National Aeronautics and Space Administration

Research & Technology for Exploration: Status & Plans

Briefing to Aeronautics and Space Engineering Board

October 13, 2009

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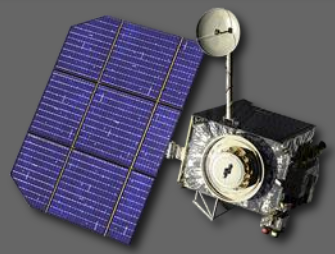
Topics

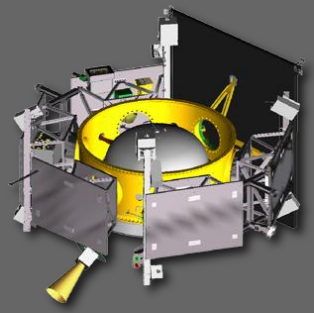
- Status of ACD programs
- NRC studies
- Review of U. S. Human Space Flight Plans
- ISS utilization through 2020
- A new vision for exploration research & technology
- International collaboration
- Technology development for Mars exploration

NASA Programs Enabling Exploration

Advanced Capabilities Division (ACD)

Lunar Precursor Robotic Program

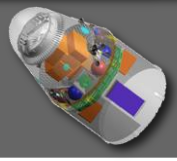




Human Research Program

Exploration Tech. Development Program

Commercial Crew Cargo Program

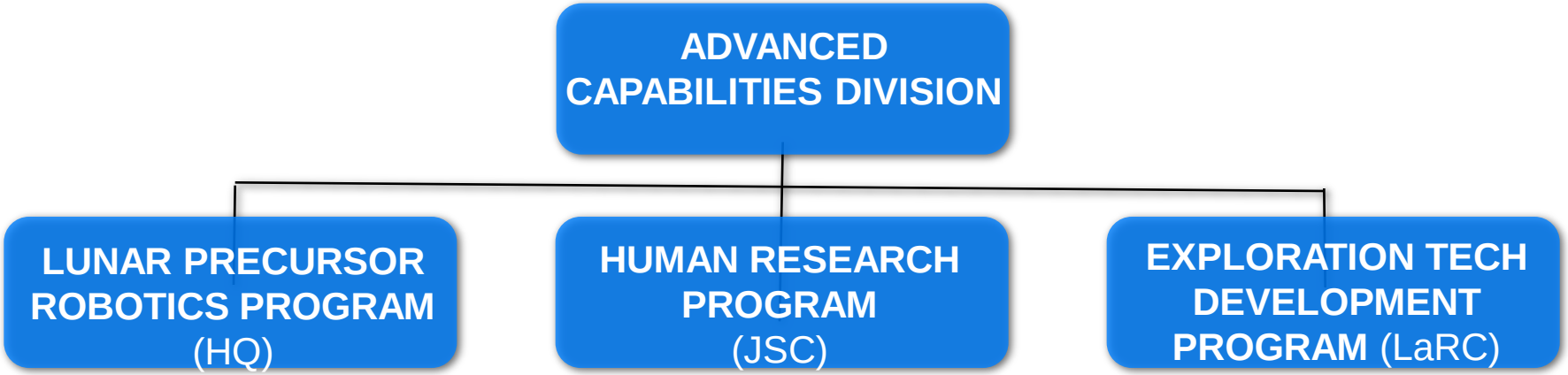


Constellation Program

Advanced Capabilities Division

Mission: ACD creates knowledge, technologies, and capabilities to enable safe and sustainable human exploration, while providing benefits for life on Earth.

- This organization represents a major investment in the full spectrum of R&T
  - Basic life-sciences → Crew Safety & Performance
  - Basic physical sciences → Tech to support Constellation
  - Flight projects to research the lunar environment



- Study the lunar environment with instruments for exploration and science

- Research to understand health risks to crew
- Develop countermeasures and standards

- Enabling tech for the Constellation Program
- Innovative concepts & technologies for exploration
- Conduct basic research using ground & flight facilities

