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Microgravity Combustion Science and Fluid Physics Experiments and Facilities for the ISS

Richard W. Lauver, Fred J. Kohl, Karen J. Weiland, Robert L. Zurawski,
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Abstract

At the NASA Glenn Research Center, the Microgravity Science Program supports both groundbased and flight experiment research in the disciplines of Combustion Science and Fluid Physics. Combustion Science research includes the areas of gas jet diffusion flames, laminar flames, burning of droplets and misting fuels, solids and materials flammability, fire and fire suppressants, turbulent combustion, reaction kinetics, materials synthesis, and other combustion systems. The Fluid Physics discipline includes the areas of complex fluids (colloids, gels, foams, magnetorheological fluids, nonNewtonian fluids, suspensions, granular materials), dynamics and instabilities (bubble and drop dynamics, magneto/electrohydrodynamics, electrochemical transport, geophysical flows), interfacial phenomena (wetting, capillarity, contact line hydrodynamics), and multiphase flows and phase changes (boiling and condensation, heat transfer, flow instabilities).

A specialized International Space Station (ISS) facility that provides sophisticated research capabilities for these disciplines is the Fluids and Combustion Facility (FCF). The FCF consists of the Combustion Integrated Rack (CIR), the Fluids Integrated Rack (FIR) and the Shared Accommodations Rack and is designed to accomplish a large number of science investigations over the life of the ISS. The modular, multiuser facility is designed to optimize the science return within the available resources of onorbit power, uplink/downlink capacity, crew time, upmass/downmass, volume, etc. A suite of diagnostics capabilities, with emphasis on optical techniques, will be provided to complement the capabilities of the subsystem multiuser or principal investigatorspecific experiment modules. The paper will discuss the systems concept, technical capabilities, functionality, and the initial science investigations in each discipline.

Introduction

Through the first decades of the 21st century, the International Space Station will provide convenient, longterm access to the environment of nearEarth orbit at an unprecedented scale. The station is truly international in scope and offers multiple opportunities for unique and cooperative activities in both scientific and engineering endeavors. The 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.

The potential for significant scientific and technical advances through conduct of experiments in the unique environment of microgravity remains a key element for justification of the

International Space Station. Such advances have been demonstrated during the recent history of microgravity experiments on the Space Shuttle and the promise of expanded access and extended times in orbit provide increased opportunity for improved understanding of Earthly processes and demonstration of technologies required to explore the universe.

Glenn Research Center provides leadership for the NASA Microgravity Science Program in two scientific disciplines, Combustion Science and Fluid Physics, which will provide a primary focus of the Microgravity Program for both scientific and technological activities. These discipline program elements have initiated a facilityscale development project which will evolve from independent, standalone capabilities for combustion (the Combustion Integrated Rack or CIR) and fluid physics (the Fluids Integrated Rack or FIR) to a fully integrated 3 rack facility called the Fluids and Combustion Facility (or FCF) with addition of a third rack of hardware (called the Shared Accommodations Rack or SAR). The fully integrated FCF will provide existing capabilities (as well as great flexibility for upgrades and customization) to implement most, if not all, the experiments brought to the program. The full potential of the modular, integrated FCF will support the longterm, lowgravity requirements of investigators from academia, industry, and our international partners throughout its 10 to 15 year lifetime.

This paper briefly summarizes the early science and facility hardware to be flown by the Combustion Science and Fluid Physics discipline programs and endeavors to describe the overall capabilities of the Fluids and Combustion Facility.

Combustion Science Experiments

The Fluids and Combustion Facility (FCF) will support extensive study of combustion in microgravity. The combustion experiments that may be conducted in the FCF include, but are not 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 flamesynthesized materials. The facility will provide most of the capability with a small amount of unique hardware developed for each investigation and, when possible, similar investigations will be flown at the same time to increase the use of common hardware and diagnostics. To further reduce hardware requirements, an initial set of three multiuser chamber inserts is being designed. The inserts will, to the greatest extent possible, include experimentspecific hardware needed for a class of investigations. Custom inserts for singular investigations having requirements not amenable to the multiuser inserts will be developed as resources permit and it is expected that commercial and international investigations will provide their own chamber insert (or barter other resources in exchange for use of a multiuser insert). A total of fourteen flight and flightdefinition investigations supported by the NASA Microgravity Science Program and one or more commercial investigations are currently foreseen to use the CIR over the first few years of operation. Several international investigations are at the conceptual stage, and additional microgravity science investigations will be solicited every two years through NASA Research Announcements. The order in which a particular investigation flies is subject to change based upon results from science reviews, engineering development time, and other factors. A more extensive description along with figures of the hardware inserts are in Ref. 1.

Four investigations are being planned to study the combustion of small droplets of pure and bicomponent alcohol and hydrocarbon fuels. Liquid fuels are a primary source for energy production in the world and the study of their combustion has been ongoing for decades. Nearly all practical uses of combustion involve nonpremixed conditions; these are more easily studied using a welldefined system such as an isolated droplet and the study of droplet combustion remains a classic combustion problem. One investigation, Droplet Combustion Experiment2, is a reflight; the remaining three are in early phases of development. A multiuser hardware insert based upon the apparatus developed for the Droplet Combustion Experiment (Ref. 2) will be utilized as possible. This insert contains the droplet deployment mechanisms, hot wire igniters, a fuel supply system, and a gasmixing fan. The droplet is generated by issuing fuel from a pair of needles brought together in the center of the test region. The droplet is formed between the tips of the needles; the tips are stretched apart slightly after the droplet reaches the proper size (1 to 6 mm diameter) and then are withdrawn rapidly to deploy the droplet. At the moment of deployment, the hotwire igniters are activated to ignite the droplet and then they too are withdrawn. The droplet may be deployed into free space or onto a small ceramic fiber. The insert structure is open to permit viewing of the droplet and flame. It is anticipated that at least two droplet investigations will be the first users of the Combustion Integrated Rack after its launch.

