NASA
National Aeronautics and
Space Administration

February 9, 2001

NRA-01-OBPR-02

RESEARCH ANNOUNCEMENT

Fluid Physics: Research and Flight Experiment Opportunities

Notice of Intent Due: .... March 12, 2001

Proposals Due: ....May 11, 2001

OMB Approval No. 2700-0087

FLUID PHYSICS:
RESEARCH AND FLIGHT
EXPERIMENT OPPORTUNITIES

NASA Research Announcement
Soliciting Research Proposals
for the Period Ending
May 11, 2001

NRA-01-OBPR-02
Issued: February 9, 2001

Office of Biological and Physical Research (OBPR)
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

NASA RESEARCH ANNOUNCEMENT
FLUID PHYSICS:
RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

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NASA RESEARCH ANNOUNCEMENT

FLUID PHYSICS:
RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

This NASA Research Announcement (NRA) solicits proposals for flight experiments and for ground-based experimental and theoretical research in microgravity fluid physics. The Office of Biological and Physical Research (OBPR) has a need for revolutionary research focusing on space exploration issues (heat transfer, multi-phase flow, fluid management, and biofluid transport). The microgravity fluid physics discipline represents a broad range of research areas ranging from heat and mass transfer to condensed matter physics. Fluid physics research proposals in more fundamental areas are also solicited. Descriptions of fluid physics research activities and interests are given in Appendix A.

Investigations selected for flight experiment definition must successfully complete a number of subsequent development steps, including both NASA and external peer reviews of the details of the proposed flight experiment, in order to be considered for a flight assignment. NASA does not guarantee that any investigation selected for definition will advance to flight experiment status. Proposals are sought for a number of upcoming flight opportunities. Investigations selected for support as ground-based research under the Physical Sciences Division (PSD) ground-based research program generally must propose again to a future solicitation in order to be selected for a flight opportunity.

Participation is open to U.S. and non-U.S. investigators and to all categories of organizations: industry, educational institutions, other nonprofit organizations, NASA centers, and other U.S. Government agencies. **Though NASA welcomes proposals from non-U.S. investigators, NASA does not fund Principal Investigators at non-U.S. institutions.** Proposals may be submitted at any time during the period ending May 11, 2001. Proposals will be evaluated by science peer reviews and engineering feasibility reviews. Late proposals will be considered if doing so is in the best interest of the Government.

Appendices A and B provide technical and program information applicable only to this NRA. Appendix C contains general guidelines for the preparation of proposals solicited by an NRA.

This announcement will not comprise the only invitation to submit a proposal to NASA for access to the reduced-gravity environment and is part of a planned sequence of solicitations inviting proposals in the disciplines of the microgravity program.

NASA Research Announcement Identifier: **NRA-01-OBPR-02**

NRA Release Date:	**February 9, 2001**
Notice of Intent Due:	**March 12, 2001**
Proposals Due:	**May 11, 2001**
Selection Announcement:	**October, 2001**

This NRA is available electronically and Notices of Intent should be submitted electronically via the Physical Sciences Research Division web page at:

http://peer1.idi.usra.edu/

Submit Proposals to the following address:

Dr. Gerald Pitalo
c/o NASA Peer Review Services
Subject: NASA Research Proposal (NRA-01-OBPR-02)
500 E. Street, S.W., Suite 201
Washington, D.C. 20024
Telephone number for delivery services: (202) 479-9030

NASA cannot receive deliveries on Saturdays, Sundays or federal holidays.

Proposal Copies Required:………………..**15**

Proposers will be notified by electronic mail confirming receipt of proposal, approximately 10 working days after the proposal due date.

Obtain programmatic information about this NRA from:

Dr. Gerald Pitalo
Enterprise Scientist for Fluid Physics
Code UG
National Aeronautics and Space Administration
Washington DC 20546-0001
(202) 358-0827
gpitalo@hq.nasa.gov

Obtain additional reference information at the following address:

Dr. Bhim Singh
MS 500-102
Microgravity Sciences Division
Glenn Research Center
National Aeronautics and Space Administration
21000 Brookpark Road
Cleveland, OH 44135-3191
(216) 433-5396

Selecting Official:

Dr. Eugene Trinh, Director
Physical Sciences Research Division
Office of Biological and Physical Research
NASA Headquarters

Your interest and cooperation in participating in this effort are appreciated.

Dr. Kathie Olsen,
Acting Associate Administrator
Office of Biological and Physical Research

APPENDIX A
NRA-01-OBPR-02

TECHNICAL DESCRIPTION

FLUID PHYSICS: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

I. INTRODUCTION

A. BACKGROUND

The Office of Biological and Physical Research (OBPR) Enterprise, one of five National Aeronautics and Space Administration (NASA) strategic enterprises, conducts a program of basic and applied research using the reduced-gravity environment to improve understanding of fundamental physical, chemical, and biological processes. The scope of the program sponsored by the Physical Sciences Division (PSD) ranges from basic research that uses low gravity to create test conditions to probe the fundamental behavior of matter to applied research into the effects of low gravity on the processing of various materials. A contract, grant, cooperative agreement, or other agreement may be used to accomplish an effort funded in response to this NASA Research Announcement (NRA). This announcement is part of an ongoing effort to develop research in a specific space-relevant scientific discipline, Fluid Physics. The Division last released a NRA for Microgravity Fluid Physics Research in 1998.

NASA has supported research in microgravity fluid physics for over three decades. An extensive research program supports theoretical and experimental investigations in ground-based laboratories. Many investigations are conducted using fluid physics research apparatus built to take advantage of the limited low gravity test times available in ground-based facilities such as the drop-towers at NASA Glenn Research Center, or NASA's parabolic low gravity flight research aircraft. These ground-based experiments, along with theoretical modeling, form the basis for most of our current understanding of the effects of gravity on fluid processes and phenomena, and represent the bulk of the research program.

In the PSD program, ground-based research has been used to gain a rigorous framework to define experiments to be conducted in extended low gravity test times available in spacecraft in low-Earth orbit. PSD also anticipates limited near-term flight opportunities for investigations capable of making use of existing hardware where no or minor modifications would be required.

PSD is preparing for flight opportunities using the International Space Station (ISS) by developing modular research instruments that will accommodate multiple experiments and multiple users. Fluid physics flight investigations planned for ISS are in the following sub-discipline areas:

- Complex Fluids
- Interfacial Phenomena
- Multiphase Flow and Heat Transfer
- Dynamics and Stability
- Exploration
- Biofluids

This announcement is being released as part of a coordinated series of discipline-directed solicitations intended to span the range of the PSD program. Other PSD supported solicitations which are planned for periodic release over the next several years include the following:

- Biotechnology
- Combustion Science
- Fundamental Physics
- Materials Science

B. RESEARCH ANNOUNCEMENT OBJECTIVES

This NRA focuses and enhances the PSD fluid physics program described in Section II, through the solicitation of:

1) Experiment concepts defining and utilizing new instruments for space-based experiments in fluid physics with an emphasis on research concepts that can be accommodated by compact and innovative instrumentation.

2) Experimental studies requiring the space environment to test clearly posed hypotheses, using existing or slightly modified instruments in space-based experiments to increase the understanding of fluid physics, and supporting space exploration by elucidating low-gravity fluid and transport phenomena.

3) Ground-based theoretical and experimental studies leading to potential new flight investigation or enhancing the understanding of existing experiments in fluid physics with an emphasis on research that will provide a scientific foundation for technologies required by future human and robotic space missions.

4) Interdisciplinary research projects that can support development programs and novel research approaches. This research announcement is also soliciting a fourth type of proposal that encourages the formation of teams of researchers where physicists, biological researchers, and researchers from other areas (optics, materials science, combustion, bioengineering, etc.) can advance the research through an interdisciplinary approach. Research groups from the same or from different institutions may team and submit a joint research proposal. Proposals in this category must be formed through a cooperative arrangement between the research groups with one research group having, for example, comprehensive bioengineering and fluid dynamic capabilities and the other an outstanding background in the biological sciences. The goals of the interdisciplinary research projects are to develop advanced technology, promote ground-breaking research, and support technology transfer. These interdisciplinary proposals will allow the teaming of science research groups to address complex problems.

   A single researcher who is able to identify past work that has an interdisciplinary thrust may also propose with a well defined proposal citing all of his/her previous work which incorporates the interdisciplinary approach.

   Interdisciplinary proposals should identify key personnel and their expertise. It must be clearly stated who the Principal Investigator and the lead institution are and how the effort will be integrated (see Appendix C). A science team, for example, may wish to work with a strong engineering team, at its own or another institution. Proposals should state how teaming and cooperation between the engineering and science teams would be managed.

   Management structure, goals, and cooperation with the research community to facilitate the transfer of technology must be evident in the proposal.

Further programmatic objectives of this NRA include objectives broadly emphasized by the civil space program, including: the advancement of economically significant technologies; technology infusion into the private sector; enhancement of the diversity of participation in the space program, public education and outreach and several objectives of specific importance to the research program. These latter objectives include the support of investigators in early stages of their careers, with the purpose of developing a community of established researchers for the International Space Station and other missions in the next 15 years, and the pursuit of research that shows promise of contributing to economically significant advances in technology.

In support of the OBPR goal of human space exploration through science and technology, individuals participating in the research program are encouraged to help foster the development of a scientifically informed and aware public. The research program represents an opportunity for NASA to enhance and broaden the public's understanding and appreciation of the value of research in the environment of space. Therefore, all participants in this NRA are strongly encouraged to promote general scientific literacy and public understanding of the microgravity environment and fluid physics through formal and/or informal education opportunities. Where appropriate, supported investigators will be required to produce, in collaboration with NASA, a plan for communicating to the public the value and importance of their work.

C. DESCRIPTION OF THE ANNOUNCEMENT

With this NRA, NASA is soliciting proposals to conduct ground-based and space-based research in fluid physics, with an emphasis on experimental efforts that are sufficiently mature to justify near-term space flight development and are broad in scale, providing sufficient flexibility for various research platforms. Goals of the discipline along with some currently identified research areas of interest are described in Section II. Proposals describing innovative low gravity fluid physics research beyond that described herein are also sought.

NASA is currently developing several types of flight instruments for fluid physics research. Experiments which propose use of the microgravity science glovebox on ISS are encouraged. Brief descriptions of current and future capabilities are given in Appendix B, Section I. NASA anticipates several near-term space flight opportunities for investigations with requirements which can be met by existing apparatus with only minor modifications. Successful proposals for use of the existing apparatus will be funded for advanced definition studies which will produce a detailed Science Requirements Document (SRD). Authorization to proceed into flight development is contingent upon successful peer review of the experiment and SRD by both science and engineering panels. NASA does not guarantee that any experiment selected for definition, which plans to use existing hardware, will advance to flight experiment status.

NASA also encourages submission of experiment proposals for which none of the existing flight instruments are appropriate. NASA anticipates the development of new fluid physics research experiment apparatus for the International Space Station. The hardware descriptions included in Appendix B, Section I should be viewed as examples to allow researchers to consider capabilities that might meet their science requirements. However researchers should not feel limited by these capabilities. Selected proposals requiring development of new capabilities will be funded for definition studies to determine flight experiment parameters and conditions and for the appropriate flight hardware. The length of the definition phase will be based on experiment requirements, but will normally range from 6 to 24 months and will culminate in the preparation of a Science Requirement Document.

As in the case of near-term flight opportunity, the authorization to proceed into flight development is contingent upon successful peer review of the SRD by both science and engineering panels. NASA does not guarantee that any experiment selected for definition, which requires new instrument development, will advance to flight experiment status. Investigations that do not proceed into flight development will normally be asked to submit a proposal for continuation of support at the conclusion of a typical four-year period of funding. Promising proposals that are not mature enough to allow development of a flight concept within two years of definition may be selected for support in a ground-based research program. Investigations selected into the ground-based research program must generally propose again to a future announcement in order to be selected for a flight opportunity.

II. FLUID PHYSICS RESEARCH

The fluid physics program encompasses a wide range of research in physics and engineering science, including studies of heat and mass transfer processes, fluid dynamics, and the physics of complex fluids. In this NRA an emphasis on exploration is being established to enhance understanding of fluid physics phenomena in support of space flight and the safety and health of astronauts "living in Space."

Fluid physics is the study of the properties and motions of liquids and gases. Such studies arise from nature (e.g. in meteorology, oceanography, and living plants or animals) and technology (e.g. in biological, chemical and material processing, and fluid systems). Fluid phenomena span scales that range from nanometers to light years and constitute by their ubiquity one of the fundamental areas of science and engineering. The need for better understanding of fluid phenomena has created a vigorous, multi-disciplinary research community in fluid physics, whose continuing growth has been marked by the steady emergence of new fields of relevance in both basic and applied science. Areas of technological and ecological importance such as global atmospheric change, groundwater pollution, oil production, and advanced materials manufacturing often rely for their progress on advances in fluid physics.... Scientists studying basic problems from chaotic systems to the dynamics of stars also turn to fluid physics for their models. Through the history of fluid physics, theory and experiment have maintained a synergetic relationship in building scientific knowledge. In recent years, research in fluid physics has been at the forefront in applying large-scale computational techniques to physical problems. The continuing advance of high-performance computing will drive new theoretical insights, which will spur a new generation of experimental fluid physics.

Microgravity research encompasses the phenomena related to gravitational fields (or equivalent accelerations with respect to inertial frames) whose magnitudes are but a small fraction of Earth's gravity. Gravity strongly affects many phenomena of fluid physics by creating forces in fluid systems that drive motions, shape boundaries, and compress fluids. Further, the presence of gravitational forces can mask effects that are ever present but comparatively small.

Fluid physics has a unique role in the NASA microgravity science program. Gravitational physics deals directly with the existence of gravity. Other scientific disciplines are interested in developing the potential of the microgravity environment as a research tool, and hope to create controlled conditions of fluid flow and heat and mass transport in specialized circumstances, e.g. the growth of protein crystals, the solidification of a molten semiconductor, or the burning of liquid fuels. The goal of much of fluid physics research is simply to comprehend fundamental physical phenomena. In doing this, fluid physics contributes to seemingly distant fields of research by providing a fundamental framework of principles and basic understanding for flow and transport that specialists in other disciplines can apply to their problems. Fluid physics also has a crucial role in the space program in support of the effort to develop new technologies, or to adapt existing technologies (e.g., power generation, materials handling and processing, gas adsorption, and life support systems) for space operations or for other extraterrestrial environments. A much sharper understanding of the detailed physics of these processes must be present before engineers can confidently design systems for use in non-Earth environments.

The PSD aims to support fundamental research and enabling technologies associated with space studies. It recognizes the need of supporting a vigorous theoretical and experimental ground-based program which nurtures space research and from which new ideas for space research can grow.

Studies of fluid phenomena and opportunities for research in space can be approximately classified according to their motivation, the known role of gravity, and the anticipated consequences of greatly diminished gravitational effects. Much research in microgravity fluid physics can be discussed within this conceptual structure: (1) how gravity, when eliminated or greatly reduced, results in putting to the fore effects otherwise masked, (2) the role of gravity, and how it produces fluid motions and compressions, and (3) how fluid-engineering systems perform in extraterrestrial environments.