Making Human Exploration Possible: Lunar Reconnaissance Orbiter (LRO) Mission

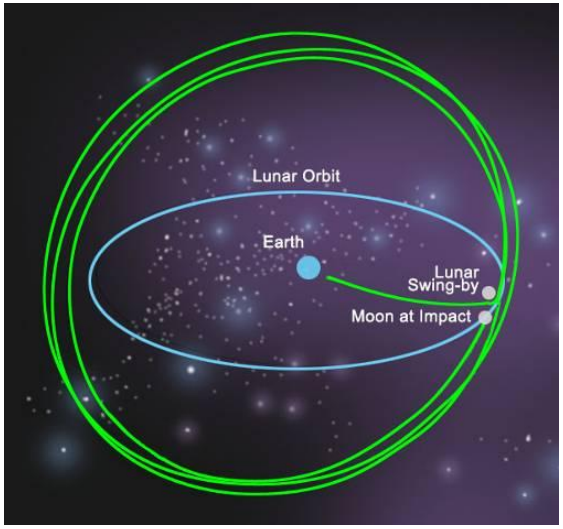
- Lunar orbiter to provide data critical to Constellation Systems' efforts to return humans to the Moon by 2020
  - Characterize landing sites
    - High-resolution mapping
    - Surface characterization (slope, roughness)
  - Identify resources
    - Water
    - Minerals
    - Sunlight
  - Characterize radiation environment
    - Energy deposited in tissue-equivalent plastic
    - Neutron albedo

- LRO was launched on June 18, 2009 on an Atlas V into a direct insertion trajectory to the Moon.
- Exploration mission began on Sept 17, 2009 after instrument checkout
- All data products are publically available via the Planetary Data Systems
- LRO is managed and built by the NASA Goddard Spaceflight Center.

Lunar Crater Observation & Sensing Satellite (LCROSS) Mission

- Lunar kinetic impactor used to investigate the presence of water ice and other volatiles on the moon.
  - LCROSS was co-manifested with LRO
  - After LRO separation, LCROSS remains attached to the Atlas upper stage (the Centaur) through ~3.5 month cruise orbit targeting a permanently shadowed crater.
  - In the final stage of the mission, LCROSS separates from the 2300-kg Centaur observing its impact and the ejecta plume.
  - Impact on October 9, 2009 will be viewable from earth.
- The LCROSS Project Office is at Ames Research Center. The spacecraft was built by Northrop Grumman Space Technologies, Redondo Beach, CA

