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Human Planetary Landing System (HPLS) Capability Roadmap NRC Progress Review

Rob Manning - NASA Chair
Dr. Harrison Schmitt - External Chair
Claude Graves - NASA Deputy Chair

May 4, 2005

Agenda

- Capability Roadmap Team
- Capability Description, Scope and Capability Breakdown Structure
- Benefits of the HPLS
- Roadmap Process and Approach
- Current State-of-the-Art, Assumptions and Key Requirements
- Top Level HPLS Roadmap
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  - 2.0 "AEDL" System Engineering
  - 3.0 Communication & Navigation Systems
  - 4.0 Hypersonic Systems
  - 5.0 Super to Subsonic Decelerator Systems
  - 6.0/7.0/8.0 Terminal Descent and Landing Systems
  - 9.0 A Priori In-Situ Mars Observations
  - 10.0 AEDL Analysis, Test and Validation Infrastructure
- Capability Technical Challenges
- Capability Connection Points to other Roadmaps/Crosswalks
- Summary of Top Level Capability
- Forward Work

Capability Roadmap Team

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Capability Description

- Safely deliver human-scale piloted and unpiloted systems to the surface of Moon & Mars.
- Safely deliver human-scale piloted systems to the surface of Earth from a return from Mars & Moon.

Capability Breakdown Structure

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Human Planetary Landing Systems CRM # 7

- AEDL Human Mission Drivers 1.0
- AEDL Systems Engineering 2.0
- AEDL Communication & Navigation 3.0
- Hypersonic Systems 4.0
- Supersonic Decelerators 5.0
- Terminal Descent & Landing 6.0
- A Priori Mars Observations 9.0
- AEDL Analysis & Validation Infrastructure 10.0

Benefits of the HPLS CRM

- This roadmap defines a potentially realizable “master plan” for developing the capability to deliver the first cargo & piloted flights to the surface of Mars by 2032 with a “reasonable” mass starting at LEO.
  - This CRM defines the initial as well as long-term milestones needed achieve that goal.
  - This roadmap was developed by consensus of many (majority) of the AEDL community within and outside of NASA.
  - This roadmap is consistent with the “The Vision for Space Exploration February 2004”
- With the development of aero-assisted Mars landing conceivably, the landed payload mass fraction from LEO is between 5 - 10x.
  - Compare with 70x from LEO for all propulsive landing on Mars.
- However, there is NO known Aerocapture/EDL conceptual design in existence today that has the ability to safely deliver human scale missions to Mars.
  - Significant work remains to determine which “system of systems” will be able to do the job. There are many options and no clear winners.
- This roadmap asserts that in order to achieve the first human scale missions to the surface of Mars (piloted or not) as early as 2032, near term work must begin with little delay.

Roadmap Process and Approach

- Three well attended workshops:
  - Workshop #1: Dec 2004 at JPL & Caltech
  - Workshop #2: Jan 2005 at NASA ARC
  - Workshop #3: Feb 2005 at NASA JSC
- A large fraction of the US EDL community was present.
  30 - 50 attendees from around the US.
- We asked:
  - Can we create an AEDL capability roadmap that provides a clear pathway to the needed capability?
  - Can we establish capability roadmaps that have appropriate connection points to each other?
  - Can technology maturity levels be accurately conveyed and used?
  - What are proper metrics for measuring the advancement of technical maturity?
- We then started at the "end" and worked backward to today.
  - The "end" here was the first Human scale Mars missions in early to mid 2030's.
  - We tried to keep the "critical path" as short as possible, but it still required some movement to the right.
- We then discussed how we intend to retire the risks of this system as expeditiously as possible.
  - First working backwards from a human landing mission in 2032
  - Then defining the full scale system qualification test program (at Earth)
  - Then defining the *scaled* model validation test flights (at Mars)
  - Then defining the methodology to figure out how to *determine* what the full scale mission would look like so that it can be scaled for the model validation test flights.
  - Very quickly we get from 2032 to 2006.

