Capability 9.2
Mobility

Presenter: June Zakrasjek

9.2 Mobility Description

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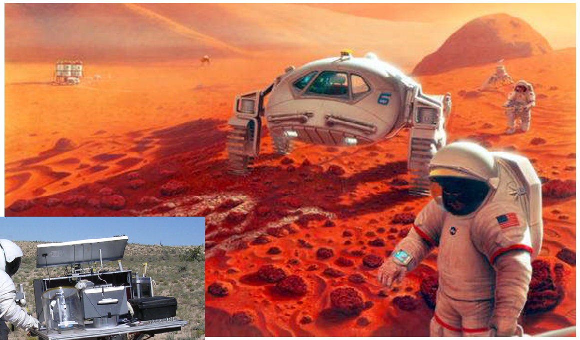
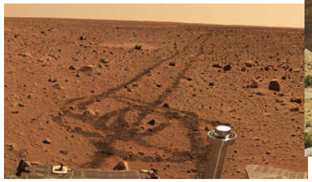
Essential for human operations In-Space and on planetary surfaces

In-Space Mobility

- Movement and positioning of astronaut ar equipment during construction and maintenance
- Deployment of scientific and monitoring equipment



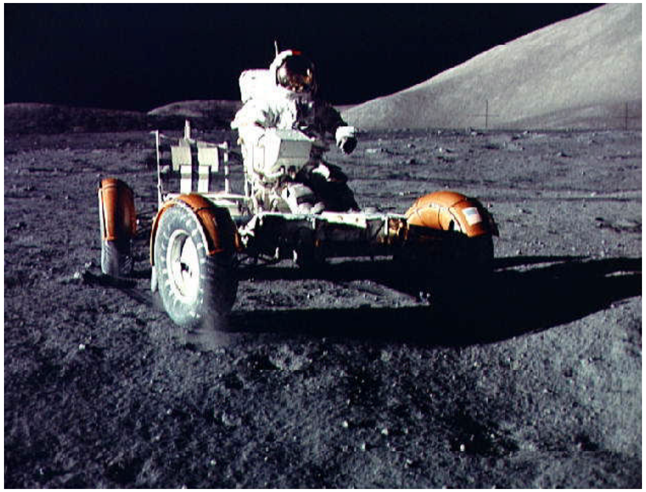


Surface Mobility

- Crew and equipment transport within:
  - Immediate vicinity (100 m) of a habitat/lander
  - Local area (10 km)
  - Regional areas (1000 km)
- Support of assembly, maintenance, and science tasks within immediate vicinity
- Autonomous, teleoperated, & direct crew control of mobility systems
- Scientific Exploration
- Site preparation, construction, Infrastructure deployment

9.2 Mobility Benefits

- Enables exploration of local site in detail
  - Immediate vicinity
  - Within approximately 10 km radius
- Provides for global access
- Enables efficient use of astronaut time
- Allows for human role in constructing and maintaining large facilities in space, thereby giving flexibility in design, construction and implementation
- Required In-Space and on the surfaces of the Moon, Mars, and other planetary environments



9.2 Mobility Challenges

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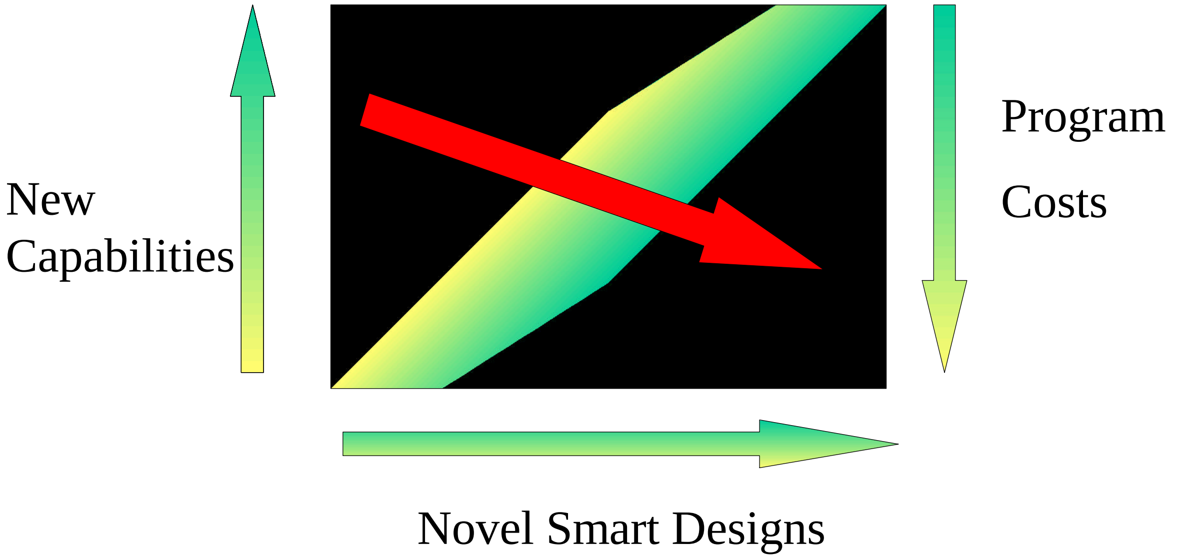
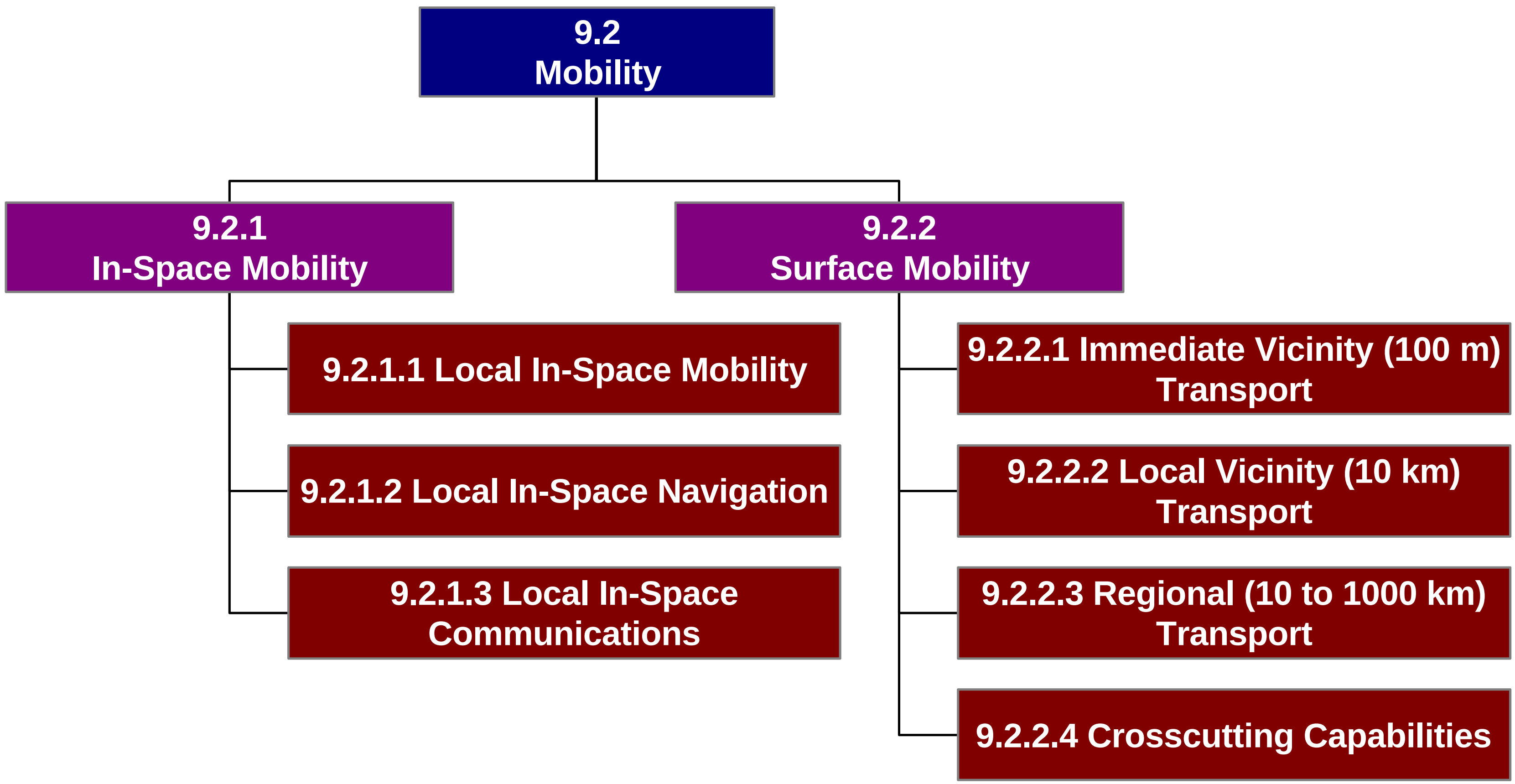
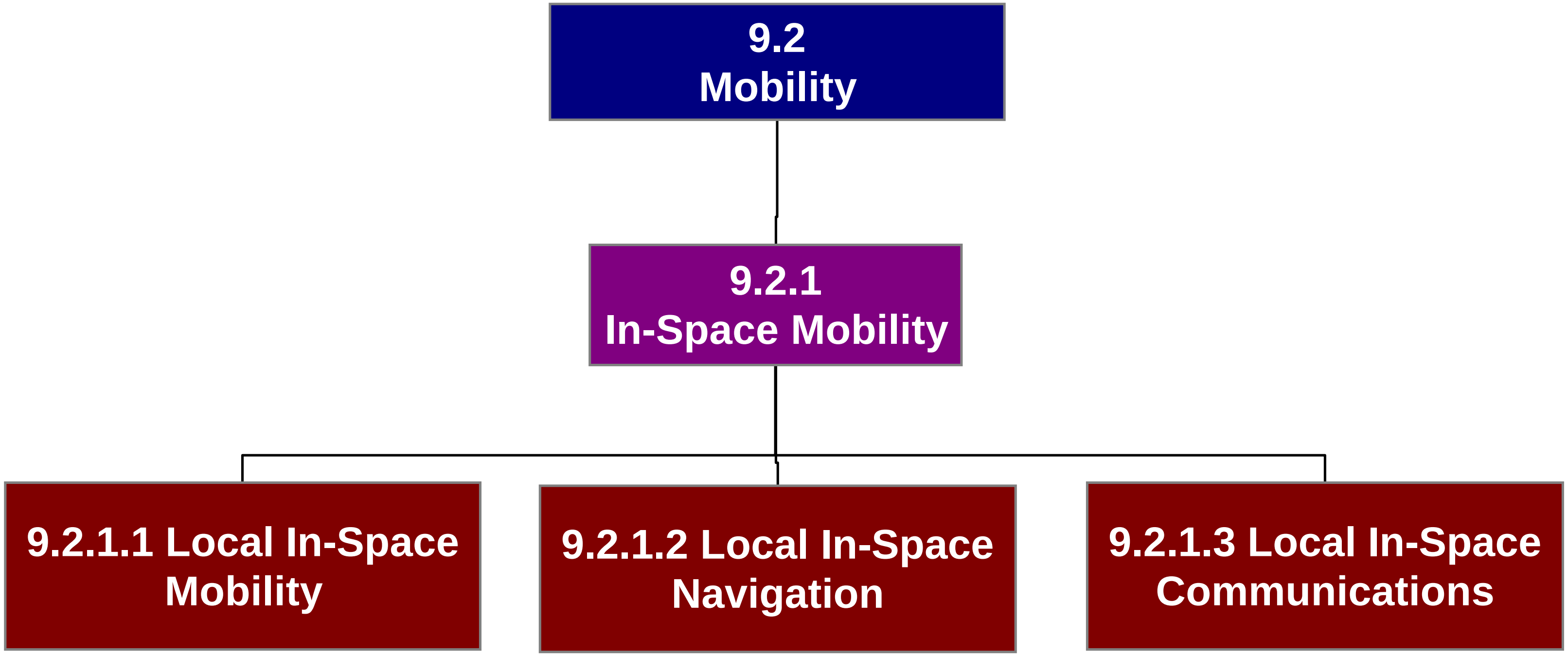
- Safely and effectively explore Moon and Mars
  - Operational differences
- Multiple systems required
- Limited budget
- Long distance travel
- Effective In-Space maintenance and deployment
- Environment

Requires a combination of cross-element commonality, smart design and capabilities




9.2
Mobility
9.2.1
In-Space Mobility
9.2.2
Surface Mobility
9.2.1.1 Local In-Space Mobility
9.2.1.2 Local In-Space Navigation
9.2.1.3 Local In-Space Communications
9.2.2.1 Immediate Vicinity (100 m) Transport
9.2.2.2 Local Vicinity (10 km) Transport
9.2.2.3 Regional (10 to 1000 km) Transport
9.2.2.4 Crosscutting Capabilities

Capability 9.2.1 In Space Mobility



9.2.1 In-Space Mobility Overview

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- **Drivers/Assumptions for In-Space Mobility**
  - Capabilities driven by assembly of large observation platforms
  - Exploration systems will not rely heavily on planned EVA operations
  - Communications with surface bases (including Earth) are relayed through the spacecraft
- **Capabilities for In-Space Mobility are well developed through ISS and Shuttle Programs (SOA)**
  - Equipment, procedures, and safety measures in-place for EVA crew mobility
  - EVA manual translation provided by handrails and CETA
  - Positioning within worksite provided by SSRMS, APFR, Body Restraint Tethers (BTRs)
  - Robotics systems move crew and equipment between worksites following very well planned scripts
  - Safety measures: Tethers and SAFER
  - Communication and Navigation to coordinate actions of Crew and robotics during EVAs

9.2.1

9.2.1.1 9.2.1.2 9.2.1.3

Capabilities for Improvement

– Real time planning and obstacle avoidance for robotic positioning of crew and equipment
  - Reduces overhead associated with robotic operations
– Deployable mobility aids (handholds, tether points, stabilization interfaces)
  - Reduces system mass
  - Reduces/eliminates permanent protrusions (snag points, aerodynamic interference)
– Additional support systems for moving equipment
  - New support equipment to increase crew carrying capacity (volume and number of items carried but not mass)
  - Expanded equipment transporters (Deployable, powered clothesline, Tethered Free Flyer Transport, Robotic Walker Equipment Transport, …)

