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Future Landing Capabilities of the Mars 2020 Entry, Descent, and Landing System

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Introduction

- 2013 Science Definition Team (SDT) report outlined a mission concept for the Mars 2020 rover, that includes:
  - "…select and store a compelling suite of samples in a returnable cache…"

- Recent studies of approaches to the return of samples from Mars propose a three-mission architecture:
  1. Sample caching rover
  2. **Sample retrieval and launch (SRL) mission**
  3. Sample return orbiter

- Although there are currently no approved plans to return the Mars 2020 sample cache, a future SRL mission would need to access the same landing site as Mars 2020
- Potential challenges:
  - SRL may be heavier than M2020
  - SRL may launch in a poorer opportunity (from an EDL perspective) than M2020
  - SRL may need to be solar powered, due to mass or configuration challenges

- Current desire is for SRL EDL system to be as close as possible to the build-to-print MSL/M2020 EDL system

Study Objectives

1. To understand the impact of a larger landed mass on the heritage MSL/M2020 EDL assumptions and performance
   – Looked at landed masses up to 1200 kg

2. To understand what landing sites can be reached (altitude) by the SRL mission under different arrival seasons and design assumptions
   – Looked at a range of arrival seasons
   – Looked at potential improvements in parachute performance
     • Based on ongoing Low Density Supersonic Decelerator (LDSD) program

Methodology

- Simulation approach:
  - Used baseline Mars 2020 assumptions for hardware, software and timeline, vehicle mass properties, and entry interface condition
  - Flew all simulation cases to Gale Crater latitude/longitude and altitude with synthetic terrain
  - Applied seasonal atmosphere assumptions for given Ls
  - Increased landed mass to 1200 kg (no change to non-landed hardware)
  - Evaluated higher Mach parachute deploy (up to Mach 2.4)

- Monte Carlo runs performed for selected arrival dates and parachute deploy Mach numbers
  - Used heritage simulation environment (POST) of the MSL/Mars 2020 EDL team

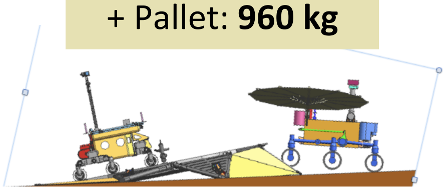
- Developed partials from the simulation results to extrapolate to other design points
  - Ls sweep: density vs. parachute deploy altitude
  - Mass sweep: ballistic coefficient vs. parachute deploy altitude
  - Terminal velocity: trade timeline margin for landed altitude

Why 1200 kg landed mass?

- Previous EDL studies identified potential fuel margin break point near 1200 kg
  - Current study produced similar results
  - Landing 1200 kg results in ≤ 5 kg of unallocated fuel margin (worst case)

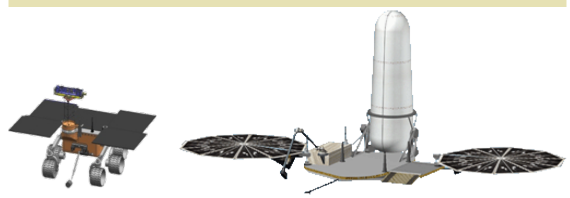
- Preliminary SRL studies suggest 1200 kg is a reasonable upper bound for landed mass

MAX-C + ExoMars + Pallet: **960 kg**



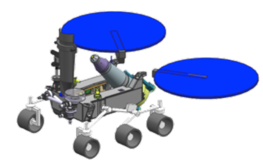
(Decadal Survey MCS, 2010)

MAV + Fetch + Lander: **1005 kg**



(Decadal Survey MCS, 2010)

Mobile MAV: **1050 kg**

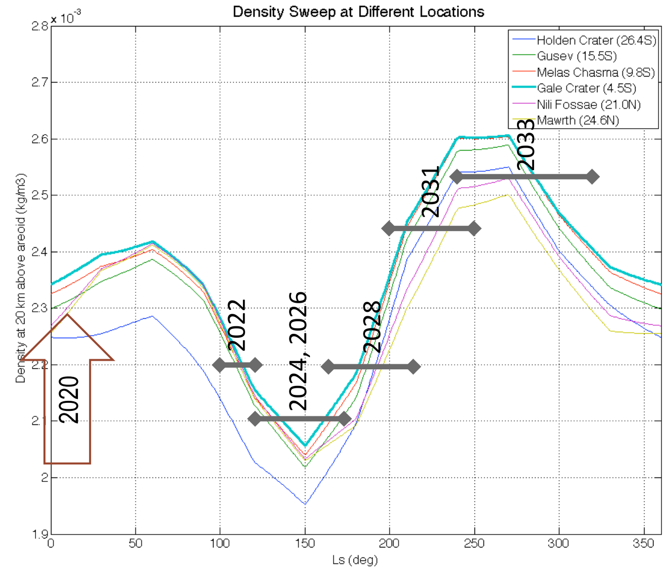


(Team X Study, 2012)