Six investigations are currently planned for the study of the combustion of small solid fuel samples. Such studies are important for the development of improved material flammability tests and predictions, and for development of improved modeling of ignition, spread, and extinction of flames in solid materials. Enhanced fire prevention and extinguishment on the Earth and in spacecraft are potential benefits of this research. Unwanted fires result in a significant number of deaths and lost property each year on the Earth, and the possibility of an accidental fire in a spacecraft remains a concern. Two solid fuel investigations are in the requirements definition and engineering concept formulation phase. The remainder are beginning the initial phase of science concept formulation. Preliminary requirements from these investigations are guiding the development of a multiuser chamber insert capable of implementing the proposed experiments. Most of the investigations require a sample holder, a flow duct to provide a low speed convective flow environment, an ignition system, and a clear volume for imaging of the flame and solid fuel surface. It is anticipated that at least two solid fuel investigations will be performed in the CIR using this new apparatus.

Six investigations are currently planned for the study of various types of gaseous fuel combustion. Premixed and nonpremixed 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 as well as in unwanted fires. The use of gaseous fuels simplifies the study of the main processes in combustion, chemical reaction and heat and mass transfer. All of these investigations are in the experiment concept formulation phase and will undergo several science reviews prior to flight. For as many experiments as possible, the hardware insert will be based upon the chamber insert developed for the Laminar Soot Processes experiment flown in the shuttlebased Combustion Module (Ref. 3). This structure contains a small fuel nozzle with a hot wire igniter, a farfield thermocouple rake, a flame radiometer, and thermophoretic soot samplers. During these experiments, fuel issues from the nozzle into a quiescent chamber filled with oxidizer where it is ignited by the hot wire igniter (positioned near the nozzle tip). When the data collection is complete, the fuel flow is ended and the flame extinguishes. The reflight of a commercial investigation studying the efficacy of water mist as a fire suppressant is also planned.

Combustion Science Facility

Microgravity combustion experiments will be performed onboard ISS in the Combustion Integrated Rack (Ref. 4). Experimentspecific equipment installed on orbit in the CIR will customize it to perform many different combustion experiments during the ten or more years that it will operate on orbit. The CIR will be the first FCF rack deployed to the Space Station in 2003. Once the other FCF racks are deployed, the CIR will function with the integrated FCF to provide enhanced capability as a complete onorbit combustion research facility. As noted above, a diverse range of combustion experiments will be conducted in the CIR. When the FCF is fully deployed, the CIR will accommodate a minimum of five and as many as ten combustion experiments per year, depending upon the availability of ISS resources.

In order to meet performance requirements, the CIR (Ref. 5) is designed as a permanent, modular facility that can perform sustained, systematic research in microgravity combustion science on board ISS. It will function on board ISS for ten or more years without the need for major rack refurbishment or changeout and will, along with associated ground equipment, provide the majority of hardware and infrastructure required to perform combustion science investigations in ISS. The CIR will be capable of operating independently or in conjunction with added services and capabilities provided by other FCF racks (i.e., SAR and/or FIR). The modular and flexible design of the CIR will enable it to support a diverse range of experiment equipment in various configurations. Key components of the CIR are onorbit replaceable to enable upgrades, incorporate new technology and/or provide for onorbit maintenance during life span of the facility. The CIR is designed to conserve ISS resources. For example, the CIR design supports autonomous operation of experiments and rapid reconfiguration, minimizing required flight crew time for experiment set up and allowing experiments to be primarily operated, monitored and controlled from the ground. The CIR also includes a standard set of sensors and imaging equipment to measure typical combustion phenomena, so as to minimize the need for PIunique equipment.

The CIR primary subsystems and hardware elements, include an International Standard Payload Rack (ISPR) with rack doors, an Active Rack Isolation Subsystem (ARIS), an optics bench assembly with combustion chamber to accommodate the experiment insert, a fuel/oxidizer management assembly (FOMA) for gas supply and distribution and exhaust venting, environmental control subsystems (air/water thermal control, gas supply and fire detection/suppression), avionics, software, electrical power supply and science diagnostics, as shown in Figure 1 (Ref. 6).

The CIR ISPR provides structural support and connections to Stationprovided utilities such as cooling water, electrical power, data interfaces, gaseous nitrogen and vacuum resources. A door on the front of the rack provides thermal containment, acoustic attenuation, crewsafe operations and full access to the internal contents of the rack. ARIS provides racklevel vibration isolation to meet acceleration requirements for combustion experiments conducted in the CIR. It attenuates onorbit, low frequency (<10 Hz), low amplitude mechanical vibrations transmitted

