FUNDAMENTAL SPACE BIOLOGY

Accomplishments Report 2000–2002

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FROM THE DIVISION DIRECTOR: TERRI LOMAX, PH.D.

The 2000-2002 period was highly important for Fundamental Space Biology (FSB). The newly established Division set a broad-based research agenda to further our understanding of the basic effects of spaceflight on living systems.

FSB adopted a new approach that would help NASA begin to take advantage of the tools and approaches brought about by the biotechnology and genomics revolution. FSB also adopted an aggressive stance in assessing and pursuing the advanced technologies necessary to enable cutting edge life sciences research in space.

Despite limited flight opportunities, FSB-funded investigators made valuable scientific advances in orbit and on the ground, many with Earth applications. Throughout the period, the FSB Outreach Program communicated the Division's accomplishments to the public through a variety of projects recognized for their excellence.

The coming year promises to be an exciting one for the Division. In conjunction with the Office of Biological and Physical Research (OBPR), FSB will help develop an Enterprise-level Research Strategy. The OBPR Strategy will be integrated with those of other enterprises in the NASA Strategic Plan. The FSB contribution will emphasize the need for understanding how space environments affect life at the cellular level, at the organismal level throughout individual life spans, across multiple generations, and in ecosystems.

FSB will participate in the development of several new research initiatives within OBPR. One is the Radiation Health initiative to better understand and lessen the radiation risks for human space exploration. Another that is being assessed is a Free-Flyer initiative. This initiative would complement the ISS with unmanned spacecraft to accommodate experiments and flight plans not compatible with human presence, e.g. pathogens, radiation, and toxins. A third initiative, still under study, would develop the capability to conduct small, automated experiments with model organisms, leading to basic understanding at the gene expression level of responses to variable gravity and, ultimately, to conduct focused multi-generation research for the first time in space.

Collaborations are anticipated with a new NASA-wide Space Architecture team to evaluate the role of biosciences for potential future research beyond low Earth orbit. Increased collaborations are anticipated with the Bioastronautics Division and the Physical Sciences Division in conduct of research designed to support human space exploration, especially in the areas of risk mitigation.

Through these activities and its core research program described herein, FSB will continue to pursue knowledge and technology to help make spaceflight safe and productive for all living things, determine life's ability to extend beyond its planet of origin, and benefit life on Earth in the process.

INTRODUCTION

TO PURSUE SAFE AND SUCCESSFUL space exploration, we must learn how Earth-based life can adapt and thrive in different space environments over the long term. Fundamental Space Biology studies basic biological processes through both spaceflight and ground-based research. By studying how organisms respond to microgravity and other unique aspects of space environments, we increase our understanding of life on Earth and develop the knowledge needed to support long-term human habitation in space.

WHAT IS SPACE BIOLOGY?

The only life we have encountered anywhere in the universe—the only life we know—is life on Earth, in all its vast diversity. Every living thing evolved under the common influences of Earth's gravity, atmosphere, and radiation.

Space exploration entails removing organisms, including humans, from the environment to which they have successfully adapted. The environments in space and on other planets differ greatly from Earth's. Can living systems adapt to and thrive in space over the long term? How can this be accomplished safely? Are there aspects of living things, buried in their genetic code, that can be observed only away from Earth's environment? These and the multitude of more specific questions they encompass are the territory of space biology.

Over the past 30 years of human spaceflight, we have discovered that humans, plants, and animals undergo changes associated with the effective absence of gravity. By conducting studies that control aspects of the artificial environment we create to live in space, we can determine how living systems sense, adapt, develop, and evolve in this novel world. Our current knowledge indicates that with appropriate support, life can successfully adapt to habitats beyond Earth. As we learn about how systems change in the response to the absence of gravity, we understand more about life on our planet.

Human adaptation to the microgravity of spaceflight must be minimized for a range of performance and health reasons, including the allowance of the quick readaptation to Earth gravity on landing. Space biology research is critical for determining which key biological mechanisms selectively counter adaptation to the space environment. With this knowledge, we are better able to ensure the safety of human beings in flight. Space biology research also supports the development of artificial ecosystems for spacecraft and planetary bases, which are essential to providing long-term life-support systems for human exploration beyond Earth.

Knowledge of space biology also helps us understand how life evolved on Earth in a constant-gravity environment. Life's evolution between sea, land, and air required special adaptive mechanisms to overcome the influence of gravity. The ability to study adaptation of small organisms over multiple generations in space at variable gravity levels provides a unique window into the history of life on Earth.

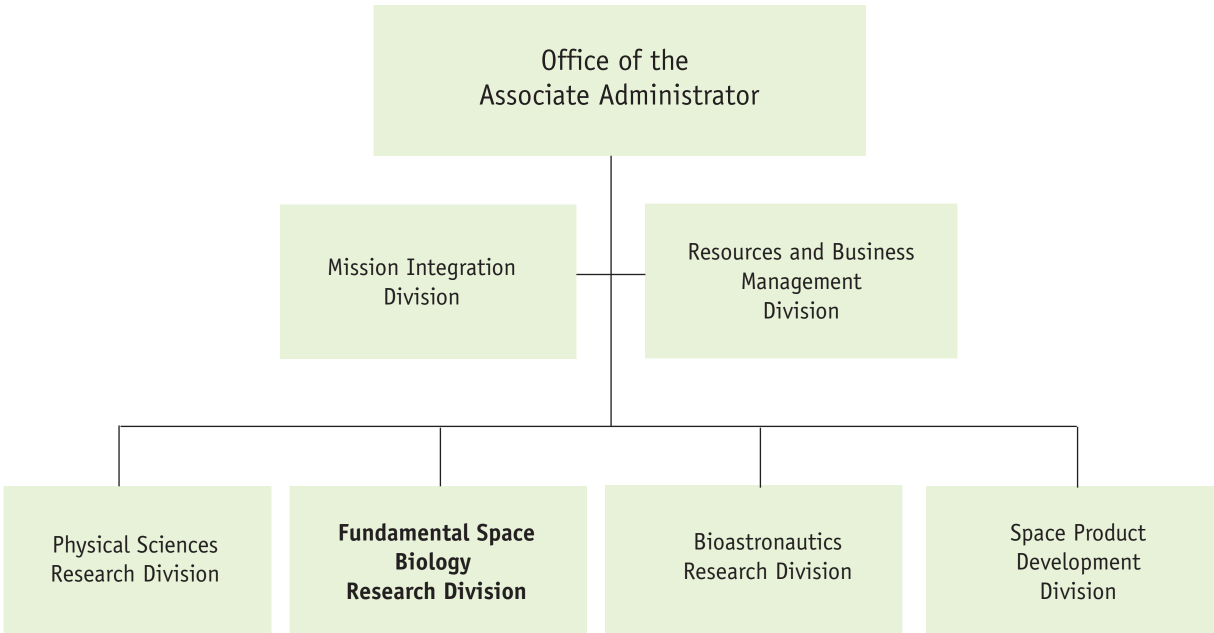
FUNDAMENTAL SPACE BIOLOGY AT NASA

Fundamental Space Biology (FSB) is one of four research divisions in NASA's Office of Biological and Physical Research (OBPR). OBPR was founded as a NASA Enterprise in 2000 in a reorganization of the Office of Life and Microgravity Sciences and Applications (OLMSA), then a part of the Human Exploration and Development of Space (HEDS) Enterprise. OBPR was designed to strengthen the agency's ability to meet the challenges brought about by the growth and new capabilities available in areas such as molecular biology, nanotechnology, information technology, and genomics. Prior to the creation of OBPR, Fundamental Space Biology was a program within OLMSA known as Gravitational Biology & Ecology.

The major goals of the Fundamental Space Biology Research Division are as follows:

- Use gravity, microgravity, and the other characteristics of the space environment to enhance our understanding of fundamental biological processes
- Develop the fundamental biological knowledge to enable a long-duration human presence in space
- Support other NASA activities related to biology

OFFICE OF BIOLOGICAL AND PHYSICAL RESEARCH ORGANIZATION CHART

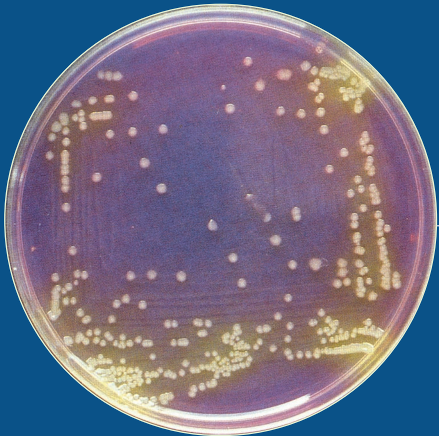


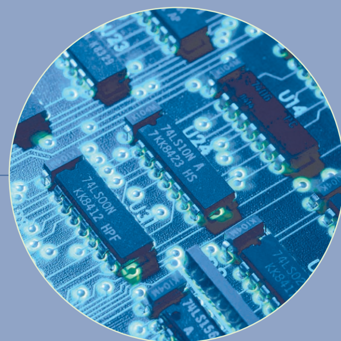
Fundamental Space Biology is one of four research entities within OBPR. Physical Sciences, Bioastronautics, and FSB compose the OBPR research divisions. Space Product Development manages commercial research activities. The Mission Integration Division and Resources and Business Management Division are support divisions.

- Apply this knowledge and technology to improve our nation's competitiveness, education, and the quality of life on Earth.

The Fundamental Space Biology Division is primarily responsible for strategic planning, developing new initiatives, acquiring and distributing funding, establishing policies, coordinating peer-review and approval of research grants, and reporting on performance to the agency and the United States Congress. Within the FSB Division, the FSB Program implements and manages research grants and other activities in support of Division goals.

FSB interacts with the other OBPR research divisions. In collaboration with the Physical Sciences Division, FSB supports research focusing on cell biology, as well as the effects of fluid physics on cell cultures. Collaborations with the Bioastronautics Division include studies of basic adaptive mechanisms to variable-g and countermeasures within research areas identified by NASA's Critical Path Roadmap. FSB and Bioastronautics also work together to understand the microecology of spacecraft and crew and develop sensors for physiological measurements. With the Bioastronautics Division's Advanced Life Support Project, FSB researches plant biology, microecology of life support, and waste management systems. FSB and the Space Product Development Division collaborate with OBPR-sponsored research partners in sharing flight hardware, overseeing FSB-relevant space biology payloads, and facilitating hardware verification for spaceflight.





PROGRAM ELEMENTS

FUNDAMENTAL SPACE BIOLOGY supports other NASA programs and offices that contribute to FSB goals, including life sciences-related research, education and outreach, technology development, life sciences data archiving, and various ground-based facilities and centers.

FSB PROGRAM OFFICE

The FSB Program office, located at NASA Ames Research Center (ARC), oversees grant management for the Flight and Ground Research Program, the FSB Outreach Program, and the FSB Technology Program.

FLIGHT AND GROUND RESEARCH PROGRAM (GRANTS)

FSB sponsors spaceflight and ground-based research in space biology by awarding grants to investigators through a peer-review process. Each fiscal year, FSB releases a NASA Research Announcement (NRA) to solicit grant proposals. FSB coordinates the release of the NRA, the review and selection of grant proposals, and the tracking of progress.

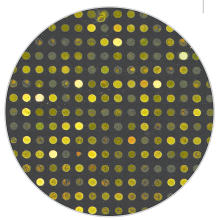
FSB EDUCATION AND OUTREACH

The Fundamental Space Biology Outreach Program (FSBOP) imparts the relevance and results of NASA's basic biology research to the general public.

FSBOP is located at NASA Kennedy Space Center (KSC) but includes science and educational specialists from NASA ARC and academic institutions. The FSBOP team works closely with the Office of Biological and Physical Research at NASA Headquarters, as well as with NASA sponsored scientists and research managers across the country.

FSB TECHNOLOGY PROGRAM

The Fundamental Space Biology Division is responsible for NASA's biological research and biological instrumentation development. This element of the FSB Program, Technology for FSB (T4FSB), tracks emerging technologies, sponsors research, and facilitates overall technology development processes through strategic planning, requirements analysis, and assessment. The NASA AstroBionics Integrated Program/Project Team manages T4FSB. Astrobionics, a NASA ARC-based resource, provides extensive programmatic and technical expertise covering specialized planning and assessment, expert definition and development, flight and ground-based hardware development and technology transfer, and assisted science/engineering interfacing.



KEY NASA ENTITIES SUPPORTED BY FSB

FSB provides funding to several NASA entities outside of its program. Although FSB funds are not always allocated for specific activities within each entity, FSB support enables these entities to produce accomplishments that relate to FSB goals.

LIFE SCIENCES AT ARC AND KSC

FSB contributes to the life sciences organizations at Ames Research Center and Kennedy Space Center, the two primary NASA centers that support research with a fundamental biology focus. Both centers are responsible for the management of payloads carrying FSB experiments.