- Additional issues related to landed 1200 kg with current EDL system
  - Available volume and packaging concerns
  - Powered Descent Vehicle (PDV) modes
  - May require redesign of parts of the EDL system (e.g., descent brake portion of BUD)
  - Mobility and touchdown performance capabilities

Drivers on Landed Elevation Capability

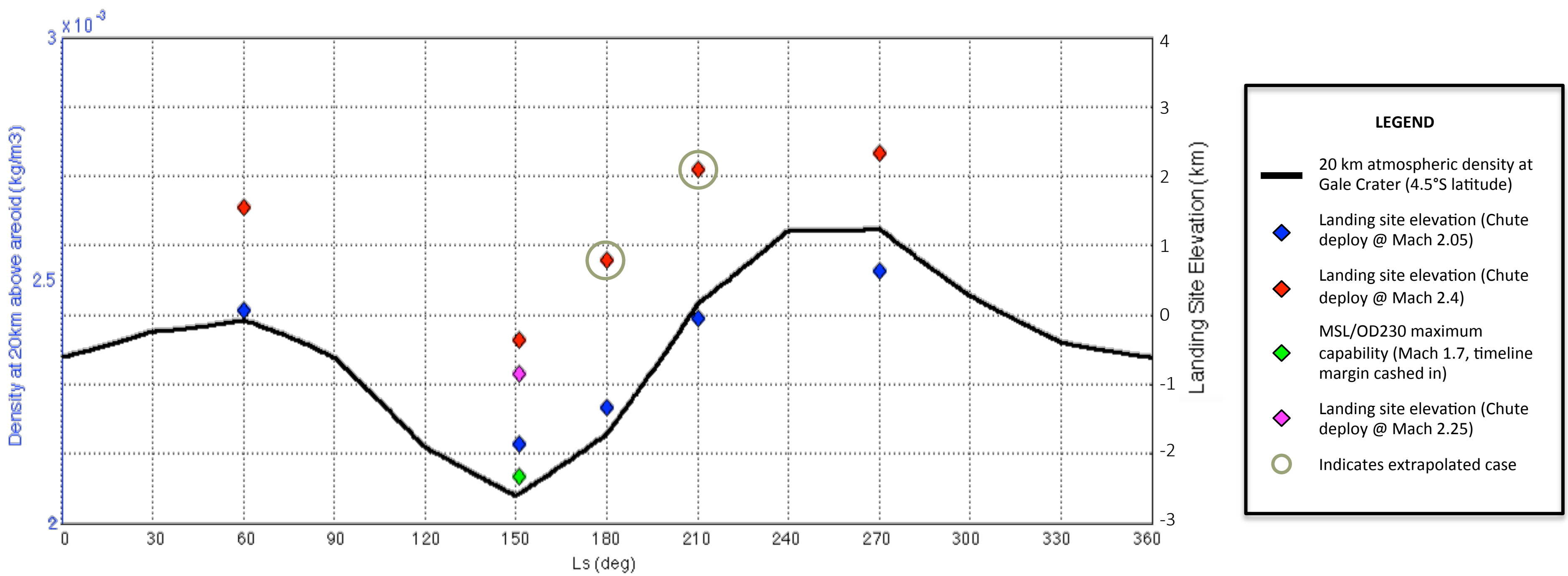
1. Landed mass
   - ~1 km effect from 900 kg to 1200 kg
2. Arrival season
   - ~2.5 km effect from pressure cycle variation
3. Parachute technology – increase in deploy Mach
   - ~1.5-2 km effect, increasing Mach to 2.4 nominal
   - Note: area oscillations not modeled



