



# The Fluids Integrated Rack and Light Microscopy Module Integrated Capabilities

Susan M. Motil, Frank Gati, John H. Snead, Myron E. Hill, and DeVon W. Griffin  
Glenn Research Center, Cleveland, Ohio

## The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to [help@sti.nasa.gov](mailto:help@sti.nasa.gov)
- Fax your question to the NASA Access Help Desk at 301-621-0134
- Telephone the NASA Access Help Desk at 301-621-0390
- Write to:  
NASA Access Help Desk  
NASA Center for Aerospace Information  
7121 Standard Drive  
Hanover, MD 21076



# The Fluids Integrated Rack and Light Microscopy Module Integrated Capabilities

Susan M. Motil, Frank Gati, John H. Snead, Myron E. Hill, and DeVon W. Griffin  
Glenn Research Center, Cleveland, Ohio

Prepared for the  
53rd International Astronautical Congress  
cosponsored by the International Astronautical Federation (IAF), the International  
Academy of Astronautics (IAA), and the International Institute of Space Law (IISL)  
Houston, Texas, October 10–19, 2002

National Aeronautics and  
Space Administration

Glenn Research Center

## Acknowledgments

The FIR and LMM are being developed within the Microgravity Science Division of the NASA Glenn Research Center. The authors of this paper would like to acknowledge the hard work and dedication of the Northrop Grumman development team. It is through their dedication and innovativeness that the FIR and LMM will be unique experiment facilities for carrying out fluids physics experiments on board the International Space Station.

This report contains preliminary findings, subject to revision as analysis proceeds.

Available from

NASA Center for Aerospace Information  
7121 Standard Drive  
Hanover, MD 21076

National Technical Information Service  
5285 Port Royal Road  
Springfield, VA 22100

Available electronically at <http://gltrs.grc.nasa.gov>

# THE FLUIDS INTEGRATED RACK AND LIGHT MICROSCOPY MODULE INTEGRATED CAPABILITIES

Susan M. Motil, Frank G. Gati, John H. Snead, Myron E. Hill, and DeVon W. Griffin  
National Aeronautics and Space Administration  
Glenn Research Center  
Cleveland, Ohio 44135

## ABSTRACT

The Fluids Integrated Rack (FIR), a facility class payload, and the Light Microscopy Module (LMM), a subrack payload, are scheduled to be launched in 2005. The LMM integrated into the FIR will provide a unique platform for conducting fluids and biological experiments on ISS. The FIR is a modular, multi-user scientific research facility that will fly in the U.S. laboratory module, Destiny, of the International Space Station (ISS).

The first payload in the FIR will be the Light Microscopy Module (LMM). The LMM is planned as a remotely controllable, automated, on-orbit microscope subrack facility, allowing flexible scheduling and control of fluids and biology experiments within the FIR. Key diagnostic capabilities for meeting science requirements include video microscopy to observe microscopic phenomena and dynamic interactions, interferometry to make thin film measurements with nanometer resolution, laser tweezers for particle manipulation, confocal microscopy to provide enhanced three-dimensional visualization of structures, and spectrophotometry to measure photonic properties of materials. The LMM also provides experiment sample containment for frangibles and fluids.

This paper will provide a description of the current FIR and LMM designs, planned capabilities and key features. In addition a brief description of the initial five experiments planned for LMM/FIR will be provided.

## INTRODUCTION

The Fluids Integrated Rack (FIR) is one of two racks that make up the Fluids and Combustion Facility (FCF).<sup>1</sup> The FCF is being designed to accommodate a wide range of combustion and fluids physics experiments. At completion the FCF will occupy two International Standard Payload Racks (ISPR's) as shown in figure 1.

The FIR, the second of the two racks to be launched, is scheduled for launch in July of 2005 on UF-3. FIR will provide standard systems required by most subrack payloads including structural, environmental, power, command and data handling, and image processing.

The Light Microscopy Module (LMM) will be the first integrated payload with the FIR and will conduct five fluid physics experiments. The LMM is planned as a remotely controllable on-orbit microscope subrack facility, allowing flexible scheduling and operation of fluids and potentially biotechnology experiments. Attached to the FIR's optics bench, the LMM will receive power, communications, air and water cooling, vacuum exhaust, avionics, image processing, data storage, and additional science diagnostic hardware through the FIR rack, as shown in figure 2. The LMM will be installed on-orbit, and remain in the FIR for a period of about 30 months performing five separate fluid physics experiments.

LMM is a sophisticated, modified commercial research imaging light microscope with laser diagnostics hardware and interfaces to conduct on-orbit colloid, fluid physics, and biological experiments, creating a

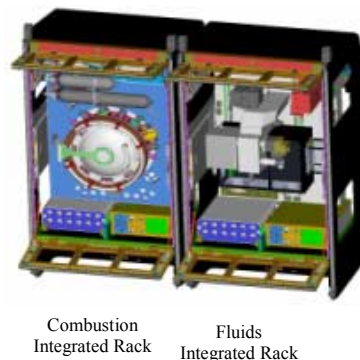
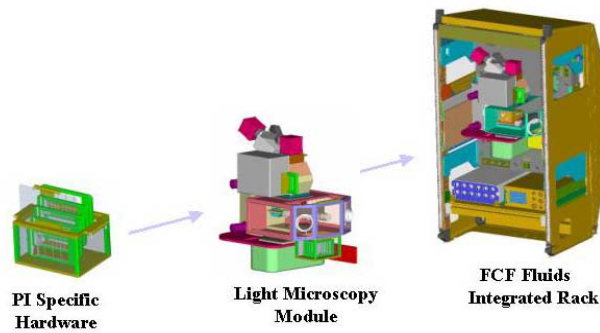


Figure 1 – Fluids and Combustion Facility



**Figure 2 – Integrated LMM and FIR Design**

one-of-a-kind, state-of-the-art microscopic research facility. The LMM will provide imaging techniques of color video microscopy, bright field, dark field, phase contrast, differential interference contrast (DIC), interferometry, spectrophotometry, and confocal microscopy combined in a single configuration. Integrated with the diagnostics are single-trap scanning laser tweezers, to perform sample particle manipulation.

