Paper Session II-B - Research Plans for the International Space Station

William P. Gilbreath

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Research Plans for the International Space Station

Dr. William P. Gilbreath

The International Space Station, now under construction by all of the leading space-faring countries around the world, will provide a tremendous asset to the international research community. It will not only enhance and broaden present research objectives, but also enable new research initiatives only achievable on such a well-equipped platform. NASA is working with the international research community to develop a coordinated plan for on-board research. The International Space Station research platform will provide an excellent sustained low gravity environment for laboratory research, as well as a robust long-term platform for observational research. Studies in fundamental physical, chemical, and biological processes will be possible. This paper provides an overview of the objectives in a variety of research disciplines, including life and biomedical science, aerospace medicine, microgravity science, earth science, technology research and commercial research and development.
Research Plans for the International Space Station

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INTRODUCTION

Concerted and continuous usage of the International Space Station, ISS, by researchers is now less than 3 years away. The first Utilization Flight (UF1) in March 1999, just following the launch of the U.S. Laboratory (USL) module, will bring seven research racks to orbit; outfitting of the USL will be completed by Utilization Flight-2 (UF2) just five months later. The outfitted USL will offer to the researcher a diverse suite of select science, engineering, and applications hardware. However, even before the presence of the USL, plans are being developed to take advantage of earlier, limited, research capabilities, both in the ISS pressurized volume and on its external structure. This paper outlines the research capabilities offered by the ISS, discusses the current research planning for this platform and describes a limited number of the research activities proposed. Although focused toward the assembly phase (through 2002), the research described here sets the framework for all future activities. In a number of cases the specific program will continue well into the Assembly Complete era.

Research utilization of the ISS falls into a number of areas of endeavor, extends across several eras of increasing resource capabilities, and includes many research communities representing five international partners (IP). Two of these dimensions depicted in Figure 1, show planned participation in various research areas by the ISS Partners. This chart further indicates the relative level of program maturity and expected ISS emphasis estimated by the IP. Commercial interests and participation mber of United States, Japan and Europe (ESA). The diversity of potential research shown reflects the capability of ISS to include the following payload categories: attached, external payloads for observational and environmental research; other viewing payloads, internally located, which require ‘hands-on’ services; and a huge variety of additional internal payloads which will utilize long-term stable microgravity conditions coupled with adequate operating resources.

Figure 2 depicts the build-up in research-utilized facilities aboard ISS over the planning period discussed in this paper. Shown is the anticipated emplacement point for each pressurized laboratory and attached site that will be available to researchers. Note that this chart is not derived from a baselined assembly sequence, and finalized launch dates are expected to differ from the ones projected here.

During an initial four-year period extending into Phase 3, users will share resources with station assembly tasks. The assembly share is in addition to those resources always required for station operations and maintenance and thus, during assembly, there is a lessened capability for research compared to post-assembly—which starts in mid-2002. (Phase 1 of the space station encompasses earlier cooperative NASA and Russian Space Agency, RSA, research utilizing Shuttle and Mir platforms.) The boundary between Phase 2 and Phase 3 occurs when the air-lock is installed and the ISS becomes self-sufficient; however, for researchers the transition is actually six weeks
earlier (February 1999) when the first research racks are installed in the USL from UF1. At this evolutionary boundary the ISS changes from a very limited platform with sparse resources supporting only limited activities in few disciplines with two participating space agencies, (NASA and RSA) to a major, expanding research platform; eventually offering full capabilities for all partners to simultaneously pursue the disciplines of Figure 1.

Figure 1: Planned utilization of the International Space Station.  
(Figure adapted from: Space Station International Science and Technology Utilization Plan, June 10, 1995, Office of Space Flight, NASA Headquarters, Washington DC 20546)

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<tr>
<th>RESEARCH DISCIPLINE</th>
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KEY
- Partner interested but no conceptual program exists for ISS and no budget currently defined.
- Active planning at agency level for eventual ISS implementation, schedules likely exist and budgets proposed but not approved.
- Program is in preliminary stage with active ground based activities and budget likely approved through at least Phase B design.
- Mature program with at least some of the Principal Investigators selected, flight hardware is in design or fabrication and program approved.
- Commercial interests defined and entities working with agency leading to eventual participation on ISS.
Figure 2: Anticipated implementation plan for ISS research modules and attached payload sites. (Abbreviations are defined in the text.)

