Aerocapture and EDL Technology Development Experiences

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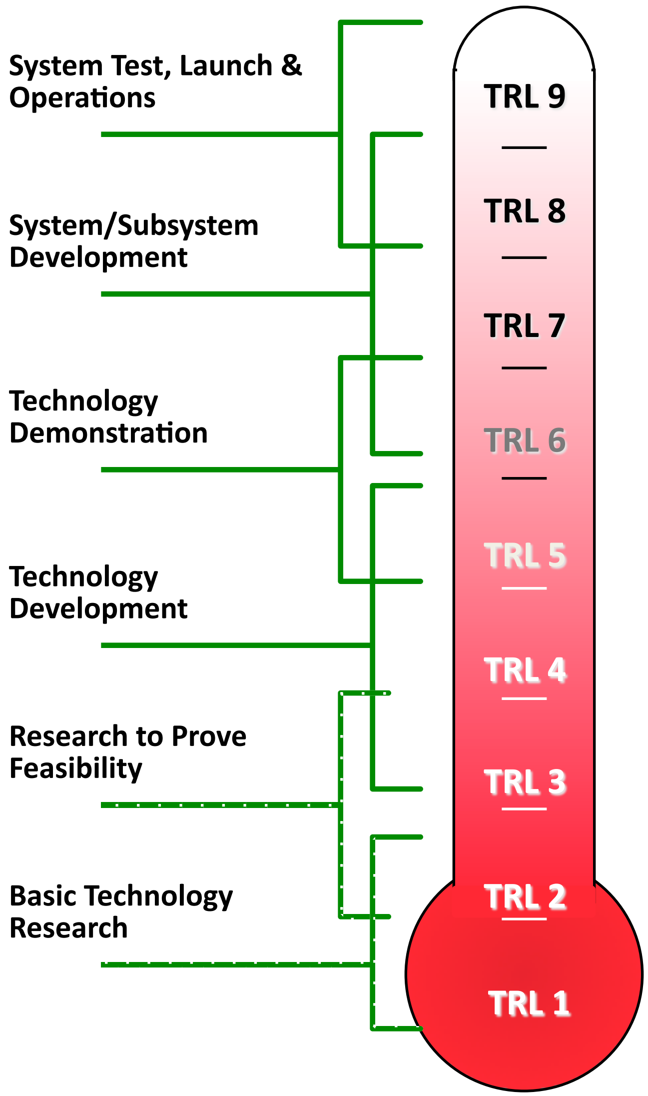
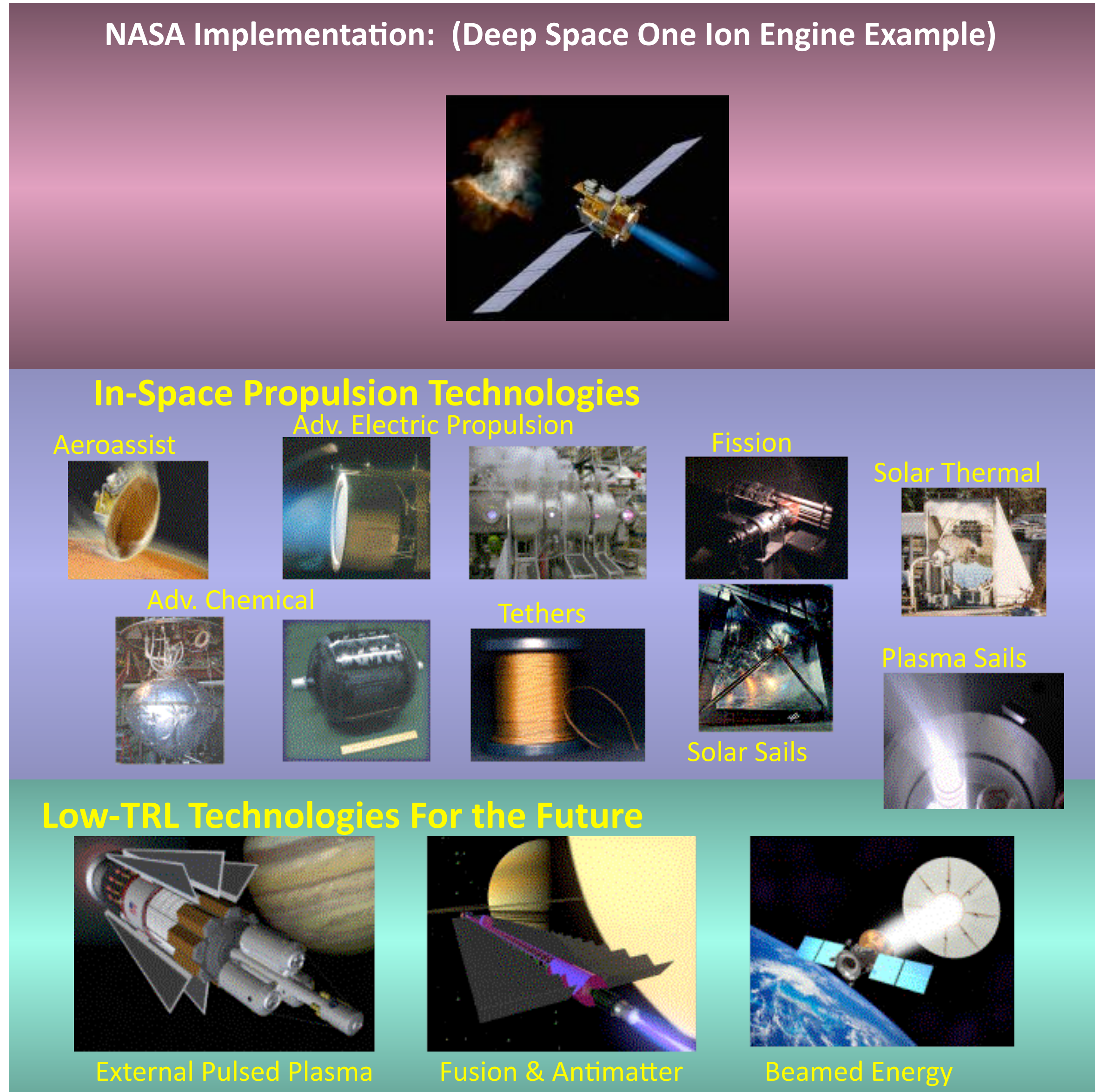
Outline

- ISPT Aerocapture
  - Background and context
  - Approach to Technology Development
  - New Millennium Experience
- Entry, Descent, and Landing Systems Analysis (EDL-SA) Activity
  - Purpose and Content
  - Current Roadmapping Efforts
- Key Observations/Lessons Learned