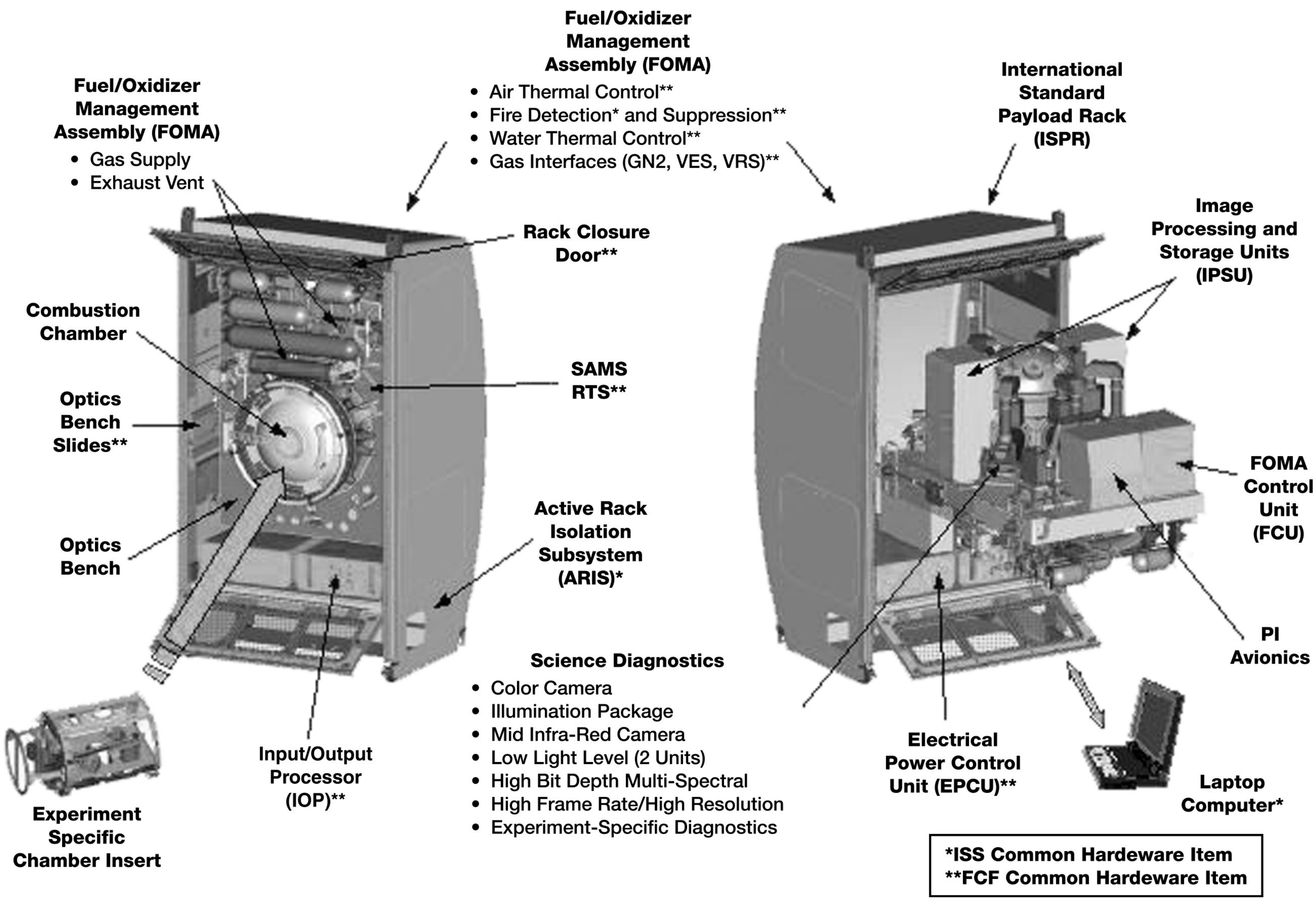


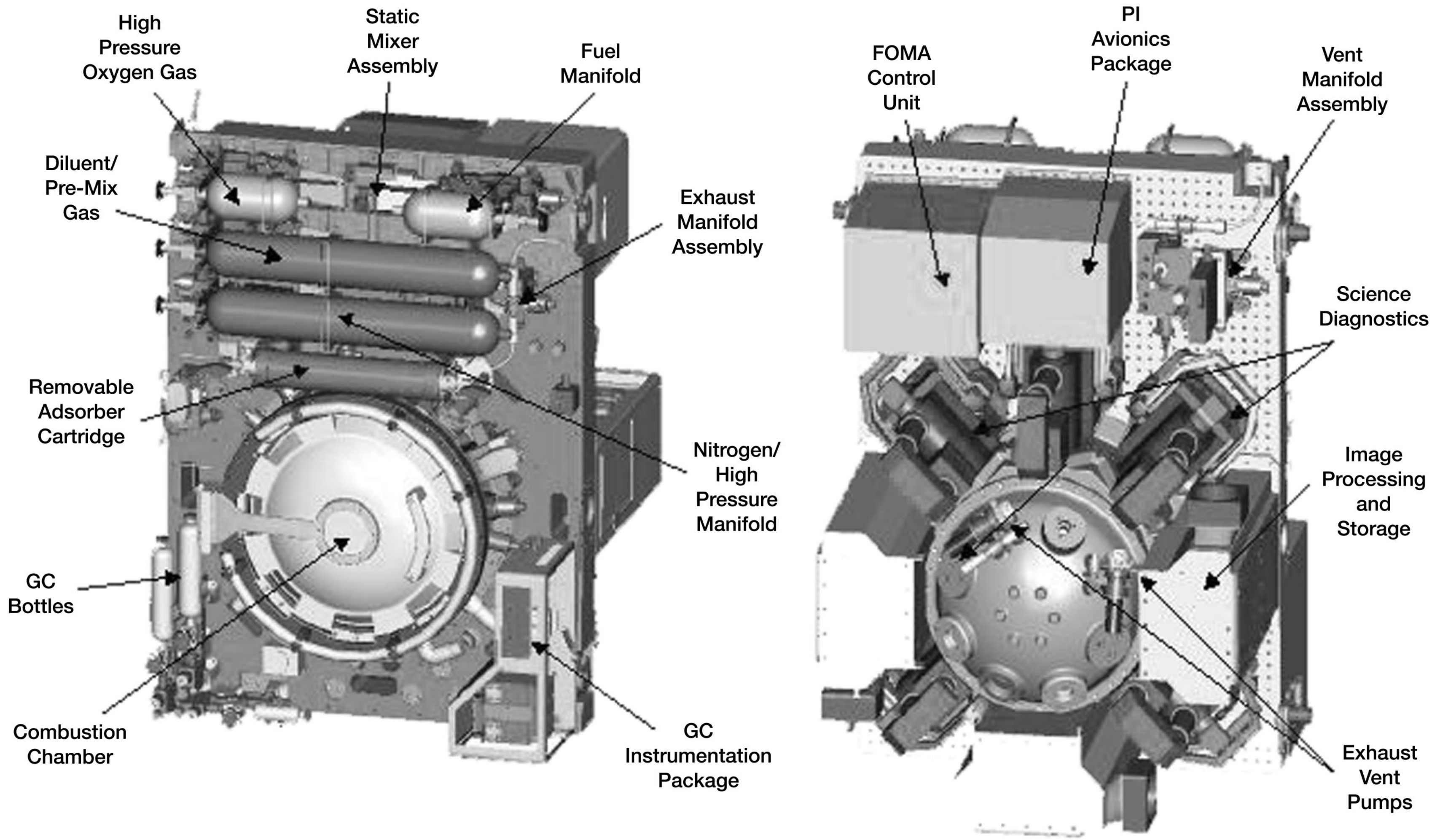
Figure 1.—Combustion Integrated Rack and Major Subsystems.

from the ISS US Laboratory Module to the CIR. For frequencies between 0.01 and 10 Hz, ARIS is expect to limit accelerations in the CIR to microg levels. 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 x 10^6 g to 1.0 x 10^2 g at frequencies from 0.01 to 200 Hz.