This paper discusses the mission, design, and the capabilities of the FIR and the LMM in carrying out initial Fluids Physics research on the ISS. A description of the LMM diagnostic capabilities, including video microscopy, interferometry, laser tweezers, confocal, and spectrophotometry, will be provided.

#### MISSION: FLUIDS PHYSICS RESEARCH

The Fluids and Combustion Facility will be a permanent facility onboard the ISS. In support of NASA's Office of Biological and Physical Research (OBPR) Microgravity Research Program objectives, the FCF will accommodate and facilitate *sustained, systematic* Microgravity Fluid Physics and Microgravity Combustion Science experimentation on the ISS.<sup>1</sup>

The FCF is being designed for a ten-year life with the ability to extend that life to fifteen years through hardware maintenance and hardware replacement. The goal of FCF is to be able to accommodate a minimum of ten experiments per year in each of the areas of Fluids Physics and Combustion science.

The primary mission of the FIR is to accommodate experiments from five major fluids physics disciplines: complex fluids, multiphase flows and phase change, interfacial phenomena, biofluid mechanics, and dynamics and instabilities. Furthermore, FIR's flexibility (i.e., large volume for experimental hardware, easily re-configurable diagnostics,

customizable software) allows accommodation of experiments from other disciplines such as biotechnology.

In order to meet its mission the FIR must provide common laboratory diagnostic hardware, in a flexible environment, in order to accommodate a variety of imaging techniques commonly used in fluid physics experiments. With this in mind the FIR is being designed to support various diagnostic techniques such as: Video Imaging, Video Microscopy, Light Scattering, Shadowgraphy, Particle Image Velocimetry, Interferometry, IR-imaging, Confocal Microscopy, Laser Tweezers, and Surface Profilometry. In addition, the design of the FIR infrastructure is such that experiment unique cameras, light sources and optical hardware can be accommodated through standard interfaces if the FIR diagnostic tools are not sufficient for a particular diagnostic technique. In order to provide a flexible environment that can accommodate the various experimental test cells and the required diagnostics, the FIR provides a large volume for experimental payloads. Within this experiment volume, experimental hardware can be precision-mounted directly to the FIR optics bench and supported with necessary cooling, power, command and data interfaces.

The LMM will be making full use of the flexibility of the FIR, its' diagnostic hardware, and numerous interfaces. The multi-user, mini-facility, integrated concept supports specific research and scientific investigations by the Microgravity Research Program as part of the Office of Biological and Physical Research (OBPR). Within the FIR, an initial complement of five fluid physics experiments will utilize the LMM instrument. These experiments are the "Constrained Vapor Bubble" experiment (Peter C. Wayner of Rensselaer Polytechnic Institute), the "Physics of Hard Spheres Experiment-2" (Paul M. Chaikin of Princeton University), the "Physics of Colloids in Space-2" experiment (David A. Weitz of Harvard University), the "Low Volume Fraction Entropically Driven Colloidal Assembly" experiment (Arjun G. Yodh of the University of Pennsylvania), and the "Micromechanics of Magnetorheological Fluids" experiment (Alice P. Gast, Massachusetts Institute of Technology). Beyond these experiments, the LMM recognizes future programs and will remain flexible to allow more Principal Investigators (PI's) to utilize the facility.

The primary mission of the LMM is to accommodate these initial five experiments, and meet the scientific objectives defined by the PI's. Key diagnostic capabilities include video microscopy to observe sample features including basic structures and dynamics, thin film interferometry to observe the

characteristics in a curved liquid film, laser tweezers for particle manipulation and patterning, confocal microscopy to provide enhanced three-dimensional visualization of colloidal crystal structures, and spectrophotometry to measure colloidal crystal photonic properties. The LMM is designed to be an accessible, modular, and flexible instrument to support the five PI experiments. In addition, the LMM utilizes FIR hardware and architecture (including interface design) and subsystems, to minimize cost and increase redundancy.

The LMM design permits on-orbit reconfiguration and maintenance that supports follow-on fluid physics or biotechnology experiments, while minimizing up-and-down-mass stowage. In order to support five PI's within a 30 month on-orbit time, the LMM will be designed for autonomous operation to minimize crew time needed to set-up, perform and acquire scientific data from experiments. The hardware and software are modular and up-gradable, permitting evolutionary implementation of capabilities to meet science requirements. Finally, the LMM is designed for long life installation on FIR. Key components are selected as long life items, on-orbit replaceable modules to enable upgrades, incorporate new technology and/or provide for on-orbit reliability for approximately 30 month operational life of the LMM.

### CARRIER - ISS

The Fluids and Combustion Facility will be located in the U.S. laboratory module, Destiny, of the International Space Station (ISS). Destiny is an environmentally controlled, pressurized laboratory. Within Destiny there are 24 International Standard Payload Rack (ISPR) locations, 13 of these are allocated for research. The FCF will occupy two contiguous research locations. The ISS supplies the necessary resources to conduct experiments at these rack locations. Resources provided by ISS include power, cooling water, gases, vacuum and command and data handling.

