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Microgravity Combustion Payload Accommodations in the International Space Station Fluids and Combustion Facility

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MICROGRAVITY COMBUSTION PAYLOAD ACCOMMODATIONS IN THE INTERNATIONAL SPACE STATION FLUIDS AND COMBUSTION FACILITY

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Abstract

The Fluids and Combustion Facility (FCF) will support sustained, systematic microgravity combustion science and fluid physics research aboard the International Space Station (ISS). It will consist of three on-orbit racks in the ISS United States Laboratory Module. The combustion integrated rack (CIR) will be uniquely configured to support microgravity combustion research. Combustion experiment equipment will be installed on-orbit to customize the CIR for many different experiments during the 10 or more years it will operate aboard the ISS. Studies are planned of laminar flames, reaction kinetics, droplet and spray combustion, flame spread, fire and fire suppressants, condensed-phase organic fuel combustion, turbulent combustion, soot and polycyclic aromatic hydrocarbons, and flame-synthesized materials. The CIR will be used for international and commercial investigations, as well as for research sponsored by NASA and the United States government. This paper overviews payload accommodations, science diagnostics, and capabilities to assist researchers in formulating experiments and in defining hardware concepts for microgravity combustion experiments in the FCF aboard the ISS.

Introduction

The International Space Station (ISS) will provide scientists from around the world access to the unique microgravity environment of near Earth orbit and unparalleled opportunities for research in space throughout the first few decades of the twenty-first century. Significant scientific and technical advances are expected from this research. The ISS will increase scientists' access to space, extend on-orbit research times, and provide unique, space-based facility capabilities for exploring various physical, chemical, and biological processes in microgravity.

Microgravity combustion science investigations to be performed aboard the ISS are motivated by the opportunity for significant scientific advancement and by practical Earth-based and space system applications of combustion research. Spacecraft fire safety is a key concern for human exploration of space, and most contemporary spacecraft propulsion systems are driven by combustion. An understanding of combustion behavior and key technologies resulting from this understanding are important for the design of safe and efficient spacecraft. On Earth, combustion is central to billion dollar industries, technologies, and systems that improve our standard of living. However, combustion also produces unwanted byproducts, such as pollutants, that affect the environment in which we live. Space offers extended opportunities for making the critical measurements needed to understand and resolve many of these practical combustion problems.

The ISS United States Laboratory Module will contain multiple facilities developed by the NASA Microgravity Science Program to enable the implementation of both fundamental science experiments and technology development demonstrations. One of these ISS facilities being developed by NASA, called the Fluids and Combustion Facility (FCF), will provide sophisticated research capabilities for microgravity combustion science and fluid physics investigations. The FCF will consist of flight systems (i.e., facility racks) aboard the ISS that work together with ground systems to accomplish a large number of science investigations over the life of the ISS. The modular, multiple-user facility will optimize the science return from the ISS within the available resources of on-orbit power, uplink and downlink capacity, crew time, up mass, down mass, and volume. It will provide a suite of diagnostics capabilities, with emphasis on optical techniques, to complement the capabilities of multiple-user or principal-investigator-specific experiment modules that enable research to be performed (1).

Fluids and Combustion Facility

The ISS Fluids and Combustion Facility will occupy three powered racks and one stowage rack in the ISS (2). Powered on-orbit racks will operate in conjunction with FCF ground systems to accommodate 10 high-quality, complex, fluids and combustion experiments annually, within nominal ISS resource constraints. It is expected that over 80 percent of microgravity fluids and combustion spaceflight experiments proposed and developed for flight over the next several decades will be accommodated in the FCF. The flexibility of the FCF allows it to accommodate additional high-quality experiments sponsored by commercial entities, ISS international partners, or disciplines outside fluids and combustion.

The FCF consists of a flight segment and a ground segment (Fig. 1). The ground segment includes ground racks and equipment to be used for hardware and software integration, experiment development, astronaut training, telescience operations, and other essential Earth-based functions supporting microgravity fluid physics and combustion experiments in the FCF. The FCF flight segment includes three on-orbit racks: the combustion integrated rack (CIR), the fluids integrated rack (FIR), and the shared accommodations rack (SAR).

The CIR features a 100-liter combustion chamber surrounded by optical and other diagnostics packages, including a gas chromatograph. It contains a gas supply and vent system for delivery of metered gaseous fuel and oxidizer and for exhaust from the combustion chamber. The FIR features a large user-configurable volume for experiments. This volume resembles a laboratory optics bench. An experiment can be built up on the bench from components, or it can be attached as a self-contained package. The SAR contains shared data storage and computational capabilities. Among other things these allow the principal investigator (PI) to optimize the science return by analyzing large volumes of image data between data point runs. The SAR can provide powered storage for scientific samples needing that capability, can serve as a sample preparation and FCF maintenance area, and can provide active storage of fluids and gases needed for certain types of fluids and combustion experiments. When not being used for the foregoing, it provides a significant volume and an optics bench configurable for experiments.

The CIR and the FIR will be deployed to the ISS first and initially will operate independently, supporting the first combustion and fluids payloads. After the SAR is on-orbit, the three FCF racks will operate together as an integrated facility to meet scientific objectives and principal investigator throughput requirements during steady-state operations.

