The International Space Station: a National Science Laboratory

Timothy W. Giblin
United Space Alliance, LLC
NASA Johnson Space Center
Houston, TX

After more than a decade of assembly missions and on the heels of the final voyage of Space Shuttle Discovery, the International Space Station (ISS) has reached assembly completion. With visiting spacecraft now docking with the ISS on a regular basis, the Station now serves as a National Laboratory to scientists back on Earth. ISS strengthens relationships among NASA, other Federal entities, higher educational institutions, and the private sector in the pursuit of national priorities for the advancement of science, technology, engineering, and mathematics. In this lecture we will explore the various areas of research onboard ISS to promote this advancement: (1) Human Research, (2) Biology & Biotechnology, (3) Physical & Material Sciences, (4) Technology, and (5) Earth & Space Science. The ISS National Laboratory will also open new paths for the exploration and economic development of space.
Outline

I. Introduction to ISS (2 slides)
   1.) ISS Program Mission Statement (NASA)
   2.) ISS Program Office
   3.) International Partners
   4.) ISS parameters (orbit, size, mass, etc)

II. ISS Assembly (2 slides)
   1.) Assembly Complete Overview
   2.) Video: Assembly Complete Mission timeline

III. Visiting Vehicles (4-5 slides)
   1.) Soyuz (properties – crew members)
   2.) Progress (properties – cargo)
   3.) ATV – ESA (properties – cargo)
   4.) HTV – JAXA (properties – cargo)
   5.) Commerical (crew members/cargo)

IV. Communication & Tracking – getting data to the ground (~3 slides)
   1.) ISS – TDRSS – White Sands – MCC (Data path)
   2.) Mission Operations Centers
      a. MCC – Houston
      b. MCC – Moscow
      c. Tskuba - JAXA
      d. Munich -ESA

V. Scientific Research onboard ISS (~8 slides)
   1.) ISS USOS National Laboratory
   2.) Research Overview video
   3.) Current statistics of published research from ISS
   4.) Facilities & Payloads:
      a. Payload Racks
      b. Express Racks
      c. External payloads
   5.) Weekly Research Highlights – current update

VI. Research Disciplines
   1.) Human Research (~3 slides)
      a. Integrated Physiology
   2.) Biology & Biotechnology (~3 slides)
      a. Cellular Biology
      b. Macromolecular Crystal Growth
      c. Microbiology
   3.) Physical & Materials Science (~4 slides)
      a. Microgravity Acceleration Measurement System (MAMS)
      b. Space Acceleration Measurement System (SAMS)
      c. MISSE (updated on ULF6 EVA)
d. Combustion science (BASS/COSMIC)
e. Fluid mechanics & surface tension studies (CCF, FASTER, Marangoni Convection)
f. Fundamental Physics (Heat, Thebas)

4.) Technology (~3 slides)
   a. Robonaut (STS133/ULF5)

5.) Earth & Space Science (~10 slides)
   a. Crew Earth Observation (CEO)
   b. WORF & EarthKAM
   c. HREP-HICO & HREP-RAIDS
   d. Solar – SOLSPEC, SOVIM (Solar Variable & Irradiance Monitor), and SOLACES
   e. SAGE III
   f. MAXI (JEF/JAXA)
   g. Alpha Magnetic Spectrometer (AMS) (~3 slides + video, http://ams-02project.jsc.nasa.gov/index.htm)

VII. Opportunities for Research Onboard ISS
    1.) Outline basic process
    2.) Provide documentation links via http://www.nasa.gov

References: published Journal papers, articles, and www.nasa.gov (all material is public domain)
“Spreading out into space will have an even greater effect. It will completely change the future of the human race and maybe determine if we have any future at all.”