### FLUIDS INTEGRATED RACK

The FIR will utilize six major subsystems to accommodate the broad scope of fluids physics experiments. The major subsystems are: structural, environmental, electrical, gaseous, command and data management and diagnostics. These subsystems combined with payload unique hardware will allow the FIR to conduct world-class science.

### Structural Subsystem

The foundation of the FIR's structural subsystem is the ISPR. The ISPR will contain all of the FIR hardware and provide a standard interface to Destiny. Enclosing the rack, in the front, will be two bi-fold doors. The doors open from the middle up and the middle down. The rack, along with the doors, provides acoustic emission attenuation, minimizes air/thermal exchange with the cabin, reduce airborne contaminate migration into the rack and prevents stray light from entering or leaving the rack.

The microgravity environment is enhanced by the Active Rack Isolation System (ARIS) for experiments in the FIR. ARIS, mounted in the ISPR, isolates the entire rack from ISS and minimizes vibratory transmission to and from the rack. ARIS utilizes three accelerometers to measure the micro-gravity environment in the rack. Based on the measured accelerations ARIS applies reactive forces, between the FIR and ISS, through eight actuators to minimize transmission of vibratory disturbances. ARIS will be particularly important for the first LMM experiment which requires micro-gravity levels below  $10^{-4}$  g (dc level).

The centerpiece of the FIR structural subsystem is the optics bench. The optics bench provides a mounting surface for FIR-provided hardware on the back of the bench and for payload hardware on the front. Depending on the use of the FIR provided hardware, the optics bench will be able to accommodate up to 179 kg of payload hardware. The front of the optics bench provides T-Slots and 1/4–28 threaded holes, as shown in figure 3, for mounting of payload hardware. The T-slots enable precise mounting of payload hardware; including optical components. The T-Slots are spaced on 50 mm centers. Detents on 12.5 mm centers will enable precise indexing when positioning hardware using the T-slots. The LMM will mount directly to the optics bench utilizing the threaded holes.

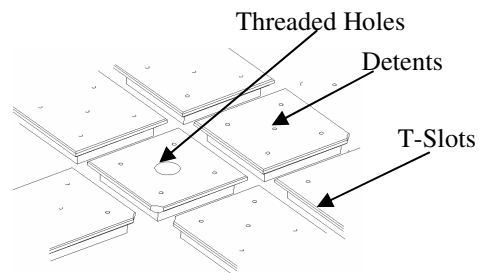
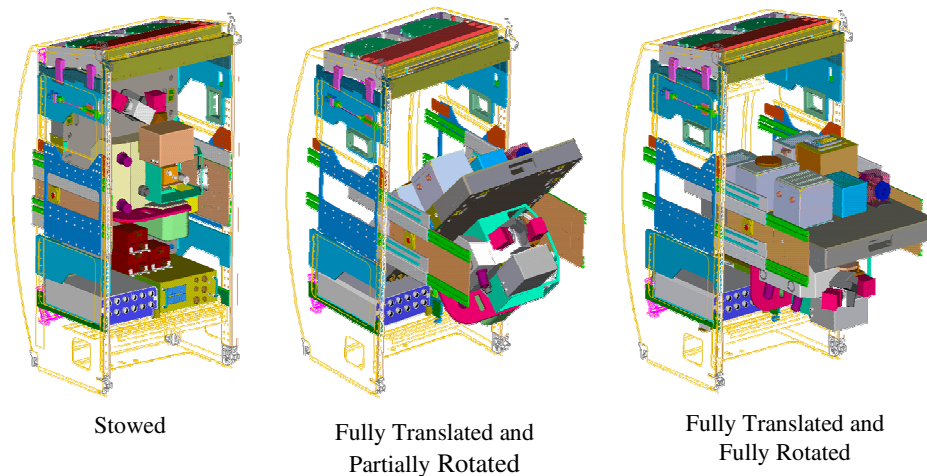


Figure 3 – Optics Bench Front Surface

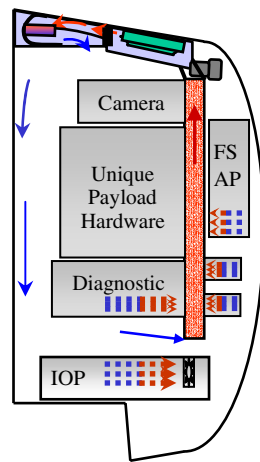


**Figure 4 – FIR Optics Bench Deployment with LMM Mounted to the Bench**

The optics bench is designed so it can be translated out of the rack and rotated forward, as shown in figure 4, to allow the crew easy access to hardware mounted on the optics bench. During powered operations the FIR optics bench is in the stowed position and the rack doors are closed. In the un-powered mode, the rack doors can be opened and the optics bench translated forward. Fully translated out, the front surface of the bench will extend past the front of the rack slightly into the aisle way of the cabin providing easy access to the front of the bench. The bench can be rotated forward ninety degrees providing access to the back of the bench for installing and/or replacing FIR hardware.

Environmental Subsystem

The environmental subsystem will utilize air and water to remove heat generated by the FIR and payload hardware. The air thermal control system will provide a temperature controlled environment for the payload. The control set-point, which can be located anywhere within the payload volume, is selectable by the payload. As shown in figure 5 air will be circulated throughout the rack and will be cooled by the Air Thermal Control Unit (ATCU), an air-water heat exchanger located in the top of the rack. The design point for the air-cooling system is 1650 W at 220 cubic feet per minute, however, the system can operate at other heat loads and air flow rates. The coolest air will leave the heat exchanger and flow over the front of the optics bench cooling payload hardware as well as the



**Figure 5 – FIR ATCS**

FIR diagnostics. Heat rejection by payload hardware to the air on the front of the bench is nominally limited to 500 W. In the case of LMM the air thermal control system will provide a stable temperature environment that will allow the optics to properly function and aid LMM in maintaining samples at a constant temperature. The heat transfer experiment and colloid experiments require temperatures between 23 and 26 °C prior to running their experiments. These temperature constraints are necessary to maintain known sample cell conditions.