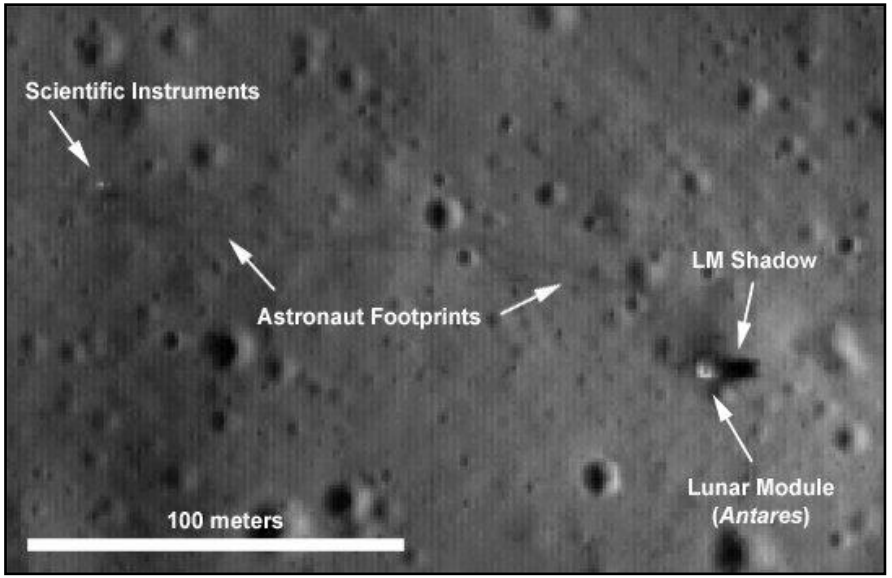
LCROSS spacecraft



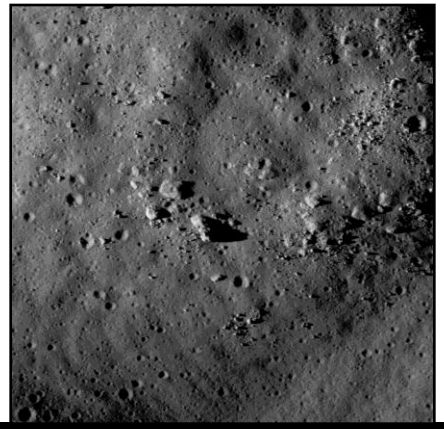
LCROSS trajectory

LRO and LCROSS are Returning First Images from the Moon

LRO/LCROSS launch
June 18, 2009



LRO image of Apollo 14 landing site



LRO image of boulders in farside crater Tsiolkovskiy

LCROSS image from lunar swingby

Expanding Knowledge: Human Research

Goals

- Reduce spaceflight risks to crew health and performance during exploration missions.
- Enable development of human spaceflight medical and human factors standards.
- Develop and validate technologies that serve to reduce medical risks of human spaceflight.

Program Elements

- **Space Radiation:** Human health effects, restrictions for vehicle environments & crew selection; shielding modeling; measurement and warning technologies.
- **Exploration Medical Capability:** Medical care and crew health; medical data management; probabilistic risk assessment.
- **Human Health Countermeasures:** Integrated physiological, pharmacological, and nutritional countermeasures; lunar Extra-Vehicular Activity related physiology research.
- **Behavioral Health & Performance:** Selection, assessment, and training capabilities; intervention and communication techniques for exploration missions.
- **Space Human Factors & Habitability:** Anthropometry, display/control, cognition, habitability, ergonomics; advanced food development; lunar dust toxicological testing.
- **ISS Medical Project:** ISS research integration and operations.

Implementation

- Over 300 investigations involving over 140 competitively-selected research grants, directed in-house research activities, and international partnerships.
- **National Space Biomedical Research Institute –** Cooperative agreement that supporting investigators at over 70 U.S. institutions .

Risk Portfolio and ISS Utilization

- **HRP is focused on reducing 27 human spaceflight risks based on evidence from science, clinical, and operational research. These risks were developed in coordination with the Office of Chief Health & Medical Officer (OCHMO) and reviewed by Institute of Medicine.**

- **21 of the 27 risks require investigations on the International Space Station (ISS) to gather information to understand the risk, validate countermeasures to mitigate a risk, or validate technologies to monitor or treat the adverse outcome. (see backup)**
  - 12 of the risks have ISS investigations that extend into the 2016 to 2020 timeframe.
  - 4 risks are critical to reduce before ISS retirement to enable long-duration lunar and Mars exploration missions.

- **For the Mars mission, the ISS is the only platform that provides the microgravity environment of a Mars transit. If these risks cannot be mitigated prior to the end of ISS, there will be no new opportunity.**

HRP uses ISS as a laboratory to reduce critical risks for long-duration human spaceflight

Crew Health and Safety Risks

Blue – ISS investigations required
Red – Critical to reduce before ISS retirement

Space Human Factors & Habitability Risks

- Risk of Error Due to Inadequate Information
- Risk Associated with Poor Task Design
- Risk of Reduced Safety and Efficiency Due to An Inadequately Designed Vehicle, Environment, Tools, or Equipment
- Risk of Adverse Health Affects from Lunar Dust Exposure
- Risk of Inadequate Food System

Behavioral Health & Performance Risks

- Risk of Behavioral and Psychiatric Conditions
- Risk of Performance Errors Due to Sleep Loss, Circadian Desynchronization, Fatigue and Work Overload
- Risk of Performance Errors Due to Poor Team Cohesion and Performance, Inadequate Selection/Team Composition, Inadequate Training, and Poor Psychosocial Adaptation

Space Radiation Risks

- Risk of Radiation Carcinogenesis
- Risk of Acute Radiation Syndromes Due to Solar Particle Events
- Risk of Acute or Late Central Nervous System Effects from Radiation Exposure
- Risk of Degenerative Tissue or other Health Effects from Radiation Exposure

