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Fluids and Combustion Facility–Combustion Integrated Rack

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FLUIDS AND COMBUSTION FACILITY - COMBUSTION INTEGRATED RACK

by David R. Francisco, NASA-Lewis Research Center, Cleveland, Ohio

Abstract

This paper describes in detail the concept of performing Combustion microgravity experiments in the Combustion Integrated Rack (CIR) of the Fluids and Combustion Facility (FCF) on the International Space Station (ISS). The extended duration microgravity environment of the ISS will enable microgravity research to enter into a new era of increased scientific and technological data return. The FCF is designed to increase the amount and quality of scientific and technological data and decrease the development cost of an individual experiment relative to the era of Space Shuttle experiments. This paper also describes how the FCF will cost effectively accommodate these experiments.

Introduction

Fluids and Combustion Facility

The CIR is one of three International Standard Payload Racks (ISPRs) of the FCF. Each of the ISPRs of FCF provides approximately 1.6 m^3 of volume for equipment to be used for performing/supporting microgravity experiments. The CIR is the first ISPR of FCF that will be onboard the ISS and it is scheduled to be launched on UF-3 (ISS Utilization Flight #3). The CIR will be self sufficient until the Shared Accommodations Rack (SAR), which is the third ISPR of FCF, is launched on UF-7. Once the FCF is complete (after UF-7), upgrades will be performed to offer enhanced capabilities that will allow the FCF to accommodate between 5 and 10 combustion microgravity experiments per year. The second ISPR of FCF, which is the Fluids Integrated Rack (reference 1) (FIR), is launched on UF-5 (approximately nine months after the CIR). The FIR also utilizes the SAR in order to accommodate between 5 and 10 microgravity Fluid physics experiments. See Figure 1.0 for a pictorial depiction of the FCF.

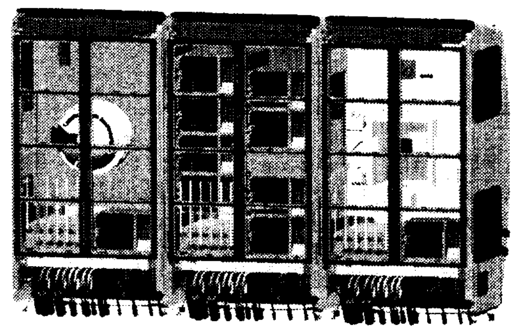

Figure 1.0. Fluids and Combustion Facility (FCF)

Microgravity Combustion Science

The purpose of the Combustion Integrated Rack (CIR) is to provide a sustained Combustion physics research in a microgravity environment. Investigators use this microgravity environment to isolate and control gravity-related phenomena, and to investigate processes that are normally masked by gravity effects and thus are difficult to study on Earth. The types of Combustion Science research that will be accommodated (but not limited to) are:

- Laminar Flames
- Reaction Kinetics
- Droplet and Spray Combustion
- Flame Spread, Fire Suppressants

- Condensed Phase Organic Fuel Consumption
- Turbulent Combustion
- Soot and Polycyclic Aromatic Hydrocarbons
- Material Synthesis

Combustion microgravity experiments can provide a unique insight into the control of the generation of combustion by-products (pollution) and the increase efficiency of fuels.

The Carrier

International Space Station

The FCF will be located in the United States Laboratory (US Lab) of the ISS. The FCF will be composed of three ISPRs with each occupying 1.6 m^3 and containing 700 kilogram (kg) of mass. Each ISPR is also allocated 2 kilowatts of power with the total expected energy allocated to the FCF in one year is in the range of 5000 to 9000 kilowatt-hours.

The following is a summary of the expected resources from the ISS to FCF.

Expected ISS Resources/Capabilities	
Rack Volume	~1.6 m^3
Rack Upmass	700 Kg/Rack
Resupply Upmass	300 Kg/year Max
Resupply Flights	2-4 year
On-Orbit Stowage	0.25 to 1.0 rack
Power	2 kW Max @ 120 Vdc
Energy	5000 to 9000 KW-hr/yr
Thermal Cooling	28-56 Kg/hr
Max Downlink	20 Mbits/s
Average Downlink	1-5 Mbits/s
Average Crew Time	1 - 4 hrs/week
ISS Resources	Vacuum Vent GN_2 Supply Water Cooling
Microgravity Environment	10^{-4} g's nominal

Table 1.0. ISS Resources

The CIR will receive approximately one third to one half of the energy, thermal cooling and crew time for the first two years until the SAR is onboard when the ISS assembly is complete (AC). During the description of the CIR, the usage of each of these resources will be discussed.