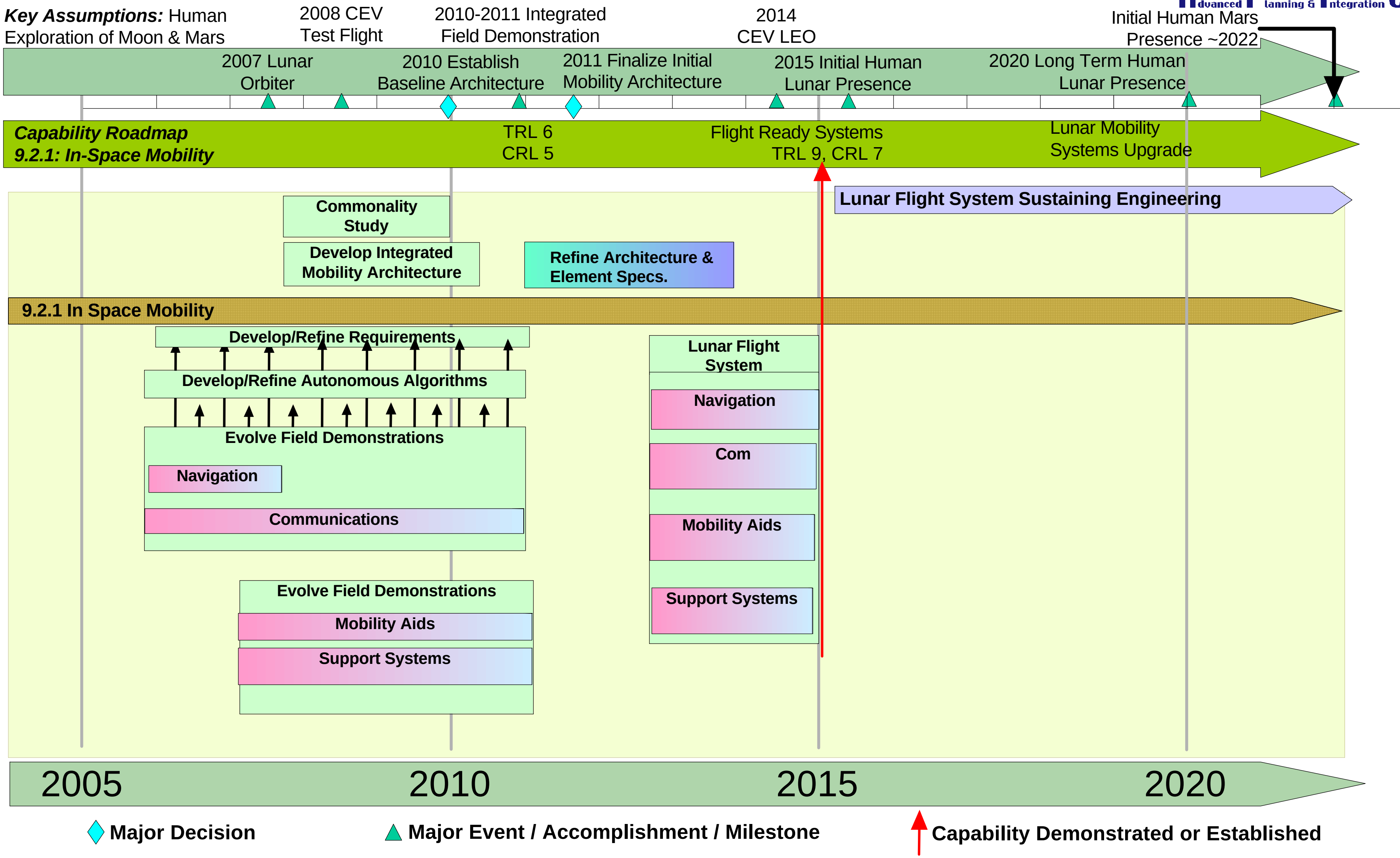
9.2.1 In-Space Mobility Assessment (Continued)

Capabilities for Improvement

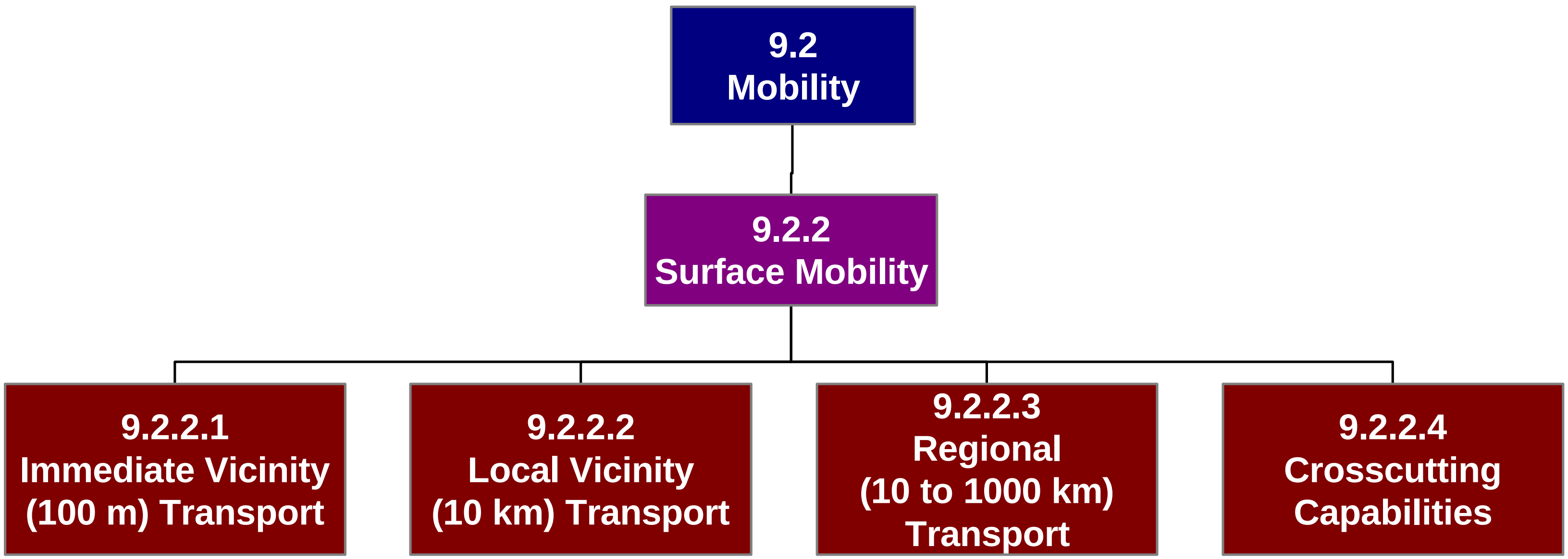
- Development of relative in-space navigation system to enable new systems to support operations
  - Free flying platforms (Camera, Tool Delivery,…)
  - Crew Maneuvering Unit
- Enhancement of in-space communications to provide:
  - EVA crew access to external video sources to enhance situational awareness
  - Command/control/video/data links between EVA crew and free flying platforms

Overall 9.2.1 Development Needed: low

9.2.1 In-Space Mobility Roadmap



Capability 9.2.2
Surface Mobility



9.2.2 Surface Mobility
Looking Back

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- "We boarded Rover again and I floorboarded it, but almost immediately reduced my speed to a crawl over the thin dark mantle of lunar dirt covering the undulating plain around the lander. The route was pocked with craters of all sizes, from tiny to large, and large boulders frequently forced me to detour. All of the hazards were partially buried, making what should have been a routine trip a rather risky undertaking. ... The wire mesh wheels collected some impressive dents when I sideswiped a few boulders." [pp. 326-327]

- "We reached our first destination -- Hole in the Wall, at the foot of the South Massif -- by driving tilted along a steep slope, dodging craters and rocks, with the TV camera capturing the bouncing, rolling terrain. In one-sixth G, the Rover felt like it was about to roll over, so I made sure that Jack was always on the downslope side." [p. 331]

The Last Man on the Moon, by Eugene Cernan with Don Davis, 1999.

9.2.2 Surface Mobility
The Environments: Moon and Mars

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Lunar Environment

- Far from a flat plain
- Fresh craters:
  - Interior slopes: 30-35 degrees
  - Steeper locally
- With erosion by impacts craters become wider and shallower, which makes undulating plains
- Surface material unconsolidated, fine-grained, gritty, and dusty
- Rock abundance: <1% of surface covered with rocks > 10 cm (except near fresh craters)
- Isotropic Geological Process - consistency across lunar surface

Martian Environment

- Far from a flat plain in many places
- Topography shaped by tectonics, impacts, water, and wind
- Surface material is highly variable (cemented dust, dust, sand dunes, rocky terrain)
- Improved knowledge of trafficability from Mars Exploration Rovers
  - Varied trafficability across planet

9.2.2 Surface Mobility Overview

- **Future Needs**
  - Future human missions (near-term) must allow crew to explore and harvest resources in the local and immediate areas (<10 km)
  - Systems must evolve/expand to allow humans to explore regional areas (up to 1000km)
  - Mobility "system of systems" must ensure safety of crew and maximize crew productivity
- **State of the Art**
  - Apollo Lunar Rover Vehicle
  - Mars Probes (Spirit, Opportunity, MSL)
  - Research activities

9.2.2 Surface Mobility Capability Breakdown Structure

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- 9.2.2 Surface Mobility
  - 9.2.2.1 Immediate Vicinity (100 m) Transport
    - 9.2.2.1.1 Mobile Robotic Platforms
    - 9.2.2.1.2 Climbing Aids
    - 9.2.2.1.3 Crew Systems
  - 9.2.2.2 Local Vicinity (10 km) Transport
    - 9.2.2.2.1 Personal Transport
    - 9.2.2.2.2 Mobile Systems
    - 9.2.2.2.3 Crew Systems
  - 9.2.2.3 Regional (10 to 1000 km) Transport
    - 9.2.2.3.1 Rapid Transport
    - 9.2.2.3.2 Long-Duration Transport
    - 9.2.2.3.3 Crew Systems
  - 9.2.2.4 Crosscutting Capabilities
    - 9.2.2.4.1 Surface Navigation
    - 9.2.2.4.2 Local Worksite Communications
    - 9.2.2.4.3 Situational Awareness
    - 9.2.2.4.4 Autonomous Drive Operations
    - 9.2.2.4.5 Multi-Mobility System Cooperation

9.2.2 Surface Mobility Assessment and Needs

General Assessment

- Current SOA addresses only small area of needed capability
- Considerable research and engineering required to mature capability to meet future mission needs

Needs

- Fast, safe, long distance travel (Local and Regional Areas)
- Radiation and dust mitigation and countermeasures
- Autonomous, cooperative vehicle placement
- Surface navigation system
- Easy maintenance, long life
- Commonality between all surface system, including robotic
- Robust PLSS in-field recharge
- Order of magnitude improvement communications BW (Earth-based Communication SOA)

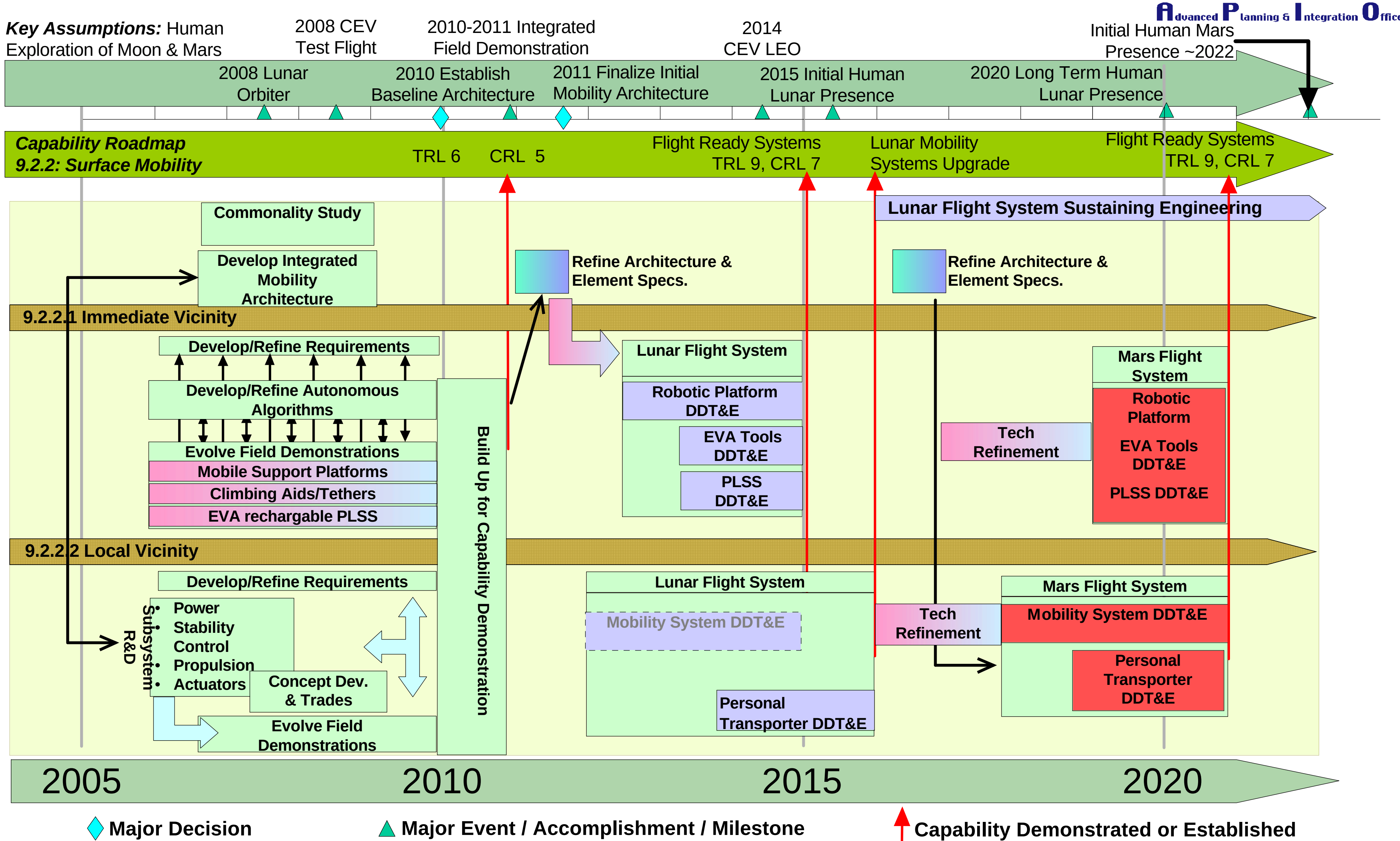
Capabilities with Development Needed HIGH

- Climbing Aids and Tethers
- Mobile Support Platforms
- Crew Systems
  - Robust PLSS in-field recharge
  - SPE Protection and Warning
- Personal Transport
- Rapid Transport
- Long Duration Transport
- Communications and Navigation
  - High Bandwidth Surface Beacons
- Autonomous Drive Operations
- Multi-Mobility System Cooperation