- Prof. Stephen Hawking
Outline

- Introduction to the International Space Station (ISS)
- ISS Operations
- Scientific Research onboard ISS

ISS Program Mission Statement

Safely build, operate, and utilize a permanent human outpost in space through an international partnership of government, industry, and academia to advance exploration of the solar system, conduct scientific research, and enable commerce in space.
ISS Introduction

- International collaboration for the long-term exploration of space

United States | Russia | Canada | Japan | Europe

- Orbital inclination 51.6
- Orbital altitude 370-460 km
- Mass ~419,000 kg
- ~1200 m³
- 108.4 m (truss) 74 m
- 110 kW power output, (30 kW payload)
Assembly Complete Configuration

10+ yrs Assembly Timeline
ISS Assembly Complete

March 2011  STS-133 Delivers final pressurized module (MPLM – *Leonardo*)
ISS Cupola
Crew of 6

Current crew
Visiting Vehicles

Soyuz – crew
Progress - cargo

Baikonur Cosmodrome
Visiting Vehicles

Automated Transfer Vehicle (ATV)

- Aianne-5 launch vehicle
- French Guiana
- 6.6 tons cargo

ATV-2 Johannes Kepler (credit ESA)

H-II Transfer Vehicle (HTV)

- H-IIB launch vehicle
- Tanegashima Space Center
- ~6 tons cargo
- trash removal

HTV-2 KOUNOTORI-2 (credit JAXA)
Communication & Tracking System

- Provides near continuous communication with the ground (MCC-H)
- Crew & vehicle safety, disseminate science data
- Flight controller commanding from the ground

TDRSS
White Sands Ground Station

S-Band
Ku-Band

MCC-H
Communication & Tracking System

Ku-Band

- payload data, video downlink, 2-way telecon
- 10.7-12.2 GHz downlink
- 14.0-14.5 GHz uplink

Z1 truss & Ku-Band antenna
Mission Operations

Mission Control Center (MCC-H) – NASA Johnson Space Center, Houston, TX

FCR-1
24/7
Mission Operations - Russia

MCC-Moscow

(credit Roscosmos)
IP Mission Operations

ESA – Columbus Control Center
(Munich)

(credit ESA)

JAXA – Japanese Experiment Module
(Tsukuba)

(credit JAXA)
2005 NASA Authorization Act designated the U.S. segment of the ISS as a national laboratory and directed NASA to develop a plan to "increase the utilization of the ISS by other Federal entities and the private sector…"

- Technology Development
- Physical Sciences
- Materials Sciences
- Biological Sciences
- Human Sciences
- Earth Observation
- Space Science

Scientific Research Onboard ISS

ISS USOS National Laboratory
Scientific Research Onboard ISS
Scientific Research Onboard ISS

Publication statistics

- 28 published *review papers* on ISS results
- 20 publications on ISS and future exploration technologies
- 216 *results publications* (*e.g.*, *scientific journals*) from specific payloads or projects

First Decade: more than 400 research experiments & 70 educational projects

(source: www.nasa.gov)
Payloads

Payload operations: Marshall Space Flight Center, Huntsville, AL

Payload components onboard ISS:

- U. S. Laboratory ("Destiny" Lab) – 24 rack locations
- Facility Class payloads – long-term or permanent payloads

- EXPRESS RACK System
- Advanced Human Support Technology (AHST)
- Human Research Facility (HRF)
- Minus Eighty Degree Laboratory Freezer ISS (MELFI)
- Materials Science Research Facility
- Microgravity Science Glovebox
- Fluids and Combustion Facility
- X-Ray Crystallography Facility
- Biotechnology Facility
Payloads

Express Rack
Payloads

• Attached payloads – located externally on the truss or the JEM Exposed Facility
  
  4 locations on S3 truss segment
  2 locations on P3 truss segment
  10 locations on the JEM EF
Human Research

Integrated Physiology

- bone density loss
- muscle tissue deterioration
- cardiovascular performance
- immune system & neurological changes
- psychological changes

National Aeronautics and Space Administration Biological Specimen Repository (Repository) - MELFI

Advanced Diagnostic Ultrasound in Microgravity (ADUM)

Copyright United Space Alliance 2011
Commercial Biomedical Testing Module (CBTM):
Effects of Osteoprotegerin (OPG) on Bone Maintenance in Microgravity

• determine effectiveness of OPG in treating bone loss
• space mouse vs. ground mouse bone tissue

(Clemson Univ.)

Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism during Spaceflight and Recovery (Pro K)

(Johnson Space Center)

Hypothesis: a diet with a decreased ratio of animal protein to potassium will lead to decreased loss of bone mineral during flight

A growing body of data suggests a direct relationship between nutrition and the effects of space.
Human Research

Changes in Nutrient Contents in Space Food After Long-term Space Flight
(Space Food Nutrient)

- Assesses the changes in nutrient contents in Japanese space foods after exposure to ISS environment for long-duration space flight. (JAXA)

Astronaut's Energy Requirements for Long-Term Space Flight
(Energy)

(Blanc, Institut Pluridisciplinaire Hubert Curien, Strasbourg, France)

- measure changes in energy balance in crewmembers following long term space flight
- measure adaptations in the components of the total energy expenditure of astronauts to derive an equation for the energy requirements of astronauts
Mechanism of bone formation during development of the limbs in quail embryos could provide basic information to help prevent bone loss in astronauts during long duration missions.

(Doty, Hospital for Special Surgery, NY)
Biology & Biological Sciences

Cellular Biotechnology Operations Support Systems: Human Renal Cortical Cell Differentiation and Hormone Production
(CBOSS-01-02-Renal) (NASA)

• one of 7 CBOSS experiments
• stable cell growth environment

Cell Growth in microgravity:

Microgravity allows the cells to grow in three-dimensional structures which are similar to how they grow in the human body. The cells were returned to Earth and were used in studies of several kidney disorders.

Space Tissue Loss - Microbial Immunity
(STL-Microbial_Immunity) (Arizona State University/NASA)

• How human cell culture responds to infection by bacteria in the microgravity environment in comparison to Earth normal gravity
• Vaccine development and other therapeutics for treatment, prevention and control of infectious diseases on Earth.

Copyright United Space Alliance 2011
Biology & Biological Sciences

Macromolecular Biology – Protein Crystal Growth

- ISS is relatively free from the effects of sedimentation and convection
- provides an exceptional environment for crystal growth

Crystals grown in microgravity could help scientists gain detailed knowledge of the atomic, three-dimensional structure of many important protein molecules used in pharmaceutical research for cancer treatments, stroke prevention and other diseases.

The knowledge gained could be instrumental in the design and testing of new drugs.

Copyright United Space Alliance 2011
Biology & Biological Sciences

Protein Crystal Growth Monitoring by Digital Holographic Microscope for the International Space Station (PromISS)

• microscope that will allow for the visualization of the protein crystal growth process

• produces protein crystals for ground-based X-ray diffraction studies

• role of the proteins in diseases?
Microbiology

Passive Observatories for Experimental Microbial Systems (POEMS) (NASA)

Demonstration of a passive system for growing microbial cultures in space and to observe genetic changes that occur in them as a result of living and growing in the space environment.
Physical & Materials Science

Combustion Science
- Burning and Suppression of Solids (BASS)
- Combustion Synthesis Under Microgravity Conditions (COSMIC)
Physical & Materials Science

Multi-User Droplet Combustion Apparatus - Flame Extinguishment Experiment (MDCA-FLEX) (UCSD, Princeton, Drexel, Glenn Research Center)

Quantitative measure of the effectiveness of various suppression agents and more importantly a set of predictive tools that will allow the effective, efficient design of future spacecraft fire suppression systems.
Chaos, Turbulence and its Transition Process in Marangoni Convection (Marangoni) (JAXA)

Experiment to fully understand a surface-tension-driven flow in microgravity

Marangoni convection is the tendency for heat and mass to travel to areas of higher surface tension within a liquid.
Physical & Materials Science

Materials on the ISS Experiment (MISSE) (NRL, NL DoD)

http://issresearchproject.grc.nasa.gov/MISSE/
Microgravity Acceleration Measurement System (MAMS)

Measures vibratory and quasi-steady acceleration within the United States Laboratory Module

- Orbital Acceleration Research Experiment (OARE) Sensor Subsystem (OSS)
- High Resolution Accelerometer Package (HiRAP)

0.01 to 300 Hz
Physical & Materials Science

Space Acceleration Measurement System (SAMS II) (Glenn Research Center)

Study of the small forces (vibrations and accelerations) on the International Space Station (ISS) resulting from the operation of hardware, crew activities, dockings and maneuvering

0.01 - 400 Hz
Demonstrate that a dexterous robot can:
- launch and operate in a space vehicle
- manipulate mechanisms in a microgravity environment
- operate for an extended duration within the space environment
- assist with tasks
- interact with the crewmembers.
Crew Earth Observations (CEO) (NASA/JSC)

Photograph natural and human-made changes on Earth

Window Observational Research Facility (WORF)
US Laboratory (nadir)

Earth Viewing Camera (EVC)
Earth & Space Science

Sun Monitoring on the External Payload Facility of Columbus (Solar) (ESA)

SOLSPEC – Solar

SOVIM – Solar Variable and Irradiance Monitor

- 180-3000 nm
- 2 % in UV
- 1 % visible/IR

Solar Cycle #23

Earth Climatology

Col-EPF

Copyright United Space Alliance 2011
HICO and RAIDS Experiment Payload - Remote Atmospheric and Ionospheric Detection System (RAIDS) (HREP-RAIDS) (NRL/NASA)

UV and visible remote sensing instrument that views the limb of the Earth to measure vertical composition and temperature of the atmosphere above 95 km.