Active Rack Isolation System (ARIS)

The ISS developers provide the ARIS to minimize disturbances to the experiments in the ISPRs from crew members and other experiments. The ARIS "floats" the entire ISPR by using actuators with feedback from accelerometers that are located on the ISPR. The ARIS will further enhance the microgravity environment on ISS to ensure the best possible environment for experimenters.

FCF Operations

The FCF will be tele-operated while on-orbit. This will allow experimenters to perform experiments on orbit while residing at their home site. Data and commands will be routed through the Lewis Research Center (LERC) from the experimenters to the FCF on orbit the ISS.

Combustion Integrated Rack

The concept behind FCF/CIR is to provide up to 90% of the required hardware to perform a majority of combustion experiments. The remaining 10+% of hardware that is required will be developed by the specific hardware development team and will be launched separately from the CIR and integrated on orbit. Since a majority of hardware is re-used, this concept saves both development cost and total upmass (mass that is launched) required to perform experiments.

The CIR system requirements were derived from the FCF Science Requirements Envelope Document (SRED) which documents requirements from eleven "basis" microgravity combustion experiments. From the requirements in the SRED and ISS requirements, the following systems were determined to be essential to perform microgravity combustion experiments in the CIR. The CIR systems are as follows:

- ISPR
- Optics Bench
- Fuel Oxidizer and Management Assembly
    - Exhaust Vent System
- (Combustion by-product "scrubber")
- Combustion Chamber

- Replaceable Diagnostics
- Power System
- Environmental Control System
- Command and Data Management System
- Active Rack Isolation System (ARIS)
- Replaceable Experimenter/Researcher Specific Hardware

ISPR - International Standard Payload Rack

The ISPR is an empty shell that houses all of the CIR equipment. The ISPR is approximately 174.6 cm (142.2 cm usable length) x 96.5 cm (93.3 usable width) x 72.5 cm (not including the bowed back) for a total usable volume of 1.6 m^3. The rack has a bowed back which allows for it to interface directly to the US Lab. See Figure 2. It is made of composite material and has a mass of approximately 110 Kg is capable of carrying a load of 700 Kg. The ISPR provides all of the mechanical interfaces to the US Lab onboard the ISS. The CIR will use the ISPR in a four post configuration so that the maximum free volume is available for science equipment. (The "standard" ISPR configuration has two additional posts that span the middle of the rack from top to bottom).

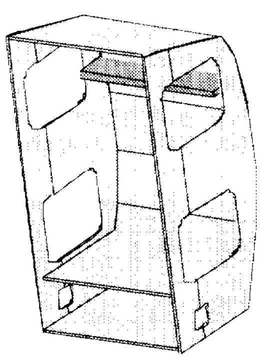

Figure 2.0. ISPR with four posts.

Optics Bench

The main component of the CIR is an optics bench. The optics bench is a aluminum structure that is 86.5 cm wide by 124.5 cm long and 10 cm deep and spans two thirds of the ISPR. See figure 3.0 for depiction of the optics bench in the CIR.

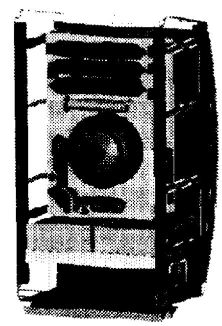

Figure 3.0. CIR with Optics Bench in upright position.

In order to utilize the surface area of both sides of the optics bench and the entire volume of the ISPR; the optics bench folds down to allow for easy access to components located on the back side. See figure 4.0.

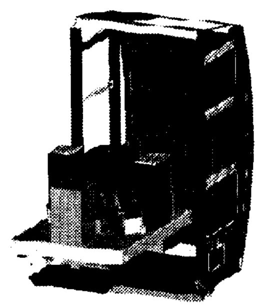

Figure 4.0. CIR with the optics bench folded down for access to components.

The structure of the optics bench is composed of a ribbed section with a plate that is fastened to one side.

