February 2010 - The ISS viewed from the Space Shuttle Endeavour following separation during the STS-130 Mission.
ISS Science Experiments by Disciplines

- **Technology Development** - studies and tests of new technologies for use in future exploration missions. Areas of emphasis include spacecraft materials and systems, and characterization and control of the microgravity environment on the ISS.

- **Physical Sciences** - studies of physics and chemistry in microgravity. Areas of emphasis include materials sciences experiments, including physical properties and phase transitions in polymers and colloids, fluid physics, and crystal growth experiments.

- **Biological Sciences** - studies of biology using microgravity conditions to gain insight into the effect of the space environment on living organisms. Areas of emphasis include cellular biology and biotechnology, and plant biology.

- **Human Research for Exploration** - human medical research to develop the knowledge that is needed to send humans on exploration missions beyond Earth orbit. These studies focus on the effect of living in space on human health and countermeasures to reduce health risks that will be incurred by living in space in future. Areas of emphasis included physiological studies related to the effects of microgravity on bone and muscle, other physiological effects of space flight, psycho-social studies, and radiation studies.

- **Observing the Earth and Education** - these activities and investigations allow students and the public to connect with the ISS mission; inspired students to excel in science, technology, engineering, and math; and shared the astronauts’ unique view of the Earth system with scientists and the public.

- **Science from ISS Operations** - in addition to the formal, peer-reviewed scientific research and experiments, the ISS supports a large body of research using data from ISS operations, including routine medical monitoring of the crew and data that are collected on the ISS environment, both inside and outside of the ISS.
Distribution is based upon the ISS Science Experiments from 2000 to 2008.

(#) Denotes quantity of science experiments that total 138.
Science Experiments by Disciplines

Technology Development

Physical Sciences

Biological Sciences

Human Research
For Exploration

Observing Earth & Education

Science from ISS Operations

Reference Information
Technology Development for Exploration

- One of NASA’s top priorities for research aboard the ISS is the development and testing of new technologies and materials that are being considered for future exploration missions.
- Through Expedition 15, 22 different technology demonstrations have been performed.
-- These experiments include research characterizing the microgravity environment, monitoring the ISS environment both inside and outside the spacecraft, testing spacecraft materials, developing new spacecraft systems, and testing picosatellites and new satellite commanding and controls.
--- Picosatellites or "picosat" is an artificial satellite weighing between 0.22 and 2.2 lbs.
---- Besides cost, the main rationale for the use of picosatellites is the opportunity to enable missions that a larger satellite could not accomplish such as: constellations for communications, the use of a formation (or “swarm”) to gather data from multiple points, and in-orbit inspection of larger satellites.
- NASA monitors 34 scientific publications recognizing that classified and proprietary proceedings include a much greater number of results documenting technology developments.
- Recent experiments range from combustion physics and soot production (important data for redesign of spacecraft smoke detectors) to the successful demonstration of micro-fluidic technologies for rapidly detecting different contaminants such as bacteria and fungi.
-- Other new technology experiments and stand-alone instrument packages monitor other air contaminants.
Technology Development for Exploration - MISSE

- The Materials International Space Station Experiment (MISSE) tests how spacecraft materials withstand the harsh space environment.
  - The environment includes: solar radiation, atomic oxygen erosion, thermal cycling, micrometeoroid and orbital debris impacts, and contamination from spacecraft.
  - For 10 years, more than 4,000 MISSE materials have been exposed to the space environment.
  - The MISSE is shown attached to the Quest Airlock in October 2002 (left) near the hatch used by crewmembers to exit/enter the space station.

- MISSE results have been used to understand and calibrate how materials, such as polymers used for insulation and solar arrays, that are already in use on spacecraft degrade in the space environment and predict the durability of new materials.
  - New materials included a special class of liquids, called ionic liquids, having a novel epoxy scientists are studying to learn how these liquids tolerate the outside environment.
  - This family of fluids have low melting points, are not as flammable as many conventional chemicals, do not easily evaporate, and are easier to retain in the vacuum of space.
  - The MISSE-8 sample trays (right) held the ionic liquid epoxy that could help build future composite cryogenic tanks.
Technology Development for Exploration - SAME

- September 2007 - Expedition 15 Astronaut Clay Anderson is shown working on the Smoke and Aerosol Measurement Experiment (SAME) hardware located in the Microgravity Science Glovebox in the Destiny laboratory.
- Smoke particulates that are produced in low gravity by SAME were found to be typically 50% larger in count mean diameter than similar conditions in normal gravity.
-- These results have significant implications for the design of smoke detection systems for current and future spacecraft.

- The SAME measures smoke properties, or particle size distribution, of typical particles from spacecraft fire smokes to provide data to support requirements for smoke detection in space and identify ways to improve smoke detectors on future spacecraft.
- The experiment also modeled the smoke transport in the Destiny laboratory using Environmental Control and Life Support System data. Numerical modeling of smoke transport predicted that actual detection times can be quite long and strongly dependent on detector location and the inside geometry of obstructions that block cabin air flow.
Technology Development - SPHERES

- July 2009 - Japan Aerospace Exploration Agency astronaut Koichi Wakata, Expedition 20 flight engineer, is pictured near three Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) floating freely in the Harmony node of the ISS.
- The first ISS operating sessions occurred in May 2006.
- SPHERES is currently being used as a platform for a variety of projects.

- SPHERES was produced by Massachusetts Institute of Technology’s Space Systems Laboratory as a way to provide the Defense Advanced Research Projects Agency, NASA, and other research institutions with a test platform for metrology, controls, and autonomous technologies in formation flight.
  - Each SPHERE satellite is self-contained with power, propulsion using CO₂ cold gas thrusters, computing and navigation equipment as well as expansion ports for additional sensors and appendages, such as cameras and wireless power transfer systems.
  - Advancement of formation flight could allow for separated spacecraft interferometry to gain higher resolution images for lower cost, flexible satellite clusters that can reconfigure their geometry for given missions including orbital debris removal.
July 12, 2011, Mike Fossum, Expedition 28 flight engineer, is shown transferring the Robotic Refueling Mission (RRM) Phase 1 module from the Atlantis space shuttle cargo bay to a temporary platform on the ISS’s Special Purpose Dextereous Manipulator (Dextre) robot.

- The RRM investigation uses the ISS’s two-armed robotic handyman, Dextre, to show how future robots could service and refuel satellites in space.
- RRM tests NASA-developed technologies, tools and procedures to refuel and repair satellites that were not originally designed to be serviced.
- RRM is expected to pave the way for future robotic servicing missions in space.
- The Dextre robot acts as a skilled spacecraft refueling and servicing technician.

RRM Phase 3 builds on Phases 1 and 2 of the ISS technology demonstrations that tested tools, technologies, and techniques to refuel and repair satellites in orbit.
Technology Development for Exploration - Robonaut 2

- February 2012 - Robonaut 2, nicknamed R2, shakes hands (left) with NASA astronaut Dan Burbank, Expedition 30 commander, in the Destiny laboratory.
  - This was the first human/robotic handshake to be performed in space.
  - R2 is the next generation dexterous robot, developed through a Space Act Agreement by NASA and General Motors.
  -- It is faster, more dexterous and more technologically advanced than its predecessors and able to use its hands to do work beyond previous humanoid robots.