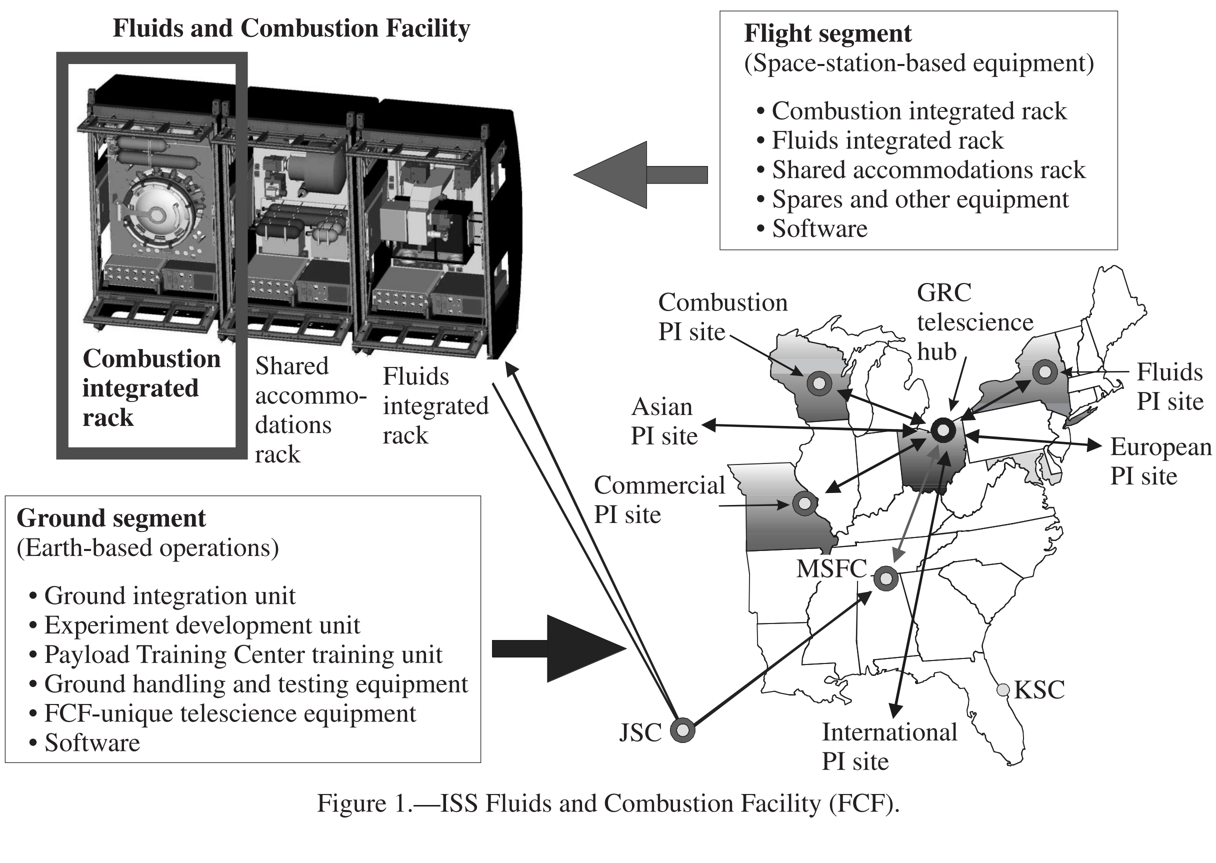


Figure 1.—ISS Fluids and Combustion Facility (FCF).

Combustion Payloads

Combustion experiments that may be performed in the ISS Fluids and Combustion Facility include, but will not be limited to, the study of laminar flames, reaction kinetics, droplet and spray combustion, flame spread, fire and fire suppressants, condensed-phase organic fuel combustion, turbulent combustion, soot and polycyclic aromatic hydrocarbons, and flame-synthesized materials. The facility will supply much of the on-orbit services and capability needed to perform these experiments, thereby minimizing the amount of unique hardware and software developed for each investigation. When possible, similar investigations will be flown in groups to increase the use of common hardware and diagnostics. To further reduce hardware requirements, an initial set of three multiple-user combustion chamber inserts are being designed (Fig. 2). The inserts will, to the greatest extent possible, include experiment-specific hardware needed for a class of investigations (3).

Initial combustion experiments planned for the CIR will study small droplets of pure and bi-component alcohol and hydrocarbon fuels burning in an oxygen or inert gas atmosphere. Liquid fuels are a primary source for energy production, and the study of their combustion has been of interest for decades. In addition, nearly all practical uses of combustion involve non-premixed conditions, which are more easily studied by using a well-defined system, such as an isolated droplet. A combustion chamber insert called the multiple-user droplet combustion apparatus (MDCA) will support these initial ISS experiments. This insert will contain the droplet deployment mechanisms, hot-wire igniters, a fuel supply system, and a gas-mixing fan. The droplet (nominally 1 to 6 mm in diameter) will be generated by issuing fuel from a pair of needles brought together in the center of the test region. Various other droplet combustion investigations using the MDCA insert are planned, including the determination of sooting and dynamic flow effects on burning droplets in microgravity.

Investigations to study the combustion of small solid fuel samples are also being planned for the ISS. Such studies are important for developing improved material flammability tests and predictions and for developing improved modeling of ignition, spread, and extinction of flames in solid materials. Enhanced fire prevention and suppression on Earth and in spacecraft are potential benefits of this research. Therefore, an insert capable of supporting these investigations and called the flow enclosure accommodating novel investigations in combustion of solids (FEANICS) is being developed and will be accommodated in the FCF CIR. Most solid combustion investigations require a sample holder, a flow duct for providing a low-speed convective flow

