

Overview of the NASA Entry, Descent and Landing Systems Analysis Studies for Large Robotic-class Missions

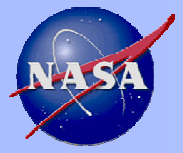
AIAA SPACE 2011 Conference

September 29, 2011

Thomas Zang, EDL-SA Project Manager

Acknowledgements

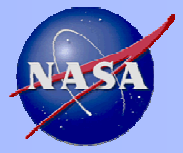
- Co-authors
  - Alicia M. Dwyer Cianciolo (NASA LaRC)
  - Mark C. Ivanov (NASA JPL)
  - Ronald R. Sostaric ((NASA JSC)
  - David J. Kinney (NASA ARC)
- EDL-SA Team
  - ~30 who made significant technical contributions
  - ~30 more who consulted
  - full list in backup
- Peer Reviewers
  - MSL-I Design Reviews
  - Exploration Feed-Forward Internal Peer Review



Outline

- Background
- MSL-Improvement (MSL-I) Study (FY 10)
- Exploration Feed Forward (EFF) Study (FY 10)
- Wrap-up

Background



EDL-SA Context

- **NASA Customers**
  - Strategic Management Council, Chief Engineer, AA's for ARMD, ESMD & SMD, and their Technology Program Managers
- **Question**
  - What technology investments should NASA make to enable landing large payloads on Mars?
- **Information Provided**
  - Recommended technology investment areas (with rationale and objectives) & high-level budget profiles
  - Documentation

Objectives of EDL-SA Study

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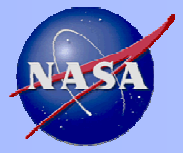
- **Overall Objective:**
  - **Develop a strategy and plan for NASA to be able to successfully land large payloads at Mars for both robotic and human scale missions**
- **Year-by-Year Foci**
  - **Identify the broad areas requiring technology development for Exploration-class missions: 40 mt landed payload [Year 1]**
  - **Identify the broad areas requiring technology development for large-robotic-class missions: 1-4 mt landed payload [Year 2]**
  - ~~**Develop detailed, costed, integrated (cross-cutting) technology development plans to TRL = 6 [Year 3]**~~

The 3 Systems Analyses
(from Executive Summary of Project Plan)

- **Exploration-class Study**
  - **"The first systems analysis will identify the optimal technologies for the 20-50 mt capability required for an Exploration-class mission"**
- **Mars Science Laboratory Improvement (MSL-I) Study**
  - **"The second systems analysis will determine the minimum technologies required to land a 1-5 mt spacecraft on the surface of Mars enabling post-MSL robotic missions. The spacecraft would have no requirement for feed-forward (to the Exploration-class mission) requirements."**
- **Exploration Feed Forward (EFF) Study**
  - **"The third systems analysis will identify those technologies that could be used for post-MSL missions that would provide significant feed forward to the Exploration-class missions."**

MSL-Improvement Study

November 2009 – December 2010



MSL-Improvement Study

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- **Goal**
  - Determine technology needs and technology development program needs to support increases in landed mass beyond the 950 kg MSL capability, performance enhancement features for: landed altitude and landed payload mass improvement
- **Key Ground Rules & Assumptions**
  - The launch vehicle is the Atlas V-551
  - The launch opportunity will be 2024 to support the Mars Sample Return lander
  - EDL architectures should be comprised of technologies that individually cost ~$200M or less to mature to sufficient TRL
  - Entry vehicle will have a 4.7 m maximum diameter (to fit Atlas V fairing), with an Apollo forebody shape

Primary Technologies Studied

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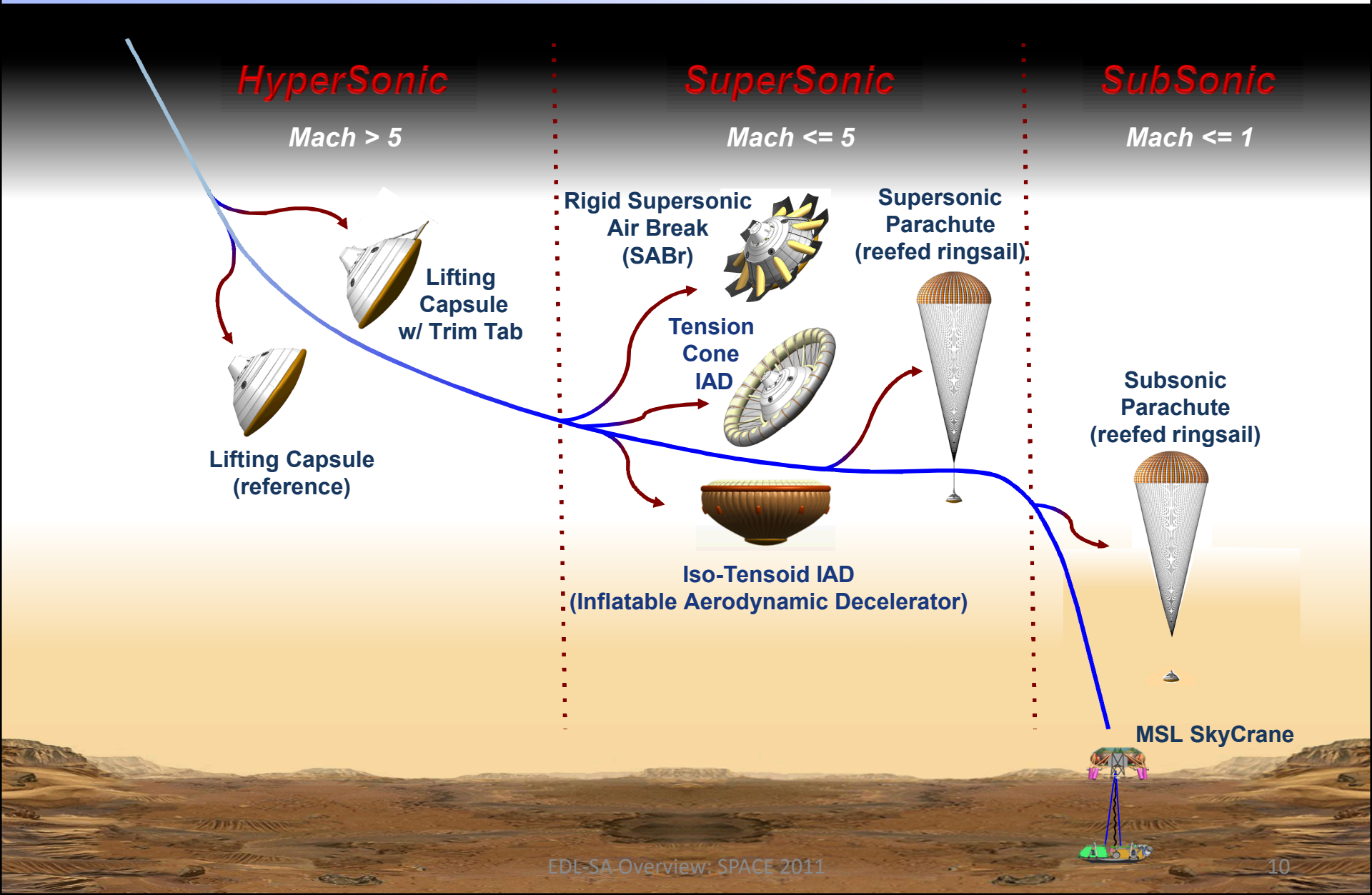