A. COMPLEX FLUIDS

Complex Fluids comprise a large class of soft materials, which often consist of mesoscale supramolecular aggregates, ranging in size from ~1nm to ~1 micron. Their physical properties are determined by the interplay of entropic and structural intermolecular forces and interfacial interactions. Examples are microemulsions, foams and suspensions of colloids or microgels, liquid crystals, biological membranes, the intracellular macromolecular scaffolds of cytoskeleton and the extracellular matrix. The highly interdisciplinary field of Complex Fluids thus bridges the gap between synthetic and living materials. Aside from the scientific challenges, Complex Fluids have a broad range of industrial, biological and environmental applications. Examples are soaps, polymeric lubricants and emulsifiers, and drug delivery systems.

Brownian motion keeps these mesoscopic particles in suspension even in the presence of gravity but the relatively small sedimentation, which normally occurs, can have profound effects on ordering, crystallization, and equilibrium structures. Near absence of gravitational force in space, therefore, provides an ideal laboratory for studying long-term equilibrium properties of complex fluids. In case of hard sphere colloids, this has been demonstrated by experiments conducted in space under NASA's microgravity research program. Experiments conducted in space show formation of dendritic crystals and crystallization of colloidal samples that stay in the glass phase for years on Earth. Some specific examples of complex fluids are provided below:

1) Colloids and suspensions: Colloids are used to study phase transitions and fluid behaviour and are a model for atomic systems. They are ideal for such studies since they have a particluate size comparable to the wavelength of light and can be probed by both real-space and reciprocal-space imaging techniques. Also, Brownian motion dominates the motion of colloids and the corresponding time scales are of the order of seconds making them accessible for experiments. Light scattering has successfully been used in space experiments to study morphology and rheology of colloids. Advanced microscopic techniques are being developed for direct imaging of colloids in space experiments. In addition to serving as model system rheology and morphology of colloids has many practical applications in food, pharmaceutical, cosmetic and chemical industries. Magnetorheological and electrorheological colloids represent another class of complex fluids that can be used as smart materials and may allow flow control without using any valves. Microgravity environment can be used as an effective tool to provide basic understanding into the properties of such complex fluids.

2) Nanoscale Fabrication in the Fluid Phase: Self-assembly of colloids offers a direct route to fabrication of nanoscale devices with controllable structure and properties. In microgravity environment the elimination of all particle sedimentation effects creates a purely thermodynamic environment for the suspensions wherein particle size, volume fraction, and interparticle interactions are the primary determinants of the resulting structures. Thus fabrication of arrays composed of nanoscale particles of materials of vastly different densities is readily possible in space. One could form novel microelectronic masks, optical filters, switches, and photonic bandgap materials for ulralow-noise light source. Such self-assembly at nanoscale, are commonplace occurrences in biological systems and a combination of biological molecules and colloids could lead to novel biocolloidal materials.

3) Granular Mechanics: Granular media represent an interesting class of materials that can exhibit a spectrum of complex flow behavior, ranging from solid-like to gas-like. Understanding and describing their rheology poses a scientifically interesting and technologically important challenge, since many industrial and agricultural processes involve handling and processing of granular materials. The mechanics of such materials are governed largely by frictional-elastic contact forces, inertia, and gravity. Granular materials in a gravitational field form dense, randomly packed structures characterized by a network of stress, often referred to as 'stress chains.' The structure and fluctuation of these 'stress chains' is believed to be responsible for such well known but ill-understood phenomenon as 'jamming.' Jamming is not only of interest in granular systems but also considered responsible for the existence of glass phase. In this respect granular materials serve as model for understanding other systems. Experimentation in a reduced-gravity environment could allow one to isolate and understand the forces of non-gravitational origin and to eliminate density-gradients associated with gravity.

4) Non-Newtonian Fluids: Complex fluids such as polymers, liquid crystals, slurries and suspensions exhibit nonlinear material response to imposed deformations. In such systems ultimate structure-property relationships of a product are often inherently linked to the processing history experienced by the material. In general, these fluids cannot be characterized by a single material parameter such as Newtonian viscosity and are thus generically termed non-Newtonian. Such fluids tend to exhibit both viscous shear stresses and elastic normal stresses that can be nonlinear functions of the temperature, the rate of deformation and the concentration and molecular weight of the material. Knowledge of material functions such as extensional viscosity are essential for developing constitutive relationships and predicting flow properties. Extensional viscosity is an example of such function that is difficult to measure on Earth because the container walls exert shear for a contained fluid and a free column sags due to its weight. Microgravity environment allows the generation of a homogeneous uniaxial deformation flow, permitting an unambiguous measurement of extensional viscosity.

5) Near-Critical Point Fluid Behavior: A pure fluid near its liquid-vapor critical point exhibits universal and interesting properties. For example, a simple fluid such as Xenon is known to exhibit non-Newtonian visco-elastic behavior near its critical point. Non-locality of thermodynamic properties will set in when the length scale of fluctuations become long enough as one approaches the critical point. These thermodynamic properties are also very temperature and density dependent. Hence, the properties are extremely difficult, if not impossible to measure, in the Earth's gravitational field. The very high compressibility of such liquid-vapor systems in 1-g creates a density gradient that either provides too inhomogeneous a sample zone or in the homogeneous bulk regions away from the gradient the sample departs from the critical density. Therefore, microgravity provides an ideal environment for making the needed precise homogeneous equilibrium measurements and prediction of flow characteristics exceedingly close to the critical point.

B. INTERFACIAL PHENOMENA:

Understanding behavior of fluids at a solid-liquid-gas tri-junction as well as liquid-gas/vapor interfaces is not only a subject of scientific curiosity but also of great technological interest. Many natural and technological processes and phenomena, such as coating and painting of surfaces, morphological stability of interface during crystallization, oil recovery from shale, and liquid mediated chemical reactors, rely on the fluid mechanics of the solid-liquid-gas tri-junction. Gravity, on Earth, tends to overwhelm the effects of surface tension force except in a very thin layer of fluid in the vicinity of the solid-fluid interface. In microgravity the region influenced by surface tension is magnified considerably, allowing one to probe the characteristics of this region with much greater precision and insight. Furthermore, the behavior of liquid-vapor/gas interface in microgravity in itself is a subject of great interest for engineers dealing with liquid management in partially filled tanks in space.

1) Capillary Phenomena: Gravity on Earth overwhelms the effects of capillary forces except for a thin layer near the solid-fluid interface. In microgravity surface tension on fluid-fluid interfaces can control the shapes of liquid bodies of even large scale. Small disturbances can shift dramatically the position of a liquid from one portion of the container volume to another, leading to configuration changes that can be important in the drainage of fuel tanks and generally in the area of fluid handling. Experimental verification of theoretically predicted of microgravity behavior is not possible in normal-gravity environment. Capillary instabilities can lead to the breakage of a liquid body into several pieces. Contact line characteristics can significantly affect configurations and transient response of such systems.

2) Solid-Liquid Interactions: Contact-line dynamics of fluid-fluid-solid trijunctions can control the coating of solid surfaces, the cooling of hot surfaces, and the behavior of vapor bubbles in nucleate boiling. Macroscopic contact angles depend on contact-line speeds and, hence, normally depend on flows driven by gravity. Liquid films less than 100 nm in thickness can rupture due to van der Waals attractions, creating new contact lines. Both fluid and thermal management in spacecraft are dependent on the behaviors of thin films and contact lines.

3) Coalescence and Aggregation Phenomena: Numerous phase-separation processes rely on coalescence or aggregation of dispersed phases to form continuous phases. Boiling, condensation, foam drainage and coarsening formation, and (Ostwald) "ripening" of solid precipitates are familiar examples. In droplet condensation and foam coarsening, relative motions caused by gravity, thermocapillary migration and van der Waals forces all contribute to foam drainage and film rupture. In precipitate ripening, large clusters grow at the expense of smaller ones. Since the densities of the various phases may vary considerably, buoyancy induced flows tend to mask other effects. Microgravity, therefore, provides an opportunity to probe these processes and provide new insight into these significant questions.

4) Drops and Bubbles: The microgravity environment allows the use of benign sample levitation methods to study the capillary dominated phenomena affecting the dynamic and static behavior liquid drops in air and gas/vapor bubbles in liquid. Potential areas of interest include: effect of acoustic radiation pressure on the shape and stability of liquid drop; static distortion of nonrotating drops due to surface charges and distributed electric field; coalescence and/or noncoalescence of two drops; thermocapillary induced motion of single or multiple bubbles in a liquid matrix and coalescence of bubbles.

C. MULTIPHASE FLOW AND PHASE CHANGE:

Because of relatively large density differences between various phases usually encountered in multiphase systems, gravity tends to exert a controlling influence on multiphase flows and phase changes. Microgravity behavior of such systems is known to exhibit pronounced differences from their normal-gravity counterparts in most cases. Total absence of stratified flow regime in microgravity that is observed in normal-gravity gas-liquid two-phase flows is an example of such pronounced differences. Many advanced concepts for power generation, energy storage, thermal management and life support in space rely on multiphase flow and phase change. An understanding of multiphase flow and phase change in microgravity is of critical importance for NASA's space exploration needs.

1) Flow Regimes and Regime Transitions: Multiphase flows normally configure themselves into distinctive flow regimes in which the various phases are nonuniformaly distributed across the duct through they flow. The modeling of pressure drop, heat transfer, mass transfer, and stability must take flow regime into consideration. In absence of gravity surface tension plays the dominant role in determining flow regime.

2) Pool and Flow Boiling: Nucleate boiling is one of the most efficient heat transfer mechanisms not only on Earth but also for space applications where the size and mass of the equipment are critically constrained. In nucleate boiling large quantities of heat can be transported with only a small change in temperature. The dynamics of the vapor bubble at the boiling surface must be understood and controlled for efficient operation. On Earth gravity can play a dominant role in affecting the dynamics of the vapor bubble. Since much of the knowledge for nucleate boiling is empirically based, it cannot be extrapolated for microgravity environment. There is thus a clear need to understand the processes of nucleation, growth, and departure of vapor bubble at the heated surface and explore the use of non-gravitational body forces to affect bubble departure in microgravity environment.

3) Condensation: Devices such as capillary pumped loops, loop heat pipes and two-phase radiators depend critically on condensation. The successful use of these devices for space application requires developing a detailed understanding of build-up, stability and drainage of condensate film away from the condensing surface. In absence of gravity, surface tension and vapor shear dominate the complicated dynamics of condensate film. Understanding the limit of vapor shear controlled drainage and use of alternative body forces in the microgravity environment to accomplish it are necessary.

4) Gas-Liquid Flow through Packed Beds: Gas-liquid two-phase flow through a fixed bed of particles occurs in many unit operations of interest to the designers of space-based as well as terrestrial equipment. Examples include separation columns, gas-liquid reactors, humidification, drying and gas absorption operations and extraction and leaching of minerals. Potential space-based applications

include: fuel cells, bioregenerative food production, watering and nutrient transport in plant root systems, waste recovery, and extraction from planetary materials. In general, flow in porous media is driven by gravitational, capillary, and viscous forces. Gravity causes phase separation and migration in the direction of the gravitational field. In microgravity, capillary and viscous forces play fundamental role in controlling phase distribution and hence, multiphase flow and transport in packed beds. Flow regime, pressure drop, flow stability and dryout, therefore, are also expected to be markedly different in microgravity. Both experimental and analytical studies are needed.

D. BIOFLUIDS

Biofluids, an intersection of fluid physics and biology, is a new area of emphasis within the Office of Biological and Physical Research. Fluid mechanics and transport processes play a critical role in many biological and physiological systems and processes. An adequate understanding of the underlying fluid physics and transport phenomena can provide new insight and techniques for analyzing and designing systems that are critical to NASA's mission. Applications derived from biology and physiology can enrich the fluid mechanics and transport phenomena investigations performed by investigators of the microgravity fluid physics community.

1) Physiological Systems: The central nervous system is responsible for overall control of human function. Redistribution of fluids and flow in the brain and spinal cord could impact neurological function, ranging from primitive reflex responses to complex cognitive tasks. The influence may be mechanically based, or involve modified nutrient/neurotransmitter transport. The microgravity environment modifies vascular fluid distribution on a short time scale, due to the loss of hydrostatic pressure, and on a longer time scale, due to the shift of intercellular flows. This fluid shift could modify transport processes throughout the body. For example, modification of flow and resulting stresses within blood vessels could modify vascular endothelial cell structure and permeability, which may be detrimental in long-term spaceflight. Furthermore, reintroduction of gravity causes large-scale fluid shifts in the body, which can influence cardiac output and induce faintness. Studies of macro-and micro-scale biofluid mechanics of the vascular system in the microgravity environment may be important to understanding these physiological events.

It is well known that reduction of weight-bearing stress in the microgravity environment induces bone loss and remodeling behavior. This is an example of removing a normally present force and seeing how cells react over both short and long time scales. On an organ level, the fluid shifts due to microgravity can cause changes in respiration frequency. This may be linked to the central nervous system effects mentioned above. The fluid shift also induces ventilation inhomogeneity and might cause ventilation/perfusion mismatch that could detrimentally impact blood oxygenation. On a micro-mechanical scale, pulmonary airway closure has been identified as occurring in spaceflight, which could detrimentally influence performance of astronauts and mission specialists.

2) Cellular Systems: Cell culture conditions in space are significantly different from those on earth. As cells grow, it is often important for the life scientist to have some control over cell differentiation. It has been shown that removal of gravity can impact cell differentiation, thus providing an important tool in the search for microenvironmental cues (bioactive molecules, local forces including adhesion), which contribute to organ assembly and tissue-specific differentiation. Understanding the stress field is key to this developing technology, and cell cultures allow the investigator to control flows and their stresses on cells. In addition, the creation of organized cellular groups for artificial organ design will, in many cases, benefit from microgravity surroundings so that orientations of cells can fit a prescribed, supportive matrix rather than compete with the effects of gravity.

3) Biocrystals and Biomaterials: Fluid physics and transport phenomena play a key role in determining the morphology of biocrystals. In normal gravity, buoyancy driven convection can alter the concentration fields and resulting properties of crystalline structures. Microgravity environment allows diffusion-controlled processes to govern such phenomena under certain circumstances. Understanding and controlling fluid mechanics and transport processes may help to clarify the underlying issues that are important for growth of biocrystals in the microgravity environment. Since there is much new direction in

the pharmaceutical industry driven by results of the Human Genome Project, it may be anticipated that biocrystal pharmaceuticals could provide an important relationship for NASA with industry.

E. DYNAMICS AND INSTABILITIES

Buoyancy is one mechanism by which Earth's gravity exercises a strong influence on the flow and properties of many fluids. Many well-known flow instabilities, such as Raleigh-Bénard instability, are controlled by gravity. When gravity is removed other forces such as surface tension start to exercise significant influence on many flows. The well-known Marangoni- Bénard instability is an example of surface tension controlled phenomena. This subdiscipline of fluid physics deals with a broad category of flow phenomena where the presence of absence of gravity can produce new flow physics whose understanding can benefit from the use of microgravity environment.

1) Thermocapillary and Solutocapillary Phenomena: When a fluid-fluid interface is subjected to a tangential gradient of temperature and/or species concentration, shear stresses are created in the interface, which drive bulk motions. Such surface effects can control the migration of droplets in bulk or along solid surfaces. They can enhance transport (compared to pure conduction) in large volumes or in menisci. Steady motions can become unstable and lead to time-oscillatory behavior in containerless systems of materials processing. When a temperature gradient is imposed normal to an interface, the pure conduction state persists until a critical value of the gradient is exceeded, leading to Marangoni convection.

