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THE INTERNATIONAL SPACE STATION AS A RESEARCH LABORATORY - A VIEW TO 2010 AND BEYOND

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ABSTRACT

Assembly of International Space Station (ISS) is expected to be complete in 2010, with operations planned to continue through at least 2016. As we move nearer to assembly complete, replanning activities by NASA and ISS International Partners have been completed and the final complement of research facilities on ISS is becoming more certain. This paper will review plans for facilities in the US On-orbit Segment (USOS) of ISS, including contributions from International Partners, to provide a vision of the research capabilities that will be available starting in 2010.

At present, in addition to research capabilities in the Russian segment, the United States *Destiny* research module houses nine research facilities or racks. These facilities include five multi-purpose ExPrESS racks, two Human Research Facility (HRF) racks, the Microgravity Science Glovebox (MSG), and the Minus Eighty-degree Laboratory Freezer for ISS (MELFI), enabling a wide range of exploration-related applied as well as basic research. In the coming years, additional racks will be launched to augment this robust capability: Combustion Integrated Rack (CIR), Fluids Integrated Rack (FIR), Window Observation Rack Facility (WORF), Microgravity Science Research Rack (MSRR), Muscle Atrophy Research Exercise System (MARES), and additional MELFI and ExPrESS racks. In addition, ExPrESS Logistics Carriers (ELC) will provide attach points for external payloads.

The European Space Agency's *Columbus* module will accommodate 10 research racks and provide four external attach sites. The European research racks are Biolab, European Physiology Module (EPM), Fluid Science Lab (FSL), European Drawer System (EDS) and European Transport Carrier (ETC). The Japanese *Kibo* elements will support 11 research racks and 10 attach sites for external payloads. The Japanese research racks are *Ryutai* for fluid science, *Saibo* for cell science, *Kobairo* for materials research and two additional future research racks.

As we look ahead to assembly complete, these new facilities represent a threefold increase from the current research laboratory infrastructure on ISS. In addition, the increase in resident crew size from three to six in 2009 will provide the long-term capacity for completing research on board ISS. Transportation to and from ISS for crew and cargo will be provided by a fleet of vehicles from the United States, Russia, Europe and Japan, including accommodations for thermally-conditioned cargo. The completed ISS will have robust research accommodations to support the multidisciplinary research objectives of scientists worldwide.

INTRODUCTION

Assembly of ISS began in November 1998 with the launch of the Russian-built *Zarya* module, followed by several assembly flights to add the *Unity* Node 1, the *Zvezda* Service Module, the first truss element, the first set of solar arrays and communications system. The first Expedition crew arrived in

November 2000, and ISS has been permanently crewed ever since, with rotating crews of astronauts and cosmonauts staying on board for four to six months, continuing assembly, maintaining the station and conducting research. The station's research capability was steadily enhanced as new racks were delivered by a number of Space Shuttle missions and installed in specific locations in *Destiny*, the US research laboratory module. In the next few years, research modules from ESA and JAXA will be added along with capabilities for external payloads.

ISS TODAY

Assembly of ISS [1] is approximately 60% complete, with an on-orbit mass of 236,700 kg. Its current configuration, with an overall length of 45 m along the core and a 58-m wingspan, is shown in Figure 1. The total habitable volume of 411 m^3 is distributed

Figure 1. ISS overall configuration today, taken by the departing STS 118/13A.1 crewmembers in August 2007.

across six permanent modules: *Zvezda* Service Module, *Zarya* stowage module, *Pirs* Russian airlock, *Unity* connecting Node 1, *Quest* US airlock and *Destiny* US laboratory module. Pressurized Mating Adapters provide a docking port for visiting Shuttles and for linking the *Unity* and *Zarya* modules. One *Soyuz* crew transport spacecraft and one or two *Progress* cargo vehicles are docked to the station at any given time. The US solar arrays provide approximately 40 kW of power, while the arrays on the SM provide an additional 1.5-2 kW of power. One additional set of US arrays is already on ISS, but the panels will remain retracted until they are relocated during a Shuttle mission in the fall of 2007. Mobile robotics system provided by the Canadian Space Agency (CSA) enables assembly and maintenance tasks. With the current emphasis on continuing and completing assembly by 2010, crew time available for research is somewhat limited, averaging between 10 and 20 hours per week distributed among the three resident crewmembers.