Current State-of-the-Art for HPLS

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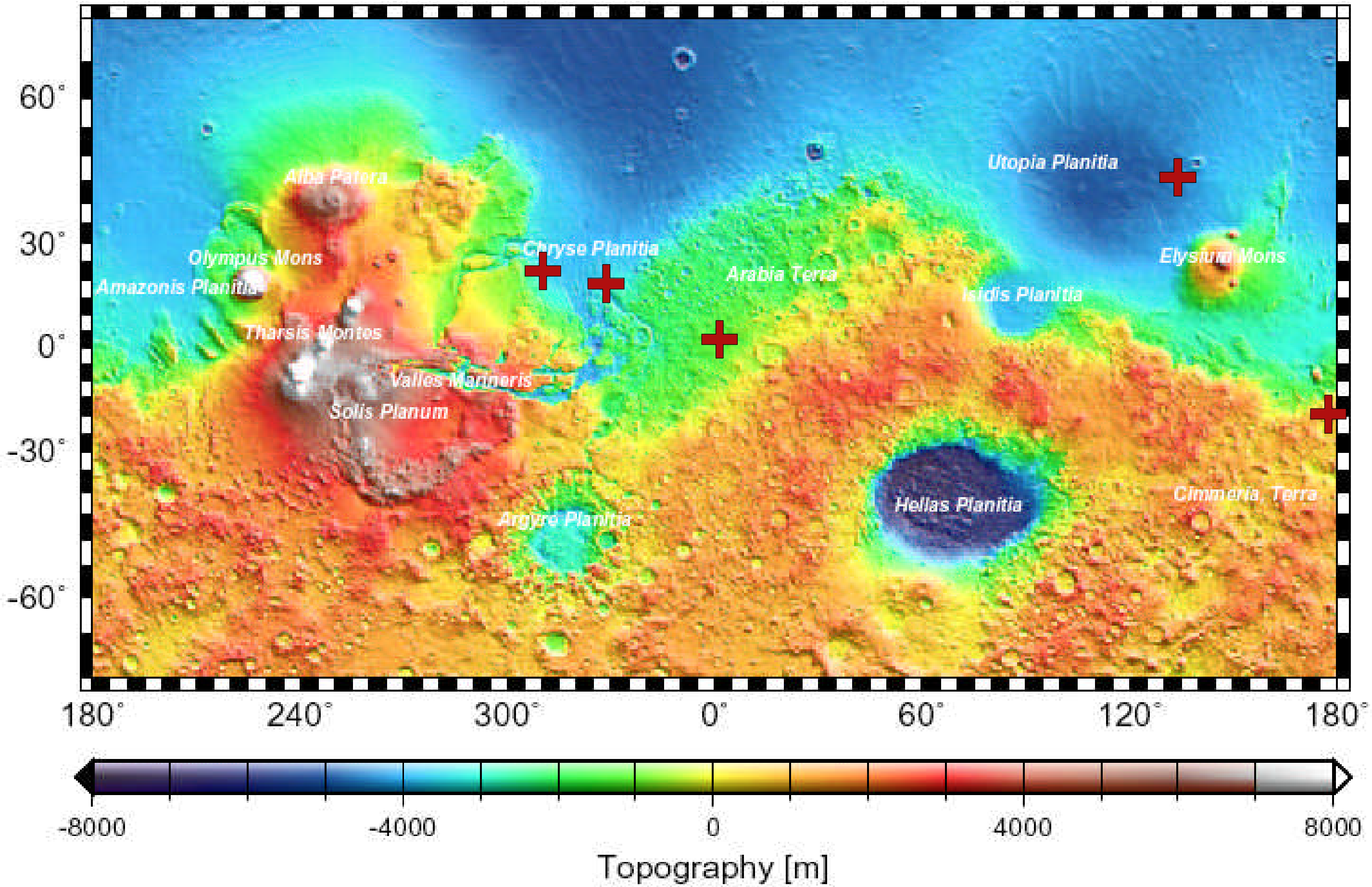
- So far the largest systems to land safely on Mars were the 2 Viking landers and the 2 MER rovers (<600 kg).
- Today NASA has "working" DESIGNS for robotic vehicles with landed mass up to about 1300 kg. These designs are expected to be realized in 2011.
- Unfortunately the EDL of recent landed missions (MER) is two orders of magnitude smaller than what is needed for human scale systems.
  - The "lightest" of the human scale systems is 45-65 MT.
- Simple scaling of the systems used to land today's robotic systems does not result in physically realizable systems.
- Shuttle provides somewhat of a model (especially for some aspects of human performance, interaction and safety systems), but it falls far far short as a relevant delivery system for Mars.
- Surprisingly, the state of knowledge of human EDL performance is very poor - this may have large consequences on the resulting system and mission designs.

Mars Landing History add moon

There have only been five successful landings on Mars

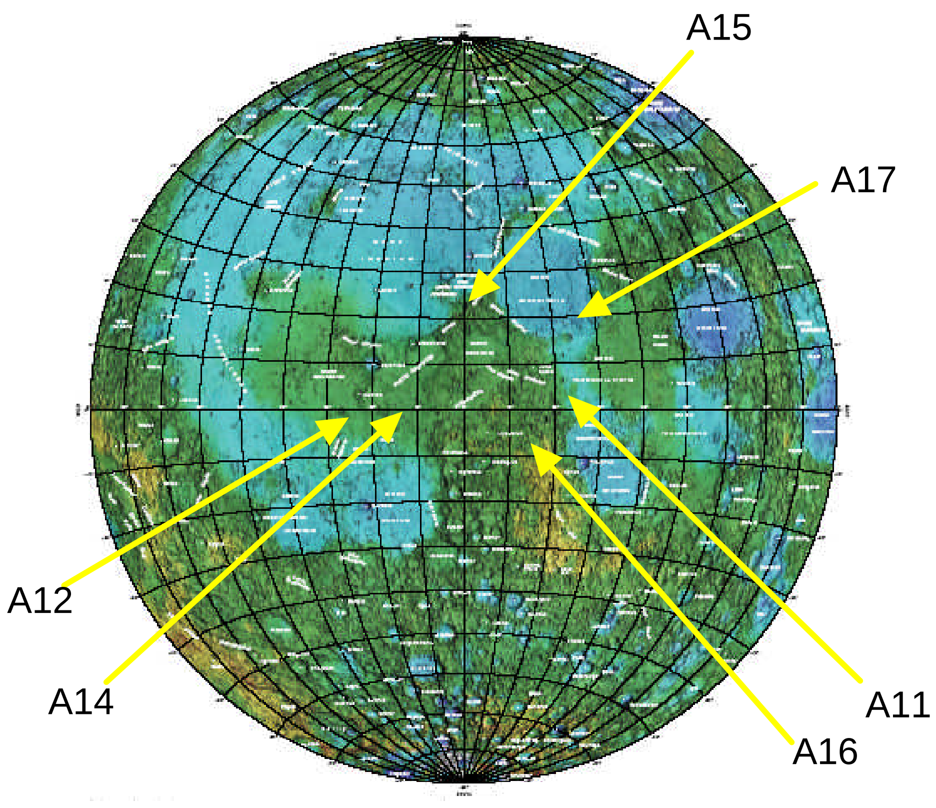
- 2 Viking landing in ‘76, 1 Mars Pathfinder in ‘97, 2 MER in ‘04
- There have been at least as many failures

These systems had touchdown masses < 0.6 MT



Lunar Landing History

- 6 Apollo (US) Lunar landings
- 7 Luna (Russian) Lunar landings
- 5 Surveyor (US) Lunar landings



Near Side

Where are we now with Mars Landers?

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We are presently attempting to develop systems that deliver 1-2 MT for Mars Sample Return and for the Mars Precursor Surface missions.

The next step is across an ocean!

- **We will need to develop AEDL systems that can get 30-60 MT down to surface per landing.**

Will these human scale AEDL systems look anything like today's robotic landers?

Probably not.