Cooling water from the ISS moderate temperature loop enters the rack and is split into two cooling loops. One loop is dedicated to the FIR hardware, including the ATCU heat exchanger, the other loop is for payload hardware. Each loop is capable of removing 3 kW of heat. The water inlet temperature to the rack is nominally 16.6 °C. Payloads have access to the cooling water through the Water Interface Panel located on the right side of the rack. LMM will utilize the cooling water for additional conditioning of the air around its samples and for removing heat from sample cooler and heaters.

Gas Interface Subsystem

The FIR will provide payloads with access to the ISS gaseous nitrogen and vacuum systems through the Gas Interface Panel (GIP) located on the left side of the rack. These systems are available to support experiment operations such as the purging of experimental test cells and pressurizing or creating flows within experimental test cells.

The gaseous nitrogen supply pressure and temperature can vary from 517 to 827 kPa and from 15.5 to 45 °C respectively. The maximum mass flow rate is 5.43 kg/hr. The FIR provides a shutoff valve isolating



payload hardware from the ISS gaseous nitrogen system. The payload must provide flow control and pressure regulation as required.

FIR provides payloads access to the two ISS vacuum systems, the Vacuum Exhaust System (VES) and the Vacuum Resource System (VRS). The VES has a higher throughput than the VRS and is intended for pulling a chamber or system from pressures up to 276 kPa down to a vacuum (0.13 Pa). The VRS can be used to hold a chamber or system at a vacuum (0.13 Pa). Payloads will be able to access the ISS vacuum systems through the FIR provided quick disconnects located in the GIP. LMM will use the VES to pull a slight vacuum in order to verify seals on-orbit.

#### Electrical Subsystem

The Electrical Power Control Unit (EPCU) is the heart of the electrical subsystem. All of FIR and PI hardware receive conditioned power from the EPCU. The EPCU will provide power management and control functions, as well as fault protection. The EPCU will take 120 VDC from ISS power bus to provide six 120 VDC 4 A and forty-eight 28 VDC 4 A fault protected circuits to the FIR and payload hardware. Payload hardware will have access to three of the 120 VDC circuits and six of the 28 VDC circuits at the PI power/data connectors on the optics bench.

#### Command and Data Management Subsystem

The FIR Command and Data Management subsystem (CDMS) provides command and data handling for both facility and payload hardware. The main components of the FIR CDMS are the Input Output Processor (IOP), the Image Processing and Storage Unit (IPSU), the Fluids Science Avionics Package (FSAP) and the Mass Data Storage Unit (MDSU).

The Input Output Processor (IOP) will provide the link from the FIR to the ISS command and data management system via the MIL-STD-1553B, Ethernet, analog video and the High Rate Data Link interfaces. The Input Output Processor provides the overall command and data management functions for the FIR. The IOP controls the core facility subsystems. The IOP will receive and store science data from the FSAP, image data from the IPSU's and ancillary rack data. The IOP will store data on two removable 182 GB hard drives. This data can be downlinked or the hard drives can be removed and replaced with new ones. The IOP can route analog video directly to the ISS for downlinking or storage on an ISS video recorder.

The FIR will be able to accommodate two Image Processing and Storage Units (IPSU) with slightly different features. Both IPSU's will perform diagnostic

control and image processing and storage functions. Both IPSU's will be able to provide control for a camera, receive image data from the camera and process or compress image data as necessary. Payloads can use existing FIR software or generate custom software to process and compress image data. One IPSU can receive images from a digital camera through a custom Serial Data Link (SDL) interface or through a standard IEEE-1394 interface. The serial data link converts image data transmitted from a digital camera through fiber back to a digital signal so it can be processed by the IPSU. The other IPSU will have an analog frame grabber in place of the serial data link interface. The IPSU will be capable of receiving raw image data at 64 MB/s. At this rate the IPSU will be capable of receiving a 1024 pixel by 1024 pixel, 16 bit image at 30 frames per second. The IPSU will be capable of performing automated real-time image analysis in order to support real-time activities such as object tracking. Payloads can utilize existing FIR software or generate custom software for object tracking. The IPSU has two 18 GB hard drives for image storage. Once the data is stored the IPSU will be capable of post processing images. LMM will use the C-IPSU to analyze images and control the microscope optics. In addition, LMM will process and compress images in the C-IPSU reducing the data to a manageable amount.

The Fluids Science and Avionics Package (FSAP) will provide the primary control in carrying out an experiment. Through the FSAP the payload will be able to execute an experiment by controlling the FIR diagnostics and avionics packages as well as payload hardware. Payload developers will be able to download their own custom software into the FSAP for experiment control. The FSAP provides a standard set of computer data acquisition and control functions for use by the payload. The FSAP will provide the following: motion control, analog to digital channels, digital to analog channels, digital inputs and outputs, external and internal triggers, RS-422, analog frame grabber and CAN bus. The FSAP has two 18 GB hard drives for storing analog and digital data as well as analog video images captured by the analog frame grabber. LMM will use the FSAP to conduct experiment operations. The FSAP will control the experimentation, controlling and coordinating operations between the various FIR and LMM hardware packages. The FSAP will also be used to record analog data.

The Mass Data Storage Unit (MDSU) provides supplemental data storage for the rack. The MDSU will have a data storage capacity of approximately 1 Terabyte. The current design utilizes 6 removable

hard drives in a single package. The unit will be compatible with locations in both the Fluids Integrated Rack and the Combustion Integrated Rack. Within the FIR the MDSU will be compatible with locations on the front and back of the optics bench. It is an ORU and therefore can be removed from the rack and placed in stowage if not required.