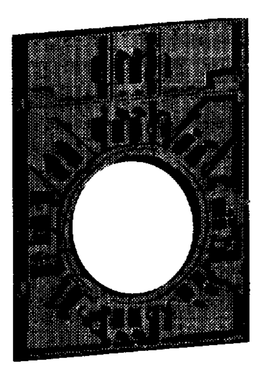

Figure 5.0. Ribbed portion of the optics bench. Note the openings for connectors and air cooling.

This "sandwich" assembly allows for electrical wiring and tubing to be routed internal to the structure much the same as a wall in a building that contains electrical wiring and plumbing pipes. Since tubing and wiring can be routed internally, the optics bench easily allows for integrated assemblies which saves mass and volume. To capitalize on this mass and volume savings, the following components are mounted to the optics bench:

- Combustion Chamber
- Diagnostics
- Image Processing Packages (IPP)
- Fuel Oxidizer and Management Assembly
    - Exhaust Vent System (Combustion by-product "scrubber")
- Experimenter Specific Electronics

Refer to Figure 6.0 for a detailed depiction of the backside of the optics bench.

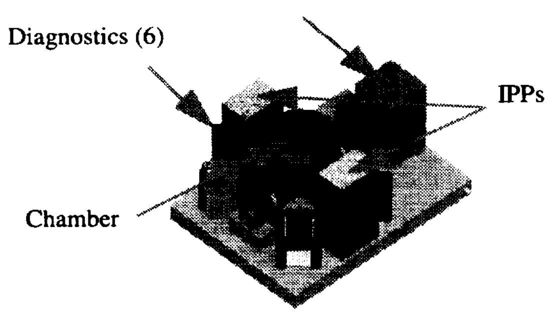

Figure 6.0. Back side of Optics Bench.

Each of the surfaces of the optics bench is machined with 25 mm hole spacing which is identical to a researchers' optic benches in a Earth based laboratory. This feature allows the option of mounting standard "off the shelf" optical components to the optics bench.

Combustion Chamber

The combustion chamber provides standardized mounting and interfaces for the experimenter's specific apparatus to perform his/her specific area of research. The experimenters specific apparatus is installed into the combustion chamber via a hinged breech lock lid which is mounted on the front of the optics bench. The combustion chamber which is 40 cm in diameter (internal diameter) and ~ 90 cm in length (for ~ 101 free Liters) is mounted "through" the optics bench. The front lid and a resource interface ring protrude through the front of the optics bench to allow for easy crew member access. The remaining portion of the chamber protrudes through the backside of the optics bench and is only accessible by folding down the optics bench. Refer to figure 5.0.

The backside of the chamber contains eight viewing ports (windows) each with a viewable diameter of 12 cm. See Figure 7.0.

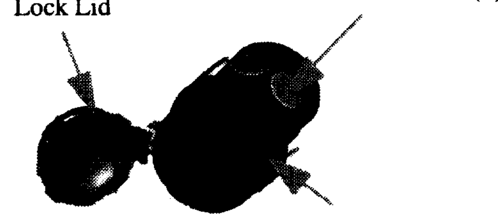

Figure 7.0. Combustion Chamber.

The windows are located in 4 pairs that are 180° apart. The windows are also easily replaced from inside the chamber by using an integrated handle that is part of the window assembly. See Figure 8.0.

Figure 8.0. Chamber window with integrated handle.

A racheting mechanism that is also part of the window assembly allows for the replacement of the window without any tools. This unique feature will save many hours of crew time over the life of the FCF and allows for the maximum flexibility for experimenters to change window material to accommodate their needs.

The combustion chamber is designed with redundant seals and is designed for a maximum pressure of ~ 10 atmospheres. Higher pressure experiments may be accommodated by placing a smaller chamber (on the order of 10 Liters) within the combustion chamber.

The resource interface ring provides the experimenters specific hardware access standard resources such as:

- Vacuum port
- Electrical Power
- Sensor Connections
- Spare Electrical Connections
- Gas Delivery Ports
  - Nitrogen
  - Gaseous Fuel/Premix
  - Partial Pressure Mixer
  - High Pressure Supply
- Exhaust Vent Ports (2)
- Gas Sample Port
- Water Cooling Ports (2)

After the experimenters specific apparatus is installed into the combustion chamber the above interfaces are mated. All of the fluid connections utilize quick disconnects and the electrical connections are made via circular bayonet type connectors.