Exploration Medical Capability Risks

- Risk of Inability to Adequately Treat an Ill or Injured Crew Member

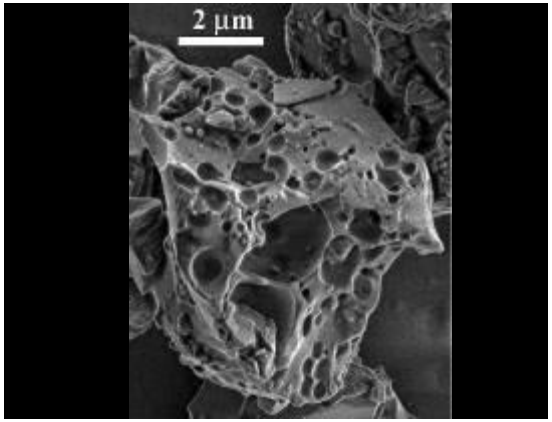
Human Health Countermeasures Risks

- Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems
- Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance
- Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity
- Risk of Accelerated Osteoporosis
- Risk of Orthostatic Intolerance During Re-Exposure to Gravity
- Risk Factor of Inadequate Nutrition
- Risk of Bone Fracture
- Risk of Invertebral Disc Damage
- Risk of Renal Stone Formation
- Risk of Cardiac Rhythm Problems
- Risk of Crew Adverse Health Event Due to Altered Immune Response
- Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions
- Risk of Impaired Ability to Maintain Control of Vehicles and Other Complex Systems
- Risk of Therapeutic Failure Due to Ineffectiveness of Medicine

Research & Technology Highlights

Lunar analog feasibility in bedrest study testing began

Completed new capability to simulate Solar Particle Events at NSRL



Performed lunar dust characterization, activation, and toxicity testing

Validated renal stone potassium citrate countermeasure

Completed study on crew performance during combined acceleration and vibration for Cx

Lightweight Trauma Module delivered to ISS as operational crew health care

Creating Capabilities: Exploration Technology Development

Goals:

- Reduce human and robotic exploration mission risk by developing advanced technologies and capabilities.
- Mature critical near-term technologies to support development of the Orion Crew Exploration Vehicle and Ares I launch vehicle
- Develop innovative technologies to enable Exploration
- Conduct fundamental microgravity research and test technologies for exploration on the International Space Station.

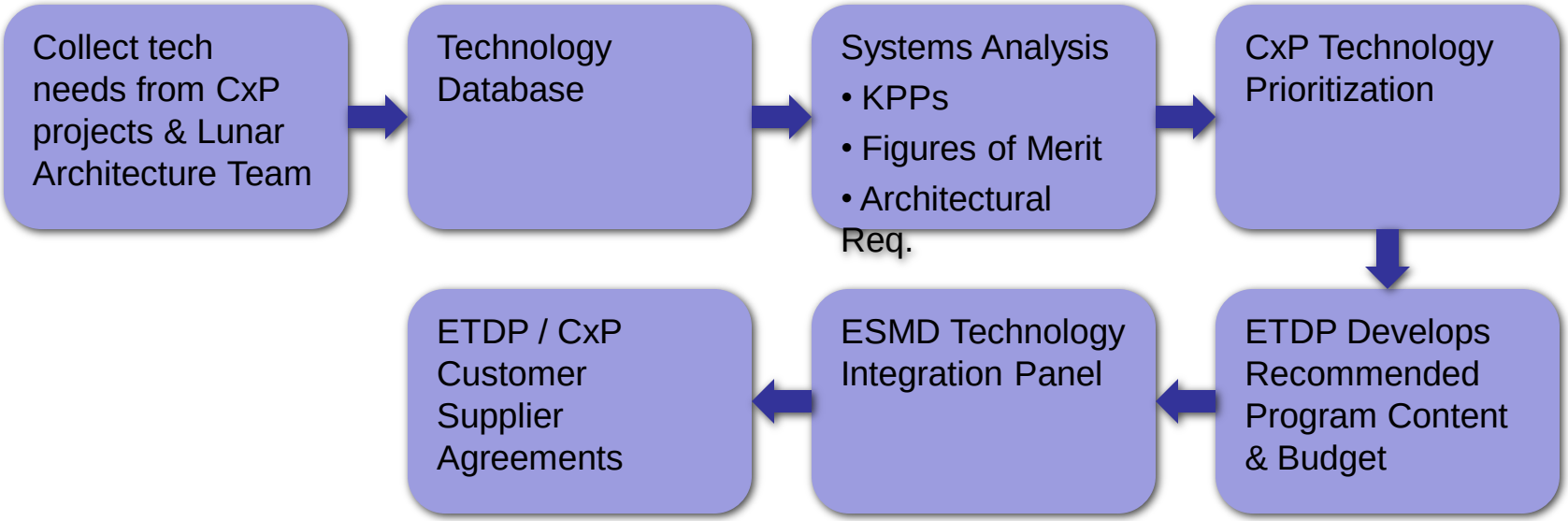
Projects:

- ETDP consists of 22 focused technology development projects
- Major projects include power and propulsion, structures and materials, life support, robotics, in-situ resource utilization, and microgravity research.



