Mission Concept Engineering Assessments to support ICE-SAG (2019)

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Context for these engineering studies

- The Ice and Climate Science Analysis Group (ICE-SAG) was chartered by MEPAG (Oct 2019) to identify mission concepts that could address key Mars ice- and climate-science questions.
  - Identified mission concepts should seem feasible to execute in the next decade.
  - Of particular interest were mission concepts that could fit within $850M = the NASA New Frontiers mission cost class.
- To aid this work, engineering studies were undertaken to provide some estimation of cost and technology needs to undertake key science investigations.
  - A Team X architecture study (JPL) was undertaken to concepts focused on in situ/surface measurements of the subsurface and meteorological environment. Drawing from orbiter engineering studies completed for NEX-SAG (2015), a study of an orbiter/lander concept focused on atmospheric investigations was studied by the Mars Program Office.
  - These studies were designed to explore key architecture trades for the concepts under discussion within ICE-SAG.
- These slides summarize the results of those studies, and serve as Supplemental Materials to the full ICE-SAG report.
  - This document and the full ICE-SAG report can be downloaded at: *https://mepag.jpl.nasa.gov/reports.cfm?expand=topical*.

Static Lander Concept Study Overview

Study Purpose

- The purpose of this study is to determine if there is an architecture for a Mars Ice and Climate Evolution science mission that fits within the Financial ($850M Cost Cap) and Technical (Launch Vehicle Mass and Volume) boundary conditions of a New Frontiers Announcement of Opportunity

Study Objectives

- From customer supplied information for the instrument and mission functional requirements for a
  - 1) North Polar Surface Science Static Lander concept
  - 2) North Polar Mechanically Sub Surface Science (Drill) Static Lander concept
  - 3) North Polar Radar Sub Surface Science (Radar) Static Lander concept

Study Approach

- Examined five lander concept architectures to explore the mid to high latitude regions of Mars
- Rather than create a detailed design from the ground up, the team took a known lander design/cost from Phoenix and Insight and assessed deltas
  - This allowed for the exploration of many architectures very quickly to make an initial assessment of technical and cost feasibility

Study Considerations

- The study focused on the lander design and thus did not evaluate in detail what changes to the entry system and cruise stage may or may not be required
  - Costs were scaled for these elements based on the New Frontiers allocations, but that scaling may not account entirely for the added complexity of thermal control of an RTG during cruise or packaging of larger solar arrays, for example
- While the design of key subsystems was considered, other subsystems were assumed to be identical to Insight (Telecom, CDH, ACS) which may not be accurate
- The cost estimation methodology took the simple approach of “mass = cost”; costs were scaled from a known design, with some additional detail for known elements, such as a potential RPS, drill, and rover
  - This form of cost estimation provides a good initial evaluation of the architectures, but should not be taken as a final cost estimate

Summary of Static Lander Mission Concepts

- **Lander Concept Option 1**: Static lander at 82-degree latitude with radioisotope power, operating for one full Martian year
  - **1A:** MMRTG Power System
  - **1B:** a notional SMRTG Power System
- **Lander Concept Option 2**: Solar-powered static lander at 82-degree latitude with 1 meter drill, operating only through the Martian summer
- **Lander Concept Option 3**: Solar-powered static lander at 60-degree latitude operating for one full year
  - **3A:** with an AXEL rover carrying a GPR
  - **3B:** without an AXEL rover but with GPR + TEM on lander

Legend

Exceeded

Met

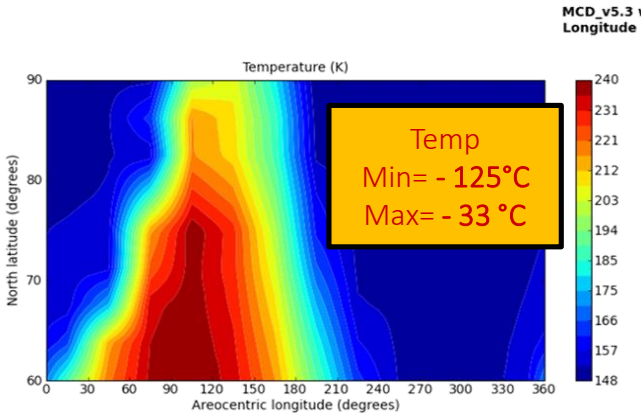
Below

	InSight Design Allocations	**1A:** 82N Lander powered by an MMRTG	**1B:** 82N Lander powered by an a Next-Gen RTG	**2:** 82N Solar Lander with Drill	**3A:** 60N Solar Lander with Rover & GPR	**3B:** 60N Solar Lander with GPR & TEM
Lander Mass	324 kg	450 kg	365 kg	400 kg	440 kg	380 kg
Payload Mass	50 kg	30 kg	30 kg	28 kg	22 kg	23 kg
Power System	5 m^2 solar array	MMRTG (~110 W_e)	SMRTG-2 (~40 W_e)	~4 m^2 solar array w/ tracking	~11 m^2 solar array w/ tracking	~11 m^2 solar array w/ tracking
Met Cost Cap ($850M FY19)	-					