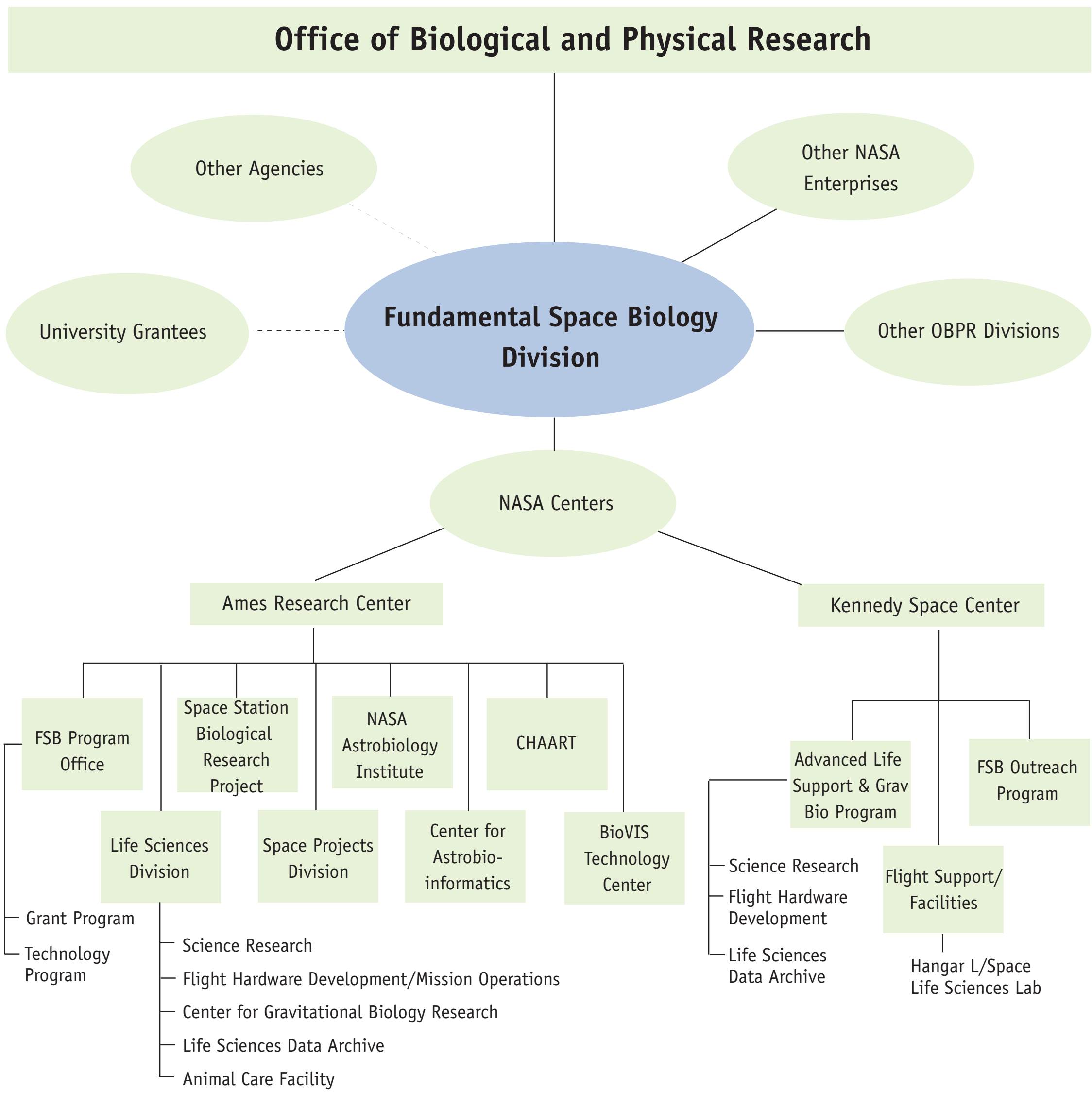
The goal of the Life Sciences Division at ARC is to study how the unique environment of space affects living systems, from cells in culture to the whole organism—both animal and human. FSB also contributes funding to the Center for Gravitational Biology Research and the Animal Care Facility—both managed within the ARC Life Sciences Division.

The Advanced Life Support and Gravitational Biology Program at KSC seeks to develop bioregenerative life-support systems to enable human long-duration missions. The primary research focuses on plants that produce food, purify water, and create oxygen from carbon dioxide. Beyond this research, life sciences activities at KSC include payload processing and ground support of flight experiments at KSC's Life Sciences Support Facility and other science support laboratories.

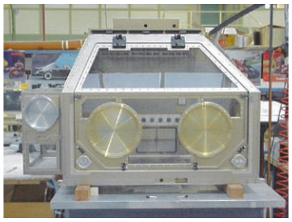
SPACE STATION BIOLOGICAL RESEARCH PROJECT

The Space Station Biological Research Project (SSBRP), located at ARC, is an integrated project team, which

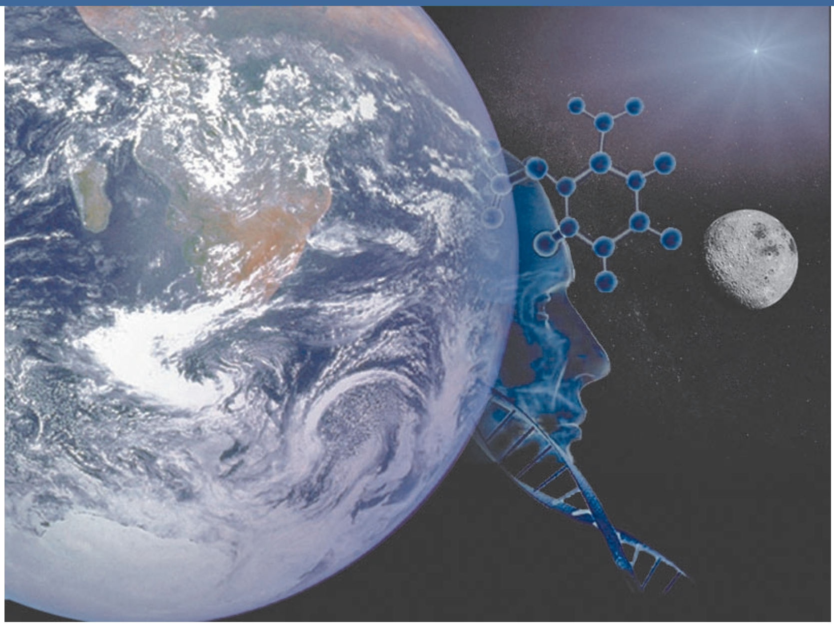
FSB RELATIONSHIP TO OTHER ENTITIES



includes ARC staff matrixed from various organizations. Its mission is to design and develop the systems required to support the wide range of FSB-sponsored gravitational biology research conducted on the International Space Station.



The Life Sciences Glovebox, developed by the Japanese space agency for SSBRP, will support research on the International Space Station.



FSB is interested in bringing life on Earth into novel space environments. The NASA Astrobiology Institute, partially funded by FSB, supports this goal.

SPACE PROJECTS DIVISION

The Space Projects Division, within the Astrobiology and Space Research Directorate at ARC, supports a wide range of space-related programs and projects. In that role, it provides staff to the SSBRP Integrated Project Team (IPT) and supports the IPT in habitat development, systems engineering, and mission planning. During 2002 the Division coordinated a Free-flyer study workshop in conjunction with OBPR and the FSB Program Office.

NASA ASTROBIOLOGY INSTITUTE

The NASA Astrobiology Institute (NAI) is a virtual organization that represents a partnership between NASA and competitively selected NAI Lead Teams across the U.S. It serves to promote, conduct, and lead integrated multidisciplinary astrobiology research. These and other partnerships are helping to train a new generation of researchers in the discipline of astrobiology and foster outreach to teachers, students, and the general public. The director and administrative staff of the NAI are located at ARC. FSB funding supports activities and grants, especially those that address the Astrobiology Roadmap Objective No. 16, "Bringing Life with Us Beyond Earth."

LIFE SCIENCES DATA ARCHIVE

NASA's Life Sciences Data Archive (LSDA) contains information and data from spaceflight experiments, which are available on the LSDA Web site. These experiments were conducted from 1965 to the present, and include human, animal, and plant studies. The goal of the LSDA is to archive life sciences data from the past 40 years and from future experiments on Shuttle missions and the International Space Station. The intended audience for the LSDA Web site ranges from scientists and teachers to space enthusiasts.

CENTER FOR ASTROBIOINFORMATICS

This center, housed at ARC, is supported by peer-reviewed FSB grants. It is a subsidiary program of the NASA Center for Computational Astrobiology and Fundamental Biology. Astrobioinformatics refers to the use of computational biology, computer science, knowledge management, and visualization to understand how organisms interact and live in the space environment; and how life adapts and evolves in the context of extreme environments. The tools and data being gathered will aid NASA researchers in understanding fundamental biological processes, which is key to the success of NASA's ongoing and future missions. The center is committed to working closely with scientists to help NASA in its investigations into genomics and proteomics.

CENTER FOR HEALTH APPLICATIONS OF AEROSPACE RELATED TECHNOLOGIES

Using satellite technology, the Center for Health Applications of Aerospace Related Technologies (CHAART) provides support for investigators researching the relationship between the environment and the spread of epidemics, known as landscape epidemiology. Knowledge of disease outbreaks and forecasts based on environmental factors assists governments in predicting disease vectors.

CHAART uses remote imaging to understand the relationship between Ebola outbreaks in Zaire and other environmental factors.

One of many CHAART projects focuses on the Ebola Virus in Zaire. Beginning with the January 1995 outbreak in Kikwit, Zaire, the CHAART staff have been working with investigators from the Special Pathogens Branch at the Centers for Disease Control and Prevention in Atlanta to generate images of the area where the first Ebola cases were found.

CHAART helps developing countries and pharmaceutical companies prepare for disease outbreaks before they strike. It is part of the Ecosystem Science and Technology Branch of the Earth Science Division at ARC and is currently part of the FSB Division.

BIOVIS TECHNOLOGY CENTER

The BioVIS Technology Center at ARC develops and applies advanced visualization, imaging, and simulation technologies to support NASA life sciences research. Applications relevant to FSB objectives include mathematically-based modeling, three-dimensional reconstruction of cells and tissue, and virtual environments for crew training. Collaboration with the National Biocomputation Center at Stanford University extends BioVIS intellectual resources and medical applications.



RESEARCH APPROACH

BY COMBINING STATE-OF-THE-ART science and technology, Fundamental Space Biology seeks to understand how space affects every level of biological organization, from the function of genes to the interaction of ecosystems. Multiple facilities, both in space and on the ground, support FSB research.

SCIENCE

Fundamental Space Biology strives to expand our understanding of basic biological processes and the mechanisms by which these processes sense, respond, and adapt to the space environment. By applying this knowledge, NASA enables human exploration of space and advances fundamental principles in the biological sciences.

FSB seeks to answer these key questions:

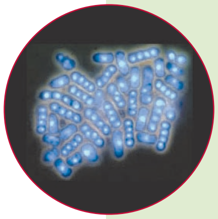
- How does space affect life at its most fundamental levels, from the gene to the cell?
- How does long-term exposure to space affect organisms?
- How does space affect the development and life cycles of organisms?
- How do systems of organisms and their interactions change in space?

The answers to these questions will provide a thorough understanding of the consequences of long-term exposure to space and give rise to novel information about the functioning of biological processes and systems on Earth.

The following objectives guide FSB toward this goal.

- Understand how physical forces encountered in spaceflight impact biological structure and function
- Determine the role of the genome and cellular structures in sensing and responding to gravitational force
- Detemine whether, and to what extent, the normal development of cells, systems, and organisms depends on gravitational force
- Understand how, and for what purposes, different organisms in the animal and plant kingdoms sense and use gravity
- Elucidate the role of gravity in determining how the structure, function, and interactions of space and planetary ecosystems change over time.

These objectives are accomplished by using a spectrum of gravitational conditions (microgravity, hypergravity, and levels in between) and model systems as research tools. Studies are conducted using a range of organisms and living systems, including animals, plants, tissues, and cells. Species selected for research include model organisms such as drosophila (fruit flies), yeast, arabidopsis (mouse-ear cress plants), and rodents.



MODEL ORGANISMS

Multigenerational studies of humans in space are not feasible in the foreseeable future. The use of simple model organisms allows investigators to begin to look at the complex issue of adaptation to the space environment. Experiments will determine the ability of organisms to survive, thrive, and reproduce in space. What we learn from them can be applied to biological issues in human space exploration. Model organisms offer large sample sizes and short replication times, making them ideal for multigenerational studies. Most common model organisms also have completely sequenced genomes.

Various model organisms are needed to answer the different FSB science questions. While simple organisms and cell cultures can be used for initial baseline studies, whole mammalian systems are required for more complex questions about the effects of spaceflight as they apply to humans and other complex organisms. Cells do not necessarily act the same in vitro as they do in vivo; reactions to the space environment seen in cell culture must also be studied at the systemic level.

FSB supports study at both the fundamental and strategic levels. FSB fundamental research is basic, addressing the effects of the space environment across a range of model organisms. Investigations use variable gravity and other characteristics of the space environment to enhance understanding of fundamental biological processes. FSB strategic research applies the basic biological knowledge necessary to support long-duration human presence in space. This level of inquiry is guided by the questions in NASA's Critical Path Roadmap (CPR), which identify the biomedical risks of spaceflight and the research questions that must be answered to reduce those risks. FSB research in support of the CPR provides the basic underlying biological information necessary to address CPR questions.

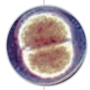
FSB RESEARCH ELEMENTS

Fundamental Space Biology flight and ground research is currently funded in six different areas.

Molecular Structures and Physical Interactions

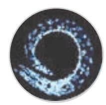
This area emphasizes the physical effects of spaceflight on cells and organisms. These physical interactions may include static-boundary-layer influences on gas exchange, changes in heat transfer, and alterations in diffusion-limited metabolic processes. Research seeks to determine how these factors affect the growth, development, and function of single-cell and multicellular organisms.