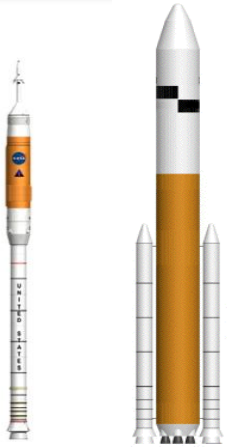

Identifying & Prioritizing Technology Needs

- ESMD conducts an annual process to collect technology needs from CxP projects and the Lunar Architecture Team.
- Technology needs are prioritized using systems analysis based on Key Performance Parameters (KPPs), Figures of Merit, and architectural requirements.
- ETDP content is aligned with CxP technology priorities.
- Customer Supplier Agreements are established between ETDP and CxP to insure that technology products will meet performance and maturity requirements, and are delivered in time to be incorporated into flight system designs.



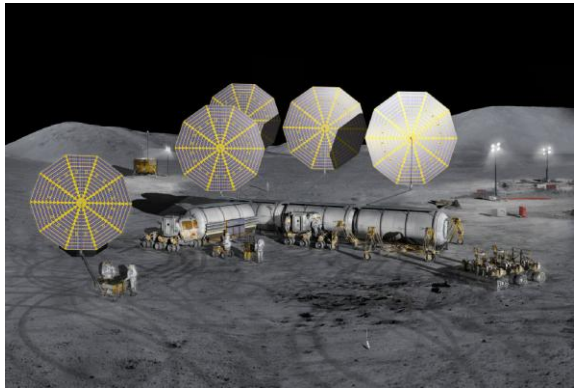
Critical Technologies for Constellation - Current Investment Areas

Orion
- TPS materials & heat shield
- Automated rendezvous & docking sensors
- Life support – air revitalization
- Automation of mission ops



Ares Launch Vehicles
- Propellant tank manufacturing
- Composite structures
- Solid rocket motor health management system

Lunar Lander
- Cryogenic propulsion
- Cryogenic propellant storage
- Autonomous precision landing & hazard avoidance



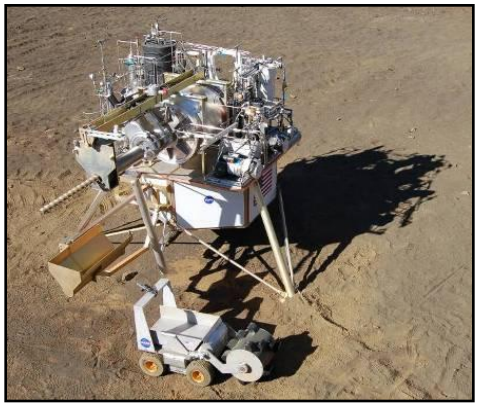
Lunar Surface Systems
- Surface mobility systems
- EVA surface suit
- Dust mitigation
- Energy storage
- Habitation
- Radiation shielding
- Closed-loop life support
- In-situ resource utilization

Mars Forward
- Fission surface power systems
- Entry, descent, & landing
- Optical communications

Research & Technology Highlights

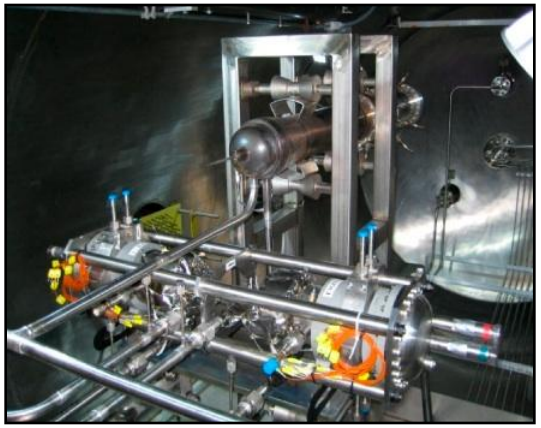
Conducted flight test of flash lidar sensor for Altair's autonomous landing and hazard avoidance

Demonstrated Lunar Electric Rover and suit-port concept for enabling travel beyond the lunar outpost.



