The Future of Human Space Exploration
NASA’s Building Blocks to Mars

- Pushing the boundaries in cis-lunar space
- Developing planetary independence by exploring Mars, its moons, and other deep space destinations
- Mastering the fundamentals aboard the International Space Station
- The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion crew capsule

U.S. companies provide affordable access to low Earth orbit

Missions:
- 6 to 12 months
- 1 month up to 12 months
- 2 to 3 years

Return:
- hours
- days
- months

Earth Reliant
Proving Ground
Earth Independent
Low Earth Orbit (LEO) Challenges:
- Spacecraft design to endure harsh flight environments and maintain crew safety.
- Mass and volume constraints.
- Program budget constraints.
- Fluctuating flight schedule(s).
- Complex program level systems engineering.
International Space Station

AS BIG AS A FOOTBALL FIELD

5 Space Agencies Representing 15 Countries

Completion: ~1 million lb (~454,000 kg)
Velocity: 17,500 mph (28,100 kph)
Altitude: 220 miles (350 km) above Earth

Every day, station travels the equivalent distance to the moon and back seeing:
16 sunrises / 16 sunsets
24 hours a day
7 days a week
365 days a year
Requires Extensive Logistics & Maintenance
International Space Station

LIVING AND WORKING IN ORBIT
ON THE INTERNATIONAL SPACE STATION

CREWS HAVE EATEN ABOUT
25,000 MEALS
SINCE THE FIRST CREW IN 2000

APPROXIMATELY
SEVEN TONS
OF SUPPLIES SUPPORT A CREW OF THREE FOR ABOUT
SIX MONTHS

SPACEWALKING
ASTRONAUTS AND COSMONAUTS
HAVE SPENT MORE THAN
1,000 HOURS
WORKING OUTSIDE THE STATION

MORE THAN 1,500 SCIENTIFIC INVESTIGATIONS
PERFORMED ON THE INTERNATIONAL SPACE STATION

INTERNATIONAL SPACE STATION
BENEFITS FOR HUMANITY

ADVANCED
ROBOTIC SURGERY

CLEAN DRINKING WATER
FOR PEOPLE LIVING FAR FROM
WATER TREATMENT FACILITIES

REMOTE
MEDICAL DIAGNOSTICS

EDUCATIONAL EVENTS
42 MILLION STUDENTS REACHED

MICROGRAVITY AND LOW-EARTH ORBIT
RESEARCH LABORATORY
CONDUCTING EXPERIMENTS IN:

HUMAN RESEARCH
LIFE SCIENCES

PHYSICAL SCIENCES

EARTH SCIENCES

ASTrophysics
TECHNOLOGY RESEARCH

ONE THING YOU CAN SAY ABOUT THE INTERNATIONAL SPACE STATION
IT'S BIG

LARGER THAN A
6-BEDROOM HOUSE

INTERNAL VOLUME OF A
BOEING 747

WEIGHS ALMOST A
MILLION POUNDS
(EQUIVALENT TO MORE THAN 320 AUTOMOBILES)

TRAVELS THE EQUIVALENT DISTANCE
TO THE MOON AND BACK
IN ABOUT A DAY
ISS Top Research Accomplishment

- New Targeted Method of Chemotherapy Drug Delivery
- Robotic Assist for Brain Surgery
- Understanding Mechanisms of Osteoporosis and New Drug Treatments
- Developing Improved Vaccines
- Improving Eye Surgery with Space hardware
- 43 Million Students and Counting Touched by ISS Education
Low Earth Orbit Access

Commercial Cargo
Facilitate U.S. private industry development of safe, reliable, and cost effective cargo space transportation capabilities to low-Earth orbit and the International Space Station.

- Two companies (SpaceX and Orbital Sciences) have successfully completed ISS cargo missions to date.

Commercial Crew
Commercial Crew Program (CCP) is an innovative partnership to help the aerospace industry in the United States develop space transportation systems that can safely launch humans to low-Earth orbit and to the International Space Station in a safe, reliable, and cost effective way.

- JSC Engineering provides technical insight/oversight, recommendations, and shared practices for safety and mission success.
Beyond Earth Orbit (BEO) Challenges:

- Spacecraft design to endure harsh flight environments and maintain crew safety.
- Spacecraft resupply for BEO missions not feasible.
- Increased reliability due to harsh radiation environment.
- Program budget constraints.
- Fluctuating flight schedule(s).
- Complex program level systems engineering.
- Mass and volume constraints.
Energy Required

- 0 mph
- 8,200 mph
- 2,400 mph
- 2,400 mph
- 3,900 mph
- 3,900 mph
- 700 mph
- 700 mph
- 0 mph

42,000 mph
1) SLS offers far greater mass and volume lift capability than any contemporary launch vehicle. This capability allows SLS to perform missions that no other vehicle can carry out, shorter travel times, and greater mission assurance. SLS is not designed to compete with industry launch vehicles, but to complement them by enabling new types of missions.