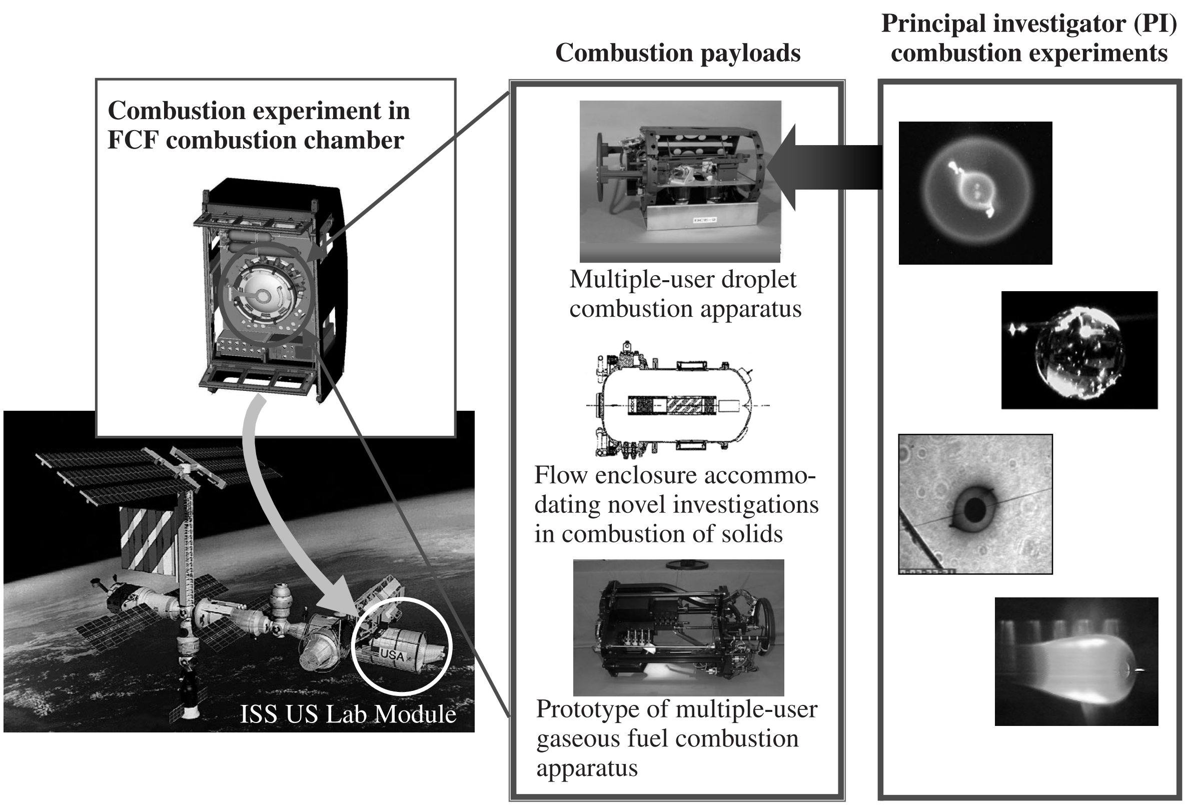


Figure 2.—Multiple-user combustion chamber inserts.

environment, an ignition system, and a clear volume for imaging the flame and the solid fuel surface. It is anticipated that at least two solid fuel investigations will be performed in the CIR using FEANICS.

Other investigations to study various types of gaseous fuel combustion are being planned for the ISS. Mixed and non-premixed gaseous combustion using nozzles of various sizes, flame vessels and tubes, and porous spherical burners will be studied. Gaseous combustion occurs in many practical systems, and the use of gaseous fuels simplifies the study of the main processes in combustion, chemical reaction, and heat and mass transfer. For some of these experiments a multiple-user gaseous fuel combustion apparatus (MGFA) will be used. Concepts for this combustion chamber insert are being developed and are anticipated to be similar to those for the insert used on combustion modules 1 and 2 for the laminar soot process experiment.

Customized inserts for singular investigations having requirements not amenable to the multiple-user inserts will be developed as resources permit. It is expected that commercial and international investigators will provide their own chamber inserts (or barter resources in exchange for using a multiple-user insert) and associated experiment-unique equipment for their accommodation in the FCF.

Resources

Table 1 shows the typical annual, steady-state ISS resources expected to be available for facility and payload operations using the FCF combustion integrated rack. For a steady-state facility utilization rate of five combustion payloads per year, approximately one-fifth of the resources shown in Table 1 would be available for a typical, individual experiment run in the CIR. Resource allocations will vary according to experiment-specific needs, the evolving ISS configuration, and on-going ISS needs. However, the CIR and the payloads currently in development are being designed to operate within the resource envelope shown in Table 1.

TABLE 1.—STEADY-STATE RESOURCES FOR PAYLOAD OPERATIONS IN FCF COMBUSTION INTEGRATED RACK

ISS resources	Resource quantity per year
On-orbit volume (rack equivalent volume)	1.0 Facility's international standard payload rack plus 0.76 m^3 (26.6 ft^3) of stowage volume
Up mass, kg/yr (lb/yr)	750 (1653)
Down mass, kg/yr (lb/yr)	750 (1653)
Up volume, m^3/yr (ft^3/yr)	1.86 (66)
Down volume, m^3/yr (ft^3/yr)	1.86 (66)
Energy, kW-hr/yr	3200
Crew time, hr/yr	180
Communications downlink, terabits/yr	22.3
Communications uplink, terabits/yr	1.082×10^{-4}
Late/early access (launch/return/both/none)	N/A

FCF Combustion Integrated Rack

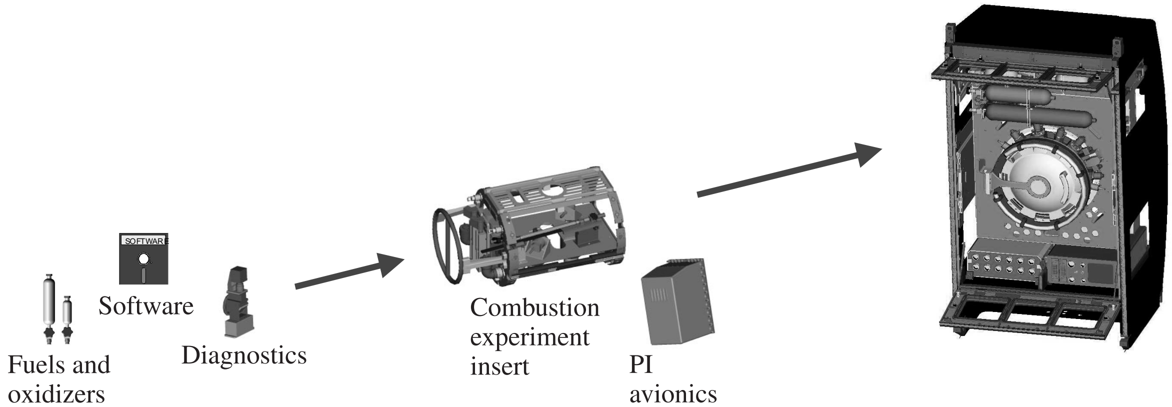
Combustion experiment equipment will be installed on-orbit in the FCF combustion integrated rack (CIR) to customize it for performing many different combustion experiments during the 10 or more years that it will operate on-orbit. A diverse range of combustion experiments will be conducted in the FCF CIR. When the FCF is fully deployed, the CIR will accommodate a minimum of 5 and as many as 15 combustion experiments per year, depending on the availability of ISS resources.