#### Diagnostics Subsystem

With the initial deployment of the FIR and through facility upgrades, the FIR will provide a suite of cameras and illumination sources to support a wide range of diagnostic capabilities typically required by fluids physics experiments. The FIR cameras will offer color and black and white imaging. These cameras will be capable of frame rates up to 32,000 frames per second. Lenses for these cameras will provide for macroscopic imaging. The FIR will provide two illumination sources, 532 nm Nd:YAG laser and a white light source for use with the FIR or payload cameras. FIR will provide a color camera, Nd:YAG laser and white light source as part of the initial deployment.

The FIR color camera is a 24 bit, 3-chip Charged Coupled Device (CCD) analog color camera. The camera has a one-third inch array with a pixel density of 768 pixels by 484 pixels. The camera's frame rate is settable up to 30 frames per second (fps) and shutter speed is settable from 1/60 of a second down to 1/10,000 of a second. In auto shutter mode, shutter speeds down to 1/50,000<sup>th</sup> of a second can be achieved. The color camera has a small remote head, 32 mm (W) by 40 mm (H) by 40 mm (D), to facilitate camera integration with PI hardware. The color camera utilizes a standard C-mount for lenses. LMM will utilize this camera for imaging samples and will use the images from the camera to control position of its optics.

The FIR white light package, figure 6, will be located on the back of the FIR optics bench. The package consists of two 50 W metal halide bulbs subassemblies. Each subassembly has a fiber optic quick disconnect for attachment of a fiber bundle. Manually adjusting an aperture knob located on a subassembly will vary the light intensity delivered through the fiber bundle attached to that subassembly. While the FIR is providing a fiber bundle with a lens attachment, payloads can provide a specialized fiber bundle such as a bundle incorporating a light panel or ring light. Fibers will be routed to the front of the optics bench from the white light package on the back through the fiber feed through located in the bench. LMM will utilize the white light for imaging the samples, spectrophotometry and interferometry. In this case LMM is using both the FIR provided fiber and a LMM provided liquid filled fiber.



**Figure 6 – White Light Package**



**Figure 7 – Nd:YAG Laser**

The FIR 532 nm Nd:YAG laser package, shown in figure 7, will be located on the back of the FIR optics bench. When using the laser, a fiber optic cable from the laser will be routed from the back of the bench, through the fiber feed through, to payload hardware on the front. A quick disconnect at the end of the fiber optic cable allows for easy hookup to payload hardware.

The laser is capable of providing a minimum power of 100 mW to the payload out of the FIR provided fiber optic cable. The laser output power can be varied from 0 to 100 percent of the maximum power. A tap coupler located at the output of laser will measure laser power delivered to the payload. LMM will utilize the laser to take confocal images of crystalline structures. The colloid particles used by the PIs fluoresce at 532 nm, making the FIR-provided laser ideal for confocal microscopy.

### LMM CAPABILITIES

The LMM flight unit features a modified commercial off-the-shelf (COTS) Leica RXA microscope, which is enhanced to operate automatically with some interaction from the ground support staff or the astronaut crew.<sup>2</sup> The microscope is modified and enhanced to provide additional capabilities including: 1) Video microscopy to record sample features including basic structures and crystal growth dynamics, 2) Interferometry, to measure vapor bubble thin film thickness, 3) Laser tweezers for sample particle manipulation and patterning, 4) Confocal microscopy to provide three-dimensional visualization of sample structures, and 5) spectrophotometry to measure photonic properties.

The imaging techniques of high resolution color video microscopy, bright field, dark field, phase contrast, differential interference contrast (DIC), fluorescence, spectrophotometry, and confocal microscopy are combined in a single configuration. An experimenter can choose from six (6) objective lenses of different magnifications and NA to achieve the required science data. This suite of measurements allows a very broad characterization of fluids, colloids, and two-phase media, including biological samples. Sample manipulation technique is integrated with the microscope's single-trap scanning laser tweezers. The LMM utilizes cameras and light sources provided by the FIR to accomplish these imaging techniques.

The LMM provides containment for fluids and shatterable materials. Essential components include an Auxiliary Fluids Container (AFC), which will be attached to the microscope, an Equipment Transfer Module (ETM) that will attach to the AFC, and the microscope itself, as shown in figure 8. In general, PI experiment samples will be launched and transported in the ETM, and then the ETM will be attached to the AFC. A crewmember will use gloves attached to the AFC gloveports, to remove the PI experiments from the ETM, and place the samples on the microscope stage. After the sample has been positioned, the remote operation of the microscope, and processing of the samples can begin.

The crew will need to set up the system in the LMM/FIR, reconfigure the LMM, and perform on-orbit maintenance. The ability to modify system parameters to expand the science investigation after early data is analyzed is a design feature.

### Video Microscopy

Video microscopy will be performed via transillumination imaging techniques already resident within the Leica RXA microscope itself, namely, bright field, dark field, phase contrast, and differential interference contrast (DIC). A variety of condenser apertures, objectives, and prisms are required to support these techniques, but the Leica RXA comes well suited for the task. Optical microscopy of colloidal suspensions will be performed using the four transillumination techniques.

The microscope will be configured to have a 0.9 Numerical Aperture (NA) condenser and microscope objectives up to 100x and 1.4 NA (oil immersion) to support the required transillumination techniques. The light source for Köhler illumination is to be provided by an FCF-provided Metal Halide Lamp.<sup>3</sup> Images, such as those shown in figure 9, will be captured by the FCF provided Toshiba color analog camera on the microscope's multi-port imaging head and subsequently downlinked for data processing.