2) Electrokinetics and Electrochemistry: Electrokinetics concerns transport phenomena involving charged fluid interfaces and their associated diffuse layer of space charge. The motion from such processes usually results in response to an imposed electric field, which in turn offers a means of manipulating multiphase systems. External fields are also used in separation processes such as electrophoresis, isotachophoresis, and isoelectric focusing. Due to the presence of intrinsic charge on interfaces, electrical effects also play pre-eminent roles in the behavior of a myriad of colloidal systems, including many of biological origin. Electrochemistry deals with phenomena associated with the transfer of electrons at electrodes, resulting in chemical reactions. Although electrolysis reactions comprise the most familiar examples, there are a host of electrochemical synthesis processes where fluid motion affects transport processes. Electrochemistry and Electrokinetics overlap whenever electrical double-layers are involved. Microgravity can have a role in issues where hydrodynamic considerations are involved in the electrochemical processes. Density differences may arise from Joule heating or from concentration changes as a consequence of electrochemical reactions. On the other hand, without natural convection, rates of electrochemical processes are typically diffusion-limited and, hence, low. In the electrochemical engineering practice, significant electrolyte circulation is often achieved through buoyancy effects due to the presence of gas bubbles in parts of the electrolyte. Limitations on earth-based experiments in electrokinetics and electrochemistry arise due to density differences in the fluids; these differences lead to buoyancy-driven bulk motion or sedimentation of particles.

3) Geological Flows: Accurate prediction of weather is an everyday concern, with enormous ramifications for most human activity and economic impact to massive to tally. It is the coupled ocean-atmosphere fluid system that controls the weather, and its long-term trend, the climate. The fluid mechanics of this system falls in the realm of geophysical fluid flows. Fluid mechanics in stars and the giant gaseous planets and the fluid mechanics of the Earth's interior, which shape the distribution and drift motion of the continents, volcanic activity and the generation of the magnetic field of our planet by the dynamo motions of its molten iron interior are other areas of geophysical flows of interest. Some key features of these geophysical flows are: spherical geometry with a centrally directed radial gravity, rotation, and thermal convection driven by various types of heating. The first of these features is extremely difficult to replicate in a terrestrial lab due ubiquitous unidirectional gravity. A microgravity environment provides an unique opportunity to study such rotational flows.

4) G-jitter Induced Flows: Any orbiting platform utilized to provide low-gravity environment invariably introduces g-jitters. G-jitters may be caused by orbital maneuvering devices, onboard machinery, crew activities in case of human-tended spacecraft, and a host of other possible causes. These ever-present

disturbances can have significant effect on stability of fluid-fluid interfaces and associated flow fields. A study of these effects is, therefore, critical to understanding and interpreting observed low-g flows in most cases.

F. HEDS (HUMAN EXPLORATION AND DEVELOPMENT OF SPACE)-SPECIFIC FLUID PHYSICS RESEARCH

As one of NASA's five core Strategic Enterprises, the Office of Biological and Physical Research (OBPR) Enterprise will provide the research efforts required to obtain fundamental understanding and achieve science breakthroughs to enable safer, more efficient, more productive, and more affordable Human Exploration and Development of Space (HEDS). The Space Studies Board of the National Research Council has concluded in a recent report ("Microgravity Research in Support of Technologies For The Human Exploration and Development of Space and Planetary Bodies," Space Studies Board, National Research Council, 2000) that extraordinary improvements need to be made in several areas for NASA to achieve exploration goals. These areas include power generation and storage, space propulsion, life support, hazard control, material production and storage, and fabrication and maintenance. Fluid Physics plays a significant role in a number of systems and subsystems related to these areas. The need for improved understanding of both gravity and non-gravity-based fluid phenomena to enable future space technologies and operations should be recognized as one of the primary opportunities of the discipline. The proposer is referred to the above reference for more detailed information. Identified below are HEDS-specific Fluid Physics Research areas of importance (although the proposer is not limited to these areas):

1) <u>Gravity-Dependent Phenomena:</u>

i) Development of an integrated, reliable, physically-based, multidimensional two-fluid model for the computational fluid dynamics (CFD) analysis of multiphase flow and heat transfer phenomena of importance to the HEDS program. Although there will be a continuing need for experimental variable gravity data and appropriate empirical correlations, the driving force for this priority is the reality of limited ability to conduct repeated experimentation on large-scale structures such as full-scale radiators as they would be deployed in space. These models could be used to 1) optimize system design, 2) direct and support the scale-up of those space experiments used to evaluate subsystems and systems that cannot be tested at full scale in space and 3) provide the necessary basis for establishing desired reliability and safety level for HEDS systems.

ii) Characterization of two-phase (gas and liquid) flow through packed beds in variable gravity environments such as for chemical processing and for the flow of nutrients and gases in soils used for plant cultivation in space. Both with and without heat addition are important areas of study.

iii) Detailed stability data on boiling and condensing systems in variable gravity environments focusing on static and dynamic instabilities in phase-change systems, and the data should be used to assess the predictive capabilities of various analytical models (including two-fluid CFD models) for the linear stability thresholds and the various nonlinear instability phenomenon (e.g., limit cycles, chaos) that may occur in multiphase systems.

iv) Surface-tension-related phenomenon including the physical basis of wetting, hysteresis effects, dynamics of wetting, the correct description of wetting below the scale of the correlation length of the wetting fluid, capillary-driven flows and transport regimes that occur in evaporation and condensation heat transfer, determination of flow regime boundary scaling with gravity, Marangoni convection, dynamical work on the oscillations of liquid drops or bubbles and on the resonances between the applied forces or accelerations (e.g., g-jitter), and capillary modes of motion of a mass of liquid in a container including the so-called sloshing problems and unstable modes.

v) Experimental determination of the parameters that enter into the Marangoni and other relevant dimensionless numbers, including the investigation of tensioactive agents that influence the magnitude and sign of the effect. Thermal and concentration gradients need to be taken into account in assessing the merits of HEDS-related system and subsystem designs where Marangoni flow is possible.

vi) Detailed description of granular flow and behavior in variable gravity environments that accounts for sample history, internal variables, energy fluctuations between particles, the effects of agitation, and particle size and shape, especially for operation at low pressure.

vii) Fundamental understanding of behavior of dust in spacecraft and extraterrestrial environments. Predictive capability that permits calculation and control of dust transport and deposition.

viii) Establishment of scaling laws with respect to gravitational effects (from microgravity to Mars (3/8g)) on fluid physics processes of importance to HEDS missions (flow, heat transfer, boiling, stability) and definition of where such laws break down due to changes in governing physics (e.g. as the gravity level is reduced, Marangoni convection increasingly dominates gravity-induced convection.)

2) Non-gravity-Dependent Phenomena:

Nanotechnology and Biomolecular Applications**:** Recent breakthroughs in using biomolecular based nanoscale motors and switches have opened up the possibility of a new class of devices/sensors for space as well as terrestrial applications. Such devices offer the promise of extreme compactness with potential for self-healing and adapting to the changing environmental conditions. Many processes used to achieve biomolecular self-assembly are likely to take place in a fluid phase. Therefore, an understanding of associated fluid mechanics, heat and mass transport may be crucial to the development of practical biomolecular/nanoscale technologies. NASA would like to encourage groundbreaking cross-disciplinary research in this evolving field. Proposals in this area need not provide a strong justification for microgravity relevance.

III. EXPERIMENT APPARATUS AND FLIGHT OPPORTUNITIES

A. EXPERIMENTAL APPARATUS

In order to accommodate aspects of the research described in Section II, a number of pieces of flight hardware are in development stage by NASA and its international partners. These are described in Appendix B, Section I. Section II of Appendix B lists the ground-based facilities that are available to support definition studies.

Flight opportunities under this NRA will be on the Space Shuttle or the International Space Station (ISS). For the Shuttle opportunities, the experimental apparatus are located in the middeck or Spacehab, allowing direct human interaction, or in the cargo bay which does not permit such interaction. Residual acceleration levels on the order of 10^{-4} g are available in the Shuttle for limited periods of time. Flights range from 7 to 16 days in duration. The Space Acceleration Measurement System (SAMS) is expected to be available to measure and record actual accelerations at or near the apparatus for both Shuttle and ISS experiments.. Considerable additional information on the Shuttle accommodations and capabilities can be found in the STS Investigators' Guide (see Bibliography). Experimental apparatus for the early utilization of the International Space Station will primarily be in facilities such as the Glovebox and Express rack (ISS versions of Shuttle middeck class experiments) followed by the Fluids Integrated Rack after the completed assembly of the ISS. A high-capacity communications network supports Shuttle and ISS payload operations. Down link channels enable users to monitor their instrument status and science data streams in real time. An uplink channel enables them to act on that information. The effective use of these downlink and uplink capabilities enables telescience on a near real time basis.

B. DIAGNOSTIC MEASUREMENTS

The capability to characterize science experiments in reduced-gravity is essential to scientific progress in this program. NASA, in ground-based normal and reduced-gravity studies, is developing techniques for enhancing imaging and visualization, and improving measurements of temperature, velocity, and particle-size distributions. As these techniques mature, those most required by investigators will be reviewed for space flight development as part of the future flight equipment capability.

C. FLIGHT OPPORTUNITIES

Missions available for this program may include Shuttle flights and missions on the International Space Station. These flight opportunities are dependent on the progress of the construction of the International Space Station. The complexity of the hardware required to complete the investigation may have a significant impact on the flight definition selection.

D. EXPERIMENT DEFINITION AND FLIGHT ASSIGNMENT PROCESS

Ground-based research is usually necessary to clearly define flight experiment objectives. This research may involve experimentation in NASA-provided ground-based facilities, including those which can provide a limited duration low gravity environment. (These facilities are described in Appendix B, Section II.) Successful proposals for flight opportunities will be supported for a ground-based definition phase before review for flight assignment. The amount of support (technical, scientific, and budgetary) and the length of the definition period (usually from 6 months to 2 years) will depend on the specific investigator needs and the availability of resources from NASA. However, in preparing their budget plan for this research announcement, all proposers should estimate their annual costs for four years.

Shortly after selection of projects for flight definition, NASA will initiate a process to identify fundamental technical feasibility issues. A small team of engineers and scientists at the NASA field centers will work with the Principal Investigator to translate requirements into the appropriate experiment technical requirements. The result is a systems engineering approach that prioritizes and links the facets of the experiment's development process assuring that the objectives of the experiment can be met. The process will help determine whether there are any outstanding issues that would inhibit the success of the flight project, considering both technical challenges and required resources. At that point NASA may make a judgment as to whether a project will continue the flight definition process or revert to the ground-based program (see below).

1) <u>Near-Term Flight Opportunities:</u> Successful proposals for use of the existing instruments will be funded for a period of advanced definition work, after which time the investigator will generate a detailed SRD. The SRD, a detailed experiment description outlining the specific experiment parameters and conditions, as well as the background and justification for flight, must be prepared jointly by a NASA-appointed project scientist and the Principal Investigator and submitted for peer review. This formal review by both science and engineering panels will determine if space flight is required to meet the science objectives and if instrument capabilities can be provided to meet the science requirements. Following approval by the panels, subject to program resources, continuation support will be awarded and the hardware will be modified to meet the science requirements. NASA does not guarantee that any experiment selected for definition will advance to flight experiment status. Investigations with unresolved science or engineering issues at the review of the SRD may be placed in ground-based status with support of limited duration (normally from one to three years), and asked to submit a proposal to a subsequent solicitation for further support.

2) <u>Future Flight Opportunities:</u> Successful proposals for the development of new apparatus will be funded for a period of definition. The length of the definition period will be based on the experiment requirements, but will generally range from 6 to 24 months. At the end of the experiment definition phase, the investigator will generate a detailed SRD. Following successful peer review of the SRD by science

and engineering panels, the experiment will proceed into flight development and be considered for flight. As with opportunities for existing instruments, NASA does not guarantee that any experiment selected for definition will advance to flight development status, and the possibility exists that investigations may be placed in ground-based status, with continuing support from NASA for a limited period.

3) Ground-Based Definition Opportunities: Promising proposals for experimental research which are not mature enough to allow development of an SRD after two years of definition and proposals for development of theory in areas of current or potential microgravity experiments, may be selected for support in the PSD ground-based research program. Ground-based studies are funded for periods of up to four years. A new proposal to a future announcement is currently required in order to be selected for a flight opportunity or to continue ground-based studies if appropriate. Proposals for development of new technologies for flight experiments that will provide new capabilities for fluid physics research are encouraged.

IV. PROPOSAL SUBMISSION INFORMATION

This section gives the requirements for submission of proposals in response to this announcement. The research project described in a typical proposal submitted under this announcement must be directed by a Principal Investigator who is responsible for all research activities and it may include one or more Co-Investigators. Proposers must address all the relevant selection criteria in their proposal as described in VI and must format their proposal as described in this section. Additional general information for submission of proposals in response to NASA Research Announcements may be found in Appendix C.

A. NOTICE OF INTENT

Organizations planning to submit a proposal in response to this NRA should notify NASA of their intent to propose by electronically sending a Notice of Intent (NOI) via the OBPR Web Page:

http://peer1.idi.usra.edu/

The Notice of Intent, which should not exceed two pages in length, must be typewritten in English and must include the following information:

- The potential Principal Investigator (PI), position, organization, address, telephone, fax, and e-mail address.
- A list of potential Co-Investigators (Co-I's), positions, and organizations.
- General scientific/technical objectives of the research.
- The equipment of interest listed in this NRA, if appropriate.

The Notice of Intent should be received at NASA Headquarters no later than March 12, 2001. The Notice of Intent is being requested for informational and planning purposes only, and is not binding on the signatories. Institutional authorizations are not required. The Notice of Intent allows NASA to better match expertise in the composition of peer review panels with the response from this solicitation. In the Notice of Intent, investigators may request more detail on the capabilities of the specific equipment (Appendix B) that might be used to accomplish their scientific objectives and/or items listed in the Bibliography (Appendix A, Section VIII).

B. PROPOSAL

The proposal should not exceed 20 single-spaced, single-sided pages in length, exclusive of appendices and supplementary material, and should be typed on 8-1/2 x 11 inch paper with a 10- or 12-point font. Extensive appendices and ring-bound proposals are discouraged. Reprints and preprints of relevant work will be forwarded to the reviewers if submitted as attachments to the proposal.

The guidance in Appendix C, Section d regarding the content of renewal proposals is not applicable to this NRA. Proposals should not rely on references to previous proposals for any information required for a complete proposal. **It is particularly important that proposers who seek to extend an existing NASA research activity that is relevant to this NRA must submit proposals that clearly identify and document achievements on their current effort and how it supports their request for additional sponsorship.. Such follow-on proposals will be reviewed on an equal basis with all other submitted proposals.**

Fifteen copies of the proposal must be received at NASA Headquarters by May 11, 2001, 4:30 PM EST. Treatment of late proposals is described in Appendix C. Send proposals to the following address:

Dr. Gerald Pitalo
C/O NASA Peer Review Services
500 E Street, S.W., Suite 200
Washington, DC 20024
Subject: NASA Research Proposal (NRA-00-OBPR-02)
Telephone number for delivery services: (202) 479-9030

NASA cannot receive deliveries on Saturdays, Sundays or federal holidays.