The basic concept behind the FCF CIR is to provide up to 90 percent of the hardware required to perform most future microgravity combustion experiments aboard the ISS. The remaining 10+ percent of the required experiment-specific hardware will be provided by the principal investigators' hardware development teams. The FCF provides support systems and diagnostics commonly used by most combustion experiments. Multiple-user chamber inserts, avionics, diagnostics, and other hardware and software customize the facility for specific combustion subdisciplines. PI-specific items, such as fuels, oxidizers, consumables, and unique instrumentation, configure the facility to perform a given PI's research (Fig. 3). PI-specific hardware will be launched separately from the CIR and integrated with the CIR on-orbit. A significant amount of PI-specific hardware is expected to be multiple use and/or reused for follow-on experiments. This concept reduces development cost, total up mass (mass launched), and other ISS resources required to perform experiments aboard the ISS.

CIR Hardware Description

The FCF combustion integrated rack incorporates an optics bench, a combustion chamber, a gaseous fuel and oxidizer management assembly, an exhaust vent system, science diagnostics, power, an environmental control system, a command and data-handling system, space acceleration measurement capability, and an active rack isolation system (4). An experiment insert will be installed in the combustion chamber for each investigation. The combustion chamber insert will include equipment such as a sample holder or burner, solid or liquid fuels, an ignition source, a flow duct, small diagnostics such as radiometers, and experiment-specific instrumentation such as thermocouples. A computer that controls the experiment equipment in the rack is installed on the optics bench. It includes circuit boards, power supplies, software, and other avionics specific to the experiment. Consumable items, such as fuels, exhaust vent filters, and gas bottles, will be resupplied for each experiment (Fig. 4).

The CIR's international standard payload rack (ISPR) provides structural support and connections to ISS-provided utilities, such as cooling water, electrical power, data interfaces, gaseous nitrogen, and vacuum resources. A door on the rack's front provides thermal containment, acoustic attenuation, crew-safe operations, and full access to the internal contents of the rack. The active rack isolation subsystem (ARIS) isolates rack-level vibrations to meet acceleration requirements for combustion experiments conducted in the CIR. It attenuates on-orbit, low-frequency (<10 Hz), low-amplitude mechanical vibrations transmitted from the ISS United States Laboratory Module to the CIR. For frequencies between 0.01 and 10 Hz, ARIS is expected to limit accelerations in the CIR to approximately 10^{-6} g. A space acceleration measurement system (SAMS) sensor is mounted in the CIR to measure the microgravity acceleration environment in the rack. SAMS measures accelerations from $1.0{\times}10^{-6}$ to $1.0{\times}10^{-2}$ g at frequencies from 0.01 to 200 Hz.



Experiment-specific items

- Fuels, oxidizers, and consumables
  - Gaseous fuels and oxidizers
  - Liquid or solid fuel supplies
  - Gas chromatograph check gases
  - Adsorber cartridge filters
- PI-unique hardware and software
  - Specific avionics and software
  - Specialized diagnostics or modules (e.g., cameras, lenses, filters, optics, control avionics, and software)
- Specific instrumentation

Multiple-user PI equipment

- Combustion experiment insert
  - Experiment orientation
  - Support structure
  - Flow ducts; test sections
- PI avionics package
  - Multiple-use control electronics, motor drivers, etc.
  - Software modules
- Multiple-use diagnostics and lighting
  - Radiometers
  - PI-unique illumination sources

FCF combustion integrated rack

- Combustion chamber
- Diagnostics
  - Eight standard locations (with SAR)
  - Image processing and storage
- Gaseous fuel and oxidizer management
  - Gas supply and blending
  - Exhaust vent or gas chromatograph
- Electrical power control unit
  - Power conditioning and control
- Command and data handling
- Active rack isolation
- Environmental control
  - Water and air cooling
  - Gas interface and fire detecction

Figure 3.—FCF combustion integrated rack and payload equipment used for combustion experiments.