Cellular and Molecular Biology



The principal aim of Cellular and Molecular Biology is to support research at the genetic, molecular, and cellular levels to uncover specific cellular phenomena that are affected by conditions of microgravity, and to develop an understanding of the molecular mechanisms that generate these effects. Research addresses how altered gravitational force and other space-related effects may directly or indirectly impact basic cellular functions and properties.

Developmental Biology



NASA's goal in Developmental Biology is to determine the role of gravity in normal development and function and other effects of the space environment on the capacity of organisms to reproduce. Critical to this is understanding the mechanisms by which subsequent generations are affected. Also, the influence of the space environment on behavior, life span, and senescence is of interest.

Organismal and Comparative Biology

In this area, the comparative approach is used to understand how organisms transduce, perceive, integrate, and respond to a gravitational force; to investigate the effects of hyper- and hypo-gravity on developmental, regenerative, and reproductive processes and the regulation of physiological systems (e.g., nervous, musculoskeletal, cardiovascular); and to study how gravity and other environmental factors interact. Organismal and Comparative Biology outlines the physiological, cellular, and molecular mechanisms of the effects of gravity and spaceflight on the growth, development, composition, and physiological and behavioral functions of animals and higher plants across the phylogenetic scale.

Evolutionary Biology

This area seeks to understand the role of gravity in the processes of biological evolution. Studies are designed to pinpoint the fundamental mechanisms and pathways that have caused multicellular organisms to evolve on Earth and investigate the processes that allow organisms to evolve in response to environmental changes.

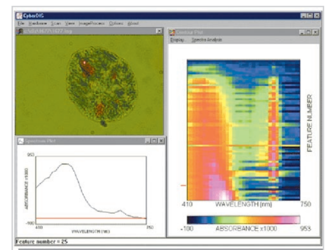
Gravitational Ecology

The goal of investigations into gravitational ecology is to understand how gravity affects the structure, function, and the stability of ecosystems, especially with regard to spacecraft or planetary habitats. Of particular interest are studies of microbial populations or communities. By conducting ecological research at different gravity and space radiation levels, it is possible to determine their influences on ecosystems as well as the effects on life-support-system environments for human crews.

TECHNOLOGY

The FSB Technology Program integrates, miniaturizes, and adapts technologies available in the commercial sector to produce small, self-contained systems suitable for use in space. The focus of the program is driven by FSB's research requirements, descriptions and examples of which follow:

Sample Management Advanced, integrated technologies are essential in the development of automated experiment systems for sample management, manipulation, and preservation.



- Microfabricated platforms
- Microfluidic networks
- Modular, miniaturized freezers

Bioanalytical Systems Precise and reliable multiparameter bioanalytical technology is required to generate accurate physical and biological data while maintaining experiment integrity.

- In situ cell-flow cytometry and spectrophotometry
- DNA array chips
- Automated gene sequencing

Imaging Automated microscopy and advanced imaging systems permit analysis across the molecular, cellular, and physiological levels.

- Photonics
- Fluorescent microscopy
- Multi-spectral imaging

In Situ Monitoring and Control Integrated organism and environmental monitoring permits the development of self-sustaining and auto-correcting habitats.

- Biosensors
- Digital video imaging

Data Management Capabilities for automated acquisition, processing, communication, archiving, and retrieval of data support remote telescience applications.

- Telemetry systems
- High-speed data downlinks

RESEARCH FACILITIES AND HARDWARE

FSB uses multiple flight and ground research platforms and facilities to study life in space and the effects of gravity on living systems.

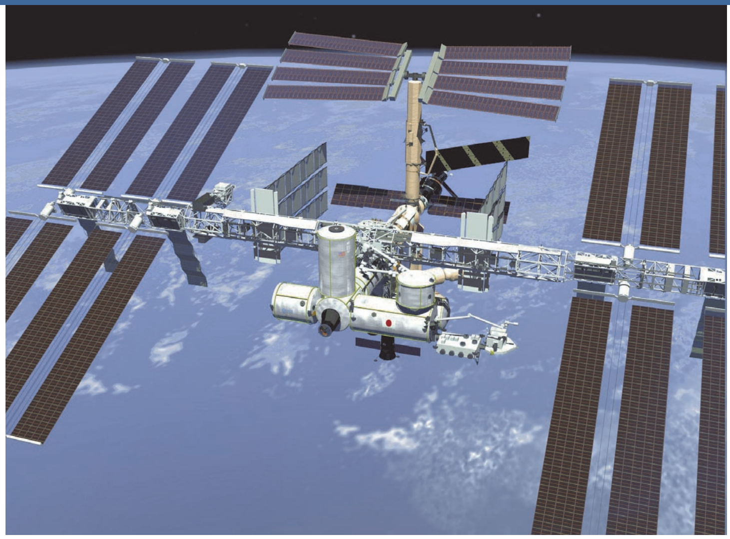
FLIGHT

Space Shuttle/Space Transportation System

For more than 20 years, the Space Shuttle has been used as a platform for conducting fundamental space biology research and for transporting experiments to the Mir space station and, recently, to the International Space Station (ISS). Some experiments have required significant crew interaction, such as in-flight tissue dissections and fixations, while others have been much more automated. In the years 2000-2002, most Shuttle missions were assembly flights, with the objective of transporting elements for the construction of the ISS. Several secondary payloads included FSB experiments.

International Space Station

The ISS provides a continuous on-orbit platform for microgravity experiments. It will enable fundamental biology research never before conducted in space, including multigenerational studies and variable gravity habitation for cell, plant, and animal research subjects. Due to reduction of crew size and delays in construction and hardware development, the ISS is not yet operating at full capability. FSB has been working with OBPR and the science community to define research objectives and science and technology requirements for conducting experiments on the ISS over the next few years, with these minimized capabilities in mind.



The International Space Station makes possible Fundamental Space Biology research never before conducted in space.

Space Station Biological Research Project

The Space Station Biological Research Project is responsible for the development of a space station variable-gravity research facility called the Centrifuge Accommodation Module (CAM). Developed by the Japanese space agency, under FSB/SSBRP management oversight, the CAM provides artificial gravity, life support, and monitoring for animal, plant, insect, and cell research subjects on a variable-speed 2.5-m diameter centrifuge.

The CAM will accommodate the study of:

- long-duration, single, and multigeneration life cycles
- adaptation to various g levels (0.1 to 2.0 g) and other controlled environments
- on-orbit 1 g controls and reconditioning to 1 g after adaptation to micro-g
- a statistically significant number of samples by accommodating multiple habitats.

In addition to the centrifuge, the CAM will be outfitted with several habitat types to support a variety of organisms, a holding rack to house specimens at microgravity, and a fully equipped workstation/glovebox so that the crew can conduct experiment procedures in containment.

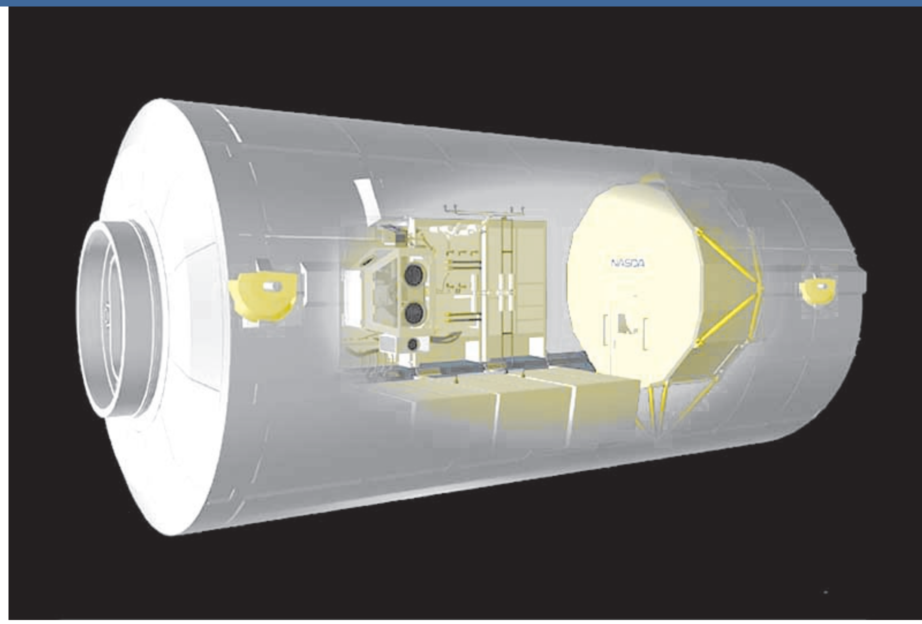
GROUND

Life Sciences Support Facility/Hangar L

Hangar L at Kennedy Space Center (KSC) supports life sciences flight experiments and ongoing research in Controlled Ecological Life Support Systems. Hangar L has accommodations and lab space for specimen holding and handling of aquatic animals, small mammals, plants, cells, tissues, and microorganisms. The facility also contains limited areas for surgery, X-ray, data management, synchronous ground control experiments, and flight-experiment monitoring.

Space Life Sciences Labarotory

The Space Life Sciences Laboratory (SLS Lab) will be a new research facility at KSC's International Space Research Park, developed in partnership with the state of Florida. This 100,000-square-foot lab will host NASA, NASA life sciences services contractors, and University of Florida researchers. The Office of Biological and Physical Research will use the facility to process life sciences experiments that will be conducted aboard the ISS and ground-based investigations in fundamental and applied biological sciences. The SLS Lab will open in Summer 2003 and replace Hangar L.



The Centrifuge Accommodation Module will host gravitational biology investigations on board the International Space Station. The 2.5-m-diameter centrifuge allows for experimentation at various g levels.

Center for Gravitational Biology Research

The Center for Gravitational Biology Research at Ames Research Center (ARC) hosts facilities that allow experiments with cells, animals, and humans, for flight simulation and non-flight related studies. Facilities include 10 acceleration and hyper-g systems of various types and a human flight simulation (bed-rest) research area.

Animal Care Facility

The Animal Care Facility (ACF) at ARC supports the care, housing, testing, and surgery of animals. The ACF is accredited by the Association for Assessment and Accreditation of Laboratory Animal Care and all animals are housed according to the National Research Council Guide for the Care and Use of Laboratory Animals. Review of all NASA-managed animal experiments is conducted by an Animal Care and Use Committee.

KC-135 Reduced Gravity Research Program

The Reduced Gravity Research Program at Johnson Space Center enables NASA FSB staff and investigators to carry out studies and hardware testing in a spaceflight environment, but at reduced cost and effort. The program's KC-135 aircraft simulates periods of microgravity for seconds at a time during each parabolic flight trajectory.

BioVIS Technology Center

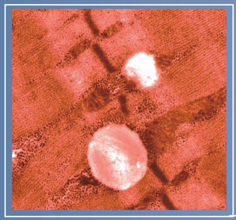
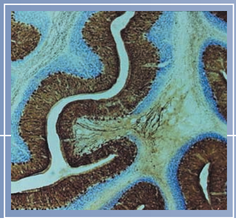
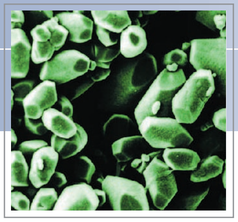
The BioVIS Technology Center at ARC is dedicated to the development and application of advanced visualization, computation, and simulation technologies, supporting NASA's space life sciences research. Continuing studies range from biomedical and clinical applications to scientific imaging, 3-D cell-structure analysis, and astrobiology. The center offers serial-section tissue reconstruction software to interested investigators.

Center for Astrobioinformatics

The Center for Astrobioinformatics, located at ARC, promotes the use of modern genomics analysis applied to problems involving, but not limited to, the origins of life, gravitational biology, ecosystem dynamics, the biology of spaceflight, and life in extreme environments. These areas are of particular interest to NASA because they support research goals for both crewed and uncrewed missions.

ACCOMPLISHMENTS

IN RECENT YEARS, Fundamental Space Biology has built upon the achievements of the past and furthered our understanding of life processes in space. This work has benefits outside of NASA. FSB research has led to Earth-based applications, and education and outreach efforts have imparted the excitement of discovery to the public.

WHAT HAVE WE DISCOVERED SO FAR?

For several decades, NASA's Fundamental Space Biology Program and its predecessors have conducted significant scientific and technological research.

This research characterizes a broad spectrum of biological effects associated with spaceflight. Many physiological systems are affected, from changes in cardiovascular, metabolic, and immune function, to altered development, motor skills, and musculoskeletal integrity. Examples of discoveries are provided below.

ANIMAL RESEARCH

Bone and Muscle Physiology

The absence of weight-bearing activity in microgravity has proven detrimental to the formation, function, and repair of bones and muscles. In rats, bone growth is suppressed, with the repair of bone fractures impaired as seen postflight, and, more important, no indication that non-weight-bearing bones repair in space. At the cellular level, bone-forming cells exposed to microgravity show changes in surface structure, as well as weakened attachment and mineral production.

In space, tendons, ligaments, and muscles are also weakened and show impaired attachment and repair. In rats, muscles atrophy causes a decrease in endurance, while in both rats and monkeys the microgravity environment contributes to structural changes and immediate and dramatic atrophy in all muscles needed for moving and standing. Countermeasure experiments demonstrate that resistive exercise reduces bone and muscle degeneration. Ground-based experiments in rats suggest hormone treatment may also be beneficial.

