Capability 9.4
Servicing

Presenter: Rud Moe
Servicing Description

- Inspection and detection of faults, maintenance, repair, resupply, and upgrade of accommodating in-space and extraterrestrial systems.
  - Maintenance: refurbishment of wear-out items, resupply of consumables, adjustment and realignment, cleaning or recoating of surfaces, exchange of degraded fluids, lubricants, filters, materials
  - Repair: replacement of or substitution for worn, damaged, or failed items at several levels of hierarchical modularity, reconstruction of structures or surfaces with fresh material
  - Upgrade: replacement or supplement of obsolete items with version having higher-performance or increased functionality

- All servicing operations include reverification of system integrity and functionality
Benefits of Servicing

• **Extended mission life and systems reusability for increased sustainability**
  – Versatile ability for life extension allows efficient use of high-capitalizations systems
  – Extended reuse of heritage systems for new purposes or objectives

• **Increased performance through upgrade improves affordability**
  – Decoupling of systems to accommodate differential rates of technology advancement and obsolescence
  – New capability establishment
  – Exploitation through extended reuse of high-capitalization systems to support unique performance items

• **Mission rescue**
  – Reduction of consequences of failures or unexpected events and situations results in preservation of capital value and continuation of operations
  – Intervention using available items, tools, and materials for temporary (possibly degraded) operation
  – Revisit with design-to-case permanent replacement or supplementary components
Drivers & Assumptions for Servicing

- **Logistics for provisioning of spares and upgrades**
  - Manufacture, inventory, launch, in-space and extra-terrestrial transport and storage of components, modules, spares, materials, tools, test equipment

- **Accommodation of systems to servicing agent abilities**
  - Modularity and separable interfaces, local force/torque reaction, self-alignment, self-protection, available power and data ports, built-in test, configuration databases

- **Accessibility of systems to servicing agents**
  - Affordable access Earth-to-space, in-space or extra-terrestrial transport from operations venue to servicing venue, proximity operations and capture/handling, gross positioning systems

- **Supporting systems for servicing operations**
  - Handling and temporary stowage, inventory controls, environmental protection, clean workspace, information and communication systems, general-purpose tools and test equipment, in-situ fabrication and feedstock

- **Servicing agent availability**
  - Robotics and/or human presence in-space and extra-terrestrial sites with supporting logistics and utilities, medicine and life support, transport, information and communication systems

- **Servicing agent abilities**
  - Mobility, sensing, handling and dexterous manipulation, positioning, aligning, connecting, disconnecting, advanced controls, on-board databases, autonomy, team coordination
9.4.1 Inspect & survey (monitoring)
9.4.2 Detect & isolate faults (diagnostics)
9.4.3 Perform planned maintenance
  9.4.3.1 Replace modular component
  9.4.3.2 Replenish supplies
9.4.4 Perform unplanned repair
  9.4.4.1 Assess repair options and available materials
  9.4.4.2 Repair/replace component
9.4.5 Install upgrades
9.4.6 Planning, logistics, training, etc.
**Roadmap for Servicing**

**Key Assumptions:** Human Exploration of Moon & Mars

**Capability Roadmap 9.4: Servicing**

- **EVA servicing & intervention**
  - Standard tools
  - Standard interconnects
  - Structural coupling
  - Electrical connections
  - Fluid connections
  - Thermal transfers
  - Beams & waves
  - Standard data formats
  - Module designs
    - Self align
    - Blind mate
    - Self protect
    - Self test

- **Robotic servicing of modular systems**
  - Modular systems
    - Robotics
      - Dexterous manipulation
      - Sensing
      - Controls
    - Flight demo

- **Routine maintenance of modular systems**
  - Flight systems integration

- **Interventions**
  - General-purpose tools & materials
  - Advanced EVA
  - Advanced Robotics
  - Flight demo

**Timeline:**
- 2005
- 2010
- 2015

- **Major Decision**
- **Major Event / Accomplishment / Milestone**
- **Ready to Use**