Derived Technology Sets (TS)

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	I	II	III	IV	V	VI	VII	VIII
Hypersonic	Lifting Capsule	Lifting Capsule	Lifting Capsule	Lifting Capsule	Lifting Capsule	Lifting Capsule	Lifting Capsule	Lifting Capsule
	Iso-Tensoid Drag Only IAD	Iso-Tensoid Drag Only IAD	Tension Cone Lifting	Tension Cone Lifting	Trim Tab		Rigid Deployable	Trim Tab+Rigid Deployable
Supersonic	Supersonic Parachute		Supersonic Parachute		Supersonic Parachute	Supersonic Parachute	Supersonic Parachute	Supersonic Parachute
Subsonic		Subsonic Parachute		Subsonic Parachute				
	MSL SkyCrane	MSL SkyCrane	MSL SkyCrane	MSL SkyCrane	MSL SkyCrane	MSL SkyCrane	MSL SkyCrane	MSL SkyCrane

MSL-I Fidelity, Risk & Cost Ratings

Fidelity	Low	Medium -Low	Medium	Medium -High	High
Risk	Low	Medium -Low	Medium	Medium -High	High
Cost	<$50M	$50M–$100M	$100M–$150M	$150M–$200M	$200M–$250M

Technology Set Evaluation

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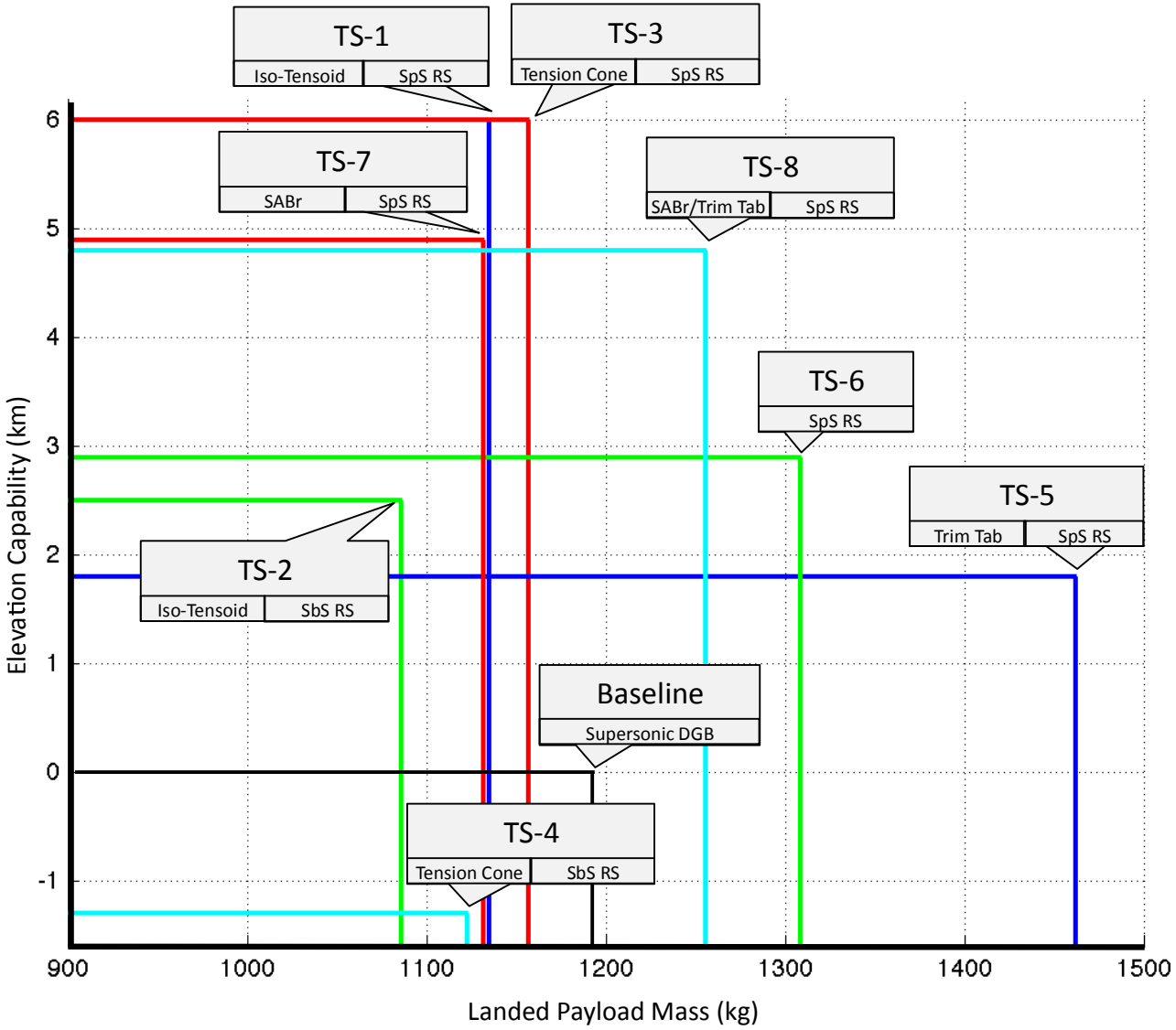