Hyperspectral Imager for the Coastal Ocean (HICO)
NASA's Stratospheric Aerosol and Gas Experiment III-ISS (SAGE III-ISS) will measure ozone, water vapor and aerosols in the atmosphere.

- 2014 attachment to ISS
- measure composition of middle + lower atm

1st Payload scheduled to be delivered by COTS Dragon
MAXI – Monitor All-sky X-Ray Imager

JAXA

- 2-30 keV Gas Slit X-Ray Camera for all-sky survey
- no Earth blockage
- X-ray transients, AGN, GRB afterglows
- JEM Exposed Facility

http://www.nasa.gov/mission_pages/station/science/experiments/MAXI.html#images
Alpha Magnetic Spectrometer

- High-energy particle physics detector under DOE sponsorship
- International partnerships: 16 countries & 56 institutions
- Led by Nobel Laureate Samuel Ting (MIT)
Alpha Magnetic Spectrometer

- Specifically searching for detection of Anti-Matter & Dark Matter (TeV energies)

08. T superconducting magnet, 4 layers of scintillators, 8 layers of Silicon detectors


Copyright United Space Alliance 2011
Alpha Magnetic Spectrometer

Particle & Photon Detection

AMS 02

TRD
(5248 Channels)

TOF (s2,s2)

Tracker
(300,000 Channels)

Superconducting Magnet
2500 l SF Helium

TOF (s3,s4)

Veto Counter

RICH

ECAL

(Spada 2007)
Alpha Magnetic Spectrometer

\[ P = mV, \quad m = P/V \]

\[ \pm Q, \quad P \]

\[ V \rightarrow C \]

\[ V < C \]

\[ E: \quad e^\pm, \quad \gamma \]

\begin{tabular}{|c|c|c|c|c|c|}
\hline
300 GeV & e^- & e^+ & P & \(\text{He}\) & \(\gamma\) & \(\gamma\) \\
\hline
TRD & \vdash & \vdash & \vdash & \vdash & \vdash & \vdash \\
TOF & \vdash & \vdash & \vdash & \vdash & \vdash & \vdash \\
Tracker & \vdash & \vdash & \vdash & \vdash & \vdash & \vdash \\
RICH & \vdash & \vdash & \vdash & \vdash & \vdash & \vdash \\
Calorimeter & \vdash & \vdash & \vdash & \vdash & \vdash & \vdash \\
\hline
\end{tabular}

(Spada 2007)
Alpha Magnetic Spectrometer

- 2-10 GRB detections per year
- ~100 new AGN per year

(Choutko 2004)
STS-134/ULF6 Mission Synopsis

- Shuttle Endeavour
- Deliver AMS-02 to ISS
- 2 S-band antennas
- Deliver ELC-3, new ATA
- Parts for Dextre
- Four spacewalks (EVAs)
Research Opportunities

Scientists: Become a Researcher

- Partner with academia, industry
- ISS Payloads Office (jsc-iss-payloads-helpline@mail.nasa.gov)

Students:

- Talk with astronauts from space
- EarthKAM

Educators: Teaching from Space (TFS)

Teaching From Space Office NASA Johnson Space Center, Houston, TX
E-mail: JSC-Teaching-From-Space@mail.nasa.gov

http://www.nasa.gov/mission_pages/station/research/opportunities.html

http://www.nasa.gov/audience/foreducators/teachingfromspace/home/index.html
Questions?