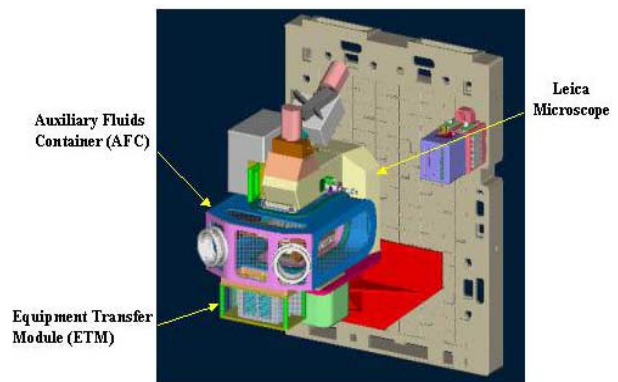


Figure 8 – Integrated microscope, AFC, and ETM

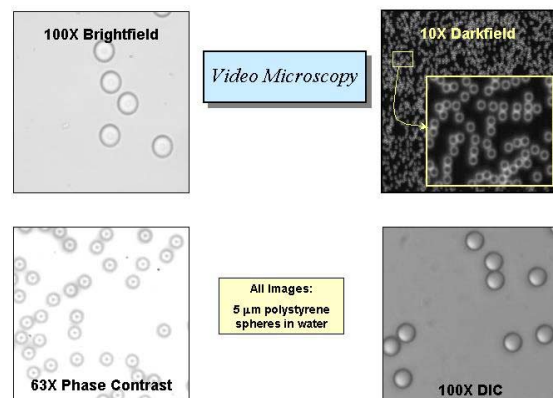
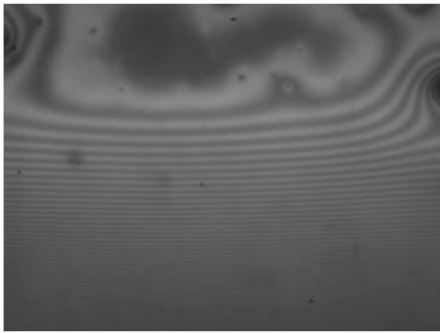


Figure 9 – Microscope images of 5 μm polystyrene spheres

### Interferometry

Observing characteristics of curved liquid films for the Constrained Vapor Bubble (CVB) experiment requires the calculation of the film curvature. Interferometry will be performed to measure the thickness of the liquid film utilizing a 50x objective. The light source in epi-illumination provides the required wavelengths to create the interference fringes. The light passes through the liquid and partially reflects at all interfaces, including the glass-liquid interface and liquid-vapor interface. The light from the two reflections interferes to form fringes that represent an increase in fluid thickness of half the wavelength of light for each bright and dark pair, as shown in figure 10. The color analog camera on the multi-port imaging head will capture the images for downlinking and processing. Analyzing the interferometry images will yield a film thickness profile.

The derivative of the thickness gives the curvature profile, and therefore the pressure field for flow in the liquid film. The thickness will be measured at multiple axial positions along the cuvette.



**Figure 10 – CVB Bubble Image at 435 nm**

### Laser Tweezers

A laser tweezer system will be included in the LMM diagnostic package. Optical tweezers use a highly focused laser beam to trap a small (~1  $\mu$ m) off-index particle. PH<sup>A</sup>SE-2 and PCS-2 will utilize the tweezers to create an array of optical traps to control a specific colloidal crystal structure and study the micro-rheological properties of the colloidal crystal.

Laser tweezers will be implemented using a custom-built system based upon a 1064 nm Nd:YAG laser, beam focusing optics, and two acousto-optic deflectors to steer the trap within the field of view of the microscope. Laser tweezers is simply the trapping of a colloidal particle using radiation pressure by focusing a laser beam through a high-numerical aperture lens and striking the particle. The LMM microscope's reflected light turret will contain a dichroic mirror to reflect the

1064 nm light down to the sample and simultaneously pass visible light in trans-illumination up to the color analog camera on the multi-port imaging head, thereby, allowing both the tweezer beam and the surrounding colloidal crystal to be imaged.

The laser tweezers have two elements of control. Changing the output laser intensity via commands to the laser controller varies the trapping force. The scanning trap position is controlled with two-axis acousto-optic modulators, or deflectors, which diffract the beam with an acoustic wave in the sample, modulated in frequency via a voltage-controlled oscillator.

Tweezers will also be employed to displace a particle by one or more lattice constants from its equilibrium position. Hence also, the tweezers will be scanned through a fixed array of points across the field of view to induce patterns that are either commensurate or incommensurate with the equilibrium configuration of the colloidal crystal. Laser tweezers also will be used to measure the viscosity of the fluid. A particle is trapped and video images taken as it is translated in an oscillatory fashion through the field of view. The velocity just before the particle falls out of the trap is measured from the video record and, along with the known force and particle diameter, used to calculate the sample dynamic viscosity (or crystal shear modulus).