Performance Assessment Fidelity
Medium-High

SpS: Supersonic
SbS: Subsonic
RS: Ringsail
DGB: Disk-Gap-Band

MSL-I Technology Risk & Cost

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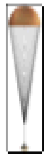
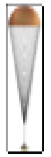
Assessment	*Assessment Fidelity*	Trim Tab	SABr	SABr + Trim Tab	Iso-tensoid	Tension Cone	Supersonic Ringsail	Subsonic Ringsail
Overall Risk	*Low*	Low-Medium	Medium	High	High	High	Medium	Low
Development Cost	*Low-Medium*	<$50M	$50M–$100M	$50M–$100M	$100M–$150M	$100M–$150M	$100M–$150M	$50M – $100M

MSL-I Technology Assessment

EDL-SA

Assessment	Assessment Fidelity	Technology						
		 Trim Tab	 SABr	 SABr + Trim Tab	 Iso-Tensoid	 Tension Cone	 Supersonic Ringsail	 Subsonic Ringsail
Optimized Performance (Paired with Supersonic Ringsail)	***Medium-High***	1.8 km, 1462 kg	4.9 km, 1132 kg	4.8 km, 1256 kg	6.0 km, 1135 kg	6.0 km, 1157 kg	2.9 km, 1309 kg	2.5 km, 1086 kg
Optimized Performance to 0 km (Paired with exisitng MSL DGB)	***Medium-High***	1132 kg	1088 kg	Unavailable	1108 kg	1101 kg	N/A	N/A
Overall Risk	***Low***	Low-Medium	Medium	High	High	High	Medium	Low
Development Cost Estimation	***Low-Medium***	<$50M	$50M-$100M	$50M-$150M	$100M-$200M	$100M-$200M	$100M-$200M	<$50M

Key MSL-I Conclusions 1
(within the MSL-I Technology Sets)

- The best altitude performers provide higher drag earlier in the supersonic phase
  - Iso-Tensoid with Supersonic Parachute (TS-1) 6.0 km
  - Tension Cone with Supersonic Parachute (TS-3) 6.0 km
  - SABr with Supersonic Parachute (TS-7) 4.9 km

- The best landed payload performers provide higher lift (Trim Tab) or higher drag (Supersonic Parachute)
  - Trim Tab with Supersonic Parachute (TS-5) 1462 kg
  - Supersonic Parachute alone (TS-6) 1309 kg
  - Trim Tab + SABr with Supersonic Parachute (TS-8) 1256 kg

- A subsonic parachute with an IAD in lieu of a supersonic parachute provides the least performance improvement
  - Iso-Tensoid with Subsonic Parachute (TS-2) 2.5 km / 1086 kg
  - Tension Cone with Subsonic Parachute (TS-4) -1.28 km / 1123 kg

Key MSL-I Conclusions 2
(within the MSL-I Technology Sets)

- The maximum payload that can be landed in 2024 using an Atlas V with an improved MSL architecture is
  - 0 km MOLA: ~1450 kg
  - +3 km MOLA: ~1250 kg
- Based on the technologies assessed, a larger supersonic parachute (30 m vs. 21.5 m MSL DGB) combined with one other technology is necessary to make any significant increase in landed payload mass and/or altitude

- The following technologies have some Feed-Forward potential
  - Trim Tab (aero control surfaces in general)
  - SIADs (as a step towards HIADs)
  - Bi-propellant engines (not included directly in the technology sets but was reviewed as a potential enhancer)

MSL-I Recommendations (for the 2024 Mission)

- Although all the technologies require more study, it can be concluded from the results to date that the following key enabling technologies strongly warrant investment:
  - Supersonic ringsail parachute (critical for all technologies identified)
  - Bi-prop engines (critical for all the heavier payload options)

- Conduct Pre-Phase A studies for all the MSL-I technologies to fill in the remaining performance, mechanical integration, risk, and cost gaps to better inform investment decisions
  - Add bi-prop engines to the technologies
    - TS-9: capsule + parachute + bi-prop engines
    - TS-10: trim tab + parachute + bi-prop engines
  - Evaluate landed accuracy for all Technology Sets
  - Conduct thorough Development Risk assessment of all technologies
  - Mature all technologies to Pre-Phase A level

Exploration Feed Forward Study

March 2010 – December 2010

Exploration-class Technologies

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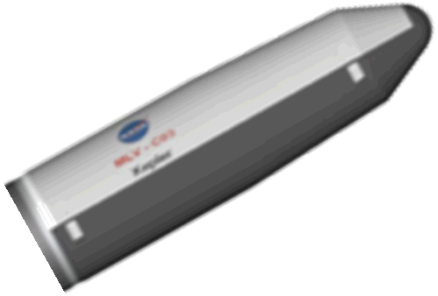
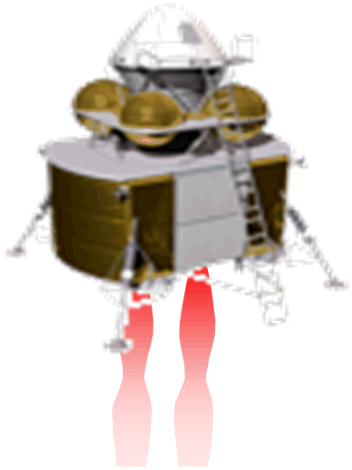
Rigid Mid-L/D AS