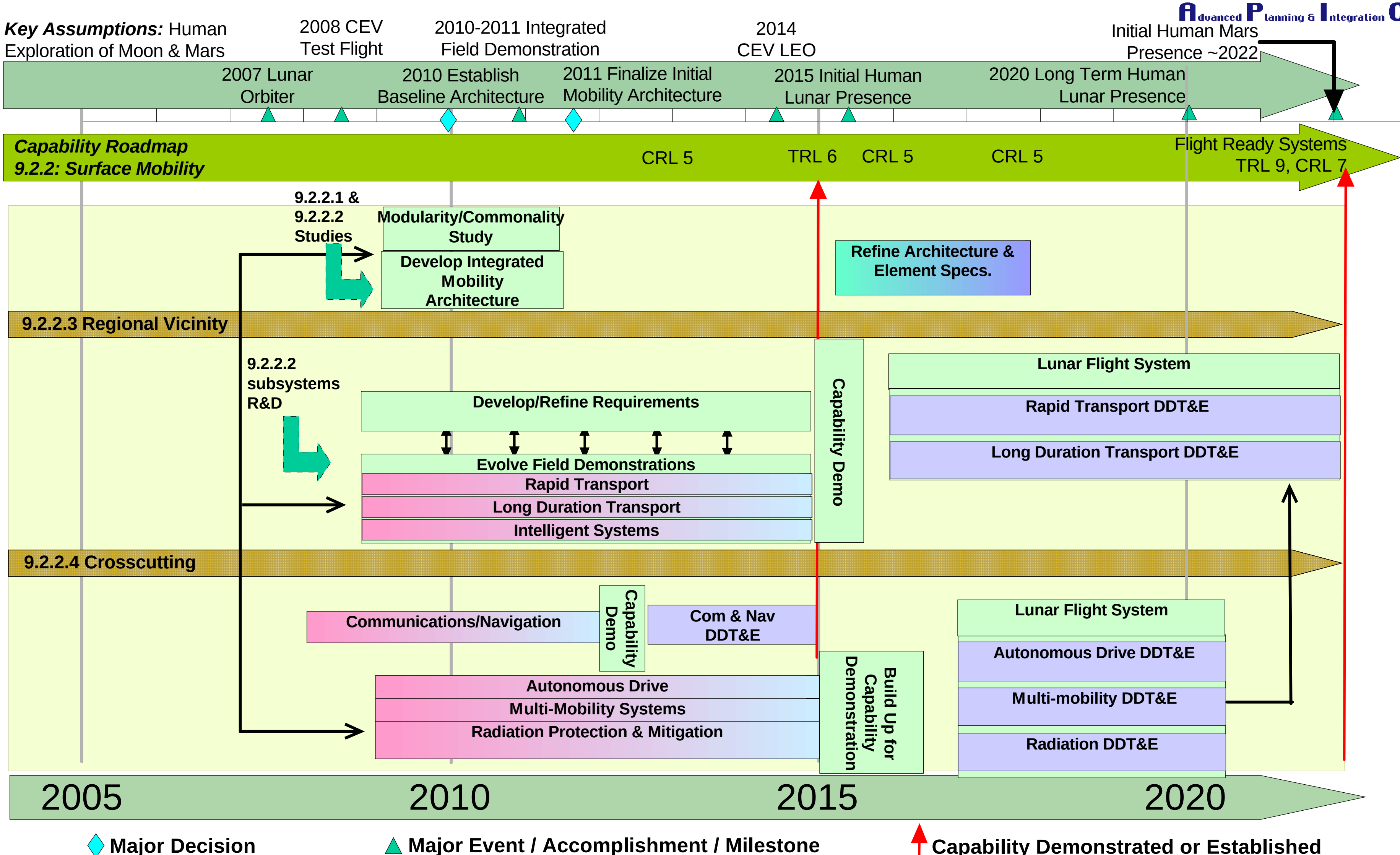
Capabilities with Development Needed HIGH

- Modular, reconfigurable Systems
- Intelligent Self Aware Systems
- Radiation and dust mitigation and countermeasures
- Easy maintenance, long life
- Commonality between all surface system, including robotic

9.2.2 Surface Mobility Roadmap

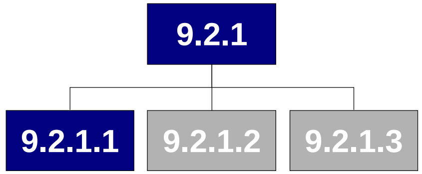


9.2.2 Surface Mobility Roadmap



Additional Detail 9.2 Mobility

Capability 9.2.1.1
Local In Space Mobility



9.2.1.1 Local In-Space Mobility

Description

– Efficiently and safely transport payloads (crew, robots, and equipment) between local worksites in space and deploy items within the new worksite

Sub-Capabilities

9.2.1.1.1 Plan and Monitor In-Space Movement **(low)**

9.2.1.1.2 Transport Payload Between Worksites **(Medium)**

9.2.1.1.3 Position Payload Within Worksite **(Medium)**

9.2.1.1.4 Align Payload to Worksite Interface **(low)**

Primary Benefit

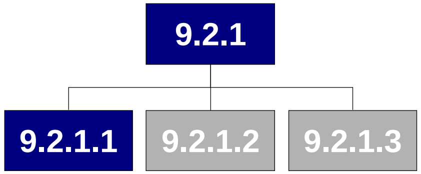
– Enables the assembly, operation, and maintenance of large scale on-orbit facilities

General Assessment

– New systems will need to be evolved from current SOA to provide more operationally efficient (faster) and more flexible on-orbit operations

– Collision avoidance

Development Needed : low to Medium



Capability 9.2.1.1
Plan and Monitor In-Space Movement

Description

- Plan and monitor in-space movements of payloads using varying levels of autonomy ranging from fully autonomous operations to direct planning/control of the movement by a crew member
- Examples: Autonomous path planner, collision avoidance planner, kinematics simulator, proximity sensors, camera platforms

Benefits

- Ensures the safety of payloads, worksites, and transport systems
- Ensures resources are capable of and available for performing the movement

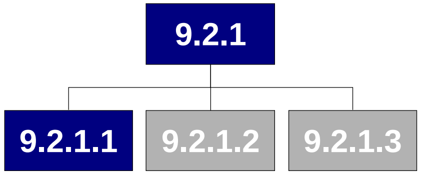
FOM

- Time to Plan, Memory/Processing Power, Crew Time, Impacts to Worksite, Impacts to Transfer System, Impacts to Payloads

General Assessment

- Components must be evolved and integrated with current elements to operate efficiently in changing worksites and unplanned environments

Development Needed low



Capability 9.2.1.1.2
Transport Payload Between Worksites

Description

- Transport payload (crew member, robotic system, or equipment) from one worksite area to another
- Examples/Components: Large Scale Robot, Powered Rail Cart, Walker, Free Flyer, Tow Line, Hand Rails, Body Restraint Tether

Benefits

- Enables on-orbit construction, operation, inspection, and maintenance of larger structures
- Provides flexibility in planning and staging for on-orbit assembly and maintenance

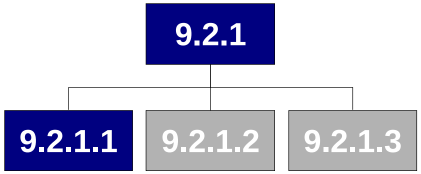
FOM

- Work Envelope/Mass, Time to Move, Power Consumption, Expandability, Impacts to Worksite/Spacecraft

General Assessment

- Current flight systems either are limited in Payload capacity (I.e. EVA crew member) or impose substantial penalties (mass, volume, limited access,…) to the worksites or spacecraft

Development Needed Medium



Capability 9.2.1.1.3
Position Payload within Worksite

Description

- Grossly position payload (crew member, robotic system, or equipment) within a worksite
- Examples/Components: Dexterous manipulator, EVA crew member, Powered Cart, Gross positioning robot manipulator

Benefits

- Provides flexibility in planning and staging for on-orbit assembly and maintenance
- Enables on-orbit construction and inspection of larger structures

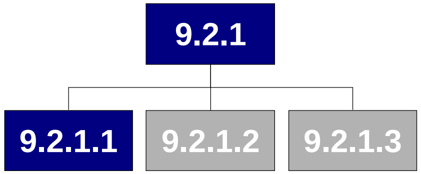
FOM

- Work Envelope/Mass, Time to Move, Power Consumption, Expandability, Worksite Impacts

General Assessment

- Current flight systems are effective at positioning payloads within a worksite but must be tailored to meet specific future mission needs and to reduce the mass, impacts to the worksite, and time to position a payload

Development Needed Medium



Capability 9.2.1.1.4
Align Payload w/ Worksite Interface

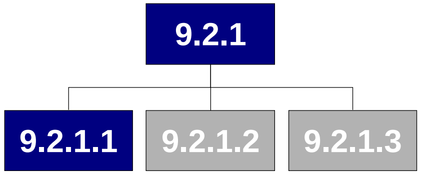
Description
- Accurately align payload to a mating interface within the worksite
- Examples/Components: Dexterous robot system, EVA crew member

Benefits
- Enables on-orbit construction and maintenance
- Use of robotic systems reduce safety risks to Crew

FOM
- Positional accuracy, access envelope, overhead to mobilize, required training and planning, availability

General Assessment
- Crew EVA capability well demonstrated
- Robotic capability demonstrated on ISS prior to exploration need
- Evolvement of systems required

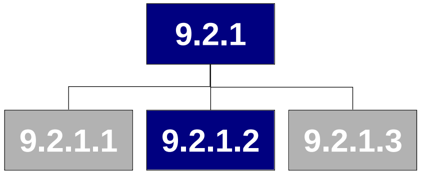
Development Needed low



Maturity Level – Technologies
9.2.1.1 Local In-Space Mobility

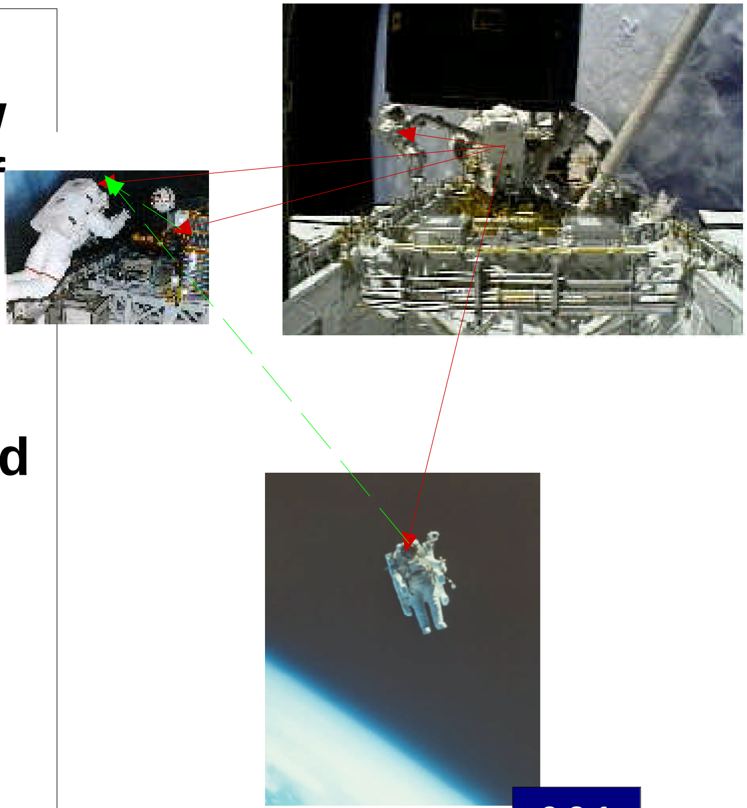
Capability	SOA	TRL	Needs	Need TRL 6	Capability Date	CRL
9.2.1.1.1 Plan and Monitor In-Space Movement *Key: Prepare for ops near Mars w/ 40 min. delay*	Shuttle / ISS Simulation; Stationary camera with TDRSS Link	*5*	Autonomous planning of paths / collision avoidance; Free-flying camera platform	2010	2015	1-7
9.2.1.1.2 Transport Payload between Worksites *Key: Assembly of large payloads by robotic support systems*	ISS Mobile Transporter	*4*	Robotic crawler with structural interfaces; Eventual flying “Tug-boat”	2010	2015	1-7
9.2.1.1.3 Position Payload within Worksite *Key: Reduce worksite impacts & time to position PL*	ISS SPDM (Special Purpose Dextrous Manipulator)	*4*	Reduce mass, worksite impact, and time to position payload	2010	2015	1-7
9.2.1.1.4 Align Payload to Worksite Interface *Key: Minimize interface constraints*	ISS Work I/F MRMS End-Effector	*3*	Momentum-wheel attitude; Electromagnetic fine positioning	2010	2015	1-7

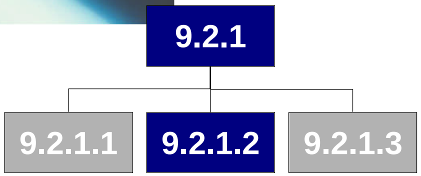
Capability 9.2.1.2
Local In Space Navigation



This capability provides relative navigation information for EVA crew personnel and equipment outside of a traversing spacecraft.

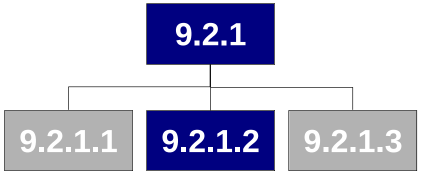
Techniques developed during previous U.S. space programs will be modified and expanded where needed to accomplish exploration EVA tasks.



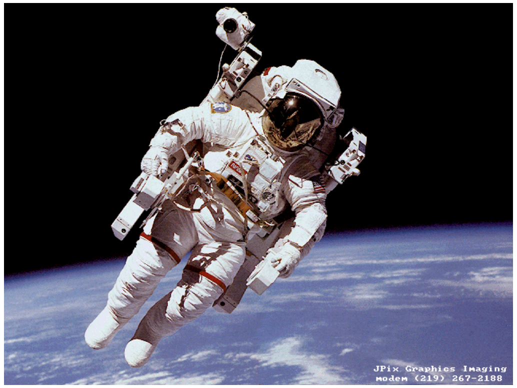


Description

- Provides relative navigation and attitude information for EVA crew personnel and detached equipment outside of a traversing spacecraft.
- Information provided includes attitude, relative position and velocity, relative range and range rate and any other needed relative navigation parameters.
- Navigation information is provided for:
    - EVA persons relative to the spacecraft
    - Detached and docking equipment relative to the spacecraft
    - Between an EVA crewperson and detached equipment
    - Among EVA crew personnel



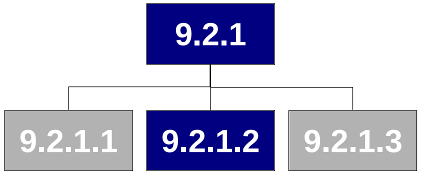
Benefits



•Allows EVA personnel to estimate traverse times

•Provides the needed elements to enable capture or rescue of crew or items that have are drifting away accidentally

•Enables automatic docking of co-orbiting equipment for examples, miniature flying camera systems, automated tool carts, equipment carriers, robotic crew assistants, etc.



FOM

•**Required one sigma relative accuracies for EVA crew or non docking equipment:**

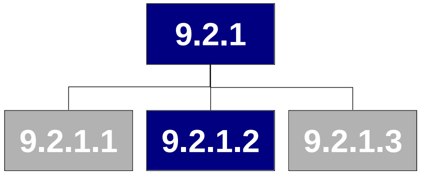
positions	2 meters
velocities	0.2 meters/sec
attitudes	1.5 degrees

•**Typical one sigma relative accuracies for docking equipment:**

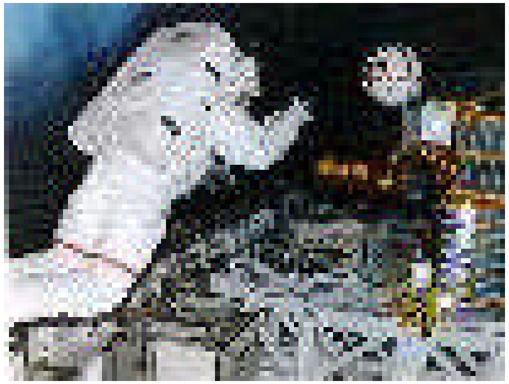
positions	2 centimeters
velocities	1 centimeter/sec
attitudes	1 degree

General Assessment : Though space relative navigation systems have not been developed for multiple users, the algorithms and navigation hardware changes are achievable.

