Persistent Platforms in Space – Next Generation Infrastructure

- Deep Space Gateway
- In Space Manufacturing
- In Space Robotic Manufacturing and Assembly

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Science and Technology Office
NASA Marshall Space Flight Center
Exploring Space In Partnership

Now
Using the International Space Station

2020s
Operating in the Lunar Vicinity

2030s
Leaving the Earth-Moon System and Reaching Mars Orbit

Phase 0
Solve exploration mission challenges through research and systems testing on the ISS. Understand if and when lunar resources are available

Phase 1
Conduct missions in cislunar space; assemble Deep Space Gateway and Deep Space Transport

Phase 2
Complete Deep Space Transport and conduct Mars verification mission

Phases 3 and 4
Missions to the Mars system, the surface of Mars
Deep-Space Habitation Development Strategy

Proving Ground Phase 0: SYSTEMS DEVELOPMENT AND TESTING ON ISS / LEO

- Bigelow Expandable Activity Module
- Spacecraft Fire Safety
- Human Research and Performance

Habitation System Projects

- Life Support Systems
- Exercise Systems
- Docking / berthing Systems
- Advanced Avionics
- EVA

Proving Ground Phase 1: DEEP SPACE TESTING

- Spaceport
- NextSTEP Habitation / Int. Partners

Proving Ground Phase 2: DEEP SPACE VALIDATION

- Spaceship

LEO COMMERCIALIZATION

Deep-Space Habitation Development Strategy
NextSTEP Habitation Overview

NextSTEP Phase 1: 2015-2016

- Partners develop required deliverables, including concept descriptions with concept of operations, NextSTEP Phase 2 proposals, and statements of work.

Cislunar habitation concepts that leverage commercialization plans for LEO

NextSTEP Phase 2: 2016-2018

- Partners refine concepts and develop ground prototypes.
- NASA leads standards and common interfaces development.

FIVE GROUND PROTOTYPES BY 2018

Initial discussions with international partners

Define reference habitat architecture in preparation for Phase 3.

Phase 3: 2018+

- Partnership and Acquisition approach, leveraging domestic and international capabilities
- Development of deep space habitation capabilities
- Deliverables: flight unit(s)
PHASE 2

Deep Space Gateway (DSG)

Deep Space Transport (DST)
**In-Space Manufacturing (ISM) Path to Exploration**

**GROUND-BASED**
- Earth-Based Platform
  - Certification & Inspection Process
  - Design Properties Database
  - Additive Manufacturing Automation
- Ground-based Technology Maturation & Demonstration
- AM for Exploration Support Systems (e.g. ECLSS) Design, Development & Test
- Additive Construction
- Regolith (Feedstock)

**EARTH RELIANT ISS**
- ISS Test-bed Platform
  - 3D Print Demo
  - Additive Manufacturing Facility
  - In-space Recycling
  - In-space Metals
  - Printable Electronics
  - Multi-material Fab Lab
  - In-line NDE
  - External Manufacturing
  - On-demand Parts Catalogue
  - Exploration Systems Demonstration and Operational Validation

**PROVING GROUND Cis-lunar**
- Planetary Surfaces Platform
  - Multi-materials Fab Lab (metals, polymers, automation, printable electronics)
  - Food/Medical Grade Polymer Printing & Recycling
  - Additive Construction Technologies
  - Regolith Materials – Feedstock
  - AM Exploration Systems

**EARTH INDEPENDENT Mars**
- Asteroids

**Text Color Legend**
- Foundational AM Technologies
- AM for Exploration Systems
<table>
<thead>
<tr>
<th>Archinaut</th>
<th>Dragonfly</th>
<th>CIRAS</th>
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<tbody>
<tr>
<td>A Versatile In-Space Precision Manufacturing and Assembly System</td>
<td>On-Orbit Robotic Installation and Reconfiguration of Large Solid Radio Frequency (RF) Reflectors</td>
<td>A Commercial Infrastructure for Robotic Assembly and Services</td>
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**Tipping Point Objective**

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<tr>
<th>Archinaut</th>
<th>Dragonfly</th>
<th>CIRAS</th>
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<tr>
<td>A ground demonstration of additive manufacturing of extended structures and assembly of those structures in a relevant space environment.</td>
<td>A ground demonstration of robotic assembly interfaces and additive manufacture of antenna support structures meeting EHF performance requirements.</td>
<td>A ground demonstration of reversible and repeatable robotic joining methods for mechanical and electrical connections feasible for multiple space assembly geometries.</td>
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**Team**

| Made In Space, Northrop Grumman Corp., Oceaneering Space Systems, Ames Research Center | Space Systems/Loral, Langley Research Center, Ames Research Center, Tethers Unlimited, MDA US & Brampton | Orbital ATK, Glenn Research Center, Langley Research Center, Naval Research Laboratory |
**In-Space Manufacturing (ISM) Program Timeline**