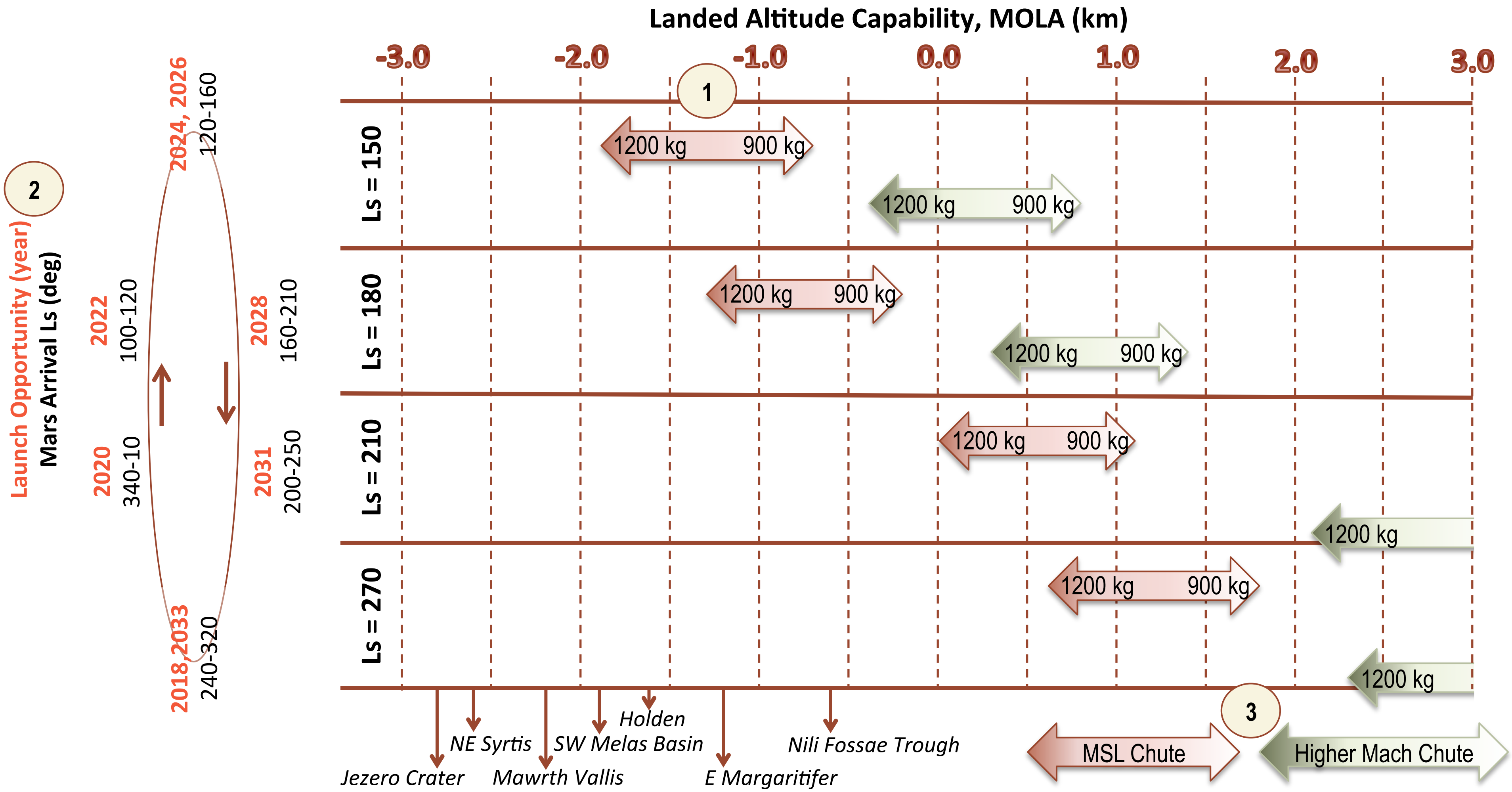
- Second order effects (≤ 0.5 km delta on landed elevation)
  - Entry velocity (~50 m altitude per +0.1 km/s entry velocity)
  - Entry FPA optimization (very small sensitivity)
  - Time of day (~2-4% density variation = up to ~350 m impact)
  - Landing site latitude (<6% density variation = up to ~500 m impact)
  - Dust storms, Ls 180-330 (impact expected to be < 0.5 km)
  - **Second-order variables were held constant in analysis