- Expedition 40 astronaut Steve Swanson poses with R2 after completing an upgrade that gave the robot legs on September 2014.
  - Future enhancements may allow R2 to move more freely throughout the station’s interior and eventually the exterior.
  - R2 operates via ground commanding with little interaction by the crew members.
  -- The exception to this is during Robonaut Tele-Operation (RTS) sessions.
  --- During RTS sessions, crew members don a 3D visor, gloves and a vest and R2 will mimic their motion.
- Select [https://www.youtube.com/watch?v=gILX_sKtu2I](https://www.youtube.com/watch?v=gILX_sKtu2I) to see the R2 first movement test on the ISS.
- R2 was returned to Earth by the SpaceX CRS-14 Dragon capsule on May 5, 2018 for analysis and repair of its electrical system.
- November 24, 2014 - The 3D printer successfully manufactured its first part on the ISS (right).
  - This is the first time that hardware has been additively manufactured in space, as opposed to launched from Earth.
  -- The part is a functional part of the printer; a faceplate for its own extruder printhead.
  - The 3D print technology creates 3D physical prototypes by solidifying layers of deposited powder using a liquid binder.
- November 17, 2014 - The 3D printer (left) is installed in the Microgravity Science Glovebox in the Columbus module.
  - 3D printing serves as a fast and inexpensive way to manufacture parts on-site and on-demand, reducing the need for costly spares on the ISS and future spacecraft.
  -- Long-term missions would benefit from having onboard manufacturing capabilities.
- NASA and Made In Space Inc. of Mountain View, CA, have joined to develop the first 3-D microgravity printing experiment for the International Space Station (ISS).
Physical Sciences in Microgravity

- The ISS physical sciences include experiments in different sub-fields of physics and material science.
- Several experiments are broadly classified as fluid physics, which test phenomena such as capillary flow, the mixing of miscible fluids, and bubble dynamics.
- Other experiments test concepts in the relatively new field of the physics of soft matter (has physical states that are deformed by thermal stresses or fluctuations) and colloidal systems (a substance microscopically dispersed evenly throughout another substance).
- Another class of experiments focuses on crystal growth, especially protein crystal growth in microgravity.
  -- Growing crystals (both protein crystals and zeolite crystals) in space, free from the gravitational effects of sedimentation and convection, provides an opportunity to grow crystals that are larger or more pure than crystals that are grown on Earth.
  --- Crystallization experiments have examined proteins, viruses, and other macro-biological molecules to better understand their structure and function for maintaining human health and fighting disease.
- The research themes of the physical sciences have shifted since the first ISS expedition in 2000.
  -- Early physical science experiments emphasized the growth of protein crystals in microgravity conditions and investigated fundamental properties in fluids as well as the specific behaviors of colloids.
  -- Today, a major research thread focuses on the fundamental properties of colloids and complex fluids.
- Through Expedition 15, 33 physical science experiments were performed up to 2008 yielding more than 40 publications.
The Advanced Protein Crystallization Facility (APCF) will perform a series of automated experiments that could be a step towards a better understanding of protein crystallization.

- Understanding proteins is basic to understanding the processes of living things.
- While we know the chemical formula of proteins, learning the chemical structure of these macromolecules is more difficult.
- This knowledge is fundamental to the emerging field of rational drug design, replacing the trial-and-error method of drug development.
- Microgravity provides a unique environment for growing crystals in an environment that is free of the gravitational properties that can crush their delicate structures.

August 2001- Astronauts Frederick W. Sturckow and Scott Horowitz of the shuttle STS-105 crew pose with the APCF by the middeck locker.

- Later in the mission, the APCF was transferred from its transport position to Express Rack 1 in the Destiny laboratory.
- The APCF is the European Space Agency’s first experiment facility to arrive at the ISS.
The Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsion (InSPACE) experiment provides new observations and unexplained structures and transitions of structures whose properties can be controlled by magnetic fields.

- The InSPACE magnetic fields are applied to the various samples, and the operation of the experiment is monitored via video.
- The experiment requires a microgravity environment because the magnetic structures settle out in gravity, precluding the observation of steady-state structures.
- Magnetically controlled materials have widespread applications in several industries including robotics, the automotive industry (suspension and damping systems), and civil engineering (bridges and earthquake-protection systems).
The primary science goal for the CFE Vane Gap experiments is to find the critical wetting angles at which fluid wicks up the edges of a perforated vane.

- An unexpected phenomenon (right) occurs when the perforations are filled prior to the running of the experiment (top container).
- A bulk shift of the fluid is identified when the perforations are filled, and stands out distinctly when compared to the relative symmetry of a test run (bottom container) with un-filled perforations.

January 2011 - Astronaut Scott Kelly (left), Expedition 26 commander, is pictured near a Capillary Flow Experiment (CFE) Vane Gap-1 experiment.

- The CFE is positioned on the Maintenance Work Area in the Destiny laboratory.
- CFE observes the flow of fluid, in particular capillary phenomena, in microgravity affecting key processes as: water purification, fuel storage and supply, and general spacecraft liquid transport.
The AMS-02 experiment utilizes a large permanent magnet to produce a strong, uniform magnetic field over a large volume. - The magnetic field is used to bend the path of charged cosmic particles as they pass through 5 different types of detectors.

- AMS-02 is studying the universe and its origin by searching for antimatter and dark matter while performing precision measurements of cosmic rays composition and flux.

-- As of June 27, 2018, AMS has collected and analyzed billions of cosmic ray events, and identified 9 million of these as electrons or positrons (an antimatter particle).

--- The number of high energy positrons increases steadily rather than decaying, conflicting with theoretical models, and indicates a yet to be identified source of positrons.

---- Results suggest high-energy positrons and cosmic ray electrons may come from different and mysterious sources.

The Alpha Magnetic Spectrometer (AMS-02), shown on the left, was installed to the ISS on May 19, 2011; it is a state-of-the-art particle physics detector. -- The AMS-02 detector is shown (right) during integration and testing at the European Organization for Nuclear Research (CERN) near Geneva, Switzerland.

--- The international team is composed of 60 institutes from 16 countries and organized by the Dept. of Energy.
Physical Sciences in Microgravity - CAL

- The Cold Atom Laboratory (CAL) is a facility for the study of ultra-cold quantum gases in the microgravity environment of the International Space Station (ISS).
- CAL (left), developed by Jet Propulsion Laboratory (JPL) in Pasadena, CA, enables research in a temperature regime and force free environment that is inaccessible to terrestrial laboratories.
- It is also a pathfinder experiment for future quantum sensors based on laser cooled atoms.
- The facility is designed for use by multiple scientific investigators and capable of being upgraded and maintained on orbit.

