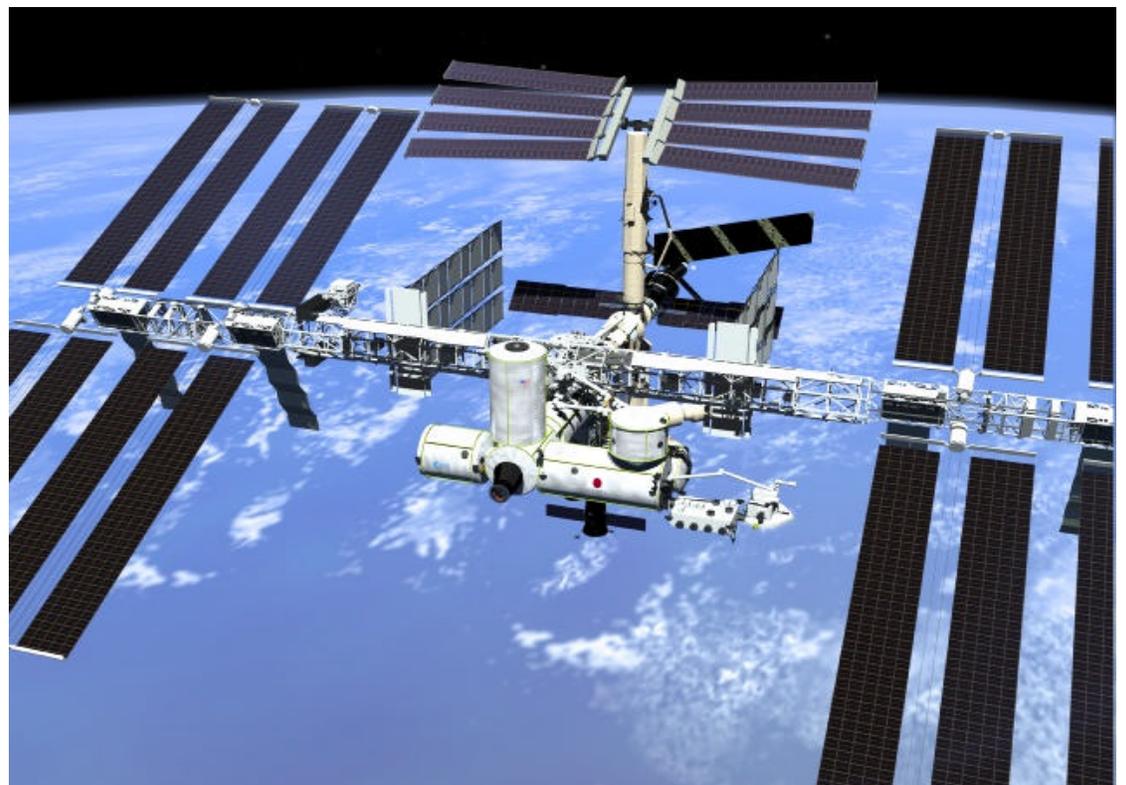




NATIONAL AERONAUTICS & SPACE ADMINISTRATION (NASA)

SCIENCE AND TECHNOLOGY RESEARCH DIRECTIONS FOR THE INTERNATIONAL SPACE STATION



9 July 1999



PREFACE

We stand today upon the threshold of a new and exciting journey of exploration and discovery. In the past year, we have concluded both the very successful Spacelab research program and Phase I of International Space Station (ISS) development aboard the Russian space station *Mir*.¹ During the next few years, we will complete on-orbit construction of the ISS and begin utilizing this valuable research facility and testbed. This journey promises to benefit our exploration of space and enhance our lives here on Earth.

Even as we prepare to move forward, we must also take the time to look back on our achievements and tally our successes. Despite comparatively few and intermittent space research opportunities, we have established that gravity profoundly affects phenomena such as convection, sedimentation, and hydrostatic pressure. We have rewritten textbooks in combustion and soot formation, challenged the prevailing theories in fluid transport phenomena, explored the relationship between gene expression and gravity, begun to probe gravity's effects on human physiology, and opened new vistas in low-temperature physics. But more importantly, we have affirmed the intrinsic value of skilled in-space operators who act both as investigator surrogates and as human subjects.

From our current vantage point, we can also see how our scientific activities have strengthened our research community as a whole, and will continue to do so. We have reinforced our peer-review process and formed new national and international alliances. Through collaboration, we are probing new areas of research to benefit health, improve industrial processes, and expand our knowledge of the universe in which we live. We have fostered relationships with the commercial and academic communities, generating new opportunities for collaboration. This ever-growing community of over 3,300 scientists and students from government, academia, and the private sector is the backbone of long-term ISS utilization. Innovations in telerobotics and telescience allow us to plan virtual "hands-on" access to the remote laboratory for hundreds of investigators separated by time and space. In turn, our ground-based investigator community will continue to strengthen as it feeds the core of scientific and engineering theory from which space flight experimentation is drawn.

As it comes online in this time of expansion and learning, the ISS will be a potent tool for uniting our research efforts and increasing our fundamental knowledge. Data collection on engineering and environmental parameters is underway aboard the two ISS elements already on orbit. As full utilization of the ISS begins, it will pave the way for newly emerging disciplines in physics, biology, and engineering, even as it provides a complementary, crewed platform for advancing work in the Earth and space sciences. Perhaps even more importantly, the ISS will be a paradigm for understanding how small, multicultural groups can live, work, and prosper in the space environment; within this novel environment, we can delve into issues of medical and social anthropology and prepare for the next steps in human space exploration.

The greatest value of the ISS lies in its versatility. It is not a single-discipline laboratory like those we use on Earth; it cannot be justified by a single research focus or area of specialization. Rather, the ISS offers long-term, uninterrupted access to the space environment, skilled human operators to participate in the experimental process, and numerous opportunities for medical and sociological studies in space flight. On

¹ For a discussion of the lessons learned from Phase I of ISS development, please see the 1998 NASA document, *The Phase I Program: Preparing for the International Space Station*. Also see the *Phase I Program Joint Report* at <http://www.hq.nasa.gov/osf/mir/issphase1.pdf>



Science and Technology Research Directions for the ISS

the ISS, in the novel environment of space, we will observe, experiment, and learn as we prepare for human space exploration in the 21st century.



INTRODUCTION

The Unique International Space Station

The International Space Station (ISS) is a unique and unprecedented space research facility. Never before have scientists and engineers had access to such a robust, multidisciplinary, long-duration microgravity laboratory. To date, the research community has enjoyed success aboard such platforms as Skylab, the Space Shuttle, and the Russian *Mir* space station. However, these platforms were and are limited in ways that the ISS is not. Encompassing four times the volume of *Mir*, the ISS will support dedicated

research facilities for at least a dozen scientific and engineering disciplines. Unlike the Space Shuttle, which must return to Earth after less than three weeks in space, the ISS will accommodate experiments that require many weeks—even months—to complete. Continual access to a microgravity laboratory will allow selected scientific disciplines to progress at a rate far greater than that obtainable with current space vehicles.