LHIAD



Propulsion



DSIAD

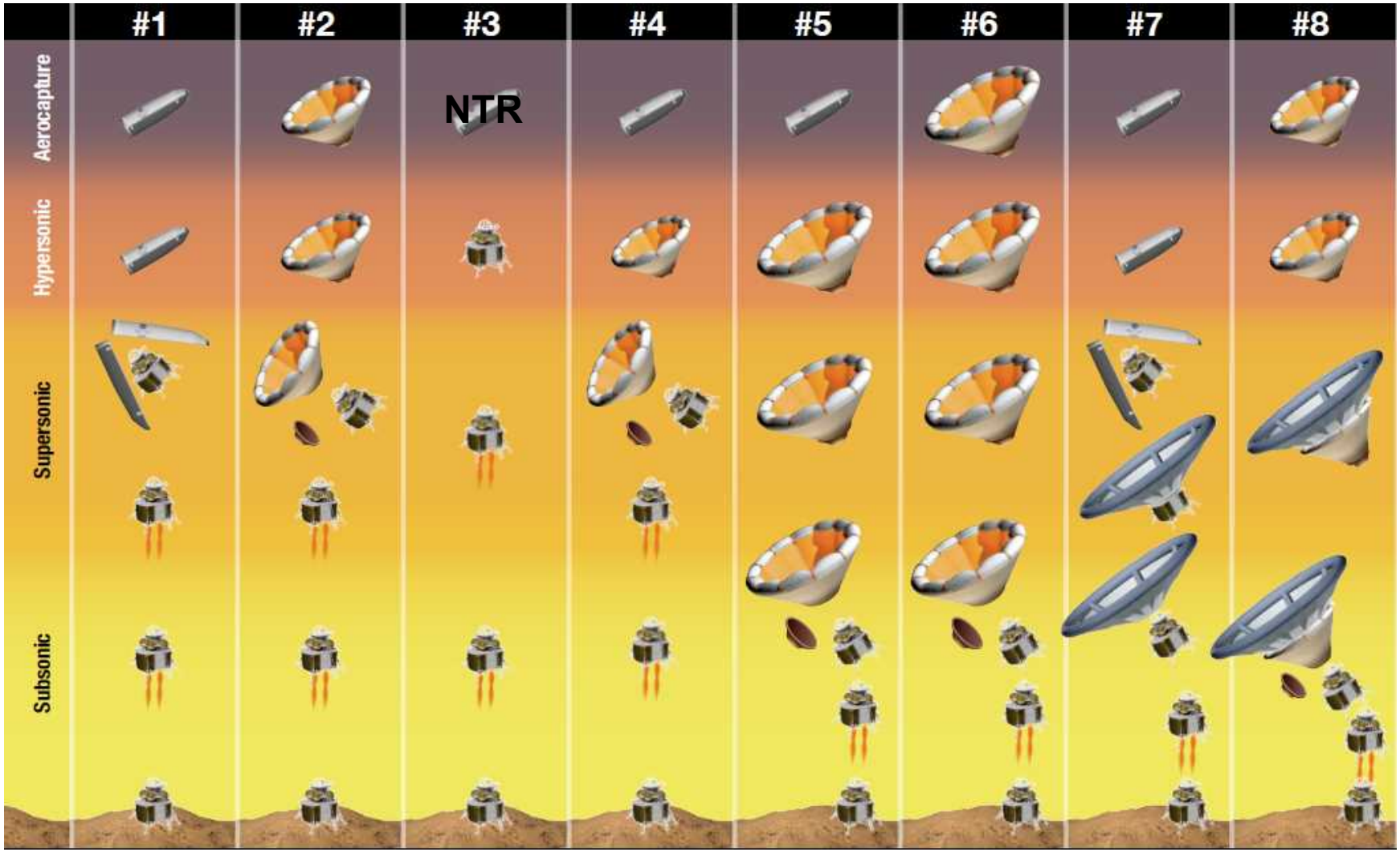


LSIAD-Skirt



HIAD:	Hypersonic IAD	SIAD:	Supersonic IAD
LHIAD:	Lifting HIAD	LSIAD:	Lifting SIAD
AS:	Aeroshell	DSIAD:	Drag SIAD

EDL-SA Exploration Architectures
(with Mars Arrival Mass underneath)



Exploration Feed Forward Study

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- **Goal**
  - Conduct EDL feed-forward robotic missions studies on 2–4 mt human precursor missions with payloads that demonstrate key ground technologies
- **Key Ground Rules & Assumptions**
  - Launch vehicle will be the Delta IV-H
  - Entry date: October 15, 2025 (2024 Mars opportunity)
    - But use the Mars Design Reference Architecture 5 entry velocity of 7.3 km/s as a TPS stress case
    - Note that MSL-I uses 5.8 km/s entry velocity
  - Landed payload will be at least 2.0 mt
  - Landed altitude capability will be a minimum of 0 km above MOLA
  - The global landing precision will be within 50 m of the desired touchdown point