Developed prototype in-situ resource utilization systems to produce oxygen on the moon

Launched Combustion Integrated Rack and E-Nose instrument to ISS on STS-126.



Demonstrated 2kW Stirling power converters and liquid metal coolant loop for fission surface power system

Demonstrated Tri-ATHLETE rover for unloading habitat module from lunar lander

Recent NRC Studies of NASA's Exploration Technology Program

- **The National Research Council has conducted three recent studies of the Exploration Technology Development Program and its elements:**
  - "A Constrained Space Exploration Technology Program: A Review of NASA's Exploration Technology Development Program" (2008).
  - "Fostering Visions for the Future: A Review of the NASA Institute for Advanced Concepts" (2009)
  - Decadal Study of Life and Physical Sciences (ongoing)

- **Recommendations from these studies are being considered in developing plans for FY11. The main features of a restructured technology program would include:**
  - Increased innovation through broadly competed solicitations for low-TRL research.
  - Advanced concept studies and long-range development of capabilities that could inspire new possibilities for NASA 10 to 25 years in the future.
  - Utilization of the ISS through 2020 as a laboratory for fundamental microgravity research and as a test bed for validating exploration technologies.

Review of U. S. Human Space Flight Plans (Augustine) Committee

- Augustine Committee considered 5 options in its summary report released on September 8, 2009:
  1. Continue flying Shuttle through 2011
  2. Extend ISS through 2020
  3. Crew launch to LEO (Ares I, Commercial)
  4. Heavy lift (Ares V Lite, Shuttle Derived, EELV)
  5. Destination (Mars First, Moon First, Flexible Path)

- NASA is assessing the options, but no decisions have been made.

- Exploration research and technology programs must be crosscutting and flexible to support multiple architectural options and destinations.

ISS Utilization Strategy

- NASA is developing an integrated ISS utilization plan through 2020 that involves four major thrust areas: life sciences, physical sciences, human research, and technology demonstrations.

- Considerations such as crew time, upmass, and downmass will be taken into account while developing options.

- Research tasks based on various National Academy recommendations.

- R&TD activities will take advantage of international partner hardware and investigations.

ISS Research in Life and Physical Sciences Enables Exploration

Research enabled by ISS

Life Sciences

- Behavioral health
- Human factors
- Cardiovascular function
- Musculoskeletal fitness
- Immune function
- Pharmacology
- Radiation protection
- Toxicity of atmospheric contaminants & dust
- Biological life support systems

Physical Sciences

- Partial gravity effects
- Mixing of cryogenic fluids
- Multiphase flow
- Heat transfer
- Materials processing & recycling

Key Capabilities for Exploration

- Maintaining human health & performance on long-duration missions
- Technology demonstration testbed (e.g., cryogenic fluid management, energy storage)
- Closed-loop life support to minimize consumables on long-duration missions
- Autonomous crew operations far from Earth

A New Vision for Exploration Research & Technology

Where are we now?

- Technology program aligned with near-term mission needs.
- Focused solely on lunar exploration
- Little pioneering research.
- Most work done in house.
- Limited use of the International Space Station as a research laboratory and test bed for human exploration.

Where can we be?

- Technology program enables far-term capabilities.
- Not limited to developing technologies for a single mission or destination.
- Greater innovation and technical excellence.
- Greater participation by external community.
- Use the International Space Station as a stepping stone.
- Inspiring new possibilities for NASA.
- Providing public value in renewable energy and biomedical research

Key Features of a Restructured Exploration Research & Technology Program

- **Enabling Development of Orion & Ares V**
  - Maintain current projects that support Constellation Program development of Orion and Ares V (Adv. Composites, Propulsion, Life Support, Autonomy for Mission Ops).
  - Focused mid-TRL technology development projects led by NASA Centers to insure infusion.