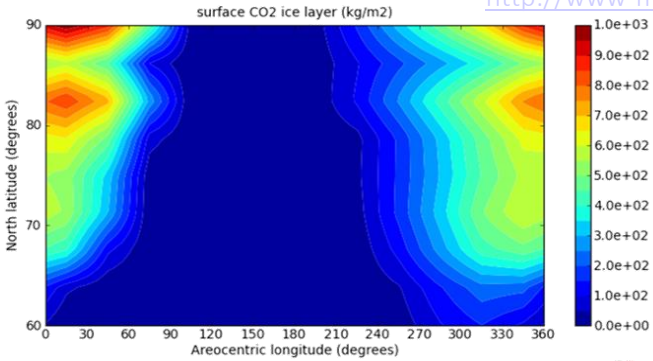
Mars Ice and Climate Evolution (ICE-SAG)

Environmental Considerations 60°N - 80°N

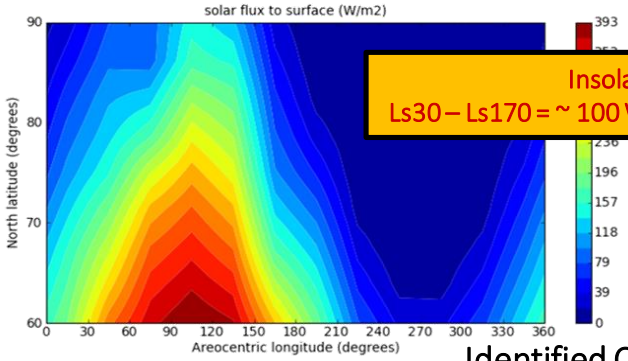
Source: Mars Climate Database v5.3, http://www-mars.lmd.jussieu.fr/mcd_python/



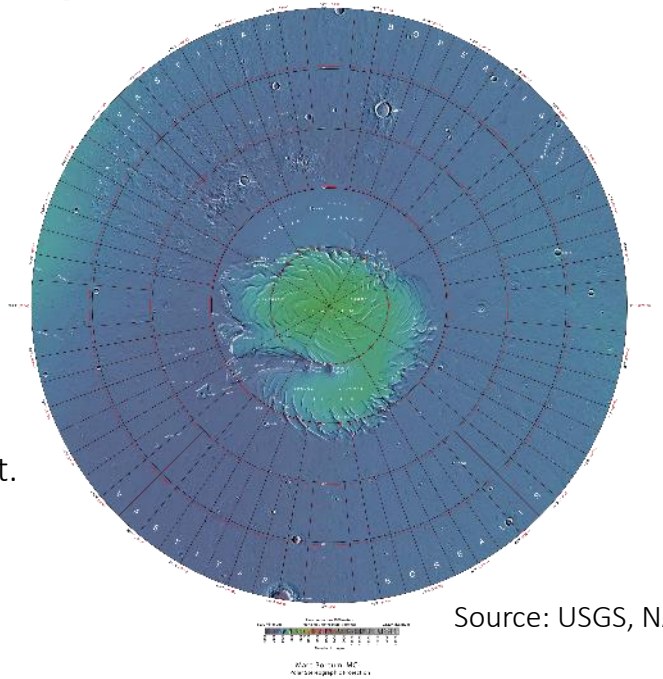
Temp
Min= - 125°C
Max= - 33 °C



Between Ls270 to –Ls60 surface CO thickness can grow up to 0.6m assuming CO2 Ice density of 1500 kg/m3



Insolation
Ls30 – Ls170 = ~ 100 W/m2 @ LMST noon



Source: USGS, NASA

Assumptions:

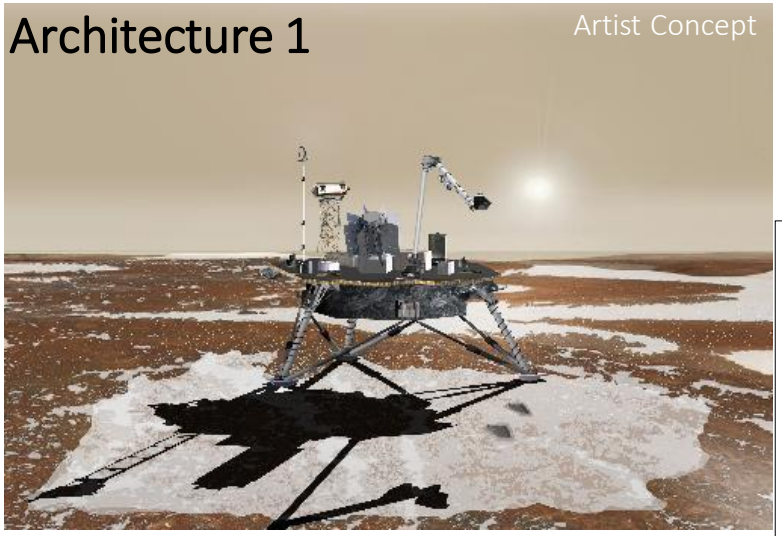
Latitude: 60° – 90 ° N
Longitude: 0 °
LMST: 12 noon
Ls: 0 ° - 360 °

Identified Challenges:

- Survival and operation during polar night.
- CO2 deposition
- Up to 60% year has little to no solar flux.
- Energy and storage
- Heat dissipation
- Landing site perturbation from lander thruster plume.

Pre-decisional. For planning and discussion only.

Mars Ice and Climate Evolution (ICE-SAG) Concept 1A/B: RPS Powered Lander



Lander Type: InSight/Phoenix
Location: 82°N
Power Type: Nuclear
Mission Duration: 1 Mars Year
Primary Science: CO_2 cycle, atmospheric monitoring.

Option 1A – MMRTG (8 GPRS)
Lander Estimated Changes:
- Power: Remove S/A, add MMRTG, add RTG electronics = + 30 kg
- Thermal: Add pumped fluid loop system for RTG thermal control = + 45 kg
- Mechanical: Add RTG thermal shield, add RTG mounting/access features = + 30 kg
- Propulsion: Add additional h/w to accomodation. added mass = + 21 kg
- Total estimated mass upper = + 126 kg

Key Assumptions:
- Insight aeroshell can be used; analysis needed to assess config.
- Insight cruise stage can accommodate thermal system

Instrument List for Lander Concepts 1A and 1B

Instrument	Qty.	CBE Mass
LIDAR (Phoenix)	1	6.0 kg
Meteorological station (MET-MPL)	1	3.0 kg
Thermogravimeter & Thermal/electrical cond probe (MECA)	1	7.8 kg
NIR Spectrometer (Exo-Mars: Micro-omega)	1	2.4 kg
Dust Particle Analyzer (LADEE: LDEX)	1	3.6 kg
TLS- single channel	1	1.0 kg
VIS Camera	1	0.5 kg
Thermal Imager (mini-TES)	1	3.2 kg
Hand Lens (MAHLI)	1	1.6 kg

Option 1B – Next Gen RTG (2 GPRS)
Lander Estimated Changes:
- Power: Remove S/A, add NextGen RTG-2, add RTG electronics = - 7 kg
- Thermal: Add pumped fluid loop system for RTG thermal control = + 22 kg
- Mechanical: Add RTG thermal shield, add RTG mounting/access features = + 20 kg
- Propulsion: Add additional hardware to accommodate added mass = + 7 kg
- Total estimated mass upper = + 42 kg

Key Assumptions:
- Insight aeroshell can be used; analysis needed to assess config.
- Insight cruise stage can accommodate thermal system

Mars Ice and Climate Evolution (ICE-SAG)
Concept 2: Lander with drill

Architecture 2

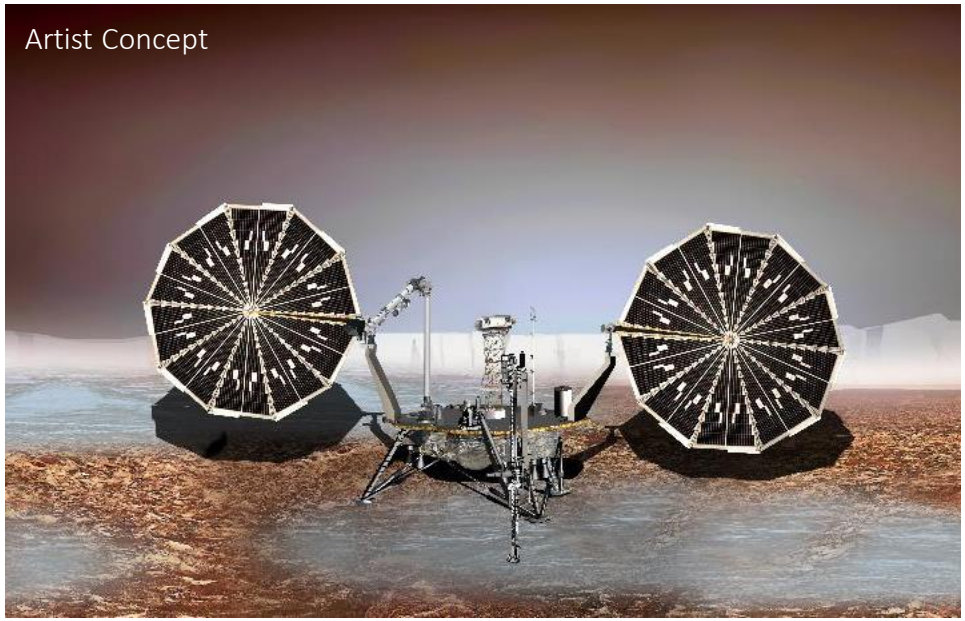
Lander Type: InSight/Phoenix
Location: 82°N
Power Type: Solar
Mission Duration: Mars Summer
Primary Science: NPLD drilling, atmospheric monitoring.
Primary Instrument: 1 m Rotary Percussive Drill