### Confocal

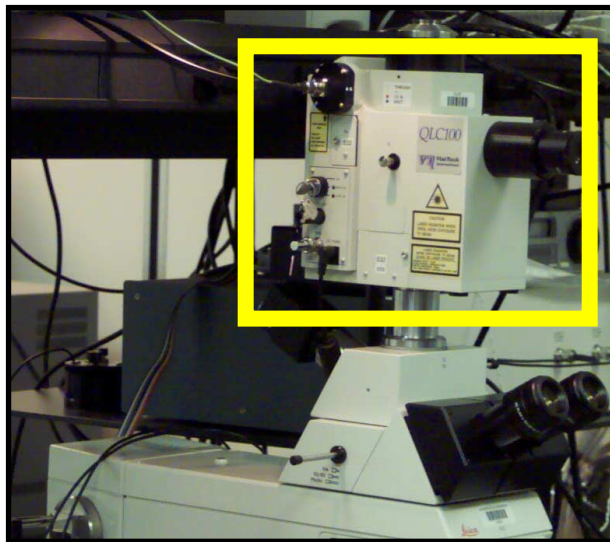
Confocal microscopy is another research technique planned for implementation within the LMM. Three fluid physics experiments, PH<sup>A</sup>SE-2, PCS-2, and L $\Phi$ CA, scheduled for the LMM will employ the technique to probe the interior structure of complex colloidal systems in order to produce detailed three dimensional models of the unique structures formed in microgravity. Figure 11 shows the kind of image that can be obtained with a confocal microscope.



**Figure 11 – Two Micron Diameter PMMA Spheres Dyed with Rhodamine (x-z slice). Taken with Yokagawa Confocal Unit—100x Objective**

Within the LMM, confocal microscopy will be implemented using a combination of commercial off-the-shelf subsystems, modified to allow non-standard operating configurations. The design involves a 532 nm frequency-doubled Nd:YAG laser, a Yokogawa Model CSU10 Confocal Scanner, a Leica RXA upright microscope, and QImaging Retiga 1300, 12 bit digital CCD camera.

The Yokogawa CSU10 confocal unit used on the LMM is a Nipkow disk-based scanner (as opposed to a laser scanning device). The Nipkow disk version of confocal microscopy was chosen for the LMM due to its inherent stability, speed, and simplicity. It uses a spinning array of matched apertures and lenses to individually map regions of the sample onto the CCD array. The rotational speed of the scanner will allow 30 frames per second of confocal images to the CCD camera. The crystal three-dimensional structure is reconstructed by assembling the slices with an image analysis program, from which colloidal growth, structure, and dynamics can be measured. The confocal module will be attached, as shown in figure 12, to the LMM using slide rails, and will access the sample through an auxiliary port on the Leica RXA.



**Figure 12 – Yokogawa Confocal System Attached to the LMM Microscope**

Confocal microscopy generally has advantages over other microscopy techniques such as phase contrast, differential interference contrast, and fluorescence due to the enhanced rejection of out-of-focus light provided by the confocal technique. Confocal is normally used on a fluorescent-dyed sample. It results in a much finer resolution in the sectioning dimension (through the sample), allowing better reconstruction of crystal

structure and lattice positions, even within somewhat turbid samples. The data is acquired by focusing at the near side of the sample and scanning a two-dimensional image at each focal plane as the focus is translated through to the far side of the sample.

#### Spectrophotometry

The spectrophotometer diagnostic capability will measure the photonic properties of crystals grown in the microscope sample cells. Different crystal and alloy structures have various spectral transmission characteristics, which can be analyzed using this technique. The photonic samples will be trans-illuminated between 400 and 700 nm wavelengths, some of which will transmit through the sample with both a different intensity and at a different scattering angle. The static light scattering distribution will be detected with a high resolution QImaging Retiga 1300 CCD array.

The spectrophotometer monochromatic input will be coupled to the epi-illumination port on the LMM microscope. Spectrophotometry will be implemented using the Metal Halide lamp in epi-illumination, a monochromator for visible wavelength discrimination, a translating pinhole in the aperture plane, and the 12 bit digital QImaging Retiga 1300 CCD camera. The monochromator is used to select narrow-band visible light (10nm bandwidth) from the collimated light in the epi-illumination path and pass it to the pin hole and on to the sample. The translating pinhole is planned to be adjustable in the X and Y directions to vary the angle of incidence (up to  $\pm 65$  degrees for normal incidence angle) at the sample. Since this technique is looking at the reflected light coming back from the sample, the detector will be seeing the stop bands of the photonic crystals. When the monochromator is tuned to a wavelength that is in the pass band of the photonic crystal, the light will pass through the crystal and only non-specular reflection will reach the detector.

#### ON-ORBIT OPERATIONS

After the initial installation and checkout of the FIR and the LMM, on-orbit operations will commence.

On-orbit payload operations begin by initially configuring the FIR for a specific payload, in this case LMM. Next the LMM hardware will be removed from stowage and installed on the front of the optics bench. Rotating the bench forward will allow inner-connecting cables, such as fiber optic cables, from the back to the front of the bench to be run. Once the LMM is installed and all cables and hoses have been run the bench can be

slid back into the rack and the rack doors can be closed. Once the doors are closed the FIR can be powered up.

Due to limited crew time, most of the powered up payload operations will be conducted from the Telescience Support Center (TSC) at the Glenn Research Center. A ground team made up of both the FIR and LMM teams will operate the FIR and LMM hardware from the TSC. These teams will be able to monitor the health and status of the FIR and LMM hardware, issue commands and review data in near realtime and post test. Once testing is completed the payload hardware will be removed and stowed until it can be returned to earth.

### SUMMARY

The FIR will provide common laboratory diagnostic hardware, in a flexible environment, in order to accommodate a variety of fluid physics experiments. In addition to providing a suite of diagnostic tools for use by the payloads, the FIR's flexible interfaces will allow payloads to utilize experiment unique diagnostic hardware. The Light Microscopy Module will be the first subrack payload in the FIR. The LMM is a sophisticated, modified commercial research imaging light microscope with laser diagnostics hardware and interfaces to conduct on-orbit colloid, fluid physics, and biological experiments, creating a one-of-a-kind, state-of-the-art microscopic research facility. There are currently five fluid physics experiments planned to be the first to use the facility. The LMM takes advantage of FIR-provided capabilities to enhance PI scheduling and flexibility and allows for increased science throughput.