2) SLS enables human exploration and decadal-class science missions:
   - Maintains reasonable number of launches per mission
   - Simplifies on-orbit operations
   - Maximizes mission reliability

5) SLS investment can be leveraged for other missions:
   - Deep Space Exploration
   - Planetary Landers
   - Human Habitats
   - Great Observatories
   - Space Solar Power
   - Outer Planet Missions
   - Department of Defense/NRO Payloads
The World’s Most Powerful Rocket

Interim Cryogenic Propulsion Stage:
Based on the Delta IV Heavy upper stage; the power to leave Earth

Core Stage:
Newly developed for SLS, the Core Stage towers more than 200 feet tall

Solid Rocket Boosters:
Built on Space Shuttle hardware; more powerful for a new era of exploration

Orion:
Carries astronauts into deep space

Stage Adapters:
The Orion stage adapter was the first new SLS hardware to fly

RS-25 Engines:
Space Shuttle engines for the first four flights are already in inventory
The Orion Spacecraft

- Launch Abort System
- Crew Module
- ESA Service Module
Orion is built for going Beyond Earth Orbit

- **Oxygen**: BEO above LEO
- **Food**: BEO above LEO
- **Propellant**: BEO above LEO
- **Advanced Carbon Dioxide Removal System**: BEO above LEO
- **Carbon Dioxide Filter**: BEO above LEO
- **Drinking Water**: BEO above LEO
- **Reentry Speed**: BEO above LEO
- **Radiation**: BEO above ISS

**LEO**: Low Earth Orbit  
**BEO**: Beyond Earth Orbit

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**Orion Built for the Future**

LEO: Low Earth Orbit  
BEO: Beyond Earth Orbit
ESA’s Contribution to Orion
The SM, comprised of two subcomponents the Crew Module Adapter (CMA) and the European Service Module (ESM), provides services to the CM in the form of propulsion, consumables storage, heat rejection and power generation.
- Provide in-space translational delta-V capability to transfer the vehicle
- Provide orbital maintenance and attitude control
- Provide high altitude ascent abort propulsion after LAS jettison
- Provide consumables to support in-space habitable environment while attached to the CM (Water, O₂, and N₂ storage)
- Provide power generation and storage required for in-space flight
- Provide primary thermal control while mated with CM

Spacecraft Adapter (SA/SAJ) Functions
- Provide structural connection to the launch vehicle from ground operations through orbital injection
- Provide protection for SM components from atmospheric loads and heating during first stage flight
ESA’s Contributions to Orion:

- ESA is providing Orion’s service module for Exploration Mission-1, when the spacecraft will launch atop the SLS rocket and venture 40,000 miles beyond the moon.
- The ESA-provided service module, built by Airbus Defense and Space, is the spacecraft’s powerhouse and will supply it with in-space propulsion, power, thermal control and air and water for crew when they are aboard.
- For the first time, NASA will use a European-built system as a critical element to power an American spacecraft, extending our international cooperation from the space station into deep space.
- NASA’s work with ESA expands an already strong partnership and ensures continued international collaboration on the journey to Mars.
Orion EFT-1 December 5, 2014

LIFTOFF! Orion Begins New Era in Space Exploration!

View of Earth from On-board Orion

Fairing Panel Jettison Complete

Orion Splashdown in Pacific Ocean
What is necessary for successful Human Space Craft development?

- **Design complexity**
  - Systems Engineering and Integration
  - Natural Environments
  - Induced Environments

- **Mass**

- **Budget**

- **Safety**

- **Reliability**

- **Example**
  - Orion Heat Shield
Orion Heat Shield Technology Development

Titanium Stringer/Skeleton

Carbon Laminate Skin (EFT1 Shown)

Carrier Structure

Block AVCOAT

Carbon Laminate Skin

Titanium Stringer/Skeleton

Compression Pads, 4 Locations

Block AVCOAT
Relative Risk of TPS Failure – Environment Differences

Orion Reentry Environments more severe than Orbiter and CCP - Increased Risk
**ST8.1 Characteristics**
- 3-chute ascent abort (with 30° roll)
- Steep theta with moderate to high Vt
- High Vn (for three chutes)
- Low x-axis loads
- Highest z-axis loads
Thermal Assessment – Gap Filler

