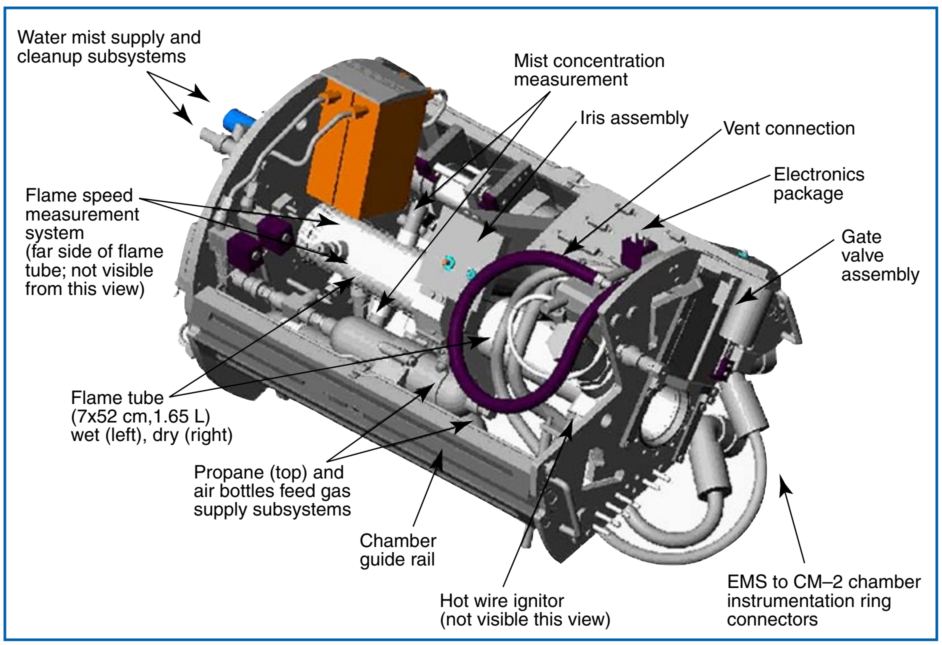
Science Objectives

The purpose of the Mist experiment is to study how water droplet diameter and water concentration affect the speed, strength, and shape of flames created in various fuel and oxygen mixtures. This will be accomplished by measuring the effect of water mist on a flame as it travels through a clear tube and passes from a dry section to a misted section.

Mist Hardware

The Mist Experiment Mounting Structure (EMS) comprises the following five main components:

- Water mist supply subsystem—A water-filled syringe driven by a pump which delivers water to an ultrasonic atomizer.
- Gas supply subsystem—Air and fuel bottles (volumes of 0.5 and 0.3 liters, respectively), mass flow controllers, and a static mixer.
- Flame tube subsystem—A clear polycarbonate tube, 52 cm long and 7 cm in outside diameter, with a volume of about 1.6 liters.
- Vent/cleanup subsystem—The Mist EMS has a direct connection to the CM–2 chamber vent, which in turn leads to the overboard vent out of the SPACEHAB module and into space. Before venting all gases to space, water and combustion products are removed with a desiccant/catalyst filter.
- Electronics subsystem—A control box that contains all of the electronics for power distribution and control of all subsystems.



A 3–D schematic of the Mist EMS with its elements identified.

Mist Operations in Space

The Mist EMS operates while it is installed in the CM–2 chamber. The flame tube, which is divided into two equal sections separated by an iris mechanism, is first evacuated and then filled with a mixture of fuel and oxygen. After closing the iris, one section is filled with a fine water mist generated by an ultrasonic atomizer. Within a few seconds, the dry section of the tube is opened to the CM–2 chamber, the iris is then opened, and the fuel mixture is ignited by a hot wire. The flame moves through the dry section of the tube toward the misted section, taking less than one second or up to several seconds, depending on the ratio of fuel to oxygen. When the flame encounters the mist, it generally slows down, breaks up, or extinguishes before it reaches the end of the tube. The flame speed is measured by a photodiode array and the flame activity is recorded by four cameras.

At the completion of the experiment, post-combustion gases are removed by the Mist cleanup system. Finally, the tube is sealed off from the CM–2 chamber and evacuated in preparation for the next test.