As of today, the *Destiny* module has been outfitted with nine research facilities or racks. Each rack is based on the generic International Standard Payload Rack (ISPR) design [1], which provides a common set of interfaces in the ISS modules (*Destiny*, *Columbus* and *Kibo*). Services available through ISPR interfaces include: power, thermal management, command and data handling, video, vacuum resources and exhaust system, and provision of gases. More details are provided in Table 1. There is variety among the ISPR locations within each module and among ISS modules with regard to what specific interfaces are provided or available. For example, the low temperature loop for thermal control is only available in *Destiny* and *Kibo*.

Power	3, 6 or 12 kW
Low Rate Data	1 Mbps (1553)
High Rate Data	100 Mbps
Local Area Network	Ethernet 10 Mbps
Video	NTSC
Gases	N, Ar, Co_2, He
Moderate Temp Loop	16.1^oC - 18.3^oC
Low Temp Loop	3.3^oC - 5.6^oC
Venting	10^{-3} torr
Vacuum	10^{-3} torr

Table 1. Standard ISPR interfaces and services.

Five of the racks in *Destiny* are called ExPrESS, short for Expedite the Processing of Experiments for Space Station [2]. These racks provide support for up to eight middeck locker-sized and two drawer-sized payloads. The layout can be single or multiple middeck locker-sized payloads. These racks support payloads in a variety of research disciplines, with payloads launched and returned on Space Shuttles based on the experimenters' requirements. Types of research supported include life sciences, biotechnology, commercial endeavors, fluid physics, materials processing and microgravity acceleration measurements. Duration of experiments has ranged from about 2 months to multiple years, with some payloads, such as those for acceleration measurements essentially becoming part of the station's permanent infrastructure. Two of the current ExPrESS racks are configured with the Active Rack Isolation System (ARIS), a system of accelerometers for sensing disturbances and actuators for countering them.

Two facilities are dedicated to the study of changes in human physiology resulting from long-duration space flight, such as pulmonary changes, cardiovascular adaptations and biochemical changes [3]. The Human Research Facility (HRF) racks 1 and 2 are equipped with a standard suite of hardware to support a wide-range of investigations, and can also accommodate experiment-unique equipment as required. The ultrasound provides high resolution imaging to perform 2D ultrasound and Doppler studies. Pulmonary function and metabolic response to exercise are monitored with the ESA-built Pulmonary Function System (PFS) and the NASA-built Gas Analyzer System for Metabolic Analysis Physiology (GASMAP). A refrigerated centrifuge allows for the separation of biological samples such as blood at +4°C. The Space Linear Acceleration Mass Measurement Device (SLAMMD) enables precise and reproducible measurement of crewmembers' body masses.

The Microgravity Science Glovebox (MSG), built by the European Space Agency (ESA) and operated by NASA, provides a safe environment for conducting research in fluid physics, combustion or other fields that use materials that require some extra level of physical containment [4]. The MSG's 255-l work volume provides this environment, which can be sealed and kept at negative pressure. Crewmembers access the work volume via glove ports on the front of the work volume to set up and manipulate the experiments. The rack provides the supporting services to the experiments.

The Minus Eighty-degree Laboratory Freezer for ISS (MELFI), also built by ESA, provides up to 300 l of continuous conditioned stowage for biological and other life science samples [5]. Four Dewars hold samples at three operating ranges of +4°C, -26°C and -80°C. Conditioned samples are launched and returned on the Space Shuttle in active and passive cold stowage devices.

External payloads have been limited to date primarily because of limited external attach sites. Several suitcase-sized payloads called Materials on ISS Experiments (MISSE) have flown on ISS, attached to handrails on the US Airlock and other sites. The 5 MISSE's flown to date have exposed hundreds of samples of various materials (paints, thermal insulation, optics, solar cells, etc.) for periods of 1 to 3 years, which were then returned for postflight analysis [6].

The infrastructure in place today supports 25-35 investigations during a given 6-month ISS increment. Of these, a small handful involve data collection on the crewmembers only before and after the mission. From five to 10 investigations are conducted during the visiting Shuttle flights, so-called sortie experiments, and do not use any ISS resources.

