National Aeronautics and
Space Administration

Advanced Combustion via Microgravity Experiments (ACME)

Planned International Space Station Research on Gaseous Flames

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ACME is focused on advanced combustion technology via fundamental microgravity research. The primary goal is to improve efficiency and reduce pollutant emission in practical terrestrial combustion. A secondary objective is fire prevention, especially for spacecraft.

ACME includes five independent experiments investigating laminar, gaseous, nonpremixed flames.

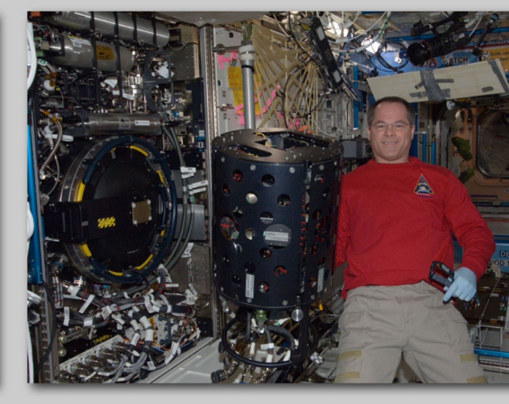
The ACME experiments will be conducted with a single modular set of hardware in the Combustion Integrated Rack (CIR) on the International Space Station (ISS).

An ACME precursor, Structure & Liftoff In Combustion Experiment (SLICE), was conducted in the ISS' Microgravity Science Glovebox (MSG) in early 2012.

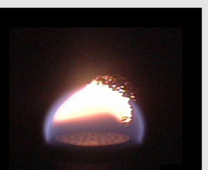
The ACME design is complete and integrated testing of the engineering hardware is underway. On-orbit testing is expected to begin in 2016 and continue for a few years.

ACME is being developed by ZIN Technologies, Inc., under the direction of NASA Glenn.

ACME



Burning Rate Emulator (BRE)

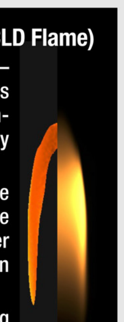


Objective: Fire Safety—To improve the fundamental understanding of materials flammability, such as extinction behavior and the conditions needed for sustained combustion, and to assess the relevance of existing flammability test methods for low- and partial-gravity environments.

Flame/Burner: Flat perforated disk fed with gaseous fuel to simulate the burning of solid and liquid fuels, where measurements are made of the thermal feedback upon which the vaporization of such fuels depend.

Investigators: Professors James G. Quintiere and Peter B. Sunderland, U. Maryland

Coflow Laminar Diffusion Flame (CLD Flame)



Objective: Energy and Environment—To extend the range of flame conditions that can be accurately predicted by computational models, especially for highly dilute and heavily sooting conditions.

Flame/Burner: Coflow flame where the gaseous fuel issues from an inner tube that is centered within a much larger outer tube, where a mixture of oxygen and nitrogen issues from the annulus.

Investigators: Professors Marshall B. Long and Mitchell D. Smooke, Yale U.

Electric-Field Effects on Laminar Diffusion Flames (E-FIELD Flames)

Objective: Energy and Environment—To gain an improved understanding of ion production in flames and investigate how an electric field can be used to control flames through those ions.

Flame/Burner: Gas-jet flame where (1) the gaseous fuel issues from a small circular tube into a still atmosphere and (2) a high-voltage electric field is established between the burner and disk-shaped copper mesh centered a few centimeters downstream of the burner. Tests may also be conducted with ACME's coflow burner.

Investigator: Professor Derek Dunn-Rankin, UC Irvine

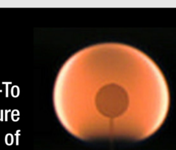
Flame Design

Objective: Energy and Environment—To improve our understanding of soot inception and control in order to enable the optimization of oxygen-enriched combustion and the "design" of nonpremixed flames that are both robust and soot free.

Flame/Burner: Spherical flame where the burner gas issues from a porous spherical burner. Tests are planned for both (1) normal flames, where the fuel flows into an oxygen/inert atmosphere and (2) inverse flames, where an oxygen/inert mixture flows into a fuel atmosphere.