Diagnostics

At each of the combustion chamber window locations on the optics bench is a standard electrical and mechanical interface for removable digital diagnostics/cameras, illumination sources and/or optical equipment. The approximate area available at each of the eight locations is 250 mm x 230 mm with a ~500 mm height. The "standard" diagnostic is configured with an electrical enclosure at the bottom and a camera with optical components mounted on top the enclosure. See figure 9.0.

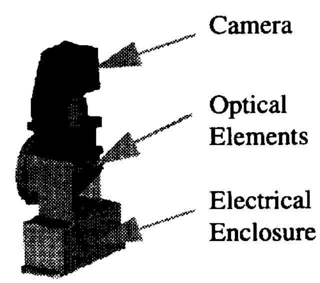

Figure 9.0. Typical Diagnostic configuration.

The electrical enclosure is designed with connectors at the bottom that mate directly to the optics bench. The connectors are designed so that they are self-aligning and are easily mated to the optics bench connectors. See figure 10.0.

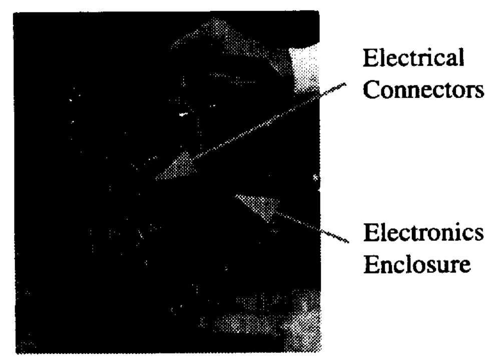

Figure 10.0. Diagnostic electronics enclosure and electrical connectors.

The electrical enclosure contains all of the electronics necessary to fully operate the camera/components with only power from the EPCU, control signals (such as RS-422) and a data connection to the Image Processing Packages required from the CIR. This allows for a well defined interface between the diagnostics and the CIR and will allow for full testing of the diagnostics prior to installation on the optics bench. This design will minimize the testing required with the CIR and will facilitate the future development of diagnostics. The IPPs control the cameras and store the digital data on hard drives and/or solid state disk drives.

The mechanical interface is an unique design that incorporates a single removable handle latch mechanism that allows removal of each diagnostic without the use of tools. This mechanism will save many hours of crew time over the life of FCF. Refer to Figure 11.0.

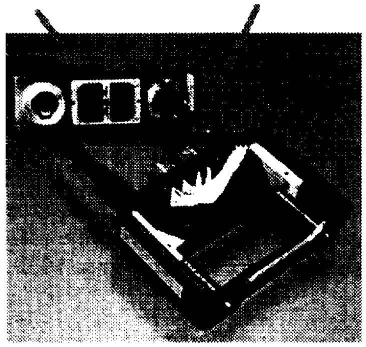

Figure 11.0. "Quick" latch prototype mechanism for diagnostic replacement.

The initial diagnostics that are planned for the CIR are the following:

- Soot Volume Fraction/Soot Temperature
- Laser/White Light Illumination
- High Frame Camera (100 FPS) with automatic Positioning and Tracking (APT)
- Low Light Level Ultraviolet Camera
- Color Camera
- Mid Range Infrared Camera

The following is a brief description of each of the diagnostics:

Soot Volume Fraction/Soot Temperature

The Soot Volume Fraction/Soot Temperature (SVF/ST) package measures the soot temperature field by using two wavelength pyrometry technique. A liquid crystal spectral filter is tuned at 650 nm and 850 nm to measure the soot temperature. This filter can be tuned to a 10 nm bandpass at any wavelength between 650 nm to 1050 nm. To measure the soot volume fraction the filter is tuned at 673 nm and the volume fraction is determined by measuring the percentage of the laser illumination absorbed by the soot. Refer to figure 12.0.

The diode emits a visible red wavelength at 673 nm. The laser diode power level is ~1 mW. A calibration lamp is also integrated into the package to provide for checkout of diagnostics and windows. Each of the illumination sources may be selected from the ground by commanding a motor driven mirror. Refer to figure 12.0.