Moon and Mars Compared

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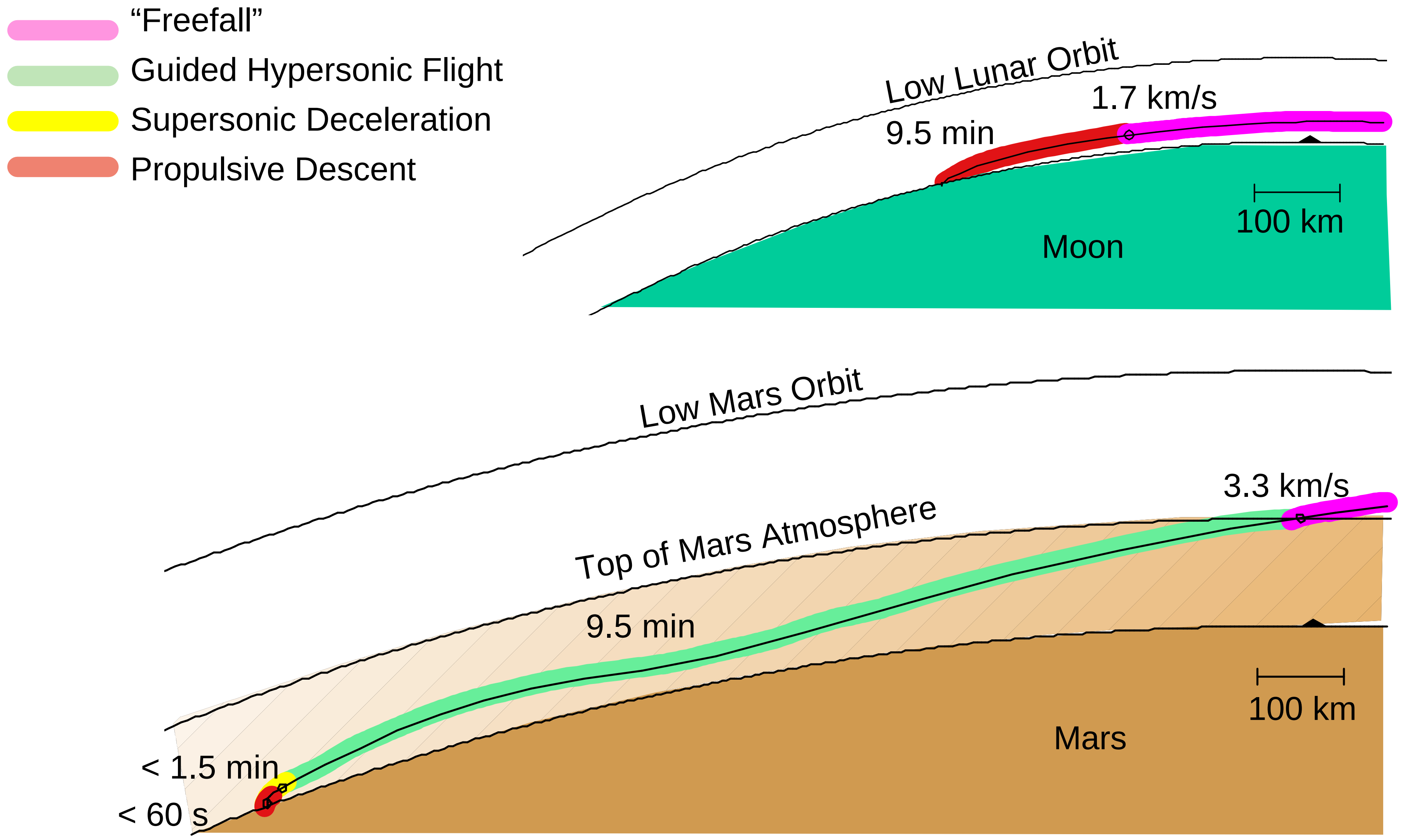
Flight Dynamics Differences:

- **Moon: Ballistic "entry" followed by long (11 min) propulsive descent to surface**
    - Start terminal descent burn around 18 km at 1.7 km/s
- **Why can't we do the same at Mars?**
    - Higher entry velocity at Mars by 2x (larger gravity)
    - Atmosphere starts high up (>100 km)
    - Need aero-thermal protection at these speeds
        - prevents melting
        - Results in complex aerodynamics & large forces (this is handy)
        - Likely need to "disrobe" aero-thermal protection < 8 km above ground
    - Natural variations (density & winds) in the atmosphere strongly perturb the system (much worse than the gravity variations at the moon).
        - System needs to muscle through these uncertainties

Human System Flight Dynamics Differences:

- **Greater need to "architect system around the "human system"**
    - Need to ensure that hypersonic and other decelerators do not disable pilots.
    - Human capabilities reduced by journey to Mars
    - Much faster and more dramatic transformations - challenge to find safe means to enable the pilots to add reliability to the system.

Moon Landing vs Mars Landing (to Scale)



The Mars Atmosphere is a Harsh Mistress

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- Too much atmosphere to land like we do on the Moon
  - Aero-heating, winds, density variations & fuel ruin it.
- Too little atmosphere to land like we do at Earth
  - With 1% of Earth, imagine landing the Shuttle at 100,000 ft.

- But we absolutely need the atmosphere so that we are not forced into unreasonably large masses in LEO.
  - With traditional propulsion and NO aerodynamic assistance from Mars, for every 1 MT on Mars surface we would need 70 MT in LEO !
  - With traditional propulsion and high performance aero-assistance at Mars, for every 1 MT on Mars surface we need only 5-6 MT in LEO.

- That is the promise, but will it work?
  - So far no feasible Human scale AEDL system has been found
  - But there are promising ideas that need assessment and testing.
  - We need a roadmap to guide us to the answers and the systems.