Investigators: Professor Richard L. Axelbaum, Washington U. in St. Louis; Professor Beei-Huan Chao, U. Hawaii; Professor Peter B. Sunderland, U. Maryland; and Dr. David L. Urban, NASA Glenn Research Center

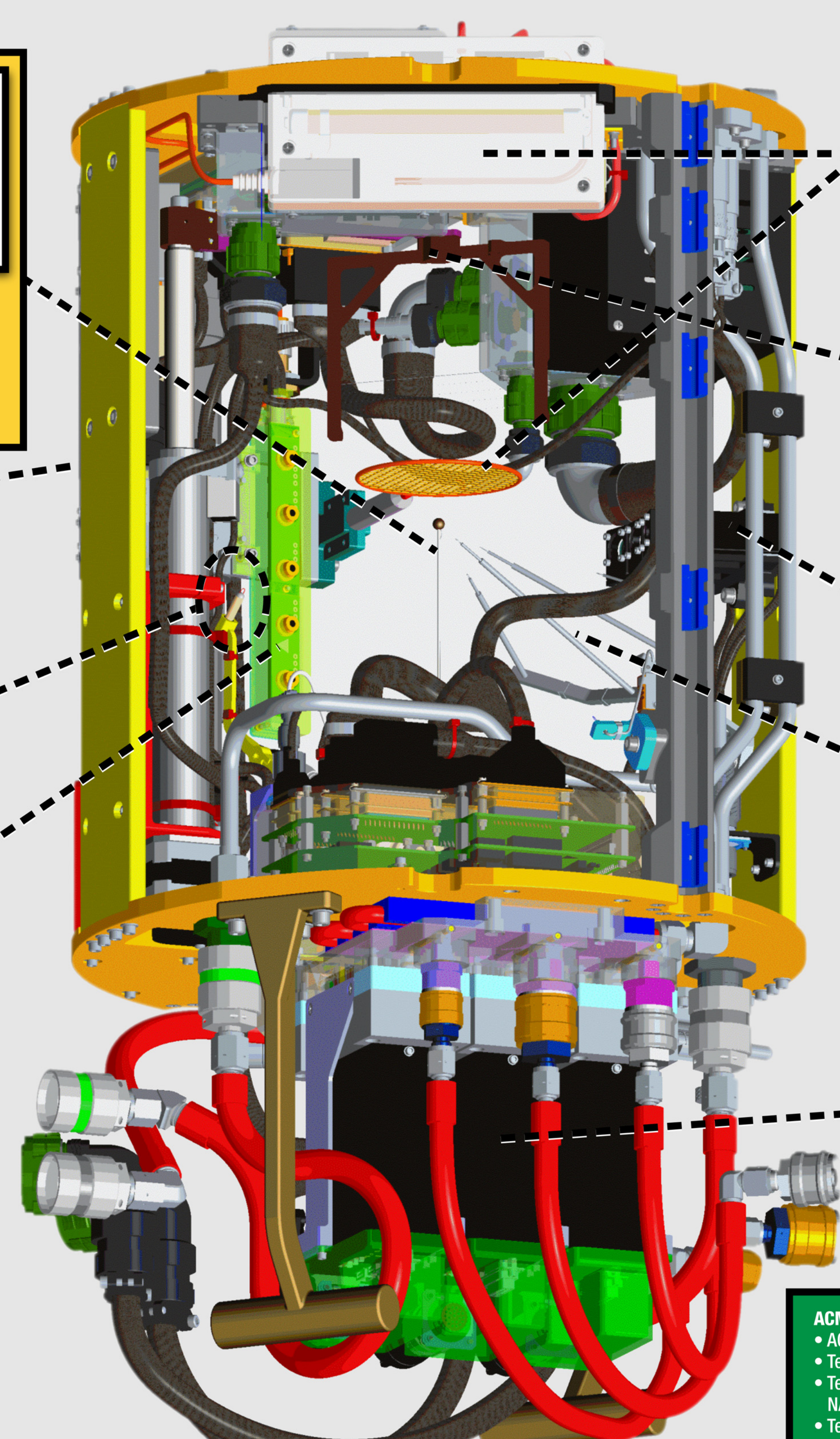
Structure and Response of Spherical Diffusion Flames (s-Flame)