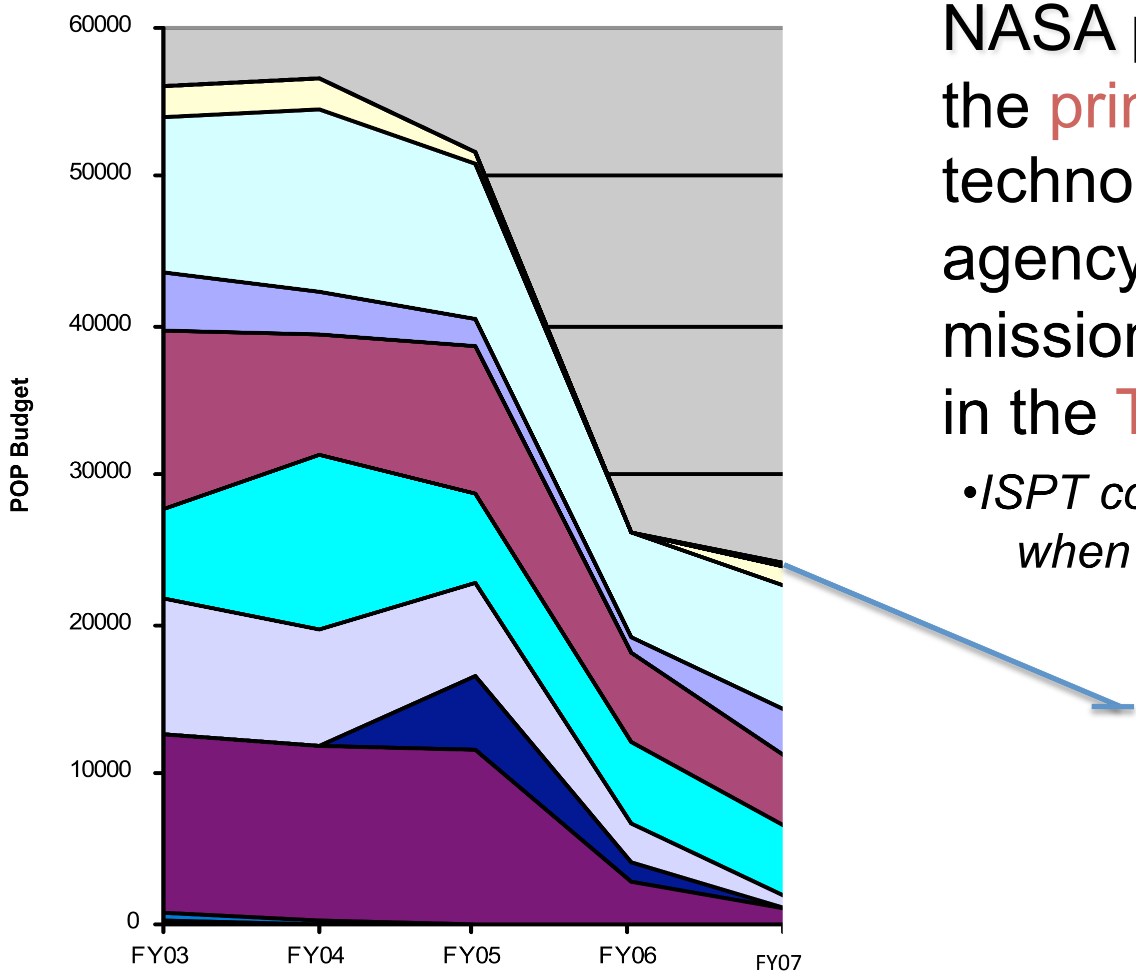
ISPT Aerocapture

In-Space Propulsion Technology (ISPT) Project Advances Mid-TRL Technologies





ISPT Purpose and Resources

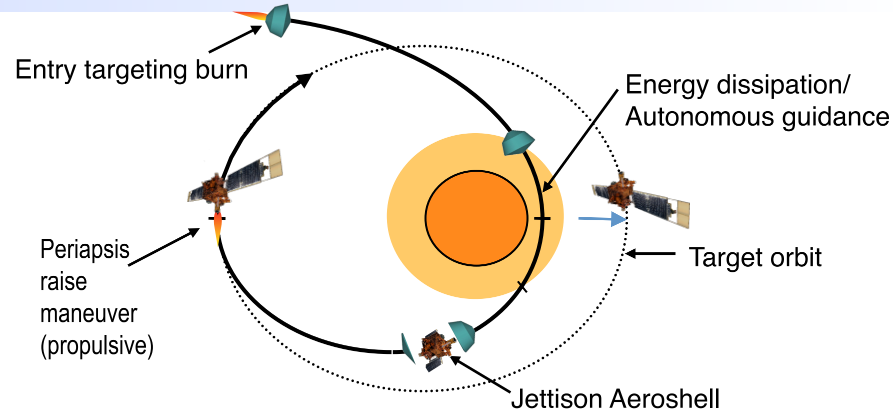


- The ISPT project is the only NASA project that addresses the primary propulsion technology needs for the agency's future robotic science missions. Development occurs in the TRL 3-6+ range.
  - *ISPT considers development complete when the product is infused onto a science mission*

Aerocapture Overview

Description

- Aerocapture: Orbit insertion via a single guided, atmospheric pass. Dramatically increases delivered payload mass.
- Aerocapture has been shown through numerous studies (Earth, Mars, Venus, Titan, Neptune) over 20+ years to be a strongly enhancing to ENABLING technology for planetary orbit insertion
- Early flight validation would build confidence and reduce risk for eventual application to Mars DRA, while benefiting multiple nearer-term missions



Mission Category	Both Exploration and Robotic
Flight Regime	Orbit Insertion (Hypersonic)
Current TRL	5+ for blunt body science mission

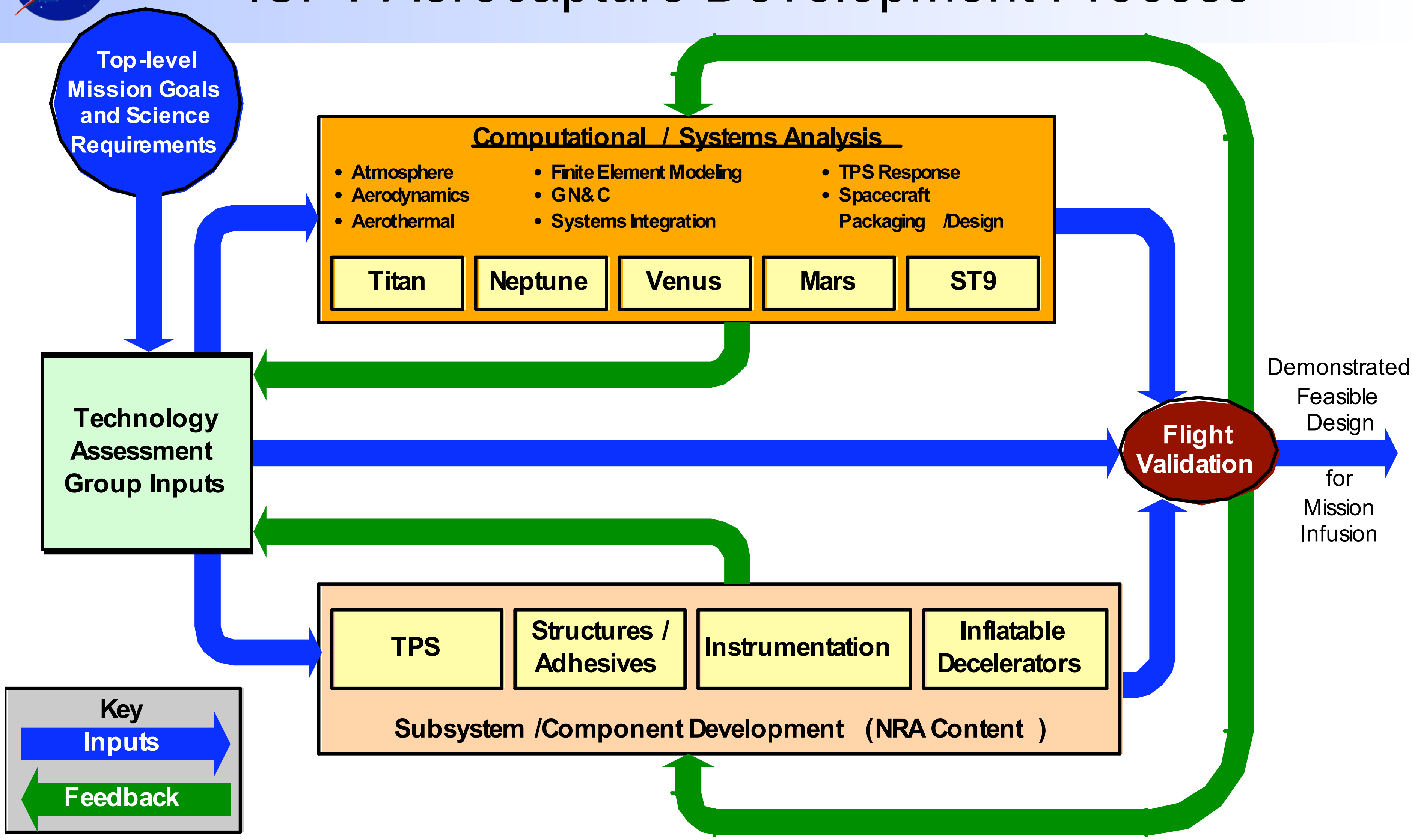
State of the Art/Current Efforts

- Studied and developed for 20+ years; nearly validated with AFE in early 90's, reached Phase B on Mars Surveyor '01, planned for MSR '03/'05 and '05/'07
- SMD's ISPT Program has been investing in subsystem improvements since 2003: planetary systems analysis, GN&C, aerothermal modeling, efficient structures and ablators, sensors
- System validation in relevant flight environment is the remaining TRL advancement step

Technology Maturation Recommendations for Directorate Technology Programs

- Complete ISPT investments in GN&C, structures and ablators, and SEE materials testing (FY10)
- Identify relevant flight test opportunities
- Formulate an aerocapture flight test ADP

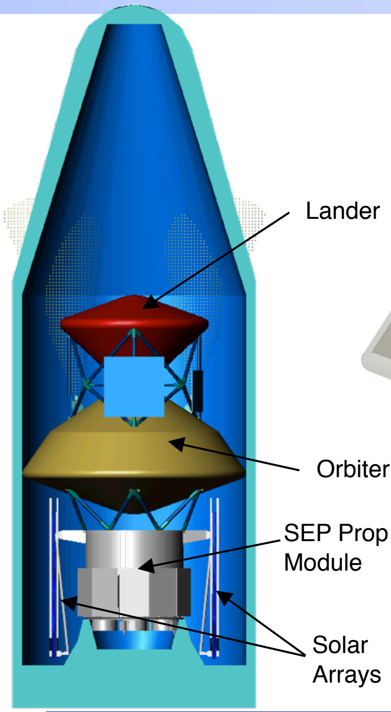
ISPT Aerocapture Development Process

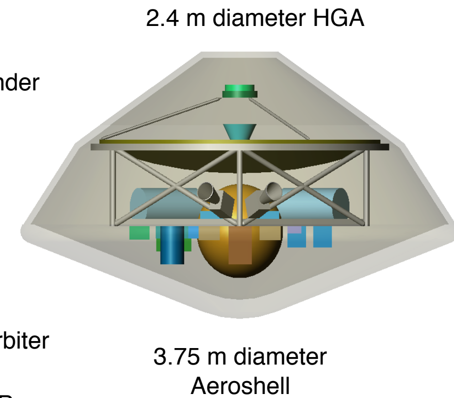


Aerocapture flight validation/demonstration provides critical feedback to the overall technology development