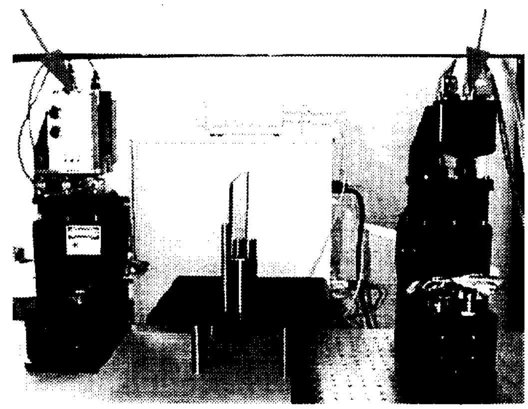

Figure 12.0. SVF/ST and Illumination Packages.

High Frame Rate/High Resolution Camera (HFR/HR)

The HFR/HR. diagnostics consist of camera capable of 110 frames per second and a telecentric imaging system. The telecentric system has a 9 mm instantaneous field of view (IFOV) within a 33 mm field of view (FOV). A centroid tracking system direct the 9 mm IFOV to any point with the 33 mm FOV via a servo motor controlled pointing mirror. Auto-focusing is also implemented to cover a 33 mm depth of field via a motor controlled stage.

The HFR/HR has a resolution on the order of 0.04 mm.

Low Light Level Camera

The Low Light Level Camera consist of a monochrome camera coupled to an intensifier (6.5 E - 8 lux sensitivity) with provisions for spectral filtering of the transmitted illumination.

Color Camera

The color camera is an RGB output camera coupled with an optical system that allows for

0.2 mm to 2 mm resolution with a 10x zoom capability.

Mid Range Infrared Camera

The Mid Range Infrared Camera design is in the initial concept stage and is to be determined.

The above diagnostics are modular and can be replaced on orbit or individual components of each diagnostic can be replaced/changed (such as filters, lens etc.).

Fuel Oxidizer Management Assembly

The Fuel Oxidizer Management Assembly (FOMA) is an integrated subsystem of the optics bench. The FOMA provides gases to the resource interface ring so that the experimenters apparatus can be supplied with the appropriate environment. The gases are supplied using up to three 3.8 Liter, 2.25 Liter and/or 1.0 Liter bottles filled to a maximum of 14 Mpa and ISS provided nitrogen.

The FOMA utilizes manifolds to minimize the number of connections, thus limiting leakage paths. Each of the four manifolds integrate pressure transducers, pressure regulators, pressure switches, mass flow controllers, filters and solenoid valves into singular modular packages. Individual components may be replaced on each manifold, or if required, the entire manifold may be replaced on orbit. See Figure 13.0.

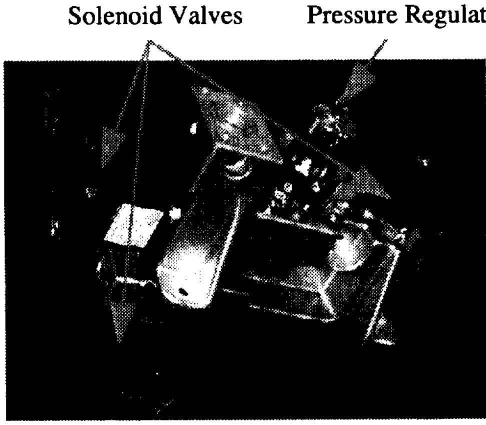

Figure 13.0. FOMA Manifold - (~ 20 cm).

All of the FOMA required electronics are housed in one location. All of the DC/DC converters, mass flow controller electronics are mounted on circuit cards in racks with card slides that allow for easy replacement and maintenance.

The FOMA incorporates three different methods of supplying the experimenters specific apparatus with gases, they are:

- Pre-mixed environments
- Static Blending Incorporating Partial Pressure Mixing On-Orbit
- Dynamic Blending On-Orbit Incorporating Mass Flow Controllers

Pre-Mixed

Each experimenter can upmass the exact environments that they require in 3.8, 2.25, and/or 1.0 Liter bottles at approximately 14 Mpa. This method requires the most upmass and is the least desirable.