- **ISS Utilization through 2020**
  - Implement research priorities of NRC Decadal Study of Life and Physical Sciences.
  - Develop ISS experiments to demonstrate next generation life support, environmental monitoring, advanced materials, and cryogenic fluid management technologies.
  - Conduct human research to reduce crew health and performance risks for long-duration missions and to develop countermeasures for microgravity effects

- **Technology Innovation**
  - Provide NASA the flexibility to implement various options studied by the Augustine Committee to extend human presence beyond low Earth orbit. Develop long-range technologies in nuclear thermal propulsion; entry, descent, & landing; cryogenic fluid management; closed-loop life support; radiation protection; in-situ resource utilization; and advanced materials.
  - Develop solar and nuclear power systems, energy storage, power management, and thermal energy conversion for NASA missions and terrestrial applications.
  - Develop remote medical technology, miniature diagnostic instruments, biomedical sensors, and human physiology models for crew and public health care.
  - Broad Agency Announcements for low-TRL research and advanced systems concepts.

- **Precursor Demonstrations**
  - Demonstrations of prototype systems and key capabilities on SMD and international robotic missions to the Moon, NEOs, and Mars to reduce risk for human exploration.

International Collaboration

Human Research Program

- Completed 105-day chamber study with Russian Academy of Sciences to investigate effects of long-duration missions on crew behavior and performance.
- Research activities coordinated through International Space Life Sciences Working Group (ISLSWG) & the U.S. – Russian Joint Working Group
- International Life Sciences Research Announcement with ESA, JAXA, DLR, ASI, CNES, and CSA.
- Canadian & Japanese crew members participating in study of medical countermeasures for bone loss

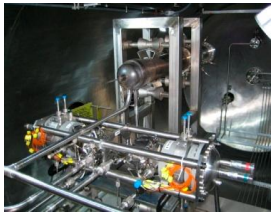
Exploration Technology Development Program

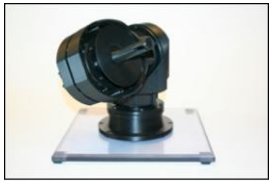
- ISS research with ESA and CNES on fluid physics, combustion, and materials processing.
- Analog field tests of surface mobility and in-situ resource utilization systems with Canadian Space Agency
- Biological experiments launched on Russian Foton-M3 mission.
- Developing Radiation Assessment Detector for Mars Science Laboratory mission with DLR

Lunar Precursor Robotic Program

- Russian Lunar Exploration Neutron Detector (LEND) instrument flying on Lunar Reconnaissance Orbiter.

Technology Development for Human Exploration of Mars





NASA has begun long-range development of critical technologies needed to enable future human exploration missions to Mars.

- **Entry, Descent, and Landing Technology**: Thermal protection system materials; inflatable aeroshells; aerothermal modeling and analysis tools; supersonic aerodynamic decelerators.
- **LOX-Methane Propulsion**: Prototype LO2/LCH4 engine for lunar lander ascent stage; RCS thrusters; reliable ignition.
- **Cryogenic Fluid Management:** Broad area cooling of propellant tanks; thermodynamic vent systems for tank pressure and temperature control; propellant mass gauges; liquid acquisition devices.
- **Closed-Loop Life Support**: Carbon dioxide and moisture removal systems for air revitalization; Sabatier reactor to produce water from carbon dioxide and methane; water recovery system to recycle urine and sweat condensed from cabin atmosphere; recovery of water from solid waste; instruments to monitor atmospheric contaminants.
- **Surface Mobility Systems**: Small pressurized rovers for exploring hundreds of kilometers beyond landing site; suit ports to enable rapid EVA.
- **In-Situ Resource Utilization**: Prototype ISRU systems to prospect for lunar resources, excavate lunar regolith, and process regolith to produce oxygen; integration of ISRU, life support, energy storage, and propulsion systems to use common reactants
- **Fission Surface Power Systems**: Concepts and technologies for 40 kWe fission power system for lunar and Mars surface applications (Stirling power conversion, liquid metal coolant loop, radiators).
- **Optical Communications**: Compact optical communications systems; superconducting photon counting detectors; multi-aperture ground receiver arrays.
- **Radiation Protection**: Particle accelerator experiments to investigate the biological effects of space radiation and reduce the uncertainty in radiation risk models; radiation transport models for use in spacecraft design; lightweight radiation shielding materials.