- CAL successfully launched to the ISS on May 21, 2018 aboard an Orbital ATK Cygnus resupply spacecraft.
- It was installed into an Expedite the Processing of Experiments to Space Station (EXPRESS) Rack (right).
- The EXPRESS Rack provides standardized power, data, thermal, and mechanical interface to scientific payloads.
- CAL is operated remotely via sequence control from JPL.
- The initial mission will have a duration of 12 months with up to five years of extended operation.
- CAL will produce clouds of ultra-cooled atoms, called Bose-Einstein condensates, chilled to a fraction of a degree above absolute zero.
- Select https://www.youtube.com/watch?v=z85AA2tF9f8 to view a video about CAL.
Biological Sciences in Microgravity

- The ISS laboratories enable scientific experiments in the biological sciences that explore the complex responses of living organisms to the microgravity environment.
  - The lab facilities support the exploration of biological systems ranging from microorganisms and cellular biology to integrated functions of multi-cellular plants and animals.
  - Several of the biological sciences experiments have facilitated new technology developments that allow growth and maintenance of living cells, tissues, and organisms.
  - Studies of plant physiology in microgravity provide insight into the basic biology of plants, and into how plants might be used as part of future exploration missions.
-- Successfully growing plants in microgravity presents challenges; from predictable distribution of water and nutrients to the reliability of biomass production.
- Through Expedition 15, 27 different biological experiments were performed on the ISS.
-- The early experiments were centered on testing new biotechnology tools.
--- Cellular biology and parameters of plant growth affected by microgravity comprised a large percentage of the research.
--- Experiments on animal biology and microbiology were also conducted.
- Through Expedition 15, 25 publications reported results from biological research on the ISS.
- One of the most exciting results reported from ISS research is the confirmation that common pathogens change and become more virulent during space flight.
The results led to a Pulse Flow Microencapsulation Processing System that has been used to make microcapsules for ground-based studies on human tumors grown in a mouse model. These microcapsules can be injected into the bloodstream or directly into solid tumors to provide local, sustained release of anti-cancer drugs. One study revealed that after 26 days of sustained release, human lung tumor growth in a mouse model was inhibited by 82% and 28% of the tumors had completely disappeared.

The MEPS-II experiment was located on the ISS in one-half of the Express Rack 3 (right).

- In 2002, the revised Microencapsulation Electrostatic Processing System (MEPS-II) research started on the International Space Station (ISS).
- Scientists were interested in looking at whether or not microencapsulation, a microballoon (left) that contained a small amount of a chemotherapy drug, could improve delivery to a tumor.
- The MEPS-II investigation proved that by removing gravity, microcapsules could be made with the desired properties.
- Since clinically useful quantities of microcapsules cannot be made in space, scientists spent the next five years perfecting a way to make them on Earth.
Many long-term space flight life-support scenarios assume the use of plants to provide food supplies for crewmembers as well as to recycle waste products. To date, Brassica rapa (field mustard plant), Triticum aestivum (super dwarf wheat), and four species of salad plants have grown in microgravity throughout their useful life cycles.

These successes came at the end of nearly a decade of repeated efforts using the same equipment to arrive at optimal settings for substrate moisture and oxygen.

The Lada greenhouse was developed to test methods for growing plants in the ISS’ microgravity atmosphere, a cooperative effort between Space Dynamics Laboratory at Utah State University and Russia's Institute of Biomedical Problems.

-- Named for the ancient Russian goddess of spring, the wall-mounted Lada has been in use in the Zvezda module since 2002 when it was delivered aboard a Russian Progress spacecraft.

November 2002 - Belgian Soyuz 5 Flight Engineer Frank DeWinne is pictured at the Russian Lada greenhouse in the Zvezda module with a fully grown mizuna lettuce.

The greenhouse consists of a control module and two independent vegetation modules allowing for comparisons in growing treatments.
- The Effect of Spaceflight on Microbial Gene Expression and Virulence (Microbe) experiment was performed in September 2006; it examined changes in three microbial pathogens.
- Initial data from one of the microbes, Salmonella typhimurium (a leading cause of human gastroenteritis), showed that 167 genes were expressed differently in flight when compared with ground controls.
-- The data indicated a response to the microgravity environment, including widespread alterations of gene expression that increased disease-causing potential.
- These results show great promise for both understanding mechanisms used by pathogens to spread disease and also designing ways to better protect humans in space.
- The original experiment was funded because of the human health risks for exploration missions; but because of the potential for applications to prevent disease on Earth, follow-on studies have been implemented as pathfinders for the use of the ISS as a National Laboratory.
Experiments conducted on the ISS examined the virulence of methicillin-resistant Staphylococcus aureus (MRSA) as well as other microbes.
- MRSA describes several strains of the bacteria, Staphylococcus aureus, that are resistant to a number of antibiotics.
-- Staphylococcus aureus is a group of bacteria that live on the surface of people's skin and inside the nose; it is normally harmless.
-- MRSA infections are a particular problem in hospitals.
- The studies of the MRSA bacteria in space are part of the pathfinder program to demonstrate the use of the ISS as a research platform for commercial research and development.
-- The pathfinder research approach uses a set of flight experiments to identify the components of the organisms that facilitate increased virulence in space, and then applies that information to pinpoint targets for anti-microbial therapeutics including vaccines.
-- The Group Activation Pack (GAP), shown to the left, is used to culture the bacteria in orbit. GAP is manufactured by BioServe Space Technologies.
Astronaut T.J. Creamer, Expedition 23 flight engineer, is shown with white spruce tree samples collected at the end of 30 days of grow-out. The Advanced Plant Experiment - Canadian Space Agency 2 (APEX-CSA2) investigation examines white spruce, *Picea glauca*, to understand the influence of gravity on plant physiology, growth, and on the genetics of wood formation.

APEX-CSA2 is the second Canadian botany study to be conducted aboard the ISS.

- APEX-CSA2 utilizes the Advanced Biological Research System facility to provide a controlled environment as well as to downlink images to the ground teams.

The results of the experiment will include:

- Improvement of the technology to grow trees in a spacecraft.

- Crews will need to be able to grow plants during long-duration exploration missions.

- Enhance the understanding of tree physiology in the space environment.

- Identify genes related to specific plant characteristics.

- These genes are expected to be used as markers for plant selection in various Earth applications and to improve sustainability of the forest.
- The first Vegetable Production System (VEGGIE) along with the Veg-01 experiment were delivered to the space station in 2014.
- They were transferred to the Columbus module for storage until installation into an experiment rack.
- On May 8, 2014, VEGGIE LED lights were activated; six plant Veg-01 “pillows” containing red romaine lettuce seeds (left) were inserted into the chamber and watered to initiate plant growth.
-- Although plant pillows performed well, modifications will be necessary for future watering procedures.