**Research and User Activities Initiated During Phase 2**

Phase 2 begins with the ISS first element launch (FEL) in November 1997, a milestone that also initiates the ISS Aerospace Medicine program “Crew Health Care System” (CHeCS). This Program is charged with developing medical requirements and ensuring ISS mission success by providing comprehensive crew health care protocols pre-, in- and post-flight. The first on-station hardware for CHeCS as well as certain research disciplines appears with the Service Module (SM of Figure 2) and the capability for Permanent International Human Presence in Spring 1998. Aerospace Medicine, although not a research discipline, through use of CHeCS’ state-of-the-art medical hardware coupled with regular and extensive access to long duration ISS crews, generates unique life science information. Provided at this early date are: all needed medical care equipment; a subset of crew health maintenance (including a treadmill) and monitoring gear; and limited environmental (air and water quality) monitors. To avoid later duplication of life science research facilities, certain of the CHeCS hardware incorporates agreed-to research level requirements. Toward the end of Phase 2, a full rack of CHeCS equipment will be installed in the USL and additional racks for CHeCS will be installed with the Habitation Module in 2002.

Within the Service Module, RSA will have limited capabilities for dedicated payloads to pursue biotechnology investigations, including protein crystallization, and Earth and atmospheric observations—the latter to study spatial and temporal variations in trace constituents. Also during this early period and continuing into Phase 3, RSA will participate with NASA in CHeCS and will also pursue independent medical research investigations.

Several early ISS-external investigations are planned. To investigate the dynamics of large space structures, flight 4A in September 1998 will carry a pre-integrated instrument package (the Autonomous Dynamics Detector, ADD) on the Port truss. Many self-contained accelerometer modules will be r/f linked to a central receiver/transmitter, enabling dynamic response data to be collected for several years. Additional plans are underway to install witness plates at several truss sites during Phase 2. These would be used to monitor the external environment experienced by the ISS and to test optics and coatings for degradation. To study performance, assembly techniques, and human factors a large format camera will be mounted in the Orbiter cargo bay on a number of flights beginning with 2A in order to film various EVA and robotic assembly tasks. This filming will continue through assembly and after the USL is brought to orbit an internal
camera will also be employed to capture research operations and film the exterior activities through the view ports.

**Research and User Activities Beginning with Utilization Flight 1**

Overall Planning and ISS Research Capabilities:

Beginning with UF1, researchers will be offered increasingly improved research capabilities over a four-year period until the ISS final configuration is achieved. Figure 3 lists the capabilities for major resources at final ISS configuration, occurring with addition of the ESA Columbus module. In comparison, a typical Spacelab flight offers 300 hours of crew-time and eight-double racks to its researchers.

Figure 3: Estimated final configuration ISS research capabilities for all Partners

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powered research internal sites</td>
<td>50 (assumes 13 for RSA) racks</td>
</tr>
<tr>
<td>Attached sites</td>
<td>4 NASA Truss, 10 JEM sites, RSA SPP</td>
</tr>
<tr>
<td>Passive stowage sites (double rack equivalents)</td>
<td>10 NASA and &gt;5 for others</td>
</tr>
<tr>
<td>Power (average annual)</td>
<td>&gt;40 kW</td>
</tr>
<tr>
<td>Crew time (annual total)</td>
<td>8000 h rs</td>
</tr>
<tr>
<td>Resupply flights (annual)</td>
<td>5 Shuttle (4 pressurized and 1 for attached payloads) plus other flights by NASA, ESA and RSA</td>
</tr>
<tr>
<td>Communications (Ku down-link)</td>
<td>&gt;35.5 mbps, NASA only</td>
</tr>
<tr>
<td>Microgravity periods (days per year)</td>
<td>&gt;180 days in at least 30 day blocks</td>
</tr>
</tbody>
</table>

Sequentially, as shown in Figure 2, Phase 3 research capabilities will be made available in-the USL, then at two RSA provided locations [the Science Power Platform (SPP) and Universal Docking Module (UDM)], the US Starboard truss sites, the NASA JEM payload module (JEM PM), a RSA Research Module (RM-1 ), the JEM Exposed Facility (JEM EF), the NASA Centrifuge Accommodation Module (CAM), a second Research Module (RM-2), and finally the ESA Columbus Orbital Facility (COF).