Cardiovascular and Hematology

Experiments on rats reveal cardiac muscle mass and volume are reduced in space. In monkeys, significant cardiovascular changes occur, including increased blood pressure and decreased heart rate and blood flow. In addition to physiological changes, studies show that enhanced programmed cell death results in a reduced red blood cell count. These findings suggest cardiovascular deconditioning and anemia are potential dangers in space.

Development

Spaceflight exerts contrasting effects on developing organisms. Chicken embryonic development is affected, but no significant changes are seen in the ovulation, fertilization, and development in frogs. Pregnant rats deliver pups postflight that appear normal but show impaired orientation, suggesting gestation in space affects development of the gravity-sensing vestibular system. Also observed in rats are a number of hormonal changes, including impaired release of growth hormone, possibly related to changes in muscle activity, and reduced testosterone levels.

Gravity-Sensing/Vestibular System

Monkeys exhibit impaired eye-hand coordination and gravity-sensing processes in response to microgravity. However, studies in rats reveal how remarkably they adapt to the altered gravity environment, suggesting a high degree of neuronal plasticity. The effects of space on other organisms include changes in the formation of gravity-sensing crystals in jellyfish.

Immunology and Metabolism

Studies of rats and monkeys in space demonstrate impairments to various elements of the immune system. These include decreased interferon production in the spleen and a smaller thymus gland, as well as altered white cell distribution and activity. Metabolic functions are also altered in

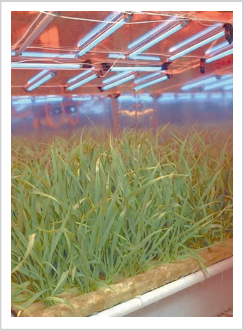
MAJOR BIOLOGICAL EFFECTS OF SPACEFLIGHT DISCOVERED FROM ANIMAL RESEARCH					
			SIGNIFICANCE		
Effects	**Organisms**	**Missions**	**Astronaut Health**	**Life on Earth**	**Countermeasures**
Loss of bone density and impaired healing	Rat Rhesus monkey	Rat/Bion Rat/SLS-2 Rat/IML-1 Rhesus/Bion	Increased risk of fracture with reduced repair capabilities	Relevant to understanding bone formation, growth and healing Useful for treatment of disuse osteoporosis	Weight-bearing activity Artificial gravity Dietary changes/ supplements
Muscle atrophy, reduced musculoskeletal attachment, and impaired healing	Rat Rhesus monkey	Rat/SLS-1, 2 & 3 Rat Bion Rhesus/Bion Rat/Pare 2	Increased risk of musculoskeletal rupture with reduced capabilities Decreased physical endurance	Important for understanding the basic principles of muscle differentiation, endurance and repair Relevant to the treatment of disuse atrophy	Resistance exercise Hormone treatment
Cardiovascular deconditioning	Rat Rhesus & pig-tailed monkey	Rat/Bion Rhesus/Bion Pig-tailed monkey/Biosat III	Decreased cardiac performance, reduced physical capacity, risk of heart failure	Relevant to understanding and treatment of cardiovascular disease	Anti-G suit/cooling garment (entry & landing) Exercise
Altered development	Chicken Rat Frog	Chick/SSIP Rat/NIH.R1 Frog/SL-J Rat/Bion Rat/SLS-2 & 3	Risks across multiple generations	Relevant to sensitivities of embryonic development	Artificial gravity
Altered gravity sensing	Rat Rhesus monkey Jellyfish	Rat/SL-3 Rhesus/Bion Jellyfish/SLS-1 IML-2 Rat/SLS-1 & 2	Susceptibility to space motion sickness Altered distance perception, orientation, and visual tracking	Imporant to the study and treatment of vestibular dysfunction (Meniere's disease, vertigo)	Treadmill exercise Artificial gravity Medication
Immune suppression	Rat Rhesus monkey	Rat/Bion Rat/SL-3 Rhesus/Bion	Increased susceptibility to infection	Useful for the study and treatment of immunodeficiency, infection, and tumor formation	Artificial gravity
Altered metabolism	Rat Rhesus monkey	Rat/Bion Rat/SL-3 Rhesus/Bion Fruit fly /Bion	Metabolic dysfunction	Relevant to the study and treatment of metabolic dysfunction	Artificial gravity

Major biological effects of spaceflight and their significance for astronaut health, life on Earth, and human countermeasures, identified through FSB animal research.

a variety of organisms. Skin and body temperature, and metabolic rate are all reduced in monkeys, while rats show reductions in enzyme concentrations and cholesterol levels.

PLANT RESEARCH

The same qualities that make plants essential to life on Earth—food production, absorption of carbon dioxide, and release of oxygen and water vapor—make them highly desirable on long-term human space missions. As a result, research on growing plants in space has become well established. Early experiments focused on growth through complete life cycles, but were mostly unsuccessful as plants did not seem to produce seeds in space. Only in the late 1990s did biologists finally achieve seed-to-seed plant growth —using *Brassica rapa* on board the Mir space station—crucially proving that gravity is not an absolute requirement for plant reproduction. At around the same time, experiments using arabidopsis generated insights into the way plants sense gravity as they grow. By using the space environment to show that starch-deficient plants have a weakened response to gravity compared with normal plants, researchers generated important data supporting the century-old starch-statolith theory of gravity perception, which proposes that plants sense gravity at the cellular level through the interaction of dense organelles (termed statoliths) with other cytoplasmic structures. More recently, biologists have begun to characterize plant responses to gravity on the genetic level, identifying two genes thought to be involved in signal transduction and transport of the growth chemical auxin. These studies have established a clear potential for growing plants in space, while contributing to our basic understanding of plant development and benefiting agricultural research on Earth.

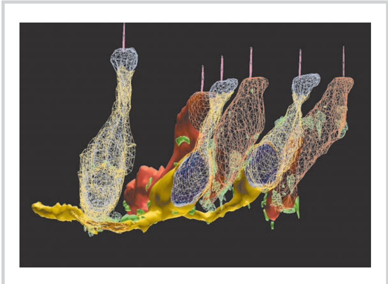


Plants grow in a wheat chamber in a ground-based lab.

TECHNOLOGY

Space biology has driven numerous advances and breakthroughs in technology, many of which have found widespread application on Earth. For example, in the 1970s micro-electro-mechanical systems (MEMS) were developed at Stanford University with funding from NASA Ames Research Center. The goal was to miniaturize biological research instrumentation components for space exploration. This led to the invention of the first microminiaturized acceleration sensors designed to be mounted on the wall of the heart to monitor mammalian cardiac contraction in space. These devices defined the MEMS field and have since been used in numerous applications, including pacemakers, navigation systems, and automobile crash sensors. In the 1980s, biovisualization software was created to analyze vestibular adaptation of rats to space, by generating three-dimensional images from a series of electron microscope pictures. The software is now widely used in surgical training to create virtual simulations of complex procedures. More recently, implantable biosensors developed for biological monitoring in space have found medical applications in the Fetal Biotelemetry System, which was designed to remotely monitor, display, and store physiological data on developing fetuses to quickly detect potential abnormalities.

Biovisualization software creates three-dimensional images for analysis.



RESEARCH HIGHLIGHTS

GRAVITY REQUIRED FOR NORMAL VESTIBULAR DEVELOPMENT

Using zebra fish in an environment designed to remove the effects of gravity, investigator **Stephen Moorman's** FSB-sponsored research has shown that a time period exists during which the vestibular system must receive a normal gravitational stimulus for proper development to occur. As with other sensory systems, absence of the stimulus during this critical period results in permanent functional deficits.

Zebra fish were used in studies showing the first evidence for a critical period for the development of the vestibular system.

Studying the development of the vestibular system is a priority for NASA. From a basic research standpoint, it sheds light on the developmental and evolutionary relationships between gravity and life. From a practical standpoint, it helps us better understand and perhaps counteract the effects of living, working, and even growing up in the absence of normal gravity. Identifying critical periods in vestibular development is a key step in addressing these issues.

To simulate microgravity on the ground, where Moorman conducted his research, he used a bioreactor, a NASA-developed instrument that rotates cells in a solution, thereby modeling microgravity. By putting zebra fish embryos in the bioreactor, Moorman was able to expose them to very small magnitude net forces that continually changed direction. This effectively put the embryos in a condition of no net gravitational force. After the zebra fish matured, Moorman's team tested them for functional deficits.

Results showed that when zebra fish are deprived of a stable gravitational force during only 24 to 72 hours after fertilization, they exhibit significant, long-lasting functional deficits in their vestibular apparatus. These results provide the first specific evidence for a critical period for the vestibular system.

CURRENT ACCOMPLISHMENTS

SCIENCE

The challenge undertaken by Fundamental Space Biology in recent years has been to exploit scientific advances to understand and build upon existing data. During 2000-2002, advances in cell and molecular biology have allowed many of the basic mechanisms underlying the known physiological, developmental, and sensory effects of the space environment to be studied in detail. In addition, great strides have been made in the fields of comparative and evolutionary biology, driven by the complete genome sequencing of a broad spectrum of organisms, including humans.

Grant Research

FSB flight and ground research during 2000-2002 was funded across five research elements: Molecular Structures and Physical Interactions, Cell and Molecular Biology, Developmental Biology, Organismal and Comparative Biology, and Evolutionary Biology. No projects were funded in Gravitational Ecology.

The projects in **Molecular Structures and Physical Interactions** contributed to our understanding of the mechanisms by which cells sense and respond to gravity, the effects of microgravity on vascular function and on protein-ligand interactions, and how bacteria proliferate and respond to antibiotics in a space environment.

In the **Cellular and Molecular Biology** element, projects advanced knowledge of gravitational effects on gene expression, signal transduction, cell cycle, cell structure and function, and bone formation. Investigations looked across a variety of species, including plants, bacteria, rodents, and fruit flies.

Developmental Biology studies involving a variety of organisms, such as rodents, insects, quail, chickens, fish, and plants, focused on development of vestibular, immune, skeletal, neuromuscular, motor, neural systems and circadian rhythms; embryonic development; fetal-maternal relationships, cell proliferation, and seed development.

Organismal and Comparative Biology experiments further clarified gravitational effects on the development and function of vestibular systems, bone formation, muscle atrophy, signal transduction, energy expenditure, cells, bacterial and microbial virulence, and gene expression. Plant research included studies of phototropism, gravitropism, seed development and maturation, and root growth.

The projects in **Evolutionary Biology** investigated the effects of microgravity on biofilm bacteria, the structural evolution of organisms, the precursors of vertebrate neurophysiology, the origins of gravitational detection in multicellular organisms, and the evolution of plants. Species studied included microorganisms, aquatic organisms, and plants.

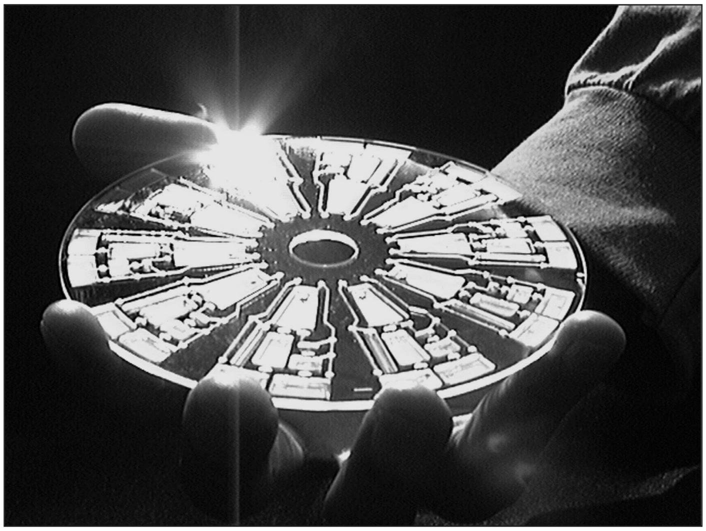
Other Funded Research

The NASA Astrobiology Institute (NAI) sponsors research projects that span topics across Astrobiology and include areas relevant to Fundamental Space Biology. As a contributor to NAI's annual budget, FSB supports this research. NAI projects that contribute to the Astrobiology objective, "Bringing Life with Us Beyond Earth," have been selected as serving FSB goals. FSB cosponsors Principal Investigator Catherine Conley's project, *The Effect of Reducing Gravity on* Caenorhabditis elegans.

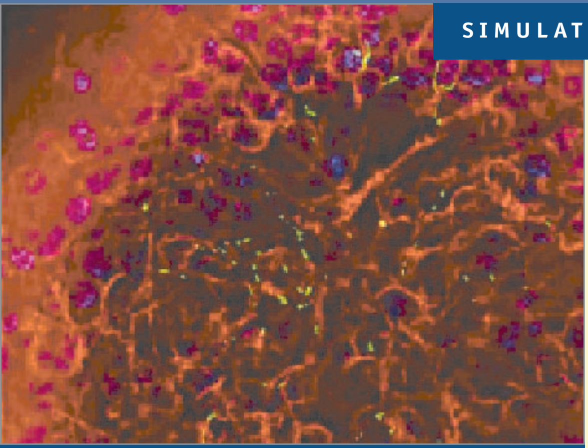
Other FSB-related projects include:

- *Life Beyond the Planet of Origin* (PI: Lynn Rothschild)
- *Self-Reproducing Molecular Systems and Darwinian Chemistry* (PI: Steven Benner; Andrew Ellington)
- *Self-Reproducing Molecular Systems and Darwinian Chemistry* (PI: Andrew Ellington)
- *Isotopic and Molecular Tracers of Life* (PIs: George Cody, Marilyn Fogel, Douglas Rumble, and Andrew Steele)
- *Genomic and Proteomic Analysis of Permafrost Bacteria* (PIs: Michael Thomashow and James Tiedje)
- *Bacterial Adaptation to Low Temperatures* (PIs: Albert Bennet and Richard Lenski).