The best laboratories on Earth combine the most advanced technology with human ingenuity and adaptability. This approach affirms the value of human intervention in the research process and serves as a model for the ISS. A modular approach to laboratory outfitting will enable NASA and its partners to modify and replace equipment as the state-of-the-art in technology and scientific theory evolves. While NASA and its partners are taking full advantage of the efficiencies afforded by the Station's advanced telescience capabilities, the ISS crew members will be invaluable resources as they shepherd ISS investigations through all stages of the experimental process. We have learned from Earth-based operations that robotic technology does have its limits, and that we have no substitute for timely human intervention. On the ISS, human intervention will allow us to respond to the unexpected and perform specific tasks in concert with the smart technologies that make the ISS a model in remote operations.

The Station's Concurrent Roles

If we aspire to explore and understand beyond the boundaries of our own planet, we must first assemble survival skills—a basic understanding of how to live and work in space. Prominent among the many great achievements of space research is our realization of how much we must learn before we can meet the challenges of human space exploration. ISS activities hold considerable promise in solidifying our knowledge base. This multinational endeavor will yield answers to questions that are of great interest to diverse communities in science, engineering, and industry. At the same time, the expansion of low-Earth orbit research will facilitate commercial investment in space development. In summary, the ISS is:

- an ***advanced testbed*** for technology and human exploration;
- a ***world-class research facility***; and
- a ***commercial platform*** for space research and development.

We will begin to reap the benefits of the ISS in the near future. The utility of ISS research will become apparent in enhanced health care, improved industrial processes and technologies, and increased

Long-term Impacts of ISS Research

- Human Exploration of the Solar System
- A Better Tomorrow with Space-enabled Commercial Products

More Immediate Outcomes of ISS Research

- Enhanced Medical Care
- Improved Industrial Processes and Technologies
- Increased Fundamental Knowledge



fundamental knowledge. In the long term, the benefits of the ISS will be measured by its impact on a society that naturally seeks to explore its universe. Ultimately, the ISS will enable the human exploration of space while serving as a platform to build a better tomorrow with commercially-developed products.

ISS Advisory Bodies and Programs

The scientific research initiatives of the ISS have been derived in consultation with numerous scientific bodies, including:

- NASA Advisory Council discipline committees,
- the National Academy of Sciences/National Research Council (including the Space Studies Board, the Aeronautics and Space Engineering Board, and the National Materials Advisory Board), and
- NASA-sponsored workshops and symposia.

The selection of research to be performed on board the ISS will be accomplished through several NASA program offices:

- the Office of Life and Microgravity Sciences and Applications,
- the Office of Space Science,
- the Office of Earth Science,
- the Office of Space Flight, and
- the Office of Aeronautics and Space Transportation Technology.

ISS Physical Capacity

The International Space Station will serve as a unique, multidisciplinary, multinational laboratory facility that will allow sophisticated investigations to be conducted in the life and physical sciences. When completed, the ISS will include:

- at least three international pressurized research laboratories,²
- multi-user, discipline-specific research facilities,
- multidisciplinary EXPRESS racks and pallets,³
- four external truss sites for payloads that require exposure to the space environment, as well as additional exposed facilities on the Japanese and European modules,
- a 2.5 m centrifuge to provide artificial gravity for gravitational research,
- supporting equipment for power generation and operations,
- crew living quarters, and
- at least 120-crew hours per week for research operations.

ISS Research Timeline

U.S. scientists will have at their disposal over 76% of all research resources available, including half of all space in the European and Japanese laboratories and exposed facilities. Use of the ISS for research will begin in the next few years, even as the ISS itself is under construction. Initially, research capability on

² The U.S. Laboratory, the European Columbus Orbital Facility (COF), and the Japanese Experiment Module (JEM).

³ The EXpedite the PRocessing of Experiments to the Space Station (EXPRESS) Racks contain standard interfaces that allow multidisciplinary payloads quick and standard access to ISS resources.



the ISS will be provided by the EXPRESS Racks. These racks allow quick, simple integration of small multidisciplinary payloads into the ISS laboratories. Additional research capability will become available for discipline-specific research with further assembly and utilization flights. The accumulation of research capabilities can be calculated by tracking the flights on which the research facilities will be launched.

Document Organization

This document links specific research questions to their disciplines and, where applicable, to the ISS utilization flights (UF) or assembly flights that will accommodate this research.⁴ An arrow symbol (➤) following the flight number indicates that the research will continue on subsequent flights.

Each discipline briefly answers the following questions:⁵

- What is the purpose of this research discipline?
- What is the “overarching question” that research in this discipline strives to answer?
- What aspects of the question are currently under investigation?

Utilization and assembly flights that are already assigned experiments to address specific research questions are noted where possible. The companion publication, *The International Space Station, Improving Life on Earth and in Space: The NASA Research Plan, An Overview*, deals in depth with the potential social, economic, and intellectual benefits to be contributed by ISS research.

⁴ These questions have been developed by the scientific community, adapted by NASA to each discipline, and recommended by external advisory boards.

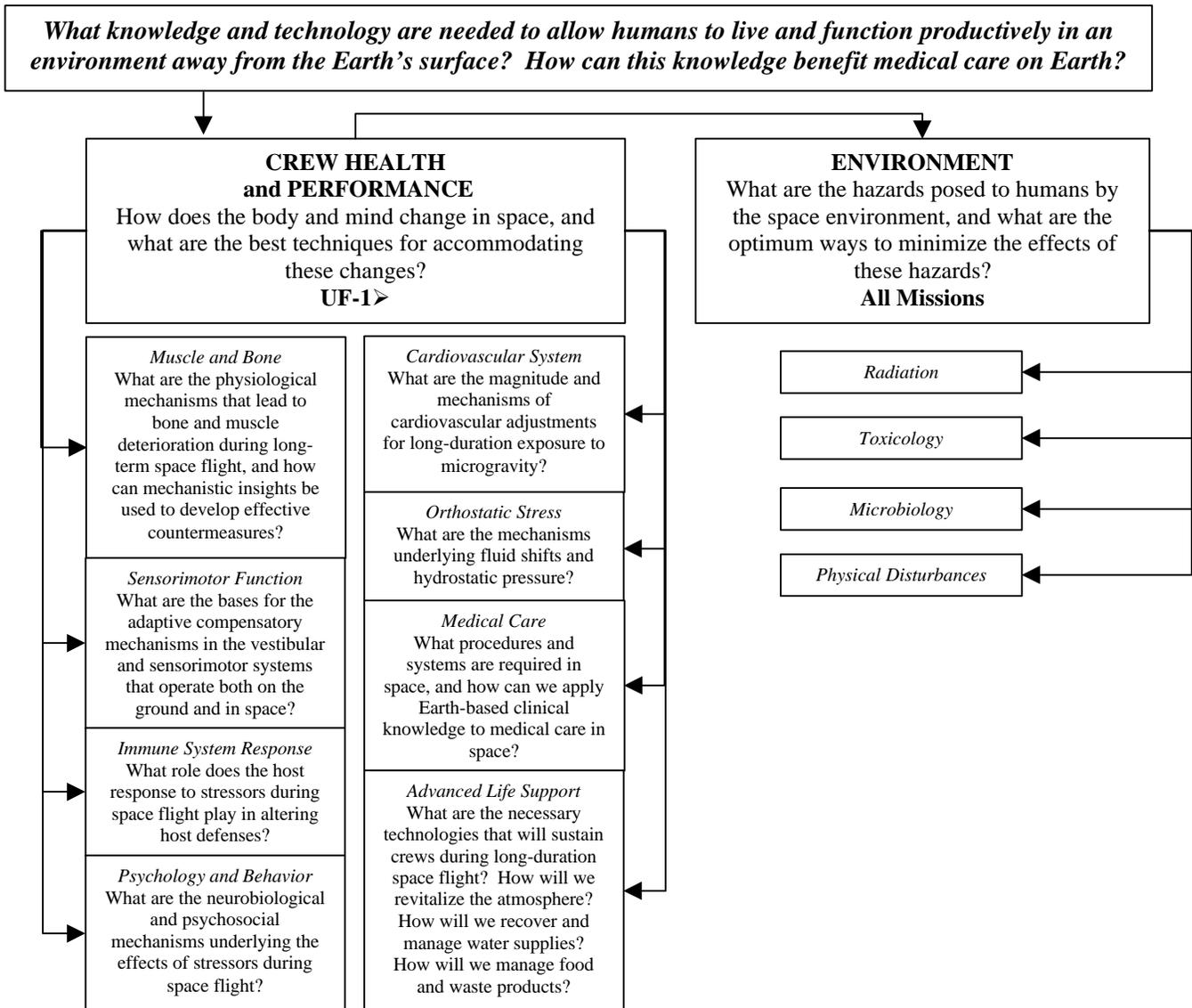
⁵ Extensive descriptions of each discipline can be found in the publications listed in the reference section of this monograph.