- On August 10, 2015, Astronauts Scott Kelly (right) and Kjell Lindgren had the first taste of Veg-01 food grown, harvested and eaten in space.
- To view a description of VEGGIE select: https://www.youtube.com/watch?v=YFdwv9yrxD0 &feature=youtu.be
- Included in Veg-03 was the third lettuce crop experiment that began to grow aboard the station on October 25, 2016.
-- This crop is the VEGGIE team’s first on-orbit attempt at a new, repetitive technique where the plant will be harvested for food and science samples as well as being left in tact to grow.
Human Research for Exploration

- The ISS is being used to study the risks to human health that are inherent in space exploration.
  - Many research investigations address the mechanisms of the risks (the relationship to the microgravity and radiation environments) and other aspects of living in space, including nutrition, sleep, and interpersonal relationships.
  - Other experiments are used to develop and test countermeasures to reduce these risks. Results from this body of research are critical enablers for exploration missions.
  - The overarching strategy that guides the ISS-based Human Research experiments focuses on filling in specific knowledge gaps and testing proposed countermeasures to determine their effectiveness and evaluate their operational feasibility for mitigating known human health problems in space.
  - Over the first 15 expeditions, 32 experiments focused on the human body, including research on bone and muscle loss, the vascular system, changes in immune response, radiation studies, and research on psycho-social aspects of living in the isolation of space.
  - Several of the early experiments have led to new experiments, testing details of observations or pursuing new questions that were raised by early results. One or two new experiments are started nearly every expedition.
  - Through Expedition 15, 43 scientific publications were based on human research performed on the ISS.
Effect of Prolonged Space Flight on Human Skeletal Muscle (Biopsy) evaluated changes in calf muscle function over long-duration space flights (30 to 180 days).

- It is well established that space flight can result in loss of skeletal muscle mass and strength known as atrophy.
-- This condition continues throughout a crewmember’s mission, even if crewmembers adhere to a strict exercise regime.
-- What researchers do not understand, however, are the effects that prolonged stays in microgravity have on skeletal muscles.
- Data collected from the crew indicated that astronauts who performed high treadmill exercise (greater than 200 minutes/week) vs. low treadmill exercise (less than 100 minutes/week) exhibited a smaller decrease in peak power.
-- Astronauts who performed high treadmill exercise showed a 13% decrease compared to a 51% decrease in peak power of astronauts who performed low treadmill exercise.

January 2002 - Cosmonaut Yury Onufrienko exercises on a treadmill in the Zvezda Service Module during the Expedition 4 mission.
Advanced Diagnostic Ultrasound in Microgravity (ADUM) tests the accuracy of using ultrasound technology in space flight.
- This investigation includes assessing health problems in the eyes and bones, as well as sinus infections and abdominal injuries.
-- ADUM also tests the feasibility of using an in-flight ultrasound to monitor bone density during long-duration space flights.
- The ISS crews have demonstrated that minimal training along with audio guidance from a certified sonographer can produce ultrasound imagery of diagnostic quality.
-- The ISS crewmembers, acting as operators and subjects, have completed comprehensive scans of the cardiothoracic and abdominal organs as well as limited scans of the dental, sinus, and eye structures.
--- They have also completed multiple musculoskeletal exams, including a detailed exam of the shoulder muscles.
--- Ultrasound video down-linked to NASA has yielded excellent results that are beginning to appear in scientific literature.

November 2004 - Astronaut Leroy Chiao performs an ADUM scan on the eye of Cosmonaut Salizhan Sharipov during Expedition 10.
Human Research for Exploration - ALTEA

- Astronaut Sunita Williams, Expeditions 14 and 15 Flight Engineer, wears the Anomalous Long Term Effects in Astronauts' Central Nervous System (ALTEA) helmet while conducting the experiment in the Destiny laboratory module.
- ALTEA measures the effect of exposure to radiation in space.

- Astronauts in orbit are exposed to cosmic radiation that is of sufficient frequency and intensity to cause effects on the central nervous system such as the perception of flashes of light that have been reported since the Apollo missions.
- The ALTEA experiment is comprised of a helmet-shaped device holding six silicon particle detectors designed to measure cosmic radiation passing through the brain.
- The detectors measure the trajectory, energy, and species of individual ionizing particles.
- At the same time an electroencephalograph measures the brain activity of the crewmember to determine if radiation strikes cause changes in the electrophysiology of the brain in real time.
Astronaut Catherine Coleman, Expedition 26 flight engineer, performs VO2max portable Pulmonary Function System software calibrations and instrument check while using the Cycle Ergometer with Vibration Isolation System in the Destiny laboratory.

- The VO2max experiment documents changes in maximum oxygen uptake for crewmembers on board the ISS during long-duration missions.

In 2006, NASA identified gaps in the scientific and medical knowledge regarding the human response to space flight.
- One of the gaps was the direct measurement of maximum oxygen uptake (VO2max) or aerobic capacity during and after long-duration space flight.
- In space, the ability to perform space walks and responding effectively to emergencies requires astronauts to be very fit.
- Researchers found aerobic capacity in space is related to the intensity of exercise.
  -- Those exercising at normal intensity saw initial decrease followed by a gradual increase over time.
  -- Maximum intensity exercise appears better at improving aerobic capacity.
- Aerobic capacity returned to preflight levels one month after landing, indicating no long-lasting effects on lungs and muscles.
- Late 2016 results concluded testing both intensities provides a more comprehensive picture, but better documentation of intensity and specific regimens is needed.
- On March 28, 2015, NASA Astronaut Scott Kelly (left) and Russian cosmonaut Mikhail Kornienko began a marathon 342-day mission on the station, the longest flight ever attempted by an American.
- The primary goal was to conduct experiments on the International Space Station (ISS) to learn more about the long-term effects of weightlessness and space radiation beyond the protection of Earth’s magnetic field.
-- The research is considered crucial before astronauts venture beyond low-Earth orbit for eventual flights to Mars.

- Kelly and Kornienko were members of four different ISS crews joining Expedition 43, and Kelly finished as the Expedition 46 Commander.
- On July 12, 2015, Scott Kelly is seen inside the Cupola that provides 360-degree viewing of the Earth and the space station.
-- The Caribbean is seen through the center window.
- Scott Kelly takes Fluid Shifts medical measurements assisted by Mikhail Kornienko (far left) and cosmonaut Gennady Padalka.
- Kelly and Kornienko returned to Earth on March 2, 2016 after a historic 340-day mission aboard the ISS.
Human Research for Exploration - Biomolecule Sequencer

- August 2016 - Astronaut Kate Rubins (left) sequenced DNA in space for the first time ever during the Biomolecule Sequencer investigation.

- DNA, or deoxyribonucleic acid, contains the instructions each cell in an organism on Earth needs to live.

- Kate Rubins, who has a background in molecular biology, conducted the test aboard the station while researchers simultaneously sequenced identical samples on the ground.

- The samples were prepared on the ground for sequencing and researchers selected organisms whose DNA had already been completely sequenced so they knew what results to expect.

- A space-based DNA sequencer could help diagnose an illness, or identify microbes growing in the spacecraft and determine whether or not they represent a health threat.