EFF Evolution

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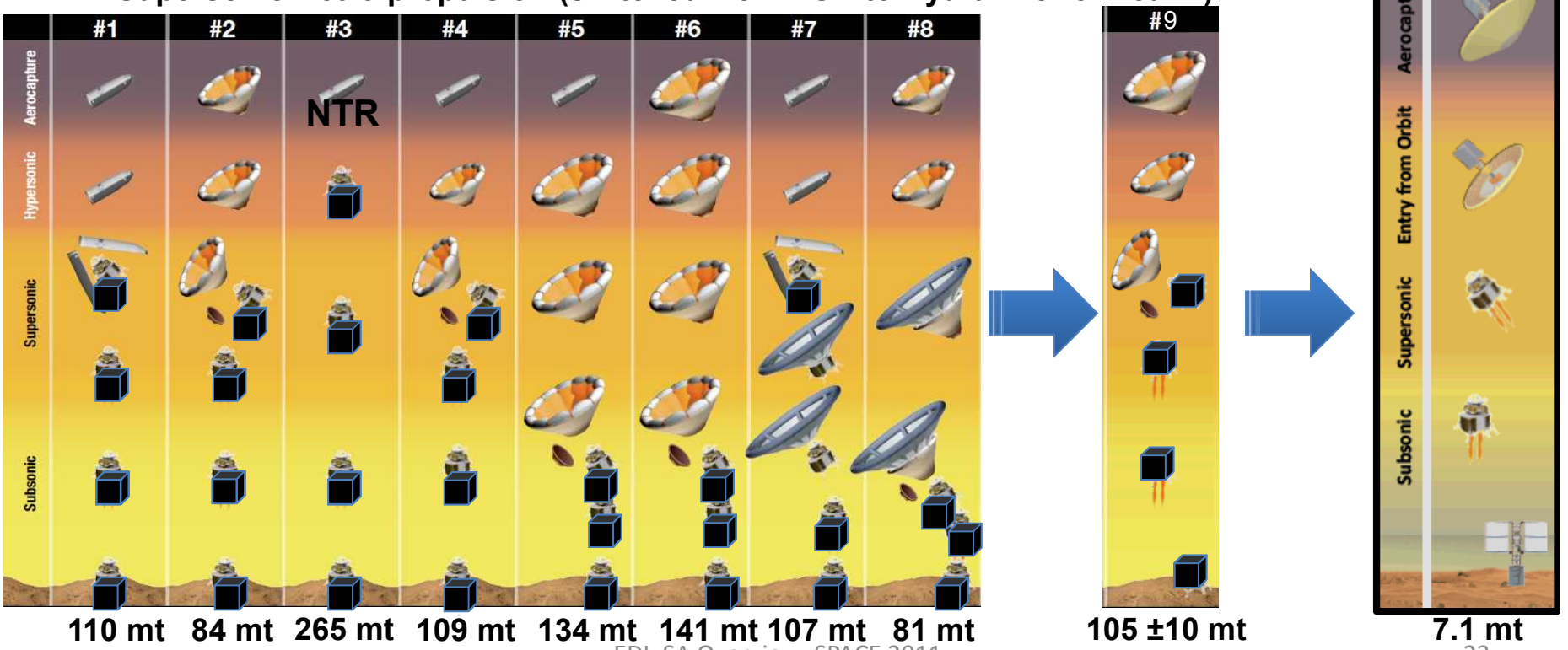
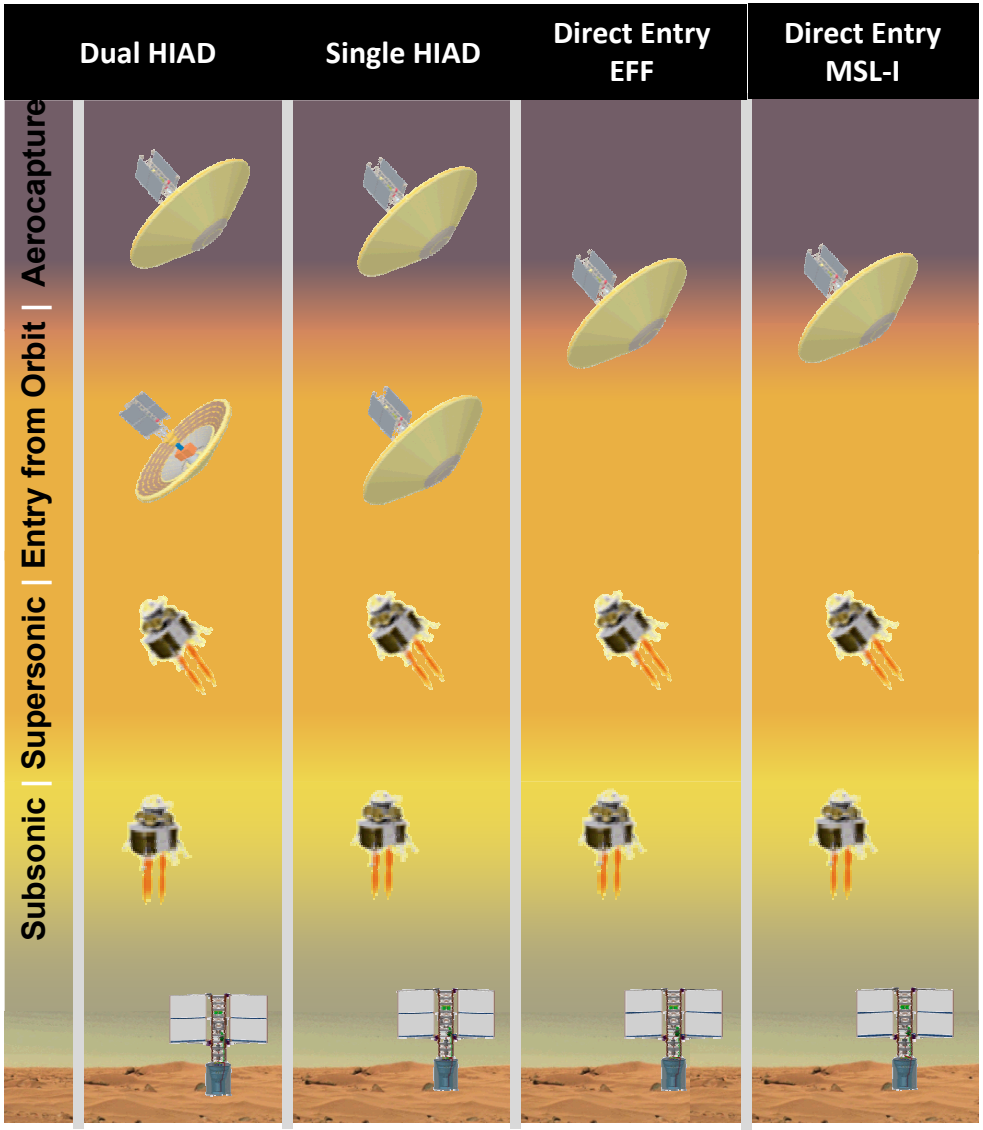
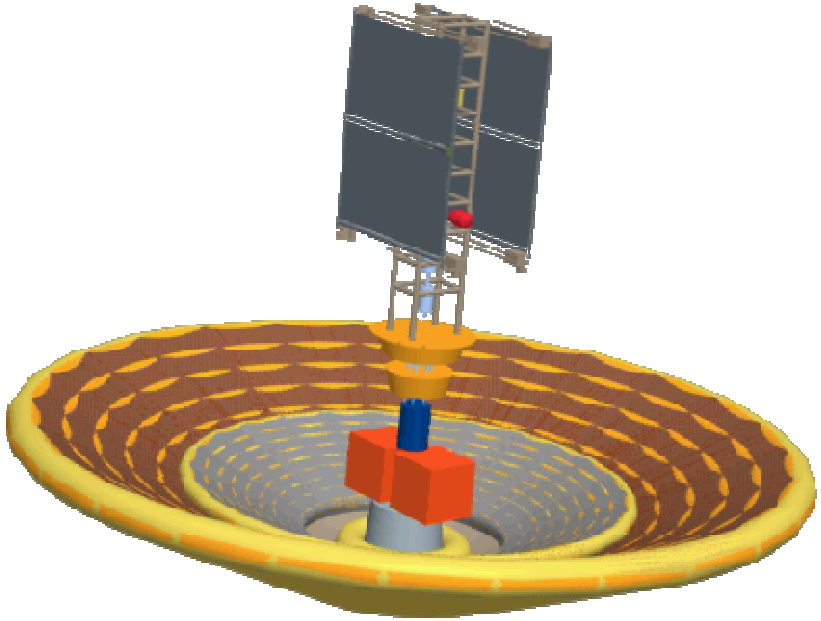
- Modified Arch 2 to Arch 9: optional separate HIADs for Aerocapture and Entry
- Refined Arch 9 to assess the next level of design detail using
  - Arrival mass limited to capability of Delta IV-Heavy for C3 = 15 $(km/s)^2$
  - 2 mt specified Payload (Movable Fission Power System)
  - HIAD TPS (Thermal Protection System): Ablator or Insulator
  - HIAD controller: Center of Gravity (CG), Bank or Combination CG/Bank
  - ALHAT sensor models
  - Supersonic Retro-propulsion (switched from LOX to Hydrazine for Year 2)