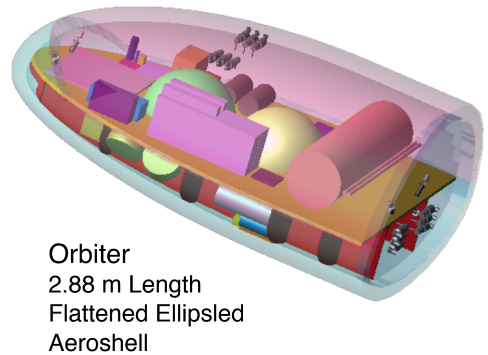
Aerocapture Systems Definition Studies

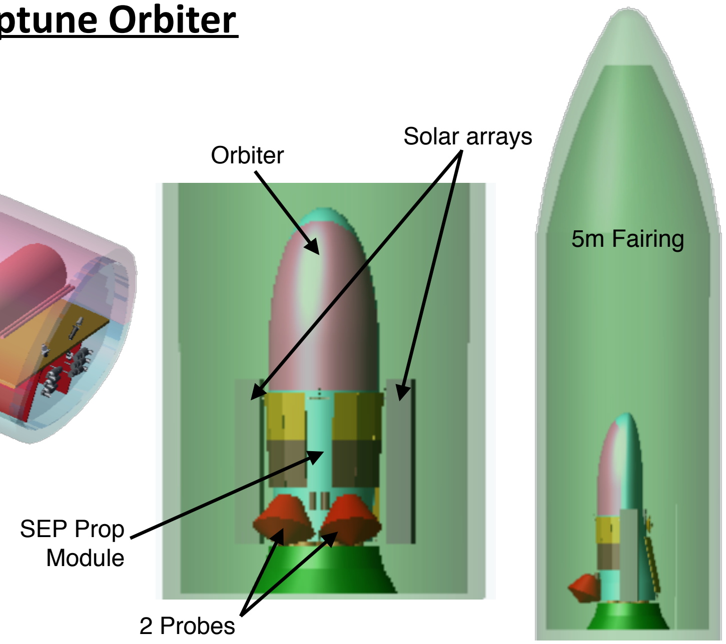
2002 - Titan Orbiter





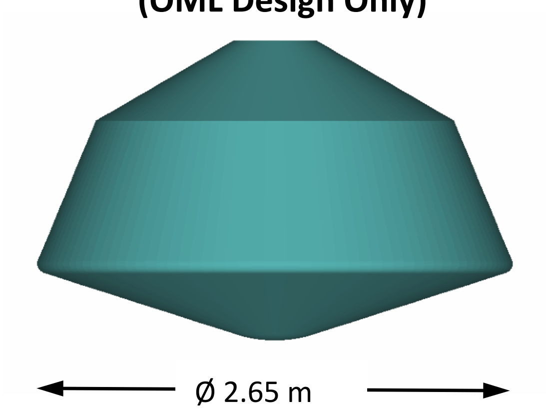
2003 - Neptune Orbiter





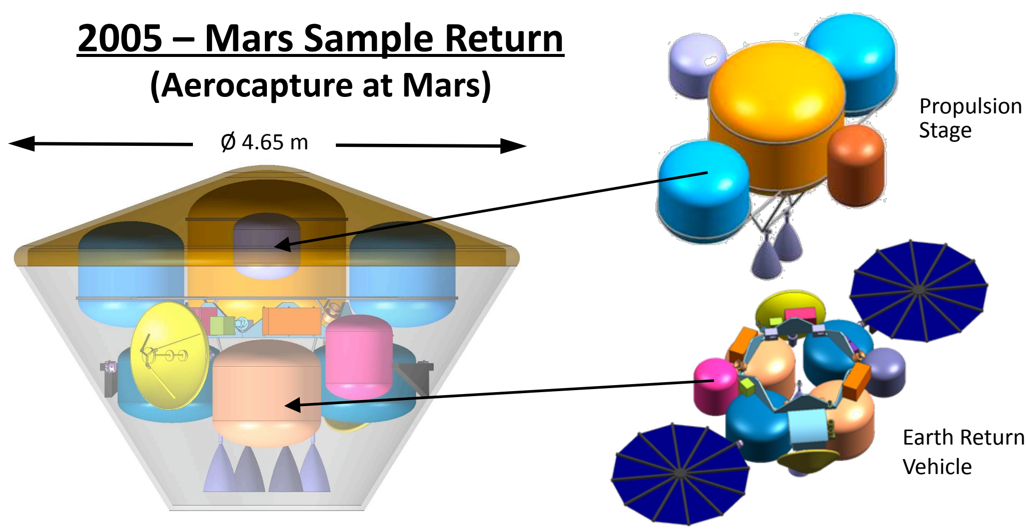
2004 - Venus Orbiter

(OML Design Only)

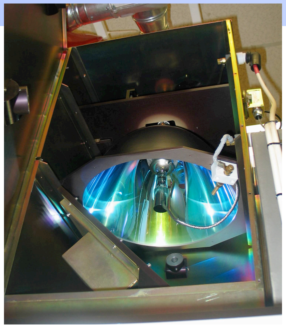


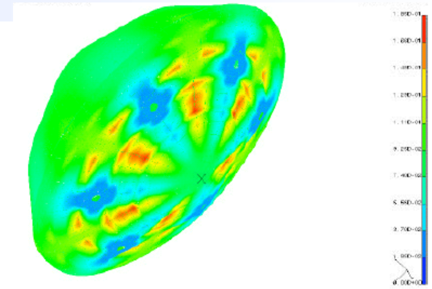
2005 – Mars Sample Return

(Aerocapture at Mars)

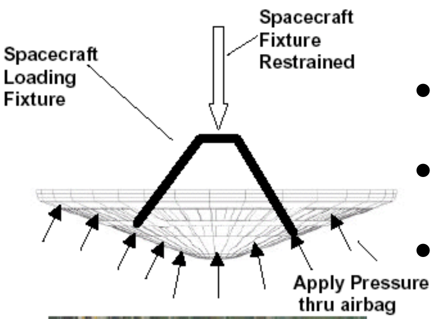


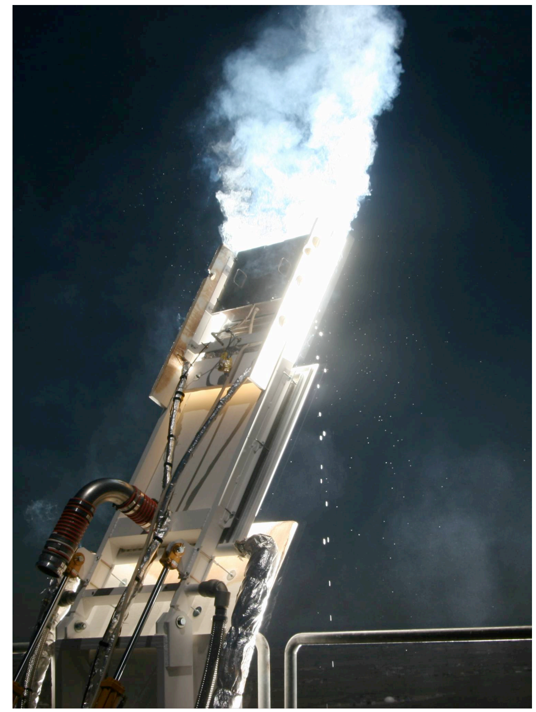
ISPT Aerocapture – Competed Products

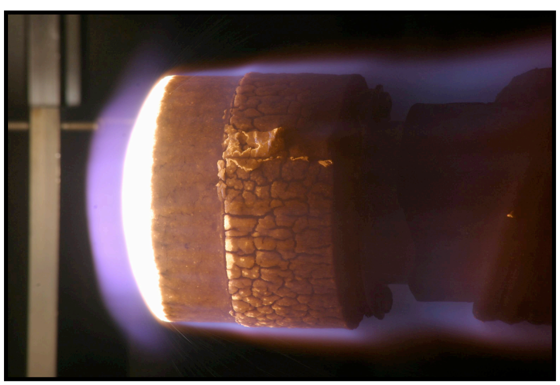


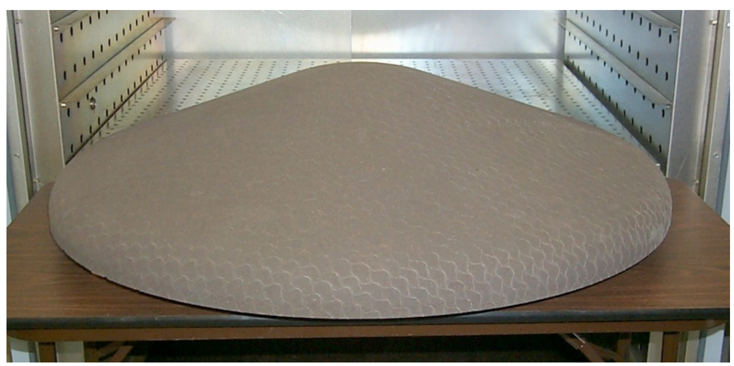


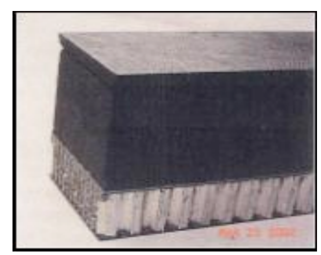
- Mass-efficient rigid aeroshells and ablators; component through article testing
- Engineering sensors *(*key to validation)*
- GN&C Testbed
- System design
- Model and tool development – some in-house (atmosphere, aerothermal, guidance algorithm, TPS response models)