Requirements & DRM Sources for HPLS CRM

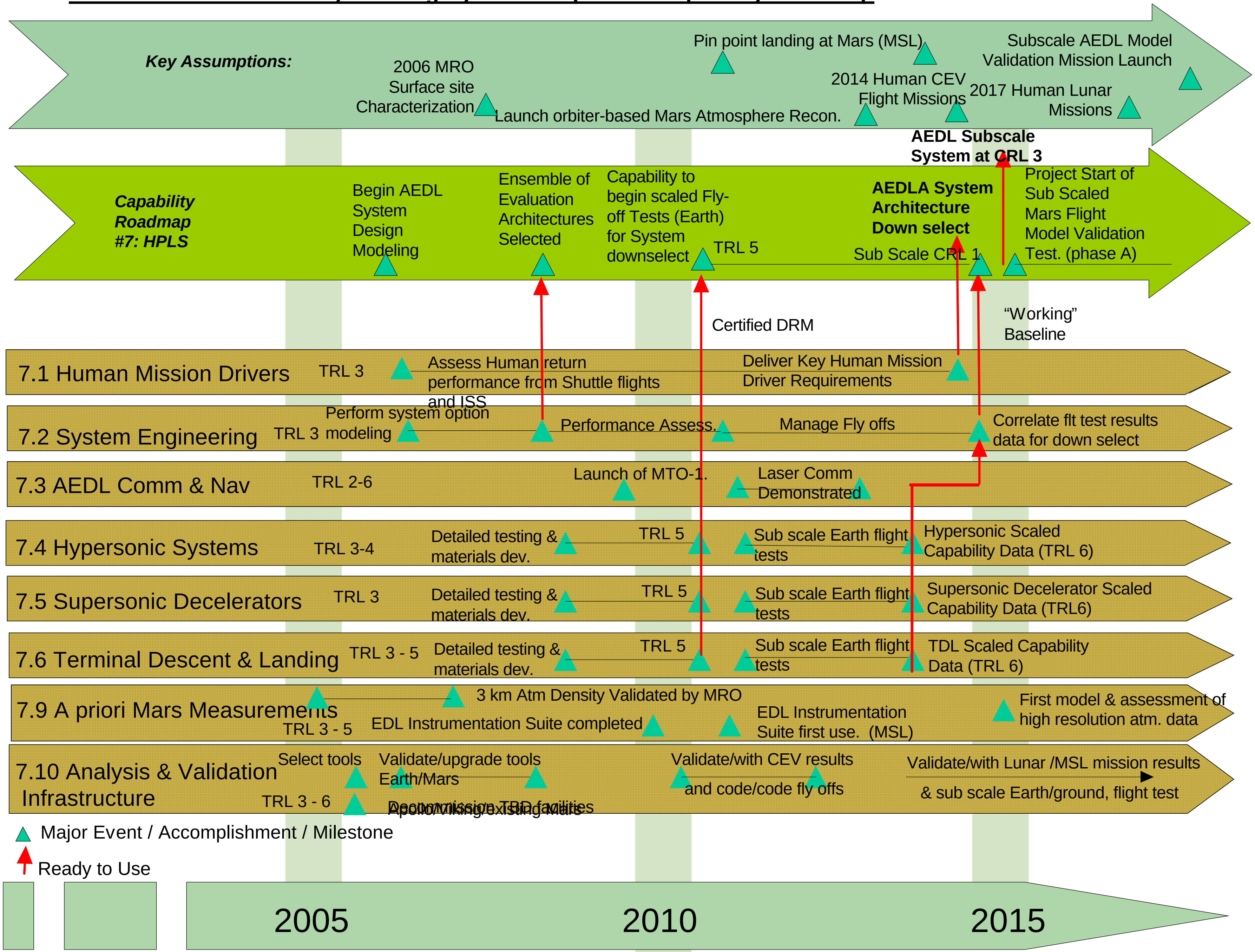
- Fortunately there is a wealth of design framework and reference mission designs to base the AEDL system on.
  - NASA Publication 6107 (Mars Design Reference Mission 1997)
  - DRM 3.0 (update to 6107)
  - JSC Dual Lander Study

- Many common aspect and requirements.   E.g.
  - 40-80 MT landing mass
  - Large volume (e.g. return ascent vehicle fuel tanks)
  - Aerocapture from high-speed Mars transfer orbit
  - “Abort to Surface” abort mode (vs Apollo’s “abort to orbit”)
  - High speed direct or aerocapture back into Earth orbit.