All partners have plans to utilize the research laboratories and attached sites as they are emplaced, as projected in Figure 2. However, in almost all cases, as the research facilities and payloads are not integrated at the launch of these laboratories or sites, outfitting must await an appropriate subsequent flight opportunity. Likewise, research operations require resupply. Beyond a limited quantity of raw materials or expendable items included with an initial payload launch most research depends on a future stream of flights. Thus, realization of full capabilities for a given laboratory module or external site may not actually occur for several years after emplacement. The general plan is to provide modest initial research capabilities for as many disciplines as possible (Figure 1), then to add more sophisticated research equipment as ISS power, volume, data, etc. capabilities increase. By 2003 the ISS will have reached steady state as far as available resources (Figure 3), including laboratory volume and attached sites. At this point (Figure 2), given an outfitting flight following the COF, all research locations will be filled. After this date, racks and new payloads must displace articles already on-orbit. Planning for some of this second generation hardware is underway. For example; in
the life science area, research hardware for a third and fourth Human Research Facility (HRF) rack to replace at least portions of the first two rack facility is planned.

The International Partners gain access to their full research share as they bring their modules or elements to ISS. The USA and Russia have immediate research access since they contribute the first elements. ESA, otherwise restricted to usage after assembly is completed because of the COF delivery schedule, is negotiating a bilateral agreement with NASA for early utilization. Thus, some of these earlier ESA-proposed cooperative payloads are describe here.

Following is a very abbreviated discussion of proposed Phase 3 payloads selected to indicate the breadth of proposed ISS research.

**Earth Science**

Payloads for Earth science research will be located so as to provide nadir viewing capability either on external framework of the ISS or when more active intervention is required internally at a window site. The Stratospheric Aerosol and Gas Experiment-III (SAGE-III) detector and electronics package is externally mounted and views the sun through the Earth's limb in order to retrieve global profiles of atmospheric aerosols, \( O_2 \), \( ClO_2 \), \( NO_3 \), \( NO_2 \), \( H_2O \), temperature, and pressure, and by measuring solar extinction at appropriate wavelengths. SAGE-III will use the spatial and temporal variability of the measured parameters to determine their role in climatic processes, biogeochemical cycles and atmospheric chemistry. This information will be used to determine and predict long-term atmospheric trends and to provide calibration data for sensors on other satellites.

Integrated into the USL and available with its launch will be an Earth-viewing, optical window. This capability will allow study of terrestrial processes and phenomena and testing of new sensors by the ISS crew working in a shirt-sleeve environment. The ISS orbital path makes available 80% of the Earth's land and sea surface for active Earth observation investigations. The nadir viewing window has 51 cm of clear aperture, consisting of three fused silica panes with spectral transmittance from mid-UV through reflected solar infrared and a desired 1/7 lambda wavefront error. Mounting hardware for sensors and full ISS utilities will also be available at the interior window workstation.

**Engineering and Technology Development**

The permanent availability of a space test-bed with the rich resources of the ISS will enable the pursuit of anticipated gains in many technological that are supportive of both Earth- and space-based needs.

**Communications:** The communications industry with its heavily space-based infrastructure will directly benefit from advances made possible in components and systems which can be demonstrated and modified on the ISS while being tested in an environment similar to that expected during normal operations.

**Instrument Systems:** The Canadian Space Agency (CSA), NASA and NASDA have the strongest interest in developing and demonstrating lighter, lower power, higher sensitivity, and lower cost instrument packages to enhance both space mission and commercially important remote sensing technologies. The ISS provides an ideal testbed for validating telescopes, spectrometers, power systems, imagery techniques, refrigerator and coolers, sensors, etc.
**Power and Propulsion:** Power is the limiting resource for many space-based operations, and the attainment of lower cost, higher specific energy, and more robust systems can be effectively pursued with the ISS test-bed. Technology studies also will be pursued to reduce the adverse effect of propulsion plumes on sensitive spacecraft systems (thermal coatings, solar panels, windows etc.) and external payloads.