ISS AT ASSEMBLY COMPLETE

Assembly of ISS is planned to be completed in 2010. Major elements to be added include the *Harmony* connecting Node 2, the European and Japanese pressurized and unpressurized elements, the Canadian dexterous robotics system, the final set of US solar arrays, the ExPrESS Logistics Carriers for external spares and payloads, the Node 3 habitation module, the Cupola for enhanced crew viewing and Russian docking, stowage and logistics modules [1]. Enhanced life support and crew habitation capabilities will allow the resident crew size to grow from three to six in May 2009, providing significantly more crew time for research. Once completed (Figure 2), ISS will have an overall mass of 419,600 kg (by far the largest space vehicle in history), with the new modules increasing the habitable volume to 935 m^3, while overall power generation will increase to 80 kW. A maximum of 34 internal rack locations and more than 22 external attach sites will be available for NASA, CSA, ESA and JAXA research in *Destiny*, *Columbus* and *Kibo* and on the truss elements to meet the exploration and other research goals of the participating Agencies. Table 2 compares ISS statistics today with post assembly complete. The crew time that will be available for research is estimated, based on the best current predictions for station maintenance.

Figure 2. Artist's impression of ISS when completed.

	ISS Today	ISS at AC
Mass (kg)	236,700	419,600
Length (m)	45	64
Pressurized modules	6	14
Habitable volume (m^3)	411	935
Power generation (kW)	40	80
Crew size	3	6
Research crew time - total (hrs/wk)	Up to 20	Est. 70
USOS internal payload racks	9	Up to 34
USOS standard external attach sites	0	22

Table 2. Major parameters of ISS today and at assembly complete (AC), excluding visiting crew and cargo vehicles.

European *Columbus* module

The European *Columbus* module will be added to ISS during a Shuttle flight in late 2007, and has the capacity to house 10 pressurized research racks within the module and four external payloads on the Exposed Payload Facility (EPF) (Figure 3) [7]. Based on interagency agreements, ESA and NASA each has rights to five racks and two external payload sites. The first five racks, all European-built, will be launched inside *Columbus*, and two external payloads will be launched and repositioned to the EPF during the same flight. Four of the five NASA racks are already on orbit and will be relocated from *Destiny* to *Columbus*, while the fifth will arrive on a later Shuttle flight and be installed directly in *Columbus*.

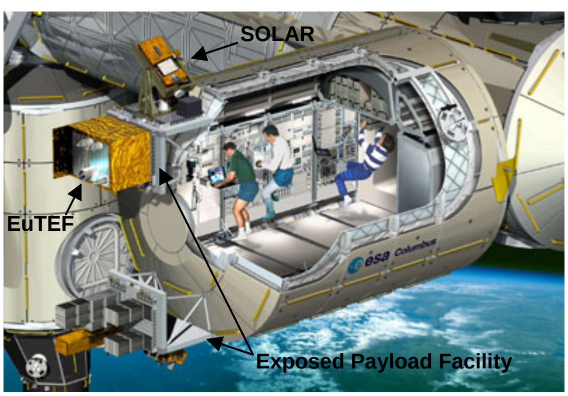

Figure 3. Artist's cutaway view of European *Columbus* Module.

Space biology experiments using microorganisms, cells, tissue cultures, small plants and small invertebrates can be conducted aboard the Biolab facility. This rack contains a 32-l glovebox for manipulating samples, a variable temperature incubator, two small refrigerator/freezers, a microscope, a spectrophotometer and two small centrifuges to provide variable artificial gravity. Biolab's life support systems can regulate the atmospheric makeup of and illumination to experiments.

The European Physiology Module (EPM) will be used to study the effects of space flight on human physiology, with specific emphasis on neurosensory changes, cardiovascular deconditioning, bone and muscle physiology and metabolic processes. The EPM will complement the suite of equipment in the two HRF racks.

The Fluid Science Laboratory (FSL) will enable investigations in fluid science to study dynamic phenomena in the absence of gravitational forces. The rack contains a set of optical diagnostic instruments for visual, thermographic and interferometric observations.

The European Drawer Rack (EDR) is functionally similar to ExPrESS racks, in that it can house multiple (up to seven) payloads in various disciplines, which can be interchanged over time. The rack provides power, cooling, command and data handling, vacuum and nitrogen, as required by the payloads.

The European Transport Carrier (ETC) will provide stowage inside the *Columbus* module to support the other research facilities. Configured to accommodate standard Cargo Transfer Bags, it will also transport supplies to ISS during the Shuttle flight.