A NASA engineer inspecting the Mist EMS in CM–2.

This panel of images taken during a low-gravity test shows a flame after ignition in the left frame, encountering water mist after clearing the iris in the middle frame, and slowing down and breaking up in the right frame.

Expected Results

The knowledge gained from the Mist experiment will be used to design and manufacture more effective commercial water mist fire-suppression systems that will help save lives and reduce property damage from fires.

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Benefits

- Determine optimum water concentration and water droplet size to suppress fires
- Improve models for designing the next generation of environmentally friendly and low-cost fire-fighting systems

Applications

- Ships (machinery spaces)
- Aircraft (passenger cabin and cargo)
- Spacecraft
- Libraries, museums
- Telecommunication racks
- Commercial cooking areas

For more information, please see the NASA Glenn Microgravity Combustion Web Site at
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National Aeronautics and
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Critical Viscosity of Xenon-2 (CVX–2) on STS–107

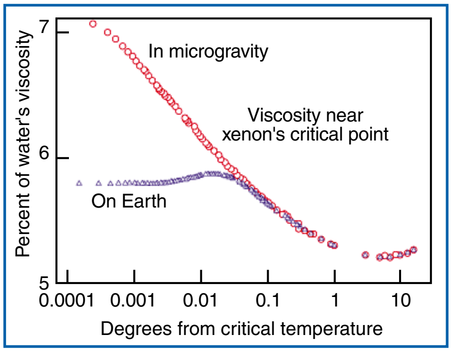
Stirring Up an Elastic Fluid

Whipped cream stays in place even when turned upside down. Yet it readily flows through the nozzle of a spray can to reach the dessert plate. This demonstrates the poorly understood shear thinning phenomenon that is important to many industrial and physical processes. Modern society uses paints, film emulsions, and other complex solutions that are highly viscous under normal conditions but become thin and flow easily under shear forces.

A simple fluid, such as water, does not exhibit shear thinning under normal conditions. Very close to the liquid-vapor critical point, where the distinction between liquid and vapor disappears, the fluid becomes more complex and is predicted to display shear thinning. Behavior in a "critical" state can illuminate how a wider range of materials behave under "normal" conditions. In turn, this may help engineers understand and refine a number of manufacturing processes.

Whipped cream is a familiar material that exhibits the shear-thinning effect seen in a range of industrial applications. It is thick enough to stand on its own atop a piece of pie, yet flows readily when pushed through a tube.

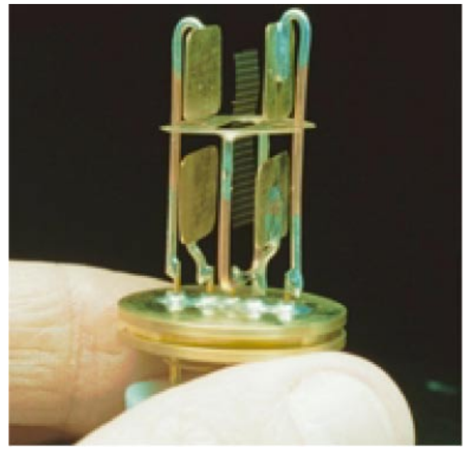
The Critical Viscosity of Xenon-2 Experiment (CVX–2) will measure the viscous behavior of xenon, a heavy inert gas used in flash lamps and ion rocket engines, at its critical point. Although it does not easily combine with other chemicals, its viscosity at the critical point can be used as a model for a range of chemicals.



Because xenon near the critical point compresses under its own weight, experiments on Earth are limited as they get closer (toward the left) to the critical point. CVX in the microgravity of space moved into unmeasured territory that scientists had not been able to reach.