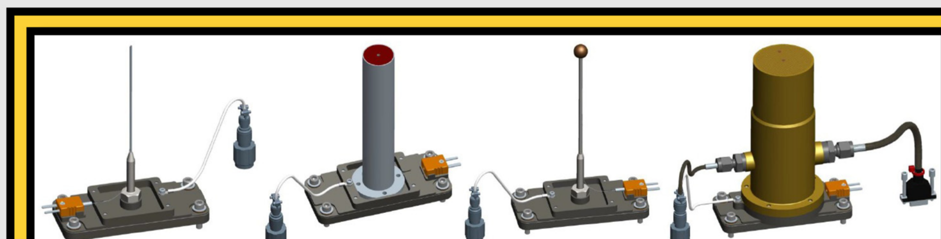


Objective: Energy and Environment—To advance our ability to predict the structure and dynamics, including extinction, of both soot-free and sooty flames.

Flame/Burner: Spherical flame—which is only possible in microgravity—where the gaseous fuel (fed through a small tube) issues from a porous spherical burner into a still atmosphere.

Investigators: Professor C.K. Law, Princeton U.; Professor Stephen D. Tse, Rutgers U.; and Dr. Kurt R. Sacksteder, NASA Glenn Research Center





Burners

- Gas-jet burners, inner diameters (IDs) from 0.4 to 3.2 mm
- Coflow burner, ID of 2.1 mm, outer ID of 25 mm
- Porous spherical burners, outer diameters (ODs) of 6.35 to 12.7 mm
- Flat porous burners for BRE, IDs of 25 and 50 mm, two heat flux transducers on each
- Surface thermocouple(s) on most burners
- Pressure differential measured across outlet of porous burners

Analog Color Camera

- Downlinked in near real time to support experiment operations
- Array of LEDs to illuminate the burner position, etc.

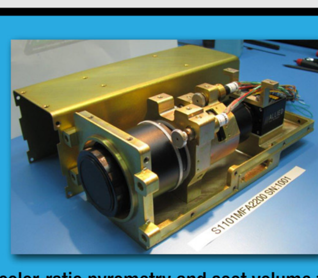
Igniter

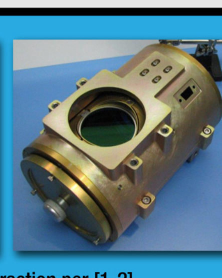
- Resistively heated, retracting, crew-exchangeable tip and arm (to accommodate the various burners), stepper-motor drive for precise positioning

Radiometers (i.e., Thermopile Detectors)

- Crew-exchangeable linear array of radiometers with two options:
  (1) one wide-view radiometer in middle of 4 narrow-view radiometers
  (2) three wide-view radiometers, burner emission masked in one view
- One additional wide-view radiometer, fixed and not crew exchangeable, downstream of the burner and flame at 30° from flame axis, quicker response than more sensitive detectors in linear arrays
- All detectors have 0.2 to 11 micron range, aperture-based field of view (FOV)

Digital Color Camera

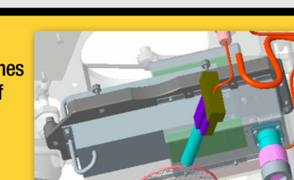


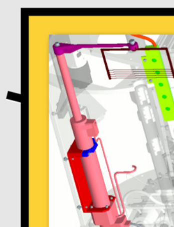


- 12-bit, up to 30 full frames per second, 1360x1024
- Motorized lens with independent control of zoom, iris, and focus
- Four-option filter barrel (which rotates slowly)
  (1) clear "filter" allows for color imaging
  (2) blue-green BG7 Schott glass filter to balance color planes for color-ratio pyrometry and soot volume fraction per [1-2]
  (3 and 4) CH* imaging, 430 and 450-nm filters, where the latter enables subtraction of interfering broadband soot emission

High-Voltage Supply and Electrode Mesh

- −10 to +10 kV to crew-removable mesh for E-FIELD Flames
- Electrode mesh at either ~35 or ~50 mm downstream of burner
- Ion current between mesh and burner determined via Ohm's law and measurement of voltage drop across known resistor