- 2007 Lunar Orbiter test flight
- 2008 CEV test flight
- 2010 CEV LEO
- 2015-2020 CEV LLO and EVA lunar surface ops

**Technology Areas:**
- Standard tools
- Standard interconnects
- Structural coupling
- Electrical connections
- Fluid connections
- Thermal transfers
- Beams & waves
- Standard data formats
- Module designs
  - Self align
  - Blind mate
  - Self protect
  - Self test
- **Robotics**
  - Dexterous manipulation
  - Sensing
  - Controls
- **Flight systems integration**
- **General-purpose tools & materials**
- **Advanced EVA**
- **Advanced Robotics**
- **Flight demo**

**Human Exploration of Moon & Mars**

**Capability Roadmap 9.4: Servicing**

**EVA servicing & intervention**

**Robotic servicing of modular systems**

**Routine maintenance of modular systems**

**Interventions**

**Timeline:**
- 2005
- 2010
- 2015

**Key Assumptions:**
- Human Exploration of Moon & Mars

**Technology Areas:**
- Standard tools
- Standard interconnects
- Structural coupling
- Electrical connections
- Fluid connections
- Thermal transfers
- Beams & waves
- Standard data formats
- Module designs
  - Self align
  - Blind mate
  - Self protect
  - Self test
- **Robotics**
  - Dexterous manipulation
  - Sensing
  - Controls
- **Flight systems integration**
- **General-purpose tools & materials**
- **Advanced EVA**
- **Advanced Robotics**
- **Flight demo**

**Human Exploration of Moon & Mars**
Roadmap for Servicing

**Key Assumptions:** Human Exploration of Moon & Mars

- 2020: Lunar surface habitat
- 2025: Mars transit and vicinity ops
- 2030+: Martian surface habitat and exploration

**Capability Roadmap 9.4: Servicing**

- Unplanned servicing
- Rescue

**Human interventions**

- Flight Demo & Mission Integration

**Robotic interventions**

- Flight Demo & Mission Integration

**Planning**

- Rapid launch
- In-space fabrication

**Logistics**

- Replace damaged/lost item
- Fab replacement damaged/lost item

**Training**

- In-situ training
- Ready availability of standard modules

**Modules**

- Tools
- Robotics
- Advanced EVA

- Replace damaged/lost item

- Fab replacement damaged/lost item

- Ready availability of standard modules

- Rapid skill acquisition
- Skill-based improvisation

**Automated planning**

- Ready availability
- In-situ training
- Rapid launch-on-need

**Ready to Use**

- Major Decision
- Major Event / Accomplishment / Milestone

2020

2025

2030
9.4 Servicing Critical Gaps

- TBD
Appendix with SOA details by WBS
Capability 9.4.1 Inspection

• **Description:**
  – Tools and operations for inspecting systems, components, structures, etc. to determine status, operating condition, physical characteristics
  – Passive inspection techniques, active sensing approaches, combination
  – High degree of autonomy needed

• **Benefits**
  – Allow determination of system configuration or status with human intervention providing interpretation of non-autonomous cases.
  – Effective inspection systems can lower risk of repairs

• **Figures of Merit**
  – Amount of human supervision required, coverage of system, resolution and bandwidth, availability of inspection capability, complexity of inspections system, versatility of inspection system

• **General Assessment**
  – Current SOA is human intensive, reliant in-situ crew. External inspection tools are limited and lack autonomy. Many inspection approaches available, not well integrated with servicing systems.