EFF Architectures & Payload

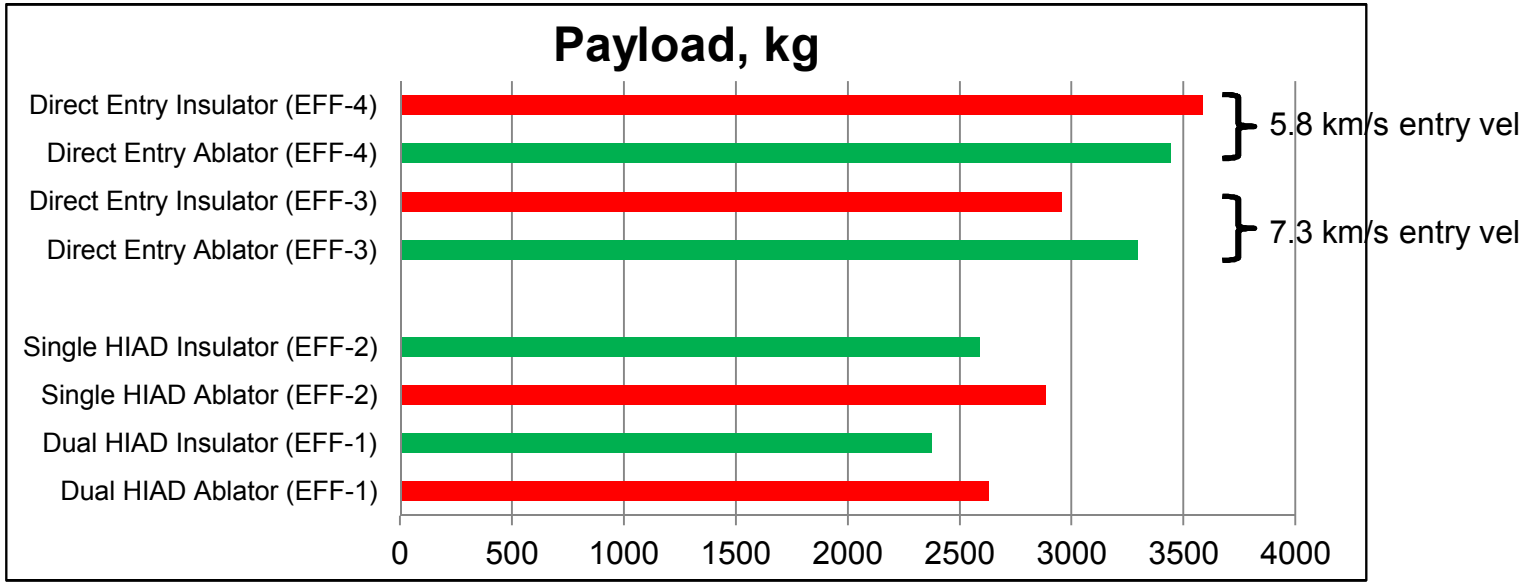




Movable Fission Power System: 10 kWe system without the water shielding

Key EFF Conclusions 1

- **Maximum payload the Delta IV-H can deliver to 0 km MOLA at Mars**



- **Required performance of supersonic retro-propulsion (SRP) system**

RS-72 Pump Fed NTO/MMH throttleable engines, Isp = 338 s

area ratio = 300, T/W = 3.7 Mars g's

1.4 > Mach at SRP initiation > 1.8

4 km >Altitude at SRP initiation > 7 km

Key EFF Conclusions 2

- **Optimum material/TPS, L/D, and size of the HIAD for aerocapture and entry**

		Dual HIAD		Single HIAD		Direct Entry, 7.2 km/s		Direct Entry, 5.8 km/s	
	Units	Ablator	Insulator	Ablator	Insulator	Ablator	Insulator	Ablator	Insulator
Payload	kg	**2627**	**2371**	**2881**	**2589**	**3294**	**2953**	**3442**	**3584**
Diameter	m	8	14	8	14	8	16	8	8

- **Sensor performance ranges for an ALHAT-like navigation & sensor system at Mars**
  - **Autonomous Landing and Hazard Avoidance Technology (ALHAT) is an on-going technology development project.**

Terrain Relative Navigation (TRN)

Expected states and ranges

Altitude: 2 – 7 km

Velocity: Mach 0.5 – 1.7

Altimeter

Activated at 6 km

Velocimeter

Activated at 2 km and 150 m/s

Hazard Detection & Avoidance (HDA)

Hazard Detection System scan

Altitude = 1 km and below

EFF Recommendations

- Continue to refine and update mass models
- Perform more extensive analysis on the feasibility of using center of gravity control for aerocapture and entry
- Develop transition concepts for separating the HIAD from the descent vehicle
- Update ALHAT sensor models and operating ranges for Mars
- Update star tracker operating range and conditions
- Perform GNC performance sensitivity to measurement quality and availability
- Trade timing, number of Terrain Relative Navigation (TRN) measurements; consider feasibility of performing TRN prior to powered descent
- Perform divert sensitivity study
- Perform detailed Hazard Detection and Avoidance analysis for Mars landing

Technology Investment Areas
(from Exploration-class & EFF Studies)