BIOMEDICAL RESEARCH AND COUNTERMEASURES/ ADVANCED HUMAN SUPPORT TECHNOLOGY

Both the Biomedical Research and Countermeasures Program and the life support program (Advanced Human Support Technology) strive to answer one question: what knowledge and technology are necessary for humans to live and function productively beyond the Earth's surface? These programs not only investigate the effects of space flight on human physiology and behavior, but they also apply this information towards developing the techniques and technologies that will sustain humans during future missions and benefit medical care on Earth. Some of these technologies have already been adapted to Earth-based applications: for example, NASA-designed telemedicine systems now provide physicians with high-quality medical expertise and education in remote parts of the world, and paramedics in the United States now carry NASA-developed technologies to treat accident victims.

The ISS allows us to pursue scientific investigation in a microgravity environment, validating models and hypotheses proposed during ground-based research. Some of these research lines focus on long-duration stays in space and require continuous monitoring of human physiological systems and human intervention, which only the ISS can provide. The Space Studies Board of the National Research Council has advised NASA that specific areas within Biomedical Research and Countermeasures and Advanced Human Support Technology should become priority research areas on the ISS (1) (2) (3).

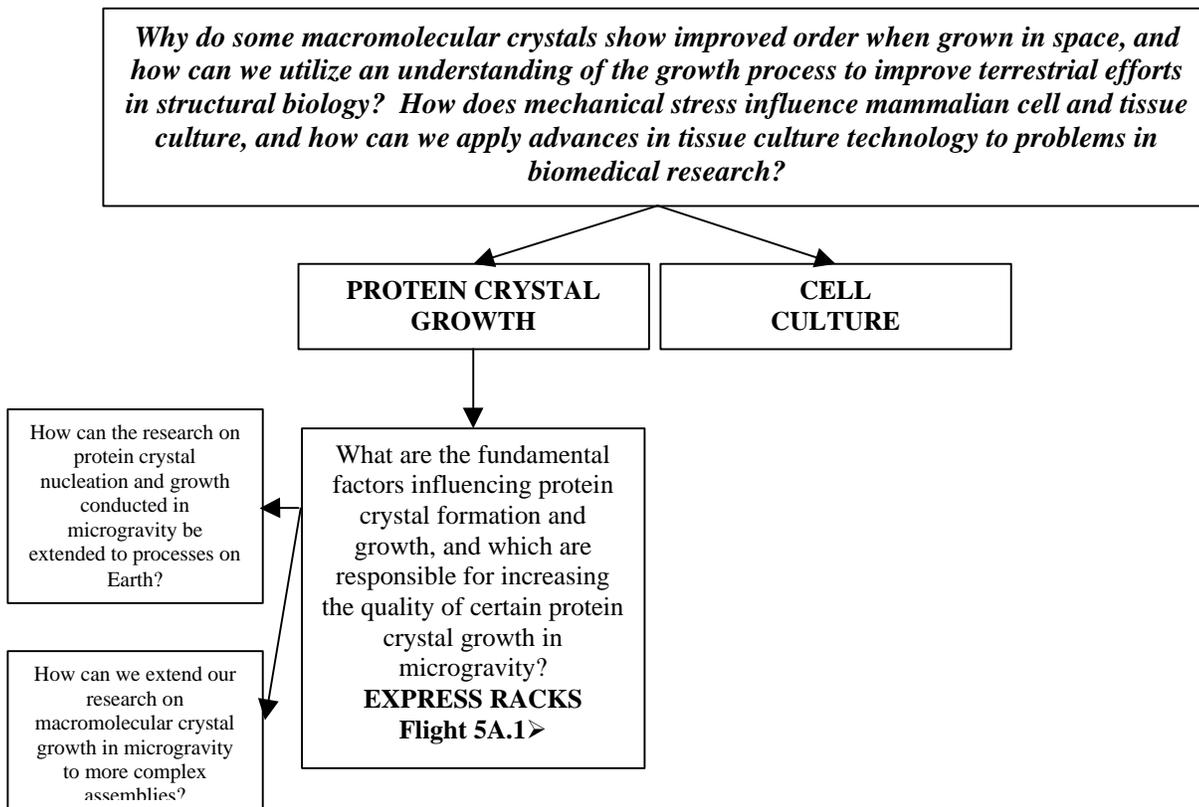




BIOTECHNOLOGY

By combining technology and engineering enterprises with advanced concepts in biology, the biotechnology program produces and characterizes biological molecules and assemblies important to basic and clinical research. Biotechnology facilities aboard the ISS will provide a platform for the growth and study of cellular structures including tissues and macromolecular crystals. Station technology may also enable investigators to analyze their results in near-real time, thereby increasing the value of station research. Commercial interests can use the ISS as a testbed and validation site for space-based biotechnology production and services.