To optimize the placement of the research racks to the capabilities of each rack location across the three research modules, several NASA facilities will be relocated from *Destiny* to *Columbus* after the latter's arrival. The two HRF racks will join the EPM to optimize the sharing of the unique capabilities of each rack (a fourth rack to study musculoskeletal changes will be added later – see below). The MSG and ExPrESS Rack 3, containing the European Modular Cultivation System (EMCS) will also be transferred to *Columbus*.

Japanese *Kibo* elements

Installation of the *Kibo* Japanese Experiment Module (JEM) elements will take place over three Shuttle flights: the Experiment Logistics Module-Pressurized Section (ELM-PS) with two research racks stowed on board; the Pressurized Module (PM) with 11 payload rack locations; and the Exposed Facility (EF), equipped with 10 attach sites for external payloads (Figure 4) [2]. A Remote Manipulator System (JEM-RMS) will transfer and service payloads on the EF. Per agreement between the two agencies, JAXA and NASA will each have rights to 5 racks in the PM plus an additional location for a shared MELFI rack, and will equally share the 10 external attach sites. The first two racks will be relocated to the PM shortly after its arrival at ISS, with future racks and external payloads arriving on H-II Transfer Vehicles (HTV). As with *Columbus*, several NASA racks will be relocated from *Destiny* into *Kibo*, including as a minimum one MELFI and one or two ExPrESS racks.

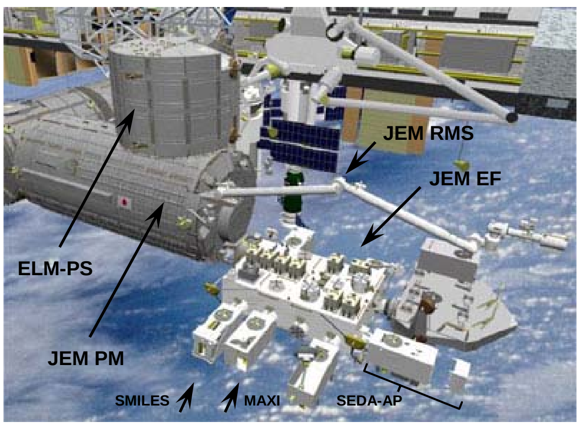

Figure 4. Artist's impression of *Kibo* Japanese Experiment Module (JEM) elements.

The *Ryutai* rack is a multipurpose facility for conducting fluid physics, solution crystallization and protein crystallization experiments. The Fluid Physics Experiment Facility (FPEF) contains various observation capabilities to allow for three-dimensional flow-field observations, surface temperature measurements, and ultrasonic velocity measurements. The Solution Crystallization Observation Facility (SCOF) contains an interference microscope to enable precise growth measurements of samples. The Protein Crystallization Research Facility (PCRF) provides temperature profiles for samples and monitoring of growth via charge-couple devices.

The *Saibo* rack is a facility for conducting cell biology experiments. The Cell Biology Experiment Facility (CBEF) consists of a small variable-gravity centrifuge and an incubator that controls temperature, humidity and CO_2 concentration. The Clean Bench consists of a glovebox with a high performance optical microscope with bright field, phase contrast and fluorescence capabilities.

The principal component of the *Kobairo* rack is the Gradient Heating Furnace, a vacuum furnace with three independently controlled heating blocks. The facility will be primarily used for high-quality crystal growth using unidirectional solidification.

Two additional Japanese research racks will be launched in the 2010-2013 time frame on HTV cargo spacecraft to complete the outfitting of the *Kibo* pressurized module.

Additional NASA facilities

NASA will have several additional racks on ISS by the time assembly is complete to expand research capabilities in the areas of combustion research, fluid physics, materials science, Earth observations, and exercise physiology [2].

The Fluids and Combustion Facility (FCF), designed to accommodate the unique challenges of working with fluids and combustion processes in microgravity, consists of two racks: the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR). Together they form a modular multi-user facility to support sustained, systematic research in fluid physics and combustion science. Both racks will be installed in *Destiny*.

The CIR is designed to conduct combustion experiments in microgravity and will be easily reconfigured on-orbit to accommodate a wide variety of combustion experiments [8]. The 100-l combustion chamber can operate at low (0.02 atm) or high (up to 3 atm) atmospheric pressures and is surrounded by optical and other diagnostic equipment including a multispectral camera. To minimize disturbances from the station's vibration environment, CIR is equipped with the Passive Rack Isolation System (PaRIS), a set of eight spring-damper isolators. Different combustion chamber inserts can be inserted into the rack to support different experiments.