Proposals submitted in response to this Announcement must be typewritten in English and contain at least the following elements (in addition to the required information given in Appendix C) in the format shown below, in the following order:

(1) Form A (Solicited Proposal Application)

(2) Form B (Proposal Executive Summary - replaces Abstract). The executive summary should succinctly convey, in broad terms, what it is the proposer wants to do, how the proposer plans to do it, why it is important, and how it meets the requirements for microgravity relevance

(3) Form C (Budget For Entire Project Period Direct Costs Only)

(4) Form D (Summary Proposal Budget - 1 copy for each year)

(5) Table of Contents

(6) Research Project Description containing the following elements:

- Statement of the hypothesis, objective, and value of this research.
- Review of relevant research.
- Justification of the need for low gravity to meet the objectives of the experiment.
- Description of the diagnostic measurements that would be required to satisfy the scientific objectives of any proposed low gravity experiments.
- Estimation of time profile of reduced-gravity levels needed for the experiment or series of experiments.
- A clear and unambiguous justification of the need to perform the experiment in space as opposed to ground-based reduced-gravity facilities.
- A description of a ground-based testing program that might be needed to complete the definition of the space flight experiment requirements in terms of experiment conditions, acceleration levels and duration, control and diagnostic measurement requirements, etc.
- Management plan appropriate for the scope and size of the proposed project, describing the roles and responsibilities of the participants.
- A clear and concise description of the outreach activities proposed.

(7) Prior Period of Support

- **For follow-on proposals of ongoing PSD sponsored projects, a summary of the objectives and accomplishments of the prior period of support, including citations to published papers derived from the existing tasks, must be included as part of the proposer's justification for continued support.**

(8) Appendices:

- Supplementary budget information and budget explanations. The cost detail desired is explained below.
- Summary of current and pending support for the Principal Investigator and Co-Investigators.
- Complete current curriculum vita for the principal and Co-Investigators, listing education, publications, and other relevant information necessary to assess the experience and capabilities of the senior participants.

(9) **3.5-inch computer diskette containing electronic copy of Principal Investigator's name, address, complete project title, and executive summary.**

<u>Proposal Cost Detail Desired</u>. Sufficient proposal cost detail and supporting information will facilitate a speedy evaluation and award. Dollar amounts proposed with no explanation (e.g., Equipment: $58,000, or Labor: $10,000) may cause delays in evaluation or award. The proposed costing information should be sufficiently detailed to allow the Government to identify cost elements for evaluation purposes. Generally, the Government will evaluate cost as to reasonableness, allowability, and allocability. Enclose explanatory information, as needed. Each category should be explained. Proposers should exercise prudent judgment as the amount of detail necessary varies with the complexity of the proposal.

V. NRA FUNDING

The total amount of funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment for award purposes can be made and the receipt of proposals which the Government determines are acceptable for an award under this NRA.

For the purposes of budget planning, we have assumed that the Physical Sciences Research Division will fund up to 4 flight experiment definition proposals. These definition-phase proposals will be funded on an average of $175,000 per year. Approximately 30 ground-based study proposals will be funded, at an average of $100,000 per year, for up to 4 years. The initial fiscal year (FY) 2002 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts. **It is particularly important that the proposer realistically forecast the projected spending timeline rather than merely assuming an equal amount (adjusted for inflation) of requirements for each year. Specifically, the resources required for the first year should not be overestimated.** The proposed budget for ground-based studies should include researcher's salary, travel to science and NASA meetings (for a flight investigation, roughly eight meetings per year with NASA should be anticipated, though travel activity will vary over the development of the experiment), other expenses (publication costs, computing or workstation costs), burdens, and overhead. During subsequent years, NRAs similar to this NRA will be issued, and funds are planned to be available for additional investigations.

VI. GUIDELINES FOR INTERNATIONAL PARTICIPATION

NASA accepts proposals from all countries, although this program does not financially support Principal Investigators in countries other than the U.S. Accordingly, proposals from non-U.S. entities should not include a cost plan. Non-U.S. proposals and U.S. proposals which include non-U.S. participation must be endorsed by the appropriate government agency in the country from which the non-U.S. participant is proposing. Such endorsement should indicate that:

1) The proposal merits careful consideration by NASA.
2) If the proposal is selected, sufficient funds will be made available from the country from which the non-U.S. participant is proposing to undertake the activity as proposed.

Proposals, along with the requested number of copies and Letter of Endorsement, must be forwarded to NASA in time to arrive before the deadline established for this NRA. All proposals must be typewritten in English. All non-U.S. proposals will undergo the same evaluation and selection process as those originating in the U.S.

Sponsoring non-U.S. agencies may, in exceptional situations, forward a proposal directly to the address given on Page (iv) of the first section of this announcement if review and endorsement is not possible before the announced closing date. In such cases, an accompanying letter should indicate when a decision on endorsement could be expected.

Successful and unsuccessful proposers will be notified by mail directly by the NASA program office coordinating the NRA. Copies of these letters will be sent to the sponsoring government agency. Should a non-U.S. proposal or U.S. proposal with non-U.S. participation be selected, NASA's Office of External Relations will arrange with the non-U.S. sponsoring agency for the proposed participation on a no-exchange-of-funds basis, in which NASA and the appropriate government agency will each bear the cost of discharging its respective responsibilities. Depending on the nature and extent of the proposed cooperation, these arrangements may entail:

1) A letter of notification by NASA.
2) An exchange of letters between NASA and the sponsoring government agency.
3) An agreement or memorandum of understanding between NASA and the sponsoring government agency.

VII. EVALUATION AND SELECTION

A. EVALUATION PROCESS

The evaluation process for this NRA will begin with a scientific and technical external peer review of the submitted proposals. NASA will also conduct an internal engineering review of the potential hardware requirements for proposals that include flight experiments. The external peer review and internal engineering review panels will be coordinated by the NASA Enterprise Scientist for Fluid Physics. Consideration of the programmatic objectives of this NRA, as discussed in the introduction to this Appendix, will be applied by NASA to ensure enhancement of program breadth, balance, and diversity; NASA will also consider the cost of the proposal. The PSD Director will make the final selection based on science panel and programmatic recommendations. Upon completion of all deliberations, a selection statement will be released notifying each proposer of proposal selection or rejection. Proposers whose proposals are declined will have the opportunity of a verbal debriefing with a NASA representative regarding the reasons for this decision. Additional information on the evaluation and selection process is given in Appendix C.

B. EVALUATION FACTORS

The following section replaces Section (i) of Appendix C. The principal elements considered in the evaluation of proposals solicited by this NRA are: relevance to NASA's objectives, intrinsic merit, and cost. Of these, intrinsic merit has the greatest weight, followed by relevance to NASA's objectives, which has slightly lesser weight. Both of these elements have greater weight than cost. Evaluation of the intrinsic merit of the proposal includes consideration of the following factors, in descending order of importance:

1) Overall scientific or technical merit, including evidence of unique or innovative methods, approaches, or concepts, the potential for new discoveries or understanding, or delivery of new technologies/products and associated schedules.

2) Qualifications, capabilities, and experience of the proposed Principal Investigator, team leader, or key personnel who are critical in achieving the proposal objectives.

3) Institutional resources and experience that are critical in achieving the proposal objectives.

4) Proposed plan for education and public outreach activities. Examples include such items as involvement of students in the research activities, technology transfer plans, public information programs that will inform the general public of the benefits being gained from the research, and/or plans for incorporation of scientific results obtained into educational curricula.

5) Overall standing among similar proposals available for evaluation and/or evaluation against the known state-of-the-art.

The peer review panel will assign each proposal a numerical merit score from 1 (worst) to 9 (best) based on the above factors. The score assigned by the peer review panel will not be affected by the cost of the proposed work nor will it reflect the programmatic relevance of the proposed work to NASA. However, the panel will be asked to include in their critique of each proposal any comments they may have concerning the proposal's budget and relevance to NASA.

The following questions should be kept in mind by proposers when addressing the relevance to NASA's scientific and programmatic objectives:

1) Is microgravity of fundamental importance to the proposed study, either in terms of unmasking effects hidden under normal gravity conditions or in terms of using gravity level as an added independent parameter?

2) Do the issues addressed by the research have the potential to close major gaps in the understanding of fundamentals of fluid physics processes?

3) Is there potential for elucidation of previously unknown phenomena?

4) Is the project likely to have significant benefits/applications to ground-based as well as space-based operations involving fluid physics processes?

5) Are the results likely to be broadly useful, leading to further theoretical or experimental studies?

6) Can another project in the specific sub-area be justified in terms of limited resource allocation?

7) Is the project technologically feasible, without requirements for substantial new technological advances?

8) How will this project stimulate research and education in the fluid physics area?

9) How does the projected cost/benefit ratio compare with other projects competing for the same resources?

10) What is the potential of this project in terms of stimulating future technological “spin-offs?”

11) Are there strong, well-defined linkages between the research and OBPR goals? (See Section II, C of this Appendix).

VIII. BIBLIOGRAPHY

Background materials are available to NRA proposers upon written request to:

Dr. Bhim Singh
MS 500-102
Microgravity Sciences Division
Glenn Research Center
National Aeronautics and Space Administration
21000 Brookpark Road
Cleveland, OH 44135-3191
(216) 433- 5396
bhim.singh@grc.nasa.gov

Documents and Web Sites that may provide useful information to proposers are listed below:

1) Office of Biological and Physical Research (OBPR) Home page at NASA Headquarters, http://www.hq.nasa.gov/office/olmsa/

2) Microgravity Research Division Homepage at NASA Headquarters, http://microgravity.hq.nasa.gov

3) Microgravity Research Program Office Homepage at NASA Marshall Space Flight Center, http://microgravity.msfc.nasa.gov

4) Microgravity Research Facilities and Fluid Physics Flight Experiments, Microgravity Science Division Homepage, NASA Glenn Research Center, http://zeta.GRC.nasa.gov

5) STS Investigators' Guide, NASA Marshall Space Flight Center.

6) Second Microgravity Fluid Physics Conference Proceedings, NASA Conference Proceedings 3267, June 1994.

7) Third Microgravity Fluid Physics Conference Proceedings, NASA Conference Proceedings 3338, June 1996.

8) Fourth Microgravity Fluid Physics Conference Proceedings, National Center for Microgravity Research on Fluids and Combustion, August 1998, http://www.ncmr.cwru.edu/events/conf-proceedings.html

9) Fifth Microgravity Fluid Physics Conference Proceedings, National Center for Microgravity Research on Fluids and Combustion, August 2000, http://www.ncmr.org/events/fluids2000/index.html

10) Microgravity Science and Applications Program Tasks and Bibliography, 1999, http://peer1.idi.usra.edu/peer_review/taskbook/micro/mg99/mtb.cfm

11) Workshop on Research for Space Exploration: Physical Sciences and Process Technology, NASA Conference Publication CP-1998-207431, http://LeTRS.lerc.nasa.gov/cgi-bin/LeTRS/browse.pl?1998/CP-1998-207431.html

12) NASA Reduced-Gravity Carrier Options for Microgravity Experiment Operations, http://peer1.idi.usra.edu/peer_review/prog/CarrierOptions.pdf

APPENDIX B
NRA-01-OBPR-02

HARDWARE AND FACILITY DESCRIPTIONS

The Physical Sciences Division (PSD) is pursuing a program for the development of Space Shuttle and International Space Station (ISS) payloads that can be configured (or reconfigured) to accommodate multiple users. This evolutionary program is expected to meet the science requirements of increasingly sophisticated microgravity investigations and to permit the eventual development of experiment payload technologies for research throughout the era of the ISS..

I. CURRENT AND PLANNED FLIGHT HARDWARE

The experimental apparatus described in this section have been developed or are under development for flight on Space Shuttle missions and/or the ISS. Minor modifications of the current hardware may be possible to make it more versatile and to accommodate users and experiments other than those for which it was originally designed. Availability of the instruments described here, with or without modification, is contingent upon the availability and allocation of resources, and cannot be guaranteed at this time.

More detailed descriptions of the current flight hardware may be requested in the Notice of Intent described in Appendix A, Section V.

A. ISS FLUIDS INTEGRATED RACK (FIR)

The International Space Station (ISS) United States Laboratory Module will support the Fluids and Combustion Facility (FCF) under development at the Glenn Research Center. The FCF is a modular, multi-user, microgravity science facility which will occupy three powered payload instrumentation racks plus the equivalent volume of one unpowered stowage rack. Together the three racks will provide the fundamental physical and functional infrastructure necessary to perform combustion science, fluid physics, and adjunct science experiments on-board the ISS.

The Fluids Integrated Rack (FIR) is anticipated for launch in year 2004, along with the Combustion Integrated Rack. It will be equipped to operate as a single integrated rack to provide the initial set of Principal Investigators with the functionality required to perform their experiments, with enhanced performance upon delivery of the third rack. The FIR is based on a “carrier” approach that provides common services needed by nearly all fluids physics researchers to minimize the required hardware development and to minimize the hardware launched for each experiment. Since a majority of hardware is reused, the FIR concept saves both development costs and total upmass required to perform the experiments. The FIR system has the following subsystems determined to be essential to perform the microgravity fluid physics experiments:

ISPR/Structural Subsystem: The FIR Rack utilizes the NASA International Space Station Rack (ISPR) as the basic structure for payload equipment to provide an enclosed volume of approximately 1.6 m^3 and supporting 700 Kg of mass (with nominally 100 Kg for specific PL on-orbit mass). The ISPR has a bowed back to provide maximum volume if properly utilized and mounts directly into the ISS US Lab. The front of the ISPR will be sealable via a door to provide containment of the air for thermal control and fire suppression, and also to minimize acoustic and thermal impacts from/to other US Lab users.

Active Rack Isolation System: FIR experiments will be sensitive to motion and vibration induced by other ISS systems, users, the crew and associated ISS activities, such as docking, EVA, thruster firings, etc. In order not to disturb these experiments, ISS designers have developed the Active Rack Isolation System (ARIS) to isolate the ISPR from major mechanical disturbances that might occur on the ISS, essentially acting as a shock absorber. ARIS provides the unique ability to ‘float’ an entire ISPR and isolate it from external vibration sources with minimal encroachment on internal rack volume through an electronic sensing and control of eight electro-mechanical rack isolation actuators. ARIS provides rack level attenuation of on-orbit low frequency/low-amplitude mechanical vibrations transmitted from the US Lab to the FIR rack when science operations are conducted.

<u>Optics Bench:</u> The FIR provides the Principle Investigator (PI) with a laboratory style “Optics Bench” on which an experiment will be configured. The optics bench features the capability to remove and replace different PI specific experiment packages. This design offers the advantage of utilizing the surface area on both sides of the bench and the entire ISPR volume. The optics bench folds down to allow access to science support packages located on the back side.

The optics bench spans two thirds of the ISPR with PI working dimensions of 85 x 120 cm (Width x Length) with a distance of 49 cm from the surface of the plate to the door. The optics bench provides nearly one square meter of surface area on the front on which experiment hardware may be configured. The front of the plate will provide an optical precision alignment surface and a stable thermal environment. This front optics plate serves as the mounting platform for the optics, samples, and experiment-specific packages. The back of the optics bench is dedicated to mounting several multi-function, non-intrusive optical diagnostics packages, and science avionics support packages to be described below. The diagnostic and avionics packages mounted on the back generate the most heat and provide a better temperature-controlled environment for the science investigations.

<u>Command and Data Management Subsystem:</u> The FCF FIR Command and Data Management Subsystem (CDMS) includes all hardware and software to provide command, control, health and status monitoring, data acquisition, data processing, data management, timing and crew interface functions for the FIR. The FIR CDMS consists of three major packages: the Input/Output Processor (IOP), the Fluids Science Avionics Package (FSAP), and the Image Processing and Storage Unit (IPSU). The overall approach to the CDMS development is to utilize commercial off-the-shelf computer cards and associated support electronics to the extent practical.