- It would also help protect astronauts’ health during long duration missions to Mars, and future explorers could potentially use the technology to identify DNA-based life forms beyond Earth.

- Crew member Matthias Maurer (right) of ESA, is shown inserting samples into the DNA sequencer.
Neutron Radiation Environment Study

- Canadian Space Agency Astronaut Chris Hadfield is holding “bubble detectors” for the Neutron Field Study (Radi-N2) experiment.
- Radi-N2 is a follow on investigation designed to characterize the neutron radiation environment aboard the ISS Destiny Laboratory Module.
- The objective of this investigation is to better characterize the ISS neutron environment and define the risk posed to the crew members’ health and provide the data necessary to develop advanced protective measures for future spaceflight.
- Eight bubble detectors are attached to fixed locations inside the Destiny module (below) as well as one carried by a crew member.

-- As of March 2016, the neutron exposure measured by the ongoing Radi-N2 experiment is similar to the previous Radi-N measurements conducted in the same locations within the ISS; Radi-N2 will continue until 2020.
--- The data shows that changes in ISS location, altitude, and solar activity do not appear to create a notable increase or decrease in neutron passes through the bubble detectors.
---- This agrees with earlier bubble-dosimeter readings in the Russian ISS segment, suggesting that these potential influences have little effect on the neutron field in the ISS.
Observing the Earth and Education Activities

- The crew continues to perform Earth observations investigation that supports a variety of Earth science initiatives.
  - Crew observations document urban growth, monitor changes along coastlines and long-term ecological research sites, record major events such as volcanic eruptions or hurricanes, and provide observations to support the International Polar Year.
  - Researchers working with the National Snow and Ice Data Center requested images of icebergs that broke from the Larsen ice shelf in Antarctica.
  - The high-resolution ISS images provided the first observations of ponded meltwater on the icebergs as they drifted into the South Atlantic Ocean.
  - The data allowed scientists to use the icebergs as analogs of ice sheets and model the accelerated breakup of an ice shelf.
- The data are fully accessible to scientists around the world.
- ISS Earth observations have supported more than 20 publications and one patent, several web-based articles, and a robust database that provides more than 325,000 images of Earth that were taken by astronauts on the ISS.

- ISS education activities have touched millions of students around the world.
  - Tens of thousands of students have participated in the EarthKAM (Earth Knowledge Acquired by Middle School Students) experiment; even more have participated in crew conferences with schools through HAM radio.
  - ISS crews continue to create short videos demonstrating elements of life in microgravity, profiling technologies involved in living off the planet, and providing a behind-the-scenes look at some of the science experiment hardware.
  - Recent examples of these include a feature called “Toys in Space” and a demonstration of Newton’s Laws of Physics.
Middle School Students take Images from ISS

- Not everyone can go to space, but students can see Earth from an astronaut’s perspective with the Sally Ride Earth Knowledge Acquired by Middle School Students or Sally Ride EarthKAM program.
- Sally Ride was the first American woman in space in 1983 aboard the space shuttle Challenger.

- Thousands of students can remotely control a digital camera mounted on the ISS, and use it to take photographs of cities, such as Chicago (above), coastlines, mountain ranges and other interesting features and phenomena; the program began in 1996.
- The EarthKAM team posts the students’ images on the Internet, where the public and participating classrooms can view Earth from a unique vantage point.
- During the week of October 22, 2018, the crew prepared and initiated Mission 64 of the program.

--- At the start of the week, the EarthKAM program had served more than 19,000 students from 34 countries; by the end of the week, more than 20,000 students from 37 different countries were involved.
- Since 1996, more than 24,000 photos have been taken during 30 missions on the space station via this program, the only one that gives students such direct control of an instrument on a spacecraft orbiting Earth.
Observing the Earth and Education Activities

- ESA “Lessons Online”

- October 2003 - ESA astronaut Pedro Duque of Spain watches a water bubble float between him and the camera that shows his image refracted.

- On the ISS, Pedro has demonstrated basic scientific principles in lessons provided by ESA for use on the Internet.

- The European Space Agency (ESA) has developed a series of “Lessons Online” for primary and secondary school students and their teachers.

- Space-related topics are being used to increase understanding of a number of subjects related to many scientific disciplines.

- Computers in the classroom expose students to space-related topics using texts combined with illustrations, videos, animations and links to more in-depth information.

- The lessons are based on demonstrations and/or experiments performed on board the station.

- Each text lesson contains recorded short videos related to topics in the standard European curricula.

- The lessons give a general approach to topics, not all of which are related to space, with the support of videos made with contributions from the ISS astronauts.
Through Crew Earth Observation (CEO), crewmembers share their view of the Earth with the public and take pictures of some of the most dramatic examples of change on the Earth’s surface.

- These sites have included major deltas in south and east Asia, coral reefs, cities, alpine glaciers, volcanoes, large mega-fans (major fan-shaped river deposits), and features on Earth, such as impact craters, that are analogs to structures on other planets.

-- Dynamic events include: the 2004 and 2005 photographs of the four Florida hurricanes, the December 2004 tsunami, and hurricanes Katrina and Wilma.

- From 2000 to 2008, crewmembers took more than 300,000 images of Earth - almost half of the total number of images that have been taken from orbit by astronauts since the first Mercury missions.

-- Between 400,000 and 1,000,000 digital images of Earth taken from the CEO collection are downloaded by the public each month.

January 2004 - ISS astronauts, working with scientists studying the breakup of the Antarctic ice shelves, tracked Iceberg A39B near South Georgia Island as it collected ponded melt-water on the surface and disintegrated in the South Atlantic Ocean.
The Commercial Generic Bioprocessing Apparatus (CGBA) Science Insert-03 (CSI-03) is the third in a series of experiments for the K–12 education program from BioServe Space Technologies at the University of Colorado-Boulder.

- This program provides students learning opportunities based on research that was conducted on the ISS through down-linked data and imagery, which was distributed directly into the classroom via the internet.
- National Standards-based curriculum materials, including teacher guidebooks, student workbooks, and complementary classroom experiments, were used to ensure the greatest possible benefit to the participating students.
- The objective of the CSI suite of experiments was to launch small education experiments to be processed in CGBA on an annual basis so that during every academic school year, a “live,” on-orbit experiment is available to participating schools.

- November 2008 - CSI-03 included examining the ability of an orb weaving spider to live in space.
- Students compared how the spider differed in behavior, feeding, and web spinning in microgravity compared to spiders on Earth.
- CSI-03 began operations during Expedition 18 and was completed during Expedition 19.
- The “Arachnonauts - Spiders in Space” DMNS Space Odyssey exhibit includes the CSI-03 spider habitat that flew on the ISS.

Credit: BioServe Space Technologies, Boulder, CO
Observing the Earth and Education Activities - HICO

- The map (right) shows chlorophyll-a for Pensacola Bay derived from HICO data.
  - Higher values (yellow and red) indicate high chlorophyll concentrations in the water suggesting algal blooms are present.
  - Algal blooms can reduce oxygen levels in the water, leading to fish and other animal deaths.
  - Some algal blooms also contain organisms that produce toxins harmful to other life, including humans.