• **Development Needed:** Medium
<table>
<thead>
<tr>
<th>Capabilities</th>
<th>State-of-the-Art</th>
<th>TRL</th>
<th>Needs</th>
<th>Need TRL</th>
<th>Capability Date</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.4.1 Inspection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.4.1.1 Passive sensors: cameras (resolution, positioning, lighting, focus, iris, É ), nonvisual sensors (proximity, haptic, acoustic conduction)</td>
<td>Shuttle, ISS, HST Robotic Servicing (HRSDM), AerCam</td>
<td>9</td>
<td>Multispectral sensing Hi Def resolution Coverage &amp; positioning</td>
<td>2012</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>9.4.1.2 Active sensors &amp; scanners</td>
<td>LIDAR</td>
<td>6</td>
<td>Interferometry</td>
<td>2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.4.1.3 Built-in</td>
<td>Telemetry</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• **Description:**
  – Interpretation of inspection surveys and instrumentation data analysis and projection into the mission performance context

• **Benefits:**
  – Provides systems assessments of extant and impending degradations; provides specifics for servicing mission planning content and timing, design-to-case repair components and operations development

• **Figures of Merit:**
  – Percent coverage of possible failures/degradations
  – Percent of manual vs. automated assessment and planning
  – Time to failure/degradation identification
  – Impact to operations of reconfiguration for test
  – Amount of system resources required (MIPS, bytes, etc.)

• **General Assessment:**
  – Built-in instrumentation trend analysis is best current capability; in-situ assessment of overall configuration is reliant upon human interpretation; no autonomous capability to characterize and project system performance

• **Development Needed: High**
## State-of-the-Art /Maturity Level /Capabilities for 9.4.2 Diagnostics

<table>
<thead>
<tr>
<th>Capability/Technology</th>
<th>SOA</th>
<th>TRL</th>
<th>Needs</th>
<th>Need TRL 6</th>
<th>Capability Date</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-in test equipment</td>
<td>Boeing aircraft</td>
<td>9</td>
<td>Broader</td>
<td></td>
<td>2010</td>
<td>7</td>
</tr>
<tr>
<td>Integrated computational diagnostics and prognostics</td>
<td>Livingstone (L2)</td>
<td>4</td>
<td>Continued development; testing/demo under operational conditions</td>
<td>2008</td>
<td>2010</td>
<td>5</td>
</tr>
<tr>
<td>Diagnostic test planning and execution during operations</td>
<td>Livingstone (L2)</td>
<td>4</td>
<td>Continued development; testing/demo under operational conditions</td>
<td>2008</td>
<td>2010</td>
<td>5</td>
</tr>
<tr>
<td>Maintenance/repair planning and execution monitoring</td>
<td>Livingstone (L2)</td>
<td>4</td>
<td>Continued development; testing/demo under operational conditions</td>
<td>2008</td>
<td>2010</td>
<td>5</td>
</tr>
</tbody>
</table>
Capability 9.4.3 Perform Planned Maintenance

• **Description:**
  - Installs replacement modular components or consumable materials having standardized interfaces and procedure accommodations

• **Benefits:**
  - Versatile ability for life extension and efficient use of high-capitalizations systems
  - Extended life and reuse of heritage systems for new purposes or objectives
  - Reduced impact on mission times, costs, and risks relative to unplanned servicing

• **Figures of Merit:**
  - Compliance of modular systems with standard or generic interface connectors and formats
  - Number of disassembly steps needed for access
  - Robustness of modules designs for self-protection in space environment
  - Completeness of modules self-test functions
  - Type and complexity of agents required;
  - Type and complexity of infrastructure required

• **General Assessment:**
  - Depends strongly on modular systems design, human and robotic capabilities, logistics, and supporting systems; limited in size and mass of modular systems and sub-systems that have been replaced

• **Development Needed: Medium**
### State-of-the-Art / Maturity Level / Capabilities for 9.4.3 Perform Planned Maintenance

<table>
<thead>
<tr>
<th>Capabilities</th>
<th>State-of-the-Art</th>
<th>TRL</th>
<th>Needs</th>
<th>Need TRL 6</th>
<th>Capability Date</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3 Perform planned maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.3.1 Replace modular component</td>
<td>ISS, HST</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVA supported</td>
<td>ISS, HST</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robotic</td>
<td>HRSDM</td>
<td>5</td>
<td>Robotic</td>
<td>2008</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Task Autonomy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.3.2 Replenish supplies</td>
<td>Flight demo hardware</td>
<td>7</td>
<td>Mission integration</td>
<td>2010</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Capability 9.4.4 Perform Unplanned Repair