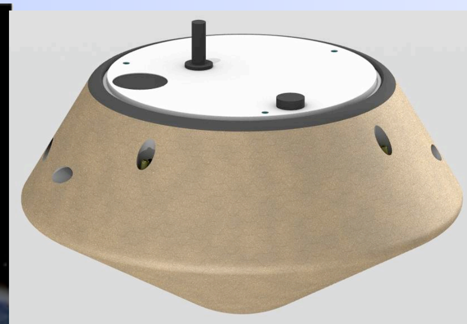








Aerocapture Flight Validation Concept



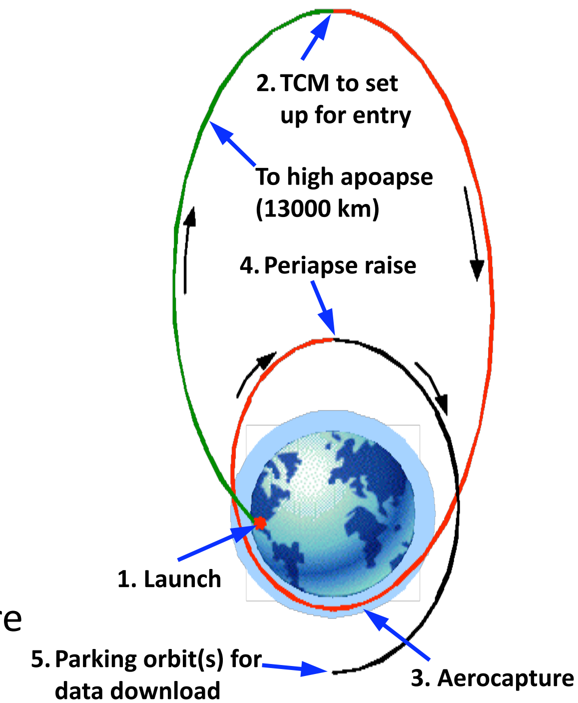
ST9 Vehicle Concept

Mission Parameters

Vehicle Type	60° sphere-cone aeroshell
Vehicle Mass (CBE)	148 kg, 1.2 m diameter
Access to space	Delta-II dual launch to 13000 km
Mission Duration	9.1 hours
Atmospheric Entry Speed	9.6 km/s
Atmospheric ΔV	1.7 km/s
Nominal Launch	June 2010
NMP ST9 Funding	$85 M
ISP ST9 Funding	$22 M

- Aerocapture System Technology for Planetary Missions was one of five competitors for NASA's New Millennium Program Space Technology-9 mission
- The ST9 Aerocapture concept would have validated:
  - Aerocapture as a system technology for immediate use in future missions to Solar System destinations possessing significant atmospheres
  - The performance of the autonomous Aerocapture guidance system based on bank angle control
  - Efficient and robust new TPS for multiple applications
  - Computational modeling tools used for aero/ aerothermodynamic design and trajectory performance
  - New aeroshell sensors to improve margin and risk postures on future aeroentry missions

Mission Sequence



NMP: TRL 5 Definitions & Exit Criteria

- Generic TRL 5 Definition-Component and/or breadboard validation in a relevant environment.
- At TRL 5, the fidelity of the environment in which the component and/or breadboard has been tested has increased significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level, or system-level) can be tested in a “relevant environment”.
- Aerocapture TRL 5 Definition- A set of Aeroshell components (coupon and panel level with sensors) that have been tested in a relevant environment. A set of models that can replicate and predict the performance of Aerocapture components, subsystem or system in a relevant environment.
- TRL 5 Exit Criteria-
  - The “relevant environment” is fully defined (natural space environment, ground environment, launch environment).
  - The technology advance has been tested in its “relevant environment” throughout a range of operating points that represents the full range of operating points similar to those to which the technology advance would be exposed during qualification testing for an operational mission.
  - Analytical models of the technology advance replicate the performance of the technology advance operating in the “relevant environment”.
  - Analytical predictions of the performance of the technology advance in a prototype or flight-like configuration have been made.

ST9 TPS TRL Definitions

	TRL 4	TRL 5	TRL 6
Official NASA Definition	Component and/or breadboard validation in a laboratory environment.	Component and/or breadboard validation in a relevant environment.	System/subsystem model or prototype demonstration in a relevant environment (ground or space).
NMP Interpretation	Component or breadboard version tested in laboratory environment.	Component or breadboard version tested in a relevant environment.	Prototype or flight-like version tested in a relevant environment.
	Predictive models replicate lab tests and provide performance estimates for future relevant environment tests.	Predictive models replicate relevant environment tests and provide performance estimates for future relevant environment tests at the system prototype level.	Predictive models replicate relevant environment tests and provide performance estimates for future space test at the system prototype level.
ST9 Aerocapture Interpretation for SRAM-20 Thermal Protection System	Component = Small (few centimeter scale) samples of SRAM-20 TPS material.	Component = Multiple flat samples of SRAM-20 ranging from few centimeter to half meter sizes, including samples bonded to structural substrate using flight-like adhesives.	Subsystem = Prototype heat shield (meter scale) with SRAM-20 TPS material bonded onto a flight-like blunt body structural substrate. Includes verified quality control and inspection techniques with repair criteria defined and repair techniques established.
	Laboratory environment tests = (1) Stagnation point arc jet heating at nominal fluxes expected for ST9. (2) Mechanical properties measurements (density, strength, modulus). Approximately 10 tests of each type to establish statistical variability.	Relevant environment tests = (1) Stagnation point and wedge angle arcjet heating tests under ST9 stress conditions (three-sigma heat loads plus margin); (2) Combined heating and structural tests (tensile, shear) on sample + substrate using low cost radiative facility. (3) SRAM-20 tested at maximum heat flux expected for future missions to Earth, Mars and Titan. (4) Arcjet tests on samples with flight-like embedded instrumentation to verify integrity and performance. Sufficient number of tests conducted in each case to define the boundaries on statistical variability of material performance.	Relevant environment tests = (1) Standard spacecraft vibration, acoustic, and thermal vacuum chamber tests on prototype heatshield. (2) Prototype thermal test of the bond and induced stress between TPS and structure in low-cost radiative facility.

ST9 TPS Exit Criteria

	TRL 4	TRL 5	TRL 6
	Pass criteria = (1) Material response model (temperature and thermochemical recession) as a function of time and depth, matched arcjet experiments with +/- 20% accuracy; (2) Mechanical property variation less than +/-10%. (3) Maximum tolerable heat fluxes shown to be consistent with future missions to Earth, Titan and Mars.	Pass criteria = (1) Material response model (temperature and thermochemical recession) as a function of time and depth, matched to arcjet experiments with +/- 15% accuracy. (2) Combined heating plus structural test results show no debonding or delaminating of TPS and structure. (3) Combined heating plus structural test load-deflection data matched to finite element models to within +/- 15%. (4) Embedded instrument tests demonstrated structural integrity and match expected parameters to within +/-15%. (5) SRAM-20 performance models for ST9 and future missions to Mars and Titan show efficient performance at a Concept Definition level. (6) Analysis of thermal expansion affects on bondline junction show no problems scaling up to 4 m diameter heat shields.	Pass criteria = (1) No structural failures in any subsystem tests. (2) Thermal expansion and structural loading models matched to thermally-induced stress experiments with +/- 15% accuracy. (3) Performance model extrapolations to ST9 flight mission show adequate design margins.
Current TRL Assessment	TRL 4 achieved already for SRAM-20. Published papers available describing materials, test results and predictive models.	Close to TRL 5 at the end of the Concept Definition Study. Coupon wedge tests not complete, but instrumented samples on relevant structure have been stagnation tested. Predictive models for aerocapture missions at Mars and Titan show that SRAM-20 has efficient performance at the heat loads and fluxes required by those missions.	TRL 6 will be attained in Phase B. A 1 m scale prototype heat shield was fabricated during Concept Definition Study, but testing will not be complete until Phase B.

