NASA recognizes the critical role that fluid mechanics and transport processes, along with their supporting technologies, play in many biological and physiological events. A wide variety of fundamental problems in the categories of physiological systems, cellular systems, and biotechnology may be addressed. The objective of this research is to deliver new technology in the form of devices and instruments of use in microgravity missions to the Moon and Mars and/or for commercial application on Earth in the areas discussed below.

**Micro-Optical Technology for Interdisciplinary and Biological Research**

Technologies are sought for measuring and manipulating Space Station and long-duration mission experiments, and for monitoring and managing astronaut health and the health of structures and systems affecting astronauts’ environments. Areas of innovative technology development include:

- Diagnostic methods to assess the performance of labs-on-a-chip, including detecting the presence of bubbles and particles and removing or characterizing them;
- Measurements for fluids including spatially and temporally resolved chemical composition and physical state variables;
- Optically-based biomimetics for self-aware, self-reconfiguring measurement systems;
- Measurement and micro-control technologies for health monitoring and health management of experiments, astronauts, and astronauts’ environments;
- Optical quantum technologies for measurement systems including signal detection and transmission; and
- Technologies enabling optically-based mobile sensor platforms for detection and maintenance, using optical sensing, control, power, and/or communication.

**Biological Fluid Mechanics (Biofluids)**

Biofluids, an intersection of fluid physics and biology, is a new area of emphasis within NASA's Office of Biological and Physical Research (OBPR). 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. The microgravity environment modifies vascular fluid distribution on a short time scale, because of the loss of hydrostatic pressure, and on a longer time scale, because of 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 inter-planetary space flight. Furthermore, reintroduction of gravity causes large-scale fluid shifts in the body, which can influence cardiac output and induce faintness. Studies of macro- and microscale biofluid mechanics of the vascular system in the microgravity environment may be important to understanding these physiological events. Innovations sought include but are not limited to the following:

- Studies of biological fluid mechanics that seek answers to questions related to effect of long-term exposure to microgravity on human physiology;
- Understanding the role of fluid physics and transport phenomena in the "fluid shift" observed in the human body when exposed to prolonged microgravity; and
- Understanding the role fluid physics plays in human physiological processes such as cardiovascular flows and its effect on arteriosclerosis, and pulmonary flows and asthma.

**BioMicroFluidics**

Many biotechnology applications need manipulation of fluids moving through micro channels. As a result, microfluidic devices are becoming increasingly useful for biological/biotechnological applications. Because capillary forces can have a significant effect on the flow at this scale, a strong similarity with microgravity flows exists. Innovations sought include but are not limited to the following:

- Understanding of fluid mechanics underlying the operations of microfluidic devices crucial to their successful operation and continued miniaturization; and
- Tools for prediction, measurement, and control of fluid flow in microchannels and microchannel network.

**Models of Cellular Behavior**

The simplest living cell is so complex that models may never be able to provide a perfect simulation of its behavior, however, even imperfect models could provide information that could shake the very foundations of biology. We are now at the point where we can consider models of molecular, cellular and developmental biological systems that, when coupled to experiments, result in an increased understanding of biology. Quantitative models of cellular processes require. Innovations sought include but are not limited to the following:

- New methods for better handling of large numbers of coupled reactions, increases in computing power, and the ability to transition among different levels of resolution associated with quantitative models of cellular processes; and
- Development of models to form the basis of tools to aid in optimization of existing biological systems and design of new ones, enabling engineers to evolve biological systems by rounds of variation and selection for any function they choose.

**Functional Imagery**

Research on-orbit has demonstrated that the microgravity environment affects the skeletal, cardiovascular, and
immune systems of the body. Few of the investigations to date examined functional changes due to microgravity at either the cellular or molecular scale. NASA, therefore, seeks innovations that would lead to an enhanced capability to image functioning biological systems at either length scale. All proposals should recognize the power, volume, and mass constraints of orbital facilities. Examples of possible innovations include but are not limited to the following:

- Development of novel fluorophores that tag proteins mediating cellular function, particularly those that can be excited using solid-state lasers;
- Systems that can simultaneously image multiple fluorophores following different processes at standard video frame rates;
- Devices that enable three-dimensional imagery of the sample; and
- Imaging hardware that can follow a metabolic process in a turbulent system.

Understanding Living Systems Through Microgravity Fluid Physics

Developing strategies for long-duration space flight requires an understanding of the effects of the microgravity environment on biological processes. Interdisciplinary fundamental and applied research is required in biology, physiology, and microbiology to human, and microbial systems from the standpoint of physics. Of particular interest are studies with technology development that develop theoretical, numerical, and/or experimental understanding of the effects of acceleration, and other factors in microgravity environments on these systems. Exploring the effects of Martian and lunar gravity and the quasi-steady, oscillatory, and transient accelerations that are typical of a space laboratory are of great interest, as well as fundamental studies with technology development of acceleration sensitivity. The knowledge obtained should contribute to related agency activities, such as the development of self-sustaining ecosystems and treatment of bacterial infection in space. Moreover, we expect that the knowledge and technologies derived will also provide ground-based economic and societal benefits. Major research disciplines include the fluid transport in microbiology, human physiology, hematology, and drug delivery systems. Innovations are sought in a number of areas.

Delineation of the effects of acceleration and environment at the macro- and microscale levels on processes such as bacterial growth, growth rates, resistance to antibiotics and disinfectants, interactions among microbes, microbial locomotion and interaction with the surrounding fluid or solid medium, transport through cell membranes, electro-osmotic flows, and cytoplasmic streaming, as well as quantification of metabolic processes and other phenomena that permit the examination of these problems:

- Effects of bulk fluid flows on biofilms and liposome formation.
- Transendothelial transport.
- Microscale modeling of fluid flows and mass transfer for drug delivery systems.