- HICO operated for 5 years, during which it collected approximately 10,000 hyperspectral scenes of the Earth, before its computer was damaged in 2014 during a solar storm.

The Hyperspectral Imager for the Coastal Ocean (HICO) is the first imaging spectrometer to specifically sample the coastal ocean from space. HICO was installed in the HICO-RAIDS Experiment Payload (HREP) on the Japanese Experiment Module Exposed Facility (left).

- HICO was developed by the Naval Research Laboratory.
- The HREP started performing science operations on October 23, 2009.
The image outlined in red in the montage was derived from the above large-scale Edouard image.

The bright “eyewall” clouds lie just outside the eye and whirl around it at speeds up to 110 miles per hour (mph) and up to 230 mph in the most intense hurricanes.

The tops of these clouds lay 30,000 - 50,000 ft. above sea level.

The altitude of these clouds is related to the intensity of a strong tropical cyclone.

In 2013, Visidyne, MA began to study tropical cyclones using images taken by ISS fixed cameras.

- September 16, 2014 - This image of Hurricane Edouard over the Atlantic Ocean was taken from the ISS and used to determine its intensity.
- Advance warning of a tropical cyclone’s intensity is crucial for protecting lives and property in the face of a storm.
- The altitude of these clouds is related to the intensity of a strong tropical cyclone.
- The montage of 12 images (below), each covering an area of 62 x 62 miles, centered on the cloud-free eye of Edouard, was taken from the ISS over an 82-second interval.

Credit: Visidyne/NASA
Teams from the United States and abroad gathered at Massachusetts Institute of Technology in Cambridge, MA and competed in the fifth annual Zero Robotics SPHERES Challenge on January 17, 2014.

- The competition included 27 U.S.A. high schools that successfully advanced to the finals out of 108 who entered; 18 European schools advanced out of an original 57.
- Participants spent most of the summer learning to write computer programs and formulating strategies for their SPHERES in anticipation of the final competition.
Seven areas of ISS operations that have generated valuable scientific data that enable scientists and engineers to better define problems and understand the space environment are:

1) **Crew-Initiated Science** - This science encompasses activities that are initiated by the crew.
   - These activities are performed at the discretion of the astronauts on board ISS using simple materials that would not impact ISS operations.
   - They often take the form of simple demonstrations of life or physical phenomena in microgravity; videos of the activities are down-linked to Earth for use in informal education materials.

2) **Educational Activities** - Everyday life aboard the ISS provides topics that can be used as springboards for classroom activities.
   - Crewmembers and collaborators with certain payloads have creatively worked with ground-based crews to produce educational activities and materials that grow from normal operations aboard the ISS.

3) **Environmental Monitoring** - Research has been performed on all ISS expeditions and will continue to be performed on future station missions to ensure the health of the spacecraft as well as of the crew.
   - While the monitoring, both inside and outside the spacecraft, supports daily life aboard the ISS, the data that are collected are useful for addressing a wide set of questions, such as understanding the evolution of contamination, determining the detectable limits of contaminants, quantifying assessments of environmental conditions that impact the crew, and more.
Seven areas of ISS operations (continued):

4) **Medical Monitoring of Crewmembers** - Monitoring of ISS crewmembers includes tests before, during, and after space flight to follow the effects of space flight on their health and to ensure that they receive proper medical care.
- Medical data collection in support of baseline monitoring of crew health is separate from, but supports, the hypothesis-driven medical experiments that are sponsored by the Human Research Program.

5) **Supplementary Medical Objectives** - These objectives are designed to use data that are collected by another investigation to answer new questions that are posed by investigators concerning the effects of space flight on crew health.
- Small studies can provide the data that are required for defining a full, hypothesis-driven experiment.

6) **Station Development Test Objectives (SDTOs)** - SDTOs are designed to refine or expand ISS models, assess future ISS capabilities or improvements, and test capabilities for future exploration systems.
- The objects of SDTOs are often elevated to operational status after successful demonstration on orbit.
- Data collected from the SDTOs can provide new scientific and engineering insights into aspects of ISS operations or technologies that are relevant to future space flight missions.

7) **Exploration Lessons Learned from the Operation of ISS** - Constructing and operating ISS serves as a test bed for new technologies and techniques in support of crew exploration mission hardware design and development.
Science from ISS Operations - Crew-Initiated Science
- Saturday Morning Science

- Growing plants in Zero-G; using materials (ear plugs, underwear, toilet paper, drinking straw, basil and tomato seeds) readily available aboard ISS, basil and tomato seeds were germinated and sprouted on ISS.

- Science of opportunity, which was dubbed “Saturday Morning Science,” was done at the discretion of Expedition 6 science officer Don Pettit to shed the light of science on a variety of subjects for students of all ages.
- ISS crewmembers have access to world-class laboratory facilities in the unique environment of microgravity; the topics for “Saturday Morning Science” were, therefore, spawned by living and working in the microgravity environment.
- During Expedition 6, a number of scientific principles were demonstrated through “Saturday Morning Science."
- The value of this science is the ability to provide observation-based insights for the reduced gravity environment.
A better understanding of how nutritional status and general physiology are affected by the microgravity environment helps provide nutritional recommendations for crewmembers on long-duration space travel.

- Dietary intake during space flight has often been inadequate and this can greatly compromise nutritional status.
- The space environment itself results in physiologic changes that can alter nutritional status.

-- For example, changes in iron metabolism are closely associated with blood chemistry alterations during space flight.

- In-flight body mass measurements were obtained using a body-mass measuring device; this device exerts a known force on the body and measures body acceleration.

-- Body mass was then calculated.
-- Body weight, total bone mineral content, and bone mineral density decreased during flight.
In 2008, Paige Nickason (left) became the first patient to have brain surgery performed by a robot called neuroArm. Paige is shown pointing to where neuroArm entered her head.

- NeuroArm is the first robot capable of performing surgery inside magnetic resonance imaging (MRI) machines.

- The neuroArm technology is from the Canadian Space Agency's family of space robots used on the International Space Station (ISS).

-- The robots were developed by MacDonald, Dettwiler and Associates Ltd (MDA) to perform the heavy-lifting and maintenance on the ISS.

- MDA worked with a team at the University of Calgary to develop a highly precise robotic arm that works in conjunction with the advanced imaging capabilities of MRI systems.

- The ISS robots developed by MDA include the Special Purpose Dextrous Manipulator (SPDM) or Dextre shown on the right handling an ISS component.

- Dextre is a dual-armed (each 11 ft long) robot with a body including two shoulder structures providing support for the arms.
CRE-1 advances the state of knowledge and experience involved in manual component-level electronics repair by demonstrating the repairs in an operational environment.

- The current ISS strategy for the repair of electronics components replaces the failed hardware depending on spares provided by resupply flights from Earth.