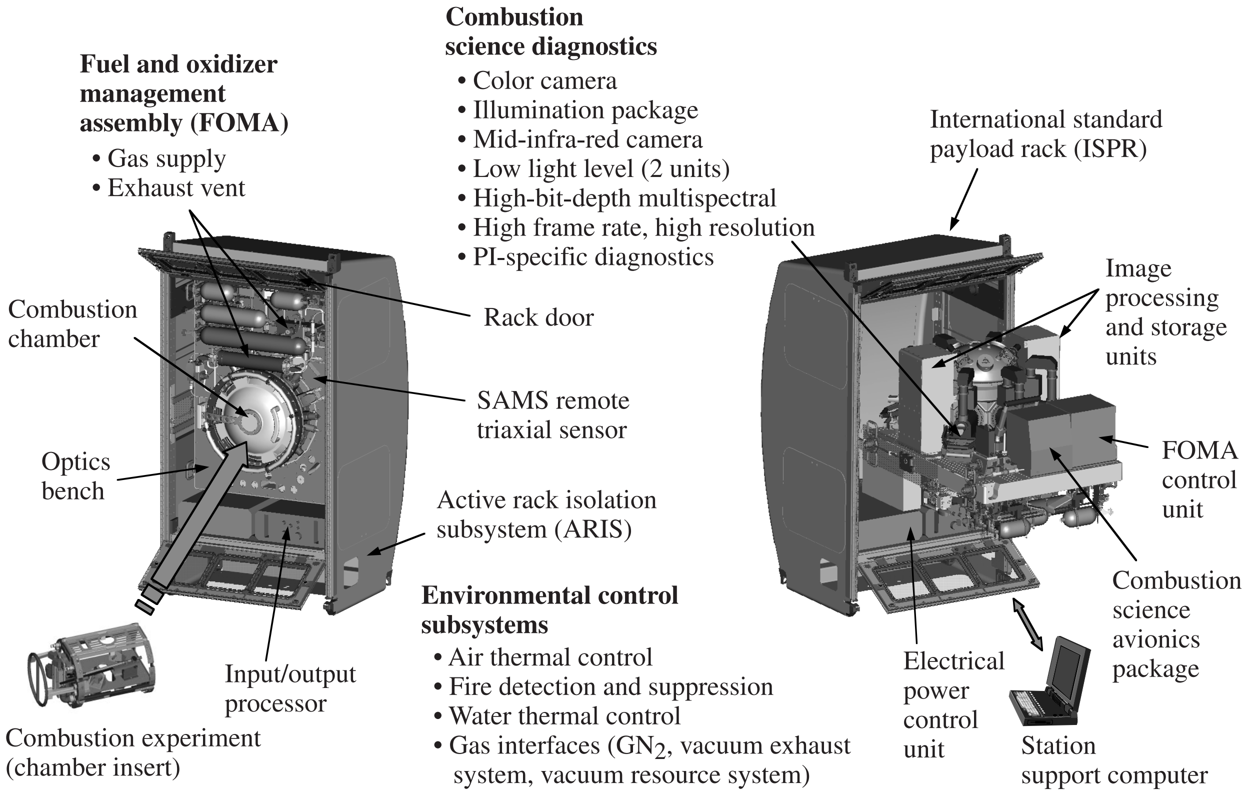


Figure 4.—Elements and subsystems of FCF combustion integrated rack hardware.

CIR environmental control subsystems remove waste heat, provide rack-level fire detection and suppression, and provide interfaces to ISS-supplied gases and vacuum. These subsystems include a water thermal control subsystem, an air thermal control subsystem (ATCS), a fire detection and suppression subsystem, and a gas interface subsystem. The ATCS nominally removes up to 1500 W of waste thermal energy by flowing air through the avionics equipment. A primary water loop cools all nonscience hardware by means of cold plates in the CIR power controller, the ARIS controller, and the CIR air-to-water heat exchanger. A secondary loop supplies water to experiment-specific equipment in the combustion chamber. The CIR also gives access to ISS-provided nitrogen, exhaust, and vacuum services.

CIR avionics provide power, command processing, caution and warning, health and status monitoring, data processing, data storage, time synchronization, and hardware control functions associated with the operation of the CIR. Image processing and storage units (IPSU) in the CIR control the operation of science diagnostics packages, acquire and store images from the diagnostics, capture and record ancillary data such as date and time, transfer images and ancillary data to the input/output processor for downlinking, and allow real-time analog video output. Each IPSU can control one imaging diagnostics package. A fiber optic umbilical connects the three FCF racks to permit high-speed data transfer between racks, independent of the ISS data system. The fiber optic interface enables control and acquisition of images from diagnostics in the CIR if IPSU computers are located in other FCF racks. An electrical power control unit supplies up to 3 kW of 28-Vdc power to loads in the CIR on 48 fault-protected, 4-A circuits. Six fault-protected, 120-Vdc, 4-A circuits are also available for large, single-experiment loads.

An optics bench supports the CIR combustion chamber, the fuel and oxidizer management assembly (FOMA), the science diagnostics packages, the image processing avionics, and the experiment-specific electronics in the rack. Items frequently accessed by the crew, such as gas bottles, filters, and the combustion chamber lid, are located on the front of the optics bench. Diagnostics and avionics packages are mounted on the rear of the optics bench at one of nine mounting locations that provide standard mechanical, data, power, and air-cooling interfaces (Fig. 5). The optics bench is 90.2 by 124.5 by 10 cm.

The CIR fuel and oxidizer management assembly is used to deliver gaseous fuels, diluents, and oxidizers to experiments in the combustion chamber. Up to four gas bottles can be installed simultaneously. The maximum gas pressure in each bottle is 13 790 kPa (2000 psi). Gases are bottled in three sizes: 1.0, 2.25, and 3.8 liters and can be either pure or premixed. Premixed