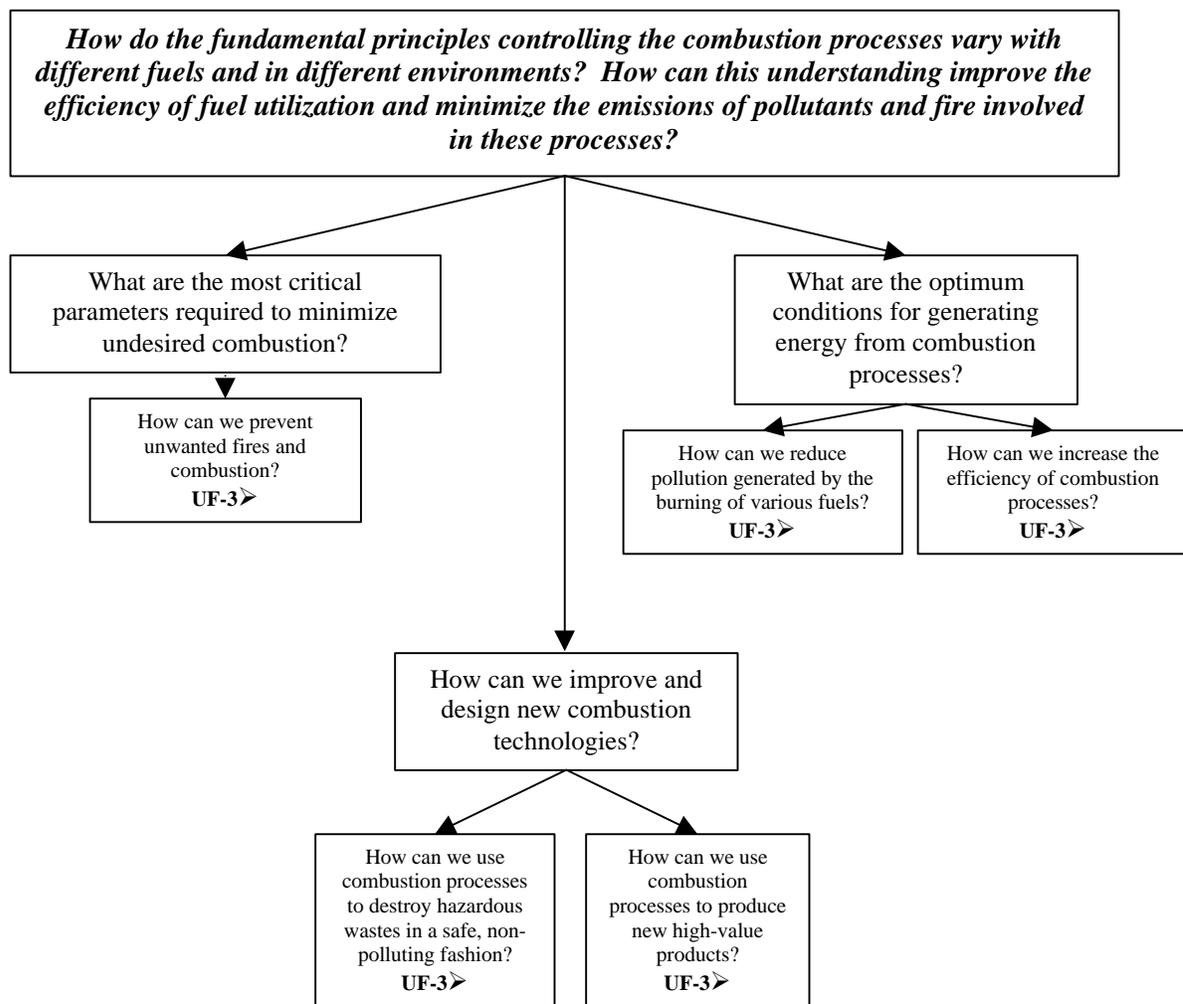
This state-of-the-art research will benefit health care on Earth. The determination of macromolecular crystal structures, for example, is key to the design of bioactive molecules with the potential to treat diseases such as AIDS, diabetes, and cancer. The bioreactor, developed by NASA for three-dimensional tissue growth, useful in pharmacology, is currently under redesign by biomedical researchers for applications in pharmacology and medical research. The likelihood that biotechnology will continue to reap benefits from space-based research has led the Space Studies Board of the National Research Council to identify biotechnology as a prime candidate for space-based research (4).





COMBUSTION SCIENCE

Combustion is a dominant process in our everyday lives; it accounts for approximately 85% of the world's energy use and a significant percentage of the world's atmospheric pollution. Three components are required for self-sustaining combustion reactions to occur: fuel (solid, liquid, or gas), oxygen, and an ignition source. On the ground, gravity-driven heat and fluid transfer processes make combustion a very complex phenomenon. In a low-gravity environment, some of this complexity is eliminated, and the basic mechanisms of such processes can be more easily studied. Microgravity conditions on the ISS will allow scientists to make critical observations and measurements of combustion and the systems and processes it enables. Continuous access to space facilities will allow researchers to take advantage of unanticipated research results. NASA's contributions to combustion science research have already created numerous applications for Earth use: stabilizers that allow natural gas appliances to operate more efficiently and cost-effectively; highly sensitive smoke detectors for use in the home and in industry; and environmental detectors that monitor the output of automobile and airplane engines. Further space-based research, recommended by the Space Studies Board, will bring additional practical applications in fire safety, combustion diagnostics, combustion systems design, and solutions to industrial pollution problems back to Earth (4).