- Description:
  - Address mission unplanned events and situations during operations using available components, materials, tools, procedures, skills, and creativity; preserve valuable assets for continued operation

- Benefits: Mission rescue
  - Reduce consequences of failures or unexpected events and situations for preservation of capital value and continuation of operations
  - Intervention using available items, tools, and materials for temporary (possibly degraded) operation
  - Revisit with design-to-case replacement or supplementary components

- Figures of Merit:
  - Number of types of intervention possible

- General Assessment:
  - Highly advanced capabilities needed for robotic implementation; general-purpose tools and materials provide limited intervention capability even for human agents in-situ; rapid launch capability and in-space fabrication capability have potential for greatly reducing loss-of-mission risk

- Development Needed: High
### State-of-the-Art /Maturity Level /Capabilities for 9.4.4 Perform Unplanned Repair

<table>
<thead>
<tr>
<th>Capabilities</th>
<th>State-of-the-Art</th>
<th>TRL</th>
<th>Needs</th>
<th>Need TRL 6</th>
<th>Capability Date</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perform unplanned repair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention kit, EVA supported</td>
<td>Shuttle, ISS, HST</td>
<td>9</td>
<td>Robust capability</td>
<td></td>
<td></td>
<td>2015</td>
</tr>
<tr>
<td>Intervention kit, robotic supported</td>
<td>HRSDM</td>
<td>4</td>
<td>Robust capability</td>
<td>2015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvisation skills, human supported</td>
<td>ISS, HST</td>
<td>6</td>
<td>Rescue capability</td>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvisation skills, robotic autonomy</td>
<td>none</td>
<td>0</td>
<td>Auto-rescue capability</td>
<td>2030</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Capability 9.4.5 Install Upgrade

• Description
  – Many components and subsystems have technology advancement rates significantly shorter than the systems they are incorporated into and as a result become obsolete long before the system’s intended duration of useful life is over.
  – As technology improves, replace or augment original hardware and software with higher performance, increased functionality, or new capability.
  – Examples: HST servicing, nuclear reactor robotics, spacecraft software uploads
  – Upgrade potential is dependent on degree of interface standardization.

• Benefits
  – Enable adaptation to new circumstances and evolve faster than the systems-of-systems rate
  – Increase Functional Capability/Performance
  – Increase Reliability (MTBF) and Safety
  – Increase Maintainability/Supportability
  – Allow space systems to be entered into service more quickly (initial capability) and upgrade capability at a later time
Capability 9.4.5 Install Upgrade

- **Figures of Merit**
  - Time to Upgrade
  - Supporting Infrastructure Required
  - Cost of Use of Human and/or Robotic Agents

- **General Assessment**
  - SOA is advanced for upgrade by humans in space environment, but unproven for robotics in space environment. Need to significantly increase robotic capability.

- **Development Needed:** Medium

HST Servicing Mission  ➔  Nuclear Power Plant Telerobot  ➔  Robonaut Space Telerobot
<table>
<thead>
<tr>
<th>Capability/Technology</th>
<th>SOA</th>
<th>TRL</th>
<th>Needs</th>
<th>Need TRL 6</th>
<th>Capability Date</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVA upgrade of science instruments and components</td>
<td>HST servicing missions; ISS</td>
<td>9</td>
<td>Beyond LEO; control of harsh environmental</td>
<td>2012</td>
<td>2015</td>
<td>5</td>
</tr>
<tr>
<td>IVA upgrade of components</td>
<td>ISS</td>
<td>9</td>
<td>Cleanliness</td>
<td>2012</td>
<td>2015</td>
<td>5</td>
</tr>
<tr>
<td>Upgrade of spacecraft software</td>
<td>Upload to various spacecraft</td>
<td>9</td>
<td>Increased reliability</td>
<td>2008</td>
<td>2010</td>
<td>5</td>
</tr>
<tr>
<td>Autonomous upgrade of components</td>
<td>DARPA Orbital Express Advanced Technology Demo</td>
<td>5</td>
<td>Continued development. Launch of demo scheduled for 2006.</td>
<td>2015</td>
<td>2020</td>
<td>2</td>
</tr>
<tr>
<td>Teleoperated upgrade of components</td>
<td>HST robotic servicing mission; operational nuclear reactors; Robonaut</td>
<td>4-5</td>
<td>Continued development; testing/demo under operational conditions</td>
<td>2015</td>
<td>2020</td>
<td>2</td>
</tr>
</tbody>
</table>
• **Description:**
  - These are broad capabilities that span the entire sequence. Planning is defined as the ordering of steps required to complete a task or maneuver. Logistics is all of the support and movement planning of assemblies, parts, tools, equipment, and supplies necessary to meet the objectives of the servicing task. Training is the teaching and practicing of a skill or maneuver to be able to perform as expected.