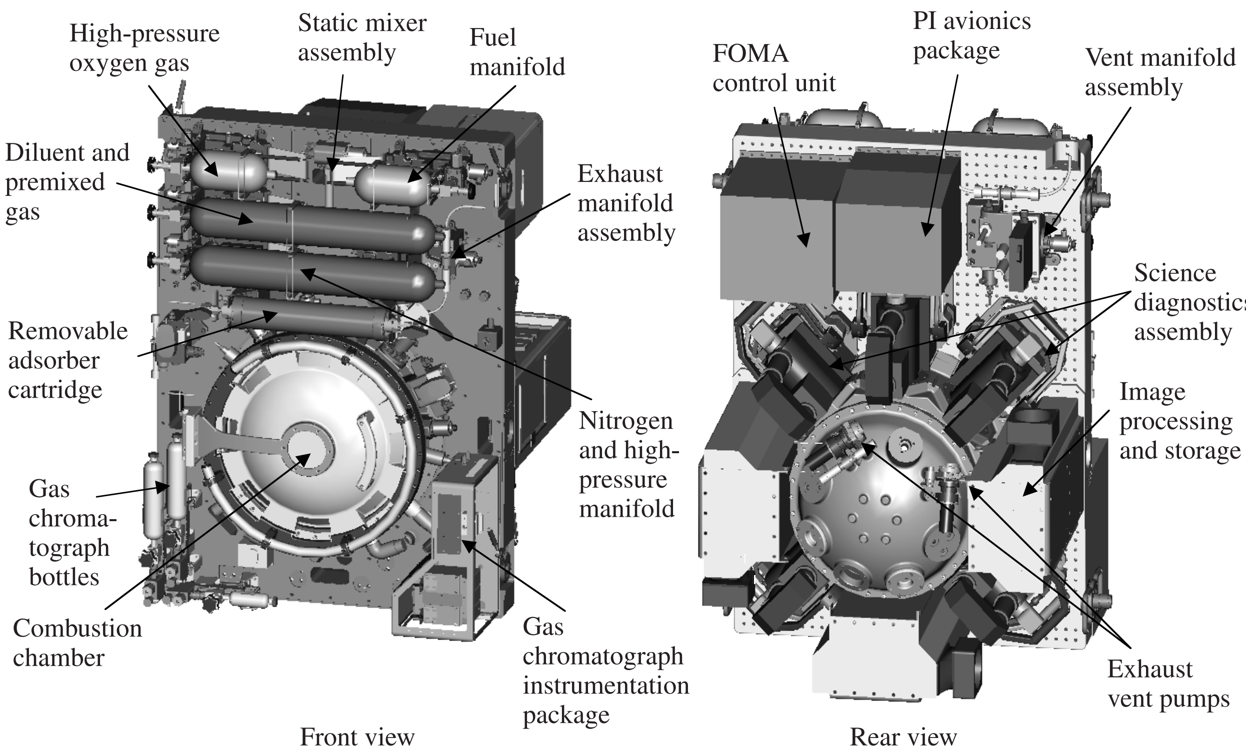


Figure 5.—Optics bench assembly in FCF combustion integrated rack.

gases are used if an experiment requires a unique gas mixture or precise constituent accuracy exceeding the FOMA on-orbit gas blending capability. On-orbit gas blending will typically be used because it reduces up mass and on-orbit stowage needs for experiments. The FOMA can provide a desired gas ratio by using either static or dynamic gas mixing. Static gas mixing uses the partial pressures to establish the desired gas ratio. Dynamic gas mixing uses mass flow controllers to achieve the desired gas mixture and chamber atmosphere. For some experiments real-time venting may be required to maintain the desired pressure and chemical constituency in gases near the experiment in the combustion chamber.

The FOMA also controls the venting of chamber gases at acceptable concentration levels to the ISS exhaust system. The exhaust vent system includes an adsorber cartridge and a recirculation loop and is used to condition the chamber gas environment for sequential test points or to convert postcombustion gases into species acceptable for venting. Two recirculation pumps pump chamber gases through the recirculation loop. The vent package scrubs combustion gases to acceptable compositions for venting by removing moisture, particulates, and trace amounts of unburned fuels and chemically alters some trace species (e.g., CO to CO_2). The combustion chamber gases may be sampled by a gas chromatograph to verify that they meet ISS requirements for venting or to measure pre- and postcombustion gas compositions in the chamber as part of the experiment.

The CIR combustion chamber accommodates an experiment insert that is 60.0 cm long and 39.6 cm in diameter. The chamber has a 100-liter free volume and a design pressure of 827 kPa (120 psig), permitting combustion studies at ambient and elevated pressures (initial gas pressures of 0.02 to 3 atm). Diagnostics packages are arranged outside the chamber on the optics bench and are aligned to view the combustion event through one of eight optical windows (11.5 cm in diameter), allowing for three simultaneous orthogonal views. The chamber has eight fused-silica windows 8 mm thick with a transmission wavelength of 200 nm to 5 mm and two ports 63.5 mm in diameter in the rear endcap for additional chamber access. These ports can be used for additional windows if the experiment requires them. Because the windows are removable, experimenters can provide other windows that match the spectral requirements of their diagnostics and/or remove the windows for cleaning and replacement (Fig. 6).

Combustion Science Diagnostics

The FCF provides advanced imaging systems capable of microscopic to macroscopic imaging at low to very high frame rates and over ultraviolet to infrared wavelengths. Some are intensified systems for low-light imaging. Some are capable of intelligent,

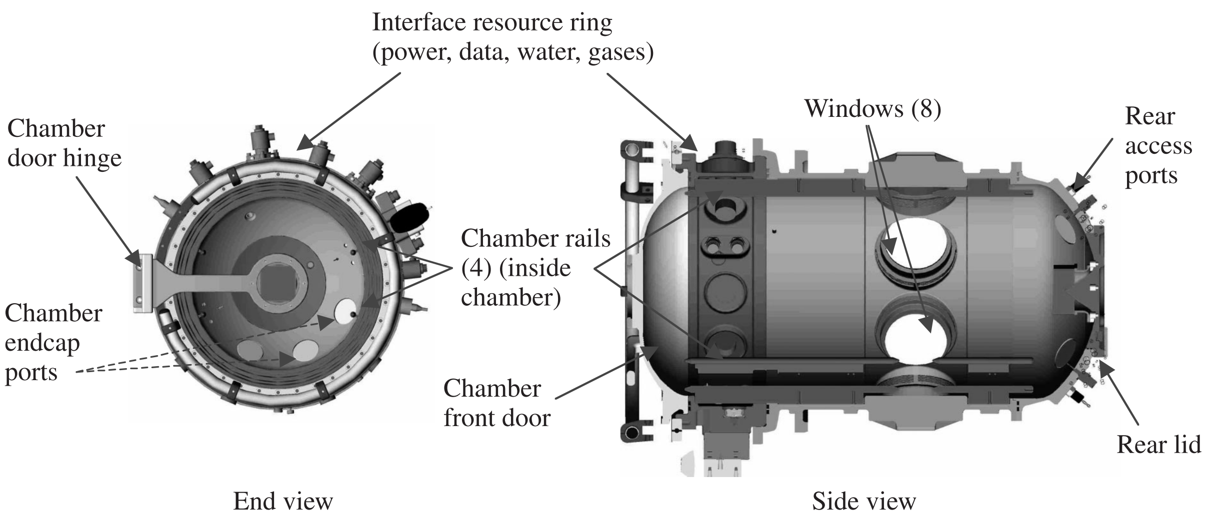


Figure 6.—Combustion chamber in FCF combustion integrated rack.