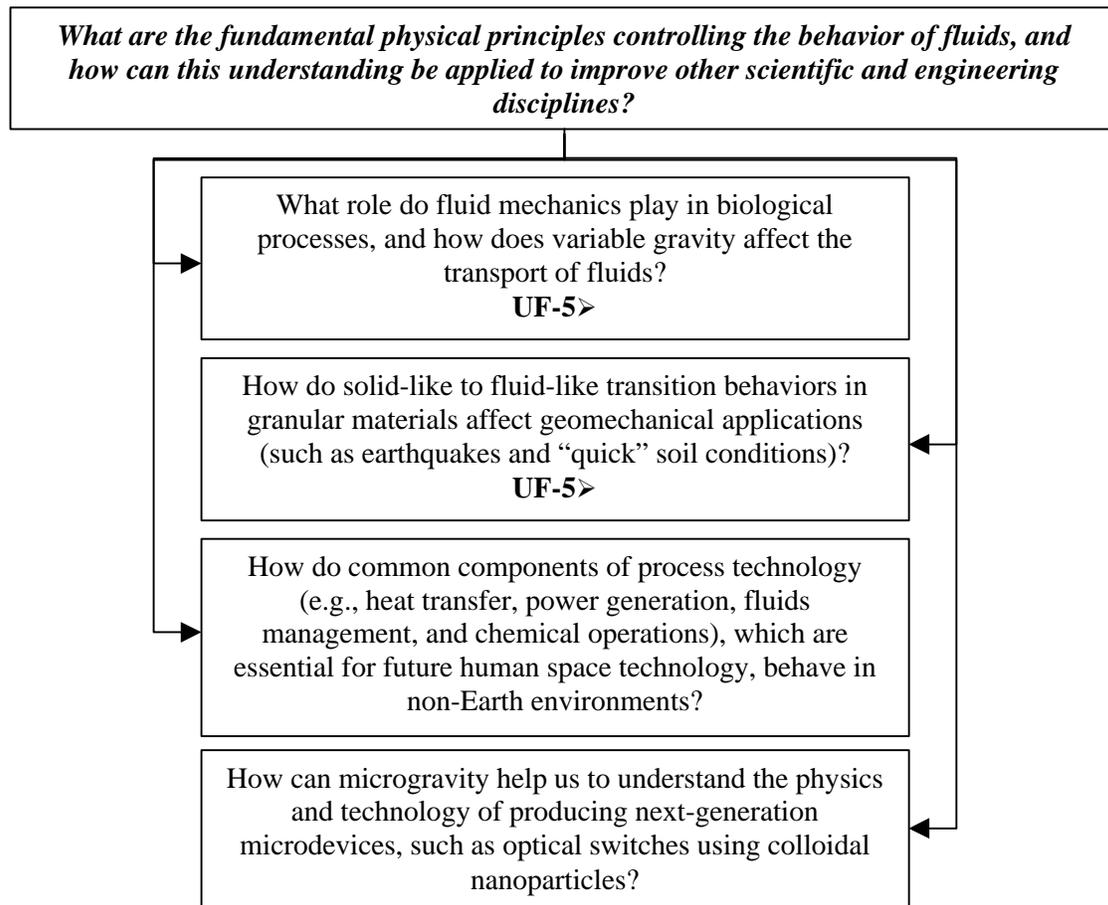




FLUID PHYSICS

Fluid physics is concerned with the mechanisms that govern the behavior of fluids. The universal nature of fluid phenomena, which affect everything from transport dynamics in the human body to the mixing characteristics of the atmosphere, makes this research fundamental to all areas of science and engineering. Because gravity is a controlling factor in many fluid behaviors—it creates boundaries, drives motion, and compresses fluids—microgravity conditions allow fluid physicists to study the basic behavior of fluids without this distorting influence. In response to the importance and widespread applications of this research, the Space Studies Board has recommended further space-based research into fluid physics (4).

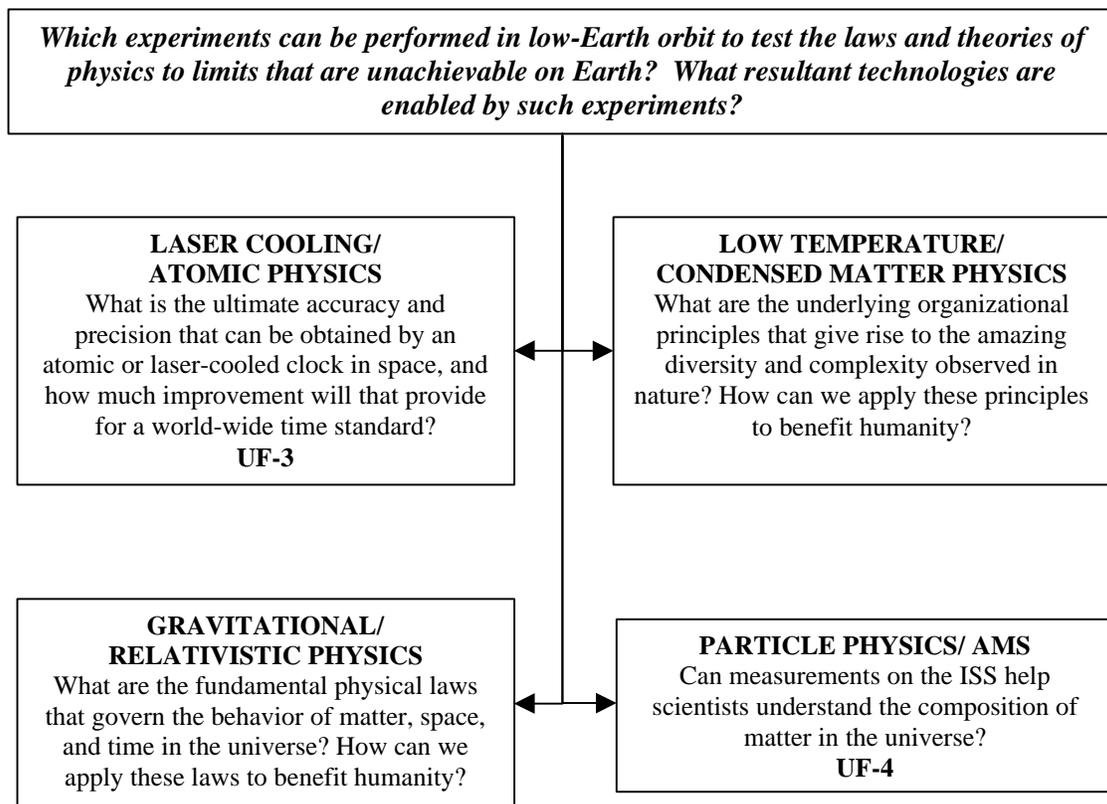
NASA’s previous fluid physics research has already influenced our lives on Earth. Studies conducted on the Space Shuttle, for instance, demonstrated how the boiling process works and may lead to more efficient designs for power production. Other research created improved shock absorbers and clutch controls, leading to safer automobile designs. Long-duration, continuously monitored research aboard the ISS will provide researchers unparalleled opportunities to increase our understanding of fluid physics. The knowledge gained from such research holds the potential to influence a wide range of technological processes on Earth: improved power plant performance, more efficient oil recovery, safer building engineering techniques, and other industrial processes.





FUNDAMENTAL PHYSICS

Fundamental physics is the foundation upon which virtually all scientific knowledge and applied technology rest. Certain research is best performed in a microgravity environment, where the development of uniform samples, the free suspension of objects, and the lack of mechanical disturbance on an experiment allows scientists to test the fundamental laws that govern the physical world. Without the obscuring effects of gravity, selected ISS experiments will allow scientists to obtain new or substantially better results than can be achieved through ground-based research. Until recently, experiments in low-gravity focused primarily on low temperature and condensed matter physics experiments. Based on a recommendation by the Space Studies Board (4), research has been expanded to include laser cooling and atomic physics. Airline safety, for example, has already benefited from ground-based research with atomic clocks; in the future, space-based atomic clock research will enable the increased precision necessary when we venture beyond the Earth-Moon environment. Additional fundamental physics research conducted in the microgravity environment of the ISS will enable the technologies of tomorrow.





GRAVITATIONAL BIOLOGY AND ECOLOGY

Studies in gravitational biology and ecology seek to advance our understanding of how the ubiquitous force of gravity affects the many stages of plant and animal life. These investigations probe basic processes in the novel environment of microgravity in order to reveal the role of gravity in the evolution, development, and functions of living systems, and similarly, to characterize the role of gravity in an organism’s interaction with its environment. Variable gravity conditions on the ISS centrifuge will provide a unique opportunity to investigate fundamental questions of gravitational biology, leading the Space Studies Board of the National Research Council to suggest that additional studies into this discipline be given high priority in future NASA research, both on the ground and on the ISS (1).

A better understanding of the role that gravity plays in the growth and development of microorganisms and plants, for example, will validate the feasibility of using these organisms in life-support systems (e.g. environmental control and food production) during long-duration space missions. Further research into seed-to-seed germination, built on the success of previous Space Shuttle and *Mir* missions, may allow Earth’s farmers to increase their crop productivity. Additionally, gravitational biology research will increase our understanding of the fundamental biological mechanisms that regulate plant and animal life on Earth, promising a wealth of benefits for terrestrial industries.