An optics bench (Figure 2) supports the CIR combustion chamber, fuel and oxidizer management assembly (FOMA), science diagnostics packages, image processing avionics and experimentspecific 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. 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) which will permit combustion studies at ambient and elevated pressures (initial gas pressures of 0.02 to 3 atmospheres). Diagnostic packages are arranged outside of the chamber on the optics bench and are aligned to view the combustion event through one of eight optical windows (11.5 cm dia). The windows are removable and interchangeable from inside the chamber to match the spectral requirements of the diagnostics and/or for window cleaning/replacement.

The CIR Fuel and Oxidizer Management Assembly (FOMA) 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 (2,000 psi). Gases are bottled in three sizes: 1.0 liter, 2.25 liter and 3.8 liter and can be either pure or premixed. Premixed gases are used if an experiment requires a unique gas mixture or very precise constituent accuracy exceeding the FOMA onorbit gas blending capability. However, onorbit gas blending will typically be used since it reduces upmass and onorbit stowage needs for experiments. The FOMA can provide a desired gas ratio using either a static and dynamic gas mixing technique. The static mixing method uses the partial pressures to establish the desired gas ratio. For experiments requiring gas flow during a test, the desired gaseous fuel mixture and chamber atmosphere is provided using the mass flow controllers. Realtime venting is performed to maintain the desired pressure in the combustion chamber.

The FOMA also controls the venting of chamber gases at acceptable concentration levels to the ISS exhaust system. An 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 that are acceptable to vent. Chamber gases are pumped through the recirculation loop using two recirculation pumps. The vent package scrubs combustion gases to acceptable compositions for venting by removing moisture, particulates, trace amounts of unburned fuels and chemically alter some trace species (e.g., CO to CO_2). The combustion chamber gases are sampled using a gas chromatograph to verify that the chamber gases meet ISS requirements for venting or to measure pre and postcombustion gas composition in the chamber as part of the experiment.



Optics Bench Assembly (Front View)

Optics Bench Assembly (Rear View)

Figure 2.—CIR Optics Bench Assembly and Subsystems.

CIR environmental control subsystems remove waste heat, provide racklevel fire detection and suppression and provide interfaces to ISSsupplied gases and vacuum. These subsystems include a Water Thermal Control Subsystem, Air Thermal Control Subsystem (ATCS), Fire Detection and Suppression Subsystem and Gas Interface Subsystem. The ATCS removes up to 1500 Watts of waste thermal energy via air flow through avionics equipment. A primary water loop cools all nonscience hardware via cold plates in the CIR power controller, ARIS controller and CIR air to water heat exchanger. A secondary loop supplies water to experimentspecific equipment in the combustion chamber. The Gas Interface Subsystem provides access to ISSprovided 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 IOP for downlinking and provide for realtime analog video output. Each IPSU can control one imaging diagnostic package. A fiber optic umbilical connects the three FCF racks to allow 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 using IPSU computers located in other FCF racks. An Electrical Power Control Unit supplies up to 3kW of 28 Vdc power to loads in the CIR on fortyeight, faultprotected, 4 amp circuits. Six, faultprotected 120 Vdc x 4 amp circuits are also available for large, singleexperiment loads.

Seven standard diagnostic packages (Figure 3), constructed from modular elements, are planned as initial capabilities for the CIR. Science diagnostics consist of modules (i.e., imaging module,

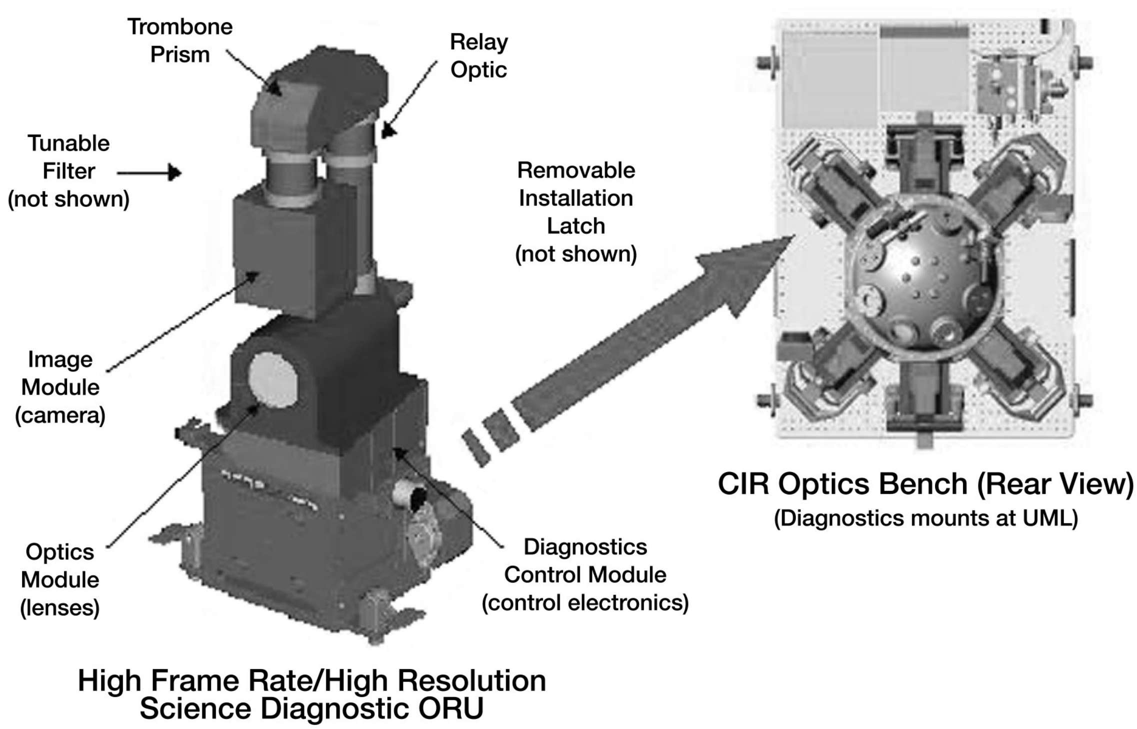


Figure 3.—Configuration of Modular Diagnostic Subsystems.