automatic target acquisition, tracking, focusing, and zoom. The FCF also contains several combustion science diagnostics packages, allowing for measurements commonly needed by many combustion experiments. The determinations of flame shape, structure, and color; soot volume fraction; soot temperature measurement; high-frame-rate monochrome imaging; OH, CH, and H_2O emission measurements; thermal mapping; and background illumination are of common interest. Functions such as automated positioning and tracking and autofocus reduce manual reconfiguration and data storage and acquisition requirements. The FCF also has mass storage and postprocessing capability for digital image data.

Facility diagnostics packages are constructed from modules connected at standard interfaces to enable easy, on-orbit diagnostics package reconfiguration and technology upgrades that extend imaging capabilities. These modules include a diagnostics control module, an optics module, filter modules, reflective optics, relay optics, and an image acquisition module (Fig. 7). Combustion diagnostics packages operate together with an illumination package and an image processing and storage unit to collect image data from an experiment. Entirely new diagnostics assemblies may be installed for an experiment, or optical components, such as special optics, lenses, cameras, or filters, may be provided to modify the capabilities of seven standard, facility-provided combustion science diagnostics packages.

The seven standard diagnostics packages planned as facility-provided capabilities in the FCF CIR are a high-bit-depth multispectral imaging package (HiBMs); a high-frame-rate, high-resolution package (HFR/HR); a low-light-level ultraviolet package; a low-light-level infrared package; a color camera package; an infrared imaging (mid-IR) package; and an illumination package. The HiBMs package is used to measure the soot volume fraction and soot temperature of soot-producing flames. Soot temperature is measured by using a two-wavelength (or more) pyrometry technique. Soot volume fraction is determined by measuring the percentage of laser illumination, from the illumination package, that is blocked by soot in the flame region. Measurements are made at the wavelength of the illumination package laser diode (675 nm) and at the wavelengths chosen for soot temperature measurements.

The HFR/HR diagnostics package provides programmable frame rates up to 110 fps and high optical resolution performance (1024 by 1024 pixels at frame rates up to 30 fps). It can automatically track an object within the total field of view while maintaining a sharp focus over a full object distance displacement range of 30 mm. The HFR/HR package may be used with the illumination package, which supplies object backlighting and can be set to operate with a laser diode or an incandescent light. The HFR/HR package can also serve as a high-resolution broadband imaging package. Adding a liquid-crystal tunable filter could allow for narrowband multispectral imaging, including two- or three-wavelength pyrometric measurements to determine soot temperature. When combined with a suitable external illumination source, the package could be used for particle imaging velocimetry.

Two low-light-level (LLL) packages supply images of events or objects at low radiance levels. The packages provide imaging capabilities in the spectral ranges 280 to 700 nm (UV shifted) for OH imaging and 500 to 875 nm (IR shifted) for H_2O imaging. The LLL packages are positioned on the optics bench to provide orthogonal views of an experiment. The investigator will have

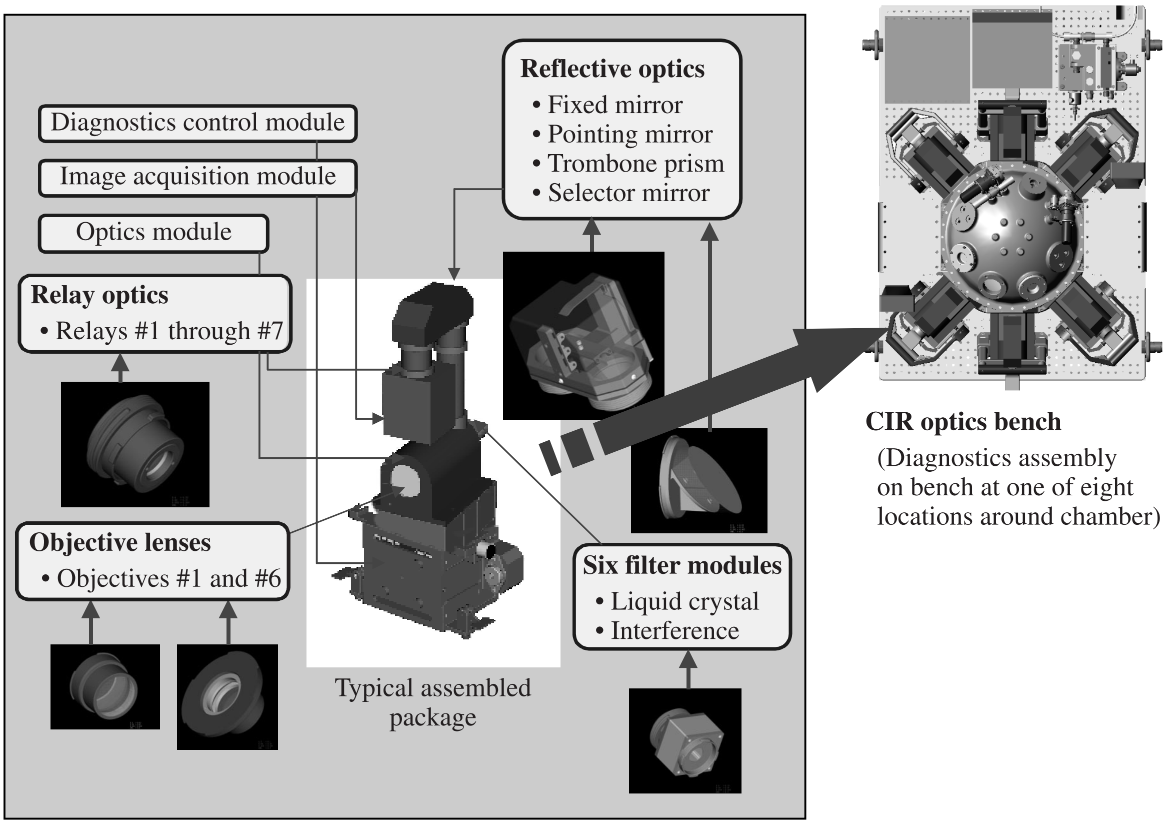


Figure 7.—Modular design of facility-provided combustion science diagnostics package.

the option to configure these packages by using two identical LLL units or to view the combustion event in two different spectral regions. For low-frame-rate requirements a red-green-blue liquid tunable filter could be installed in an LLL package to acquire color images.