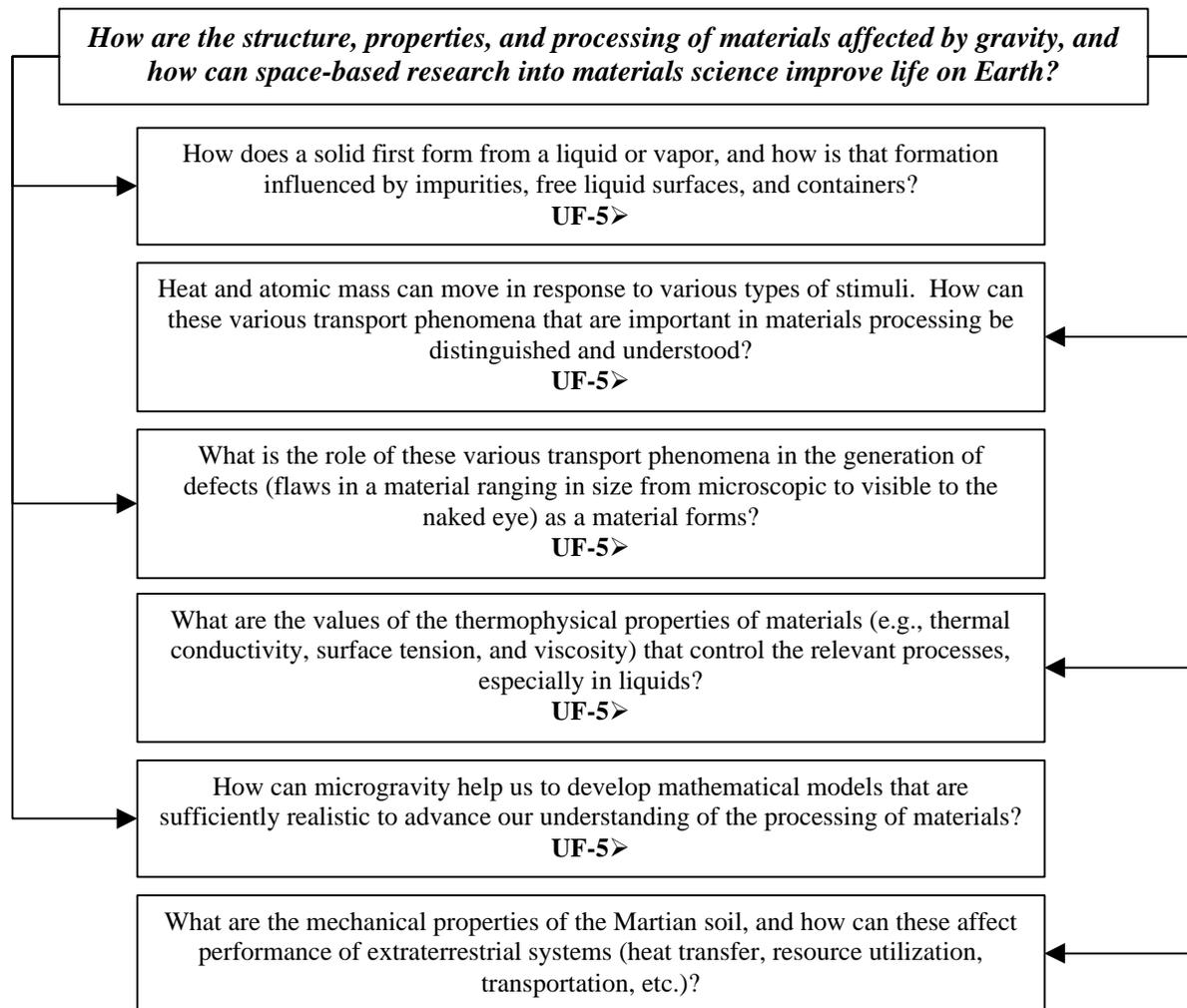




MATERIALS SCIENCE

Materials science research investigates the relationships between the structure, properties, and processing of materials. On Earth, these relationships are strongly influenced by gravity. Microgravity conditions, on the other hand, give researchers the opportunity to study materials processing without buoyancy-induced convection, sedimentation, or hydrostatic pressure, the effects of which often yield sub-optimal properties for a material. Microgravity also provides the chance to investigate “containerless processing,” an approach which removes the possibility that a material’s container may contaminate or influence the final product.

The potential benefits of materials science research have led the Space Studies Board to recommend long-duration, space-based research into materials science (4). Previous research has generated numerous technologies for Earth applications. Semiconductors and infrared and X-ray detectors developed through space research are used in industries ranging from medicine to remote sensing. Other space-based research has improved ground-based production processes for ceramics and glasses, which prevent the formation of imperfections that can lead to catastrophic failures. Additional long-duration studies conducted on board the ISS will increase and improve materials and production processes for a number of Earth-based products, ranging from improved glass materials, ceramics, and semiconductors to efficient engine designs, safer structures, and new technologies.

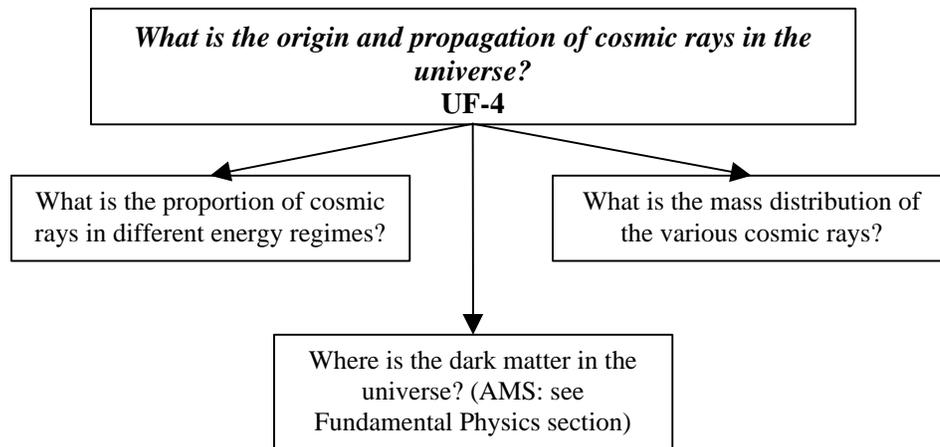




SPACE SCIENCE

From its orbital position, the ISS affords researchers a long-term “window on the universe” from which to study the structure and evolution of the cosmos. The ISS will provide externally attached exposed sites for payloads, as well as a view of deep space in all directions. This unique venue offers the opportunity to pursue investigations into solar studies, cosmic rays, the physical and chemical composition of the space environment, as well as the presence of dark matter in the universe (5, 6, 7). In addition, the ISS serves as a long-term testbed for technology that can be utilized on robotic missions to other planetary bodies. Astronauts will be able to observe trends, respond to the unexpected, and refine and alter research plans when necessary. The ISS crew will also be able to repair damaged systems that otherwise might jeopardize the achievement of scientific objectives.