-- For future exploration missions beyond low Earth orbit, logistical support will be more constrained.

- Repairing electronics at the lowest component level could potentially ease the logistical burden by minimizing the mass and volume of required spares.

-- Implementation of such a strategy on the ISS could serve as a test bed for future operations as well as offer additional options for actual contingency maintenance.
Science from ISS Operations - Medical Monitoring

- December 2011 - Astronaut Dan Burbank (foreground), Expedition 30 commander, and Russian cosmonaut Anton Shkaplerov, flight engineer, participate in a Crew Health Care System (CHCS) medical contingency drill in the Destiny laboratory.
  - The drill gives crewmembers the opportunity to work as a team in resolving a simulated medical emergency onboard the space station.
  - The CHCS includes the Health Maintenance System (HMS).
  - The HMS provides inflight life support and resuscitation, medical care, and health monitoring capabilities.
  - The medical kit includes the:
    -- Ambulatory Medical Pack,
    -- Advanced Life Support Pack,
    -- Crew Contamination Protection Kit,
    -- Defibrillator,
    -- Respiratory Support Pack,
    -- Crew Medical Restraint System, and
    -- Medical Checklist.
Science from ISS Operations - ISS FIT App

- October 2016 - The International Space Station Food Intake Tracker (ISS FIT) iPad app (application) simplifies the way astronauts track their meals.
- The ISS FIT app gives astronauts real-time feedback about their dietary habits and offers greater insight for physicians and researchers on Earth to keep crews healthy and fit.
- **Astronaut Michael Hopkins** (right), Expedition 37 flight engineer, holds a spoon containing a piece of food in the Harmony module.

- The app provides real-time information on key nutrients including calories, sodium and fluid.
- For example, crew members at lunch can see they need to consume more water later in the day.
- Fluid intake is important for hydration but specifically for reducing kidney stone risk, which is higher during flight.
- The app replaces a weekly computer questionnaire that provided an estimate of dietary intake over the week.
- **Japan Aerospace Exploration Agency astronaut Koichi Wakata**, Expedition 18/19 flight engineer, is pictured near food and drink containers floating freely in Harmony.
November 19, 2018 - The Crew Interactive Mobile Companion (CIMON) arrived at the ISS onboard the Northrop Grumman resupply spacecraft Cygnus NG-10.

- ESA astronaut Alexander Gerst (left) interacts with technology demonstrator CIMON in the Columbus Laboratory Module.

- CIMON is a spherical device weighing 11 lbs, a bit larger than a basketball, intended to support and increase astronaut efficiency by displaying and explaining information needed to carry out scientific experiments and repairs.

- Ultimately, CIMON can serve as a mobile camera to provide crew members with video-assisted instructions and document procedures for either live or retrospective analysis.

- During the first week on the ISS, crew members prepared CIMON for demonstrations; the crew adjusted his microphone, checked the camera view and charged his batteries.

- In several days, CIMON was able to demonstrate free flying and navigation in the ISS.

- CIMON was developed and built by Airbus in Friedrichshafen and Bremen, Germany, on behalf of German Space Agency DLR and uses artificial intelligence software by IBM Watson.

- Ludwig Maximilians University Clinic in Munich, Germany is in charge of the project’s scientific features.

- Select https://www.youtube.com/watch?v=3_2Jy1Ur0js to view a video about CIMON.
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All images are from NASA except as noted

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CIMON demonstration
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ISS Overview (as of December 31, 2018 or noted)

- **ISS Characteristics**
  - *Orbit*: 250 to 254 statute miles altitude; 17,100 miles per hour speed; 51.6 degree inclination above and below the equator
  - *Weight*: 925,335 lbs (462.7 tons)
  - *Size*: 239.4 ft (solar array length) and 357.5 ft (truss length)

- **Spacewalks (as of August 16, 2018)**
  - *Assembly and maintenance support total*: 212
  - *Total time*: 1327.3 hours (55.3 days)

- **Crew Support (as of March 9, 2011)**
  - *In flight*: 6 crew members
  - *Ground*: more than 100,000 personnel
  - *States*: 37
  - *Countries*: 16

- **ISS Flights**
  - *American (crew)*: 37 Space Shuttle flights
  - *Russian (crew)*: 56 Soyuz flights
  - *Russian (launch & cargo)*: 73 Proton and Progress flights
  - *European (cargo)*: 5 Automated Transfer Vehicle flights
  - *Japanese (cargo)*: 7 H-II Transfer Vehicle flights
  - *American (commercial cargo)*: 2 test flights and 26 operational flights by SpaceX’s Dragon and Northrop Grumman’s Cygnus
The ISS celebrated 10 years of crew-occupied operations in November 2010.
- The Russian Zarya control module was the first ISS element launched November 1998 and placed in-orbit.
- The American Unity Node 1 module was launched on the Shuttle Endeavour and berthed to Zarya December 1998.
- The Russian Zvezda service module providing living quarters is launched and docked to Zarya July 2000.
- The Russian Soyuz-TM docks to the ISS and the three crewmembers are the first to occupy the station in November 2000.
- The American Destiny laboratory module is launched on the Shuttle Atlantis and berthed to Unity February 2001.
- The American P6 Truss Segment is launched on the Shuttle Endeavour November 2000 and two of its 240 ft photovoltaic arrays are deployed.
- The Harmony node 2 module is launched on the Shuttle Discovery and berthed to Destiny October 2007.
- The European Columbus laboratory module is launched February 2008 on the Shuttle Atlantis and berthed to Harmony.
- The American S6 Segment with the fourth and final pair of solar arrays is launched on the Shuttle Discovery March 2009 and deployed.
- The Japanese Experiment module laboratory is launched May 2008 on the Shuttle Discovery and berthed to Harmony.
- The crew of the ISS increases to six for the first time May 2009 with the arrival of three new residents aboard the Soyuz TMA spacecraft.
- The Tranquility Node 3 module with the Cupola is launched on the Shuttle Endeavour and berthed to Unity February 2010.
- The Shuttle Atlantis is launched on May 14, 2010 delivering the Russian-built Rassvet Mini-Research Module-1 to the ISS where it is installed on the Earth-facing port of the Zarya module.
- The Italian-built Permanent Multipurpose Module is launched on the Shuttle Discovery and berthed to Unity March 2011.
- The Alpha Magnetic Spectrometer-02, state-of-the-art particle physics detector, is launched on the Shuttle Endeavour May 2011 and attached to the truss.
ISS Science Overview

- Parts of the science and technology research in the presentation is based upon the NASA report titled *International Space Station Science Research Accomplishments During the Assembly Years: An Analysis of Results from 2000-2008;* NASA/TP-2009-213146, Revision A; NASA Johnson Space Center, Houston, TX; June 2009.
  - The report focuses on the experimental results collected through 2008, including scientific publications from studies that are based on operational data.
  - The report is available at: [http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090029998_2009030907.pdf](http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090029998_2009030907.pdf)

- NASA’s priorities for research aboard the ISS center on understanding human health during long-duration missions, researching effective countermeasures for long-duration crewmembers, and researching and testing new technologies that can be used for future exploration crews and spacecraft.
  - Experiment results have already been used in applications as diverse as the manufacture of solar cell and insulation materials for new spacecraft and the verification of complex numerical models for the behavior of fluids in fuel tanks.
  - Most research also supports new understandings, methods, or applications that are relevant to life on Earth, such as understanding effective protocols to protect against loss of bone density or better methods for producing stronger metal alloys.
Instead of the typical teardrop shape seen on Earth, the microgravity flame becomes spherical.
- On Earth, the flame is drawn into a tip by the rising hot gases; convection currents are greatly reduced in microgravity.
-- Fresh oxygen is not being delivered to the candle by these currents. Instead, oxygen works its way slowly to the flame by the process of diffusion. Soon, the flame temperature begins to drop because the combustion is less vigorous.