The Fluids Integrated Rack (FIR) is built to accommodate a wide range of experiments in the field of fluid physics, studying the behavior of complex fluids, interfacial phenomena, dynamics and instabilities, multiples flows and phase changes. The facility's user-configurable volume resembles an optics bench, and for its initial mission will include the Light Microscopy Module (LMM), a remotely controllable microscope allowing flexible imaging such as bright field, dark field and phase contrast. To isolate sensitive experiments from the station's vibrations, the FIR facility is configured with the ARIS.

The Materials Science Research Rack (MSRR) will be installed in *Destiny* and used to support basic materials research in microgravity, to study the behavior of metals, alloys, polymers, semiconductors, ceramics, crystals and glasses. The facility is built by NASA under a cooperative agreement with ESA, who is providing the Materials Science Laboratory (MSL), the first experiment module occupying nearly half of the rack. The MSL in turn can accommodate a number of exchangeable module experiment inserts. To minimize acceleration disturbances from the station, MSRR is outfitted with the ARIS.

A 50.8-cm diameter high quality optical window is located on the nadir side of *Destiny*, the highest quality window ever flown on a crewed vehicle. The Window Observation Research Facility (WORF) rack will be placed in this window location to enable Earth observations using both hand-held cameras and remotely operated sensors. The WORF rack, based on the ExPrESS rack design, provides mounting for multiple remotely operated instruments such as cameras, camcorders, multispectral and hyperspectral scanners, as well as power and data and commanding support.

One of the significant effects of long-duration microgravity on human physiology is muscle atrophy. The ESA-built and NASA-launched Muscle Atrophy Research and Exercise System (MARES) rack will be used to carry out research on musculoskeletal, biomechanical and neuromuscular human physiology and to evaluate the effectiveness of countermeasures to mitigate muscle atrophy. Consisting of an adjustable chair, subject restraint system and associated drive motors and electronics, MARES is capable of supporting measurements and exercise on seven different human joints, encompassing nine angular and two linear movements for upper and lower extremities. The MARES facility will be installed in *Columbus*, in proximity to the HRF and EPM racks.

To accommodate potential additional middeck-locker type payloads, up to three more ExPrESS racks may be installed on ISS, the exact number partially determined by user demand. One of these racks will be shared with the Galley systems, which include a potable water dispenser, one or more refrigerator/freezers, and food warmers. One or two more MELFI racks may also be added, to support an expanded demand for cold stowage and to serve as on-orbit backups for the first MELFI freezer. To support transportation of conditioned samples, active and passive units will be available (Table 3). Active units include the MERLIN (Microgravity Experiment Research Locker/Incubator) single-middeck locker sized refrigerator/incubator and the Glacier (General Laboratory Active Cryogenic ISS Experiment Refrigerator) double middeck locker sized refrigerator/freezer. Both MERLIN and Glacier can also be placed in ExPrESS Racks for on-orbit operations. Passive units include Single and Double Cold Bags, aerogel-insulated devices that use phase change materials for thermal mass.

	MELFI 	MERLIN 	Glacier 	Single and Double Coldbag 
On-orbit Stowage	Yes	Yes	Yes	No
Transport	No	Yes	Yes	Yes
Active or Passive	Active	Active	Active	Passive
On-orbit temp (^{o}C)	+4, -26, -80	+45 to -20	+4 to -185	N/A
Transport temp (^{o}C)	N/A	+45 to -5	+4 to -160	+4 to -32
Useable volume (L)	175	19	30	6.8/18.7
External volume	1 rack	1MLE	2 MLE	0.5/ 1 MLE

Table 3. Capabilities of conditioned stowage hardware that will be available for ISS research.

External payload accommodations

The *Columbus* External Payload Facility can accommodate four payloads, two pointing in the nadir direction and two in the zenith direction [7]. Three of the sites will be occupied temporarily beginning with and shortly after the launch of *Columbus*. The first two facilities, the ESA-built Solar and European Technology Exposure Facility (EuTEF), will support three solar observation instruments and eight investigations in materials exposure, radiation and exobiology, respectively. The third payload will be the US-built MISSE-6 materials exposure facility. These initial payloads will be returned to Earth after 16-24 months in space for postflight analysis.