• **Benefits:**
  - Planning, logistics, and training are integral to each other, and necessary to complete all servicing operations. Pre-planning and contingencies will increase the probability of success of the servicing operations. Logistics determines the whereabouts and timing of all the tools, consumables, and parts required. Training is necessary to insure that the task of servicing will occur as planned by man or robot.

• **Figures of Merit:**
  - Number of steps in the plan, Completeness of plan, including acceptable contingencies, Timeline for logistics, Transport Manifest, Skills Training Plan and competency test, Number of skills in training, Realistic Simulation based on update rate, fractal & polygon count, field-of-view

• **General Assessment:**
  - Planning, Logistics, and Training are commonplace today in NASA type missions, typically in a manual mode with some automated tools. Fully automated planning tools exist, but with less maturity at the mission level. Logistic tools are mature and verifiable through comprehensive checklists. Training exist, but could benefit from better tools and technologies to insure a higher level of preparedness.

• **Development Need:** Low, with room for technological improvements as available except for human-robot training
## State-of-the-Art /Maturity Level /Capabilities for 9.4.6 Planning, Logistics, & Training

<table>
<thead>
<tr>
<th>Capability/ Technology</th>
<th>SOA</th>
<th>TRL</th>
<th>Needs</th>
<th>Need TRL 6</th>
<th>Capability Date</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Planning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mission Planning</td>
<td>Apollo, Soyuz, Shuttle</td>
<td>6</td>
<td>Auto</td>
<td>-</td>
<td>2010</td>
<td>6</td>
</tr>
<tr>
<td>Strategic Planning</td>
<td>Shuttle</td>
<td>7</td>
<td>Auto</td>
<td>-</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Vehicle Planning</td>
<td>Shuttle</td>
<td>8</td>
<td>Integ.</td>
<td>-</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Trajectory Planning</td>
<td>Shuttle, Soyuz</td>
<td>9</td>
<td>Auto</td>
<td>-</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Collision Avoidance</td>
<td>Manual Visualization</td>
<td>3</td>
<td>Dev.</td>
<td>2006</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Dynamic Replanning</td>
<td>XSS-11</td>
<td>4</td>
<td>Real-Time</td>
<td>2006</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td><strong>2. Scheduling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated</td>
<td>Shuttle</td>
<td>6</td>
<td>Real-Time</td>
<td>2010</td>
<td>2012</td>
<td>7</td>
</tr>
<tr>
<td><strong>3. Logistics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logistics Planning</td>
<td>Shuttle PIC</td>
<td>9</td>
<td>Auto</td>
<td>-</td>
<td>2010</td>
<td>6</td>
</tr>
<tr>
<td>Resource Allocation</td>
<td>New Millennium</td>
<td>6</td>
<td>Auto</td>
<td>2008</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Automated Tracking</td>
<td>Shuttle GSE</td>
<td>8</td>
<td>Common</td>
<td>-</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Inventory Control</td>
<td>NASA Pre-Flight</td>
<td>8</td>
<td>Implement</td>
<td>-</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td><strong>4. Training</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competency Program</td>
<td>Astronaut Program</td>
<td>9</td>
<td>Update</td>
<td>2008</td>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>Skill-based</td>
<td>Astronaut Program</td>
<td>9</td>
<td>w/ robot</td>
<td>2008</td>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>Knowledge-Based</td>
<td>Astronaut Program</td>
<td>4</td>
<td>experts</td>
<td>2006</td>
<td>2008</td>
<td>6</td>
</tr>
<tr>
<td>Simulation</td>
<td>Shuttle Training</td>
<td>6</td>
<td>hi-res</td>
<td>2006</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Immersion</td>
<td>Laboratory</td>
<td>4</td>
<td>mature</td>
<td>2008</td>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>Testing &amp; Checkout</td>
<td>Conventional</td>
<td>9</td>
<td>Auto</td>
<td>-</td>
<td>2012</td>
<td></td>
</tr>
</tbody>
</table>
## State-of-the-Art /Maturity Level /Capabilities for 9.4.6 Planning, Logistics, & Training