Static Blending

This method incorporates partial pressure mixing. Environments of various concentrations may be mixed on orbit by utilizing ISS supplied nitrogen and oxygen bottles (up to 85 % O_2) that have been upmassed to the CIR. This method requires the least upmass and provides the experimenters with a gas mixture concentration accuracy of ~ 0.4 %. This method will save ~ 3 to 5 times the upmass of using premixed bottles.

Other diluents (other than nitrogen) and oxidizers may also be used with the static blending system. The diluent will have to be upmassed along with the oxygen bottles, filters and experimenter specific hardware.

Dynamic Blending

This method incorporates the use of mass flow controllers to mix and deliver the gases to the combustion chamber. This method provides for a flow rate of an oxidizer up to 1500 cc/sec to the experimenter specific hardware within the combustion chamber. The accuracy of the environment concentrations using this method is ~ 2.0 % based on the types of gases being mixed.

Exhaust Vent System

After the combustion experiment is complete, the combustion by-products must be scrubbed. A chemical bed and particle mesh filter is used to clean the resultant environment. A blower is used to circulate the environment in the combustion chamber through the filter until it is cleaned sufficiently to pass through the ISS vent system.

Different size filters may be used to maximize the effectiveness of cleaning the post combustion by-products and minimize upmass.

The CIR Exhaust Vent System is designed to clean the following:

> Propanol, Ethylene, Butanol, n-Decane, Methane, Propane, n-Hepthane, CO, CO_2, Sulfur Dioxide, Nitrous Oxide, Water plus others.

Custom filters may be designed to clean other by-products and meet safety requirements.

Gas Chromatograph

The FOMA also has a gas chromatograph that is utilized to sample pre and post combustion gases. The GC is capable of measuring gas concentrations to 2 % of reading.

Power System

The ISS provides 120 Vdc to each of the ISPRs. The CIR utilizes an Electrical Power Control Unit (EPCU) to convert the 120 Vdc to 28 Vdc. The EPCU is capable of regulating the voltage to 28 Vdc at an efficiency of ~92%. The EPCU is capable of handling 3 KW from two separate busses. The EPCU switches 48 different channels and current limits each channel to 4 A. Multiple channels may be paralleled to increase its amperage capability. The EPCU is also capable of prioritizing loads so that if a power shortage occurs, critical components will be the last subsystems to be turned off.

The EPCU occupies the lower left hand portion of the CIR. The EPCU is housed in an enclosure (drawer) that is ~18 cm x 45 cm x 50 cm and has a mass of ~ 55 Kg. The EPCU is water cooled.

Environmental Control System

The environmental control system (ECS) provides cooling to all of the components (except for the EPCU which is water cooled) in the CIR. The ECS also provides for fire detection and suppression. The environmental control system is housed in an enclosure at the top of the ISPR. The enclosure houses two fans, a radiator and air filters. An area smoke detector which is mounted in the back of the ISPR provides for fire detection.

The fans circulate the air in the ISPR through the radiator, the optics bench and the IOP. The ISS provides water cooling to the radiator to dissipate heat. The ECS is designed to cool approximately 1800 Watts, but it is dependent on the ISS provided cooling water. A bifold door provides containment for the ECS and also provides a path for circulation of cooled air. See figure 14.0.

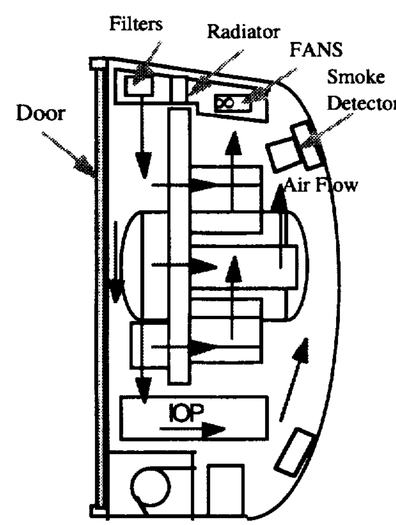

Figure 14.0. Environmental Control System.

Each of the nine (9) locations on the optics bench (for the diagnostics and Image Processing Packages) have holes through the optics bench allowing air to pass through the optics bench and cooling the electronics in each of these packages. If required, these packages may have "booster" fans to enhance the cooling capability. Refer to figure 5.0 in the section on the optics bench.