optics modules, diagnostics control module) which are connected at standard interfaces. The diagnostic package operates together with an illumination package and an image processing and storage unit to collect image data from an experiment. The modularity of these packages permits performance and technology upgrades to the basic capabilities. The initial suite of CIR diagnostics will includes a High Bit Depth/Multispectral Imaging Package (HiBM), High Frame Rate/High Resolution (HFR/HR) Package, two Low Light Level (LLL) Packages, a Color Camera Package, an Infrared Imaging Package and an Illumination Package.

The HiBM Package is used to measure soot volume fraction and soot temperature of sootproducing flames. Soot temperature is measured using a two (or more) wavelength 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 Diagnostic provides programmable frame rates up to 110 fps and high optical resolution performance (1024 x 1024 pixels at frame rates up to 30 fps). It is capable of automatically tracking 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 provides 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 broad band imaging package. The addition of a liquid crystal tunable filter could allow for +narrow band multispectral imaging including two or three wavelength pyrometric measurements to determine soot temperature. When combined with a suitable external illumination source, the package can also be used for Particle Image Velocimetry (PIV).

The Low Light Level (LLL) packages provide images of events or objects at low radiance levels. The Packages provide imaging capabilities in the 280700 nm spectral range (UV shifted) for OH imaging and 500875nm (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 the option to configure these packages by selecting the utilization of two identical LLL units or to view the combustion event in two different spectral regions. For low frame rate requirements, an RGB liquid tunable filter could be installed in a LLL Package to acquire color images. A Color Camera Package provides color images used by the crew and ground personnel for checkout and verification during pre and postcombustion events. A midinfrared 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 backlight illumination. Illumination sources include a current stabilized tungsten halogen lamp for radiometric calibration and laser diodes for coherence 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 package 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 could be used for interferometric or Schlierren applications.

Typically, the CIR will provide up to 90% of the required hardware to perform combustion experiments. The remaining hardware will be provided by the experiment. Experimentspecific hardware is launched separately from CIR and integrated with the CIR on orbit. An experiment insert is installed in the combustion chamber to control the desired flame geometry and perform other functions unique to an experiment. The insert may include PIunique diagnostics (e.g., thermocouples, radiometers, cameras, etc.), igniters, sample cells, liquid or solid fuel supplies, flow tunnels, translation stages or other equipment attached to the insert mounting structure, nominally 39.6 cm in diameter by 60 cm in length. Multiuser inserts are being planned to accommodate multiple experiments with common characteristics. The first such insert being developed is a MultiUser Droplet Combustion Apparatus that will accommodate four different droplet combustion experiments.

The CIR is in the detailed design and fabrication phase (Crew Review completed November 1998; Phase 0/1 Flight Safety Review completed in December 1998; Preliminary Design Review completed in April 1999). Engineering models for most CIR subsystems are currently being fabricated and procured and several are now being tested. Racklevel engineering model testing is expected to begin in the fall of 2000, and a Critical Design Review of the CIR is planned early in 2001.

Fluid Physics Experiments

The Microgravity Fluid Physics program (Ref. 7) currently has four major research thrust areas: Complex Fluids, Interfacial Phenomena, Dynamics and Instabilities, and Multiphase Flows and Phase Change. There are currently more than 140 groundbased and 20 flight/flight definition investigators conducting experimental research. Theoretical frameworks for understanding the effects of gravity on processes involving fluids are being developed as well. Within the subdiscipline areas, the following topics are included:

- Complex Fluids includes colloids, foams, granular media, rheology of nonNewtonian fluids, and emulsions and suspensions;
- Interfacial Phenomena includes liquidvapor interface configurations, contact line dynamics, capillary driven flows and shape stability and breakup of liquid bridges and drops;
- Dynamics and Instabilities includes thermocapillary and thermosolutal flows, biofluid mechanics, geological fluid flows, pattern formation, and electrokinetics and electrochemistry;
- Multiphase Flows and Phase Change includes flow patterns in liquidvapor/gas flows in microgravity, nucleate boiling and its control using acoustic and electric fields in microgravity, and flows of gassolid and liquidsolid mixtures in microgravity.

To minimize the quantity of hardware required to implement these experiments, selected early experiments have been grouped to permit development of multiuser modules which fit within the FIR and take full advantage of its capabilities.

The first multiuser module is the Light Microscopy Module (LMM), Figure 4. LMM (Ref. 8) is a selfcontained microscope which offers microscopy, sample changeout and fluid containment capabilities, and an impressive array of optical diagnostics including various kinds of microscopy (bright field, dark field, phase contrast, differential interference contrast, confocal,