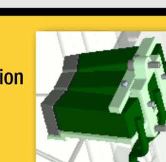


Thin Filament Pyrometry

- Crew-replaceable array of 5 silicon carbide (SiC) fibers (5 mm apart) orthogonal to flame axis
- Alternate array with platinum wire for calibration
- Fiber array translates along flame axis

Photomultiplier Tube (PMT) Modules

- Three PMTs, with wide view angles, to detect extinction
  (1) Broadband, 230 to 700 nm (near UV and visible)
  (2) OH* emission, 310-nm filter
  (3) CH* emission, 430-nm filter

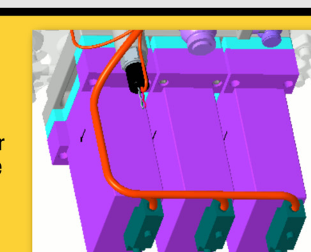


Thermocouples (TC)

- Up to six far-field TCs to measure the thermal field spread for Flame Design and s-Flame
- Two versions of four-TC rake to vary proximity

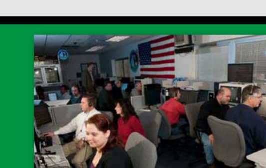
Mass Flow Controllers (MFCs)

- Three MFCs for the delivery of fuel, oxidizer, and/or N_2 to burner (and chamber for filling)
- Maximum fuel flow is 2 slpm (N_2 basis)
- Capable of on-orbit dilution of fuel or oxidizer (but not both at once), coflow flames, inverse flames, and premixed flames



ACME Operations

- ACME experiments are constant volume, ~85 liters free volume
- Tests typically 0.5 to 2 min to limit pressure rise
- Tests manually set up by ISS crew and then commanded from NASA Glenn's Telescience Support Center (TSC)
- Tests conducted in (1) a nominally automated mode using preprogrammed scripts and/or (2) a "manual" mode where changes can be made in response to analog video downlink and/or other telemetry, e.g., adjusting burner flow to approach a soot or stability limit



Color-Ratio Pyrometry

- Carried out with (1) digital color camera by comparing color planes per [1] and/or (2) monochrome camera (with telecentric optical system) and Liquid-Crystal Tunable Filter (LCTF) for imaging at multiple spectra, 30 frames per second at 512x512

Soot Volume Fraction

- Determined from (1) digital color camera per [1-2] and/or (2) extinction measurement [3-5] using monochrome camera (with telecentric optical system) and illumination package (with two fiber-coupled laser diodes), 30 frames per second at 1024x1024

OH* Imaging

- Monochrome camera, intensifier, 310-nm filter, 30 frames per second at 512x512

Gas Chromatograph (GC)

- CIR's GC used for pre- and post-test analysis of chamber atmosphere for O_2, N_2, CO_2, CO, and fuel gases

Three-Axis Accelerometer

- Provided by Space Acceleration Measurement System II (SAMS–II)

References

[1] P.B. Kuhn, B. Ma, B.C. Connelly, M.D. Smooke, and M.B. Long, "Soot and Thin-filament Pyrometry Using a Color Digital Camera," Proceedings of the Combustion Institute, 33 (2011) 743-750.

[2] B. Ma, M. B. Long, "Absolute light calibration using S-type thermocouples," Proceedings of the Combustion Institute, 34 (2) (2013) 3531-3539.

[3] P.S. Greenberg and J.C. Ku, "Soot Volume Fraction Imaging," Applied Optics, 36 (22) (1997) 5514-5522.

[4] D.L. Urban, Z.G. Yuan, P.B. Sunderland, K.C., Lin, Z. Dai, and G.M. Faeth, "Smoke-Point Properties of Nonbuoyant Round Laminar Jet Diffusion Flames," Proceedings of the Twenty-Eighth Symposium (International) on Combustion 28 (2000) 1965-1972.

[5] F.J. Diez, C. Aalburg, P.B. Sunderland, D.L. Urban, Z.-G. Yuan, G.M. Faeth, "Soot properties of laminar jet diffusion flames in microgravity," Combustion and Flame, 156 (2009) 1514-1524.