Landing Site Elevation Capability

- Landing site elevation capability as a function of landing season
  - Blue points assume current parachute (DGB) capability
  - Red points assume higher Mach parachute capability
  - Study result partials applied to get cases beyond those run directly
  - Results have a ~ +/- .5km error



Summary of Retrieval Altitude Considerations



<u>*Notes:*</u>

- *Results assume baseline M2020 hardware, software and timeline, vehicle mass properties, and entry interface condition*
  - *Close to equatorial landing site (Gale Crater)*
  - *Effects of dust not considered (Ls ≈ 180-330)*
- *Results are accurate to within ± ~0.5 km*
- *High fidelity cases were run at 1200 kg; altitude performance at other landed masses was calculated using ballistic coefficient partial*
- *Each launch opportunity has a range of viable arrival Ls values; ranges shown for realistic values of C3, entry velocity, and TOF*

Conclusions

- There is sufficient fuel to land 1200 kg, but available development margin is thin
- Sites at or below ~ -1.0 km MOLA should be reachable by future SRL missions using existing EDL capabilities
  - Within capabilities for consecutive opportunities from 2028 – 2035
  - Ability to reach -1.0 km before 2028 will depend on landed mass required
  - Maximum possible elevation for a 1200 kg SRL is ~+0.5 km
- Higher altitude landing sites (> -1.0 km MOLA), if chosen, can still be accessed but may require:
  - Delaying retrieval mission to opportunities with more favorable landing conditions (2028+), or
  - Adopting technologies to improve delivered mass (LDSD parachute), or
  - Investing in technologies to reduce landed mass requirements (esp. MAV)
- Other factors not considered in this study:
  - Landed precision
  - Landing site latitude
  - Design of future SRL rover

Backup

MSL/M2020/SRL Comparison

	MSL	Mars 2020 Baseline	Assumed SRL
Launch Vehicle	Atlas V 541	Atlas V 541 (pending LV selection)	TBD
Arrival Ls	150.6°	6° - 7°	Depends on Opportunity
Entry Mass	3152 kg	~3250 kg	~3550 kg
Landed Mass	899 kg	Up to 960 kg	1200 kg
Parachute Deploy Mach	1.75	Nominal: 2.05 Spread to: 2.2-2.3	TBD
Ballistic Coefficient	136 kg/m^2	140 kg/m^2	153 kg/m^2
Landed Elevation	-4.4 km (actual)	TBD	TBD
Max Elevation Capability	-1 km MOLA	+0.5 km MOLA	TBD
Landed Ellipse	• Original: 25 km x 20 km • Final: 19 km x 7 km	• 25 km x 20 km • Final expected with range trigger: 13 km x 7 km	TBD

Detailed Assumptions for Performance Simulations

- Flew all simulation cases to Gale latitude/longitude and altitude with synthetic terrain
- Didn't increase mass of non-lander hardware (also didn't look at TPS)
- Entry vehicle fixed at MSL-like conditions (~6 km/s inertial, ~5.7 km/s atmosphere relative, EFPA = -15.5°, entry time of day ~3 PM)
- Seasonal dust assumptions, no dust storms considered
- "Engineering" winds applied for all cases, regardless of landing season
- Didn't tune entry guidance for landing season, but did tune guidance for higher Mach parachute deploy cases
- Didn't take advantage of potential higher subsonic Cd from a disksail parachute
- Didn't look at larger diameter chute
- Turned off area oscillations modeling (significant lien on high Mach results)
- Used a floor of 20 s of timeline margin

Liens Against Study Results

- Disabled area oscillations model
  - Results in severe angular rates and accelerations; magnified with greater exposure time due to high Mach deploys
  - Models based on one data point from BLDT
  - Upcoming LDSD tests may provide additional insight
- Did not increase mass of non-lander hardware
- Dust storms were ignored
  - Applicable to Ls 180 – 330
  - Impact on altitude performance expected to be < 0.5 km (density reductions less than previously believed)
  - Principal issue is changes in expected wind fields (landing precision)
- Fuel for TRN
  - Did not consider fuel impact for longer TRN/Multi-X diverts

Arrival Ls for Future Opportunities ($C_3 < 15\ km^2/s^2$)