The *Kibo* Exposed Facility can accommodate up to 10 attached payloads, with possible orientations in the nadir, zenith, ram and wake directions. The facility will launch without payloads in 2009, with subsequent Japanese and US payloads arriving via HTV cargo craft. The first three Japanese experiments will study the radiation and cosmic dust environment in the ISS orbit (SEDA), X-ray sources in space (MAXI) and stratospheric phenomena using submillimeter-wave spectrometry (SMILES). Two US payloads, Hyperspectral Imager for the Coastal Ocean (HICO), a hyperspectral remote sensing instrument, and Remote Atmospheric and Ionospheric Detection System (RAIDS), a system for thermospheric and ionospheric constituent measurement, will share one attach site. Table 4 describes the capabilities of the *Columbus* and *Kibo* external payload accommodations.

	Col-EPF	JEM-EF
No. of sites	4	10
Mass capacity (kg)	230	500 stndrd 2,500 large
Volume (m3)	1	1.5
Power (kW)	2.5 total	3 total
Thermal	Passive	3 kW cool.
Low data rate (Mbps)	1	1
Medium data rate (Mbps)	2 (shared)	10
High data rate (Mbps)	N/A	95 (shared)

Table 4. Capabilities of the *Columbus* and *Kibo* external payload facilities.

Current plans call for the launch of four ExPrESS Logistics Carriers (ELCs) to support on-orbit research payloads and stowage of station external spares [2]. There are two sites per ELC dedicated to science payloads (Figure 5). The first two ELCs (ELC1 and ELC2) are planned for launch in mid-2009. Upon arrival to the ISS, ELC1 will be installed on the S3 Upper Truss (starboard). Therefore, it will have zenith-facing orientation. ELC2 will be installed on the P3 Lower Truss (port), with nadir-facing orientation (looking towards Earth). Each one of these sites have power, communication, and data downlink capabilities (Table 5). ELC3 and ELC4 are planned for launch in July 2010. Both of these carriers are planned to be installed on the S3 Lower Truss (starboard), with nadir-facing orientation. The S3 Upper Truss can also support the installation of a single large zenith-facing payload.

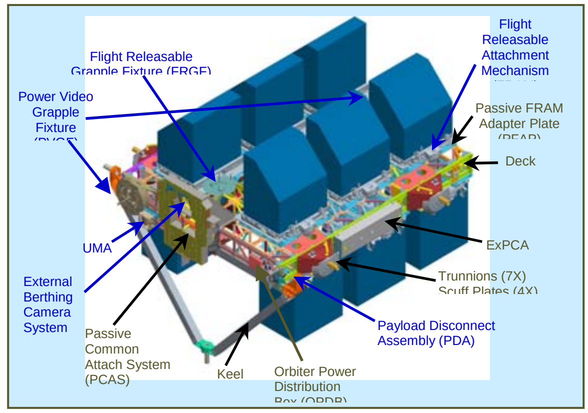

Figure 5. Express Logistics Carrier configuration

ELC Single Adapter Resources	
Mass Capacity	227 Kg
Volume	1 m^3
Power	750W at120 VDC 500 W at 28VDC
Thermal	Active heating, passive cooling
Low-rate data	1 Mbps (MIL-STD-1553)
Medium-rate data	6 Mbps (Ethernet)

Table 5. ExPrESS Logistics Carrier capabilities.

According to current plans, the first ELC will carry the MISSE-7 materials exposure payload and the Italian Space Agency-built Facility for Exo-Biology Observation (FEBO). Both are planned for return to Earth on a later Shuttle mission. Payloads for later ELC's include: Communications, Navigation, and Networking reConfigurable Testbed (CONNECT) will provide an adaptable facility for future technology risk reduction; First Alert and Cueing (FAC) will support early launch detection technology; Ocean Data Telemetry Microsat Link (ODTML) will demonstrate technologies for networking multiple ocean monitoring platforms; W-Band Beacon (WBB) will develop a wide-band radar system for imaging small satellites; and SCIENCE, will focus on educating future naval officers in space programs and technology.

Transportation capabilities

Today, crew transportation to and from ISS is handled by a combination of US Space Shuttles and Russian *Soyuz* spacecraft. Shortly after 6-crew operations begin in 2009, all crews will rotate on *Soyuz* spacecraft. Once the *Orion* Crew Exploration Vehicle (CEV) begins flying to ISS in the middle of the next decade, it will perform crew rotations for US crewmembers [2].