FSB's Technology element develops emerging microanalytical systems like the Lab CD.



SIMULATED MICROGRAVITY INCREASES VIRULENCE OF A COMMON PATHOGEN



Epifluorescent microscopy image of 3-D human intestinal tissue (stained in red) infected with *Salmonella typhimurium* (stained in green).

FSB funded scientists, using technology developed by NASA engineers, have found that simulated microgravity increases the virulence of the common bacterial pathogen *Salmonella typhimurium*. Using the same technology, the researchers also developed an improved model of human intestinal tissue for studying how salmonella causes disease. This work is laying the scientific foundations for the development of new drugs and vaccines to treat and prevent salmonella infections.

Numerous studies have shown that spaceflight weakens the immune system, making astronauts more susceptible to disease. But no published research had examined the effect of microgravity on the disease-causing potential of microbes.

Salmonella is the leading cause of an estimated 2 to 4 million cases of gastrointestinal illness each year in the U.S. Although rarely fatal on Earth, salmonella infections could be disastrous in space, with the potential to endanger crew and disrupt missions at the cost of millions of dollars.

To simulate spaceflight, researchers used a bioreactor known as a Rotating Wall Vessel (RWV), developed at NASA Johnson Space Center for the Bioastronautics Program. The bioreactor balances the force of gravity using equal and opposite forces, such as turbulence. Lead researcher **Cheryl Nickerson** and her colleagues cultured salmonella cells both in the RWV and under normal gravity conditions, and then infected two groups of mice. Mice infected with the microbes cultured under simulated microgravity died three days earlier than the control mice. Investigators also found larger numbers of the microbes cultured in simulated microgravity in the livers and spleens of the experimental mice, indicating that simulated microgravity enhances the virulence of *S. typhimurium*.

Other significant differences in physiology and patterns of gene expression were also observed in the microbes cultured in simulated microgravity compared with those in normal gravity. Results will ultimately provide insights into the molecular basis of salmonella virulence.

TECHNOLOGY

The Technology element of FSB, managed by AstroBionics, focused on researching the kinds of technologies appropriate for use in supporting FSB investigations. Technology areas under evaluation were sample management, bioanalysis, advanced imaging systems, in situ monitoring and control, and data management systems.

Also, AstroBionics established a seminar series in which speakers were invited to introduce various technological topics to FSB Program management. Examples of key technology accomplishments are given below.

In the **Advanced Technology Development** area, grant recipient Sylvia Daunert developed a microanalytical system, based on compact disc technology. The format integrates in-flight characterization and monitoring of cells and simple organisms, microfluidic sample management and handling, and data acquisition. With colleagues Marc Madou and James Lee, Daunert created the lab CD by incorporating biomimetic principles and molecular biology signature detectors as well as more traditional sensors that meet requirements of FSB experiments.

NASA Ames Research Center partnered with Stanford University to develop the BioExplorer I, the first in a series of small, autonomous spacecraft containing integrated, miniaturized biolabs to serve as research and technology test beds. BioExplorer I is just 10 cm x 20 cm x 30 cm in size, weighs less than 6 kg, and contains a biology module, sensor and control electronics, a video system, and a number of environmental sensors. Initially, the BioExplorer missions will enable researchers to perform autonomous cell-culture-based biological experiments, but they are ultimately intended to drive the development, of small free-flying orbital spacecraft to support peer-reviewed, PI-led science missions.

INTERNATIONAL SPACE STATION

The International Space Station (ISS) became operational in 2000, opening the doors to a host of novel gravitational biology research opportunities with facilities developed under the management of the Space Station Biological Research Project (SSBRP).

Development of the Centrifuge Accommodation Module, the Glovebox, six habitat types supporting various organisms, habitat holding racks, and a variety of laboratory support equipment continued during 2000-2002.

In 2001, the Avian Development Facility was the first SSBRP habitat to fly, followed by the Biomass Production System in 2002. The successful operation of both of these habitats was a significant accomplishment for SSBRP and FSB.

Reduced funding has caused delays in ISS construction and hardware development, limiting the opportunities for FSB research during 2000-2002 and in the future. To explore the type of science that could be enabled over the next five years, FSB management and the research community participated together in the "Space Biology on the Early Space Station Workshop," conducted at ARC in March 2002.

MISSIONS

FSB participated in four missions flown between 2000-2002. Three of these missions conducted FSB experiments entirely on the Shuttle, a key element of the Space Transportation System (STS), and the fourth brought an FSB experiment via the Shuttle to the ISS.

STS-101

On the STS-101 mission, launched on May 19, 2000, Kennedy Space Center flew the Biotube Precursor Experiment. The experiment tested the newly developed technologies involved in the BioTube Magnetic Field Apparatus, a device for growing seeds in microgravity, targeted to be flown on STS-107. The research was designed to evaluate the water delivery system and seed germination substrates of the apparatus.

STS-106

This mission, launched on September 8, 2000, carried two FSB experiments. In a reflight of an experiment flown on STS-93, investigator Haig Keshishian examined the effects of spaceflight on nervous system development in *Drosophila melanogaster* (the fruit fly), which is a model organism. A specially developed transgenic drosophila line, in which the central nervous system expresses Green Fluorescent Protein, was used as a test specimen.

The second experiment was a follow-up to an STS-90 investigation, in which investigator Timothy Hammond discovered that microgravity causes large-scale alterations in kidney-cell genes. The goal of the STS-106 study was to examine how microgravity alters the gene expression in kidney cells that ultimately enables the kidney to develop and function normally. The experiment was supported by OBPR's Physical Sciences and Mission Integration divisions, in addition to Fundamental Space Biology.

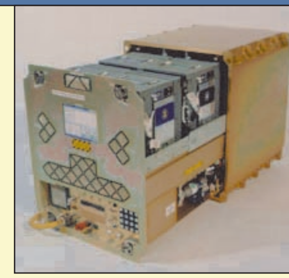
The hardware flown in support of the

One quail egg fits into each of the Egg Holders of the Avian Development Facility.

ACCOMPLISHMENTS

RESEARCH HIGHLIGHTS

BIOMASS PRODUCTION SYSTEM PRODUCES EXTENSIVE DATA



Apogee wheat grows in the Biomass Production System on the International Space Station, generating a wealth of plant growth and photosynthesis data.

Understanding plant growth in space is crucial to future long-term missions. Plants are a potential food source for the astronauts, as animal products will be minimally available. By generating oxygen, removing carbon dioxide, and purifying water, living plants could help maintain a proper spacecraft atmosphere, and reduce the costs of air and water resupply on long-duration missions.

The Biomass Production System (BPS) is a plant-growth hardware system, which performed successfully on board the International Space Station (ISS) from April 8 to June 19, 2002. The BPS is an engineering development unit for a future ISS plant habitat that will be capable of supporting long-term plant growth and botanical experimentation in space.

During its employment on the ISS, the BPS supported a technology validation test and two plant experiments funded by Fundamental Space Biology. Investigator Robert Morrow, of Orbital Technologies, used *Brassica rapa* seedlings to test the growth of a developmentally complex plant. FSB Investigator **Gary Stutte**, of Dynamac Corp. studied the growth, photosynthesis, gas exchange, and metabolism of Apogee wheat in microgravity. More plant growth and photosynthesis data were collected from this single flight payload than from any other to date.

The BPS was developed for NASA's Space Station Biological Research Project by Orbital Technologies Corp., Madison, Wisconsin

two experiments was the Commercial Generic Bioprocessing Apparatus, developed by BioServe (a NASA-sponsored Commercial Space Center).

STS-108

STS-108 flew on December 5, 2001, carrying two FSB experiments in the Avian Development Facility (ADF). Developed by Space Hardware Optimization Technology Inc. for SSBRP, the ADF is an automated avian egg incubator designed for Japanese quail eggs. The primary objective of the payload was to validate the hardware subsystems and reduce the risk in developing the next generation of avian development hardware, the Egg Incubator. Both experiments researched how the lack of gravity affects the development of avian embryos. Investigator Stephan Doty studied the effects of spaceflight on embryonic skeletal development, while investigator David Dickman researched the development and function of the avian vestibular system.

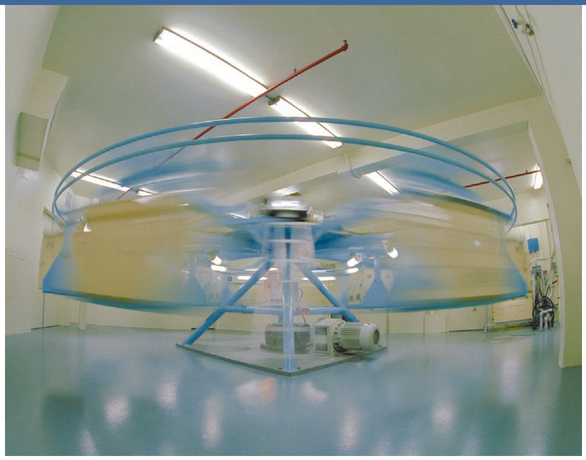
STS-110

On April 8, 2002, STS-110 delivered the Biomass Production System (BPS) and the FSB-supported Photosynthesis Experiment and System Testing Operation (PESTO) to the ISS. The BPS, developed by Orbital Technologies, was designed to support the continued growth and development of plant specimens and to provide the capabilities necessary to perform scientific investigations. The primary objective of the payload was a technology validation test, intended to evaluate hardware performance in order to select subsystems ideal for the design and development of a permanent plant research unit for the ISS. In the PESTO experiment, investigator Gary Stutte studied the effects of microgravity on photosynthesis and metabolism in wheat plants.

GRAVITATIONAL BIOLOGY FACILITIES

In 2000-2002, the Center for Gravitational Biology Research (CGBR) at Ames Research Center hosted 40 ground-based hypergravity projects conducted by principal investigators—many funded directly by FSB. These included studying the effects of hypergravity on zebra fish development, growth of bone cell cultures, gene expression in nematode worms, and the maternal-fetal system in rats. Several non-FSB funded studies addressed questions of fundamental biology closely related to FSB goals. These projects made full use of CGBR facilities and contributed to several peer-reviewed publications on the biological impacts of hypergravity and acceleration across different cells, tissues, and organisms.

Several key upgrades to CGBR facilities were completed during this period, including enhancement of safety, stability, and control systems, and completion of the ISS Test Bed Centrifuge, which will be used to develop and refine flight experiment protocols before transition to the ISS.



The 24-foot-diameter centrifuge (spinning) is one of the Center for Gravitational Biology Research facilities.

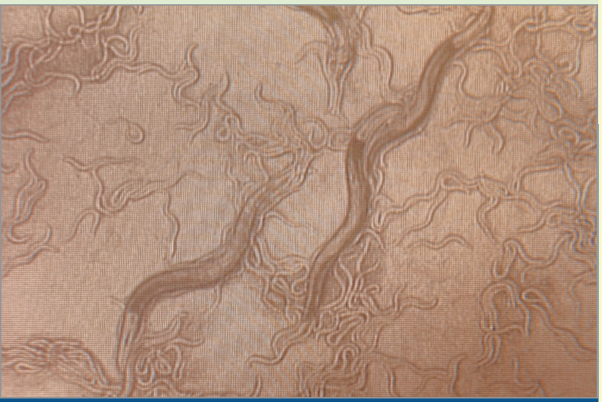
One of CGBR's largest facilities, the 20-g centrifuge, has been used extensively in pioneering human research conducted by Malcolm Cohen, chief of the Human Information Processing Research Branch at NASA ARC. Cohen recruited human volunteers—from teachers to mountain climbers—to spend up to 22 hours in the centrifuge at gravitational forces up to 2 g. The experiments generated valuable data on the effects of hypergravity on human physiology, and provided important insights into the potential benefits of artificial gravity in countering the effects of the space environment.

COMPLETED CGBR STUDIES 2000–2002

FACILITY	2000	2001	2002	TOTAL
24-Foot-Diameter Centrifuge	6	4	1	11
1-Foot-Diameter Centrifuge	2	4	3	9
20 G Centrifuge	1	2	3	6
Human-Powered Centrifuge	1	0	0	1
Low Vibration Rotation Device/ Hypergravity Facility for Cell Culture	1	2	2	5
30-Foot Linear Sled	1	2	1	4
Programmable Linear Sled	1	1	1	3
Multi-Axis Centrifuge	1	0	1	2
TOTAL	**14**	**15**	**12**	**41**

Studies conducted in the Center for Gravitational Biology Research facilities.

WORMS IN SPACE: HYPERGRAVITY ALTERS GENE EXPRESSION IN C. ELEGANS



Caenorhabditis elegans **worms exposed to hypergravity exhibited changes in gene expression that seemed to help them adapt to their changed conditions.**

By spinning tiny worms (*Caenorhabditis elegans*, a soil-dwelling nematode) on a centrifuge at 20-100 times Earth's gravity for as long as four days, scientists at Ames Research Center were able to examine how worms respond to altered gravity at the genomic level. By subjecting the worms to these high gravitational forces (hypergravity), FSB-sponsored investigator **Catherine Conley** hopes to make predictions about the kinds of changes that will occur when the worms are exposed to microgravity (hypogravity) conditions during spaceflight. Understanding gained from these studies may contribute to the development of better countermeasures for long-duration spaceflight in humans.