The FIR’s master control is provided by the Input/Output Processor (IOP) which provides command processing, control, resource allocation, data processing, caution and warning, software and data table upload and timing functions. The IOP will perform data acquisition of system, environmental and ancillary sensor data to provide rack health and status information. In addition, the IOP will process and transmit data in support of the fluids science including experiment sequencing, and control of predetermined functions. The IOP will function as the rack interface to the ISS by supporting the High Rate Data Link (HRDL), Ethernet, and MIL-STD-1553 interfaces.

The Fluids Science Avionics Package (FSAP) is a data acquisition and control package that will provide an enhanced set of science I/O, controllers, and signal conditioning capable of supporting a wide array of fluid science categories. The FSAP will provide closed loop control of the science experiment packages that include controllers for motion and temperature, support of motorized positioners and Thermo Electric Coolers (TEC), and interfaces for specialized devices such as Photomultiplier Tubes and Avalanche Photodiodes. Signal Conditioning will also be provided to support measurement devices such as thermocouples and transducers to measure pressure, strain, force, and flow rates. Additionally, the FSAP provides storage of the acquired data and is capable of transferring the data to the IOP for subsequent downlink.

The FIR will support the capability of providing extensive image acquisition, processing and management, as is typically required for fluids physics experiments. There will be two Image Processing and Storage Units (IPSU) to provide this capability. The IPSUs provide the image capture and processing for two high-resolution digital cameras. Each camera interface consists of a PowerPC-based, single board computer, a MIL-STD-1553B communications interface, an Ethernet communications interface, image collection, processing, and memory cards, and a removable 18 GB hard drive of which 16 GB will be available for image storage. The IPSU will be capable of collecting data at 40 Mbytes / second nominally. Data can be passed from IPSU memory (256 MB) to a more permanent storage area or directly to the IOP for downlink. The IPSU will store video data in a digital format. The data acquired will be compressed (if required) to reduce memory and transfer bandwidth and processed to support closed loop control scenarios such as focus, zoom, and particle auto-track capability.

Electrical Power Subsystem: The FIR Electrical Power Subsystem (EPS) consists of an Electrical Power Control Unit (EPCU), cables from ISS to the EPCU, harnesses from the EPCU to user/facility loads, and associated interface connectors. Electrical power from the ISS is controlled and distributed throughout the FIR by the EPCU Package. The EPCU performs electrical power conditioning, optimized distribution, switching, and fault protection for the FIR. The EPCU is capable of regulating the voltage to 28 VDC at an efficiency of 92%. The EPCU switches 48 different channels and current limits each channel to 4 amps. For crew safety, all twelve EPCU front panel output connectors are 28 VDC. If necessary, limited 120 VDC from the EPCU rear panel connector can be supplied to a large (500 W to 1500 W) single load.

FIR Diagnostics: High resolution digital cameras and associated lenses will be provided as the standard means of image acquisition in the FIR. Utilizing cameras, motorized lenses, configurable mirrors and support equipment, the imaging packages will provide a feature-rich environment for acquiring high-quality digital images. Also, the FIR will be capable of supporting an analog camera and converting the images to digital. Three cameras (two digital, one analog) have been identified as standard FIR resources that consist of two monochromatic (black and white) high resolution (1024 x 1024 12-bit pixels, 30 frames per second) digital cameras and one analog color camera to achieve color images. One high-resolution camera package will provide x-y translation particularly for microscopic alignment. A high speed digital camera is being designed for a high frame rate camera capable of acquiring images at up to 1000 frames per second or greater.

The cameras will accommodate various fixed focus and motorized zoom lenses that can be interchangeable between the cameras. Two unique primary lenses will provide a nominal field of view of 10 cm by 10 cm when used with the high resolution cameras and will have motorized focus capability. With special lens attachments, the fields of view of these lenses will be 2.5 cm by 2.5 cm, 5 cm by 5 cm, and 7.5 cm by 7.5 cm. These attachments will be small and easily changed without removing the motorized primary lens. The f-stop will be variable from f/1.9 to f/11. A third lens will provide fields of view of 2.6 mm by 2.6 mm, 5.6 mm by 5.6 mm, 10.4 mm by 10.4 mm, and 12.5 mm by 12.5 mm with resolutions (twice the distance between pixel centers) of 4, 8.5, 16, and 18.8 micrometers, respectively. An additional lens will provide a 10 cm by 10 cm filed of view for the color camera. Optical component mounting is designed for easy astronaut changeout and reconfiguration. In addition, the PI has the option to replace a camera lens with a specific lens to accommodate specific experimental needs.

The illumination sources will consist of white light, laser light, and collimated laser beams. The illumination sources provided will be at a light intensity level at the test cell compatible with the sensitivities of the selected cameras required by science. 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 which 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 exceptions to this are PI-provided diode lasers, which may be integrated with the experiment but will be powered by the facility-provided diode drivers

The facility will provide white light sources (halogen bulbs) in order to meet the requirement for acquiring color images as well as the requirement for preventing “ringing” in the image caused by light that is highly coherent. The facility will provide a range of light intensities, between 0.01 mW/cm2 and 0.3 mW/cm2, at a 10 cm by 10 cm area test cell. The white light sources will be delivered via an optical fiber to a woven fiber backlight which will provide uniform lighting while requiring only minimal volume.

In addition to the white light sources, the facility will provide three lasers. The FIR provided lasers consist of a Nd:YAG, and a pair of laser diodes with associated driver modules. The Nd:YAG is a high quality, diode-pumped, solid state laser whose wavelength is 532 nm with a laser power of at least 60 mW from the optical fiber. The Nd:YAG beam will provide a laser suitable for critical applications, as well as sufficient power to illuminate relatively large test cell areas.

The laser diodes are available for illuminating large test cell areas when the beam structure is not critical. These laser pairs have a wavelength of 680 nm. The power delivered by each of these lasers is at least 10 mW at the test cell. The diode lasers output intensities can be attenuated by lowering their drive currents to accommodate a wide range of needs. Two well-conditioned power supply modules (diode drivers) will be provided in order to support the FIR laser diodes and PI-provided diode lasers. This allows the FIR to accommodate some PI-specific requirements which are not met by the facility-provided lasers.

Environmental Control Subsystem: The Environmental Control Subsystem (ECS) performs thermal control, fire detection, fire suppression, and gas distribution functions associated with the operation of the FIR. The FIR's thermal energy is removed directly through thermal transfer to water or indirectly through a forced convection air system. The thermal subsystem will be designed to remove up to 2.0 kW of waste thermal energy from the Fluids Integrated Rack.

The thermal control subsystem consists of a distributed network of plumbing to carry supply and return water flow to and from the FIR hardware, including the air-to-water heat exchanger at the top of the ISPR. The heat exchanger removes waste thermal energy (nominally 1500 Watts) using the ISPR internal atmosphere as the medium for thermal energy transfer. This is the main vehicle for removing bulk heat from the FIR. Air-cooled packages will be supplied with cooling air ranging from 30˚ C (86˚ F) to 43˚ C (110˚ F). It is anticipated that the PI Unique H/W cooling will be approximately 400 W of air cooling with the option of using two 200 W Cold Plate(s) integrated into Optics Plate. The heat exchanger package consists of a set of impeller fans driving hot air over the air/water heat exchanger which includes air filtration (~300 micron) to remove the bulk of particulates that infiltrate into the airstream. The fans provide generic air flow down the front of the optic bench, though the IOP and under the plate and up the back, thus cooling the packages in the air stream. For components requiring a precise control of temperature, thermoelectric coolers, localized fans and or heat sinks will be used.

The gas distribution package provides access to ISS gaseous nitrogen, vacuum exhaust, and vacuum resource services through an interface panel. A convenient location for the FIR interface panel is currently being evaluated. The panel will provide one quick disconnect for each resource. Flexible umbilicals will be used to interface with experiment specific hardware.

Operations and Telescience: The FIR is being designed to minimize the crew time involved in reconfiguring diagnostics and setting up the specific experiments. Scheduled maintenance will be required of the ISS crew to recalibrate or replace sensors, replace or clean filters, and replace end-of useful-life components. It is not anticipated that on-orbit repairs will be performed; instead Orbital Replacement Units (ORU) will be transported to ISS or taken from on-orbit stowage. Stowage will be provided for science research on the ISS in passive rack locations for ORUs, science hardware, tools, etc.

During the performance of the PIs experiment the FCF will need to provide near-real-time data down-link and near-real-time command up-link to permit the PI to perform remote interaction with the experiment. The PI will need to be provided with adequate and timely data to react to unexpected scientific phenomena in order to alter the experiment procedures. The FCF will be teleoperated from the NASA Glenn Research Center Telescience Support Center. In concert with the Cleveland-based Operations Team, the Principal Investigator's experiment can be remotely monitored and controlled from the PI's homesite.. The ISS 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 day-to-day operations of the ISS.. Instead, the ground team at the TSC and the PI at the remote site will monitor the health and status of FCF and the experiment and control facility functions.

B. FIR EXPERIMENT-SPECIFIC HARDWARE

The FIR features the capability to remove and replace different PI specific experiment packages. The PI experiment specific package(s) may consist of a single self-contained unit and/or several separate components. The PI hardware will typically be a unique design, but may re-use 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 "mini-facility" 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 and mixing devices, motors, critical temperature hardware, magnetic field generation not provided by the FIR.

A number of investigation specific hardware packages are currently under development or are planned for development and are listed below as typical examples of FIR experiment specific hardware.

1) Bubbly Suspension Research Apparatus: A couette cell is being developed to study the flow of bubbly suspensions. The couette device is 30 cm high, with an outer cylinder diameter of 30cm and gap-thickness of 3 cm. The outer cylinder is capable of rotating at variable speeds (up to 100 rpm), while the inner cylinder remains stationary. Bubbles are introduced into the couette cell at gap-averaged volume fractions ranging from 0.1 to 0.2. The bubble diameters vary from 2 to 3 mm and are uniform within 10% of the mean bubble radius. The instrumentation consists of hot wire probes to measure liquid velocity and impedance probe to measure bubble velocity and the bubble collision rate, wall shear stress probes, and photography to visualize the flow cell.

2) Light Microscopy Module (LMM): The Light Microscopy Module (LMM) is a subrack module within the Fluids Integrated Rack (FIR) of the Fluids and combustion Facility and the first payload planned to operate in the FIR. The LMM, designed around a high-end optical microscope, will provide the more traditional bright field, dark field, phase contrast, and differential interference contrast (DIC) imaging techniques, but also will provide sample particle manipulation through the use of optical tweezers, thin film interferometry, confocal microscopy, and spectrophotometry. To accomplish this, the LMM provides coherent and incoherent light sources, objectives of various magnifications, filters, detectors, exposure control, sample manipulation, sample homogenization, oil immersion, and containment. The sample cells, procedures, and any specialized measurements (e.g., cell instrumentation, special light source, etc.) are customized for each Principle Investigator's use. Utilizing such a subrack module goes one step further in enabling cost and timesavings on each experiment by reusing modular facility test equipment, rather than the traditional approach of designing stand-alone experiments for each Principle Investigator.

3) Microscopy and Optical Manipulation Module (MOMM): This multiuser facility is an upgraded LMM with a number of additional capabilities. It may be located in the FIR or SAR. The following upgrades are currently under consideration: Upgrade to the optical microscope to reflect the state of the art; Dynamic and Static Light Scattering; Bragg Scattering; Multiple Beam Laser Tweezers; Laser Scissors Two-photon fluorescence; Electric/Magnetic Field Induction Capability; and Advanced sample cell designs including accommodation of biological samples.

4) Granular Flow Module: The Granular Flow Module (GFM) is a multi-user module planned to accommodate the needs of a number of PIs studying the flow of granular materials in microgravity. The unit is designed for containment in the Fluids Integrated Rack (FIR) or the Shared Accommodation Rack (SAR) of the FCF. The core of the GFM is a PI-specific annular couette or cell, with the granular material sample contained between two concentric cylinders. In the current design configuration, the cylinders rotate, and images are obtained through the end-cap. Additional effort is now underway to explore the feasibility of changing out the granular material contained in the cell. Anticipated diagnostic capabilities include normal and high-speed video imaging through the transparent cover, as well as measurements of the rotational speed, ambient pressure and temperature. Image processing capabilities should allow particle tracking by size and gray-scale. Video processing could subsequently be used to determine particle velocity. Data acquisition and control will be provided by the FCF.

5) Contact Line Dynamics Apparatus: A flight instrument to conduct steady state moving contact line experiments is under development. The hardware utilizes a mechanical system to drive sets

of concentric, thin cylinder rods (approximately 2 inches in diameter) through a liquid free surface at velocities ranging from 0.002 to 4.00 cm/sec to create a smoothly moving contact line. The metal cylinders are coated with a wetting material. An optics system allows visualization of the three-phase interface, fluid velocity close to this interface, and the entire fluid-air interface shape. Special precautions are being taken to insure the cleanliness of the surfaces and fluids. A single optics module is fixed onto separate fluid system modules that contain the different viscosity fluids, sets of rods, and translation systems. The instrument may be adaptable to other types of contact line experiments.

6) <u>Foam Experimentation Apparatus:</u> A cone and plate rheology cell is being developed for research on aqueous foams. The cone and plate radius is 10 cm, with a cone angle of 0.2 radians and gap thickness varying from zero to two centimeters. The plate remains stationary while the cone rotates. The cone and plate materials are nonwetting, and their inner surfaces are roughened in order to provide a no-slip condition for the foam. The sidewall is optically smooth on the inner and outer surfaces in order to provide a slip condition and to permit access for video microscopy. The apparatus will produce foam samples of variable liquid content and chemical composition in sufficient quantity to fill the sample cells (approximately 100 ml). The instrumentation consists of video microscopy to image the foam at the inner surface of the sidewall (resolve 30 micron to 300 micron bubbles), a rheometer to measure shear deformation throughout the foam sample, and diffusing-light spectroscopy to analyze the time scales of bubble motion. The imaging components and the diffusing-light spectroscopy components (laser, Avalanche Photo Diodes) are not part of the Foam Experimentation Apparatus, but are provided by the Fluids Integrated Rack.

7) <u>Pool Boiling Module (PBM):</u> is a multi-user module designed to study pool boiling in a microgravity environment. A metallic cylindrical test container of approximately 30-cm diameter and 30-cm long serves as the boiling chamber. A number of optical access ports allow video imaging (normal (30 fps), as well as high speed (500 fps)) and interferometry for temperature measurement. The boiling chamber has a bellows type device to allow control of pressure and sub-cooling. PI specific heaters can be installed opposite the bellows, such as strain-gauge heaters with a silicon nucleation surface, micro-heater arrays, etc. The chamber is compatible with water and PF5060. The unit is being designed for containment in the Fluids Integrated Rack (FIR) or the Shared Accommodation Rack (SAR) of the FCF. Although the PBM is designed for pool boiling adaptations for flow boiling are being considered. Data acquisition and control will be provided by the FCF.