Development Needed : Medium



Capability/ Technology	SOA	TRL	Needs	Need TRL 6	Capability Date	CRL
Relative sensors						
Radar ranging	NSTS, GPS	9,8	less power, mass	2008	2010	5,5
Laser ranging	HTV rendezvous	4-5	space qualified	2006	2008	3
Optical LED tracking	Mini Aercam, ISS CBCS	6,9	adapt for specific docking vehicles	2008	2011	4,6
Optical shape/ color tracking	NSTS SVIS, JSC Scout	9,5	Explor.-focused space qualified	2009	2012	5,3
Relative navigation algorithms						
Single body	NSTS rendez.	9	CPU efficiency	2009	2008	6
2-body docking	ISS	9	CPU efficiency	2007	2009	6
n-body tracking	ICBM defense	7	Modify for explor.	2009	2012	4
Relative guidance algorithms	Closhesy-Wilshire equations	7	Modify for explor.	2008	2011	6



This capability provides communications for EVA crew personnel and equipment outside of a traversing spacecraft.

Current space methods need to be upgraded to use multi-point techniques and to provide expanded bandwidth to provide operational efficiencies.

Description

- Provides two-way voice, video and data communications while on EVA outside a traversing spacecraft:
    - Among EVA personnel
    - Between EVA personnel and the spacecraft
    - Between EVA personnel and detached or docking equipment
    - Between detached or docking equipment and the spacecraft

- Communications with surface bases with Earth are relayed through the spacecraft.

Benefits

- Provides situational awareness for EVA personnel

- EVA crew will be able to execute procedures using up-to-date textual and graphical data.

- Enables crew to monitor and control detached or docking equipment

- Spacecraft and ground/planetary personnel can monitor EVA procedures and operational status.

FOM Required total bandwidths (Megabits/sec) & Video Resolution

To \ From	EVA Person	Spacecraft	Robot	External Equipment
EVA Person	1 scalable	1 CHDTV	1 CHDTV	1 CHDTV
Spacecraft	1 CHDTV	n/a n/a	1 CHDTV	1 CHDTV
Robot	0.2 n/a	1 n/a	2 n/a	n/a n/a
External Equipment	0.2 n/a	1 n/a	n/a n/a	n/a n/a

General Assessment : Though space relative communication systems have not been developed for multiple users, the algorithms and new hardware changes are achievable.

Development Needed : Medium

Capability/ Technology	**SOA**	**TRL**	**Needs**	**Need TRL 6**	**Capability Date**	**CRL**
Low mass 3DHD cameras	surveillance personal cameras, Soni full concept 3DHD prototype	9 5	Add funding to full-concept 3DHD cameras	2009	2012	4
Crew/robot/Mobile transmitter/recv./ant.	surveillance personal rf devices	4	I MBPS, low mass, space qualify, 2 km range	2009	2012	2

Capability 9.2.2
Surface Mobility

Presenter:

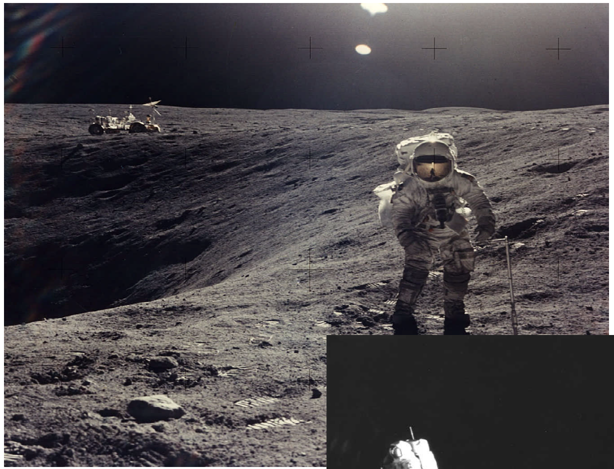
Team Lead

- **"We boarded Rover again and I floorboarded it, but almost immediately reduced my speed to a crawl over the thin dark mantle of lunar dirt covering the undulating plain around the lander. The route was pocked with craters of all sizes, from tiny to large, and large boulders frequently forced me to detour. All of the hazards were partially buried, making what should have been a routine trip a rather risky undertaking. ... The wire mesh wheels collected some impressive dents when I sideswiped a few boulders." [pp. 326-327]**

- **"We reached our first destination -- Hole in the Wall, at the foot of the South Massif -- by driving tilted along a steep slope, dodging craters and rocks, with the TV camera capturing the bouncing, rolling terrain. In one-sixth G, the Rover felt like it was about to roll over, so I made sure that Jack was always on the downslope side." [p. 331]**

The Last Man on the Moon, **by Eugene Cernan with Don Davis, 1999.**

- Far from a flat plain
- Fresh craters:
  - interior slopes: 30-35 degrees
  - (steeper locally)
- With erosion by impacts craters become wider and shallower, which makes undulating plains
- Surface material is unconsolidated, fine-grained, gritty, and dusty
- Rock abundance: <1% of surface covered with rocks > 10 cm (except near fresh craters)
- Isotropic Geological Process - consistency across lunar surface



- Far from a flat plain in many places
- Topography shaped by tectonics, impacts, water, and wind
- Surface material is highly variable (cemented dust, dust, sand dunes, rocky terrain)
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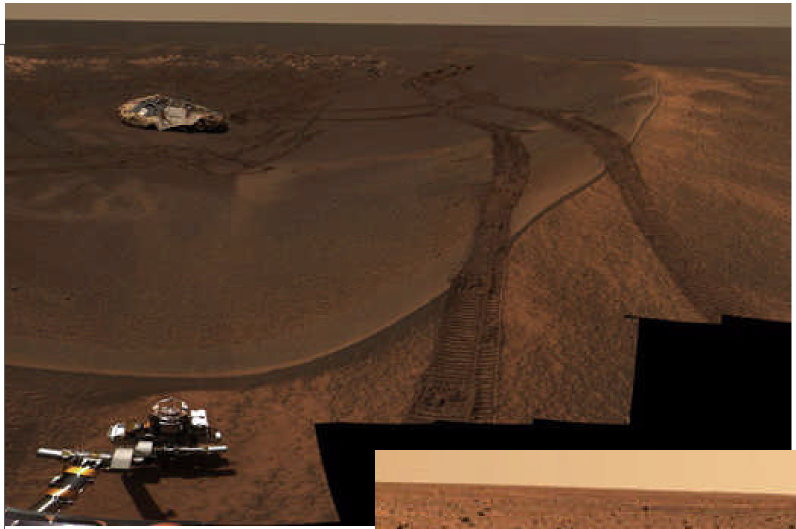
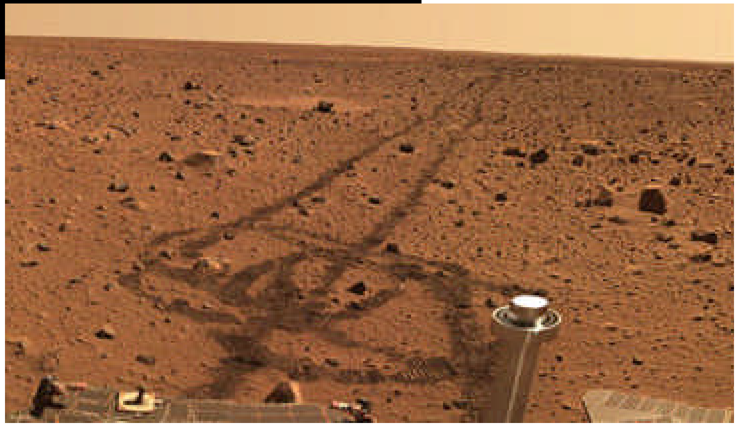
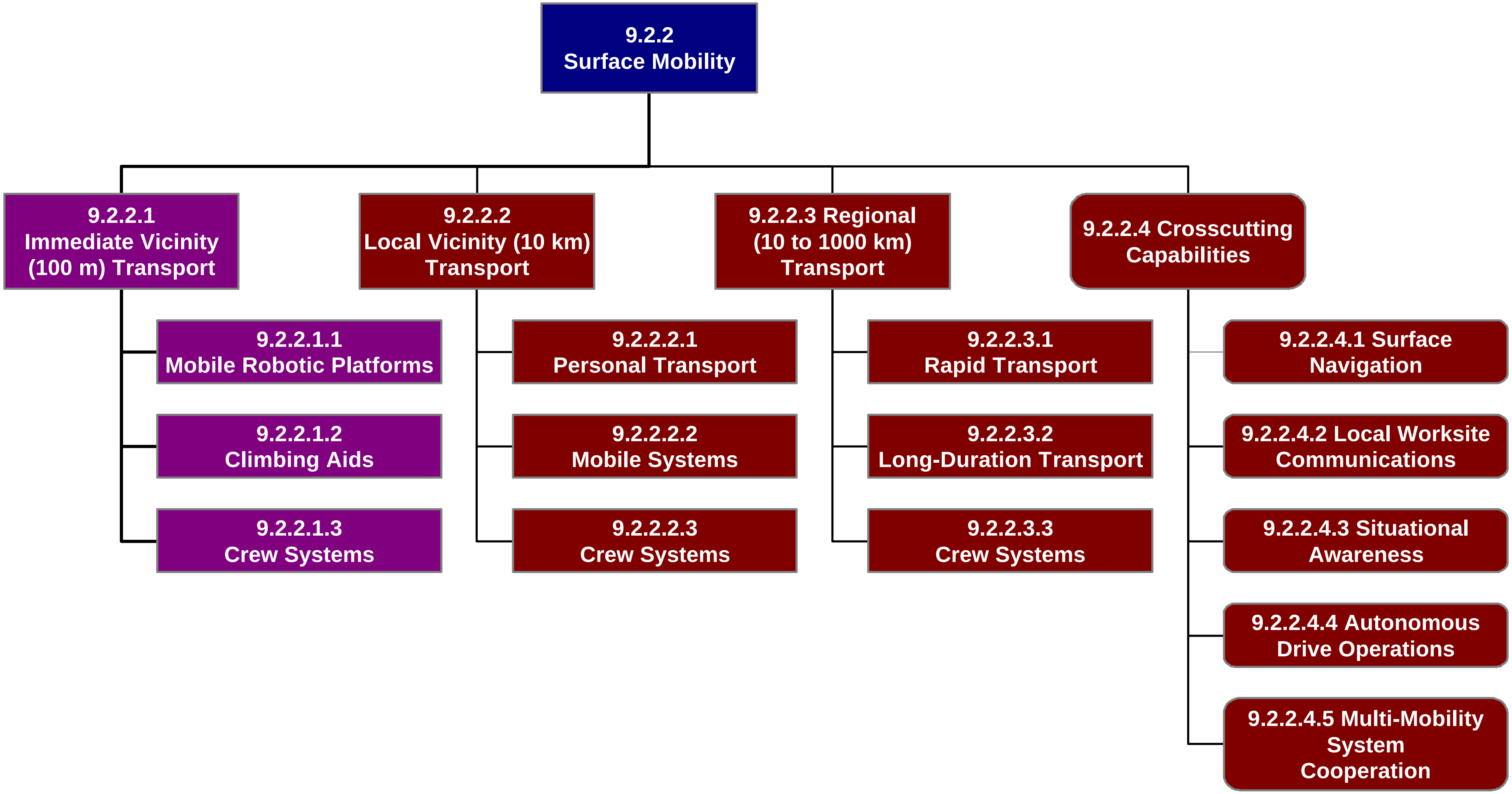


Opportunity: Sandy route from Eagle crater



Spirit: Long traverse

- **Fast, Safe, Long distance travel**
- **Autonomous, cooperative vehicle placement**
- **Order of magnitude improvement BW for communications (Earth-based Communication SOA). Enables heads up display**
- **Surface Navigation System**
- **Robust PLSS recharge**
- **Radiation and Dust Mitigation and Countermeasures**
- **Easy maintenance, long life**

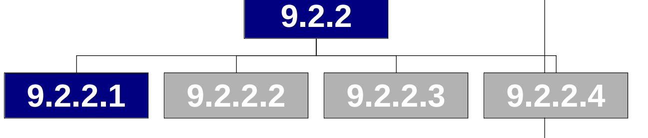

9.2.2
Surface Mobility
9.2.2.1
Immediate Vicinity
(100 m) Transport
9.2.2.1.1
Mobile Robotic Platforms
9.2.2.1.2
Climbing Aids
9.2.2.1.3
Crew Systems
9.2.2.2
Local Vicinity (10 km)
Transport
9.2.2.2.1
Personal Transport
9.2.2.2.2
Mobile Systems
9.2.2.2.3
Crew Systems
9.2.2.3 Regional
(10 to 1000 km)
Transport
9.2.2.3.1
Rapid Transport
9.2.2.3.2
Long-Duration Transport
9.2.2.3.3
Crew Systems
9.2.2.4 Crosscutting
Capabilities
9.2.2.4.1 Surface
Navigation
9.2.2.4.2 Local Worksite
Communications
9.2.2.4.3 Situational
Awareness
9.2.2.4.4 Autonomous
Drive Operations
9.2.2.4.5 Multi-Mobility
System
Cooperation

Description: Support human surface operations in immediate vicinity (on the order of 100 meters) of landing vehicles, habitation areas, and regions reached by larger scale, longer distance surface mobility systems (9.2.2.2 and 9.2.2.3). Major systems are the following:

9.2.2.1.1 Mobile Support Platforms
9.2.2.1.2 Climbing Aids/Tethers
9.2.2.1.3 Crew Systems

Benefits: Improves Astronaut safety and provides for efficient explorations

General Assessment: Earth terrestrial Climbing Aids/Tethers models evolved for space exploration. Technology development and system engineering required.