The hypergravity experiment was conducted in March 2001 on the 20-g centrifuge, a Center for Gravitational Biology Research facility at Ames. This experiment marked the first time the centrifuge ran for 96 hours continuously at level of 15 g, a milestone for the facility.

With support provided by the NASA Astrobiology Institute, Conley was able to observe the spinning worms using a video system designed and constructed by students at Harvey Mudd College in Claremont, California.

Conley discovered that during spinning, there are changes in the gene expression of the worms that seem to help them compensate for the increased apparent gravity.

The next step is to test the gene expression in worms that have flown in space versus those that have not. Future studies with *C. elegans* will also look at the hypothesis that spaceflight accelerates the aging process.

AWARDS AND SPECIAL RECOGNITION

Grantee Awards

A.M. Anterola
Graduate Student Award, Cellulose, Paper, and Textile Division of the American Chemical Society, 2000.

Sylvia Daunert
Arthur F. Findeis Award, Division of Analytical Chemistry, American Chemical Society, 2001.

Michael L. Evans
Founders Award for Distinguished Career Research in Gravitational Biology, American Society for Gravitational and Space Biology, 2001.

Kathryn L. Eward
Pfizer Foundation Fellowship Award to defray expenses to present research at Keystone conference, "Genomics and Genetics of Senescence and Cancer," 2002.

Donald Ingber
MIT Bioengineering Society Distinguished Lecture, 2002
Broadhurst Distinguished Lecture, Schepens Eye Research Institute, 2002.

Anna Lysakowski
Awarded to A. Chu, Graduate Student. Intel Science Talent Search Semifinalist, 2001.

Larry McIntire
Elected to National Academy of Engineering, 2001
Editor, *Annals of Biomedical Engineering*, 2001.

Antonios G. Mikos
Clemson Award for Contributions to the Literature, Society for Biomaterials, 2001.

Gloria K. Muday
Thora Halstead Young Investigator Award, American Society of Gravitational and Space Biology, 1999.

Cheryl A. Nickerson
Charles C. Randall Lectureship Award for Outstanding Young Faculty Member, South Central Branch ASM Meeting, 2000.

David William Niesel
Awarded to C. Orihuelam, Graduate Student. Texas Space Grant Consortium Scholarship, 2000-2001, 2001-2002.

William Rhoten
Alumni Profile, Penn State Medicine, Winter, 2001.

Gary Stutte
Chair, Controlled Environment Working Group, American Society for Horticultural Sciences, 2001-2002.

Grantee Patents

Christopher S. Brown
U.S. Patent Application No. 09/844,006, April 27, 2001. Wyatt, S.E., P.-L. Tsou, P.-L., Boss, W. F., and Robertson, D. "Transgenic Plants with Increased Calcium Stores."

Norman G. Lewis
U.S. Patent No. 6,210,942, April 3, 2001. Lewis, N.G., Davin, L.B., Dinkova-Kostova, A.T., Fujita, M., Gang, D.R., and Sarkanen, S. "Recombinant Pinoresinol/Lariciresinol Reductase, Recombinant Dirigent Protein, and Methods of Use."

Larry McIntire
U.S. Patent Pending, 2002, McIntire, L.V., Hssk, M. and McDevitt, D. "Methods for Inhibiting Platelet Aggregation and Thrombosis."

Antonios G. Mikos
U.S. Patent No. 6,306,821, October 23, 2001. Mikos, A. and Jo, S., "Functionalized Poly (Propylene Fumarate) and Poly (Propylene Fumarate-co-Ethylene Glycol)."

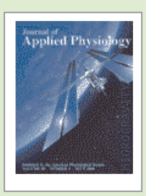
D. James Morre
U.S. Patent No. 6,361,961, March 26, 2002. Morre, D. J. "Gravity Responsive NADH Oxidase of the Plasma Membrane."

Cheryl A. Nickerson
U.S. Patent Pending, 2002. Hammond, T. and Nickerson, C.A. "Methods for modeling infectious disease and chemosensitivity in cultured cells and tissues."

Joseph Tash
U.S. Patent No. 6,309,815, October 30, 2001, Tash, J. and Bracco, G. "Composition and Method for Preparation, Storage, and Activation of Large Populations of Immotile Sperm."

FEATURED PUBLICATIONS

Numerous publications result from grantee research funded by FSB. Over 700 articles were published in peer-reviewed journals by investigators funded in 2000-2002. Some of these articles were featured on covers of journals published in that time period, as shown below.

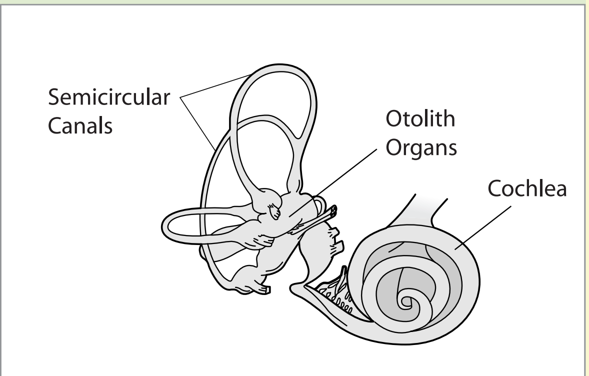


Highlighted Topics Series: Physiology of a Microgravity Environment. FSB PIs contributed to the 19 OBPR PI papers presented herein. *Journal of Applied Physiology*, 2000 Jul-Sept; 89 (1-3).

Special issue on Plants and Gravity, exploring the effects of gravity on plant growth and development from the different perspectives of ground-based research at 1 g or spaceflight research. The issue contains six PI papers and four other related papers. The cover graphic is most closely associated with: E.B. Blancaflor: "The Cytoskeleton and Gravitropism in Higher Plants." *Journal of Plant Growth Regulation* 2002 Jun; 21(2): 69-190.

FSB PI: Elison B. Blancaflor

HOW THE BRAIN DETECTS GRAVITY



The otolith organs and the semicircular canals, both located in the inner ear, make up the vestibular system. The brain may use signals from both to sense gravity.

The human brain quickly adapts to major changes in the environment, even to the absence of gravity. Yet exactly how the brain senses and processes gravity (or the absence thereof) remains a mystery. FSB investigator **Dora Angelaki** is providing new insight into this question by studying how the brain distinguishes gravity from head and body movements using nonhuman primates. Her work suggests that the brain senses gravity by integrating signals from two different sets of balance organs, an idea known as multisensory convergence.

The two sets of balance organs that make up the vestibular system—the structures that allow us to balance on two feet and orient ourselves in the world—are the semicircular canals and the otolith organs, both found in the inner ear. The semicircular canals sense angular movements, such as head nodding; the otolith organs provide signals about the position of the head relative to gravity (such as the up-and-down motion of jogging) or movements along a straight line (accelerating in a car, for instance). The conventional view has been that these two sets of organs operate independently. However, it was not understood how the brain distinguishes linear movements from changes with respect to gravity, since the effect on the otolith organs is physically the same.

According to the multisensory convergence hypothesis, the brain uses signals from both the otolith organs and the semicircular canals to sense gravity. Testing this hypothesis on Earth is difficult, since gravity is a constant, and because it is hard to isolate the different types of movement outside of controlled laboratory conditions. This project was the first experimental test of the multisensory convergence hypothesis.

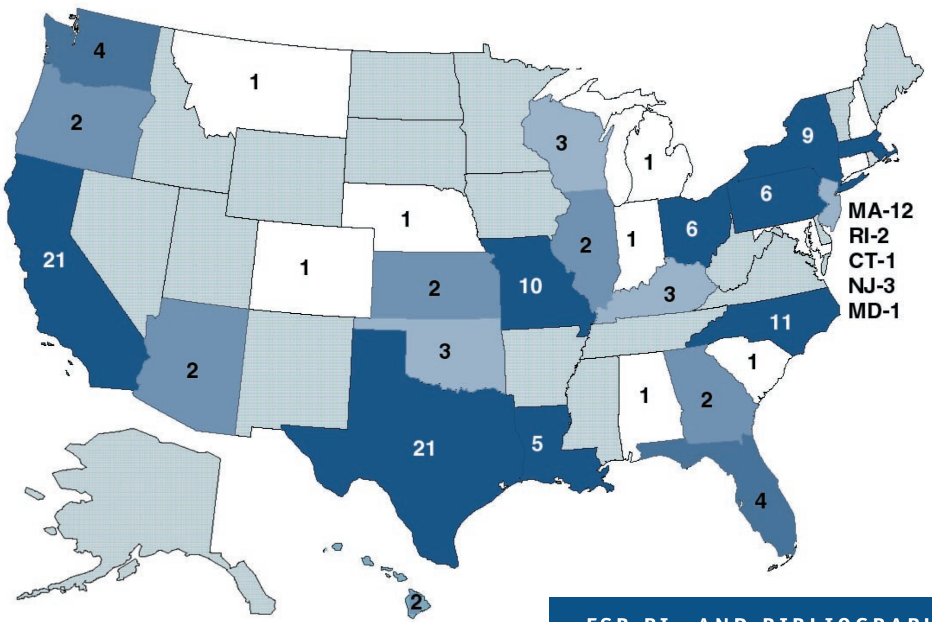
The test subjects were rhesus monkeys wearing specially designed contact lenses that measured their reflexive eye movements, a method that allows researchers to indirectly measure signals from the vestibular organs to the brain. The researchers recorded animal eye movements during a complex series of experiments that used a variety of movement types to affect the otolith organs and semicircular canals, both in isolation and together.

The results showed that the brain does indeed use signals from both sets of balance organs to distinguish gravity from movements of the head and body. This supports the multisensory hypothesis and provides valuable insights into the complex and flexible processes by which the human brain perceives gravity. Ultimately, this research contributes to the understanding of neurovestibular adaptation to altered gravity and supports development of countermeasures to vestibular-related symptoms that adversely affect spaceflight crews.

Rachel, R.A., Dolen, G., Hayes, N.L., Lu, A., Erskine, L., Nowakowski, R.S., and Mason, C.A. "Spatiotemporal Features of Early Neuronogenesis Differ in Wild-Type and Albino Mouse Retina." *Journal of Neuroscience*, 2002 Jun 1;22(11): 4249-63.
FSB PI: Richard S. Nowakowski

Erwin D.H., and Davidson, E.H. "The Last Common Bilaterian Ancestor." Review. *Development*, 2002 Jul;129(13):3021-32.
FSB PI: Eric H. Davidson

DeFelipe J., Arellano J.I., Merchan-Perez, A., Gonzalez-Albo, M.C., Walton, K, and Llinas, R. "Spaceflight Induces Changes in the Synaptic Circuitry of the Postnatal Developing Neocortex." *Cerebral Cortex*, 2002 Aug;12(8):883-91.
FSB PI: Kerry Walton



The map above shows the distribution of year 2002 FSB-funded PIs across the U.S. Similar maps for 2000 and 2001 are available in the OBPR Research Taskbooks.

The table at the right shows bibliographies for 2001 and 2002. Data for 2000 are not available separately for FSB-funded PIs and therefore not included.

The table below shows the number of ground-based and flight projects funded for 2000, 2001, and 2002 across the research elements.

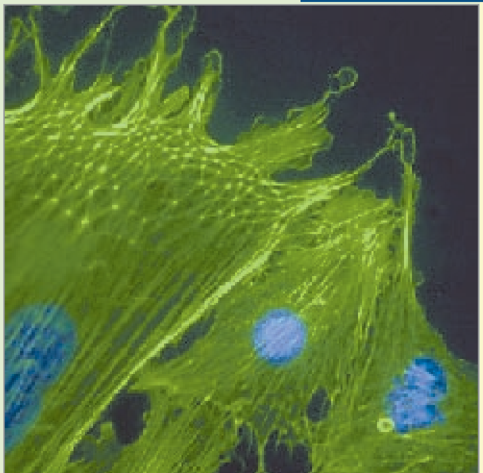
FSB PIs AND BIBLIOGRAPHIES 2001-2002

	2001		2002	
Bibliography Type	**PIs**	**Bibs**	**PIs**	**Bibs**
Peer Reviewed Articles	53	223	74	325
Abstracts	51	202	66	186
Presentations	23	94	33	131
Books	7	13	17	32
Other Journals	5	8	13	19
Dissertations/Thesis	6	10	7	17
Patents	2	2	6	15
Awards	5	6	6	7
Proceedings	6	8	5	30

SUMMARY OF NASA FSB GROUND-BASED (G) AND FLIGHT (F) RESEARCH PROJECTS

	2000			2001			2002		
Element	**G**	**F**	**Total**	**G**	**F**	**Total**	**G**	**F**	**Total**
Advanced Technology and Development	1	0	1	1	0	1	1	0	1
Cellular and Molecular Biology	57	11	68	63	10	73	67	8	75
Developmental Biology	13	11	24	20	3	23	21	7	28
Evolutionary Biology	12	0	12	16	1	17	17	0	17
Molecular Structures and Physical Interactions	1	0	1	4	0	4	3	0	3
Organismal and Comparative Biology	28	11	39	23	8	31	19	11	30
Total Projects	**112**	**33**	**145**	**127**	**22**	**149**	**128**	**26**	**154**

FLEXIBLE AND STRONG SKELETONS OF CELLS



The cytoskeleton of a human endothelial cell glow green in this immunoflourescent micrograph.