EDL-SA

Objectives of EDL-SA Study

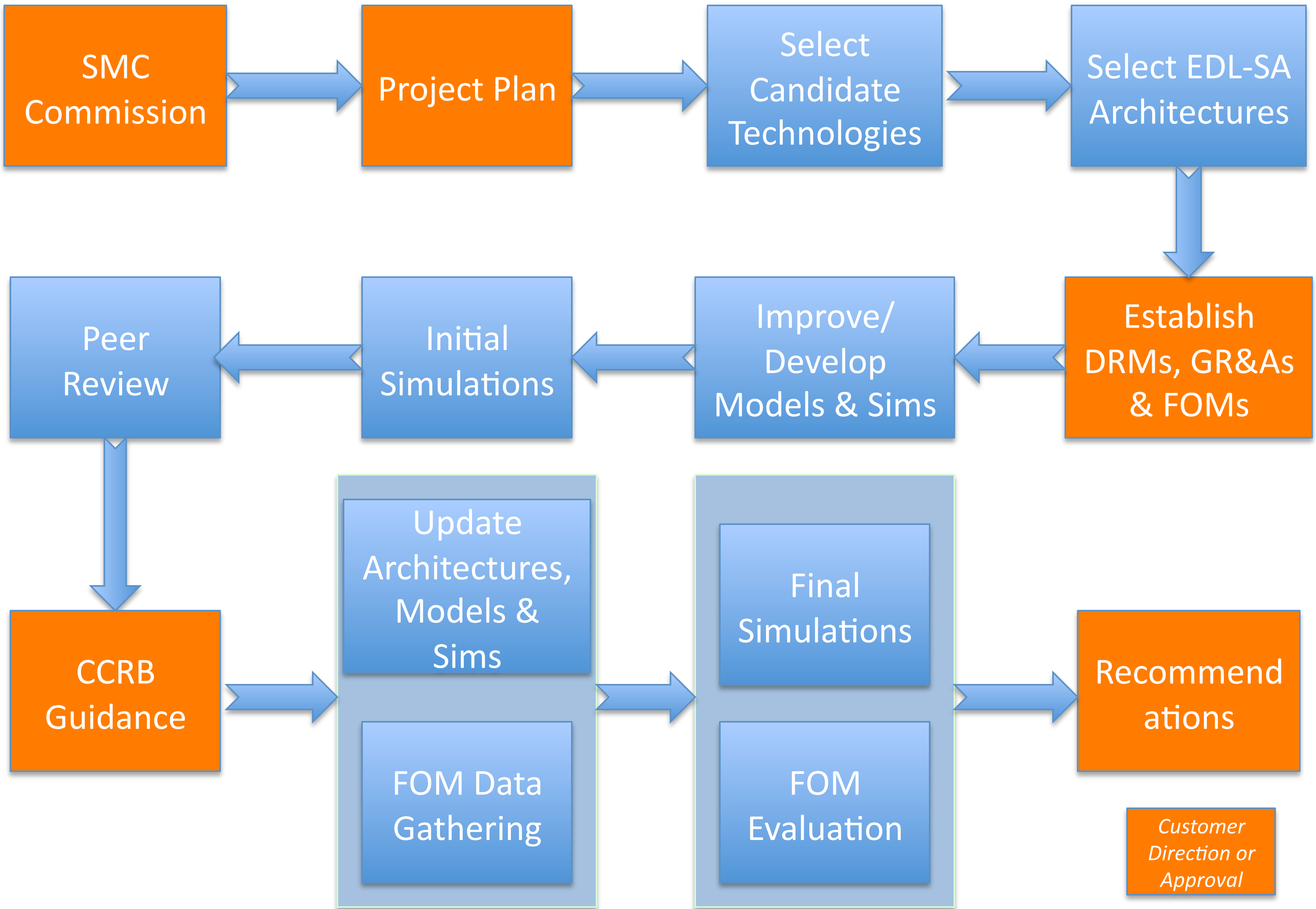
- Overall Objective:
  - Develop a strategy and plan for NASA to be able to successfully land large payloads at Mars for both robotic and human scale missions (per DRA 5.0)
- Year-by-Year Foci
  - Identify the broad areas requiring technology development for Exploration-class missions (Year 1)
    - e.g., dual-heat pulse-capable TPS
  - Identify the broad areas requiring technology development for large-robotic-class missions (Year 2)
    - e.g., supersonic deceleration
  - Develop detailed, costed, integrated (cross-cutting) technology development plans to TRL = 6 (Year 3) **started already*
    - e.g., dual-pulse TPS
    - e.g., supersonic retro-propulsion, inflatable decelerators

EDL-Systems Analysis Customers

- Study Results Provide Guidance and Informs EDL Technology Investment Strategies to Mission Directorate Technology Development Programs:

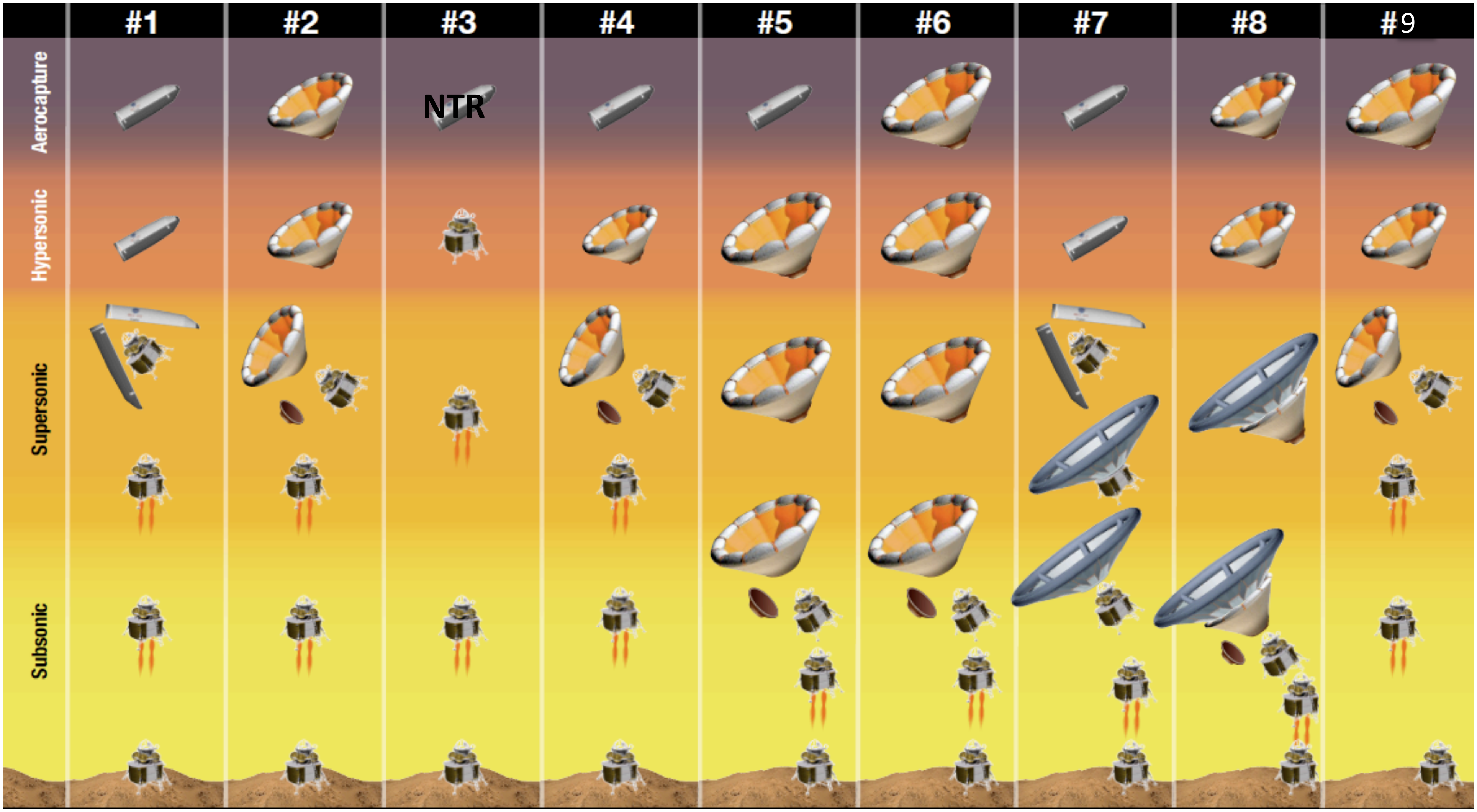
- ARMD: Fundamental Aeronautics Program
  - Existing investments since 2008 in High Mass Mars Entry Systems
- ESMD: Exploration Technology Development Program
  - New EDL TDP formed in FY10 to implement EDL-SA outcomes
- SMD: In Space Propulsion Technology Program
- SMD: Mars Technology Program