Development Needed: **Medium**

9.2.2.1.1 Mobile Support Platforms

Description: Mobile Platforms perform direct operated/teleoperated/autonomous operations supporting astronauts during immediate vicinity EVAs, including equipment/cargo mass handling. Examples of such platforms include:

- – Sensor Platform/ Data Relay Station
- – Equipment Carriers (Carts, Sleds, lifts)
- – Resource Carts

Benefits:

- – Mobile Data Relay Stations will allow communications without a direct line-of-sight, essential for exploration of deep craters and rilles
- – Equipment carriers/sleds reduce astronaut exertion, and mitigate the chance of damaging equipment by dropping it from height or in a fall
- – Resource Carts carry large reserves of power and human consumables
- – Improved crew productivity

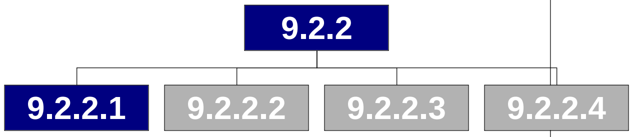
Figures of Merit

- Power, Dual utility, EVA efficiency, Ease of repair, access, use

General Assessment

- Current SOA is from Apollo (Modular Equipment Transport), Spirit/Opportunity sensor platform, EVA Robotic Assistant (TRL 6)

Development Needed: **Medium**



9.2.2.1.2 Walking and Climbing Aids

Description: Equipment to improve access to exploration targets

- Flat Terrain: Walking aid (e.g., “walking stick” for balance, stability, get-up)
- Unstable/Dark Areas: “Snowshoes” or “Skiis” / Power Umbilical or Lamp
- Steep Slope: “Ice Axe”, Ladder, Crampons, Shovel, “Ski” Poles, Rope
- Rope Interfaces: Harness, Carabineer, Belay/Arrest/Ascend Device, Reel, Knife
- Ground Interfaces: Piton, “Ice Screw”, Grapple, “Anchor”; Load Equalization
- Container/ Carriers: Rope Bag, Gear Clip, Tent/Bivouac sack, Hammock

Benefits:

- Flat Terrain: Improved safety, walking speed and fall recovery
- Unstable/Dark Area: Access permanently shadowed areas with unique regolith
- Steep Slope: Access lunar rilles and mountains, Allow rapid, safe motion
- Rope Interfaces: Access extreme terrain safely (cliff outcropping, lava tube, ...)
- Ground Interfaces: Safe anchoring in extreme environments, prevent fatal falls
- Container/ Carriers: Minimize dust effects on equipment, allow easy access

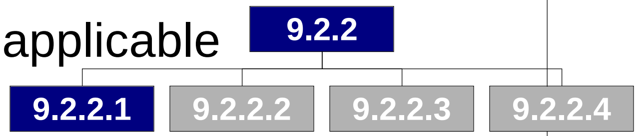
Figures of Merit

- Stowed volume, Dual utility, Ease of repair, Ease of use, Safety

General Assessment

- Neglected during Apollo missions, Earth analogue applicable

Development Needed: **Medium to HIGH**



9.2.2.1.3 Crew Systems

Description: Equipment carried by astronauts. Examples:

- Emergency Life Support Systems
  - Integration of fuel cell consumables with human consumables
  - Ensure ability to walk home after loss of larger scale surface mobility
  - Share power/life support
- Knapsacks/tool belt carry consumables, tools, and cargo (e.g., rocks)
- Hand/foot interfaces to improve habitation ingress and egress

Benefits

- Life support: Potential life saver in contingency
- Knapsack/tool belt: Allow Astronaut to work with free hands and tools at ready
- Hand/foot I/F Example: Magnetic doormat can remove dust before entry

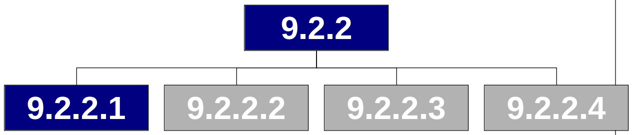
Figures of Merit

- Health, Safety, Volume, Lifetime, Dual use, Easy use,

General Assessment

- Longevity, reusability, serviceability (replenishing and repairing) are key technology challenges

Development Needed: **Medium for life support**



Capability	SOA	TRL	Needs	Need TRL 6	Capability Date	CRL
9.2.2.1.1 Mobile Support Platforms *Key: Assist local crew mobility and safety*	Apollo experience	*5*	Mobile Data Relay Station, Carriers for Equipment & Resources	2010	2015	1-7
9.2.2.1.2 Walking and Climbing Aids *Key: Improve safety and enable access to important, presently unexplorable areas*	Apollo flat Terrain; Mountain Climbing tools on the Earth	*4*	Interfaces for Flat Terrain, Unstable / Dark Areas, Steep Slopes, Rope, Ground Anchors, and Containers	2010	2015	1-7
9.2.2.1.3 Crew Systems *Key: Assist local crew safety and utility*	Apollo experience with some gains from ISS	*3*	Contingency Life Support systems, Backpacks, and Hand/Foot I/Fs (magnet doormat)	2010	2015	1-7

Capability 9.2.2.2
Surface Mobility: Local Vicinity Transport

Presenter:

Team Lead

Description

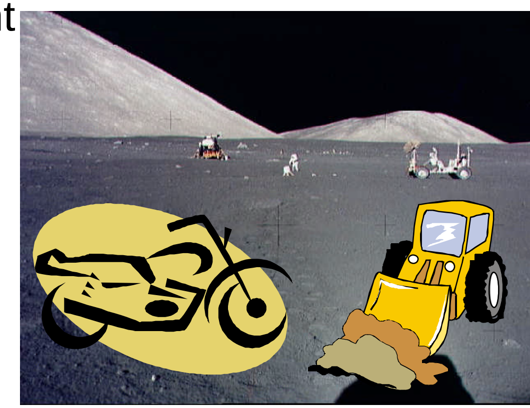
- Efficiently transport crew, supplies, and equipment to desired locations that are up to approximately 10 km from a habitat or other pressurized, protective shelter, and ensure the crew's safe return to their starting point
- **Sub-Capabilities**

  9.2.2.2.1 Personal Transport

  9.2.2.2.2 Mobility System

  9.2.2.2.3 Crew Systems

  9.2.2.2.4 Mobile Construction Systems

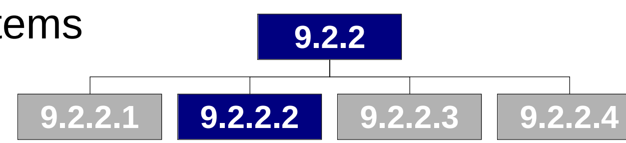


Primary Benefit

- Enables the assembly, operation, and maintenance of large scale facilities and increase reach for science and facilitates ISRU

General Assessment

- The Lunar Roving Vehicle represented the Apollo SOA and will generally suffice for upcoming missions. Durability and commonality across architectural elements need to be addressed.
- Technology development and a significant amount of systems engineering is required



9.2.2.2.1 Personal Transport Overview

Description

- Transport single crew member with very limited equipment to a remote worksite and/or back to a habitat or other pressurized, protective shelter that is up to approximately 10 km away
- Examples: All Terrain Vehicle, Sled, Motorcycle, Gyrostabilized Wheeled Vehicle "Segway", Jet Pack, Mechanical Hopper, Exoskeleton

Benefits

- Increases EVA efficiency by providing quick transport to a pre-setup or remote site
- Preserves EVA consumables
- Reduces crew fatigue
- Increases flexibility in planning exploration excursions
- Improves crew safety by providing return to habitat or protective shelter
  - Contingency return for long duration transport

FOM

- Transit time, range, resource usage (Power, Propellant…), lifetime, maintenance, payload capacity, environmental (T, dust, daylight, radiation…), portability, EVA consumable savings, metabolic rate and crew fatigue reduction, safety redundancy

General Assessment

- Component technologies need to be developed and integrated to meet mission constraints and provide the mobility required to traverse the terrain

Development Needed HIGH

9.2.2.2.2 Mobile Systems Overview

Description

- Transport crew (2-4 people) and/or various size paylods, up to 1000 kg and TBD m3, to remote worksites that are up to approximately 10 km away from a primary habitat or base camp using various levels of autonomy (direct piloted to fully autonomous)
- Examples: Wheeled system (car), Tracked system (tank), Walker, Mechanical hopper, Propulsive hopper, Rail based train, Rocket plane

Benefits

- Allows further separation of support infrastructure (I.e. Habitat, power station, landing areas, etc.) to increase mission safety
- Preserves EVA consumables
- Reduces crew fatigue
- Increases carrying capacity
- Increases surface area for exploration (ISRU, science research, etc.)
- Increases available staging area for storage and construction

FOM

- Transit Time, Payload Capacity/System Mass, Range, Power, Terrain Agility, infrastructure requirements, lifetime, maintenance, environmental, EVA consumable savings, metabolic rate and crew fatigue reduction, safety redundancy

General Assessment

- Some component technologies need to be optimized (e.g. motors) while others need substantial development work
- Substantial system engineering and integration is required to architect a useful system that is applicable to a wide range of tasks

Development Needed **Medium**

9.2.2.2.3 Crew Systems Overview

Description

- Enable the crew to interact and control the mobility system effectively
- Supplement a crew member's Portable Life Support System (PLSS)
- Examples: Deployable Crew Aides, EVA Compatible Crew Controls, PLSS Resupply System, PLSS Consumable ORUs,

Benefits

- Enabling capability for crewed mobility systems (Option within Subcapability 9.2.2.2.2)
- Increases EVA duration
- Reduces mass required for PLSS thereby reducing crew fatigue during EVA

FOM

- EVA duration, EVA efficiency, EVA suit and PLSS weight, environmental

General Assessment

- Crew interface requirements and associated support systems (hand rails, displays,…) are well understood
- Ability to resupply a PLSS is highly dependent on the PLSS architecture but this issue has been studied by the advanced EVA community and demonstrated in a variety of environments/conditions (In flight, prototype testing, field testing, …)
- Advances need to develop robust connectors to reduce environmental contamination

Development Needed Low

9.2.2.2.4 Construction Systems Overview

Description

- Enable the capability to transport large items (e.g. habitat modules), shape the environment and mine for in-situ resources (ISRU)
- Examples: Dump truck, mobile crane, bull dozer, back hoe, tractor

Benefits

- Allows construction of support infrastructure (I.e. Habitat, power station)
  - Prepare roadways
  - Flatten landing areas
  - Move payloads from lander to other site
- Increase mission safety by providing distance separation between Lander and base
- Radiation shielding via excavating and covering modules with regolith, meters in thickness
- Supports ISRU

FOM

- Common components/subsystems, Reliability in lunar environment, Power consumption, Ease of use/Required training, maintenance, payload capacity, towing capacity

General Assessment

- Capability has not been demonstrated in the target environment
- Key issue will be how this system relates to other mobility systems and will thus require significant SE&I effort to develop an optimal mission approach
- Capability lacking

Development Needed HIGH

Capability 9.2.2.3
Surface Mobility: Regional Transport Transport

Presenter:

Team Lead

Description:

- This capability provides for the development of systems that enable regional transport* of Crew, Supplies and Equipment. Regional Transport is required for extended (Spiral 2) and permanent presence (Spiral 3) on Moon, surface area of 38 Million km^2 and for exploration of Mars, surface area of 144 Million km^2.

Major Sub-Capabilities:

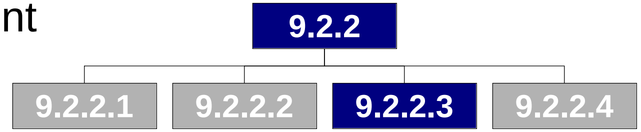
- 9.2.2.3.1 Rapid Transport
- 9.2.2.3.2 Long Duration Transport
- 9.2.2.3.3 Crew Systems

Benefits:

- Provides Crew Safety and enables exploration, and extended and permanent presence on Moon and Mars

General Assessment: Only current deployed system is the Lunar Roving Vehicle which does not meet long duration, long traverse, extreme terrain, rapid transport requirements. Needs significant development

Development Needed: **HIGH**



Drivers:

•Unimproved Surface Conditions regulate maximum speed for wheeled vehicles of 15 km/hr

Assumptions:

•Environmental protection of Crew criticality 1

•Mission must maximize crew productivity – minimal traverse time a priority

•.Missions will include regional distances traversed (500-1000km)

•Sufficient fuel is available for propulsion potentially In-Situ Propellant Production

•Improved surfaces (i.e. roads, railed systems) for travel not within roadmap timeframe

Capability for suborbital mobility or CEV precision landing to pre-identify location required for crew safety and productivity

Description: Capability to quickly transport Crew back to safe haven or base

Examples: Ballistic Hopper, Motorcycle, Improved surface rovers,…

Benefits:

- Safety of Crew
  - Emergency return to safe haven
  - Reduced exposure time to radiation flux
- Increases Crew Productivity

FOM: Transport time <1 hour up to days with advanced SPE warning, Traverse distances of 10km to 1000km; load capacity (Volume, weight, crew size), Size (Volume, weight), Environment Protection

General Assessment: Apollo 17, record of 17 km/hr driving downhill during return trip to the lunar module. Average of 7 km/hr. Non-rechargeable, power system designed maximum traverse of 92km.

Development Needed: **HIGH**

Capability/ Technology	SOA	TRL	Needs	Need TRL 6	Capability Need Date	CRL
9.2.2.3.1 Rapid Transport					**2016**	**1**
Active Stability Control	None	1 - 2	1) Gyroscopic stability control 2) Stored energy/rocket braking 3) Enhancement of existing thruster controls 4) Architecture	2014		
Highly reliable throttleable, restartable, refuelable, high energy density green, bi-propellent propulsion system	Concepts developed, minor component testing	2	1) Selection of propellant type that minimizes weight penalty 2) Propellant storage/creation 3) Refuelling technologies 4) IVHM (Automated/Rapid Launch Sequence)	2013		
Real-Time landing site detection	None	1 - 2	1) Long range terrain definition 2) Automated landing site planning	2016		
Mars Flying Machine	Concepts	1	Propulsion/Aerodynamic system		2030	1

Drivers:

•Unimproved Surface Conditions regulate maximum speed for wheeled vehicles of 15 km/hr

Assumptions:

•Environmental protection of Crew criticality 1

•Mission must maximize crew productivity – minimal traverse time a priority

•.Missions will include regional distances traversed (500-1000km)

•Improved surfaces (i.e. roads, railed systems) for travel not within roadmap timeframe

Capability for robust, autonomous mobility systems required to deploy and preposition safe-havens for crew safety and productivity

Description: Capability to efficiently transport Supplies, Equipment, and possibly Crew

- Examples: Tractor, "RV", Trains……

Benefits: Enables Exploration and Reduces Lander requirements

FOM: Long life, rechargeable systems, 10:1 carrying capacity (payload mass/empty mass), load capacity (Volume, weight), Size (Volume, weight)

General Assessment: The Lunokhod had a life of 3 lunar days (3 earth months) and total mass of 840kg. The LRV had a life of 4 days, and an empty mass of 210 kg and a payload capacity of 490 kg.