One of NASA's research priorities is to understand how cells will behave in the absence of mechanical stresses, such as gravity. To do this, scientists must first improve our understanding of how cells sense and respond to these stresses, a question that FSB-funded researcher **Donald Ingber** and his colleagues are working to answer. Their results so far have shown that receptor proteins mediate cell responses to force, and that a change in shape can prompt cells to divide or to die.

Cells have an internal skeleton, called a cytoskeleton, consisting of protein molecules assembled into chains. The cytoskeleton gives the cell its shape, helps it move, and holds the nucleus in place. But unlike our rigid bone structure, cytoskeletons are both flexible and strong, with the ability to balance compression with tension, and yield to forces without breaking. Researchers call this quality tensegrity, short for tensional integrity.

Ingber and his colleagues wanted to test the theory that cytoskeletons respond to mechanical stress via receptor cell proteins called integrins, which are linked both to the cytoskeleton and to the extracellular matrix, the fibrous scaffolding to which cells are anchored in our bodies. Small magnetic beads, about 1 to 10 microns in size, were coated with special molecules that bind to integrins. The beads were then attached to the integrins and exposed to a magnetic field. As the beads turned to align with the magnetic field, the integrins were twisted, which caused the cytoskeleton to stiffen. The more force that was applied, the stiffer the cytoskeleton became.

Importantly, tugging on the integrins also activated certain genes within the cell. Ingber's group had already found that changing a cell's shape also alters its fate—flattened cells tend to divide, whereas rounded, cramped cells often die.

In expanding our knowledge of how cells sense and respond to mechanical stresses, Ingber's findings help to understand how an absence of such forces—such as in the microgravity of space—might impact cellular function, and as a result, the health of human explorers. In addition, there are implications for human health here on Earth; every tissue in the body can develop disease as a consequence of abnormal responses to mechanical stress. Ingber's work has already led to a prospective new drug for cancer, and has potential to provide new treatments for osteoporosis, cardiac disease, lung problems, and developmental abnormalities.

EDUCATION AND OUTREACH

NASA has a long-term commitment to supporting education and sharing its knowledge and expertise. The Fundamental Space Biology Outreach Program (FSBOP), managed at KSC, conducts a range of outreach and education activities targeted to K-12, higher education, and the general public. Outreach groups within other organizations such as SSBRP and the ARC Life Sciences Division also contributed to FSB's education and outreach endeavors in 2000-2002.

Web of Life

The Web of Life site, the online presence of FSBOP, features learning resources, general readings, and FSB research overviews. In June 2002, the Web of Life was relaunched with a new design and significantly more content, from hardware profiles and articles about ground-based and flight studies to an overview of educational materials available upon request. A major site promotion endeavor was initiated, resulting in substantially increased awareness and use. Site visits more than doubled by the end of 2002.

Spaceflight and Life Sciences Training Program

The Spaceflight and Life Sciences Training Program (SLSTP) is a six-week summer course at KSC for undergraduate college students. Each summer students learn how to successfully design and conduct biological research and operations in space. The year 2000 marked the 16th annual SLSTP program. Each summer during 2000-2002, about 30 trainees participated, including two from Canada and a diverse group of students from across the U.S. As many as 12 trainees presented posters at the American Society for Gravitational and Space Biology annual meetings.

SpaceBio.net

Space Biology: An Educator's Resource, better known by its Web address SpaceBio.net, is an online resource for undergraduate life science educators and their students. The goal of the site is to facilitate inclusion of space biology content in standard biology courses. Launched in 2000, the site contains a large and growing collection of downloadable teaching materials organized by topic area, profiles of publications and resources, and annotated links to relevant Web sites. Much of the content is unique to SpaceBio.net and was developed by members of the space life sciences education and research communities. In 2001, SpaceBio.net received an award from NASA's Astrobiology program for excellence in science education. Through 2002, site traffic reached an average of 60,000 page hits and 7,000 visits per month, representing users from over sixty countries. Site usage and content remain on a strong growth path.

FSB Outreach Manager Tom Dreschel conducts a workshop with teachers for the Brassicas and Butterflies project.

Brassicas and Butterflies Project

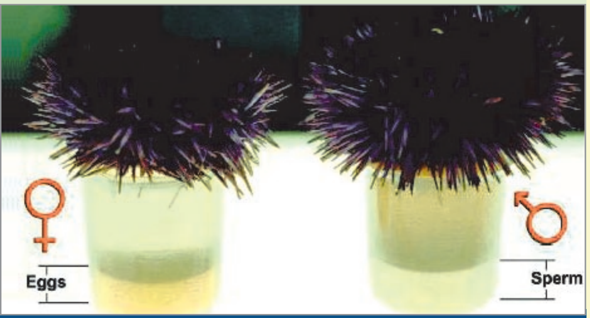
FSBOP in collaboration with the Wisconsin Fast Plants Office at the University of Wisconsin-Madison has developed a series of educational activities centered on *Brassica rapa* plants and Brassica butterflies for teachers and students. This project, called Brassicas and Butterflies, provides teachers and students with specific activities that can be conducted easily in a classroom and can be used as a basis for designing experiments to be conducted in space. The parallel growth and development of the Brassica plant and the butterfly demonstrate the process of coevolution. Teacher workshops have been conducted with the intent that their students will do research in the classroom with these organisms and develop experiments to propose to the NASA Student Involvement Program.

Events and Site Visits

FSB-related outreach groups visited numerous schools, providing thousands of students in grades 1 through 12

RESEARCH HIGHLIGHTS

SPERM SENSITIVITY TO GRAVITATIONAL FORCES



Sea urchins, a species commonly used in fertilization research, were studied to determine the effects of gravity on reproduction.

Joseph Tash, a NASA FSB researcher, has found that both microgravity and hypergravity (greater than Earth's 1 g) have significant effects on sperm activity and on fertilization. This work furthers our understanding of how gravity influences reproduction, an important area of research as long-term presence in foreign gravity environments becomes more common.

Along with his colleagues, Tash flew two experiments on the Space Shuttle using the sperm of sea urchins, a species commonly used in fertilization research. He found that the phosphorylation of proteins in the sperm's tail—the chemical process that fuels the sperm's movement—occurred three to four times faster in microgravity than in controls on the Earth's surface.

Tash also tested sperm function under hypergravity conditions, using a centrifuging microscope. The result was the opposite of what was observed in space: hypergravity slowed the phosphorylation process and sperm motility. It also decreased the rate of both the binding of sperm to eggs and of fertilization by 50 percent. The fact that both binding and fertilization were inhibited to the same degree suggests that sperm are more sensitive to changes in gravity than are eggs, a hypothesis Tash will continue to investigate.

Tash plans to work on understanding why sperm activation is enhanced in microgravity and impeded in hypergravity. Tash has successfully isolated proteins, called flagellar proteins, that may help answer this question. It is the flagellar proteins, which reside in the tails of sperm and aid in motility, which are altered in different gravity environments. Investigating how they work may be the key to understanding sperm-tail activation on the molecular level and exactly what role gravity plays in this system.

Technology Spinoff:
In the process of preparing sea urchin sperm for the Shuttle experiments, Tash developed a new way of storing immotile sperm. Recently patented, this new technology allows for the storage and transport of nonfrozen sperm by employing chemical simulation of the sperm's environment both inside and outside of the testes. This method, which permits the sperm to be stored for longer periods of time at nonfreezing temperatures without damage, could have widespread applications for commercial animal breeding and human infertility.

with learning and discussion opportunities as well as career information about NASA and space life sciences research. Several outreach efforts targeted groups underrepresented in math and sciences. FSB outreach booths were displayed at a variety of meetings, such as the World Space Congress, OBPR annual outreach workshops, the annual American Society for Gravitational and Space Biology meetings, and the North American Science Teachers Association.

Educational Materials

FSB-related educational products developed in 2000-2002 included bookmarks for SpaceBio.net and the Life Sciences Data Archive, brochures covering various life sciences topics, and research overview articles. In addition to making these materials available from the Web of Life site, many were displayed at FSB-related outreach booths at a variety of events.

Mission Outreach

To excite and educate the public about the science on STS-107, a significant outreach effort began in years prior to the mission's 2003 launch. With six Fundamental Space Biology experiments onboard, FSB contributed to the outreach endeavor by supporting development of educational materials describing the research.

CONFERENCES AND WORKSHOPS

Additional FSB activities include various workshops, meetings, and conferences. The following were sponsored or supported by FSB.

Cell Science Conferences
March 6-8 2001, February 26-28, 2002

The annual NASA Cell Science Conference represents a collaboration between the Cellular Biotechnology Program, based at Johnson Space Center, and the FSB Program. The conference originated as the annual working group meeting for principal investigators (PIs) in the Cellular Biotechnology Program. In 2001, the conference was expanded to include PIs from FSB. Scientists from universities, medical centers, NASA field centers, the National Institutes of Health, National Space Biomedical Research Institute, and commercial cell culture enterprises were in attendance.

Yeast *(Saccharomyces cerevisiae)* Workshop
April 19, 2001

The working group met to determine the scientific value and feasibility of flying the yeast, *Saccharomyces cerevisiae*, in space. Yeast, a model organism, is a key subject for fundamental space biology experiments because of its short generation times, which enable multigenerational studies.

Space Biology on the Early Space Station co-chaired by Baruch Blumberg and Kenneth Baldwin
March 14-15, 2002

Sponsored by FSB, the goal was to explore the type, scope, and value of biological research possible over the next five years within current STS and ISS constraints.

OBPR Free Flyer Study Workshop
July 26, 2002

Sponsored by Ames Research Center, this workshop was conducted to identify research justifications for a NASA OBPR Free Flyer concept. FSB participated with the Physical Sciences, Bioastronautics, and Space Product Development divisions to define requirements in terms of mission, schedule, and costs associated with performance of scientific research on a free flyer spacecraft.

T4FSB Workshop
October 23-34, 2002

The workshop was hosted by NASA Ames Research Center and Stanford University in support of the FSB Program. Its goals were to identify technologies that significantly amplify biological discoveries on the International Space Station and Space Shuttle, open new discovery opportunities on free-flying biological spacecraft, and enable safe human exploration of the solar system.

RESEARCH BENEFITS

NASA

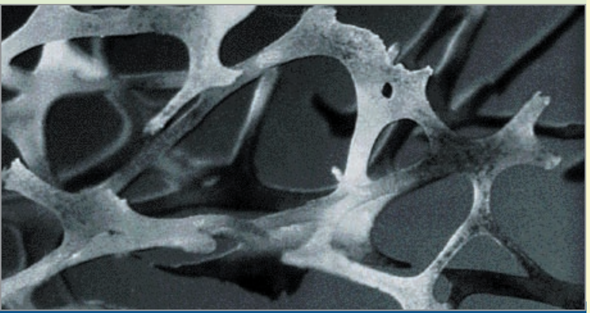
FSB offers special support to NASA and the agency's research objectives. Here are some examples of the many associated benefits:

- New insight into the fundamental biological mechanisms behind physiological changes observed in space
- Increased knowledge of gravity's effects on living systems
- Increased relevance of NASA's research to the non-space life sciences research community
- More current research to draw outside researchers to the field of space life sciences
- New level at which to evaluate options for future medical countermeasures
- Knowledge directly applicable to Bioastronautics issues
- Direction for future human-centered research.

Real-World Applications

Many societal benefits have arisen from NASA life sciences R&D. Often, applications for Earth-based use continue to emerge years after the science and technology was funded. NASA HQ and the FSB Program have

GENETIC LINKS FOR BONE LOSS ON EARTH AND IN SPACE



Space flight mimics the loss of bone mass that occurs in aging, making it a good model for studying osteoporosis (shown above).

Using customized microarray technology and state-of-the-art genetics techniques, FSB investigator **Eugenia Wang** is working to understand the genetic response to microgravity and how it relates to the loss of bone mass associated with space travel. This work could reveal similar genetic changes caused by the effects of space flight and the aging process, and eventually contribute to countermeasures for the bone loss associated with both.

The loss of bone mass that humans and other vertebrates experience in space represents both a risk and an opportunity. It potentially jeopardizes astronaut health, but it also mimics the slow loss of bone mass that occurs during aging, in a time frame of just weeks and months. This makes spaceflight a good model for studying osteoporosis, which affects millions of Americans.

Wang flew cultures of human fibroblasts—the standard cell type for research on cellular aging—on the STS-93 Space Shuttle mission. The cell cultures, composed of young cells, were exposed to microgravity for almost five days, then compared to control cells on Earth that had reached the late stage of their life cycle. Wang's goal was to see whether the cells she sent into space functioned more like young cells or old ones. She examined a particular set of genes, those that are the first to react in situations that are damaging or stressful to a cell, such as changes in gravity, and which are potentially related to both adaptation to spaceflight and aging.

Wang found 10 genes that exhibited altered expression as a result of spaceflight, and identified a series of changes in their response to microgravity. These changes may, as she stated in a *FASEB Journal* article, "underlie a mechanism attempting to counteract the bone loss occurring as a result of spaceflight."

The next step of this research will be to look at other genes that are not on the cell's first line of defense. This will give a more thorough picture of the genetic effects of microgravity on bone loss by identifying the signal pathways involved. Wang also plans to determine whether the genetic changes exhibited in space also occur as a result of normal aging. These further studies may lay the groundwork for developing countermeasures for minimizing bone loss during spaceflight and the normal aging process.

sponsored the development of the Life Sciences Applications Database (LSAD), which profiles many of these Earth benefits. A number of the items featured in the LSAD have become commercial spin-offs through a license from NASA. In 2002, the LSAD was launched on the FSB Program Web site. The following examples relevant to FSB have significant Earth benefits.