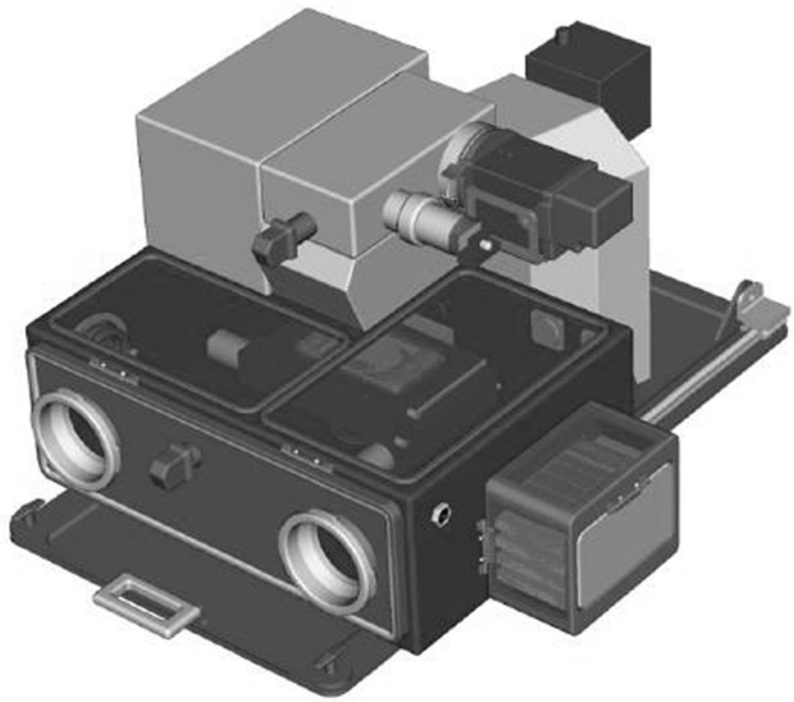


Figure 4.—Concept for Light Microscopy Module for Fluids Integrated Rack.

and fluorescence); various kinds of light scattering (static, dynamic, and Bragg); and specialized optical features (laser tweezers, spectroscopy, and interferometry).

There are four investigations which will be using LMM in the FIR:

- Physics of Colloids in Space2 (PCS2) PCS2 will study the nucleation, growth, morphology and coarsening of crystal structures as well as rheological properties. Three general classes of samples are planned: binary hard sphere alloys (highly ordered), colloid polymer mixtures, and fractal aggregates.

- Physics of Hard Spheres Experiment2 (PHaSE2) PHaSE2 will study nucleation, growth, rheological properties and morphology of crystal structures in the context of hard sphere colloidal suspensions. The intent is to create novel structures, to study the dynamics of their formation, and their phase transitions in order to differentiate kinetic and equilibrium structures.

- Colloidal Assembly in Entropically Driven LowVolumeFraction Binary Particle Suspensions This experiment will study the nucleation and growth of surface crystal structures from colloidal suspensions. The study will focus on lowvolumefraction particle suspensions of unagglomerated spheres having small diameters so that thermodynamically driven Brownian motion maintains the suspension. These entropicallydriven crystallization experiments will explore the creation of new colloidal structures of potential industrial importance (e.g., photonic bandgap crystals). By eliminating particle sedimentation effects, microgravity creates a purely “thermodynamic” environment for the suspensions where particle size, volume fraction and interparticle interactions are the primary determinants of the resulting structures.

• Constrained Vapor Bubble Experiment (CVB)   CVB will study vapor bubbles pertinent to the understanding of heat pipes and heat transfer mechanisms. The experiment will improve our understanding of the heat and mass transport mechanisms that are controlled by the interfacial phenomena. Specific objectives are: to determine the overall stability of the device; to study flow characteristics; to determine average heat transfer coefficients in the evaporative and condensing parts of the CVB; and to determine these transfer coefficients as functions of void fraction and heat transfer rates. A more detailed discussion of the experiments using LMM is given in Ref. 9.

A second multiuser module is the Granular Flow Module (GFM). It will be designed to conduct several experiments utilizing granular media – the first two of which are described below.

• Microgravity Segregation of Energetic Grains (µgSEG)   The primary goal of µgSEG is to induce and maintain particle segregation in a collisional flow of two different types of spheres. In the absence of gravity, segregation will be driven by a gradient in the kinetic energy of the mixture which is produced in a closed loop, annular shear cell (Figure 5). The inner and outer walls of the shear cell provide moving boundaries which are rotated at different speeds.

Figure 5.—Granular media cell showing shear flow with moving boundaries.

• Particle Interactions in µg Flow Cell   The main objective is to study the interaction between a flowing gas with relatively massive particles (constant diameter spheres) that collide with each other and with the moving boundaries of the cell. Over the range of nonturbulent flow conditions, the objectives are to characterize the viscous dissipation of the energy of the particle fluctuations, to measure the influence of particlephase viscosity on the pressure drop along the cell and to observe the development of localized inhomogeneities likely to be associated with the onset of clusters. The cell, expected to be essentially the same as for the above experiment, has annular geometry with bumpy frictional boundaries to control the energy of particular fluctuations. Specific to this experiment, cocurrent and countercurrent gas flows will be introduced into the particle flow. The measurement of the particle and gas mean velocities, the fluctuation energy and the particle concentrations in the fully developed regions will be required.

A third multiuser facility is the Pool Boiling Module (PBM). It will be designed to conduct pool boiling experiments – one of which is described below.

• Nucleate Boiling in Microgravity The proposed study will provide basic knowledge of the phenomena (e.g., heat transfer and vapor generation and removal processes during nucleate boiling conditions) that enables the development of simulation models and correlations used in the design of space and Earthbased boiling systems.

Fluid Physics Facility

The Fluids Integrated Rack (Figure 6) is a modular, multiuser scientific research facility designed to accommodate a wide variety of microgravity fluid physics experiments noted above. The FIR design is based on a “carrier” approach that provides common services needed by nearly all fluids physics researchers to minimize the need to extensive experimentspecific hardware required to be developed and launched for each experiment (Ref. 10).

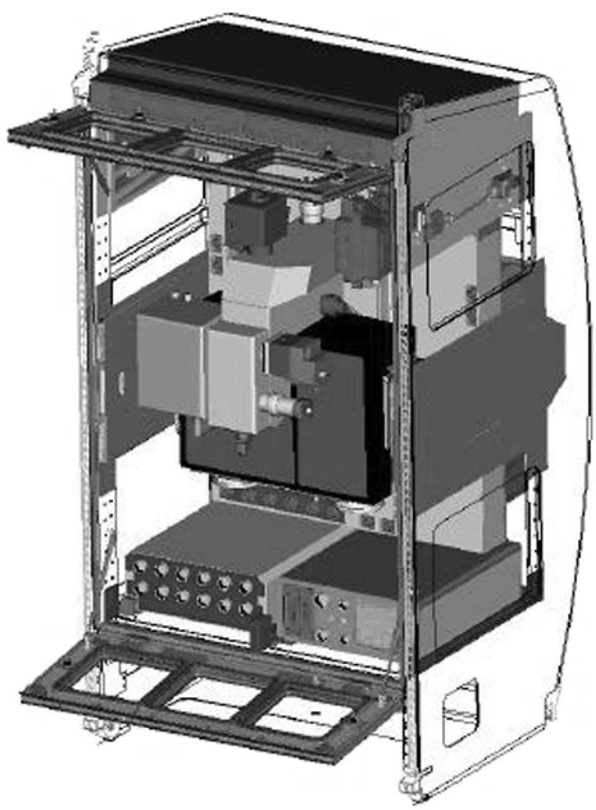


Figure 6.—Concept for Fluids Integrated Rack.