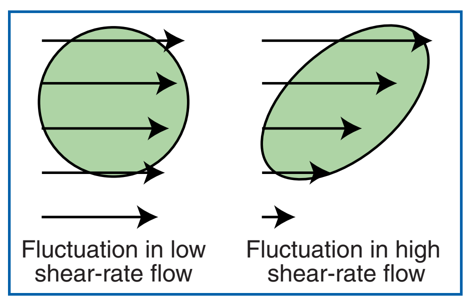
Viscosity originates from the interactions of individual molecules. It is so complicated that, except for the simplest gas, it cannot be calculated accurately from theory. Tests with critical fluids can provide key data, but are limited on Earth because critical fluids are highly compressed by gravity. CVX–2 employs a tiny metal screen vibrating between two electrodes in a bath of critical xenon. The vibrations and how they dampen are used to measure viscosity.

The Critical Viscosity of Xenon (CVX) flew on the STS–85 mission, where it revealed that, close to the critical point, the xenon is partly elastic: it can "stretch" as well as flow. For STS–107, the hardware has been enhanced to determine if critical xenon is a shear-thinning fluid.



Resembling a tiny bit of window screen, the oscillator at the heart of CVX–2 will vibrate between two pairs of paddle-like electrodes. The slight bend in the shape of the mesh has no effect on the data.

On CVX, the screen oscillated at less than 13 cycles per second (13 Hz) through a distance of less than 0.01 mm, less than the thickness of a hair, to avoid disrupting the density fluctuations in the xenon. On CVX–2, the screen vibrates at up to 25 Hz and amplitudes of 0.3 mm in a deliberate attempt to disrupt the density fluctuations and cause shear thinning.



Shear thinning will cause a normally viscous fluid to deform and flow more readily under high shear conditions.

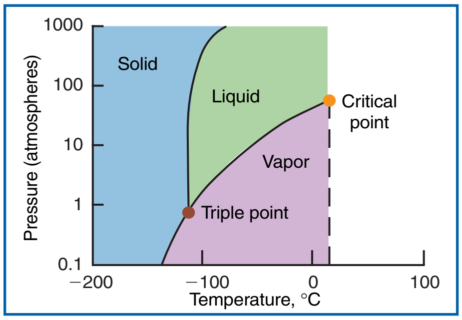
Applications

An understanding of shear thinning in a simple fluid such as xenon will help scientists understand shear thinning in more complex, industrially important fluids, such as

- Paints, emulsions, and foams
- Polymer melts
- Pharmaceutical, food, and cosmetic products

Science

Viscosity—the "thickness" of fluids—is determined by complex interactions between molecules. Except for low density helium, fluid viscosity cannot be predicted accurately by current theory. Progress is being made with experiments using simple fluids near their critical points, a combination of pressure and temperature at which a fluid is balanced between the states of liquid and gas. This balance causes the fluid to fluctuate spontaneously between liquid and gas at a microscopic scale.



Phase diagram of xenon. There is no distinction between liquid and vapor above the critical point.

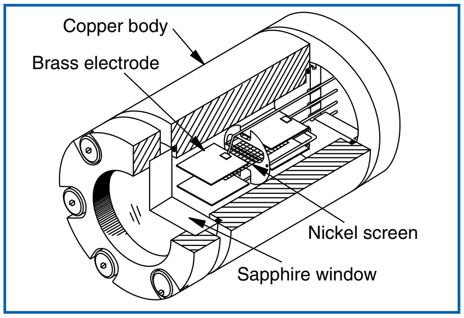
Experiments on Earth are highly limited. At 0.001 °C above the critical temperature, or Tc, xenon is 6000 times more compressible than air. Even a fluid layer as thin as a dime (1 mm) compresses under its own weight, thereby increasing the density at the bottom. Experiments in the microgravity of orbit eliminate density differences and allow extended experiments to achieve the precision that scientists need.

Shear thinning occurs in complex fluids, such as paints and blood, that become "thin" and easily flow under a shear stress such as stirring or pumping. CVX–2 will be the first experiment to examine the shear-thinning phenomenon in a simple fluid.

Hardware

The heart of CVX is a viscometer comprising a nickel screen that vibrates between two pairs of brass electrodes in a xenon bath near the critical point. The grid is 7 × 9 mm and weighs less than 1 mg. An electrode is positioned 4 mm to each side of the screen. An electrical charge applied by the electrodes will oscillate the screen. The electrodes then measure the screen's displacement and period, like a pendulum swinging in a liquid.