Technology
Sub-Scale Component Analysis, Testing & Evaluation
Rigid Aeroshell Tools
Dual Heat-Pulse TPS
Rigid Aeroshell Vehicle Design Studies
Supersonic Retro-Propulsion*
Flexible Aeroshell Tools
Deployable, Flexible Materials
Flexible Aeroshell Vehicle Design Studies
Autonomous Precision Navigation with Hazard Avoidance
Aerocapture Development
Sub-Scale System Testing
Supersonic Retro-Propulsion Flight Test Program
Deployable/Inflatable Decelerator Flight Test Program
Aerocapture Flight Test
Full-Scale System Testing
Feed-Forward Technology Mars Flight Test

*SRP is highest priority, as it is only plausible solution for supersonic deceleration

Details given in the EFF NASA TM

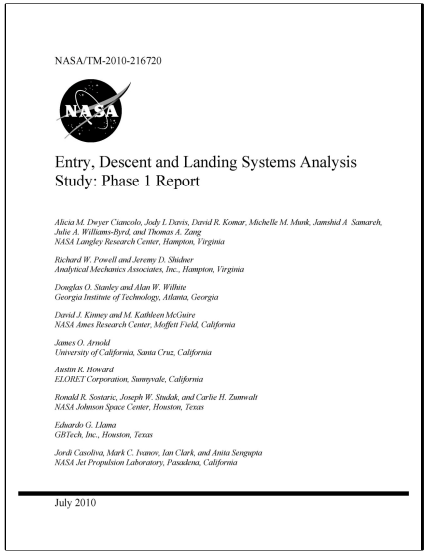
Wrap-up

Closing Comments

- EDL-SA results served multiple customers over 2+ year history
  - ARMD's Fundamental Aeronautics EDL investment portfolio
  - ESMD's ETDP EDL investment portfolio
  - SMD's In Space Propulsion Technology and Mars Technology Programs
  - Augustine "Human Spaceflight Commission"
  - OCE/OCT accelerated HIAD/SIAD technology developments
  - Human Exploration Framework Team (HEFT)
- Schedule limitations precluded additional technology sets and alternate architectures assessments (e.g. rigid deployable aeroshells, bi-prop descent engines, range triggers for precision landing, etc)
- EDL-SA study continued to foster strong cross-agency EDL technology teaming and focused efforts

EDL-SA Documentation

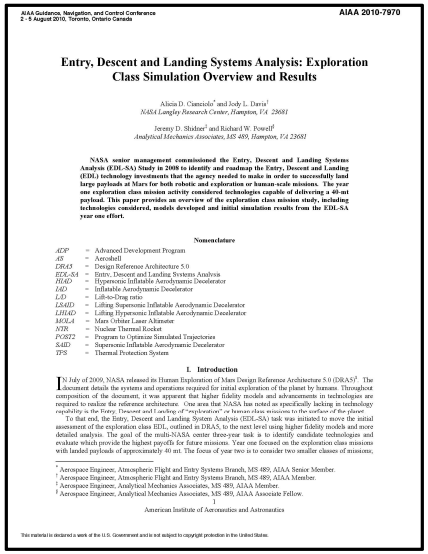
- 5 NASA TMs
  - Exploration-class Study
  - EFF Study (high-level)
  - MSL-I Study (high-level)
  - EFF Review Charts
  - *MSL-I Review Charts*
- 11 AIAA Papers
- 2 IPPW8 Papers
- EDL-SA Final Report
  - Summarizes results of the studies and contains programmatic assessment



NASA/TM-2010-216720

Entry, Descent and Landing Systems Analysis Study: Phase 1 Report

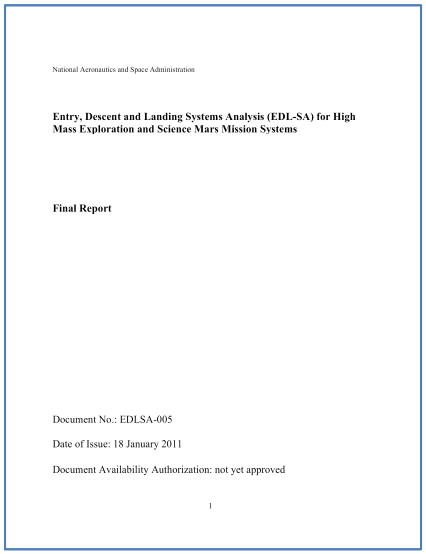
July 2010



AIAA Guidance, Navigation, and Control Conference
2 - 5 August 2010, Toronto, Ontario Canada

AIAA 2010-7970

Entry, Descent and Landing Systems Analysis: Exploration Class Simulation Overview and Results



National Aeronautics and Space Administration

Entry, Descent and Landing Systems Analysis (EDL-SA) for High Mass Exploration and Science Mars Mission Systems

Final Report

Document No.: EDLSA-005

Date of Issue: 18 January 2011

Document Availability Authorization: not yet approved

Backup

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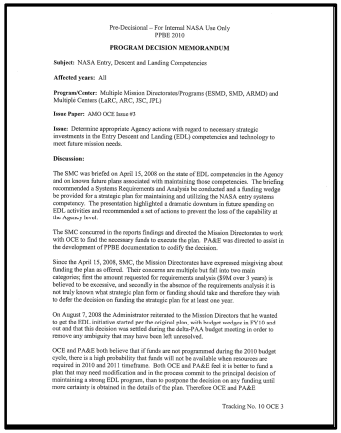
Key Documents

EDL Program Decision Memorandum



Pre-Decisional – For Internal NASA Use Only
PPBE 2010

PROGRAM DECISION MEMORANDUM

Subject: NASA Entry, Descent and Landing Competencies

Affected years: All

Program/Center: Multiple Mission Directorates/Programs (ESMD, SMD, ARMD) and Multiple Centers (LaRC, ARC, JSC, JPL)

Issue Paper: AMO OCE Issue #3

Issue: Determine appropriate Agency actions with regard to necessary strategic investments in the Entry Descent and Landing (EDL) competencies and technology to meet future mission needs.

Discussion:

The SMC was briefed on April 15, 2008 on the state of EDL competencies in the Agency and on known future plans associated with maintaining those competencies. The briefing recommended a Systems Requirements and Analysis be conducted and a funding wedge be provided for a strategic plan for maintaining and utilizing the NASA entry systems competency. The presentation highlighted a dramatic downturn in future spending on EDL activities and recommended a set of actions to prevent the loss of the capability at the Agency level.