The unique structural feature of the FIR is the incorporation of a laboratory style optics bench which provides the flexibility to remove and replace different size and shaped PI specific experiment packages. The optics bench approach is a common feature between all three FCF rack designs and offers the advantage of utilizing the surface area on both sides of the bench and efficient access to the entire rack volume. Standardized interfaces will be utilized to permit flexibility in equipment placement and replacement/upgrades. The standard interfaces will provide electrical power, video and digital data acquisition, and control. Electrical harnessing will be inside the plate to provide maximum volume for the experiment and simplify crew interfaces. The front of the optics bench is dedicated to the experiment hardware setup while the back of the bench (Figures 7 and 8) is populated with several multifunction, nonintrusive optical diagnostics packages, and science avionics support packages. In addition, those diagnostic and avionics packages mounted on the back generate the most heat and are thus segregated to provide a better temperaturecontrolled environment for the science investigations.

Since a significant portion of the fluid physics experiments are imaging intensive, the FIR Diagnostics provides a suite of imaging and illumination services. These services include cameras, lasers, illumination back lighting, and optics for collimated laser beams. High resolution digital cameras and associated lenses will be provided as the standard means of image acquisition in the FIR. The cameras consist of two monochromatic (black and white) high resolution (1024 x 1024 12bit pixels, 30 frames per second) digital cameras, one analog color camera to achieve color images, and a high frame rate camera capable of acquiring images at up to 1000 frames per second. Various optical lenses will be provided consisting of fixed focus and motorized zoom lenses that can be interchangeable. The range of fields of view FIR will

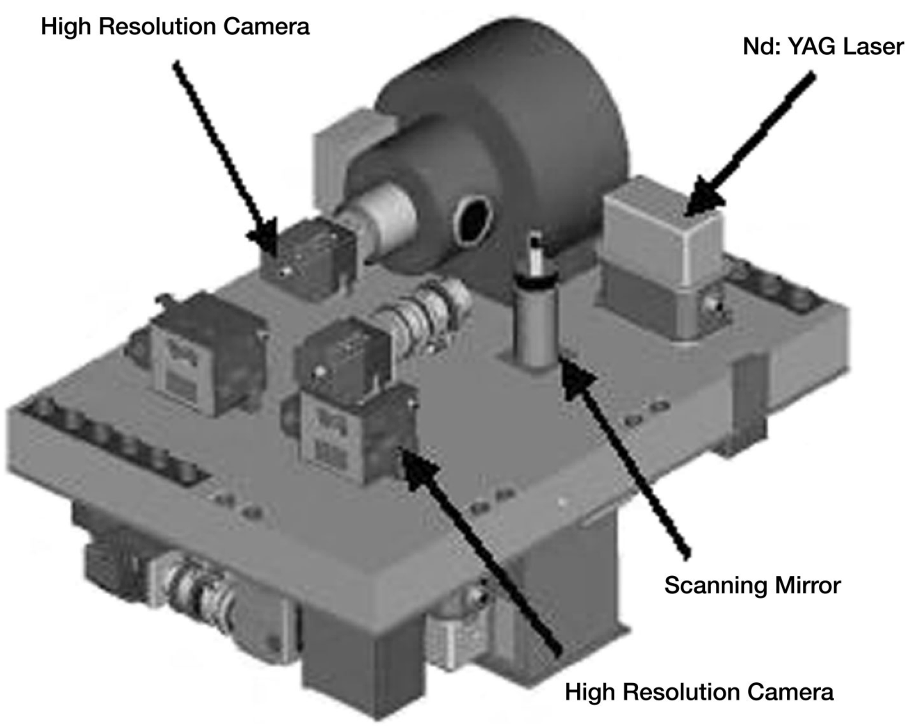


Figure 7.—Conceptual layout for front of Optics Bench with selected diagnostics subsystems.