The sample cell (left) at the heart of CVX will sit inside a thermostat (right) providing three layers of insulation. The cell itself (below) comprises a copper body that conducts heat efficiently and smoothes out thermal variations that would destroy the xenon's uniformity.



Xenon is a heavy inert gas. The CVX–2 cell holds a small quantity of xenon near the critical temperature (Tc = 16.6 °C, or 62 °F) and critical density (1.1 times that of ordinary water). The resulting pressure is 58 atm, equivalent to a depth under water of 0.6 km.

Because the critical condition requires microdegree control, the sample cell is a copper cylinder, 62-mm long by 38-mm wide that conducts heat well and adds thermal inertia to ensure slow, even changes in temperature. The cell is enclosed in a three-layer thermostat to improve thermal control.

The complete CVX–2 system is contained in two Hitchhiker canisters mounted on the Multi-Purpose Equipment Support Structure (MPESS) in the shuttle payload bay as part of the FREESTAR payload. One canister holds the thermostat, batteries, and analog control electronics. The second canister holds the control electronics, data recorders, and communications system.

CVX–2 will start functioning after the Space Shuttle crew activates it on orbit. Normal operations are automated, but CVX–2 can be controlled from a payload control center at NASA's Goddard Space Flight Center. The experiment plan involves 4 "sweeps" through Tc. That is, the temperature will be gently moved up and down through Tc while the screen oscillates and data is continuously recorded.

Following activation, CVX–2 cools and stabilizes at Tc + 1 °C. Then it is slowly cooled to Tc − 0.02 °C during the next 3 days. CVX–2 will determine Tc to within 0.001 °C. These first results will be compared to those from CVX. Over the next 7 days, the temperature sweeps from Tc + 1 °C to just below Tc while the screen oscillates at different frequencies and amplitudes.

Previous Results

CVX operated well on its first flight on STS–85 in 1997. It accurately measured the viscosity of xenon to within 0.0001 °C of Tc and showed a viscosity increase of 37 percent, double the best measurements on Earth. CVX also showed that xenon's viscoelastic response (a partly elastic response to shear stress) was twice as great as predicted by theory. The results have been published in *Physical Review Letters* (**82**: 920-923, Feb. 1, 1999).

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Space Acceleration Measurement System (SAMS) on STS–107

STS–107 SAMS System

The primary means for scientists to learn more about the microgravity conditions affecting their research is from the SAMS. The SAMS system is produced by the Microgravity Environment Program (MEP) at the NASA Glenn Research Center. The MEP produces a variety of microgravity measurement hardware for on-orbit spacecraft (the International Space Station (ISS) and the space shuttle) and ground-based flights (drop towers, parabolic aircraft, and sounding rockets). Together the various SAMS (SAMS, SAMS–FF (free flyer), and SAMS–II) have supported 22 shuttle missions, the Mir Space Station, and provides ongoing long-term support on the ISS.

The version of the hardware flying on STS–107 is SAMS–FF. This is the second space shuttle flight for the SAMS–FF system, which is a third-generation SAMS system. SAMS–FF uses one-half the power and is only one-third the weight of the original SAMS hardware. It is constructed using industrial-grade components to provide a flexible, modular system that is easily customized for each particular mission. SAMS–FF takes advantage of its flexibility by supporting various ground-based experiments such as sounding rockets between shuttle flights. Characterizing these more quiescent ballistic flights has led to ongoing design improvements. The free flyer name is derived from these ongoing investigations on unmanned vehicles.

The SAMS–FF triaxial sensor head is a small and compact acceleration sensor designed to measure the general vibratory environment. The accelerometers protrude from the enclosure, which contains the microprocessor-based data acquisition system.

The PC/104-based CDU is a small embedded computer system that interfaces between the external sensors and the SPACEHAB module.

The SAMS–FF system consists of a control and data acquisition unit (CDU), three remote acceleration sensor heads, and a fiber-optic gyroscope. The CDU is similar to a desktop computer, except that it is packaged to meet the rigors of spaceflight. It is used to control the operation from the ground and process data from the sensors through a telemetry data stream, which can be seen on NASA computers on the ground. This allows experimenters to view the data collected during the mission so they can correlate their science results with the SAMS data in real time.