<table>
<thead>
<tr>
<th>Sub-Capabilities</th>
<th>SOA</th>
<th>TRL</th>
<th>Needs</th>
<th>Need TRL 6</th>
<th>Capability Date</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Planning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto Mission Planning</td>
<td>Apollo, Soyuz, Shuttle</td>
<td>5</td>
<td>Auto</td>
<td>2008</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Auto Strategic Planning</td>
<td>Shuttle</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Auto Vehicle Planning</td>
<td>Shuttle</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Smooth Trajectory Planning</td>
<td>Shuttle, Soyuz Manual</td>
<td>9</td>
<td>Dev.</td>
<td>2006</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Auto Collision Avoidance</td>
<td>Shuttle Visualization</td>
<td>3</td>
<td>Real-Time</td>
<td>2006</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Auto Dynamic Replanning</td>
<td>XSS-11</td>
<td>4</td>
<td>Real-Time</td>
<td>2006</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td><strong>2. Scheduling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground</td>
<td>Shuttle</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>On-board</td>
<td>Shuttle</td>
<td>6</td>
<td>Real-Time</td>
<td>2008</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td><strong>3. Logistics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real-time Log. Planning</td>
<td>Shuttle PIC</td>
<td>5</td>
<td>Auto</td>
<td>2008</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Off board Log. Plan</td>
<td>Shuttle</td>
<td>9</td>
<td>-</td>
<td>-</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Resource Allocation</td>
<td>New Millennium</td>
<td>6</td>
<td>Auto</td>
<td>2008</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Real-time Tracking</td>
<td>Shuttle GSE</td>
<td>8</td>
<td>Common</td>
<td>-</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Auto Inventory Mgt</td>
<td>NASA Pre-Flight</td>
<td>8</td>
<td>Implement</td>
<td>-</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Real-Time Traffic Model</td>
<td>Shuttle</td>
<td>8</td>
<td>Auto</td>
<td>-</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Spares Planning</td>
<td>ISS</td>
<td>9</td>
<td>-</td>
<td>-</td>
<td>2008</td>
<td></td>
</tr>
</tbody>
</table>
## State-of-the-Art /Maturity Level /Capabilities for 9.4.6 Planning, Logistics, & Training