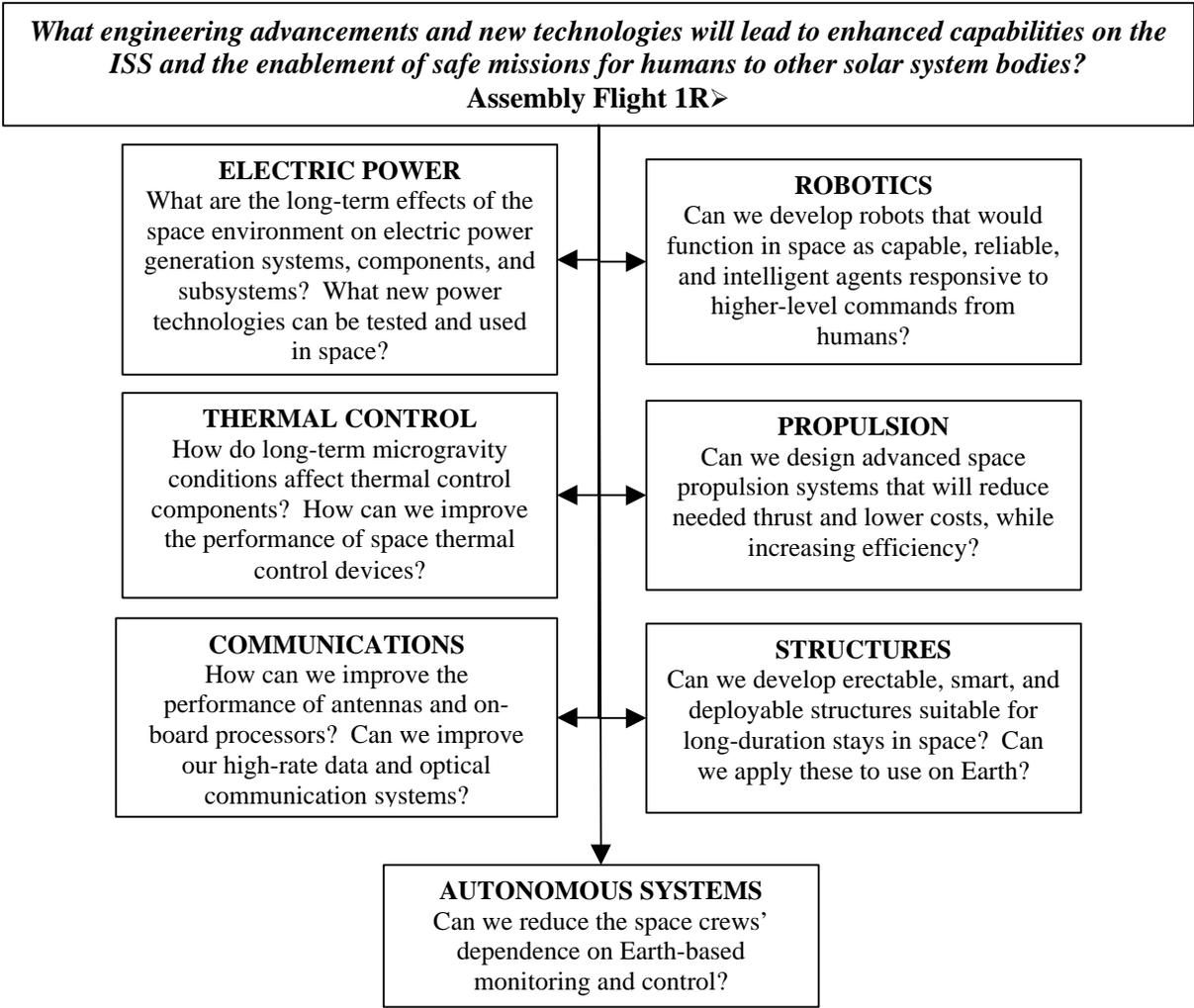
NASA’s previous space science research uncovered evidence of water on our Moon, the possibility of frozen seas on Jupiter’s moons, and a developing solar system around a nearby star. The Hubble Space Telescope has allowed scientists to see farther across space and time than ever before. With a vision for the near-Earth environment and beyond, space scientists can gain further understanding of the sun and our planet’s spatial environment that will have practical applications. Studies of the sun’s effects on Earth, for instance, will improve our forecasts of events ranging from the temporary disruption of telecommunications to the long-term alterations in climate. ISS research will bring us knowledge and insight not only about the far reaches of space, but also about our own planet.





ENGINEERING RESEARCH AND TECHNOLOGY DEVELOPMENT

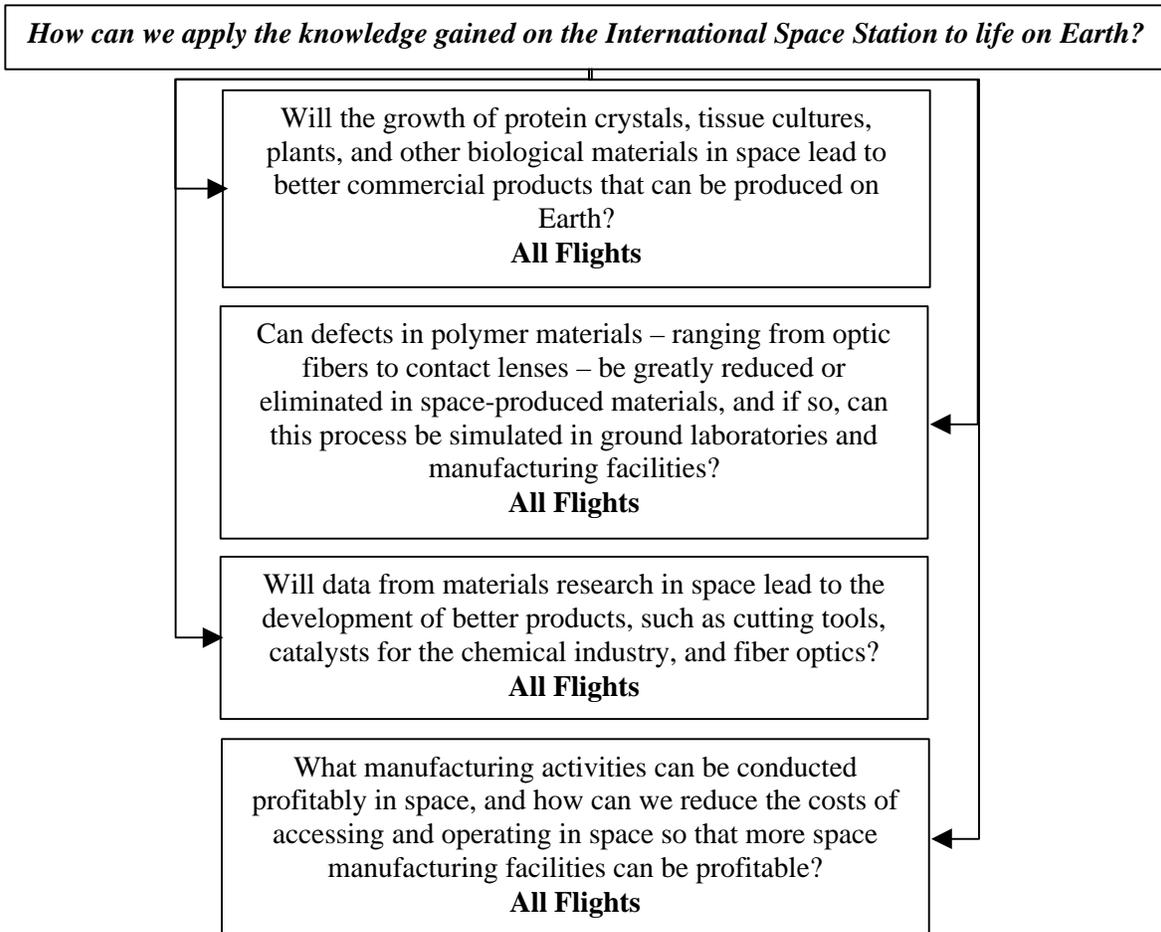
Advances in engineering research and technology development (ERTD) have the significant potential to affect many facets of life on Earth, by reducing costs and improving the performance of future government and commercial activity in space, and enhancing the quality of life on Earth. Because of the numerous benefits of ERTD research, the National Research Council has identified several areas of ERTD that would benefit from experimentation aboard the ISS (8). ISS research will allow us to validate the engineering systems necessary for long-duration space exploration, including power generation and storage, robotic manipulation capabilities, automatic maintenance, and spacecraft control. Eventually, these new technologies will allow future space explorers to rely less on the support systems of Earth and to devote more time to research and exploration. New applications, processes, and technologies developed by ISS engineering research also promise to benefit the telecommunications, water and power, construction, and other industries on Earth.