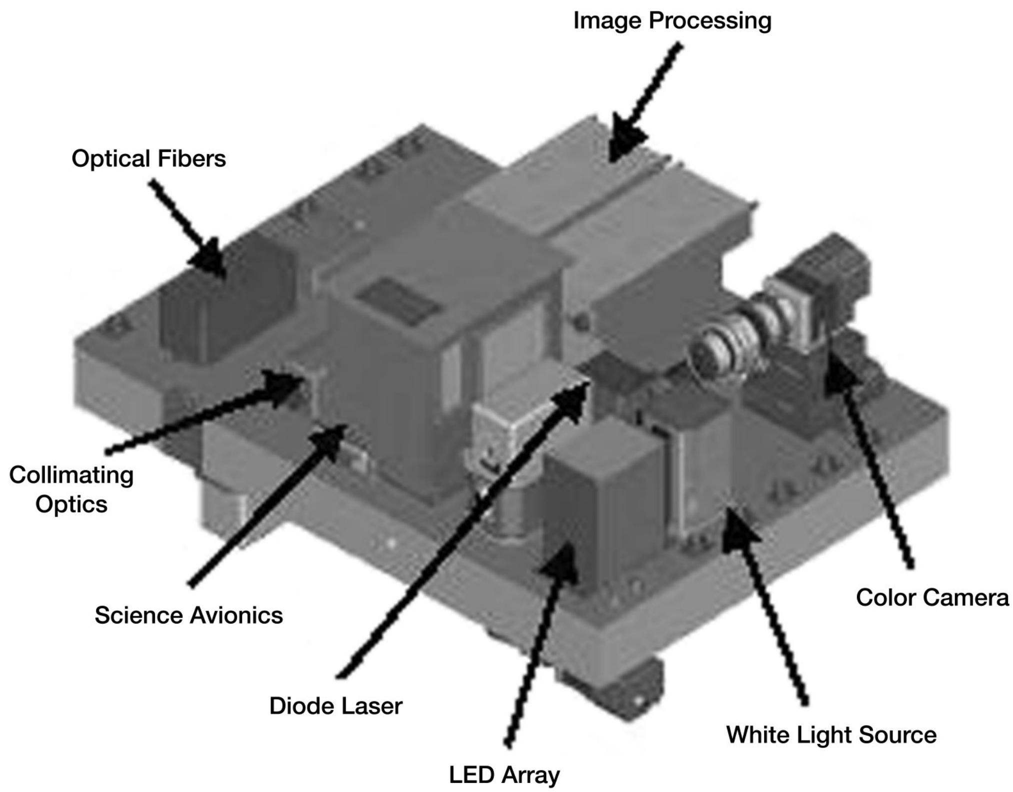


Figure 8.—Conceptual layout for back of Optics Bench with selected subsystems.

accommodate will be (nominally) 300 µm by 300 µm to 100 mm by 100 mm. The zoom function, as well as the focus and aperture functions of each lens will be motorized and remotely controllable.

The FIR illumination sources will consist of white light, laser light, and collimated laser beams. The light from each source will be transmitted to the experiment through an optical fiber; each fiber will have an industry standard optical fiber interface that is accessible from the front of the Fluids rack. The use of fiber optics also helps isolate the test cell from the heat that the light source generates.

The FIR features the capability to remove and replace different PI specific experiment packages. The experimentspecific package(s) may consist of a single selfcontained unit and/or several separate components. The experiment hardware will typically reflect a unique design, but may reuse hardware and designs from previous experiments. A set of similar experiments investigating common phenomena and/or using similar diagnostics may permit the development of a multiuser modules that can accommodate multiple PIs to significantly lower overall PI development costs. The experiment package will typically consist of the fluids test cell(s), precision optical diagnostic instrumentation (shearing interferometry, schlieren, surface profilometry, etc.) that interface with FIR services previously discussed, and any support equipment such as injection or mixing devices, motors, critical temperature hardware, magnetic field generation, etc.

The initial mission of the FIR will accommodate four investigations within a "minifacility" called the Light Microscopy Module (LMM). The LMM package (Figure 4) combines a full featured research imaging light microscope with powerful laser diagnostics, creating a oneofakind, stateoftheart microscopic fluids research instrument. The imaging techniques of high resolution color video microscopy, bright field, dark field, phase contrast, differential interference contrast, fluorescence, and confocal microscopy are combined in a single configuration. This suite of measurements allows a very broad characterization of fluids, colloids, and twophase media. LMM may also incorporate sample manipulation techniques such as singletrap scanning optical tweezers. The significant operational feature of the LMM is the incorporation of a glovebox with the microscope to allow manipulation of sample trays within a containment area that is sealed against escape of fluids and frangibles.

The FIR is being designed to minimize the crew time involved in reconfiguring diagnostics and setting up the specific experiments. Each new experiment will require installation of experiment hardware and configuration of the diagnostics by an astronaut. When setting up a new experiment, the astronaut will fold open the FCF doors, slide out the optics bench, tilt the optics plate to obtain access to the back side, unstow/install experimentspecific hardware and diagnostics, reconfigure facilityprovided diagnostics on the back, translate/fold the optics plate back to its upright position, unstow/install the experimentspecific hardware on the front to the optics plate, return the optics plate to its operational position and, finally, close the doors for checkout and experiment operations. The crew will not be the primary FCF operators since they will have very limited time to dedicate to a specific facility due to their overall work load in daytoday operations of the ISS. Instead, the ground team at the NASA Glenn Research Center and the PI will monitor the health and status of FCF and the active experiments and will control facility functions. During experiment operations, the FCF will provide nearrealtime data downlink and command uplink to permit the PI to remotely interact with the experiment. The PI will be provided with essential and timely data to react to unexpected scientific phenomena in order to alter the experimental procedures.

Conclusion

The pending availability of the International Space Station offers significant opportunities for research and development. The Combustion Science and Fluid Physics discipline programs will have access to a major facility offering extensive capabilities and flexible implementation of microgravity experiments. Preparation of the initial flight experiments and facility hardware has begun and are planned for flight in 2003.

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13. ABSTRACT *(Maximum 200 words)*

At the NASA Glenn Research Center, the Microgravity Science Program supports both ground-based and flight experiment research in the disciplines of Combustion Science and Fluid Physics. Combustion Science research includes the areas of gas jet diffusion flames, laminar flames, burning of droplets and misting fuels, solids and materials flammability, fire and fire suppressants, turbulent combustion, reaction kinetics, materials synthesis, and other combustion systems. The Fluid Physics discipline includes the areas of complex fluids (colloids, gels, foams, magneto-rheological fluids, non-Newtonian fluids, suspensions, granular materials), dynamics and instabilities (bubble and drop dynamics, magneto/electrohydrodynamics, electrochemical transport, geophysical flows), interfacial phenomena (wetting, capillarity, contact line hydrodynamics), and multiphase flows and phase changes (boiling and condensation, heat transfer, flow instabilities). A specialized International Space Station (ISS) facility that provides sophisticated research capabilities for these disciplines is the Fluids and Combustion Facility (FCF). The FCF consists of the Combustion Integrated Rack (CIR), the Fluids Integrated Rack (FIR) and the Shared Accommodations Rack and is designed to accomplish a large number of science investigations over the life of the ISS. The modular, multiuser facility is designed to optimize the science return within the available resources of on-orbit power, uplink/downlink capacity, crew time, upmass/downmass, volume, etc. A suite of diagnostics capabilities, with emphasis on optical techniques, will be provided to complement the capabilities of the subsystem multiuser or principal investigator-specific experiment modules. The paper will discuss the systems concept, technical capabilities, functionality, and the initial science investigations in each discipline.

14. SUBJECT TERMS

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