C. NASDA FLUID PHYSICS EXPERIMENT FACILITY (FPEF)

The Fluid Physics Experiment Facility (FPEF) is undergoing development by the National Space Development Agency of Japan (NASDA) for the Japanese Experiment Module (JEM) of the International Space Station. The FPEF is a multi-user facility and designed to perform fluid physics experiments in an ambient temperature environment. The FPEF consists of a main body and an experiment section, and occupies a quarter-rack of the JEM. The experiment section will be configured to satisfy the needs of individual experiment. The overall dimensions of the experiment cell are 350 mm (W) x 350 (D) x 300 (H). The maximum electric power available is 978 watts. Currently, thermocapillary flow research in a liquid bridgs is used as a model experiment for the FPEF design. Several diagnostic techniques are being developed for the experiment. The capability of the FPEF for thermocapillary flow research is summarized below.

The FPEF can perform three-dimensional, in-situ observation of tracer particles in a transparent liquid column. It can also measure the fluid velocity by the UVP (Ultrasonic Velocity Profile) technique. The photochromic dye activation method can be applied to determine the free surface velocity accurately, which has not been done in past thermocapillary flow experiments. An infrared imager can measure the free surface temperature. It is being discussed to design a new experimental cell that deals with liquid bridges of molten materials with relatively low melting points, up to about five hundred degrees centigrade. Such an experiment has not been performed in microgravity.

The experiment section and the observation and measurement systems of the FPEF are exchangeable. Various experiments, such as bubble generation and behavior, heat transfer, liquid wettability, and combustion experiments, will be performed in the FPEF.

D. ESA FLUID SCIENCE LABORATORY (FSL)

The European Space Agency (ESA) is developing the Fluid Science Lab (FSL) to be operated in the Columbus Orbital Facility (COF) of the International Space Station (ISS). FSL provides the interfaces for a thermally controlled environment to perform experiments in the field of fluid physics, i.e. experiments with optically transparent media. The FSL is therefore equipped with a large standard set of advanced optical diagnostics, especially different types of interferometers. FSL is an upgrade of a previous ESA developed fluids facility -- the Bubble Drop Particle Unit.. As with BDPU, the FSL supports scientific microgravity research in the many fields of fluid physics. Phenomena can either be observed inside transparent media or on opaque surfaces. Examples of these types of investigations are, but not necessarily limited to the areas of hydrodynamic behaviors of fluid systems; phase interface behaviors of non-equilibrium fluid systems; surface deformations and oscillations of fluid bridges; nucleation and condensation phenomena in over-saturated and sub-cooled liquids; and critical point phenomena. Examples of new areas are: Aerosol/Colloid Research, Plasma Crystals and Solution/Gel Crystal Growth.

Facility Design: Given the long-term operations and multiple access opportunities in an ISS environment, the FSL concept emphasizes reusable multi-user capability with a high high degree of modularity at both the facility and individual test container levels. Functionally self-contained modular units will facilitate servicing and maintenance operations. The basic facility integrates functional and operational subsystems into one six-post double wide International Standard Payload Rack (ISPR). The facility-provided functions include: power conditioning and distribution; command and data handling; various modes of experiment processing; video/imaging management; active alignment of interferometric diagnostics; active thermal control; and vacuum / vent interfaces. The facility provides up to 3 kW of power and about 400 W of thermal rejection capability for the Experiment Test Containers and about 1200 W for all other components.

The heart of the facility is the Facility Core Element (FCE), which includes the Optical Diagnostics Module, Central Experiment Modules 1 (microgravity measurement assembly, the experiment test container as well as supporting optical equipment), and 2 (other supporting optical equipment and electronics). Other FSL components include: the Master Control Unit, the Power Control Unit, the Video Management Unit, laptop computer and thermal control equipment.

Facility Diagnostics: Optical diagnostics are housed in the Facility Core Element. During experiment operations the FCE will be detached from the rack. This supports a precise stable alignment and minimizes possible distortions by external loads. The maximum field of view of the standard diagnostic tools is 80 x 80 mm. The two observation directions are perpendicular. White and monochromatic background, sheet and volume illumination are provided. Various optical diagnostics capabilities are available simultaneously or quasi simultaneously. Due to the opto-mechanical design there are 53 simultaneous “pair applications” possible with about 10 diagnostic tools. Diagnostics include: Particle Image Velocimetry, Photogrammetric Particle Tracking, Electronic Pattern Speckle Interferometry for transparent and surface deformation measurements, Holographic and Differential Interferometry, Schlieren Measurements. Recording of images is possible with: analog and digital electronic monochrome cameras with different spatial and time resolution. There is an interface for quantitative color measurements with 3 Chip RGB cameras. There are means to perform telescience with a maximum digital data downlink rate of about 2 Mbit/sec and a maximum digital rate of image data of about 240 Mbit/sec can be recorded in realtime for about 17 minutes. Variable realtime compression is also available for the recording of quantitative image data; this automatically extends the recording time by the applied compression factor. Interfaces will be provided for dedicated Front Mounted Cameras specializing in non-standard imaging functions such as infrared imaging and high speed/high resolution imaging. In place of the Front Mounted Cameras it is also possible to mount a traditional photographic film camera, utilized for extreme imaging requirements.

Experiment Test Container (ETC): The EC volume has been increased compared to the BDPU design. The experiment container volume will be about 450 x 270 x 280 mm. The maximum field of view of 80 x 80 mm is centered. The experiment container reflects the particular experiment requirements of the investigation. For example this may include such things as fluid containment (the fluid cell together with the whole fluid loop), fluid transfer and mixing equipment (injection, extraction, stirring), sensors (p,T), dedicated diagnostics such as LDA/LDV and dedicated electronics such as more accurate thermal conditioning.

Facility Operations: An autonomous control approach is used for housekeeping and experimental data set generation, transmission, displaying and storage. Command uplink and image downlink will be accommodated. Telemetry and telecommanding will neither disrupt continuous experiment processes nor contribute to the loss of data. Minimal crew support is anticipated.

E. DISPOSITIF POUR L'ETUDE DE LA CROISSANCE ET DES LIQUIDES CRITIQUES (DECLIC)

DECLIC is a new, modular, multi-user facility currently being designed and built by the French Space Agency, CNES for use aboard the International Space Station, initially in the US Laboratory followed by the Japanese Experiment Module, the Columbus Orbital Facility or the Russian module. The facility is being designed to conduct microgravity investigations in critical phenomena and directional solidification of transparent alloys.

Specifically, DECLIC will accommodate chemical-physical studies of supercritical pure fluids with a critical temperature lower than 100°C and a critical pressure lower than 100 bar such as CO_2, SF_6, and Xe, and supercritical pure fluids and solutions with a critical temperature lower than 600°C and a critical pressure lower than 500 bar such as H_2O and aqueous solutions. It will also accommodate microgravity investigations in morphological stability at the solid/liquid interface during crystal growth in transparent alloys. In addition, investigations in condensed matter physics requiring a long term microgravity environment can also take advantage of the capabilities offered by DECLIC.

DECLIC is the follow-on to the ALICE-2 facility, still onboard the Russian MIR space station, but will accommodate wider classes of experiments. The facility provides advanced optical diagnostics, including wide field imaging, microscopy, interferometry and small angle light scattering as well as highly accurate measurements of thermophysical parameters (pressure, temperature). All experiments can be conducted within a very stable and accurately thermally controlled environment. Operation of the facility is via quasi real-time telescience.

More detailed information about DECLIC and its capabilities can be obtained at the CNES web site:

http://www.cnes.fr/espace_pro/declic/declic.html

F. PHYSICS OF COLLOIDS IN SPACE APPARATUS (PCSA)

The PCSA apparatus is under developed at the Glenn Research Center to study colloidal phenomena in the microgravity environment of the International Space Station. The apparatus can study fractal phenomena, growth of super-lattice structures from binary (two-component) solutions of hard-sphere colloidal particles, and behavior of polymer-colloidal mixtures (e.g. depletion flocculation). The apparatus is not limited to these studies. It offers a much broader scope in studying a wide range of fundamental problems in colloid physics, physical chemistry, chemical physics, materials science, and biological fluids.

The PCSA provides four basic diagnostic measurements. These include non-invasive dynamic light scattering (DLS), static light scattering (SLS), Bragg scattering, and rheological measurements. The light scattering measurements are provided by two Nd-Yag lasers (maximum incident power of 40 mW), and either avalanche photo diodes or digital cameras for scattered light detection/measurement. In the PCSA, the DLS and SLS measurements can be performed via optical fibers and APDs at forward scattering angles of 11 to 169 degrees with a 0.1 degree increment resolution. The low angle light scattering measurements can be performed over forward scattering angles of 0.3 to 6.0 degrees with an imaging resolution of 0.01 degrees using optics and a digital camera. Bragg scattering measurements also uses optics and a digital camera, and can be performed over scattering angles of 10 to 60 degrees with an imaging resolution of 0.5 degrees. The apparatus also provides in-situ mixing of aqueous samples and sample images via two CCD color cameras (full sample view and magnified). Sample oscillations can be performed at an oscillation amplitude of 0.125 to 1.5 degrees at 0.02 to 20 Hz to support rheological measurements via DLS. All these measurements are made through an optical sample cell that has a cylindrical volume of 20 mm diameter x 10 mm high. The PCSA provides eight sample cells that are mounted on a carousel in order to rotate them in and out of the diagnostic stations.

The PCSA is accommodated in the ISS EXPRESS Rack, the first available research facility on the ISS. The PCSA provides for onboard data storage and data downlink. Operation is controlled via ground commanding with limited options for crew commanding. The apparatus provides for containment of the eight sample cells that prevents any crew interaction with the samples.

G. EXTENSIONAL RHEOLOGY INSTRUMENT

A flexible and adaptable scientific instrument that can accommodate various classes of non-Newtonian liquids is under development at the Glenn Research Center. For example, to perform direct unambiguous measurements of the uniaxial extensional viscosity of a viscoeleastic polymer solution, and to characterize systematically how this fundamental non-Newtonian material varies with time and imposed deformation rate.

The apparatus allows for the stretching of a freely suspended cylindrical column of fluid (Boger fluid) by gripping the column with a drive mechanism that imposes the correct kinematics, eliminating unwanted shear gradient in the fluid and generating an homogeneous uniaxial stretching flow. The column is supported by a fixed and a moving endplate.. The stationary endplate will have a reducing diameter device to achieve a 4:1 reduction in endplate diameter during the stretch to minimize shear stresses in the fluid. The end plate of the column will have a very sensitive force transducer capable of measuring forces in the range of 1 to 1,000,000 dynes. Diagnostics include a digital particle image velocimetry system using CCD cameras and a laser light sheet to record fluid motion near the endplates and a two point flow-induced birefringence measurement system for non-invasive probing of the molecular level of stress generated by the extensional flow.

H. MECHANICS OF GRANULAR MEDIA APPARATUS (MGMA)

The MGMA, developed by the Marshall Space Flight Center, will use the weightless environment of orbital flight to study the dynamics of soil columns confined by water under very low pressures of 1,300, 520, and 52 Pascals. Information to be examined will be load, deformation, and fluid pressure data gathered during testing, as well as changes in the soil structure, including the formation of shear bands and change in density.

The heart of the MGMA is a set of three prismatic test cells, each containing a 7.5 cm in diameter by 15 cm sleeves of Ottawa F-75 banding sand, a natural quartz sand (silicon dioxide) with fine grains and little variation in size. The soil specimen, mixed with either air or water, is contained in a latex sleeve that is 0.3 mm thick and printed with a grid pattern so cameras can record changes in shape and position. The sample is held between a fixed and a movable plate driven by a stepper motor and is viewed by an array of three CCD cameras illuminated with banks of small light-emitting diodes. Each camera observes through a different side of the Lexan prism to provide full coverage of the specimen. The MGMA video control system electronically interleaves the images and delivers the video signal to a portable video recorder.

The stepper motor can be commanded, via a laptop computer, to drive the platen against the specimen in a cyclic manner at speeds of 35-1000 mm/hr. The latex sleeve will move with the sand so the grid pattern changes shape, thus revealing changes to the cameras. At the same time, additional air will be pumped into the specimen, and excess water will be removed from the jacket, to maintain specified test pressures.

I. GLOVEBOX

The overall philosophy of the Glovebox program is to provide the ability to conduct smaller, less complex science experiments or technology demonstrations in a microgravity environment. The hardware development cycle can be approximately 2-3 years. The Glovebox is intended to be used a generic platform for conducting a wide range of experiments. It is especially well suited for experiments that require containment of materials, both fluid and solid. Experiments developed for the Glovebox are expected to be relatively small and self-contained yet can be of a sophisticated nature using state of the art diagnostics. Various services are available in the Gloveboxes including power, video, still photography, a laptop computer for experiment control and data acquisition, and cleaning supplies. In general these experiments are less automated and require significant crew involvement in their operation and in the scientific decision making process. At this time, 12 Glovebox Investigations in the disciplines of materials science, fluid physics, biotechnology, and combustion science are under development. Several versions of Gloveboxes have been flown on the Shuttle Spacelab and Middeck as well as the Russian Mir Space Station. A larger Microgravity Science Glovebox for the International Space Station is currently under development.

The Microgravity Science Glovebox (MSG) facility is an enclosed volume that provides physical isolation of various experiments from the cabin and enables crew member manipulation of these experiments through gloveports. The MSG provides containment of powders, splinters, liquids, flames, or combustion products that may be produced from experiment operations. The MSG is a double rack facility to be accommodated in the US Lab of the ISS. The Glovebox provides a 0.26 m^3 sealed environment with a cleanliness level of 100,000, which is achieved by continuously circulating and filtering the air inside the Glovebox. The pressure in the MSG is below cabin pressure. As the MSG may be one of the first payload racks on the ISS, it will be of special importance as a working area for small experiments. Experiments shall be supplied with ISS resources such as 120 VDC power, data links, cooling, vacuum/venting, and gaseous nitrogen and with MSG converted power levels. The MSG will provide up to 1000 watts of experiment power.. Heat rejection in the working volume via air cooling up to 200 W is provided along with a cold plate in the working volume providing a heat rejection capability of up to 800 W at 50 °C. Equipment can be accommodated in the working volume through side ports with a diameter of 0.406 m.

There are three illumination units in the top of the work volume and a stray light cover is available. There are two 5-hour and two 40-minute video recorders and two video monitors. The video signal can be simultaneously recorded and passed through to the monitors and the MSG interface board for downlinking. There are four full color cameras and one black and white camera. A standard lens and wide-angle lens and mounting systems for the cameras are provided. Experiments may be commanded from the ground or via a touchpad from inside the work volume.

Additional information on the MSG can be found at http://floyd.msfc.nasa.gov/msg/

J. GLOVEBOX EXPERIMENT HARDWARE

1) Glovebox Laser Light Scatterer: A compact instrument has been designed that is capable of both static and dynamic light scattering. This instrument was designed to operate in the various versions of the Glovebox facility and occupies the volume of an 8" cube. It accepts cylindrical test cells with an outer diameter of 10 mm. A translation motor enables interrogation of a 2 cm length of a test cell with a translation velocity of either 24 μm/sec or 0.6 mm/sec. It is equipped with a pigtailed laser diode which delivers approximately 6-8 mW of power at 780 nm to the test section. A fiber optic pickup at 90° delivers scattered light to an avalanche photodiode detector. A Glovebox facility camera can be positioned to record static light scattering data incident on a semi-cylindrical diffuse screen (approximately 30°-160°). Test samples can be oscillated about the cell axis with a fixed 1° or 2° amplitude. The instrument is capable of inducing single impulses or sinusoidal oscillations with variable frequency (1-16 Hz). The samples may also be rotated at variable speeds ranging from 0.3 - 3.0 rpm. The instrument is controlled via software

resident in a laptop computer which also contains a digital correlator card to compute the temporal autocorrelation function from the avalanche photodiode output.