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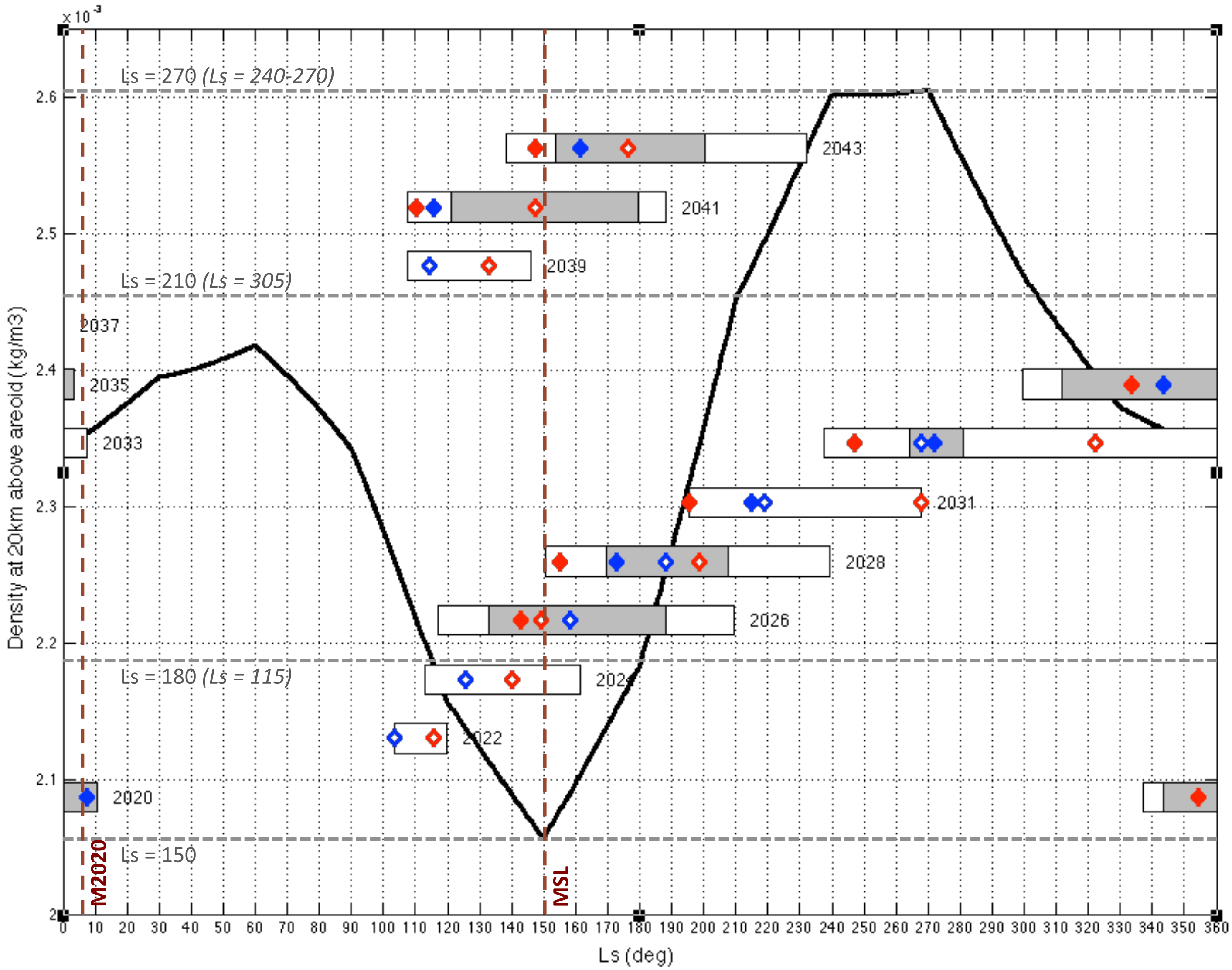
Mars Formulation



LEGEND

- 20 km atmospheric density at Gale Crater (4.5°S latitude)
- Arrival Ls range for $C_3 < 15\ km^2/s^2$ and at least one inertial entry velocity < 7 km/s
- Arrival Ls range for $C_3 < 15\ km^2/s^2$ and at least one inertial entry velocity < 6 km/s
- Minimum C_3 (Type I)
- Minimum C_3 (Type II)
- Minimum Inertial Entry Velocity (Type I)
- Minimum Inertial Entry Velocity (Type II)

Note:

- $C_3 = 15\ km^2/s^2$ corresponds to a launch mass of 4585 kg (~10% margin)
- 1200 kg landed mass requires launch mass of at least 4194 kg (assuming no additional mass required above MSL other than landed mass)