Development Needed: **HIGH**

Capability/ Technology	SOA	TRL	Needs	Need TRL 6	Capability Date	CRL
Long Duration Transport					2022	2
Modular, Reconfigurable, rechargeable, long life power systems	LRV: Two non-rechargable independent battery systems; Primary 36 volt, 23 cell, silver-zinc using potassium hydroxide; 0.75 kW; 0.08 Watt-hrs/km-kg for wheeled motion STS: Non-rechargable Fuel Cells; Extended Duration Orbiter with crew use of water;	2	40kW -100kW hybrid, rechargable power system Modular, Plug and Play Architecture and components with common interfaces to allow for spiral growth Cross-Subsystem Synergy - use of reactants for water as a resource and for radiation protection	Architecture - 2010 Components 2015		

Capability/ Technology	**SOA**	**TRL**	**Needs**	**Need TRL 6**	**Capability Date**	**CRL**
Long Duration Transport					2022	2
Thermal Management				2015		
Radiation Protection				2015		
Noise Abatement	Terrestrial standards	2	Improved energy efficient components Noise conscious designs and materials	2015		
Integrated Wireless Network Systems			Virtual Presence Increased capacity	2015		
Compact, low power, digital mixed media devices		2	Devises with the ability to process data and retrieve information during IVAs and EVAs	2015		

Description: Capabilities to safely and reliably support human life for mission duration and Effectively perform IVA and EVA operations

Examples: Self-Contained ECLSS, Limited vs. Full radiation protection, …

Benefits: Safety of Crew and Ability for extended operations and permanent presence

FOM: Replenishable resources for 5-6 Crew, X REM over X days

General Assessment:

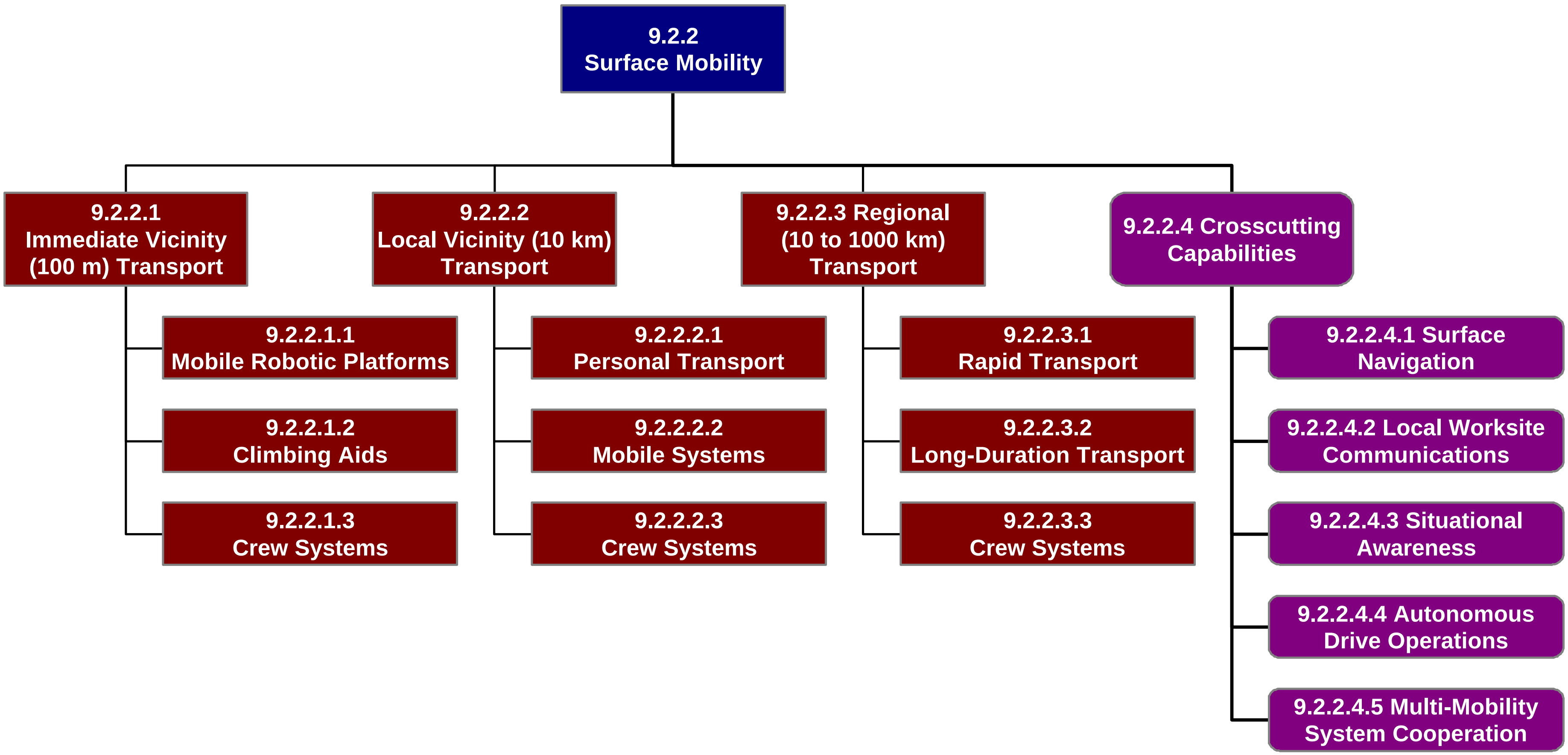
Development Needed: **HIGH**

Capability/ Technology	SOA	TRL	Needs	Need TRL 6	Capability Date	CRL
Crew Systems					2020	2
Robust Consumable EVA Interfaces			Advanced environmentally robust connections Fast re-supply	2015		
SEP Protection	None	2	24 hour response protection Advanced warning system	2015		
Noise Abatement	Terrestrial standards	2	Improved energy efficient components Noise conscious designs and materials	2016		
Integrated Wireless Network Systems			Virtual Presence Increased capacity	2016		
Compact, low power, digital mixed media devices		2	Devises with the ability to process data and retrieve information during IVAs and EVAs	2015		

Capability 9.2.2.4
Surface Mobility: Crosscutting Capabilities

Presenter:

Team Lead


9.2.2
Surface Mobility
9.2.2.1
Immediate Vicinity
(100 m) Transport
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Local Vicinity (10 km)
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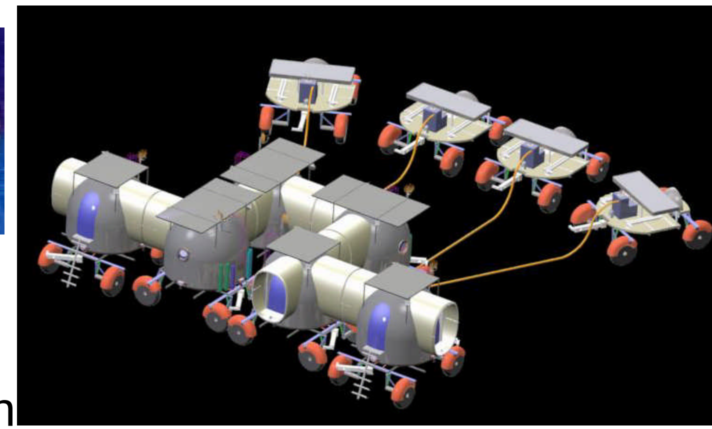
Long-Duration Transport
9.2.2.3.3
Crew Systems
9.2.2.4.1 Surface
Navigation
9.2.2.4.2 Local Worksite
Communications
9.2.2.4.3 Situational
Awareness
9.2.2.4.4 Autonomous
Drive Operations
9.2.2.4.5 Multi-Mobility
System Cooperation

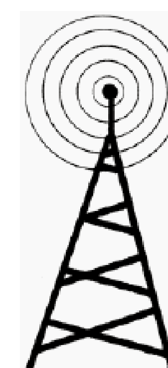
Description: Capabilities that are required to enable successful mission operations across all of the surface mobility elements. Capabilities required do not vary significantly between elements.

Major Sub-Capabilities:

- 9.2.2.4.1 Surface Navigation
- 9.2.2.4.2 Surface Communications
- 9.2.2.4.3 Situational Awareness
- 9.2.2.4.4 Autonomous Drive Operations
- 9.2.2.4.5 Multi-Mobility Systems Cooperation

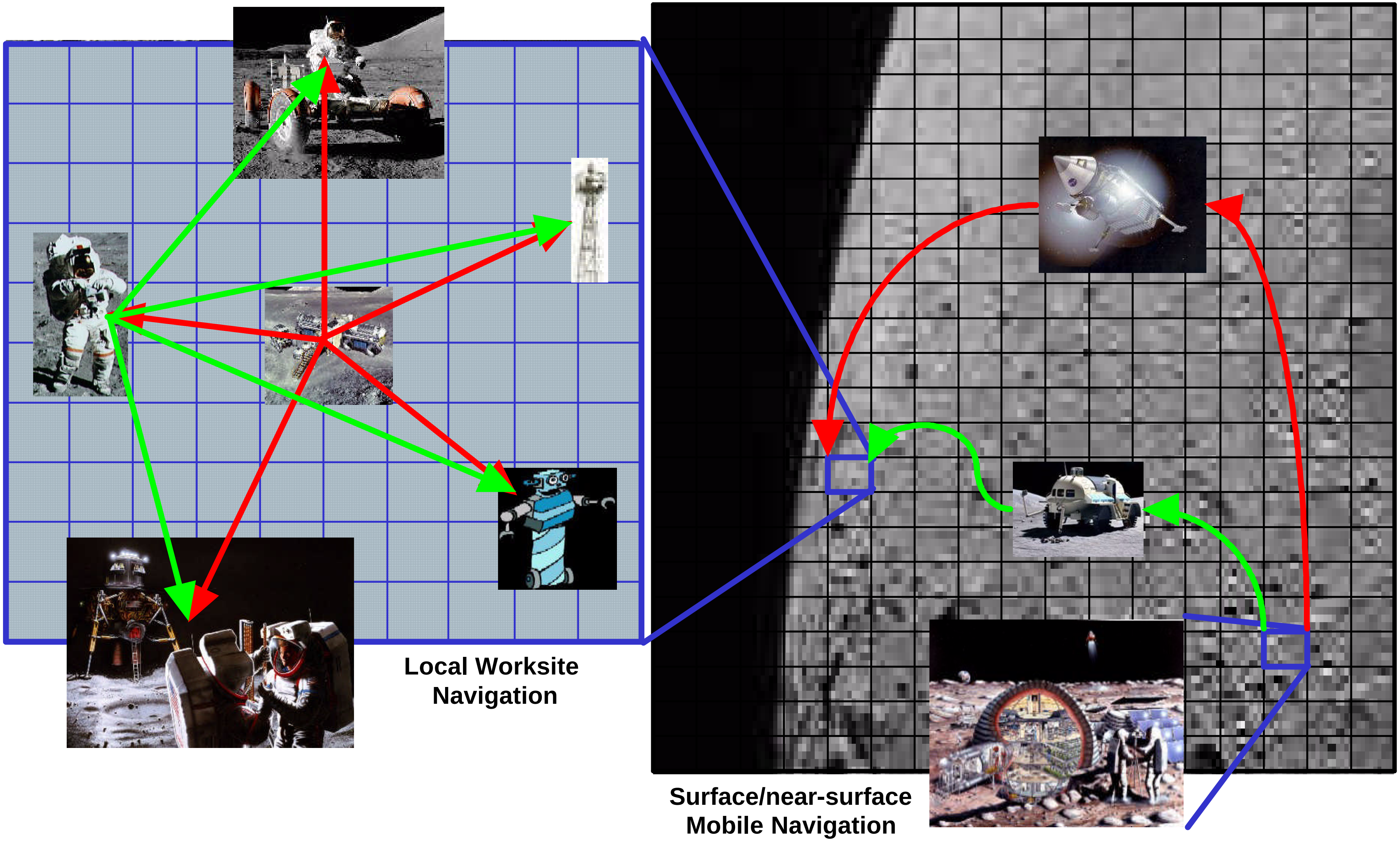


Modular Roving Planetary Habitat, Laboratory, and Base (MORPHLAB) *(2004, University of Maryland)*



Benefits: Provides Crew Safety and Enables Exploration and Extended Presence on Moon and Mars

Development Needed: **HIGH**


Local Worksite
Navigation
Surface/near-surface
Mobile Navigation

Description

- **Provides relative navigational information for personnel and equipment on the surface of the moon (or Mars/other similar body)**

- **Local work site area defined as a range of approximately 1 kilometer from the center of the work site or permanent base**

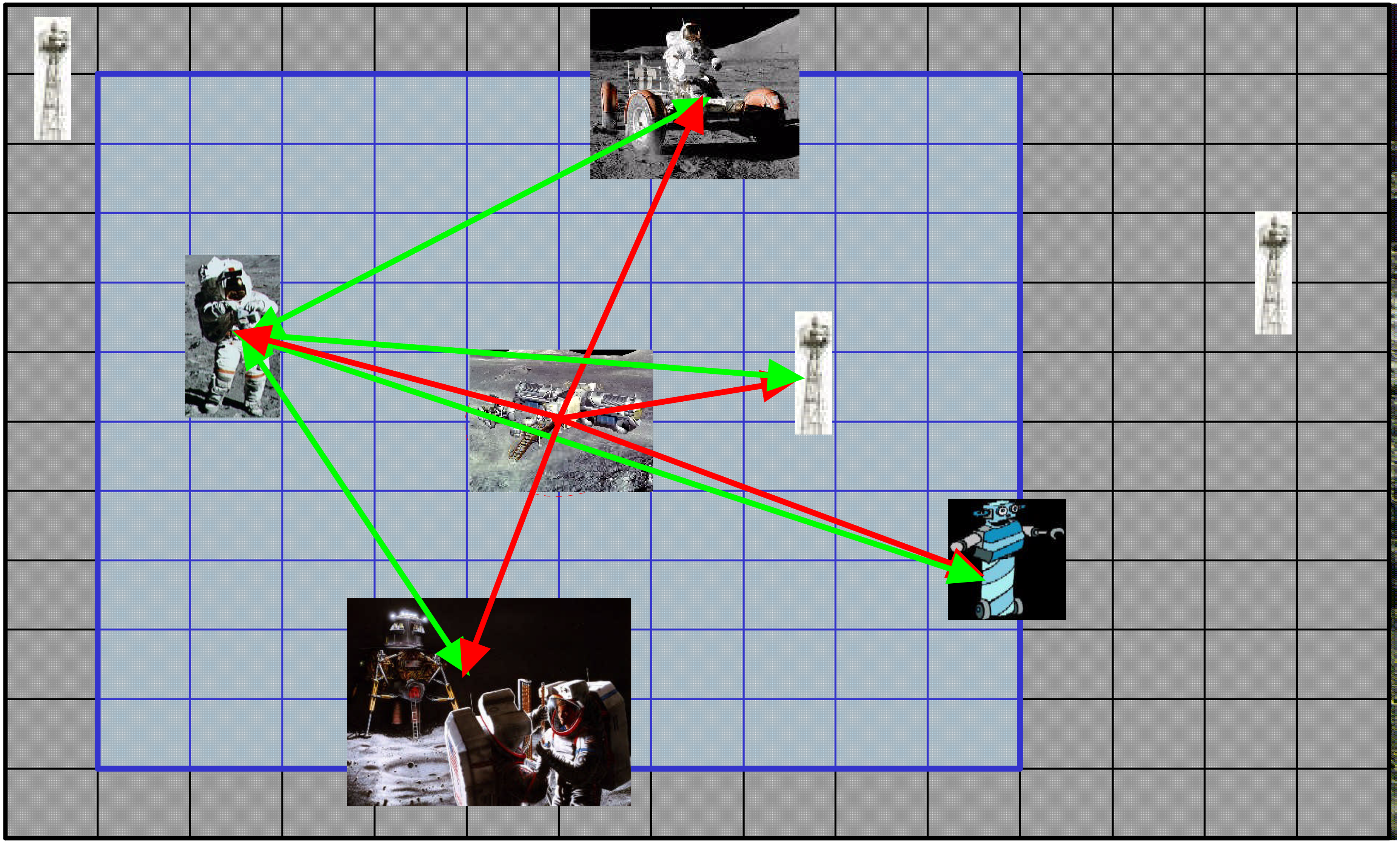
- **Work site personnel and equipment include, but are not limited to, EVA personnel, robots, rovers, surveyed navigational beacons or landmarks, fixed equipment, specimen locations, and local transports.**

- **Provides position, velocity, bearing, and other navigational parameters relative to a local rectangular or similar site grid.**

Lunar or Planetary surface navigation is composed of navigation tasks performed:

- **at local surface worksites (9.2.2.4.1.1),**
- **on vehicles moving along the surface (9.2.2.4.1.2),**
- **on suborbital transports (9.2.2.4.1.2), and**
- **on overhead reconnaissance vehicles (9.2.2.4.1.2).**

Techniques developed during Apollo, Martian, and more recent lunar programs along with current advances in terrestrial hardware and software are a starting point for the required moderate development of surface and near-surface exploration navigation systems.



