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MEASURING EDL SYSTEM PERFORMANCE AT MARS:

A COMPARISON OF THE INSIGHT AND M2020 PERFORMANCE METRICS

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Outline

- Brief history of EDL systems
- Genesis for specifying “Critical EDL Metrics”
- InSight EDL overview
  - Similarities / differences to Phoenix
- M2020 EDL overview
  - Similarities / differences to MSL
- A summary of the InSight and M2020 critical performance metrics and supporting rationale

Brief History of EDL Systems

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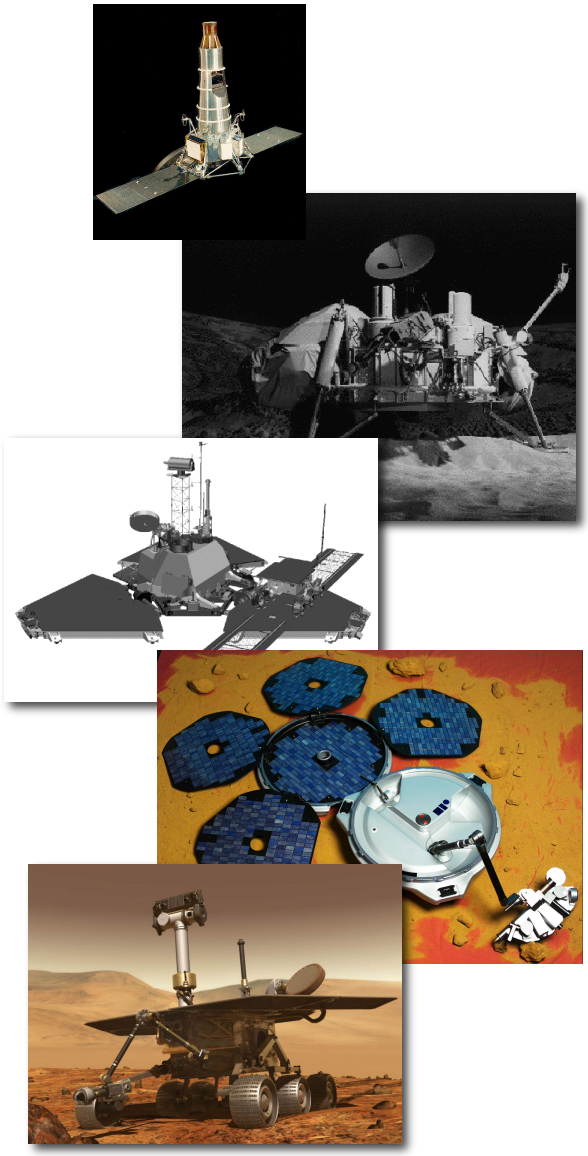
- One of the earliest EDL systems was for the moon:
  - Ranger series – mid-1960s, Lunar impact probes
  - Surveyor series – late 1960s – 1970s, first “soft lander”
- The USSR made the first Martian lander attempts, with one partially successful landing. Viking was ~5 years later, landing in 1976
- Recent (last ~20 years) EDL history has had “almost” overlapping EDL missions in development, primarily for Mars and Earth-return
  - 1997 – Mars Pathfinder; 1999 – Mars Polar Lander, Stardust; 2001 – Genesis; 2004 – Mars Exploration Rovers; 2008 – Phoenix; 2012 – Mars Science Laboratory



Genesis of today’s talk:

- *There is a long history of EDL missions, but we have yet to consistently capture and communicate EDL system performance.*

Genesis of Codifying Critical Performance Metrics

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- The InSight EDL system margin was challenged due to the differences between InSight and Phoenix EDL
  - Differences include higher entry velocity, higher landing site elevation, increased payload mass, and landing during global dust storm season
- InSight developed an EDL margin policy that ensures robustness under all credible conditions
- The margin policy forms a framework in which margins can be assessed for critical EDL metrics
- M2020 is facing similar “mass growth” and other development challenges. Thus M2020 is developing a similar margin policy framework.

Comparison of Heritage Systems

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	InSight	Phoenix	M2020	MSL
Arrival Date	**September 28, 2016**	**May 25, 2008**	**February 19, 2021**	**August 6, 2012**
Inertial Entry Velocity (km/s)	**6.3**	**5.6**	**5.6**	**6.1**
Landing Site Elevation (km, MOLA)	**-2.5**	**-4.1**	**-0.5 (max)**	**-4.5**
Entry Mass (kg)	**625 (max)**	**572.7**	**~3300**	**3152**
Ls / Dust Season	**226°** (Northern Autumn/Global Dust Storm Season)	**76.7°** (late Northern Hemi Spring)	**6°** (Northern Spring/Southern Autumn)	**151°** (early Southern Spring)
Entry Flight Path Angle (deg)	**-12.5 ± 0.21 [3-sig]**	**-13.0 ± 0.27 [3-sig]**	**-15.5°**	**-15.5°**
Landing Site Latitude	**4.5°N**	**68°N**	**30°S to 30°N (capability)**	**4.6°S**

Commonalities Between InSight and M2020 in Metric Selection

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Both InSight and M2020 are missions that:

- Have predecessor flown heritage missions (Phoenix and Mars Science Lab)
- Are being required to increase their EDL system capability
- Are Mars EDL missions

InSight and M2020 are different in that they have:

- Distinctly different architectures (e.g. triggers, landed configuration)
- Unique mission challenges (e.g. global dust storm season)

These traits result in a set of overlapping metrics as well as unique metrics specific to each mission. The following set of rationale capture the primary intent behind each critical metric.