Thank you

Timothy.W.Giblin@nasa.gov
Backup Slides
ISS Core Systems

- Command & Data Handling (CDH)
- Communication & Tracking (C&T)
- Electrical Power System (EPS)
- Thermal Control System (TCS)
- Motion Control System (MCS)
- Environmental Control & Life Support System (ECLSS)
- Robotics
- Extravehicular Activity (EVA)
- Payload Systems
Communication & Tracking System (con’t)

Redundant S-Band strings
Electrical Power System

Solar Energy (photons) → Electrical Energy

• Provide continuous power to ISS during insolation and eclipse

Photovoltaic Modules (PVM)

• 2 power channels
• generate primary power (150-160 V DC)
• Si solar cells series (81 panels/blanket) (~262,000 cells)
• sequential shunt unit – set pt voltage 160 V
Electrical Power System (con’t)
Primary power storage – NiH$_2$ batteries (0-10°C)

- 3 pairs per power channel
- each pair controlled by a Battery Charge-Discharge Unit (BCDU)
Direct Current Switching Unit – routes power to one of 4 Main Bus Switching Units (MBSUs) located on the S0 truss.

Direct Current Control Units (DDCUs) – step down transformer (~124 V DC) routes secondary power to downstream user loads (called Remote Power Control Modules).
Electrical Power System (con’t)

Solar Alpha Rotary Joint (SARJ)
Thermal Control System

Maintain ISS equipment & payloads at optimum nominal operating temperature range

Passive thermal control

- MLI (Multi-Layer Insulation) blanket
  3.2-6.4 mm
  single aluminized outer layer (O₂ & MMOD protection)
- surface coatings – anodized coatings & paint w/ varying emissivity and absorbtivity
- heaters – electrically powered (>300 on ISS)
- heat pipes – latent heat of vaporization (NH₃ fluid))
Thermal Control System (con’t)

- Anodized coating
- Heaters (bonded to the inside of the lab pressure cell)
Thermal Control System (con’t)

Active thermal control

- **Internal Thermal Cooling System (ITCS)**
  - Working fluid = H$_2$O with teflon/Ti lines
  - Heat collection: cold plates & heat exchangers
  - Pump Package Assembly
  - Moderate Temperature Loop (MTL): 17 °C
  - Low Temperature Loop (LTL): 4 °C

- **External Thermal Cooling System (ETCS)**
  - Working fluid – NH$_3$
  - Heat collection: interface heat exchangers
  - Two loops: Loop A (S1 truss) & Loop B (P1 truss)
  - Heat rejection: Thermal Radiators
Motion Control System

- Determines ISS state vector
  - Position \((x, y, z)\) and velocity \((v_x, v_y, v_z)\) at a given time

- Determines ISS attitude
  - Rotational angles (yaw, pitch, roll) and the rate at which these angles are changing

- Provides attitude and translation control
  - Provides attitude hold
  - Maintains a microgravity environment
  - Performs reboosts via SM or Progress

- Provides state vector and attitude information to other ISS core systems
Motion Control System (con’t)

USOS Attitude Control

Control Moment Gyros

- 600 lbs each
- 6600 rpm
- 4880 N-m-s

CMGs (Z1 truss)

GPS
Motion Control System (con’t)

Translational Control (Reboost)
Robotics System

International collaboration:

NASA, CSA, & JAXA

Functions:

- ISS assembly and maintenance
- EVA support and payload handling

Systems:

- Mobile Servicing System (MSS)
- Japanese Experiment Module Remote Manipulator System (JEM-RMS)
Robotics System (con’t)

Mobile Servicing System (MSS)

(17 m, 7 joints, “walk-off”)

Special Purpose Dexterous Manipulator (SPDM)
Mobile Remote Servicer Base System (MBS)
Mobile Transporter (MT)

MSS External Components

Robotic Workstation (RWS)

(2.54 cm/sec)
Extravehicular Activity

Over 600 tasks must be successfully completed for ISS assembly, requiring more than 540 hours of EVA.

Extravehicular Mobility Unit (EMU)

• pressurized to 4.3 psid
• 7 hrs (15 min to egress A/L, 30 min to ingress A/L, 30 min reserve)
• secondary oxygen pack (30 min)
• UHF comm

Copyright United Space Alliance 2010
Extravehicular Activity (con’t)

“Quest” Joint Airlock

[Image of the “Quest” Joint Airlock]

- Equipment Lock
- Crew Lock

- High pressure gas ORUs (two O₂ and two N₂)
- Starboard
- Nadir
- EVA tool boxes
- EVA hatch
Extravehicular Activity (con’t)