Command & Data Management System

The Command and Data Management System (CDMS) is comprised of an Input/Output Processor (IOP) and two Image Processing Packages (IPPs). The IOP controls the operation of the CIR, stores digital data and provides the data link to ISS for transmission of data to Earth. These functions are achieved through the use of ethernet, MIL-STD-1553 B command and timing protocol, and a high rate data link (HRDL). The IOP may be used by each experimenter to condition and store data.

The IOP will have the following capabilities:

- Signal conditioning of thermistors
- Minimum of 48 Analog inputs (0 to 10 Volts nominal)
- Conversion of analog signals to digital data (16 Bits minimum)
- Up to 100 KHz sampling rates (1 KHz nominal)
- A minimum of 10 digital to analog outputs
- Storage of a minimum of 9 Gbytes of data

Each of the IPPs contain two Image Processing and Storage Units (IPSUs). Each of the four IPSUs controls a camera/diagnostic and stores the digital data from the cameras by using up to four VME 6U circuit cards. The nominal IPSU will contain a single board computer, two custom control cards for a given diagnostic and a disk drive with a minimum storage capacity of 9 GBytes. All or any one of the circuit cards may be easily changed out on orbit to accommodate new diagnostics. The IPPs are limited to controlling four cameras simultaneously. If additional control is required, two additional IPSUs can be added in the ninth location on the optics bench. Once the SAR is added, full capability for the control of eight diagnostics will be available.

The ninth location or any location not required by a diagnostic on the optics bench may be utilized by the experimenter to provide for a specific function not present on the CIR.

Software

The FCF is utilizing Embedded Web Technology (EWT) for the control/communication of the CIR. EWT will allow for a graphical representation of the CIR and allow for individual experimenters to communicate and command their experiment from their home site much the same way the internet is accessed.

For control of the individual experimenters apparatus, a script like format will be used to simplify commanding and control.

Experimenter Specific Hardware

Each experimenter must develop/provide any equipment required to operate his/her experiment that is not provided as a "standard" service by the CIR. An example of the equipment that must be provided is:

- Intrusive diagnostics (i.e. thermocouples)
- Ignitors
- Sample cells
- Mounting structure to the combustion chamber (40 cm diameter by 60 cm in length max.)
- Electrical harness and fluid connections to interface ring
- Flow tunnels (if required)
- Bottle(s) for gases *
- Exhaust vent filter(s) *
- Specific diagnostics
- Specialized electronics
- Control software (scripts)

* These items will be "controlled" by the CIR operations team to ensure safety requirements.

Refer to Figure 15.0 for a typical experimenters apparatus.

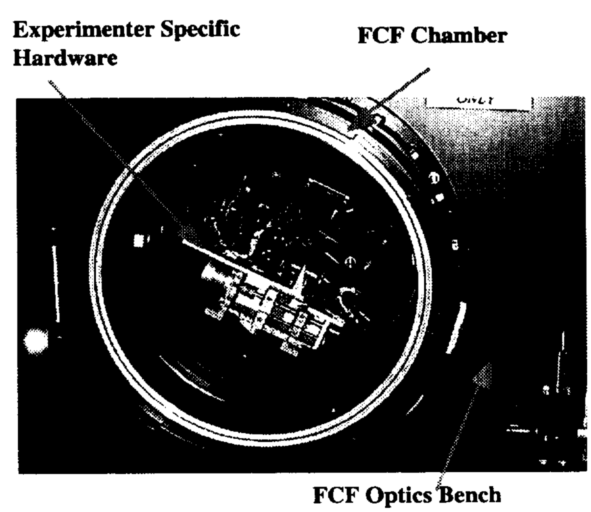

Figure 15.0. Individual experimenter apparatus in the CIR combustion Chamber.

The CIR operations and sustaining engineering team will provide development guidelines and an User's Accommodations Handbook to aid the development of experimenter specific hardware.

All of the above hardware will be part of the upmass required for each individual experimenter.

CIR Design Approach and Status

The CIR development approach is to design, fabricate and test the following:

1. A high fidelity mockup for crew evaluation and training.
2. An Engineering Model that will be eventually used as a ground integration unit for checkout of specific experimenter hardware and software.
3. A Protoflight unit that will be flown on the ISS.
4. A Ground Integration Unit to be configured the same as the unit on board the ISS.