Benefits

-

- **Enables situational awareness for the personnel and autonomous equipment**

- **Provides the location of the other equipment or personnel with respect to each other and to the work site or the permanent base**

- **Ensures a degree of safety and mission success**

- **For example, EVA personnel or robots can return to the location where a previous specimen was taken for a second sample, or choose a new unexplored specimen location.**

FOM

•**Required one sigma position accuracies, relative to the local grid :**

A) position of fixed equipment, such as recharging stations - 10 meters

B) position of mobile equipment and personnel - 20 meters

C) position of specimen locations, excavation sites and navigation beacons - 5 centimeters

•**D) The local site grid must be matched to local overhead photography within 3 meters (1 sigma).**

•**E) The local site grid must be tied to an inertial coordinate system within an accuracy of 100 meters (1 sigma).**

General Assessment : Existing Earth- and Apollo lunar-surface mapping and nav techniques are a good starting point for development of exploration algorithms. Surface beacons or equivalent need to be developed.

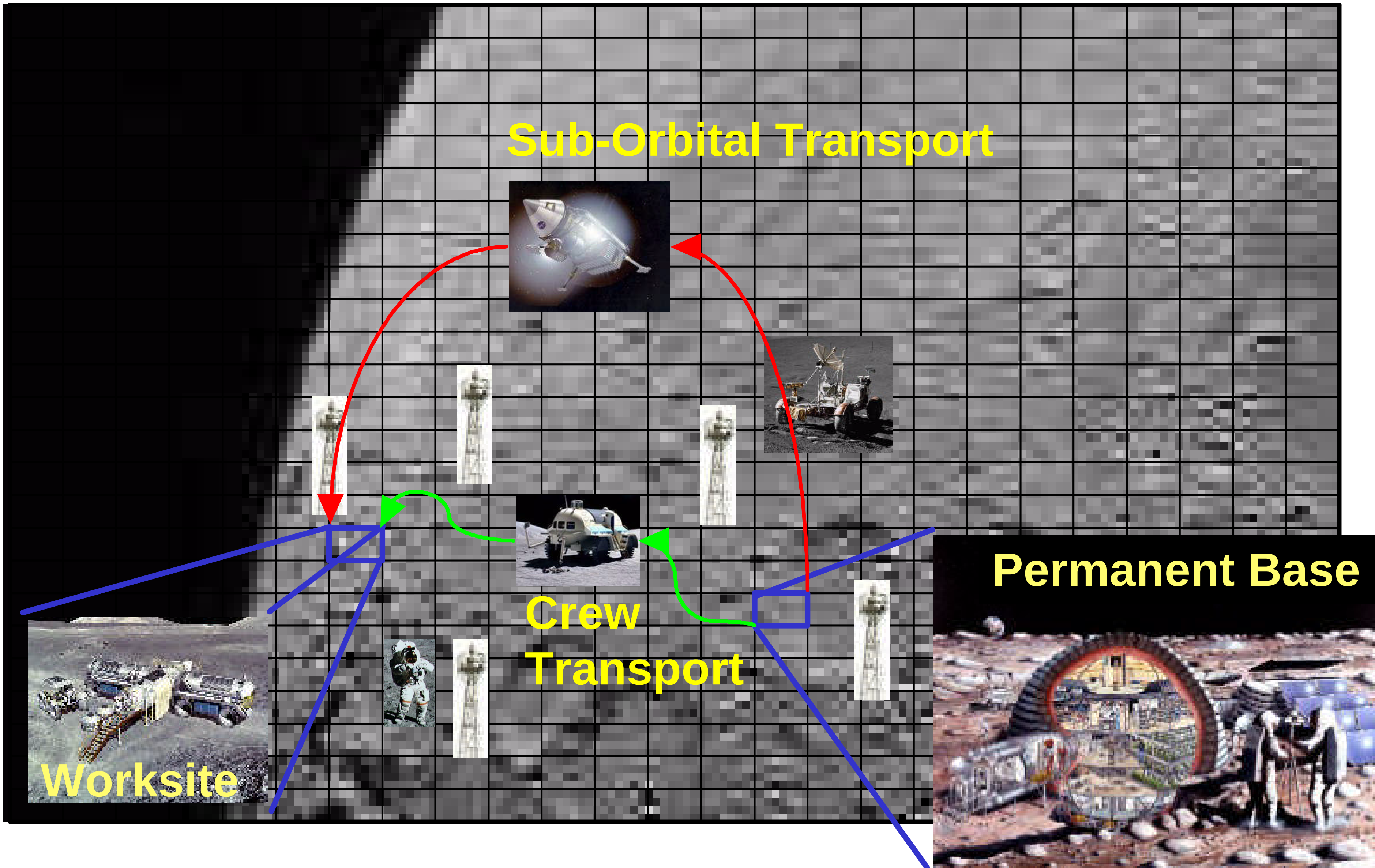
Development Needed : algorithms – A,B, & E Medium; C & D High

hardware – surface beacons High; small nav sets Medium

Capability/ Technology	SOA	TRL	Needs	Need TRL 6	Capab. Date	CRL
Range-bearing Nav/comm beacons or equivalent	TACAN	4	space qualify, combine with comm, less power	2009	2012	2
Fixed equipment relative location system (A)	laser transit	5	space qualify	2008	2010	4
Mobile equipment/crew relative location system (B)	Opt. POSE laser,range from 2-way comm. link	5 5	space qualified, lighter weight, less power	2009	2012	2
Navigation beacon/sample site location system (C)	same as for **(B)**	5 5	same as for **(B)**	2008	2010	2
Calibration of local grid to overhead photography (D)	planetary photometry	7	Explor.-focused space qualified	-	2012	5
Calibration of local grid to inertial coordinates (E)	DSN	8	strong planetary site transmitter	-	2010	5
Surface satellite navigation system	TDRSS, GPS	7	combine with comm. sat., lunar/other qualify	-	2012	5

Description

- Provides both relative and inertial navigational information for personnel and equipment traversing the surface of the moon (or Mars/other similar body)
- The range of operation extends outward from the surface base to distances defined by remote work sites (eventually on the order of several thousand kilometers).
- Personnel and vehicles include but are not limited to pressurized crew transports, unpressurized equipment movers, suborbital transports, aerial reconnaissance vehicles, mobile rovers and robots, and EVA personnel.
- Provides relative position, velocity, bearing, and other navigation parameters with respect to a planet-wide surface grid.
- Provides absolute position, velocity, and other navigation parameters in an inertial coordinate system.


Sub-Orbital Transport
Crew Transport
Permanent Base
Worksite

Benefits

-

•Traversing relative navigation enables personnel and surface mobile equipment to traverse to find their way to remote work sites and to return to a permanent base using some of the same equipment and techniques used for local worksite navigation.

•Both the traversing inertial navigational system and the relative navigational systems enable suborbital or other transports to land close enough to designated sites to accomplish mission objectives safely.

•The inertial navigation allows overflight vehicles to perform required overhead surveys of remote worksites.

FOM

- **Required one sigma position accuracies, of in-transit surface moving vehicles and personnel are:**
  - **100 meters with respect to the planetary surface grid (relative nav)**
  - **350 meters with respect to an inertial coordinate frame (inertial nav)**
- **For sub-orbital transports landing at a surface site and for overhead reconnaissance vehicles, the accuracies one sigma must be:**

  C) 100 meters in position with respect to the site surface grid (relative nav)

  D) 350 meters in position and .35 meters/sec in velocity inertially.

General Assessment : Realtime lunar inertial navigation is challenging due to the anomalous gravity field and the need to develop inertial nav sensors not dependent upon earth-based equipment. Satellites, beacons, and optical sensors are good technical candidates.

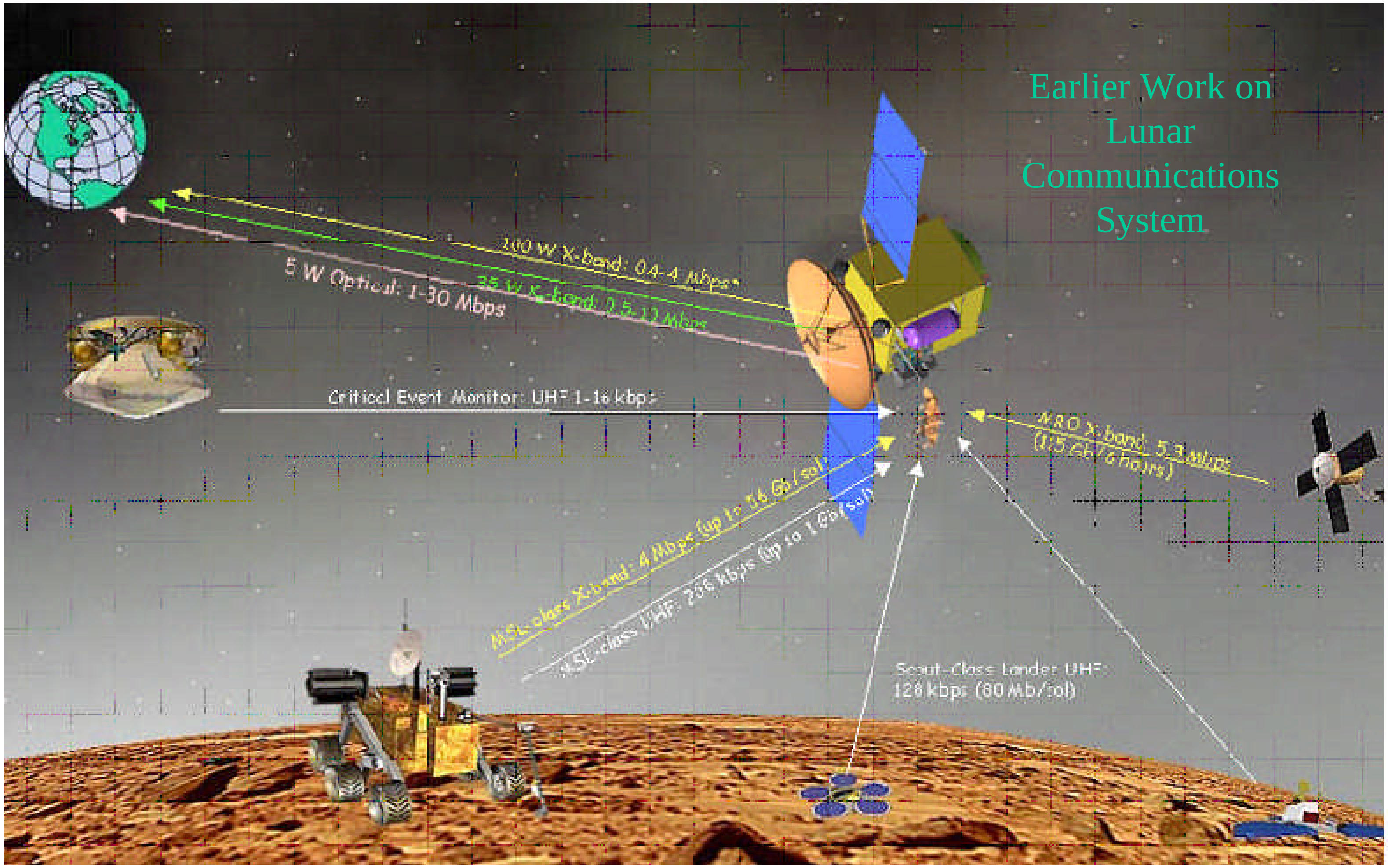
Development Needed : algorithms – A,B,C, & D Medium;

hardware – surface beacons and optical sensors High; satellites & inertial platforms Medium

In work

Capability/ Technology	**SOA**	**TRL**	**Needs**	**Need TRL 6**	**Capability Date**	**CRL**
Range-bearing Nav/comm beacons or equivalent	TACAN	4	space qualify, combine with comm., less power	2009	2012	2
Surface/near-surface beacon relative navigation system	TDRSS, GPS	7	combine with comm. sat., lunar/other qualify	-	2012	5
Surface vehicle inertial platform	In work				2015	
Near-surface inertial navigation system	NSTS onboard navigation	6	Adapt for lunar sub-orbiters, etc.	-	2015	4
Backup surface vehicle nav system	Photometry, wheel-turn counts	5	Near-complete replacement	2012	2015	4
Multi-beacon relative surface navigation algorithms	NSTS TACAN	6	Adapt for expl. vehicles	-	2015	4

Earlier Work on Lunar Communications System



Lunar or Planetary surface communications are composed of communications tasks performed :

- **among elements at local surface worksites, surface bases (9.2.2.4.2.1), and home planet facilities**
- **among vehicles moving along the surface, vehicles in suborbital transport or reconnaissance, surface elements, and home planet facilities (9.2.2.4.2.2).**

Modern operational concepts require significant bandwidths and multipoint communication capabilities.

When practical, communications and navigation can share common equipment.

- **The exploration communications architecture has requirements for:**
  - **an adaptable, high-rate communication backbone infrastructure,**
  - **access links to space and ground networks,**
  - **inter-spacecraft communication links, and**
  - **close range wireless proximity links**
- **Human and robotic endeavors will require a communication infrastructure that:**
  - **can support bi-directional, multiple video, voice, and Internet-like data transfers**
  - **will enable simultaneous communications among local work site personnel and equipment, a planetary base, orbiting facilities and Earth-based control centers.**
- **When feasible, planetary orbital satellites will be deployed to aid in both communications and navigation.**

Description

- Provides voice, video and data communications among personnel and equipment at a worksite on surface of the moon (or Mars/other similar body)

- Local work site area defined as a range of approximately 1 kilometer from the center of the work site or permanent base.

- Work site personnel and equipment include, but are not limited to, EVA personnel, robots, rovers, fixed equipment, local transports, and habitats.