The color camera package supplies color images for determining flame shape, structure, and color. It is also used by the crew and ground personnel for checkout and verification during pre- and postcombustion events. A mid-IR camera package produces images of events or objects emitting from 3600 to 5000 nm. The CIR illumination package is used in conjunction with diagnostics that require backlighting. Illumination sources include a current-stabilized tungsten halogen lamp for radiometric calibration and laser diodes for coherent interference-free illumination. The illumination package provides a uniform illumination background for soot absorption measurements in soot volume fraction applications. The package diffuse laser diode is used as the background illumination source for shadowgraph measurements with the HiBMs and for droplet size measurements with the HFR/HR. The modular design of the illumination package supports future growth considerations. The coherent laser diode illumination path can be used for interferometric or schlieren applications. Table 2 summarizes the features and capabilities of all facility-provided combustion science diagnostics.

Summary

The International Space Station Fluids and Combustion Facility will provide extensive capabilities for both microgravity fluid physics and combustion science experiments aboard the ISS. The facility design supports autonomous operation of experiments, and its modular features allow reconfiguration to support many different types of experiment over the 10 or more years that the facility will be operational aboard the ISS. The FCF combustion integrated rack is the only facility payload rack designed for the ISS that specifically supports combustion science investigations. The combustion integrated rack provides advanced diagnostics supporting imaging needs common to many different combustion investigations (i.e., diagnostics that allow measurement of soot temperature and soot volume fraction, thermal mapping, and the determination of flame shape and structure). The facility also accommodates other diagnostics provided by the principal investigator to extend measurement capabilities and meet experiment-specific requirements.

TABLE 2.—FCF-PROVIDED COMBUSTION SCIENCE DIAGNOSTICS CAPABILITIES

Capability	Package						
	HiBMs	HFR/HR	Color camera	Low light level 1	Low light level 2	Infrared imaging camera	Illumination
Application	Soot volume fraction and temperature; shadowgraph	High frame rate; high resolution	Configuration; verification	OH and CH emissions	H_2O emissions	Absorption line temperature	Calibration; background illumination; interferometry
Number of pixels	1024 or Bin 2×2	512[a] 1024[b]	512	1024	1024	320×244	(c)
Field of view, mm	80 and 50 diameter telecentric	10 square (37 total) telecentric	58 to 350 square zoom	48 to 212 square zoom	48 to 212 square zoom	183×138	80 diameter collimated
Resolution, lp/mm	5 and 10	12 at 50% mod.[a]; 20 at 50% mod.[b]	4.4 to 0.7	12.1 to 2.4	12.1 to 2.4	0.9	(c)
Bit depth, number of bits	12	8	24	8	8	12	(c)
Run time,[d] min	20	20	27	20	20	20	(c)
Frame rate, fps	15	110[a] 30[b]	30	30	30	60	(c)
Spectrum, nm	650 to 1050	450 to 750	400 to 1050	280 to 700	500 to 875	1000 to 5000	3000 K[g] 675[h]
Sensitivity	1200 K to 2000 K[e]; 0.8 K/mm[f]	600 lux	2 lux	6×10^{-9} ft-candle	4.4×10^{-9} ft-candle	–10 °C to 1500 °C	5-mW output
Features	Manual iris	Centroid tracking; autofocus; event trigger	Manual iris; manual focus	Manual iris; manual focus	Manual iris; manual focus	Manual focus	Light source selectable

[a]At high frame rate.
[b]At high resolution.
[c]Not applicable.
[d]At frame rate specified below.
[e]For soot temperature.
[f]For shadowgraph.
[g]Color temperature.
[h]Peak wavelength for diffuse and coherent laser diode sources.

NASA plans to make the Fluids and Combustion Facility available to support the experiments of ISS international partners and commercial users. It is expected that commercial and international investigators will provide their own chamber inserts (or barter resources in exchange for using a multiple-user insert) and associated experiment-unique equipment for their accommodation in the FCF. Additional information and FCF contacts are available at the FCF World Wide Web site at *http://fcf.grc.nasa.gov*

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13. ABSTRACT ***(Maximum 200 words)***

The Fluids and Combustion Facility (FCF) will support sustained, systematic microgravity combustion science and fluid physics research aboard the International Space Station (ISS). It will consist of three on-orbit racks in the ISS United States Laboratory Module. The combustion integrated rack (CIR) will be uniquely configured to support microgravity combustion research. Combustion experiment equipment will be installed on-orbit to customize the CIR for many different experiments during the 10 or more years it will operate aboard the ISS. Studies are planned of laminar flames, reaction kinetics, droplet and spray combustion, flame spread, fire and fire suppressants, condensed-phase organic fuel combustion, turbulent combustion, soot and polycyclic aromatic hydrocarbons, and flame-synthesized materials. The CIR will be used for international and commercial investigations, as well as for research sponsored by NASA and the United States government. This paper overviews payload accommodations, science diagnostics, and capabilities to assist researchers in formulating experiments and in defining hardware concepts for microgravity combustion experiments in the FCF aboard the ISS.

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