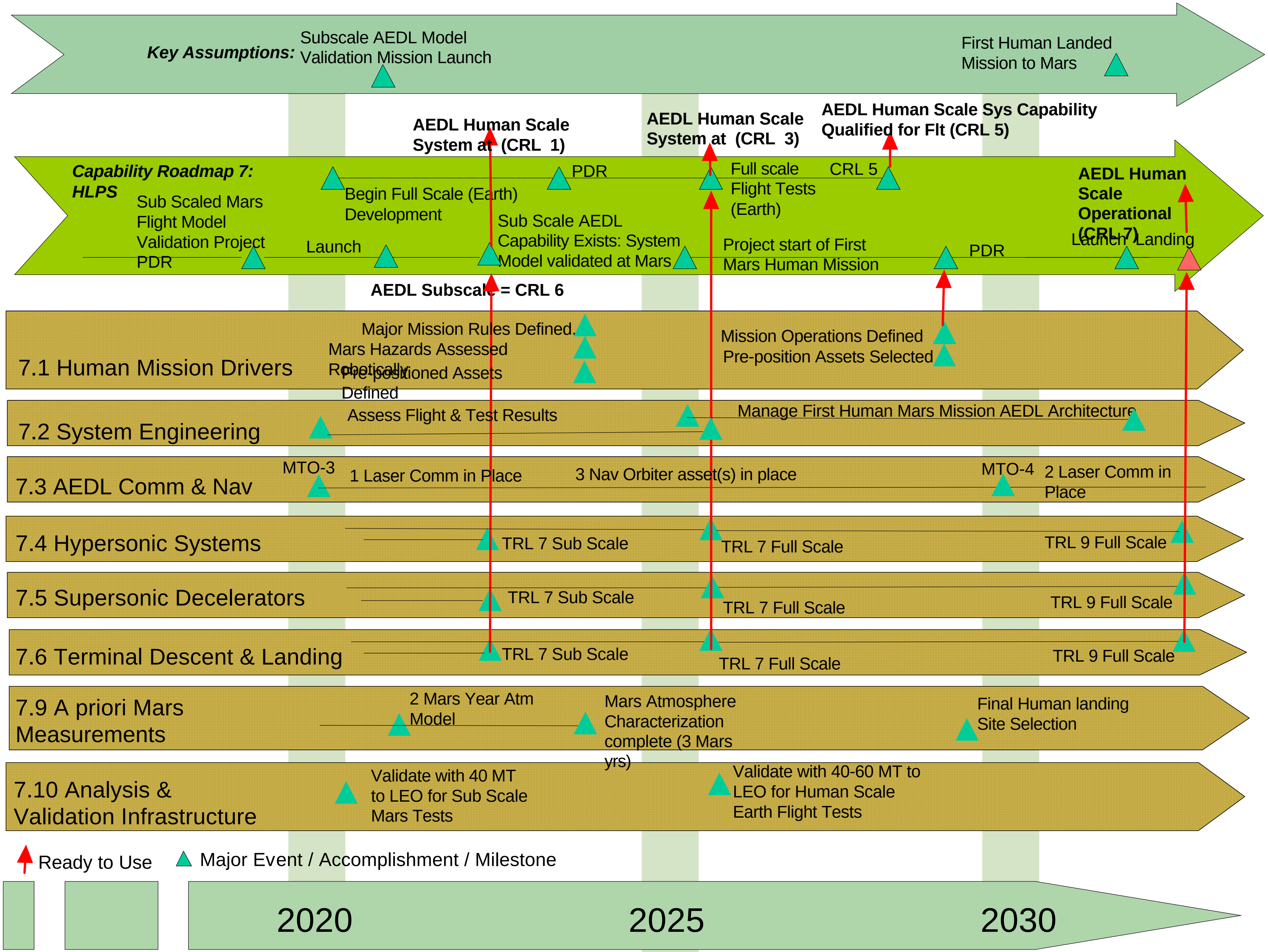
Key Assumptions for HPLS CRM

- Ongoing programs will “solve” some problems.
  - Robotic Mars Program:
    - Navigation (GPS-like & terrain relative) system designs (if not assets) to enable pin point landing.
    - Will acquire surface reconnaissance and multi-Mars year atmosphere density & wind monitoring to reduce model uncertainty.
    - Will acquire in-situ atmosphere & aero data to perform model validation of atmosphere and aero-database from robotic landings.
  - CEV/Moon Program:
    - Will develop large (but 1/4 scale) descent engine useful at Mars.
    - May develop large instrumented aeroentry earth return systems useful at Mars.
    - Will develop terminal guidance / human interactive landing & touchdown systems for terminal phase pin point landing.
  - ISS/Shuttle
    - Will begin astronaut post-landed test program to assess post gee crew performance.

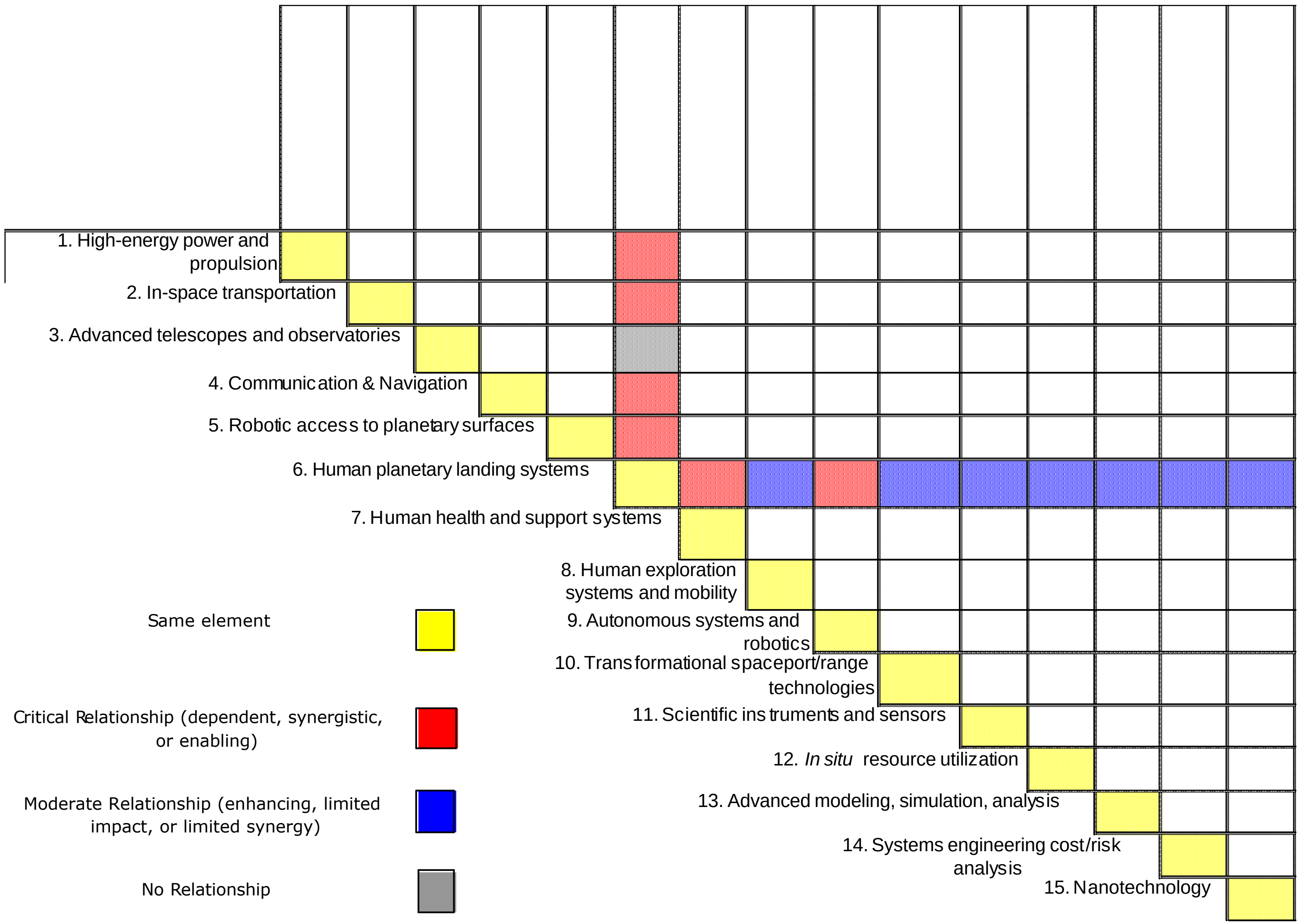
Team 7: Human Planetary Landing Systems Top Level Capability Roadmap