<table>
<thead>
<tr>
<th>FY14</th>
<th>FY15</th>
<th>FY16</th>
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<th>FY22</th>
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<tr>
<td>ISS 3DP Tech Demo</td>
<td>LAUNCH PH. 1</td>
<td>ISS OPS PH. 1</td>
<td>TESTING PH. 2</td>
<td>ISS OPS PH. 1</td>
<td>RESULTS</td>
<td>PH. 2 TEST</td>
<td>RESULTS</td>
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<td>ISS END</td>
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<td>ISS Additive Manufacturing Facility (AMF)</td>
<td>DEVELOP &amp; BUILD</td>
<td>ISS ULTEM PARTS</td>
<td>ISS COMMERCIAL &amp; NASA UTILIZATION</td>
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<td>EXPLORATION SYSTEMS OPERATIONAL</td>
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<td>In-Space Recycling</td>
<td>ISS DEMO PH. 1 SBIR</td>
<td>ISS DEMO PH. 2 SBIR</td>
<td>DESIGN, BUILD &amp; GROUND DEMO</td>
<td>ISS FLIGHT CERT</td>
<td>LAUNCH FUBLAB TECHNOLOGY DEMONSTRATION</td>
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<td>ISS Multi-Material FabLab Rack (Metallics, Polymers, etc.)</td>
<td>YET2 TECH SEARCH</td>
<td>RFI FUBLAB PH. 1</td>
<td>PH. B FUBLAB BAA</td>
<td>PH. C FUBLAB BAA</td>
<td>LAUNCH</td>
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<td>In-Space Metals Development</td>
<td>WOHLERS STUDY</td>
<td>MIS CASTING TASK</td>
<td>DESKTOP METALS</td>
<td>IN-SPACE METALS FUBLAB INFUSION</td>
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<td>Printable Electronics</td>
<td>INK DEVELOPMENT</td>
<td>ISS RFID DESIGN &amp; TEST</td>
<td>PH. 1 SBIR</td>
<td>PH. 2 SBIR</td>
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<td>Exploration Systems Design Database &amp; Component Testing</td>
<td>ISM EMC QUANTITATIVE BENEFIT ANALYSES</td>
<td>GROUND TEST EXPLORATION COMPONENTS (ECLSS, LR, Suits, CHSS, etc.)</td>
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<td>In-Space Verification and Validation (In-process NDE)</td>
<td>UTILIZATION CATALOG DEVELOPMENT</td>
<td>ISM V&amp;V DEVELOPMENT</td>
<td>IN-PROCESS NDE FUBLAB INFUSION</td>
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ISM enables the ‘Design for Maintainability’ approach Required for Sustainable Exploration missions.
**Living in Space: Short Duration Habitation**

**Initial Cislunar Habitation**
- Support crew each year for short duration stays in cislunar space
- Protect and support crew in deep space for up to 60 days
- Uncrewed operations during deployment and between uses
- Earth-independent operations

**Common Capabilities**
- 4 crew for short durations (up to 60 days)
- Support autonomous mission operations with time delay
- Common, partially closed ECLSS under approx. 800 kg (3 years MTBF and 2 crew per torr of CO₂ removal)
- Autonomous rendezvous, prox ops, and docking
- Ability to be teleoperated with <0.5 s latency
- Communications to/from Earth and between elements
- Common, lightweight pressure vessel and common hatch
- 15 year lifetime with long dormancy periods
- Design for maintainability

**Excursion Vehicle**
- Explore kilometers away from the destination habitat
- 2 crew for up to 2 weeks, contingency 4 crew for 1 week
- EVA pressure garment and PLSS <200 kg with dual-band radio avionics and radiation hardened bio-med sensors
- High frequency EVA (15 min. ingress-egress time)
- 4 years dormant before first use and between uses
- Design for reuse for 3 missions
- Lightweight exercise equipment under 25 kg

**Mars Ascent Vehicle**
- Return crew to Mars orbit
- 4 crew for up to 2.5 day crewed duration
- Open loop ECLSS under approx. 400 kg
- 5 years dormant before use

**Mars Taxi**
- Transport crew between Mars orbit and Mars moons
- 4 crew for up to 2.5 day crewed duration
- 560 days operational (uncrewed) at Mars
- 2 years dormant before use
- Up to 1.5 years dormant between uses

**Logistics Module**
- Logistics module to cislunar space
- Launched on either SLS and ELV launch vehicles
- Carries up to 5-10 t of pressurized logistics
- 10-15 t total mass
**Living in Space: Long Duration Habitation**

**Challenges**
- Protect and support crew in deep space for up to 1100 days
- Uncrewed operations during deployment and between uses
- Reduced logistics and spares
- Earth-independent operations

**Common Capabilities**
- 4 Crew for 500-1100 days
- Common pressure vessel
- 15 year lifetime with long dormancy periods
- Design for reusability across multiple missions
- 100 m³ habitable volume and dry mass < 22 t
- Autonomous vehicle health monitoring and repair
- Advanced Exploration ECLSS with >85% H₂O recovery and 50% O₂ recovery from reduced CO₂
- ECLSS System (w/o spares): <5 t mass, <9 m² volume, <4 kW power
- Environmental monitoring with >80% detection rate without sample return
- 14-kW peak operational power and thermal management required
- Autonomous mission operations with up to 24 minute one-way time delay
- Autonomous medical care, behavioral health countermeasures, and other physiological countermeasures to counteract long duration missions without crew abort
- Exercise equipment under 500 kg
- Provide 20-40 g/cm² of radiation protection
- EVA pressure garment and PLSS <200 kg
- Contingency EVA operations with 1 x 2-person EVA per month
- Communications to/from Earth and between elements

**Mars Surface Habitat**
- Live and operate on the Mars surface in 1/3 g
  - 4 crew for up to approx. 500 days
  - 48 m³ volume for logistics and spares
  - Logistics Mass: 10.7 t
  - 4 years dormant before use
  - 3-4 years dormant between uses
  - EVA system with surface mobility, dust mitigation, and atmospheric compatibility

**Phobos Habitat**
- Live and operate in microgravity at Phobos
  - 4 crew for up to approx. 500 days
  - 48 m³ volume for logistics and spares
  - Logistics Mass: 10.7 t
  - EVA system with Phobos mobility and dust mitigation
  - 4-5 years dormant before use
  - 3 years dormant between uses

**Transit Habitat**
- Live and operate in microgravity during trip to/from Mars
  - 4 crew for up to 1,100 days
  - 93 m³ volume for logistics and spares
  - Logistics Mass: 21 t
  - 4 years dormant before use and between uses