RTV560 with 5 pbw PMBs

- No fencing, very slight gapping
- 3-4 mm fence
- 2-3 mm fence

• RTV560+pmb performance is in-family with RTV560
• Gap-Filler thermal performance is successful across test range
• Upcoming tests: 40 models including stag and wedge models over the next three months.
Safety
Human Nature

- Normalization of Deviance
- Assumption that past success equals future success
- Hidden Assumptions
Opportunities

Spaceflight is hard, but the benefits are vast

- Real technical and medical benefits for life on earth as a direct result of space research
- Technical solutions invented for spaceflight that transfer to life on earth
- International cooperation
- Science, Technology and Engineering Education
- Benefits of exploration – new discoveries and new knowledge

http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20130009008.pdf
Questions
Back Up Charts
NASA Johnson Space Center

Leading Human Space Exploration

Engineering
Flight Operations
Astromaterials Research & Exploration Science
Exploration, Integration, and Science

International Space Station Program
Orion Multi-Purpose Crew Vehicle Program
Commercial Crew & Cargo Program
Safety & Mission Assurance
Human Health & Performance

Lead Human Exploration
Lead Internationally
Excel in Leadership, Management, and Innovation
Expand Relevance to Life on Earth
Orion Has Been Shaped By Its History

- Built for Beyond Earth Orbit (BEO)
- Synergistic with the Commercial Crew Program strategy
- Adapted to Significant Policy/Strategic Changes since Inception
- Orion/SLS combination is critical to extending human presence beyond low earth orbit
Mars Challenges
Technology Focus for Staying Healthy

**Life Support**
- High reliability systems
- $O_2$ recovery and reducing logistics
- Water recovery loop closure
- Solid waste volume reduction and resource recovery
- Store nutritionally-adequate food for years

**Space Suits**
- Low mass suit and power pack
- Lower torso mobility
- Enhanced dexterity
- Compatible with Mars environment
- Increase information system capabilities
- In-situ suit repair

**Microgravity Countermeasures**
- Exercise equipment for muscle and cardiovascular atrophy, and bone loss
- Low-mass, rapid deploy, low-maintenance systems

**Autonomous Medicine**
- Advanced medical diagnosis, prognosis and treatment capabilities
- In-situ analysis of biomedical samples

**Environmental Control**
- In-flight analysis capabilities
- Rapid detection and mitigation of environmental hazards
- Detect contaminants introduced via surface activities
- Automated recovery
- Fire suppression
Mars Challenges
Technology Focus for Transportation

Access to Space
- Space Launch System heavy lift for large mass and volume
- Orion crew vehicle for crew delivery to and return from deep space

Chemical Propulsion
- $\text{O}_2$/Hydrocarbon ($\text{CH}_4$) propulsion for in-space transit, landing and ascent
- Integrated main and reaction control propulsion systems
- Ability to maintain cryogenic fluids for long durations

Advanced Propulsion
- Advanced capabilities to improve mass delivery and trip time
- Under investigation
- Solar Electric
- Advanced Chemical
- Nuclear Thermal
- Nuclear Electric

In-Situ Resource Utilization
- Production of $\text{O}_2$ from the atmosphere for Mars ascent
- Production of life-support consumables
- Construction of surface infrastructure from local resources

Entry, Descent, Landing & Ascent
- Hypersonic inflatable or deployable decelerators
- Supersonic retro-propulsion
- Precision landing
- Plume blast mitigation
- High-speed Earth re-entry
- Occupant protection
Mars Challenges
Technology Focus for Working in Space

**Humans & Robots Working Together**
- Human/machine coordination to improve productivity & reduce risk
- Robots performing routine tasks (inspection, logistics)
- Robotic Explorers (reconnaissance and risk reduction)

**Autonomous Operations**
- Independent, self-reliant crew can operate with up to 40 minute time delay
- Highly automated vehicle operable by minimal crew
- MCC automation (strategic/analysis role)
- Automated rendezvous & docking

**In-Flight Maintenance**
- Component-based design for maintainability & reliability
- Vehicle-wide diagnostics, prognostics & recovery
- In-space repair & manufacturing

**Exploration Mobility**
- Routine surface exploration
- Maximize time spent and distance traveled
- Minimize “time to get out the door”
- Environmental protection including dust abatement

**Power Generation**
- Production of high, continuous, latitude independent power for crew operations
- Mobile power systems for robust exploration