Team 7: Human Planetary Landing Systems Top Level Capability Roadmap



HPLS CRM Crosswalk



Examples of Crosswalk Data

5. Robotic access to planetary surfaces		6. Human planetary landing systems	
Entry: Hypervelocity Transit	⟺	Hypersonic Entry/AeroCapture Aerothermal TPS Systems	Robotic Entry methods may be applied to Human Entry
Descent	⟺	Transonic decelerators	Robotic Descent methods may be applied to Human Descent
Landing	⟺	Terminal Descent Propulsion Touchdown Systems Terrain Relative Sensing	Robotic Landing methods may be applied to Human landing
Observations	⟺	Observations	Orbital reconnaissance requirements for surface site characterization and atmospheric characterization. Precursor surface-mission engineering observational requirements (meteorology, dust characterization, TPS/parachute performance).
Entry, Descent & Landing	⟺	Robotic-human interactions	Human interaction with Robotic systems during EDL
Navigation- Beacons & Orbital Assets	⟺	Communications and Navigation Infrastructure	Common assets can be shared for navigation
Extreme Environment Avionics	⟺	Hypersonic Entry/AeroCapture Aerothermal TPS Systems	Avionics must function in extreme environment of Mars Entry
Planetary Protection	⟺	EDL Systems Engineering, Guidance, Nav & Control Analysis & Rqmnts	Landed mass must adhere to Planetary Protection Rules Robotic methods may be employed in Human landings
Mobility	⟹	Touchdown Systems	Successful Landing includes deployment of surface asset - robotic methods may be used
Propulsion	⟺	Terminal Descent Propulsion	Robotic propulsion methods may be applicable to Human landing

CRM X SRM Crosswalk (Part 1)

SR-#	Short	Full Name	Chartered Objective	Flow	CRM #7 Human Planetary Landing Systems	Relationship	CRM Communications with SRM
1	Moon	Robotic and Human Lunar Exploration	Robotic and human exploration of the Moon to further science and to enable sustained human and robotic exploration of Mars and other destinations.	⇔		Use common methods for landing on the Moon and on Mars where possible. These common technologies include Terminal descent systems, deep throttling propulsion engines, aerocapture Earth return systems, human systems & instrumentation for data during Earth return.	- Co-Chair (Harrison Schmitt) attended Meeting #2 -Potential invititation to present at Meeting #3 -Reviewing SRM presentations on Docushare
2	Mars	Robotic and Human Exploration of Mars	Exploration of Mars, including robotic exploration of Mars to search for evidence of life, to understand the history of the solar system, and to prepare for future human exploration; human expeditions to Mars after acquiring adequate knowledge about the planet using these robotic missions and after successfully demonstrating sustained human exploration missions to the Moon.	⇔		Very Large (30-60 MT) landed masses on Mars will require new Aerocapture, Entry, Descent, Landing and Ascent (AEDLA) technologies/capabilites with long development/test times. Human factors, operations & training must be factored into AEDLA Mars mission planning and human rated design in order to safely land and return human crews from Mars. Aeroassist technologies will dramatically reduce the amount of propellant/mass that is required for human travel to Mars and safe return to Earth.	-Chair (Rob Manning) presented at Meeting #2 -Chair presented at Meeting #3 -Team Member (Bobby Braun) is on SRM Committee -Reviewing SRM presentations on Docushare
3	Solar System	Solar System Exploration	Robotic exploration across the solar system to search for evidence of life, to understand the history of the solar system, to search for resources, and to support human exploration.	NA		Not Applicable	-Reviewing SRM presentations on Docushare
4	Earth-like Planets	Search for Earth-Like Planets	Search for Earth-like planets and habitable environments around other stars using advanced telescopes.	NA		Not Applicable	NA
5	CEV / Constellation	Exploration Transportation System	Develop a new launch system and crew exploration vehicle to provide transportation to and beyond low Earth orbit.	⇔		Efficient and feasible CEV/Constellation designs and configurations will require close coordination, systems engineering and packaging of Aerocapture, Entry, Descent, Landing and Ascent (AEDLA) technologies, capabilities and systems. Very Large (30-60 MT) landed masses on Mars will require new AEDLA technologies/capabilites with long development times. Aeroassist technologies will dramatically reduce the amount of propellant/mass that is required for human travel to Mars and safe return to Earth. Large volume & area payload launch fairings will be required. Heavy Lift will be required for full scale earth based testing and actual missions	-Reviewing SRM presentations on Docushare -Chairs presented at Meeting #2
6	Space station	International Space Station	Complete assembly of the International Space Station and focus research to support space exploration goals, with emphasis on understanding how the space environment affects human health and capabilities, and developing countermeasures.	⇒		ISS will provide human health and performance data, human factors and interfaces data, training opportunities & test bed, on orbit assembly experience.	-Reviewing SRM presentations on Docushare
7	Shuttle	Space Shuttle	Return the space shuttle to flight, complete assembly of the International Space Station, and safely transition from the Space Shuttle to a new exploration transportation system.	⇒		Space Shuttle will provide human health and performance data, human factors and interfaces data, training opportunities & test bed, Earth Entry Descent & Landing (EDL) data, Thermal Protection System (TPS) Data & Earth atmospheric conditions data.	-Reviewing SRM presentations on Docushare

Critical Relationship

Moderate Relationship

Minimal or No Relationship

CRM = Capability Road Map

SRM = Strategic Road Map

CRM X SRM Crosswalk (Part 2)

8	Universe	Universe Exploration	Explore the universe to understand its origin, structure, evolution, and destiny.	NA		Not Applicable	NA
9	Earth	Earth Science and Applications from Space	Research and technology development to advance Earth observation from space, improve scientific understanding, and demonstrate new technologies with the potential to improve future operational systems.	NA		Not Applicable	NA
10	Sun-Solar System	Sun-Solar System Connection	Explore the Sun-Earth system to understand the Sun and its effects on the Earth, the solar system, and the space environmental conditions that will be experienced by human explorers.	NA		Forecasts of dangerous solar events and on board solar activity monitoring to preserve human health & performance in Aerocapture, Entry Descent & Landing (AEDL)	-Reviewing SRM presentations on Docushare
11	Aero	Aeronautical Technologies	Advance aeronautical technologies to meet the challenges of next-generation systems in aviation, for civilian and scientific purposes, in our atmosphere and in the atmospheres of other worlds.	↔		Direct Entry, Aerocapture, Aerobraking, Guided Hypersonic Flight, Supersonic deceleration, and Aerogravity Assist all require aeronautical technologies/capabilities & test facilities to successfully use the Mars atmosphere.	-Reviewing SRM presentations on Docushare
12	Education	Education	Use NASA missions and other activities to inspire and motivate the nation's students and teachers, to engage and educate the public, and to advance the nation's scientific and technological capabilities.	↔		Use Aeronautics, Science & Engineering principles to educate, inspire and motivate, which provides a skilled labor force for Human Planetary Landing Systems implementation	-Reviewing SRM presentations on Docushare
13	Nuclear	Nuclear Systems	Utilize nuclear systems for the advancement of space science and exploration.	→		Use of advanced nuclear propulsion systems could reduce the transportation vehicle's arrival velocity at Mars alowing for reduced orbital capture delta velocity (Delta V) requirements	-Reviewing SRM presentations on Docushare
	Cross Cutting		HUMAN PLANETARY LANDING SYSTEMS ARCHITECTURAL ISSUES				