- Provides communications between worksite elements, surface bases, and home planet facilities

Description, continued

- **Provides two-way voice and live high-resolution, compressible video (CHDTV) between each EVA crew person and the surface base**

- **Provides two-way voice and live video among EVA personnel**

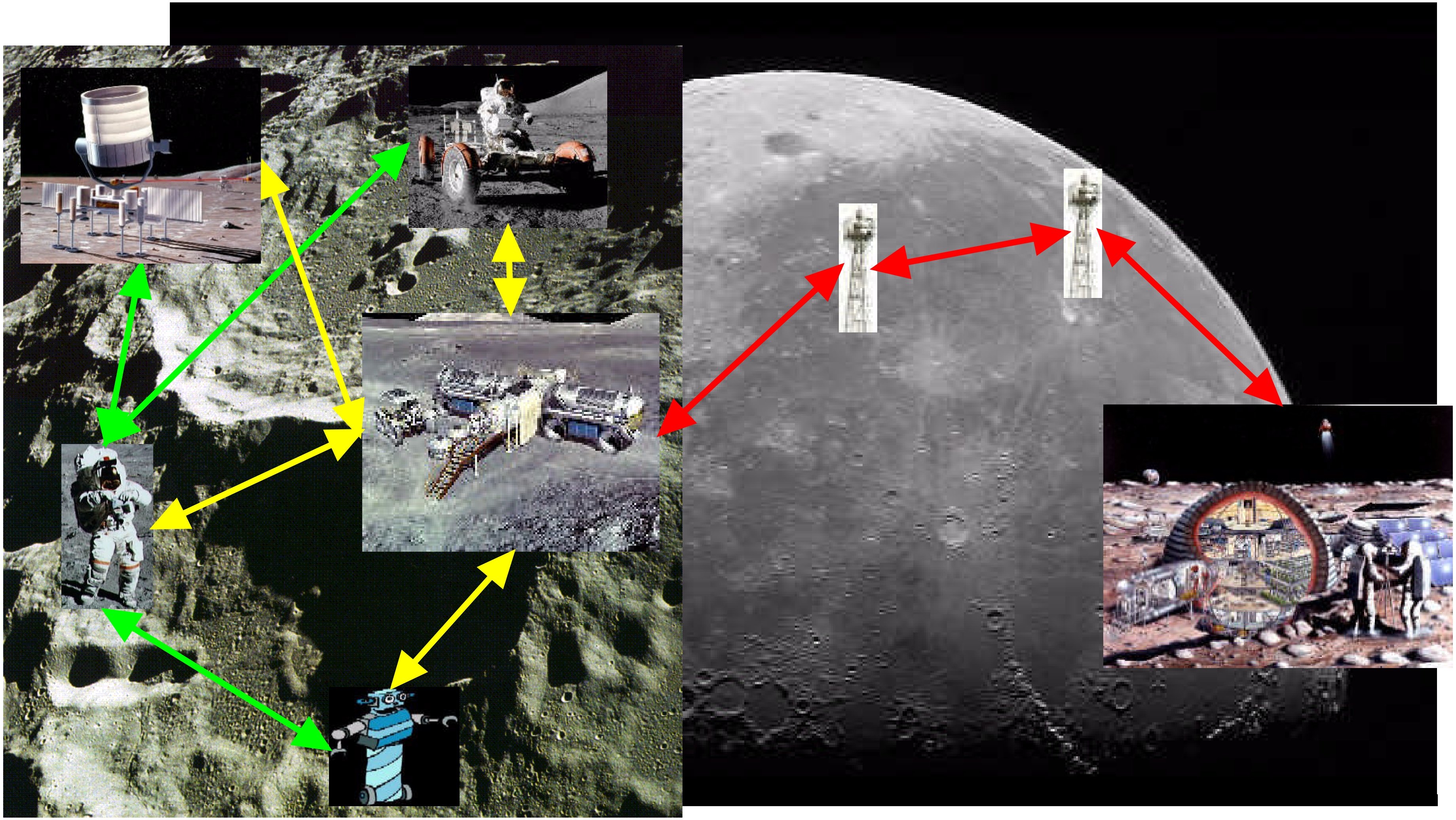
- **Provides live high-resolution video from each crew person and robot to the surface base and to Earth (can be relayed through surface base)**

- **Provides bandwidth of sufficient width to send instructional photographs, data/command, and videos from the surface base to each EVA person**

- **Provide substantial two-way data/command transfer among EVA personnel and local robots**

Benefits

- **EVA crew will able to execute procedures using up-to-date textual and visual information sent by elements external to the site.**
- **Enables local crew to perform coordinated tasks via exchange information exchange with each other.**
- **EVA time is saved using information retrieval and interchange.**
- **Enables crew to monitor and control robotic rovers and platforms**
- **Surface-based and Earth-based based personnel will able to provide operations support as needed.**
- **Improves crew morale through family email connectivity, etc.**
- **Ensures a degree of safety and mission success**



FOM Required total bandwidths (Megabits/sec) & Video Resolution

From / To	EVA Person	Site Base & Remote Base	Robot	Fixed Equipment	Surface Vehicles	Earth
EVA Person	1 scalable	10 CHDTV	1 CHDTV	0.2 scalable	1 CHDTV	n/a
Site Base & Remote Base	10 CHDTV	10 CHDTV	10 CHDTV	10 CHDTV	1 CHDTV	100 CHDTV
Robot	0.2 n/a	1 n/a	2 n/a	n/a n/a	0.2 n/a	10 n/a
Fixed Equipment	0.2 n/a	10 n/a	n/a n/a	n/a n/a	0.2 n/a	0.2 n/a
Surface Vehicles	1 scalable	1 CHDTV	1 CHDTV	1 scalable	1 CHDTV	1 CHDTV
Earth	n/a	100 CHDTV	1 CHDTV	n/a	1 CHDTV	n/a n/a

FOM (continued): **Communications among local worksite elements must not require line-of-sight clearance.**

General Assessment : In the 40 years since Apollo, communications technologies have improved dramatically. The ability to transfer megabits of information on Earth is near trivial. The greatest challenge on the lunar surface will be to communications over the horizon and to develop space-qualified equipment.

For more challenges, see assessment under 9.2.2.4.2.2.

Development Needed :

hardware – surface beacons High; satellites & other Medium

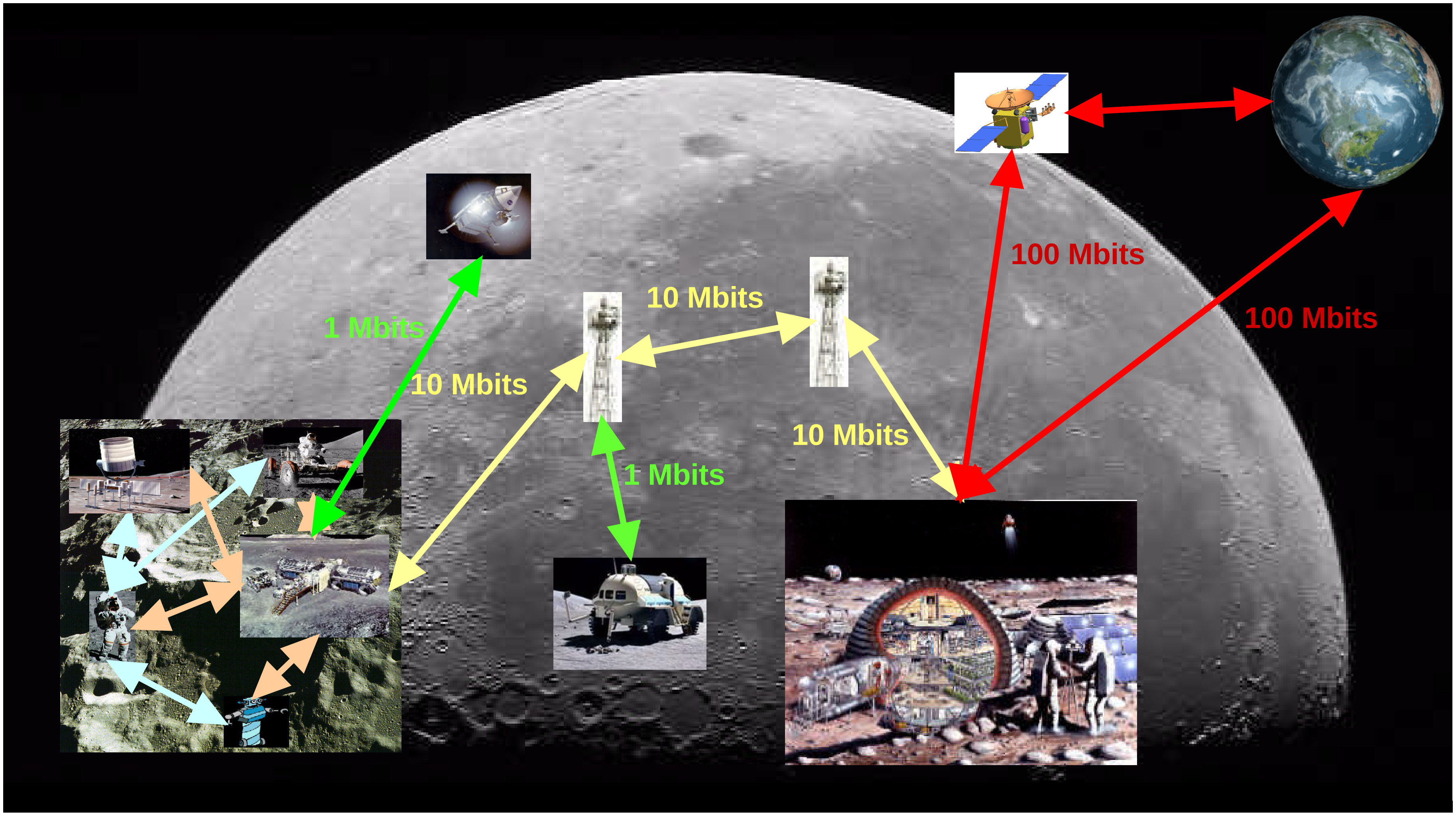
Description

Provides voice, video and data communications among vehicles moving along the surface, vehicles in suborbital transport or reconnaissance, surface elements, and home planet facilities

Benefits

Enables traversing vehicles and crew to:

- **receive procedures, maps, systems’ data from surface bases and home planet facilities,**
- **perform coordinated tasks via exchange information exchange with each other, and**
- **have full command and control of robotic rovers, platforms, and stationary equipment.**



100 Mbits
100 Mbits
1 Mbits
10 Mbits
10 Mbits
10 Mbits
1 Mbits

FOM **Required total bandwidths (Megabits/sec) & Video Resolution**

From / To	Surface Vehicles	Sub-orbital Transports	Mobile Robots	Site Base, Remote Base, & Earth	Reconnaissance Vehicles	Fixed Equipment
Surface Vehicles	1 CHDTV	1 CHDTV	1 CHDTV	1 CHDTV	1 CHDTV	1 scalable
Sub-orbital Transports	0.2 low	0.2 n/a	1 CHDTV	1 CHDTV	n/a n/a	0.2 low
Mobile Robots	0.2 n/a	n/a n/a	2 n/a	2 n/a	n/a n/a	n/a n/a
Site Base, Remote Base, & Earth	1 CHDTV	1 CHDTV	1 CHDTV	100 CHDTV	10 CHDTV	10 CHDTV
Reconnaissance Vehicles	0.2 n/a	n/a n/a	n/a n/a	0.2 n/a	n/a n/a	n/a n/a
Fixed Equipment	0.2 n/a	0.2 n/a	n/a n/a	0.2 n/a	n/a n/a	n/a n/a

General Assessment :

- Significant communication capabilities between the moon and the moon must be replaced.

- Past-used equipment is:
  - old,
  - doesn’t use current protocols,
  - Is not web –compatible, and
  - mostly inoperative.

Development Needed :

hardware – surface beacons High; satellites & other Medium

Capability/ Technology	SOA	TRL	Needs	Need TRL 6	Cap. date	CRL
Combined nav. & communications 10MBPS surface beacons	currently separate: A) TACAN, B) 300 kbps cell phone relays	3	Development of dual-use deployable low surface beacons	2011	2014	2
Low mass 3DHD cameras	surveillance personal cameras, Soni full concept 3DHD prototype	9 5	Add funding to full-concept 3DHD cameras	2009	2012	4
Crew/robot/Mobile transmitter/recv./ant.	surveillance personal rf devices	4	I MBPS, low mass, space qualify, 2 km range	2009	2012	2
100 MPBS bandwidth transmitter/recv.	1MBS DSN	2	space qualify	2012	2015	2
100 MPBS antenna	1MBS	2	Surface deployable, space qualify	2012	2015	2
Dual use Navigation & Communications Planetary Satellite	TDRSS, GPS, military laser based relays, JAXA laser satellite system in development	5	Development of dual use easily deployable satellite	2013	2016	4

Description: Capability to accurately and efficiently identify surrounding environment

- Examples: Illumination, Visualization,…

Benefits: Safety of Crew, reliable operations and mission success

FOM: X Lumens/watt, X feature identification, X bandwidth

General Assessment: LRV utilized visuals by astronauts to anchor position, Nav system accurate to 100 m

Development Need: low

Capability/ Technology	SOA	TRL	Needs	Need TRL 6	Capability Date	CRL
Situational Awareness						2021
Advanced Display Mediums		2-4	1)HMDs 2)Projectors 3) 3-D models 4)Holodecks	2019		
Advanced Processors		3	1) Graphics and CPU Intensive 2) Low Processing and graphics	2019		
High Smart Efficient Lighting	Fluorescent:91 Lumens/watt LED: 2700 Lumens/watt	4	1)Long life, low power, high lumens/watt lighting 2) Intelligent Lighting Control	2020		
Advanced Sensors		3	IR	2020		
Visualizing surrounding environement	HTDV, low power button cameras	2-3	Advanced Cameras 2) Synthetic Vision RT 3D modeling Ladar based systems Stereo based vision systems	2018		

Description: Capability to autonomously navigate and move the mobility system to mission destination. Capability includes override and hybrid drive options.

- Examples: Direct Control….Complete Autonomy

Benefits: Increased Crew Productivity, equipment reuse, decrease program costs, potential safety uses

FOM: Average of 2km/hr during autonomous drive operation, Autonomous navigation for X km, X roughness, X depth

General Assessment: Current SOA includes tele-operated systems. The Lunokhod traveled 11 km over 10 months and 37 km over 4 months. Mars exploration rovers are semi-autonomous operated. Full autonomy currently unavailable.

Development Need: HIGH

Capability/ Technology	SOA	TRL	Needs	Need TRL 6	Capability Date	CRL
Autonomous Drive Operations					2022	1
Automated Local Terrain detections	LRV: Human Visual System	2	Long and short range imaging and processing	2016		
Collision Avoidance	Manual spaced-based systems automated terrestrial-based systems	3	Long and short range imaging and processing Ability to alert and take steps to safe	2015		
Point to Point Navigation	1km/command; 1km/hour	2	GPS-like system for the moon	2015		
Automated Path Planning	Currently performed by humans	2	Sufficient mapping from survelliance	2015		

Description: Capability to have separate mobility systems that can combine and share resources and loads at and between mission destinations.

- Examples: Hierarchical Control, Shared/Learned Control, Shared resources & spares,…

Benefits: Allows “System of Mobility Systems” to be optimized to reduce mass, increase safety, and increase scientific returns.

FOM: % commonality, Position tolerance of X given surface level of x and X size obstacles

General Assessment: No automated mobility system-system cooperation. Deep Space Network has a complex schedule process to share its utilization among the 28 spacecraft

Development Need: HIGH

Capability/ Technology	**SOA**	**TRL**	**Needs**	**Need TRL 6**	**Capability Date**	**CRL**
Multi-mobility System Cooperation					2022	1
Common System Architecture	Avionics and diagnostic packages for FCF	6	1) Ability to plug and play components 2) Standard Interface connections	2014		
Resource sharing	Within system hardware redundancy	2	Ability to intelligently share resources across mobility systems and elements	2015		
Autonomous Control of docking and hookup	None for space, Terrestrial	1	Ability to mate mobility elements autonomously. Automated resource connections and verification of connection	2015		