<table>
<thead>
<tr>
<th>Sub-Capabilities</th>
<th>SOA</th>
<th>TRL</th>
<th>Needs</th>
<th>Need TRL 6</th>
<th>Capability Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Comprehension</td>
<td>Astronaut Program</td>
<td>9</td>
<td>Update</td>
<td>-</td>
<td>2008</td>
</tr>
<tr>
<td>Situation-based</td>
<td>Military</td>
<td>6</td>
<td>infusion</td>
<td>-</td>
<td>2010</td>
</tr>
<tr>
<td>Skill-based</td>
<td>Astronaut Program</td>
<td>9</td>
<td>w/ robot</td>
<td>-</td>
<td>2012</td>
</tr>
<tr>
<td>Knowledge-Based</td>
<td>Astronaut Program</td>
<td>4</td>
<td>experts</td>
<td>2008</td>
<td>2010</td>
</tr>
<tr>
<td>Computer Sim.</td>
<td>Shuttle Training Ground</td>
<td>6</td>
<td>hi-res</td>
<td>2008</td>
<td>2010</td>
</tr>
<tr>
<td>Hardware-In-Loop Sim</td>
<td>Laboratory</td>
<td>4</td>
<td>custom</td>
<td>2008</td>
<td>2010</td>
</tr>
<tr>
<td>Immersion Room</td>
<td>Laboratory</td>
<td>4</td>
<td>facility</td>
<td>2010</td>
<td>2012</td>
</tr>
<tr>
<td>Immersion Desk</td>
<td>Laboratory</td>
<td>4</td>
<td>models</td>
<td>2010</td>
<td>2012</td>
</tr>
<tr>
<td>Testing &amp; Checkout</td>
<td>Conventional</td>
<td>9</td>
<td>Auto</td>
<td>-</td>
<td>2008</td>
</tr>
</tbody>
</table>

CRL: 6
# State-of-the-Art /Maturity Level /Capabilities for 9.4.6 Planning, Logistics, & Training

<table>
<thead>
<tr>
<th>Technologies</th>
<th>SOA</th>
<th>TRL</th>
<th>Needs</th>
<th>Need TRL 6</th>
<th>Capability Date</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Planning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto Mission Software</td>
<td>COTS-Grease</td>
<td>6</td>
<td>Auto</td>
<td>2010</td>
<td>2012</td>
<td>6</td>
</tr>
<tr>
<td>Auto Strategic Software</td>
<td>4D-RCS, Mapgen</td>
<td>7</td>
<td>Auto</td>
<td>2010</td>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>Auto Vehicle Software</td>
<td>Remote Agent</td>
<td>8</td>
<td>Auto</td>
<td>2008</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Trajectory Algorithm</td>
<td>A*, D*</td>
<td>9</td>
<td>Integ.</td>
<td>-</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Col. Avoid Behavior</td>
<td>Potential Field, Occupancy-Grid</td>
<td>4</td>
<td>Dev.</td>
<td>2006</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Auto Replanning</td>
<td>State Machine Re-Planning</td>
<td>4</td>
<td>Mature</td>
<td>2006</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Real-Time</td>
<td>2008</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td><strong>2. Scheduling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground</td>
<td>COTS-Grease</td>
<td>9</td>
<td></td>
<td>-</td>
<td>2005</td>
<td>7</td>
</tr>
<tr>
<td>On-board</td>
<td>Remote Agent</td>
<td>6</td>
<td>Optimization</td>
<td>2008</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td><strong>3. Logistics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real-time Log. Planning</td>
<td>Shuttle PIC</td>
<td>9</td>
<td>Auto</td>
<td>-</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Off board Log. Plan</td>
<td>COTS</td>
<td>9</td>
<td></td>
<td>-</td>
<td>2005</td>
<td></td>
</tr>
<tr>
<td>Resource Allocation</td>
<td>New Millennium</td>
<td>6</td>
<td>Auto</td>
<td>2008</td>
<td>2010</td>
<td>6</td>
</tr>
<tr>
<td>Real-time Tracking</td>
<td>Shuttle GSE</td>
<td>8</td>
<td>Common</td>
<td>-</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Auto Inventory Mgt</td>
<td>NASA Pre-Flight</td>
<td>8</td>
<td>Implement</td>
<td>-</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Real-Time Traffic Model</td>
<td>COTS</td>
<td>9</td>
<td>Contingency</td>
<td>-</td>
<td>2005</td>
<td></td>
</tr>
<tr>
<td>Spares Planning</td>
<td>NASA Std</td>
<td>9</td>
<td>Contingency</td>
<td>-</td>
<td>2005</td>
<td></td>
</tr>
</tbody>
</table>