Exploration-class Study Flow



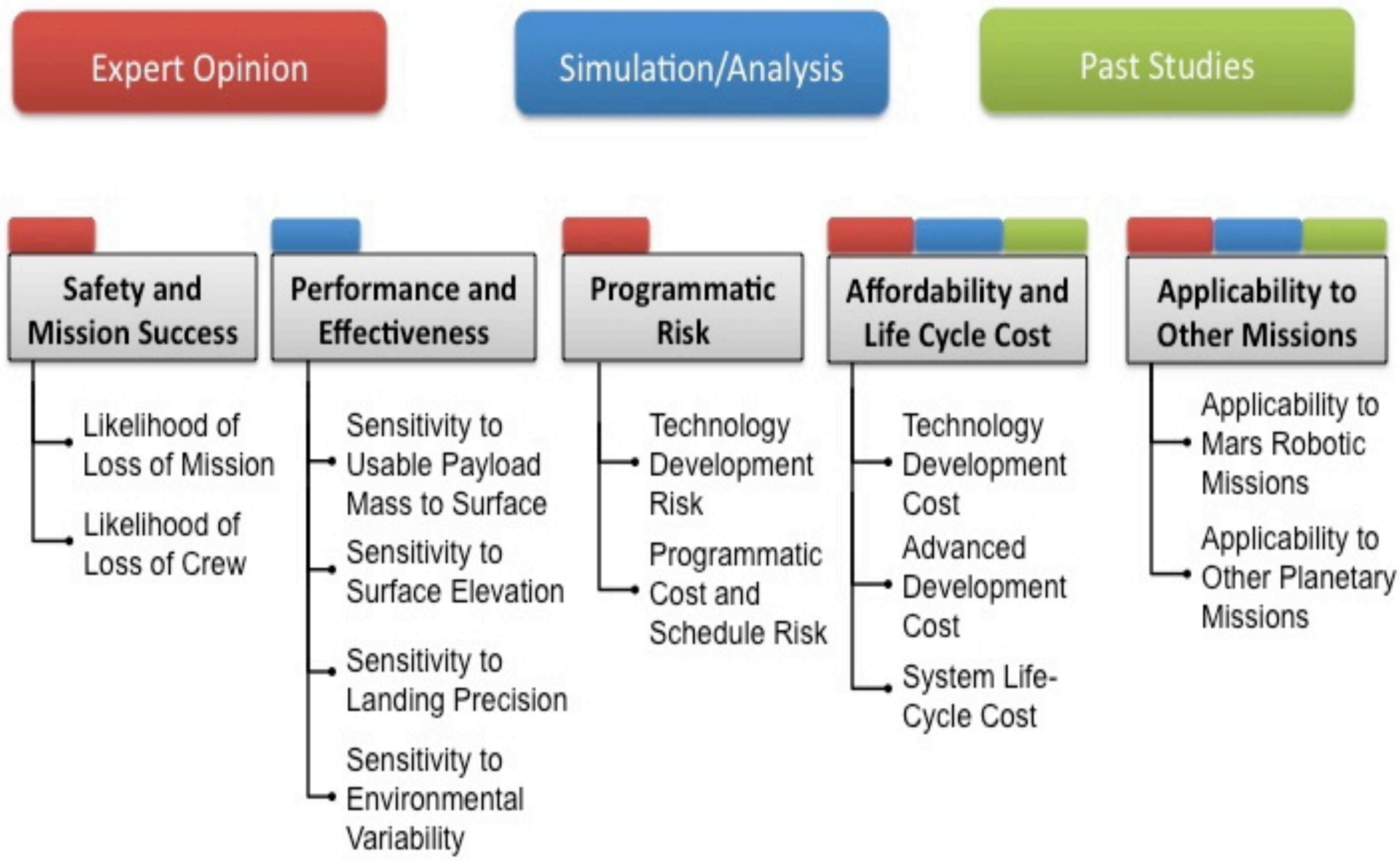
EDL-SA Exploration Architectures

(with Mars Arrival Mass underneath)



#1	#2	#3	#4	#5	#6	#7	#8	#9
110 mt	84 mt	265 mt	109 mt	134 mt	141 mt	107 mt	81 mt	? mt

Architecture Figures of Merit



Use of FOMs largely mimics ETDP portfolio ranking process

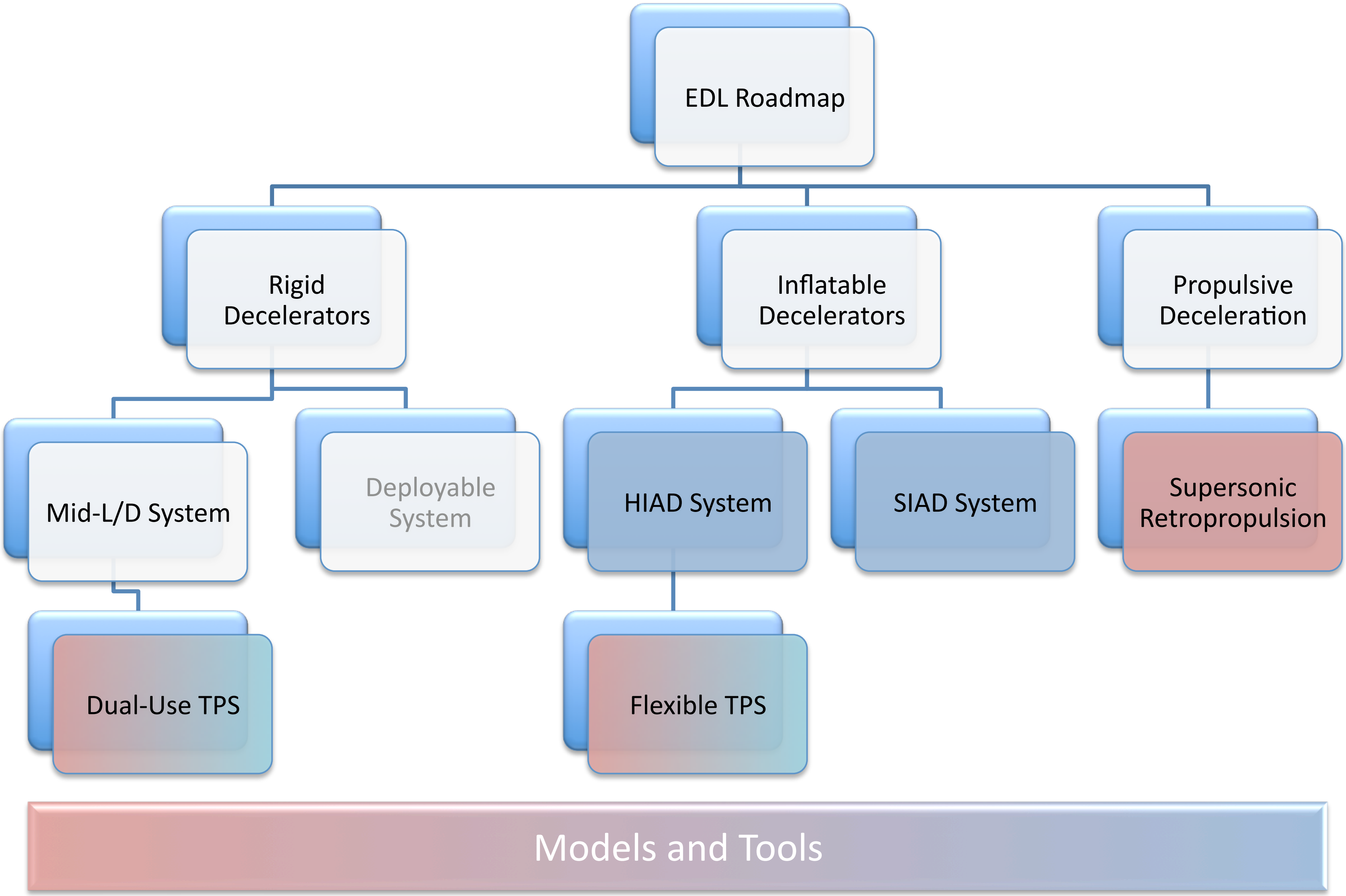
EDL Technology Investment Areas

Technology Area	TDP Content
Rigid Decelerators	Tools & processes for generating aero/aerothermal databases & mass models; rigid, dual heat-pulse capable TPS; structures; rigid decelerator (aeroshells and deployables) shapes for aerodynamic performance and controllability; vehicle designs
Flexible Decelerators	Tools & processes for generating aero/aerothermal databases & mass models for flexible entry/aerocapture vehicles; flexible materials, flexible decelerator shapes for aerodynamic performance, structural strength and controllability; vehicle designs
Precision Landing	Sensors, navigation and controls and their integration for precision landings with hazard avoidance in atmospheres
Supersonic Retro-Propulsion	Aero-propulsion interaction propulsion for supersonic deceleration—tools, controls, and configurations. Works for high supersonic initiation through touchdown.
All-propulsive Design	System studies of open issues for hypersonic phase and staging
Aerocapture Development	Requirements for an Aerocapture Technology Validation Flight Test
Supersonic Retro-Propulsion Flight Test Program	Flight demonstration (TRL=6) of controllability from initiation to simulated touchdown of supersonic retro-propulsion descent system.
Deployable Decelerator Flight Test Program	Flight demonstration (TRL=6), including controllability of Deployable, Inflatable Aerodynamic Decelerator
Aerocapture Flight Test	Flight demonstration (TRL=6–7) in upper Earth atmosphere
Parachute Flight Test Program	Flight testing of a supersonic Ringsail parachute, including reefing and deployment of a large (>21.5m diameter) parachute at Mach >2.0