Rodent Model to Simulate Spaceflight Effects

The rodent model for hind-limb unloading, developed in the 1970s at NASA ARC, has been used in various laboratories around the world to study musculoskeletal unloading. Hind limbs of rodents are elevated to produce a head-down tilt, avoiding weight-bearing by the hindquarters.

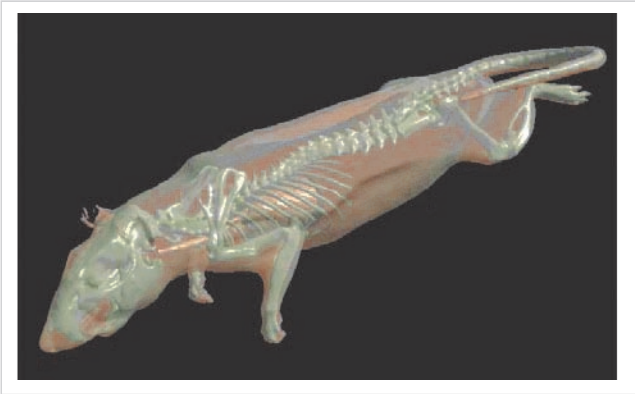
This model not only simulates spaceflight effects but also has proven to be useful for investigating physiological responses for both rats and mice to the recovery process associated with reloading and unloading. In addition to providing insights into spaceflight-based health problems, use of the technique has Earth-based applications in such fields as exercise and sports science.

In 2002, NASA ARC investigator Emily Holton, was awarded the eighth annual Alexander D. Kenny award and had 800 citations in a single year to her paper, "The Hindlimb Unloading Rodent Model: Technical Aspects," published in the *Journal of Applied Physiology*, 2002.

Virtual Environment

The Virtual Environment project, developed to give crew members training to support in-flight experiments while on Earth, combines visualization, simulation, and computation technologies to simulate operations in microgravity. NASA ARC's BioVIS Center partnered with Stanford University Medical Center to develop the hardware and software for microgravity simulation. A Virtual Glovebox and a Virtual Rat were created to provide training opportunities for astronauts.

With applications to education, biomedicine, and health care, the Virtual Environment provides a procedure development, practice, and teaching tool to allow users to learn new skills on simulated equipment, virtual animal models, and virtual medical patients. Development and refinement of this project was supported by Yvonne Cagle, MD, who was detailed to ARC as the astronaut liaison for life sciences research on the International Space Station in 2002.



The Virtual Environment, created to provide training for astronauts, has real-world benefits for education, biomedicine, and health care.

Smart Surgical Probe

The Smart Surgical Probe enables improved breast cancer detection and analysis. The device consists of a computerized tool with a needle-like tip that can be inserted into a breast lump. It decreases the size of the incision, improves accuracy, and takes less time than current biopsy techniques.

The use of the Smart Probe can eliminate unnecessary breast surgeries. It can also help health care providers to more accurately diagnose and treat cancer. The technology can be applied to diagnosing and treating other common cancers such as prostate and colon cancer.

The Smart Surgical Probe, originally developed at Ames Research Center, has been licensed to Bioluminate, Inc. to develop, produce, and market the device for cancer applications.

Robotic-Assisted Therapy for Spinal Cord Injury

Research conducted on the Bion 11 mission in 1996 by V. Reggie Edgerton and his team has led to the development of the Robotic Stepper. Key to building such a device is understanding the role of weight-bearing in Earth's gravitational environment in maintaining healthy muscle and accurate motor function. In the last several years, Edgerton and his colleagues have applied this knowledge and technologies gained from his space experiments to research in spinal cord injury rehabilitation.

The device, developed by NASA's Jet Propulsion Laboratory (JPL) and the UCLA Brain Institute, looks like a treadmill with robotic arms and is fitted with a harness to support the patient's weight. The arms resemble knee braces that attach to the patient's leg, guiding the legs properly on the moving treadmill. The Robotic Stepper device also measures aspects of the patient's movement, helping therapists monitor day-to-day progress of their patients.

The Robotic Stepper could benefit more than 10,000 patients with spinal cord injuries and more than 500,000 stroke patients who are admitted to hospitals in the United States each year by helping them regain at least partial use of their legs.

In 2000, JPL assisted UCLA in filing a patent application for the Robotic Stepper, and it is projected for clinical trials as early as 2004.

Cell Fluorescence Analysis System

The Cell Fluorescence Analysis System (CFAS) is a versatile, compact fluorometer designed to perform cellular functional assays and in vitro biochemical assays.

Originally developed for cell biology research on the International Space Station by Ciencia, Inc., with a NASA Small Business Innovation Research grant, the CFAS has commercial applications in diverse markets from food safety and in situ environmental monitoring to online process analysis, genomics, DNA chips, and noninvasive diagnostics. Ciencia has already licensed the technology to another company for high-throughput screening for drug discovery.

APPENDIX A:

GRANT RECIPIENTS

Philip G. Allen
Brigham and Women's Hospital, MA
The Cytoskeleton and Force Response Mechanisms
Molecular Structures and Physical Interactions
2000, 2001, 2002

Eduardo A. C. Almeida
NASA Ames Research Center, CA
Does Gravity Influence Matrix Survival Signaling
Cellular and Molecular Biology
2001, 2002

Dora Angelaki
Washington University Medical School, MO
Multisensory Interactions to Discriminate Gravity from Translational Accelerations
Organismal and Comparative Biology
2001, 2002

Jeffrey L. Bada
University of California at San Diego, CA
Mars Organic Detector (MOD): Looking for Clues for Life and Evaluating the Water Inventory for In Situ Resource Utilization
Cellular and Molecular Biology
2000

Richard A. Baird
Central Institute for the Deaf, MO
Physiological Maturation of Regenerating Hair Cells
Cellular and Molecular Biology
2000, 2001, 2002

Carey D. Balaban
University of Pittsburgh, PA
Vestibulo-Autonomic Circuits
Organismal and Comparative Biology
2000, 2001, 2002

Kenneth M. Baldwin
University of California, Irvine, CA
Neuro-Thyroid Interaction on Skeletal Isomyosin Expression in 0-G
Developmental Biology
2000

Thomas Barker
University of Alabama Birmingham, AL
The Effects of Microgravity on Fibroblast Migration and Thy-1 Surface Expression
Cellular and Molecular Biology
2002

Roger Beachy
Donald Danforth Plant Science Center, MO
Applications of Plant Bioengineering for Advanced Life Support Systems
Cellular and Molecular Biology
2002

Kathleen Beckingham
Rice University Institute of Biosciences and Bioengineering, TX
Gravitaxic Mutants and Mechanical Signaling in Drosophila
Organismal and Comparative Biology
2000

Kathleen Beckingham
Rice University Institute of Biosciences and Bioengineering, TX
Gravitaxic Mutants and Mechanical Signaling in Drosophila
Cellular and Molecular Biology
2002

Kathleen Beckingham
Rice University Institute of Biosciences and Bioengineering, TX
Drosophilia Behavior and Gene Expression in Microgravity
Organismal and Comparative Biology
2002

Hugo Bellen
Baylor College of Medicine, TX
Role of Math1 in Development and Function of Proprioceptors
Cellular and Molecular Biology
2000, 2001, 2002

Hugo Bellen
Baylor College of Medicine, TX
Senseless and Gfi1 in Sensory Neuron and Hair Cell Development
Cellular and Molecular Biology
2000, 2001, 2002

Amy C. Bendixen
University of Cincinnati, OH
Negative Regulation of Osteoclastogenesis by Estrogens via Direct Actions on Hematopoietic Cells
Cellular and Molecular Biology
2000

Daniel Bernstein
Stanford University, CA
Role of Adrenergic Receptors in Adaptation to Microgravity: Gene Targeted Mice as a Model of Microgravity Research
Organismal and Comparative Biology
2000, 2001, 2002

Daniel Bikle
Veterans Affairs Medical Center, University of California, CA
The Effect of Skeletal Unloading on Bone Formation
Organismal and Comparative Biology
2000, 2001, 2002

Elison B. Blancaflor
Noble Foundation, OK
Enhanced Labeling Techniques to Study the Cytoskeleton during Root Growth and Gravitropism
Cellular and Molecular Biology
2001, 2002

Frank Booth
University of Missouri, MO
Signal of Muscle Atrophy in Unloading
Organismal and Comparative Biology
2000, 2001, 2002

Janet Braam
Rice University Institute of Biosciences and Bioengineering, TX
Rice NSCORT in Gravitational Biology
Cellular and Molecular Biology
2002

Janet Braam
Rice University Institute of Biosciences and Bioengineering, TX
Molecular and Developmental Responses of Plants to Mechanical Stimuli
Cellular and Molecular Biology
2000

Scott T. Brady
University of Texas Southwestern Medical Center, TX
Space Flight, Stress, and Neuronal Plasticity
Organismal and Comparative Biology
2000

Marianne Bronner-Fraser
California Institute of Technology, CA
Evolution of the Neural Crest and Placodes
Evolutionary Biology
2000, 2001, 2002

Christopher S. Brown
North Carolina State University, NC
NSCORT – Calcium, Signaling and Gravity: An Integrated Molecular, Cellular and Physiological Approach
Cellular and Molecular Biology
2000, 2001, 2002

Christopher S. Brown
North Carolina State University, NC
NSCORT Project I. Changing Calcium Homeostasis in Transgenic Plants: A Reverse Genetics Approach
Cellular and Molecular Biology
2000, 2001, 2002

Christopher S. Brown
North Carolina State University, NC
NSCORT Project II. Isolation of a Novel Class of Arabidopsis Mutants with Impaired Transduction of the Gravity Signal
Cellular and Molecular Biology
2000, 2001, 2002

Christopher S. Brown
North Carolina State University, NC
NSCORT Project III. Changes in Plant Gene Expression during and after Gravistimulation
Cellular and Molecular Biology
2000, 2001, 2002

Christopher S. Brown
North Carolina State University, NC
NSCORT Project IV. Signal Transduction Pathways and Early Responses to Gravistimulation in Plants
Cellular and Molecular Biology
2000, 2001, 2002

Christopher S. Brown
North Carolina State University, NC
NSCORT Project V. Effects of Gravity on Plant Metabolism
Cellular and Molecular Biology
2000, 2001, 2002

Stephen Chapes
Kansas State University, KS
Bone Marrow Macrophage Differentiation in Space
Cellular and Molecular Biology
2000

Stephen Chapes
Kansas State University, KS
Differentiation of Bone Marrow Macrophages in Space
Developmental Biology
2001, 2002

Barbara Chapman
Center for Neuroscience, University of California, Davis, CA
Microgravity Effects on Developing Vestibular Afferents
Developmental Biology
2000

Roberto Civitelli
Washington University, MO
Osteoblast Regulation by Mechanical Stimuli via Gap Junctions
Cellular and Molecular Biology
2000, 2001, 2002

Catherine Conley
NASA Ames Research Center, CA
Genomic Analysis of the Hypergravity Response in Caernorhabditis Elegans
Developmental Biology
2002

Bob Conger
University of Tennessee, TN
Gravitational Effects on Embryogenesis in Poaceae
Developmental Biology
2000, 2001

Daniel Cosgrove
Pennsylvania State University, PA
Molecular Control of Cell Growth During Gravity Responses of Maize Seedlings
Organismal and Comparative Biology
2000, 2001, 2002

Daniel Cosgrove
Pennsylvania State University, PA
Gravity Effects on Seedling Morphogenesis
Cellular and Molecular Biology
2000

Richard Cyr
Pennsylvania State University, PA
The Regenerating Protoplast as a Single-Cell Model System for Studying Gravitropism in Plants
Cellular and Molecular Biology
2000, 2001, 2002

Richard C. D'Alonzo
University of Medicine and Dentistry of New Jersey – Robert Wood Johnson Medical School, CA
Transcriptional Regulation of Differentiating Osteoblasts
Cellular and Molecular Biology
2000

Michael Danilchik
Oregon Health and Science University, OR
How Do Cell-Division Planes Specify Regional Gene Expression Patterns in Embryos?
Developmental Biology
2000, 2001, 2002

Sylvia Daunert
University of Kentucky, KY
Biomimetic Detection Schemes Based on a Microcentrifuge Platform
Advanced Technology
2000, 2001, 2002

Eric Davidson
California Institute of Technology, CA
Transcriptional Regulation and Evolution of Bilaterian Body Plans
Evolutionary Biology
2000, 2001, 2002

Michael Delp
Texas A&M University, TX
Adaptations of Visceral and Cerebral Resistance Arteries to Simulated Microgravity
Organismal and Comparative Biology
2000, 2001, 2002

Michael Delp
Texas A&M University, TX
Arterial Remodeling and Functional Adaptations Induced by Microgravity
Organismal and Comparative Biology
2000, 2001, 2002

Dominick DeLuca
University of Arizona, AZ
Effect of Microgravity on the Development of the Immune System
Developmental Biology
2000, 2001, 2002

Arnold Demain
Drew University, NJ
Effect of Growth Starvation Under Simulated Microgravity on Bacterial Stress and Secondary Metabolite Formation Response Using Rotating Wall Bioreactor
Cellular and Molecular Biology
2000, 2001, 2002

David Dickman
Central Institute for the Deaf, MO
Development and Function of the Avian Otolith System in Normal and Altered Gravity Environments
Organismal and Comparative Biology
2000, 2001, 2002

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APPENDIX B:

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