**Robotics:** Enhanced robotics and teleoperation technologies important in servicing the ISS and its attached payloads are of special interest to CSA, provider of the ISS remote manipulator. Extension of this technology to service satellites is a key objective.

**Space Environment and Effects:** All partners have a uniform high interest in assessing the stability of materials (solar cells, optical coatings, passive thermal controls, structural elements, antennas, mechanisms, etc.) exposed to the space environment (ionizing radiation, plumes, orbital debris, thermal, solar, etc.) and will provide payloads to be mounted at several external ISS sites. ISS provides a unique platform for the long duration measurements needed in order to develop accurate models of behavior under various conditions leading to more cost-effective spacecraft designs, materials, and test protocols. The Office of Space Access and Technology, OSAT, is considering the Materials Exposure Facility (MEF) as the major platform for this work. MEF would occupy an entire Starboard Truss site and include the ESA Environment Exposure Package (EEP). RSA, with its Astra and Tros-2 payloads will be one of IPs interested in measuring the external atmosphere parameters of ISS.

**Microgravity Research and Applications**
Over half of ISS utilization falls within this very broad discipline area (see Figure 1). These research activities will utilize 13 racks of facility dedicated equipment (e.g., Human Research Facility, HRF, and Space Station Furnace Facility, SSFF) plus six racks of commercial directed equipment from the USA and at least 10 science and commercial mixed-purpose racks from other partners. Additional payloads at many attached sites will also support this research area.

Figure 1 shows that there is commercial interest among the various partners in each sub-discipline area of this category. Programs supporting both the commercial development of space and scientific investigations will provide facilities and payloads in this discipline. In certain cases separate equipment is needed to pursue quite differing science and commercial processes while in other cases, although the objectives and materials may differ—common, shared hardware will be employed. As examples, ESA is providing a microgravity sciences glovebox that is equally shared by NASA between science and commercial programs; NASA’s OSAT provides an X-ray Diffraction Facility that will be supportive to many areas. This is the particular case with the protein crystal studies as it will enable on-board analysis.

**Biotechnology:** This dominating economic influence for the twenty-first century will be a key discipline on the ISS as enhanced understanding of the manipulation of cells, tissues and biological molecules is sought by the use of sophisticated instruments and techniques for promoting growth, enhancing viability, and allowing study of living systems. The growth of large protein crystals and resulting structural analyses are central to progress in many biological sciences. The micro-g environment also promotes and allows understanding of three-dimensional tissue culturing, complex tissue culturing in vitro, and other aggregation and differentiation studies. Commercial biotechnology (including the commercial aspects of biotechnology, gravitational
biology and biomedical research) objectives are to generate biomedical and agricultural goods and services which either provide higher purities and/or greater process efficiencies and even unique products which cannot be produced on Earth and then to understand how these processes may at least be partly replicated on Earth. Activities in plant biology will focus on enhancing agricultural productivity and pharmaceutical products; protein crystal growth on both characterizing and designing specific proteins; isomorphism experiments on using animal models for immune system responses and osteoporosis studies; and bioprocessing on developing improved membrane casting, microencapsulation techniques, and liquid/liquid diffusion in order to provide superior implant and replacement materials, organs, etc.

Life Sciences: Some 10 equipment racks plus a large centrifuge facility will be provided by the partners to support the biomedical and gravitational disciplines of Figure 1. The overall life science ISS program objective is elucidating the role of gravity (or lack thereof) on living systems as it relates to Earth-based health problems. Gravity is of special importance in the development and function of all organisms. ISS will permit control of this variable and enable study of its effect over long periods in many species using sophisticated equipment and world-class scientists. The unique ISS gravitational biology and centrifuge facilities will be used to answer questions on how gravitational information is processed; how cells, animals and plants respond—including growth, development, reproduction, genetic integrity, aging and effects on subsequent generations—to both acute and long-term variations in gravity. Although fundamental, this knowledge is essential to long-term space habitation and to improving health care on Earth. The understanding of effects of space flight on human physiology and underlying mechanisms will be used to develop countermeasures for extended-duration missions. Other life science studies will focus on advanced life support technologies using the ISS as a testbed for long-duration mission modeling. Investigations in human factors engineering will prepare crews for longer duration flight and isolation by enhancing understanding of performance, motivation, social interactions, etc., under these conditions. Within the NASA cooperative program ESA will provide the Space Exposure Biology Assembly (SEBA), a thermally controlled facility with a three-year exposure period and yearly sample change-out, to examine the effects of the combined environment and microgravity on seeds, spores, lower organisms, etc.