2) SHERE: An extensional rheometer suitable for measuring the extensional viscosity of complex polymer solutions is under development. The apparatus consists of a linear translation stage with approximately 20 cm travel capable of velocities up to 100 cm/s. A small motor is mounted on the stage for inducing shear stresses in the fluid as well. A sensitive force transducer attached to the rheometer structure measures the force due to shearing and stretching the fluid. Other measurements include fluid filament diameter, linear stage position and fluid temperature. Fluid samples 10 mm in diameter and 5 mm long are individually pre-loaded into modules that are manually installed in the rheometer. Experiment operation and data acquisition is computer controlled from a laptop PC. Imaging of the experiment is possible through a window in the top of the structure with flat panel backlighting of the fluid.

II. GROUND-BASED FACILITIES

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced gravity research facilities that support the MRD fluids program include two drop towers at the Glenn Research Center (GRC), and an evacuated drop tube at the Marshall Space Flight Center (MSFC), and parabolic flight research aircraft. A variety of specialized test rigs have been constructed and used to conduct a wide range of microgravity fluid physics research. In general these rigs have been developed to accommodate specific individual investigator's requirements. In addition, other capabilities have been developed which have the potential for use by multiple investigators/investigations. These include: two-phase flow test rigs, a computational lab, complex fluids cell flight hardware lab, and quench furnace with x-ray. In general, these facilities provide a variety of capabilities that investigators can select to support their series of experiments.

A. 2.2-SECOND DROP TOWER

The 2.2 Second Drop Tower is a heavily utilized reduced gravity facility at the Glenn Research Center that plays a key role in the support of Microgravity Science. It routinely supports over 1000 test drops per year (the daily test schedule allows up to 12 drops). The facility consists of a shop for experiment buildup, integration and testing; several small laboratories for experiment preparation and normal gravity testing; electronics support rooms and an eight-story tower in which the drop area is located.

The Drop Tower at GRC provides 2.2 second of low gravity test time for experiment packages with payload weights up to 139 kg. Rectangular experiment packages are dropped under normal atmospheric conditions from a height of 79 ft. Air drag on an experiment is minimized by enclosing it in a drag shield. A gravitational acceleration level of less than 10^{-4} g is obtained during the drop as the experiment package falls freely within the drag shield. The only external force acting on the falling experiment package is the air drag associated with the relative motion of the package within the enclosure of the drag shield. A drop is terminated when the drag shield and experiment assembly impact an air bag. The deceleration levels at impact have peak values of 15 to 30 g.

High-speed motion picture cameras as well as video cameras can acquire data. Video signals are transmitted to remote video recorders via a fiber optic cable that is dropped with the experiment. Onboard data acquisition and control systems also record data supplied by instrumentation such as thermocouples, pressure transducers, and flowmeters.

B. 5.18-SECOND ZERO-GRAVITY FACILITY

The 5.18-second Zero-Gravity Facility at the Glenn Research Center has a 132 meter free fall distance in a drop chamber which is evacuated by a series of pumpdown procedures to a final pressure of 1 Pa. Experiments with hardware weighing up to 300 kilograms are mounted in a one meter diameter by 3.4

meter high drop bus. Gravitational acceleration of less than 10^{-5} g is obtained. At the end of the drop, the bus is decelerated in a 6.1 meter deep container filled with small pellets of expanded polystyrene. The deceleration rate ramps up to 65 g (in 150 milliseconds). Visual data is acquired through the use of on-board, high-speed motion picture cameras and 8mm video recorders. Also, other data such as pressures and temperatures are recorded on board with various data acquisition systems. Deceleration data are transmitted to a control room by a telemetry system. Due to the complexity of drop chamber operations and time required for pump-down of the drop chamber, only one or two tests are performed per day.

C. 105 METER DROP TUBE

A 105 meter long by 25 centimeter diameter drop tube located at the Marshall Space Flight Center provides 4.6 seconds of low gravity process time. The facility, primarily intended for containerless processing applications, can maintain a vacuum level of 10^{-6} Torr or can be backfilled with various gases to increase cooling rates. Two heating methods are currently available, an electron-beam furnace and an electromagnetic levitator. Other heating methods are possible. Samples are viewed through ports located at 8 meter intervals in the tube. The drop tube has been used for the study of undercooling, nucleation, and solidification phenomena in molten metal samples. However, the facility could also accommodate studies with ceramic or glass materials.

D. PARABOLIC FLIGHT RESEARCH AIRCRAFT

The parabolic research aircraft can provide up to 40 periods of low gravity for up to 25-second intervals each during one flight. The aircraft accommodate a variety of experiments of different sizes and is often used to refine space flight experiment equipment and techniques and to train crew members in experiment procedures, thus giving investigators and crew members valuable experience working in a weightless environment. The aircraft obtain a low gravity environment by flying a parabolic trajectory. Gravity levels twice those of normal gravity occur during the initial and final portions of the trajectory, while the brief pushover at the top of the parabola produces less than one percent of Earth’s gravity (10^{-2} g). The interior bay dimensions are approximately 3 meters wide and 2 meters high by 16 meters long. Several experiments include a combination of attached and free-floated hardware (which can provide effective gravity levels of 10^{-3} g for periods up to 10 seconds) can be integrated in a single flight. Both 28 VDC and 100/115 VAC power are available. Instrumentation and data collection capabilities must be contained in the experiment packages.

E. TWO-PHASE FLOW TEST RIGS

Two gas-liquid flow loops exist that have been used to conduct testing aboard parabolic flight research aircraft at gravity levels of 0.01, 0.05, 0.17 (lunar), 0.33 (Martian) and 0.50 g's are available. Both of these flow loops are blowdown types of systems whereby the liquid (water, a water-glycerin solution to ascertain the effects of the viscosity, and a water-surfactant solution to ascertain the effect of surface tension) and gas (air) are delivered from supply tanks to a collector tank via an instrumented test section. One flow loop can be used for testing with a 1.27 cm inner diameter test section, and the other flow loop can be used for testing with a 2.54 cm inner diameter test section. The liquid is recirculated between tests and the gas is vented into the aircraft cabin.

The air and liquid are metered into a mixer and flow into the test section that can be instrumented with conductivity probes, which necessitates the use of "conductive" liquids, differential pressure transducers and hot film anemometers. Data acquisition rates of up to 1000 Hz are possible. Photographic data can be recorded at rates of 250 or 500 full-field images per second or 500 or 1000 half-field images per second. Superficial gas velocities of 0.1 to 25 m/s and liquid velocities for 0.1 to 1.1 m/s are possible. Tests are conducted at atmospheric pressure. Adiabatic as well as sensible heat transfer tests can be conducted with the appropriately designed test sections.

F. COMPUTATIONAL LABORATORY

A laboratory for numerical modeling fluid flows as influenced by thermal gradients, concentration gradients, surface tension, magnetic fields gravitational acceleration, g-jitter, and other driving forces have been established at NASA Glenn Research Center. The emphasis is on physically based models giving quantitative flow descriptions. The laboratory has a combination of high-end UNIX workstations with extensive graphics support and an extensive selection of commercial, customized, and experiment-unique software, including most commercial CFD codes and also has access to mainframes as necessary. The laboratory and staff are available to funded investigators and their graduate students for consultation, analysis, and joint projects. It is recommended that potential lab services be discussed before submission to the NRA. Please call Arnon Chait, (216) 433-3558 or send e-mail to arnon.chait@GRC.nasa.gov

G. MOTION ANALYSIS AND OBJECT TRACKING SYSTEM (TRACKER)

The analysis of moving objects found in combustion and fluid science experiments has been made easier with the development of the Color Image Processing and Object Tracking System (Tracker). The Tracking System is a personal computer-based collection of hardware and software that automates the tracking of objects previously recorded on film or videotape.

Typical features are as follows: Tracker is Pentium-Pro-based, uses a single monitor, and supports video devices and/or movie film transport. The input video devices currently supported are a Hi8 tapedeck, an S-VHS tapedeck, a laserdisc (Sony LVR-3000), and laserdisc (Panasonic - rewritable). In addition it also accepts digital images in tif, gif, tga, dxf, eps, img, jpeg, pcx, png, wmf, wpg, PhotoCD, and bmp formats. The tracker PC has a CD-RW drive (CD writer/player which records to a recordable or rewritable CD formats). The Tracker has software to grab sequences of images, digitize, and save them as digital files (tif, etc.) to hard disk, CD-RW drive, jaz drive, zip drive, floppy, or a network drive. Tracker can run on any Windows95 or NT computer, so it can be used to analyze previously saved digital image files.

Tracking methods supported include threshold reduction, template matching, and a spline-based active contour model method. The types of data obtained from Tracker are positions, velocities, area measurements, centroids, and outlines, all as a function of time.

H. COMPLEX FLUIDS CELL FLIGHT HARDWARE LAB

This lab at GRC has been used to build test cells for a variety of complex fluids instruments. The lab is capable of designing, building, filling, and 1-g testing optical cells for liquid-vapor critical fluid experiments. The cells are capable of operating from one to tens of atmospheres using pressurized glass and glass-metal cell construction with leak detection to10^{-10} Torr-liter/sec. Instrumentation including high relative precision (100 micro-K RMS) thermometry above and slightly below room temperature and high phase and spatial resolution full-field image phase shifting interferometry with seconds to days of stability are available. A variety of other light transmission, light scattering, and optical imaging tools are also available. The lab comprises high voltage AC and DC power supplies for 20-50 kV and zero to 75 kHz used in cells with millimeter size fluid gaps between electrodes. Acoustic experiments were performed in liquid-vapor critical fluids employing continuous wave and pulse excitation and detection.

III. MICROGRAVITY FLUID PHYSICS DIAGNOSTIC/MEASUREMENT CAPABILITY

NASA has adapted or developed a number of diagnostic/measurement techniques for microgravity fluid physics research which can be utilized for ground-based research and possibly modified for flight research. Techniques currently under development that are expected to become available in the near future or are currently available are described below.

A. Laser Tweezers Facility: The NASA Glenn Research Center has a laser tweezers based on an Olympus IX-70 inverted microscope and an SDL-5762 MOPA laser. This laser operates at 985 nm and has a power level that is variable up to 1 Watt. The scanning of the tweezers and the power of the laser are independently computer controlled. The tweezers are capable of following the point-and-click of a mouse or defining two arrays of up to ten points. When scanning the arrays, the dwell time at each point and the speed of the scan are variable down to 10 ms at a point and between points. The microscope is also capable of implementing a second, though fixed tweezers. Currently, this trap utilizes a 5 mW red He-Ne laser, though any laser in the visible portion of the spectrum could be coupled through the port currently used for this laser. This trap is not computer controlled.

B. Surface Light Scattering Hardware: NASA's Advanced Technology Development (ATD) program is sponsoring the development of surface light scattering hardware. This instrument is designed to non-invasively measure the surface response function of liquids over a wide range of operating conditions while automatically compensating for gross surface motion. The surface response function can be used to compute surface tension, properties of monolayers present, viscosity, surface tension gradient, and surface temperature and its gradient. The instrument uses its optical electronic building blocks developed for the laser light scattering program at NASA Glenn along with several unique surface light scattering components and new algorithms.

C. Common-Path Interferometry (CPI): Because of a great need for measuring two-dimensional temperature and density distributions in transparent fluids used in many fluid physics experiments, the CPI is being developed and tested for some ranges of flow conditions. The CPI is a new, robust, compact, quantitative common-path interferometer that could use a low power He-Ne laser as a light source. The instrument has a minimum number of optical components that can be used for ground-based and flight experiments, and it can be phase-stepped for high data-density recording. It can be easily converted into schlieren or shadowgraph instruments capable of handling a variety of fluid experiments. This includes real-time, steady, and non-steady fluid flow conditions. In contrast to many other popular interferometers, the instrument is capable of using a variety of interferometer heads (polarizers and retarders) to provide different sensitivities to accommodate the requirements of a wider range of experiments. It has also been successfully used to measure diffusivity of miscible liquids. The CPI is a robust, compact, quantitative common-path interferometer that could use a low power He-Ne laser as a light source for typical measurements. A system of hardware and software has been designed to allow acquisition of three-dimensional vectors describing flow simultaneously throughout an experimental volume. Used for ground-based and flight experiments, the quantitative results may be compared directly with numerical or analytical predictions of flow velocities. The system requires a transparent fluid seeded with particles large enough to be viewed as a full pixel on a video screen. Two synchronized orthogonal views provide the raw data. While generally used with light the algorithms for velocity vectors could also be used with x-ray images of suspended particles. The SIV system has worked for sample volumes between 2 cm^3 and 2 m^3. For experiments planned for the ISS, the Fluids and Combustion Facility will contain orthogonal video cameras which can record the data required for three-dimensional velocity analysis.

D. Stereo Imaging Velocimetry (SIV): A system of hardware and software has been designed to allow acquisition of three-dimensional vectors describing flow simultaneously throughout an experimental volume. Used for ground-based and flight experiments, the quantitative results may be compared directly with numerical or analytical predictions of flow velocities. The system requires a transparent fluid seeded with particles large enough to be viewed as a full pixel on a video screen. Two synchronized orthogonal views provide the raw data. While generally used with light the algorithms for velocity vectors could also be used with x-ray images of suspended particles. The SIV system has worked for sample volumes between 8 cm^3 and 2 m^3.

E. Forward Scattering Particle Image Velocimetry: A technique for measuring three-dimensional particle position in a microscopic field-of-view has been developed at NASA Glenn Research Center. The technique relies on spatially sampling the forward scattered light from spherical objects using standard microscope illumination. A model has been developed which incorporates Mie scattering predictions with the optical response of a high numerical aperture microscope. The position of the particle along the optical axis (viewing direction) is determined by correlating the predicted and modeled scattering; a neural network has been used for the comparison. The technique can offer high dynamic range along all three axes. Although the model predicts the response for any size sphere, the scientists have not verified the predictions for micron size spheres.

F. Birefringence Measurements: A system for measuring flow-induced birefringence in a transient extensional flow is packaged for microgravity experimentation. The system uses modulation techniques with AC detection and a single wavelength source to simultaneously measure the retardance and extinction angle in order to determine the conformation of polymer molecules. The apparatus also provides a simultaneous measurement of the diameter of the polymer solution.

G. Laser Feedback Interferometry: Researchers at the NASA Glenn Research Center developed a phase-shifted laser feedback interferometer and incorporated the instrument into a high numerical aperture microscope. The instrument can readily measure changes in the optical path length with nm precision and the microscope possesses transverse and axial resolution typical of a confocal microscope. Object or beam scanning is required to collect information over an area. The interferometer may also be used to measure vibrational amplitudes, and is highly sensitive to changes in sample reflectivity.

H. Diffusing Wave Spectroscopy (DWS): A compact instrument for Diffusing Wave Spectroscopy measurements has been built and tested on colloidal suspensions and foams. The instrument incorporates a frequency-doubled Nd:YAG laser with 100 mW output at 532 nm. Scattered light is detected using single-mode fiber optic probes, and a high-speed digital correlator analyzes the signal. Future testing using the DWS instrument will be done on the NASA low-gravity aircraft, and it is expected to be available as a diagnostic instrument aboard the Space Station Fluids Integrated Rack.