The SMC concurred in the reports findings and directed the Mission Directorates to work with OCE to find the necessary funds to execute the plan. PA&E was directed to assist in the development of PPBE documentation to codify the decision.

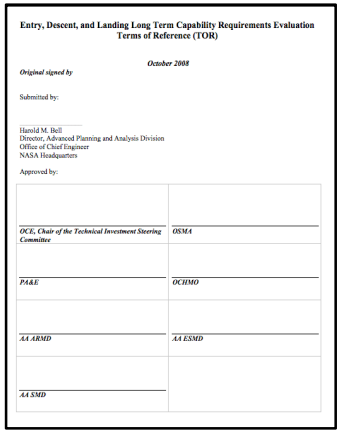
Since the April 15, 2008, SMC, the Mission Directorates have expressed misgiving about funding the plan as offered. Their concerns are multiple but fall into two main categories; first the amount requested for requirements analysis ($8M over 3 years) is believed to be excessive, and secondly in the absence of the requirements analysis it is not truly known what strategic plan form or funding should take and therefore they wish to defer the decision on funding the strategic plan for at least one year.

On August 7, 2008 the Administrator reiterated to the Mission Directors that he wanted to get the EDL initiative started per the original plan, with budget wedges in FY10 and out and that this decision was settled during the delta-PAA budget meeting in order to remove any ambiguity that may have been left unresolved.

OCE and PA&E both believe that if funds are not programmed during the 2010 budget cycle, there is a high probability that funds will not be available when resources are required in 2010 and 2011 timeframe. Both OCE and PA&E feel it is better to fund a plan that may need modification and in the process commit to the principal decision of maintaining a strong EDL program, than to postpone the decision on any funding until more certainty is obtained in the details of the plan. Therefore OCE and PA&E

Tracking No. 10 OCE 3

EDL Terms of Reference



Entry, Descent, and Landing Long Term Capability Requirements Evaluation Terms of Reference (TOR)

October 2008

Original signed by

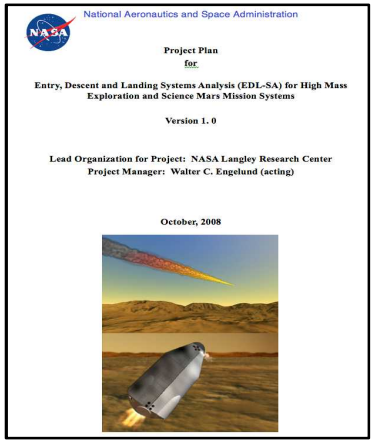
Submitted by:

Harold M. Bell
Director, Advanced Planning and Analysis Division
Office of Chief Engineer
NASA Headquarters

Approved by:

OCE, Chair of the Technical Investment Steering Committee	***OSMA***
PA&E	***OCHMO***
AA ARMD	***AA ESMD***
AA SMD	

EDL-SA Project Plan



National Aeronautics and Space Administration

Project Plan
for

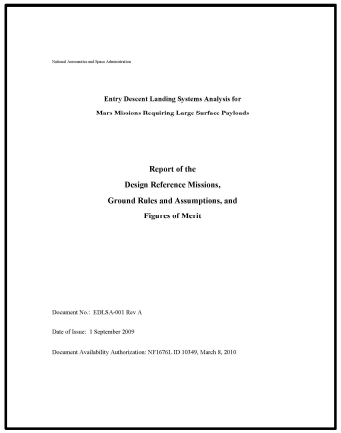
Entry, Descent and Landing Systems Analysis (EDL-SA) for High Mass Exploration and Science Mars Mission Systems

Version 1. 0

Lead Organization for Project: NASA Langley Research Center
Project Manager: Walter C. Engelund (acting)

October, 2008

EDL-SA DRMs, GR&As & FOMs/ECs



National Aeronautics and Space Administration

Entry Descent Landing Systems Analysis for Mars Missions Requiring Large Surface Payloads

Report of the Design Reference Missions, Ground Rules and Assumptions, and Figures of Merit

Document No.: EDLSA-001 Rev A

Date of Issue: 1 September 2009

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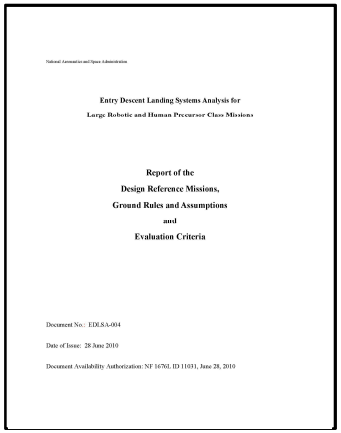

National Aeronautics and Space Administration

Entry Descent Landing Systems Analysis for Large Robotic and Human Precursor Class Missions

Report of the Design Reference Missions, Ground Rules and Assumptions and Evaluation Criteria

Document No.: EDLSA-004

Date of Issue: 28 June 2010

Document Availability Authorization: NF 1676L ID 11031, June 28, 2010

EDL-SA Study Accomplishments

EDL-SA

Charter: Develop a plan for NASA to be able to successfully land large payloads at Mars (and other destinations) for both robotic and Exploration scale missions

26 month/$6.1 M high fidelity Systems Analysis Study:

- ✓ – Assess integrated EDL architectures to enable precise delivery of landed masses (useful mass) in the 1 to 5 metric ton range for large robotic missions and 20 to 50 metric ton range for Exploration class missions
- – Develop detailed technology development roadmaps and associated development costs
- ✓ – Identify nearer term technologies which could benefit from immediate focused technology development (leveraging previous/ongoing study results)
- ✓ – Consider lower TRL technologies with potential for high payoffs, but need to be consistent with assumed mission need dates
- – Continue to solicit and assess emerging technologies at the system level
- ✓ – Document results in written reports and hold customer & peer reviews
- ✓ – Provide Informed EDL Technology Investment Strategies across multiple Mission Directorate investment portfolios
- ✓ – Develop cross Agency, multi-Center and multi-Mission Directorate Team with common goals, assumptions, analysis methodologies, and focus

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- Cianciolo, A.D., Zang, T.A, Sostaric, R.R., and Mcguire, M.K. "Overview of the NASA Entry, Descent and Landing Systems Analysis Exploration Feed-forward Study," International Planetary Probe Workshop, Jun 6–10 2011, Portsmouth, VA
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