Materials Science and Processing: Materials science seeks to understand underlying physical and chemical principles necessary to predict the relations of processing materials to their resulting structures and properties while commercial aspects focus on specific product development. The first furnace module planned for the SSFF will be the Crystal Growth Furnace. It is used for thermophysical property determinations. Materials processing activities are projected to include the following fields of commercial research: electronics to provide more defect free crystals especially materials which are difficult to grow in 1-g in order to manufacture faster computer chips, higher temperature semiconductors, improved circuitry and switching devices, and superconducting electronics; fiber optics, where commercial quantities may be prepared on the ISS using fluoride based feed stock for fibers to produce minimal crystallization and exceptional clarity products; casting technology to enhance understanding of surface tension and viscosity effects, improving computer software for process control; and, space structures based on rigidized foam material technology. Certain materials investigations will be placed at ISS external sites to take advantage of that environment. RSA, utilizing attached sites on its Science Power Platform (SPP) proposes to develop processes for fabricating materials using molecular-beam epitaxy
under the space high vacuum conditions and also to grow large, high purity, low defect, semiconductor monocrystals employing a solar furnace. The Isothermal Dentritic Growth Facility will be upgraded from its current Orbiter bay configuration to provide much longer term experiments on an attached site.

*Combustion Sciences and Applications:* ISS enhances fundamental studies of processes that are key to air pollution, global heating, waste disposal, combustion efficiency, fire safety, etc. by allowing researchers to control convection and transport conditions while precisely imaging and measuring other control parameters (e.g., fuel, atmosphere and temperature). For this work, NASA is planning a Combustion Module Facility, that will be coupled with a core controller and Fluids Module.

*Fluid and Low Temperature Physics:* The fluids work on Space Station will explore the fundamental properties of liquids and gases under micro-g conditions. Understanding this behavior is critical for precise control of processes that involve fluid phase transitions. Fluid experiments will have a test chamber and normally: cameras, laser optics, heaters, precise temperature and pressure control, sensors and necessary operating software. NASA's Low Temperature Microgravity Physics Facility (LTMPF) will be used on the JEM Exposed Facility beginning in 2002 to investigate fundamental behavior of phase transitions and the dynamics of quantum fields. The LTMPF uses a 2° K liquid helium dewar for containment and relies on telescience for operations.

*Space Science*

The Alpha Magnetic Spectrometer (AMS) is an experiment to detect and measure the abundance and composition of anti-particles outside the Earth’s atmosphere as a test of Dirac’s symmetry of matter hypothesis. The AMS experiment provides a 105 detection enhancement over previous tests as it looks for cosmic rays generated by matter-antimatter interactions. These cosmic rays are markers to determine if the universe is matter/anti-matter symmetric, and if anti-matter exists in more complex—elemental rather than sub-atomic arrangements. The AMS permanent magnet is over 2 M tons and with its instrument package requires an entire attach site. It will be placed on the Starboard Truss in a zenith viewing position for a period of at least 3 years.

As part of their NASA cooperative research ESA has proposed a long term solar observation program to study both large and small scale temporal, spatial and spectral variations in corona, flares, sun-spot activity, hydrodynamics, and other features. The Sun Monitoring Assembly (SMA), occupying part of a Starboard attached site, will provide 10 minutes of solar viewing per orbit and is expected to be autonomous except for possible instrument up-grades and sensor replacements.

**Concluding Remarks**

By 2003 there will be well over 1000 investigations assigned to the ISS. More than 10% of these will normally be operating ‘simultaneously’ during a given research interval on ISS; the remainder will be in the ‘pipeline’ either as developing programs or in the data analysis phase. Some ISS investigations have been selected and other solicitations leading to ISS research and activities are now on-the-street. Currently, Russia already has accepted 207 proposals. NASA has many investigators in ground- and shuttle- or Mir-based research activities awaiting further maturity in their studies before being assigned to the ISS. Plans are in-hand to assure that these researchers will have a premiere platform, adequate resources and state-of-the-art facilities for their work.