SPACE PRODUCT DEVELOPMENT

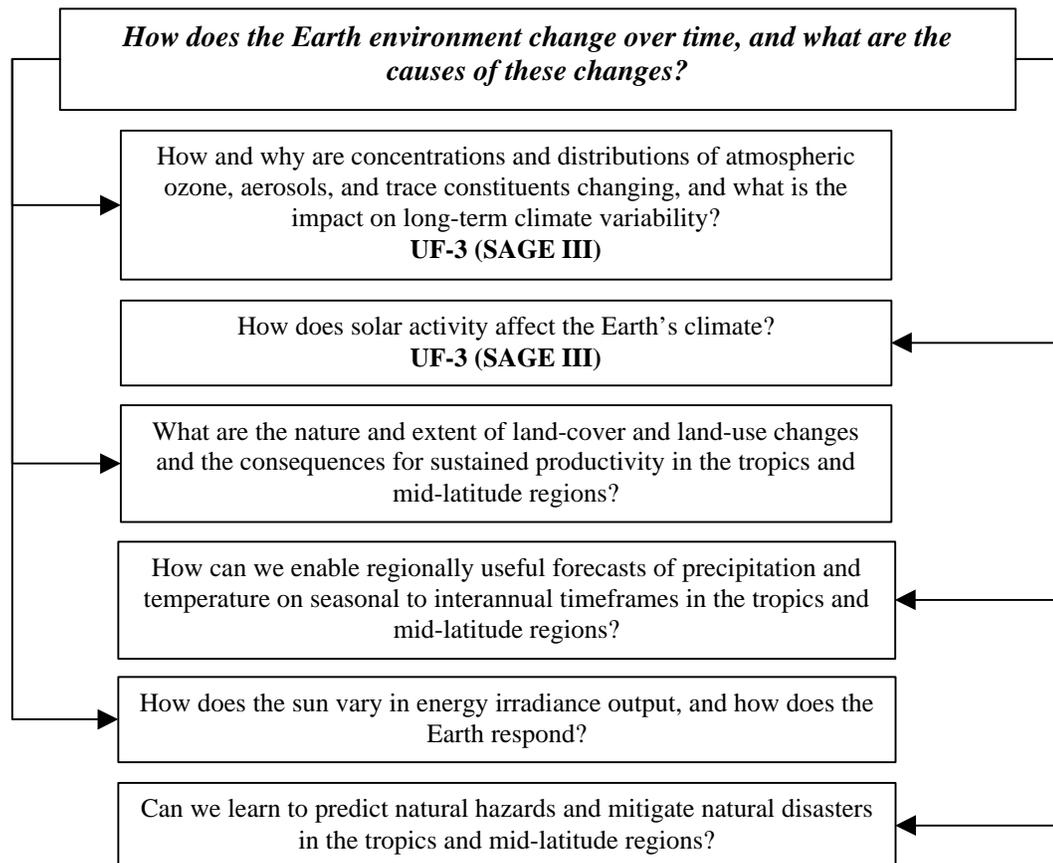
Of all of the scientific questions that can be asked and answered on board the ISS, there will be an aspect of “What can we do with this?” Commercial researchers will springboard off of basic science and engineering to use the ISS as a platform for commercial research and product development. Industries will be able to use the knowledge gained from ISS research to create new products and processes, gain competitive economic advantage, and create new jobs. Many of the new technologies will likely benefit the medical and pharmaceutical fields, the electronics and chemical industries, and the engineering community, among others.





EARTH SCIENCE

The orbit of the ISS will cover over 75% of the planet’s surface, making it a useful platform for ongoing Earth science research. From this vantage point, scientists can assess the global trends that have far-reaching implications for our future: atmospheric and climate change; weather patterns; vegetation and land use patterns; and food, water, and mineral resource use. Recent Earth science observations, for example, have given scientists new insight into global warming, the ozone layer, and El Niño. In addition to its location, the ISS also has the benefit of human operators in the research loop; that is, astronauts on board the ISS will be able to respond to the unexpected—for example, cataclysmic events such as earthquakes and volcanic eruptions—and alter the research as necessary. Earth science research on the ISS will give us a “window on the world” to monitor and understand the factors affecting the quality of life for us and for future generations.





CONCLUDING REMARKS

As the International Space Station enters the assembly phase, we are clearly on the verge of a new era in scientific research. In some instances, experimentation on the ISS will allow us to better seek solutions to overarching questions that have puzzled scientists for centuries. Away from the ubiquitous gravity of Earth, an international cadre of researchers will pursue experimentation that is possible only through continuous, long-duration access to space. Coherent and aggressive campaigns that combine appropriate ground-based efforts with ISS research will provide answers to these important questions in science and technology. As we seek out these answers, we will undoubtedly uncover new and exciting branches of research that may cause us to refine—perhaps even alter—our questions and their priority. Just as today’s science fiction may be tomorrow’s technologies, tomorrow’s industries

We do believe that the questions with which we begin today have set us upon the correct path. The peer-review process will continue to guide us in the selection of the most scientifically sound hypotheses to be tested on the ISS. The scientific and technological communities will continue to send their best and brightest to this research platform and they will be armed with innovative approaches that maximize the value of the ISS and its potential for discovery. As we embark upon our journey of discovery in this new era, we will continue to disseminate the results and benefits of space research. This approach to the utilization of space as a scientific and outreach resource will lead to the evolution of tomorrow’s advanced technologies, the development of new and exciting industries on Earth, and an improved quality of life for each of us.



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Internet Web Pages

Office of Life and Microgravity Sciences and Applications <http://www.hq.nasa.gov/office/olmsa/>

Life Sciences <http://www.hq.nasa.gov/office/olmsa/lifesci/index.htm>

Microgravity Sciences (includes biotechnology, combustion science, fluid physics, fundamental physics, and materials science) <http://microgravity.hq.nasa.gov/>

Space Product Development <http://www.hq.nasa.gov/office/olmsa/spd/index.htm>

Research Opportunities <http://peer1.idi.usra.edu/>

Office of Earth Science <http://www.earth.nasa.gov/>

Office of Space Science <http://www.hq.nasa.gov/office/oss/>

Human Exploration and Development of Space (HEDS) <http://www.hq.nasa.gov/osf/heds/>