Three accelerometers are precisely mounted at right angles to form a triaxial sensor head (TSH). This allows the sensor head to detect vibrations in three different directions of movement: what would be on Earth up and down, forward and backward, and side-to-side. Since there is no up or down in microgravity, the planes are referred to as X, Y, and Z axes. The data is processed to provide the resultant vector of the magnitude and direction, as well as the frequency content, of various time intervals.

The TSH is a microcontroller-based data acquisition system capable of measuring the microgravity accelerations of the shuttle. Sensitive inertial grade accelerometers are used to resolve the very low forces experienced during quiet periods and have the dynamic range to measure the larger vibration disturbances. The output of the accelerometers is digitized using 24-bit sigma-delta analog-to-digital converters to provide a precise readout of the acceleration level. The bandwidth of the TSH is selectable, and the SAMS team commands the operation depending on the desired frequency range of interest. The data and data rate are controlled through an RS–422 serial port connected to the CDU.

A new sensor flown on STS–107 is an inertial grade fiber-optic gyroscope (FOG). To fully capture the motion of the vehicle, not only are the forces examined in three linear or straight directions, but also the rotation of the vehicle is measured to understand the torque forces. Mechanical gyroscopes are used to measure the rotation of the shuttle so it can be controlled. The FOG has no moving parts and is used as an electronic means to precisely measure the roll, pitch, and yaw of the shuttle. It does this by comparing the speed of beams of light traveling in opposite directions around a very long coil of fiber. If there is no rotation, the beams recombine at exactly the same time. However, if the coil is rotated in a particular direction, travel takes longer in the opposite direction before it exits the the coil. This difference is detected by sensitive electronic circuits to determine the rate at which the rotation occurs. Lower grade versions of these gyroscopes are also used in automobiles, combined with GPS data for electronic positioning displays during travel. This is the first shuttle flight for this state-of-the-art device as part of the SAMS system.

Orbital Acceleration Research Experiment (OARE)

In addition to SAMS, which is mounted inside the SPACEHAB and shuttle middeck areas to measure the vibratory accelerations onboard the STS–107 mission, the OARE accelerometer system is used to characterize (measure) the quasi-steady environment. OARE is designed to measure very low frequency microgravity accelerations caused by upper atmospheric drag (as the shuttle passes through the upper atmosphere), rigid body inertial rotations, gravity-gradient effects, shuttle's mass expulsion and crew activities. OARE acceleration data complements that of SAMS by providing the scientists a more thorough understanding of the various accelerations that can affect the experiments onboard the shuttle or any orbiting spacecraft in a low Earth orbit.

The fibersense FOG (right), shown here with a TSH (center), and FOG electronics enclosure (left), precisely measures angular velocity rates without any moving parts.

Principal Investigator Microgravity Services (PIMS)

The PIMS group at NASA Glenn is responsible for processing, analyzing, and archiving the acceleration data measured by the two accelerometer systems previously described. During the STS–107 mission, acceleration data will be transmitted to the ground via telemetry links for real-time processing and analysis so that the scientists can assess the impact of the reduced-gravity environment in near real time on their experiments. Specialized displays are developed by the PIMS group to help the scientists make near real-time decisions in order to lessen the impact of the reduced-gravity environment on their science results, thereby maximizing good science data collection. PIMS will prepare an STS–107 mission microgravity characterization summary report which will highlight the reduced-gravity environment during the STS–107 mission to help the scientists take into account the adverse impact of the environment on their science results. PIMS will provide real-time support and post mission support to the Combustion Module-2 (CM–2) facility.

Specifications	**TSH**	**FOG**	**CDU**
Accelerometers:	Honeywell QA2000-30		
Resolution:	< 1 µg	0.1 Arc-sec.	
Weight:	1.1 lb	6 lb (2 boxes)	6 lbs
Power:	1.65 W	<10 W	30 W (entire system)
Interface:	RS–422	RS–232	Ethernet (external)

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http://microgravity.grc.nasa.gov/MSD/MSD_htmls/acceleration.html

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