(red)	Critical Relationship
(blue)	Moderate Relationship
(grey)	Minimal or No Relationship

CRM = Capability Road Map

SRM = Strategic Road Map

SRM X CRM Example Data

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Mars | Go Back

Capability	Requirement	Date Required	Investment Start	RM	Rationale for Capability	SRM Concurrence
Aerocapture, Entry, Descent & Landing (AEDL) Architecture Asessment	Decide what AEDL methods/technologies could work	2008	2006	TBD	Trade studies and research to define an ensemble of Evaluation architectures and AEDLA methods/technologies	
At Earth Sub Scale AEDL Component Development & Architecture Evaluation Testing	Technology development and testing to define & answer questions about AEDL architectures	2015	2009	TBD	Technology options & capabilities must be explored in order to get data for rationale of down selection	
Scaled Mars AEDL Validation Flights	4 MT Landing Capability at Mars: Validate AEDL Models	2022	2015	TBD	Use Robotic Mars program to validate scaleable Mars Human AEDL methods	
Earth Based Full Scale Development Program	Develop & Qualify the Full Scale Hardware	2028	2020	TBD	Use mostly Earth based Sub-Orbital qualification tests to develop the full scale of the hardware	
Prepare & Fly Cargo & Piloted Human Missions to Mars	Fly first Human Missions to Mars > 40 MT AEDL Systems Qualified & Flown	2032	2025		Deliver Cargo & Humans to Mars.	
Validate Mars Surface Models	Mars Odessy and MRO Surface Assessment	2010	2006	TB	DTM's and Site Hazard Maps for Human Scale Site Selection	
Utilize Mars Robotic Overlap Technology	MSL, MSR, MTO, MSR Data Analysis	2015-2034	2006	TBD	Develop Pin Point Landing Radar, Terrain Relative Navigation, Guidance, Hazard Avoidance Sensors	
Validate Mars Atmosphere Models	Entry, Descent & Landing (EDL) In Situ Measurements & 3 Mars Years Atmosphere Monitiring Mission	2022	2010	TBD	Mars Atmospheric variations and dust characteristics must be understood in order to successfully design high reliability EDL Systems.	
Interaction with Lunar & Earth Return Development	Component Development & Architecture Evaluation Testing	2008-2015	2008	TBD	Use Lunar program and CEV to gain data and test common hardware	
Shuttle & ISS Return Human Physiological Performance Data	Human Performance Data	2006-2015	2006	TBD	Use empirical human performance data to drive designs and enable Human landings on Mars	
Special Test facilities and knowledge	Specialized supersonic and large scale wind tunnels for aerodynamic testing & Other Test Facilities for Terminal Descent Landing	2015	2009	TBD	Test Facilities are required to efficiently develop Aerocapture, Entry, Descent & Landing Hardware on Earth	

Sub Teams

- Sub Teams will now present charts

Backup Charts

Technology Readiness Levels (TRL)

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- Technology Readiness Levels (TRLs) are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology. The TRL approach has been used on-and-off in NASA space technology planning for many years and was recently incorporated in the NASA Management Instruction (NMI 7100) addressing integrated technology planning at NASA.

TRL 1 Basic principles observed and reported
TRL 2 Technology concept and/or application formulated
TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4 Component and/or breadboard validation in laboratory environment
TRL 5 Component and/or breadboard validation in relevant environment
TRL 6 System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7 System prototype demonstration in a space environment
TRL 8 Actual system completed and “flight qualified” through test and demonstration (ground or space)
TRL 9 Actual system “flight proven” through successful mission operations

Capability Readiness Levels

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7 Capability Operational Readiness

6 Integrated Capability Demonstrated in an Operational Environment

5 Integrated Capability Demonstrated in a Relevant Environment

4 Integrated Capability Demonstrated in a Laboratory Environment

3 Sub-Capabilities* Demonstrated in a Relevant Environment

2 Sub-Capabilities* Demonstrated in a Laboratory Environment

1 Concept of Use Defined, Capability, Constituent Sub-capabilities* and Requirements Specified

* Sub-capabilities include Technologies, Infrastructure, and Knowledge (process, procedures, training, facilities)

* Sub-capabilities include Technologies, Infrastructure, and Knowledge (process, procedures, training, facilities)