Transportation of cargo today relies on the US Space Shuttle and Russian Progress vehicles, with very limited capability on Soyuz spacecraft. In early 2008, the ESA Autonomous Transfer Vehicle (ATV) will begin flying cargo to ISS, to be joined in 2009 by the Japanese H-II Transfer Vehicle. Only the Shuttle (and to a very limited degree *Soyuz*) can return cargo to Earth. After the Space Shuttle is retired in 2010, all transportation will rely on these international vehicles, until the US Commercial Orbital Transportation System (COTS) becomes available around the turn of the decade. The greatest challenge in the transportation scheme will be the return of hardware and in particular research samples between Shuttle retirement and the advent of regular COTS capabilities. The *Orion* CEV is also expected to have cargo carrying capability in addition to providing for crew rotation. Capabilities of the various vehicles are summarized in Table 6.

	Up	Down
Shuttle	Crew; active and passive internal and external cargo	Crew; active and passive internal and external cargo
Soyuz	Crew, very limited passive internal cargo	Crew, very limited passive internal cargo
Progress	Passive internal cargo	N/A
ATV	Passive internal cargo	N/A
HTV	Passive internal cargo incl. racks, passive external cargo	N/A
COTS	Passive and active cargo; crew	Passive and active cargo; crew
Orion	Crew; active and passive internal cargo	Crew; active and passive internal cargo

Table 6. Capabilities of current and future ISS transportation vehicles.

Once ISS assembly is completed, across three research modules there will be at least 24 pressurized racks and 22 sites for external payloads. The station will support a wide variety of research discipline across the modules, as summarized below:

- Life Sciences
    - 2 HRF, EPM, MARES in *Columbus*
    - EMCS in *Columbus* (in ExPrESS Rack)
    - Biolab in *Columbus*
    - *Saibo* in *Kibo*
    - 1-3 MELFI in *Kibo* and *Destiny*
- Fluid Physics
    - FIR in *Destiny*, FSL in *Columbus*, *Ryutai* in *Kibo*
- Combustion Science
    - CIR in *Destiny*
- Materials Science
    - MSG in *Columbus*
    - MSRR in *Destiny*
    - *Kobairo* in *Kibo*
    - SpaceDRUMS in *Kibo* (in ExPrESS Rack)
- Earth Observation
    - WORF in *Destiny*
- Multidisciplinary facilities
    - 6-8 ExPrESS Racks in *Destiny*, *Columbus* and *Kibo*
    - EDR in *Columbus*

It should be noted that multi-user racks such as ExPrESS, EDR and MSG can support more than one research discipline listed above. Related capabilities, not all of them facility- or rack-based, will include:

- Gloveboxes
    - MSG, 2 levels of containment
    - Maintenance Work Area (MWA) in *Destiny*, 1 level of containment
    - Portable Glovebox (PGB) currently in Russian segment, 2 levels of containment
    - Biolab glovebox, 2 levels of containment
    - *Saibo* Clean Bench glovebox, 2 levels of containment
- Centrifuges
    - HRF2 refrigerated centrifuge for samples
    - EMCS for small organisms
    - Biolab centrifuge for small organisms
    - *Saibo* CBEF for small organisms
- Incubators
    - Biotechnolgy Specimen Temperature Controller (BSTC) in *Destiny*
    - Commercial Generic Bioprocessing Apparatus (CGBA) in *Destiny*
    - EMCS, currently in *Destiny*
    - Microgravity Experiment Research Locker/Incubator (MERLIN)
    - Biolab incubator
    - *Saibo* CBEF incubator
- Microscopes
    - Biolab microscope
    - FIR Light Microscopy Module (LMM)
    - *Saibo* CB microscope

- *Ryutai* microscope

External sites will provide capabilities for collection of samples to characterize the environment in ISS near-Earth orbit, conduct Earth observation and remote sensing, point instruments toward celestial targets and test new technologies.

SUMMARY

With its assembly more than halfway to completion, ISS is already a productive platform for conducting research in space. The next few years will see the addition of several pressurized modules, truss elements and solar arrays to greatly expand its capabilities. By the end of this decade, ISS will become the envisioned human outpost in space bringing together many nations for the benefit of life on Earth and as a bridge to future exploration.

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The following websites contain more details on many of the payloads and facilities described in this paper:

http://www.nasa.gov/mission_pages/station/science/index.html

http://spaceflight.esa.int/users/index.htm

http://iss.jaxa.jp/en/

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