A candle flame in Earth's gravity (left) and microgravity (right) shows the difference in the processes of combustion in microgravity.

SAME will assess the size and distribution of the smoke particles that are produced by the different types of materials that are found on spacecraft such as Teflon, Kapton, cellulose, and silicone rubber.
The RRM Phase 3 (RRM3) module was delivered to the ISS on December 8, 2018 on SpaceX CRS-16 and installed on the ExPRESS Logistics Carrier-1 (ELC-1) on December 19, 2018.

The RRM3 mission has a projected two-year life on the ISS.
- However, NASA intends to accomplish its objectives within the first year.

The artistic representation shows the ISS’s Dextre robot (right) performing a RRM3 robotic refueling task with the module mounted to the ELC-1.
- During RRM3 mission operations, the Dextre robotic arm will carry out tasks to transfer cryogenic liquid methane from the source tank, in the module, to the empty receiver tank using a suite of three primary tools.
- The task sequence begins with the multi-function tool 2 (MFT2) which operates smaller specialized tools to prepare for the fluid transfer.
- The cryogen servicing tool (CST) uses a hose to connect the source tank, filled with liquid methane, to the empty receiver tank.
- To monitor the process, the Visual Inspection Poseable Invertebrate Robot 2 (VIPIR2) utilizes a state-of-the-art robotic camera to make sure tools are properly positioned.
Technology Development for Exploration
- Robonaut 2 Characteristics

**Head** - houses the vision equipment. Behind the visor are two stereo vision cameras for R2 and its operators, and two auxiliary cameras. A fifth infrared camera is located in the mouth for depth perception.

**Neck** - 3 degrees of freedom allowing R2 to look left, right, up, or down.

**Arms** - 2 ft - 8 inches long with each arm boasting 7 degrees of freedom and the strength to hold 20 lbs in any pose in Earth’s gravity.

**Hands** - A total of 12 degrees of freedom with 4 degrees of freedom in the thumb, 3 degrees of freedom each in the index and middle fingers, and 1 each in the ring and pinky fingers. Each finger has a grasping force of 5 lbs.

**Torso** - The R2 computer is included.

**Backpack** - Holds the power conversion system allowing R2 to be plugged in on Earth and on the International Space Station (ISS). Holds the batteries on the moon, asteroid or another planetary surface.

**Legs** - Each leg has seven joints and a device on the foot called an end effector allowing R2 to grasp handrails and also engage seat tracks ensuring a stable attachment at all times. The end effectors have a vision system to verify and eventually automate each leg’s approach and grasp.

**Degrees of freedom** - The number of displacements and rotations along which an object can move; a higher number indicates an increased flexibility in positioning.

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**Specifications:**

**Materials:** Primarily aluminum with steel and non-metallics

**Weight with legs:** 490 lbs

**Height:** 8 ft (with legs fully extended)

**Shoulder width:** 2 ft - 7 inches

**Sensors:** 500+, total Processors: 3 Core-i7s, 36 Power PCs, 16

**Arms & legs degrees of freedom:** 58
Before the printer was launched to the space station, it made an identical set of parts. The flight parts were delivered to MSFC for testing to compare the ground controls with the flight parts. Materials engineers will put both the space samples and ground control samples under a microscope and through a series of tests. Project engineers will perform durability, strength and structural tests on both sets of printed items as well exam them using an electron microscope to scan for differences in the objects.

April 6, 2015 - The first items ever manufactured in space with a 3-D printer were unboxed (left) in the Additive Manufacturing Laboratory at Marshall Space Flight Center (MSFC) in Huntsville, AL.

The printer used 14 different designs and built a total of 21 items and some calibration coupons. A wrench in a sealed bag made by the space station printer is shown below.

The parts returned to Earth in February 2015 on the SpaceX Dragon.
The structure evolution in an magnetorheological (MR) fluid over time is shown above while an alternating magnetic field is applied.
- The far left image shows the fluid after 1 second of exposure to a high-frequency-pulsed magnetic field; the suspended particles form a strong network.
- The images to the right show the fluid after 3 minutes, 15 minutes, and 1 hour of exposure; the particles have formed aggregates that offer little structural support and are in the lowest energy state.

InSPACE will obtain fundamental data about the complex properties of the smart material (material that has one or more controllable properties) called MR fluids.
- MR fluids are suspensions of small (micron-sized) super paramagnetic particles in a nonmagnetic medium.
-- These controllable fluids can quickly transition into a nearly solid-like state when exposed to a magnetic field and return to their original liquid state when the magnetic field is removed. Their relative stiffness can be controlled by controlling the strength of the magnetic field.
--- Due to the rapid-response interface that MR fluids provide between mechanical components and electronic controls, they can be used to improve or develop new brake systems, seat suspensions, clutches, airplane landing gear, and vibration damping systems.
Human Research for Exploration - Endurance Mission

- The Endurance Mission actually lasted for three years and not just one year.
- One year before Scott Kelly and Mikhail Kornienko left Earth, they began participating in investigations aimed at better understanding how the human body responds to long-duration spaceflight.
- Samples of their blood, urine, saliva, and more all make up the data set scientists will study.
- The same kinds of samples continued to be taken throughout their stay in space, and will continue for a year or more once they return.
- Scientists began analyzing data from Kelly and Kornienko as soon as they returned to Earth, but it could be six months to six years before research results are published.
- Data collected on both Kelly and Kornienko will be shared between the United States, Russia, and international partners.
- Kelly is the first American to complete a continuous, year-long mission in space but this is not the first time humans have reached the goal.
- Previously, four humans spent a year or more in orbit on a single mission, aboard the Russian Mir Space Station.
- During Kelly’s year-long mission, his participation in science was not limited to the one-year mission investigations, he also worked on some of the 400 station science studies.
- Kelly’s identical twin brother, Mark, a former astronaut, has taken part in a suite of studies using Mark as a human control on the ground during the one year mission.
- Kelly and Kornienko’s mission will inform future decisions and planning for other long-duration missions, whether they are aboard the space station or a mission to Mars.
- Understanding the challenges facing humans is just one of the ways research aboard the space station helps our journey to Mars.