Since a prototype unit (qualification unit) is not being developed, the CIR design philosophy incorporates the use of rapid prototypes to decrease development time and minimize risk. The rapid prototyping process utilizes stereo lithography that allows for the fabrication of components in a day for 1/10th to 1/20th the cost. These resin components are used to assess flight manufacturability, form, fit, assembly and electrical harness assessments. Refer to figure 16.0.

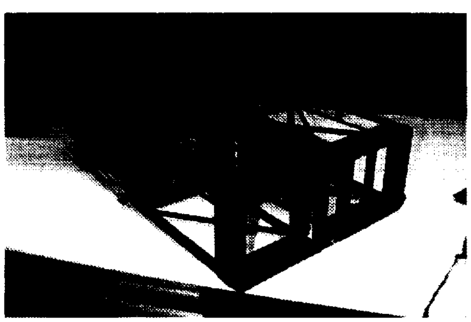

Figure 16.0. IOP rapid prototype.

CIR Mockup

Presently the CIR team has developed a high fidelity mockup, and is in the process of detailing the design of the engineering model for fabrication in 1998.

The following pictures show the high fidelity CIR mockup with the optics bench in the upright position and in the down position.

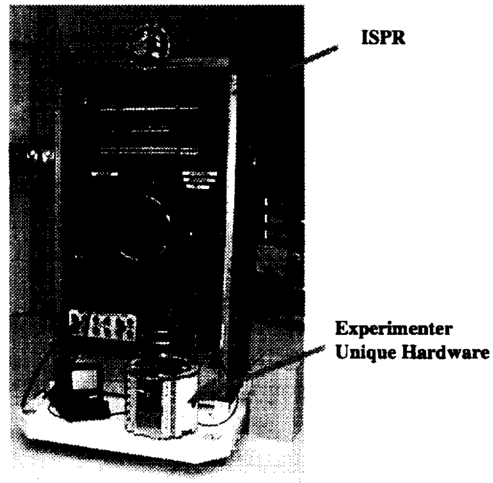

Figure 17.0. CIR Mockup, Optics Bench Upright.

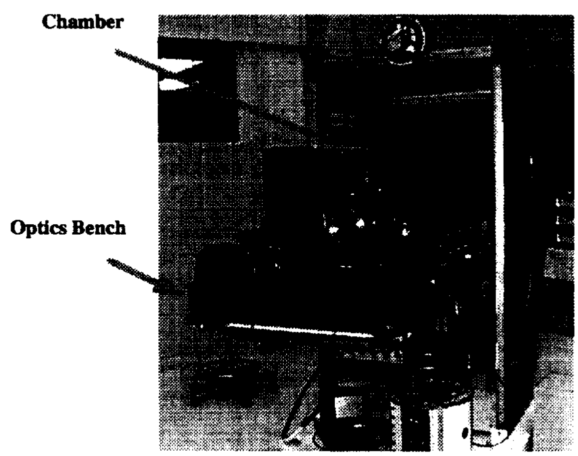

Figure 18.0. CIR Mockup, Optics Bench folded down.

Summary

The CIR is being developed with a modular cost effective design that allows for the maximum flexibility and throughput of experimenters. Many innovative designs such as the fold down optics bench, no tool change out of windows, and modular quick change out digital diagnostics have been incorporated to minimize the use of resources and minimize the return of science and technology.

The ISS will provide the long term microgravity environment that has never been available to experimenters in the past. The ISS era will truly allow for the maximum return of science and technology for the minimum investment of resources.

References

[1] Corban, Robert, R., "Fluids and Combustion Facility - Fluids Integrated Rack," AIAA 98-0258, 36th Aerospace Sciences Meeting & Exhibit, Reno, NV, 1998

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This paper describes in detail the concept of performing Combustion microgravity experiments in the Combustion Integrated Rack (CIR) of the Fluids and Combustion Facility (FCF) on the International Space Station (ISS). The extended duration microgravity environment of the ISS will enable microgravity research to enter into a new era of increased scientific and technological data return. The FCF is designed to increase the amount and quality of scientific and technological data and decrease the development cost of an individual experiment relative to the era of Space Shuttle experiments. This paper also describes how the FCF will cost effectively accommodate these experiments.

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