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EDL Critical Metric Rationale:

1) Desire to Maintain As-Flown Heritage
2) Key System Requirement
   - e.g. Architecture (or hardware) is Dependent on Meeting Requirement
3) Indicator of a Challenge to the System (Near Requirement Limits), or of Having Performance Margin to Trade
4) New Feature (e.g. range trigger)
5) Metric that has high visibility

Summary of M2020 Metrics

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M2020 Metrics	Primary Rationale
Peak Deceleration	2,5
Parachute Deploy Mach Number	2,3
Peak Opening Load at Parachute Deploy	2
Parachute Deploy Flight Path Angle	4
Parachute Deploy Range Error	4
Min Altitude at First Radar Use	2
Timeline Margin (s)	3
Range to Target	2,5
Vertical and Horiz Velocity at Touchdown	2,3
Safe Landing Fraction	5,4
Fuel Remaining at Touchdown	1,2,3

Quick key: 1) Heritage; 2) Key Req; 3) Key Margin; 4) New; 5) High Visibility

Observations:

Most common rationale: 2
Least common rationale: 1

Linking Current Mission Challenges To Specific Metrics:

- Heavy Payload -> *Fuel and Velocities at Touchdown*
- Higher Landing Site Elevation -> *Fuel at Touchdown and Timeline Margin*
- Desire to shrink "drive to" distance for Landing Sites -> *Range to Target*

Summary of InSight Metrics

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Observations:

Most common rationale: 1,2
Least common rationale: 4

Linking Current Mission Challenges To Specific Metrics:

- Faster Entry Velocity -> *Integrated Heat Load*
- Heavy Payload -> *Peak Opening Load and AoA at Parachute Deploy [mach]*
- Higher Landing Site Elevation -> *Peak opening load at Parachute Deploy and Min Altitude at First Radar Use*
- Potential for global dust storm -> *Min/Max Altitude at First Radar Use Due to Atm Variability*

Primary Rationale	InSight Metrics
5	Peak Heat Rate
3	Integrated Heat Load
2	Peak deceleration
3	Peak Opening Load at Parachute Deploy
1	AoA at Parachute Deploy [Mach]
1	Max Attitude Rate on Chute (first 10sec)
1	Max Attitude Rate on Chute (post 10sec)
2	Max Altitude at First Radar Use
2,3	Min Altitude at First Radar Use [timeline]
1	Attitude Rate at Lander Separation
2	Vertical (Min/Max) and Horiz Velocity at Touchdown
2	Attitude Rate at Touchdown
3,1	Fuel Remaining at Touchdown

Quick key: 1) Heritage; 2) Key Req; 3) Key Margin; 4) New; 5) High Visibility

Side by Side Metric Summary

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M2020 Metrics			InSight Metrics
		5	Peak Heat Rate
		3	Integrated Heat Load
Peak Deceleration	5,2	2	Peak deceleration
Parachute Deploy Mach Number	3,2		
		1	AoA at Parchute Deploy [Mach]
Peak Opening Load at Parachute Deploy	2	3	Peak Opening Load at Parachute Deploy
Parachute Deploy Flight Path Angle	4		
Parachute Deploy Range Error	4		
		1	Max Attitude Rate on Chute (first 10sec)
		1	Max Attitude Rate on Chute (post 10sec)
		2	Max Altitude at First Radar Use
Min Altitude at First Radar Use	2	2,3	Min Altitude at First Radar Use [timeline]
Timeline Margin	3		
		1	Attitude Rate at Lander Separation
		3	Attitude Rate at Touchdown
Vertical and Horiz Velocity at Touchdown	2,3	3	Vertical (Min/Max) and Horiz Velocity at Touchdown
Range to Target	2,5		
Safe Landing Fraction (%)	5,4		
Fuel Remaining at Touchdown	1,2,3	3,1	Fuel Remaining at Touchdown

Summary

- Establishing a set of high-level performance metrics for an EDL system yields a framework in which EDL margins can be assessed consistently

- Though developed independently, the InSight and M2020 Critical EDL Metrics mostly overlap where commonalities between the missions exist, and also capture details specific to the interests of each mission

- Mission-specific characteristics will drive different choices in critical performance metrics, e.g.
  - Desire to protect heritage capability or performance
  - Desire to identify or protect specific margins within the design
  - Desire to draw attention to a new or anticipated capability

- Critical metrics are continuously evaluated throughout the lifecycle of the project and may change as the design matures or as knowledge is increased