Issues

- Budget constraints have limited ETDP's flexibility to address NRC recommendation to increase low-TRL research. Broad Agency Announcement is planned for FY11.

- ISS payload up and down mass constraints have limited HRP's ability to retire all risks by 2016. ISS extension to 2020 would allow completion of studies necessary to understand the severity of certain risks, to gather evidence to quantify the risks, and to complete the development of key countermeasures.

Summary

- **ACD programs are critical to the success of exploration:**
  - HRP is addressing long-term human space flight risks, and utilizing the ISS as a laboratory.
  - ETDP is closely aligned with CxP technology priorities, and is developing exploration enabling technologies.
  - ACD is managing basic research on ISS
  - LPRP is mapping lunar resources and potential landing sites.

- **Major international collaboration involved in both the Human Research and Exploration Technology Development programs.**

- **Restructuring the exploration research and technology programs will**:
  - Increase innovation by investing in low TRL, game-changing technologies to inspire new possibilities for NASA.
  - Provide public benefits in renewable energy and biomedical research.
  - Involve the external community through Broad Area Announcements.
  - Provide optimal utilization of ISS through 2020 as a research laboratory and test bed for exploration technologies.
  - Demonstrate advanced capabilities on precursor missions.
  - Infuse technologies into the Constellation Program for Orion and Ares V development.
  - Enable flexible exploration capabilities to extend human presence beyond LEO.

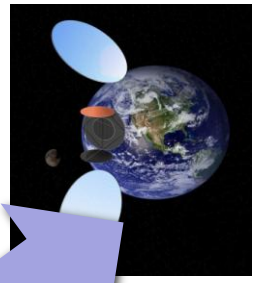
BACK-UP

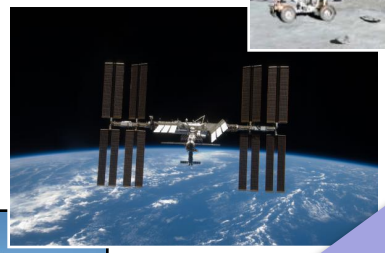
Technology Innovation for New Sources of Energy

Technology Development / Maturation

- Advanced Batteries
- Regenerative Fuel Cells
- Hydrogen Storage
- Thermal Energy Storage
- Fission Power Systems
- Stirling Power Converters
- High Efficiency Photovoltaics
- Advanced Solar Power Generation
- Intelligent Power Management & Distribution
- Wireless Power Transmission
- Space Solar Power Systems
- Embedded Power Technologies
- Electric Vehicles for Surface Mobility

Enabling Human Missions





Increasing Levels of TRL and Mission Application

Terrestrial Applications

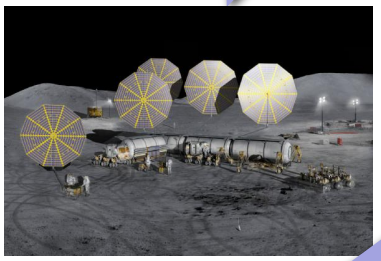
- Electric vehicles
- Green buildings
- Facility backup power systems
- Compact power sources for consumer electronics
- Solar power generation
- Power generation from waste heat
- Smart power grid
- Small nuclear power systems

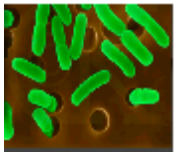
Innovations in Biomedical Research

Biomedical Research for Human Space Flight

- Remote medical technology
- Miniaturized diagnostic instruments
- Non-invasive biomedical sensors
- Real-time microbial sensors
- Biosensors for EVA
- Bioinformatics simulation & modeling
- Integrated human physiology modeling
- Radiation effects on cancer
- Advanced food technology
- Countermeasures for microgravity effects
- Behavior health & performance monitoring

Enabling Human Missions





Increasing Levels of Mission Application

Benefits for Public Health Care

- Remote medical care
- Non-invasive tests
- Real-time diagnostic instruments
- Vital signs monitoring
- Portable trauma care systems
- Renal stone formation
- Countermeasures for osteoporosis
- Muscle & cardiovascular fitness
- Predictive models of human physiology
- Improved understanding of aging
- Bioinformatics for patient records
- Cancer risk from radiation exposure