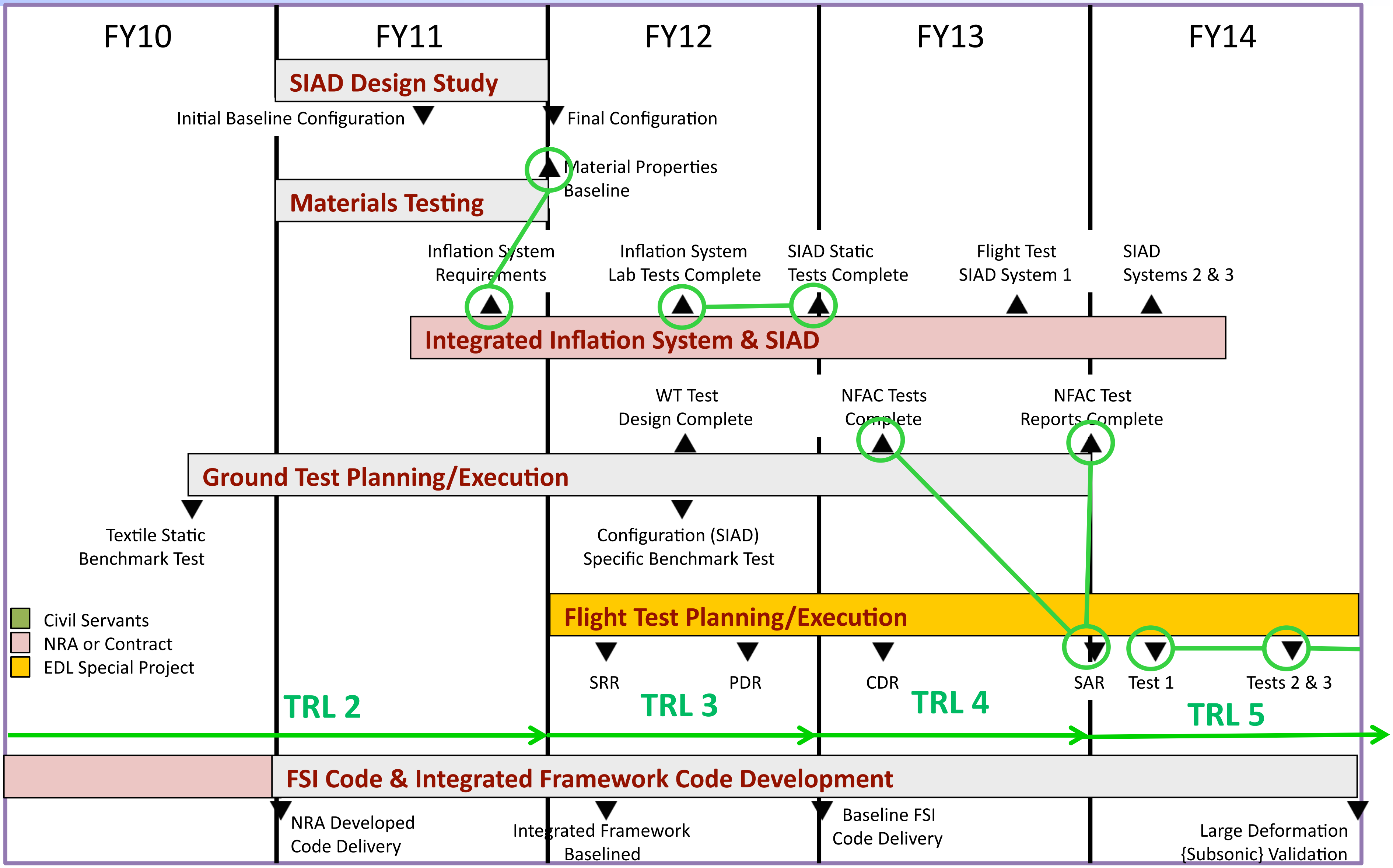
Roadmap Effort with ETDP and ARMD

- ETDP EDL TDP Element Leads and ARMD APIs are working together to develop EDL investment strategy
  - Weekly telecons since 12/09, led by Helen Hwang/ARC
  - Goal is draft EDL TDP roadmap(s) by March 31
  - Main product is PPBE content for ETDP (ARMD’s largely defined)
  - Portfolio integration began 2/11-12
- Steps so far:
  - Develop TRL definitions and exit criteria
  - Identify Key Performance Parameters (KPPs) – threshold and goal
  - Develop task and test lists to achieve TRL advancement
- In Progress:
  - Agree on overall EDL taxonomy and roadmap structure
  - Prioritization, gap and overlap identification (ETDP/ARMD)
  - Detailed plans for FY11-12, higher level through PPBE horizon
  - Cost estimation
- Needs
  - Requirements “documents” from EDL-SA

Organization of Roadmapping Effort



SIAD Technology Development TRL Progression (EXAMPLE Roadmap)



Key Observations

- Systems Analysis is a key part of technology identification and maturation; *ongoing* process
  - Is not cheap and one person with a spreadsheet is not credible
  - Is most valuable when communities of experts are engaged and using validated tools; serves to build toolset, as well as retain corporate knowledge
- A defendable roadmap is *critical* to securing and sustaining funding
  - Must be grounded in publicized mission needs (such as Decadal Survey, etc.)
  - Must have credible timeline
- New Millennium Program process of translating, defining, and peer reviewing TRL *achievement* criteria is being followed in EDL community for roadmap development
  - Requirements definition method
  - Process of systematically identifying tests and tasks supports credible costing
  - Customer communication tool
- Flight validation remains the great obstacle to infusion, but opportunities may be more prevalent within the new NASA direction

Backup

HIGH-LEVEL ROADMAP

Approach

- The HPLS roadmaps from 2005 were examined in light of our current Groundrules and Assumptions (i.e., those from DRA 5.0). The roadmaps are still highly applicable, although as we think through the implementation of this effort, some of the time scales used in 2005 are likely too short.
- The goal of this effort was to simplify and provide some high-level guidance to the technology programs.
- This is a first cut and there are some disconnects (namely, between schedule and likely budget).
- Further discussion with our funders will be required, to come to closure on the best strategy.
- With the current change in Agency direction, this effort's timelines and objectives will likely change radically

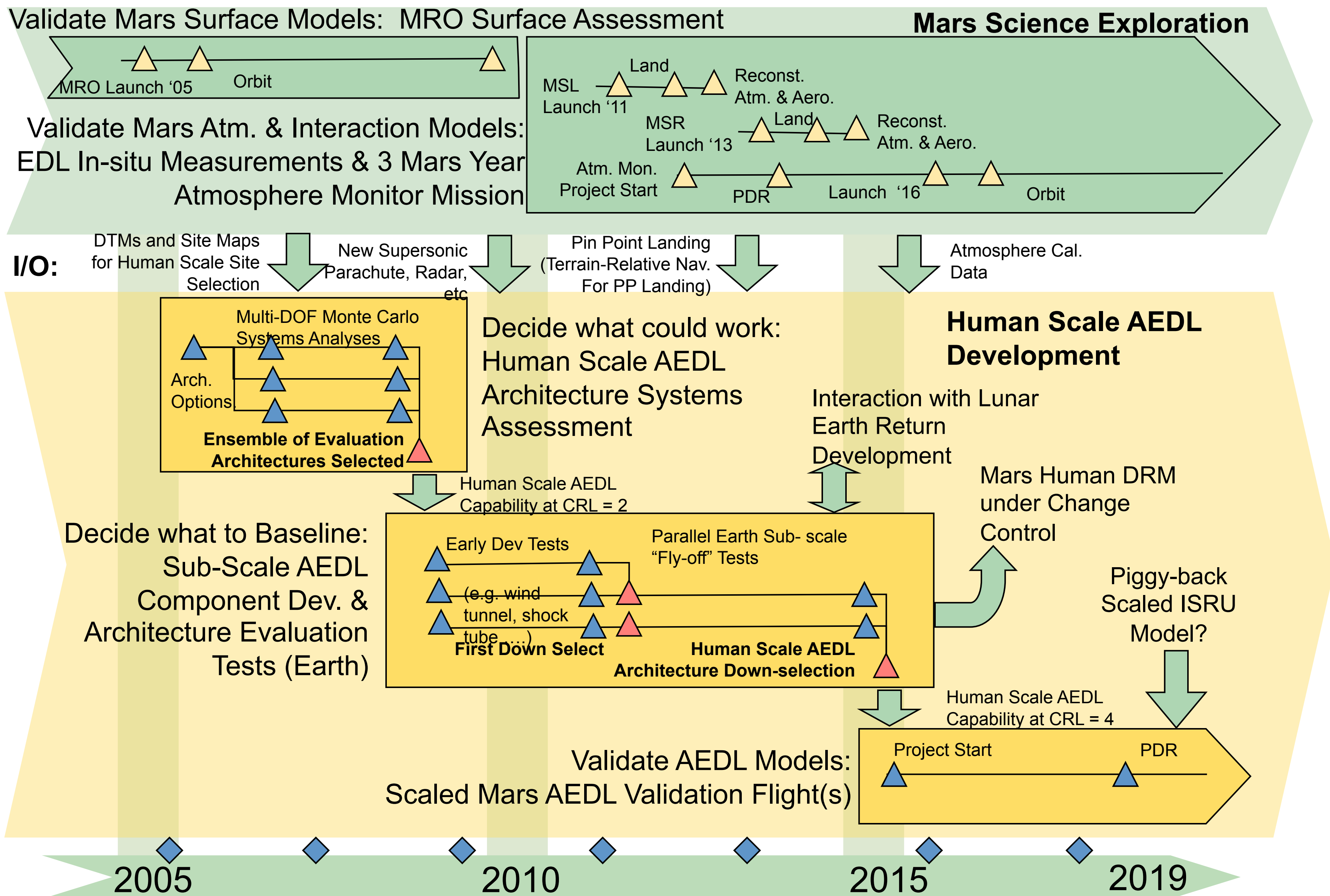
From 2005:

Mars HPLS AEDL Roadmap Observations

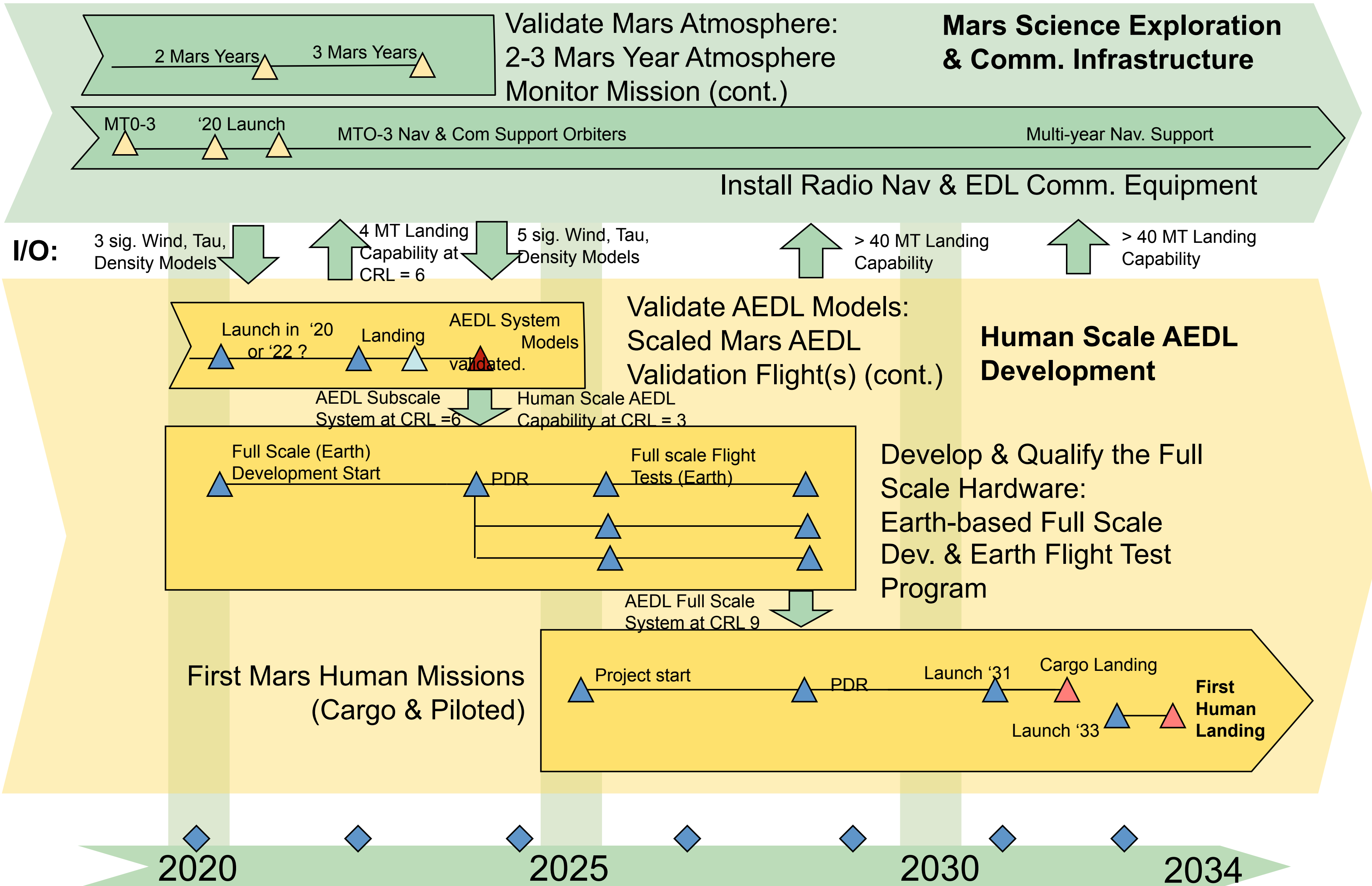
- It will take significant work and Earth-based testing to define and baseline the Human-scale AEDL system.
  - Unlikely that baseline will be selected before 2015
  - Work includes significant systems engineering, modeling, materials assessment, and sub-scale testing (at Earth).
- A scaled AEDL test flight (e.g. 1/10th) at Mars becomes important when:
  - The system being tested is truly a scaled system of the planned human mission intended to fly, therefore the full scale system design should be baselined first.
  - The purpose of the test is to validate the computational models of the full-scale Human HPLS, therefore the full scale system design should be modeled first.
  - There is no development full scale flight test prior to the first missions (cargo + piloted).
  - Results should be available for the start of full scale development testing
- A series of full scale tests at Earth will be required prior to the first Human Mars Landing.
- The HPLS AEDL system is likely to be very very different than the systems being used for robotic exploration in the next 10 years.

From 2005:

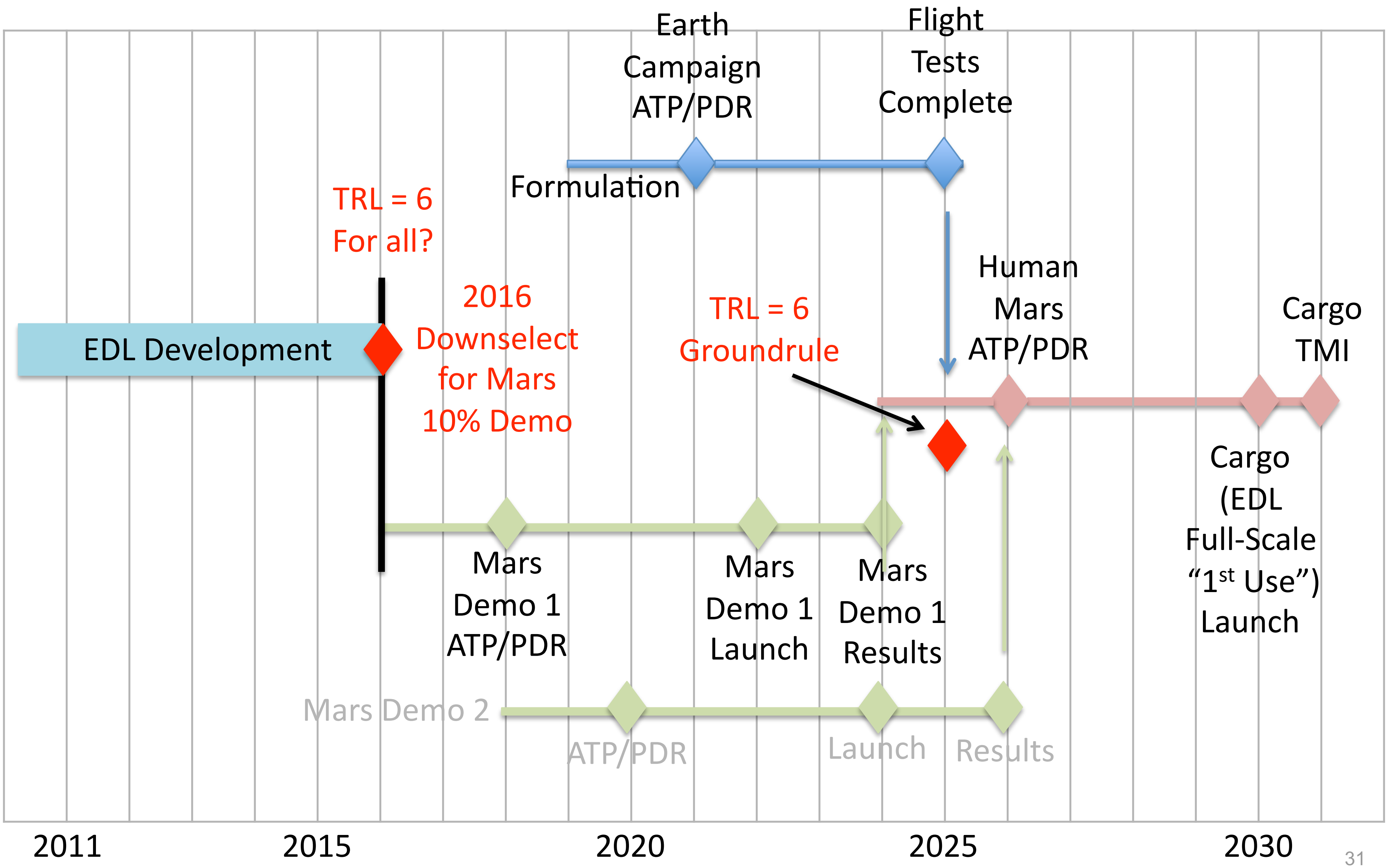
Detailed EDL Road Map: 2005 - 2019



From 2005:
Detailed EDL Road Map: 2020 - 2034



Revisit of High-Level EDL Roadmap (2010)



Example PRELIMINARY Products

HIAD TRL Entrance Criteria

TRL 5	*Component and/or breadboard validation in relevant environment*	
Subsystem 1	Materials (non-TPS)	N/A
Subsystem 2	IAD Structure	N/A
Subsystem 3	Thermal Protection System	Statistically relevant laboratory tests simulating appropriate entry mission load cycle have been completed demonstrating functional survival. Stow and deployment tests have been completed to determine minimum standards for storage and stowage volume together with defined heat shield durability limits against loss of functionality due to stowing process and storage time. Potential functionality loss from subsystem exposure to extrinsic environmental effects including vacuum, atomic oxygen, and temperature has been defined and preliminary laboratory tests of survivability have been demonstrated. Non -scalable performance metrics have been identified, solutions envisioned, and preliminary feasibility studies conducted.
Subsystem 4	Inflation System	N/A
Subsystem 5	Aerodynamics	<u>Dynamic Stability (i.e. Ballistic Range Testing)</u> Dynamic stability of mission relevant HIAD/vehicle configuration (vehicle c.g.) is verified experimentally and/or computationally.
Subsystem 6	Aerothermal	N/A
Integrated HIAD		<u>Fabrication</u> Fabrication of large-scale (large enough to capture flight-like flexibility and inflation timescale {e.g. 30% - 50%}) integrated IAD (structure + TPS + inflation system) <u>Deployment Testing</u> Vacuum chamber deployment testing from flight-like packed state to full inflation. <u>Aerodynamic Load Testing</u> Static testing at mission relevant peak loads. TRL 5 achieved if during deployment testing, IAD internal pressure, as a function of time, rises in a predictable and repeatable manner, and peak inflation loads are within expected bounds AND if during aerodynamic load testing, IAD takes the expected aerodynamic shape, within tolererance AND total IAD system mass and packed-volume are sufficient to mission relevant constraints.