Guidelines for Using CRLs

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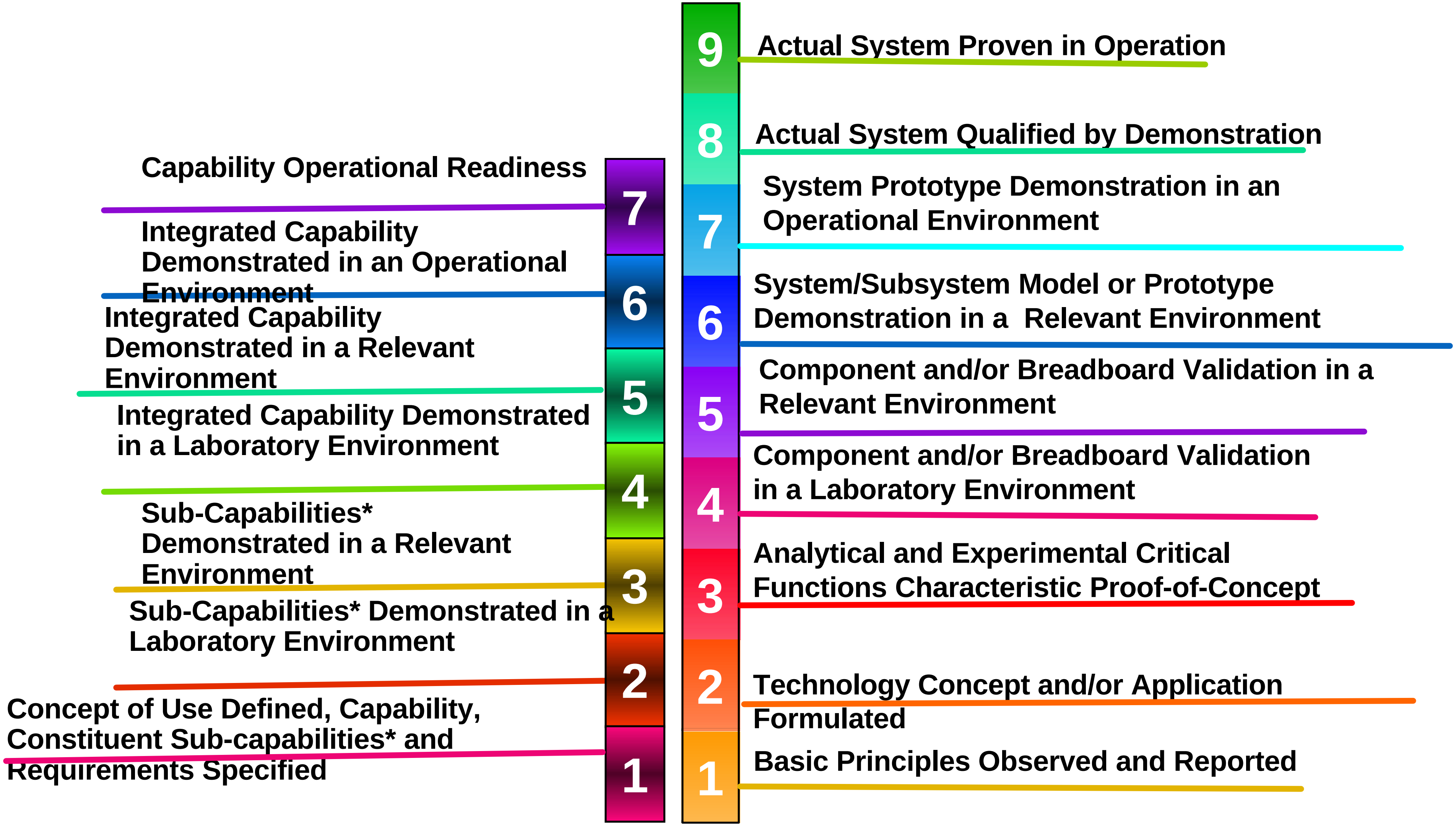
- A Capability is defined as a set of systems with associated technologies & knowledge that enable NASA to perform a function (e.g. scientific measurements) required to accomplish the NASA mission.
- The scope of a Capability includes the knowledge or infrastructure (process, procedures, training, facilities) required to provide the Capability.
- A Capability needs to be demonstrated and qualified, just as a technology does, in both laboratory and relevant environments.
  - The infrastructure and knowledge (process, procedures, training, facilities) of the Capability needs to be:
    - Demonstrated and qualified in both laboratory and relevant environments
    - Available in order for the Capability to be considered mission-ready.
- A minimum level of TRL 6 is required to integrate technologies into a Sub-capability.
- Sub-capabilities are required to reach CRL 3 before integration into a full Capability.

CRL vs. TRL



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* Sub-capabilities include Technologies, Infrastructure, and Knowledge (process, procedures, training, facilities)

Capability Readiness Levels

1 Concept of Use Defined, Capability, Constituent Sub-capabilities* and Requirements Specified

The Capability is defined in written form. The uses and/or applications of the Capability are described and an initial Proof-of-Concept analysis exists to support the concept. The constituent Sub-capabilities and requirements of the Capability are specified.

* Sub-capabilities include Technologies, Infrastructure, and Knowledge (process, procedures, training, facilities)

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2 Sub-Capabilities* Demonstrated in a Laboratory Environment

Proof-of-Concept analyses of the Sub-capabilities are performed. Analytical and laboratory studies of the Sub-capabilities are performed to physically validate separate elements of the Capability. Analytical studies are performed to determine how constituent Sub-capabilities will work together.

* Sub-capabilities include Technologies, Infrastructure, and Knowledge (process, procedures, training, facilities)

3 Sub-Capabilities* Demonstrated in a Relevant Environment

Sub-capabilities are demonstrated with realistic supporting elements to simulate an operationally relevant environment to the Capability.

- -of appropriate scale
- -functionally equivalent flight articles
- -major system interactions and interfaces identified

* Sub-capabilities include Technologies, Infrastructure, and Knowledge (process, procedures, training, facilities)

4 Integrated Capability Demonstrated in a Laboratory Environment

A representative model or prototype of the integrated Capability is tested in an ambient laboratory environment. Performance of the constituent Sub-capabilities is observed in addition to the Capability as an integrated system. Analytical modeling of the integrated Capability is performed.

5 Integrated Capability Demonstrated in a Relevant Environment

An integrated prototype of the Capability is demonstrated with realistic supporting elements to simulate an operationally relevant environment to the Capability.

- -of appropriate scale
- -functionally equivalent flight articles
- -all system interactions and interfaces identified

6 Integrated Capability Demonstrated in an Operational Environment

The Capability is near or at the completed system stage. The integrated Capability is demonstrated in an operational environment with the intended user organization(s).

-full scale flight articles

-demonstrated in the intended operational 'envelope'

* Sub-capabilities include Technologies, Infrastructure, and Knowledge (process, procedures, training, facilities)

Capability Readiness Levels

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7

Capability Operational Readiness

The Capability has been proven to work in its final form under expected operational condition. This level represents the application of the Capability in its operational configuration and under “mission” conditions.

* Sub-capabilities include Technologies, Infrastructure, and Knowledge (process, procedures, training, facilities)