The FIR's avionics provides a customizable control and data acquisition system. The FIR avionics can be augmented by payload unique data acquisition and control hardware. For LMM control, the system will allow payload and PI specific software to be uploaded providing the unique control algorithms required to operate the FIR and LMM experiments.

The design of the FIR and LMM minimizes the use of the crew. The use of ORU's in the design of both the FIR and LMM will allow for easy maintenance and

upgrades of the hardware. The translating optics bench and quick disconnect interfaces allow for easy installation and removal of FIR and payload hardware. Once the FIR/LMM is configured for a particular experiment, the FIR/LMM will be operated from the ground requiring the crew only for sample change out and troubleshooting.

The LMM provides imaging techniques of color video microscopy, bright field, dark field, phase contrast, differential interference contrast (DIC), interferometry, confocal microscopy, and spectrophotometry all combined in a single configuration. Integrated with the diagnostics are single-trap scanning laser tweezers, to perform sample particle manipulation and patterning.

The experiment-unique sample cells, procedures, and any specialized measurements (e.g., cell instrumentation, special light source, etc.) are customized within the constraints of the LMM, FIR, and ISS for each Principal Investigator. Such an arrangement allows cost and time savings on each experiment by reusing modular facility test equipment, rather than the traditional approach of designing stand-alone experiments for each Principal Investigator

### REFERENCES

1. Kohl, F.J., Singh B.S., Alexander, J.I., Shaw, N.J., and Hill, F.J., "The NASA Microgravity Fluid Physics Program—Knowledge for Use on Earth and Future Space Missions," 53rd International Astronautical Congress, The World Space Congress—2002, October 2002.
2. Motil, S.M., Snead, J.H., "The Light Microscopy Module: An On-Orbit Multi-User Microscope Facility," AIAA-2001-4956, Conference and Exhibit on International Space Station Utilization—2001, October 2001.
3. Zurawski, R.L., "The ISS Fluids and Combustion Facility: Microgravity Combustion Science and Fluid Physics Research Capability," AIAA-2001-4925, Conference and Exhibit on International Space Station Utilization—2001, October 2001.



# REPORT DOCUMENTATION PAGE

*Form Approved*  
*OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

<b>1. AGENCY USE ONLY</b> ( <i>Leave blank</i> )	<b>2. REPORT DATE</b> September 2003	<b>3. REPORT TYPE AND DATES COVERED</b> Technical Memorandum	
<b>4. TITLE AND SUBTITLE</b>  The Fluids Integrated Rack and Light Microscopy Module Integrated Capabilities		<b>5. FUNDING NUMBERS</b>  WBS-22-400-32-30-03	
<b>6. AUTHOR(S)</b>  Susan M. Motil, Frank Gati, John H. Snead, Myron E. Hill, and DeVon W. Griffin			
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191		<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>  E-13660	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  National Aeronautics and Space Administration Washington, DC 20546-0001		<b>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</b>  NASA TM-2003-212606 IAC-02-J.5.06	
<b>11. SUPPLEMENTARY NOTES</b>  Prepared for the 53rd International Astronautical Congress cosponsored by the International Astronautical Federation (IAF), the International Academy of Astronautics (IAA), and the International Institute of Space Law (IISL), Houston, Texas, October 10-19, 2002. Responsible person, Susan M. Motil, organization code 6728, 216-433-8589.			
<b>12a. DISTRIBUTION/AVAILABILITY STATEMENT</b>  Unclassified - Unlimited Subject Category: 74  Available electronically at <a href="http://gltrs.grc.nasa.gov">http://gltrs.grc.nasa.gov</a> This publication is available from the NASA Center for AeroSpace Information, 301-621-0390.		<b>12b. DISTRIBUTION CODE</b>	
<b>13. ABSTRACT</b> ( <i>Maximum 200 words</i> )  The Fluids Integrated Rack (FIR), a facility class payload, and the Light Microscopy Module (LMM), a subrack payload, are scheduled to be launched in 2005. The LMM integrated into the FIR will provide a unique platform for conducting fluids and biological experiments on ISS. The FIR is a modular, multi-user scientific research facility that will fly in the U.S. laboratory module, Destiny, of the International Space Station (ISS). The first payload in the FIR will be the Light Microscopy Module (LMM). The LMM is planned as a remotely controllable, automated, on-orbit microscope subrack facility, allowing flexible scheduling and control of fluids and biology experiments within the FIR. Key diagnostic capabilities for meeting science requirements include video microscopy to observe microscopic phenomena and dynamic interactions, interferometry to make thin film measurements with nanometer resolution, laser tweezers for particle manipulation, confocal microscopy to provide enhanced three-dimensional visualization of structures, and spectrophotometry to measure photonic properties of materials. The LMM also provides experiment sample containment for frangibles and fluids. This paper will provide a description of the current FIR and LMM designs, planned capabilities and key features. In addition a brief description of the initial five experiments planned for LMM/FIR will be provided.			
<b>14. SUBJECT TERMS</b>  Video microscopy; Confocal microscopy; Spectrophotometry; Laser tweezers		<b>15. NUMBER OF PAGES</b> 16	
		<b>16. PRICE CODE</b>	
<b>17. SECURITY CLASSIFICATION OF REPORT</b> Unclassified	<b>18. SECURITY CLASSIFICATION OF THIS PAGE</b> Unclassified	<b>19. SECURITY CLASSIFICATION OF ABSTRACT</b> Unclassified	<b>20. LIMITATION OF ABSTRACT</b>