I. Additional Techniques: The following techniques are in already in use or currently underdevelopment:

1) Two dimensional particle imaging velocimetry
2) Rainbow Schlieren for measurement of temperature distributions
3) Light sheet flow visualization and/or velocimetry
4) Miniaturized laser Doppler velocimetry
5) Liquid surface temperature and vapor phase concentration measurements via Exciplex Fluorescence

APPENDIX C
NRA-01-OBPR-02

INSTRUCTIONS FOR RESPONDING TO NASA RESEARCH ANNOUNCEMENTS (JANUARY 2000)

(a) General.

(1) Proposals received in response to a NASA Research Announcement (NRA) will be used only for evaluation purposes. NASA does not allow a proposal, the contents of which are not available without restriction from another source, or any unique ideas submitted in response to an NRA to be used as the basis of a solicitation or in negotiation with other organizations, nor is a pre-award synopsis published or individual proposals.

(2) A solicited proposal that results in a NASA award becomes part of the record of that transaction and may be available to the public on specific request; however, information or material that NASA and the awardee mutually agree to be of a privileged nature will be held in confidence to the extent permitted by law, including the Freedom of Information Act

(3) NRAs contain programmatic information and certain requirements which apply only to proposals prepared in response to that particular announcement. These instructions contain the general proposal preparation information which applies to responses to all NRAs.

(4) A contract, grant, cooperative agreement, or other agreement may be used to accomplish an effort funded in response to an NRA. NASA will determine the appropriate instrument. Contracts resulting from NRAs are subject to the Federal Acquisition Regulation and the NASA FAR Supplement. Any resultant grants or cooperative agreements will be awarded and administered in accordance with the NASA Grant and Cooperative Agreement Handbook (NPG 5800.1).

(5) NASA does not have mandatory forms or formats for responses to NRAs; however, it is requested that proposals conform to the guidelines in these instructions. NASA may accept proposals without discussion; hence, proposals should initially be as complete as possible and be submitted on the proposers' most favorable terms.

(6) To be considered for award, a submission must, at a minimum, present a specific project within the areas delineated by the NRA; contain sufficient technical and cost information to permit a meaningful evaluation; be signed by an official authorized to legally bind the submitting organization; not merely offer to perform standard services or to just provide computer facilities or services; and not significantly duplicate a more specific current or pending NASA solicitation.

(b) NRA-Specific Items. Several proposal submission items appear in the NRA itself: the unique NRA identifier; when to submit proposals; where to send proposals; number of copies required; and sources for more information. Items included in these instructions may be supplemented by the NRA.

(c) The following information is needed to permit consideration in an objective manner. NRAs will generally specify topics for which additional information or greater detail is desirable. Each proposal copy shall contain all submitted material, including a copy of the transmittal letter if it contains substantive information.

(1) Transmittal Letter or Prefatory Material.

(i) The legal name and address of the organization and specific division or campus identification if part of a larger organization;

(ii) A brief, scientifically valid project title intelligible to a scientifically literate reader and suitable for use in the public press;

(iii) Type of organization: e.g., profit, nonprofit, educational, small business, minority, women-owned, etc.;

(iv) Name and telephone number of the principal investigator and business personnel who may be contacted during evaluation or negotiation;

(v) Identification of other organizations that are currently evaluating a proposal for the same efforts;

(vi) Identification of the NRA, by number and title, to which the proposal is responding;

(vii) Dollar amount requested, desired starting date, and duration of project;

(viii) Date of submission; and

(ix) Signature of a responsible official or authorized representative of the organization, or any other person authorized to legally bind the organization (unless the signature appears on the proposal itself).

(2) Restriction on Use and Disclosure of Proposal Information. Information contained in proposals is used for evaluation purposes only. Offerors or quoters should, in order to maximize protection of trade secrets or other information that is confidential or privileged, place the following notice on the title page of the proposal and specify the information subject to the notice by inserting an appropriate identification in the notice. In any event, information contained in proposals will be protected to the extent permitted by law, but NASA assumes no liability for use and disclosure of information not made subject to the notice.

Notice
Restriction on Use and Disclosure of Proposal Information

The information (data) contained in [insert page numbers or other identification] of this proposal constitutes a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, that in the event a contract (or other agreement) is awarded on the basis of this proposal the Government shall have the right to use and disclose this information (data) to the extent provided in the contract (or other agreement). This restriction does not limit the Government's right to use or disclose this information (data) if obtained from another source without restriction.

(3) Abstract. Include a concise (200-300 word if not otherwise specified in the NRA) abstract describing the objective and the method of approach.

(4) Project Description.

(i) The main body of the proposal shall be a detailed statement of the work to be undertaken and should include objectives and expected significance; relation to the present state of knowledge; and relation to previous work done on the project and to related work in progress elsewhere. The statement should outline the plan of work, including the broad design of experiments to be undertaken and a description of experimental methods and procedures. The project description should address the evaluation factors in these instructions and any specific factors in the NRA. Any substantial collaboration with individuals not referred to in the budget or use of consultants should be described. Subcontracting significant portions of a research project is discouraged.

(ii) When it is expected that the effort will require more than one year, the proposal should cover the complete project to the extent that it can be reasonably anticipated. Principal emphasis should be on the first year of work, and the description should distinguish clearly between the first year's work and work planned for subsequent years.

(5) Management Approach. For large or complex efforts involving interactions among numerous individuals or other organizations, plans for distribution of responsibilities and arrangements for ensuring a coordinated effort should be described.

(6) Personnel. The principal investigator is responsible for supervision of the work and participates in the conduct of the research regardless of whether or not compensated under the award. A short biographical sketch of the principal investigator, a list of principal publications and any exceptional qualifications should be included. Omit social security number and other personal items which do not merit consideration in evaluation of the proposal. Give similar biographical information on other senior professional personnel who will be directly associated

with the project. Give the names and titles of any other scientists and technical personnel associated substantially with the project in an advisory capacity. Universities should list the approximate number of students or other assistants, together with information as to their level of academic attainment. Any special industry-university cooperative arrangements should be described.

(7) Facilities and Equipment.

(i) Describe available facilities and major items of equipment especially adapted or suited to the proposed project, and any additional major equipment that will be required.. Identify any Government-owned facilities, industrial plant equipment, or special tooling that are proposed for use. Include evidence of its availability and the cognizant Government points of contact.

(ii) Before requesting a major item of capital equipment, the proposer should determine if sharing or loan of equipment already within the organization is a feasible alternative. Where such arrangements cannot be made, the proposal should so state. The need for items that typically can be used for research and non-research purposes should be explained.

(8) Proposed Costs (U.S. Proposals Only).

(i) Proposals should contain cost and technical parts in one volume: do not use separate "confidential" salary pages. As applicable, include separate cost estimates for salaries and wages; fringe benefits; equipment; expendable materials and supplies; services; domestic and foreign travel; ADP expenses; publication or page charges; consultants; subcontracts; other miscellaneous identifiable direct costs; and indirect costs. List salaries and wages in appropriate organizational categories (e.g., principal investigator, other scientific and engineering professionals, graduate students, research assistants, and technicians and other non-professional personnel). Estimate all staffing data in terms of staff-months or fractions of full-time.

(ii) Explanatory notes should accompany the cost proposal to provide identification and estimated cost of major capital equipment items to be acquired; purpose and estimated number and lengths of trips planned; basis for indirect cost computation (including date of most recent negotiation and cognizant agency); and clarification of other items in the cost proposal that are not self-evident. List estimated expenses as yearly requirements by major work phases.

(iii) Allowable costs are governed by FAR Part 31 and the NASA FAR Supplement Part 1831 (and OMB Circulars A-21 for educational institutions and A-122 for nonprofit organizations).

(iv) Use of NASA funds--NASA funding may not be used for foreign research efforts at any level, whether as a collaborator or a subcontract. The direct purchase of supplies and/or services, which do not constitute research, from non-U.S. sources by U.S. award recipients is permitted. Additionally, in accordance with the National Space Transportation Policy, use of a non-U.S. manufactured launch vehicle is permitted only on a no-exchange-of-funds basis.

(9) Security. Proposals should not contain security classified material. If the research requires access to or may generate security classified information, the submitter will be required to comply with Government security regulations.

(10) Current Support. For other current projects being conducted by the principal investigator, provide title of project, sponsoring agency, and ending date.

(11) Special Matters.

(i) Include any required statements of environmental impact of the research, human subject or animal care provisions, conflict of interest, or on such other topics as may be required by the nature of the effort and current statutes, executive orders, or other current Government-wide guidelines.

(ii) Proposers should include a brief description of the organization, its facilities, and previous work experience in the field of the proposal. Identify the cognizant Government audit agency, inspection agency, and administrative contracting officer, when applicable.

(d) Renewal Proposals.

(1) Renewal proposals for existing awards will be considered in the same manner as proposals for new endeavors. A renewal proposal should not repeat all of the information that was in the original proposal. The renewal proposal should refer to its predecessor, update the parts that are no longer current, and indicate what elements of the research are expected to be covered during the period for which support is desired. A description of any significant findings since the most recent progress report should be included. The renewal proposal should treat, in reasonable detail, the plans for the next period, contain a cost estimate, and otherwise adhere to these instructions.

(2) NASA may renew an effort either through amendment of an existing contract or by a new award.

(e) Length. Unless otherwise specified in the NRA, effort should be made to keep proposals as brief as possible, concentrating on substantive material. Few proposals need exceed 15-20 pages. Necessary detailed information, such as reprints, should be included as attachments. A complete set of attachments is necessary for each copy of the proposal. As proposals are not returned, avoid use of "one-of-a-kind" attachments.

(f) Joint Proposals.

(1) Where multiple organizations are involved, the proposal may be submitted by only one of them. It should clearly describe the role to be played by the other organizations and indicate the legal and managerial arrangements contemplated. In other instances, simultaneous submission of related proposals from each organization might be appropriate, in which case parallel awards would be made.

(2) Where a project of a cooperative nature with NASA is contemplated, describe the contributions expected from any participating NASA investigator and agency facilities or equipment which may be required. The proposal must be confined only to that which the proposing organization can commit itself. "Joint" proposals which specify the internal arrangements NASA will actually make are not acceptable as a means of establishing an agency commitment.

(g) Late Proposals. Proposals or proposal modifications received after the latest date specified for receipt may be considered if a significant reduction in cost to the Government is probable or if there are significant technical advantages, as compared with proposals previously received.

(h) Withdrawal. Proposals may be withdrawn by the proposer at any time before award. Offerors are requested to notify NASA if the proposal is funded by another organization or of other changed circumstances which dictate termination of evaluation.

(i) Evaluation Factors.

(1) Unless otherwise specified in the NRA, the principal elements (of approximately equal weight) considered in evaluating a proposal are its relevance to NASA's objectives, intrinsic merit, and cost.

(2) Evaluation of a proposal's relevance to NASA's objectives includes the consideration of the potential contribution of the effort to NASA's mission.

(3) Evaluation of its intrinsic merit includes the consideration of the following factors of equal importance:

(i) Overall scientific or technical merit of the proposal or unique and innovative methods, approaches, or concepts demonstrated by the proposal.

(ii) Offeror's capabilities, related experience, facilities, techniques, or unique combinations of these which are integral factors for achieving the proposal objectives.

(iii) The qualifications, capabilities, and experience of the proposed principal investigator, team leader, or key personnel critical in achieving the proposal objectives.

(iv) Overall standing among similar proposals and/or evaluation against the state-of-the-art.

(4) Evaluation of the cost of a proposed effort may include the realism and reasonableness of the proposed cost and available funds.

(j) Evaluation Techniques. Selection decisions will be made following peer and/or scientific review of the proposals. Several evaluation techniques are regularly used within NASA. In all cases proposals are subject to scientific review by discipline specialists in the area of the proposal. Some proposals are reviewed entirely in-house, others are evaluated by a combination of in-house and selected external reviewers, while yet others are subject to the full external peer review technique (with due regard for conflict-of-interest and protection of proposal information), such as by mail or through assembled panels. The final decisions are made by a NASA selecting official. A proposal which is scientifically and programmatically meritorious, but not selected for award during its initial review, may be included in subsequent reviews unless the proposer requests otherwise.

(k) Selection for Award.

(1) When a proposal is not selected for award, the proposer will be notified. NASA will explain generally why the proposal was not selected. Proposers desiring additional information may contact the selecting official who will arrange a debriefing.

(2) When a proposal is selected for award, negotiation and award will be handled by the procurement office in the funding installation. The proposal is used as the basis for negotiation. The contracting officer may request certain business data and may forward a model award instrument and other information pertinent to negotiation.

(l) Additional Guidelines Applicable to Foreign Proposals and Proposals Including Foreign Participation.

(1) NASA welcomes proposals from outside the U.S. However, foreign entities are generally not eligible for funding from NASA. Therefore, unless otherwise noted in the NRA, proposals from foreign entities should not include a cost plan unless the proposal involves collaboration with a U.S. institution, in which case a cost plan for only the participation of the U.S. entity must be included. Proposals from foreign entities and proposals from U.S. entities that include foreign participation must be endorsed by the respective government agency or funding/sponsoring institution in the country from which the foreign entity is proposing. Such endorsement should indicate that the proposal merits careful consideration by NASA, and if the proposal is selected, sufficient funds will be made available to undertake the activity as proposed.

(2) All foreign proposals must be typewritten in English and comply with all other submission requirements stated in the NRA. All foreign proposals will undergo the same evaluation and selection process as those originating in the U.S. All proposals must be received before the established closing date. Those received after the closing date will be treated in accordance with paragraph (g) of this provision.. Sponsoring foreign government agencies or funding institutions may, in exceptional situations, forward a proposal without endorsement if endorsement is not possible before the announced closing date. In such cases, the NASA sponsoring office should be advised when a decision on endorsement can be expected.

(3) Successful and unsuccessful foreign entities will be contacted directly by the NASA sponsoring office. Copies of these letters will be sent to the foreign sponsor. Should a foreign proposal or a U.S. proposal with foreign participation be selected, NASA's Office of External Relations will arrange with the foreign sponsor for the proposed participation on a no-exchange-of-funds basis, in which NASA and the non-U.S. sponsoring agency or funding institution will each bear the cost of discharging their respective responsibilities.

(4) Depending on the nature and extent of the proposed cooperation, these arrangements may entail:

(i) An exchange of letters between NASA and the foreign sponsor; or

(ii) A formal Agency-to-Agency Memorandum of Understanding (MOU).

(m) Cancellation of NRA. NASA reserves the right to make no awards under this NRA and to cancel this NRA. NASA assumes no liability for canceling the NRA or for anyone's failure to receive actual notice of cancellation.

APPENDIX D
NRA-01-OBPR-02

NASA RESEARCH ANNOUNCEMENT (NRA) SCHEDULE

MICROGRAVITY FLUID PHYSICS: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

All proposals submitted in response to this Announcement are due on the date and at the address given below by the close of business (4:30 PM EST). NASA reserves the right to consider proposals received after this deadline if such action is judged to be in the interest of the U.S. Government. A complete schedule of the review of the proposals is given below:

NRA Release Date: .... February 9, 2001

Notice of Intent Due: ....March 12, 2001

Proposal Due: .... May 11, 2001

Submit Proposal to:

Dr. Gerald Pitalo
c/o NASA Peer Review Services
Subject: NASA Research Proposal (NRA-01-OBPR -02)
500 E Street, S.W., Suite 200
Washington, DC 20024

Telephone number for delivery services: (202) 479-9030

Final Selections: ....September, 2001

Funding commences: .... No sooner than October, 2001
(dependent upon actual selection and procurement process)