–Lander Estimated Changes:
- Power: Potential battery upper for drilling = + 7 kg
- Thermal: No change
- Mechanical: Add drill, add solar array gimbals, add robotic arm enhancements = + 53 kg
- Propulsion: Add additional hardware to accommodate added mass = + 12 kg
- Total estimated mass upper = + 72 kg

–Key Assumptions:
- Insight aeroshell can be used; analysis is needed to assess configuration
- Large drill can be accommodated on the lander deck and robotic arm can be modified for drilling
- Solar arrays can be articulated with sufficient ground clearance
- Warm electronics box is no more than 0.2 m3 in volume

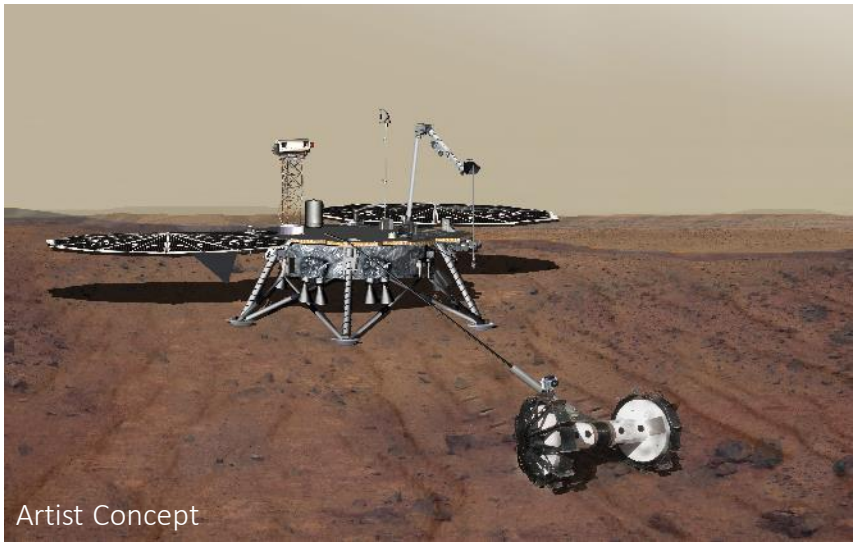
Instrument List for Lander Concept 2

Instrument	Qty.	CBE Mass
LIDAR (Phoenix)	1	6.0 kg
Meteorological station (MET-MPL)	1	3.0 kg
Sonic Anemometer (Mars Acoustic Anemometer)	1	1.5 kg
Simple Raman Spec (RLS on ExoMars)	1	2.5 kg
TLS- single channel	1	1.0 kg
VIS Camera	1	0.5 kg
Bolometer (Diviner)	1	12.0 kg
Hand Lens (MAHLI)	1	1.6 kg



Mars Ice and Climate Evolution (ICE-SAG) Concept 3A: Subsurface Lander with GPR rover

Architecture 3A



Lander Type: InSight/Phoenix, AXEL rover
Location: 60°N
Power Type: Solar
Mission Duration: 1 Mars Year
Primary Science: Subsurface characterization, using mobile Ground Penetrating Radar (GPR), atmospheric monitoring

Note: For option 3A, the GPR on the rover is not included here, but is included in the total cost and mass rollup.

Lander Estimated Changes:
- Power: Add additional solar arrays = + 25 kg
- Thermal: No change
- Mechanical: Add rover, add rover egress, grow deck for rover, add solar array gimbals = + 68 kg
- Propulsion: Add additional hardware to accommodate added mass = + 19 kg
- Total estimated mass upper = + 112 kg

Note: Mechanical carried 15 kg for solar array gimbals, but this is within the error bounds of an architecture study

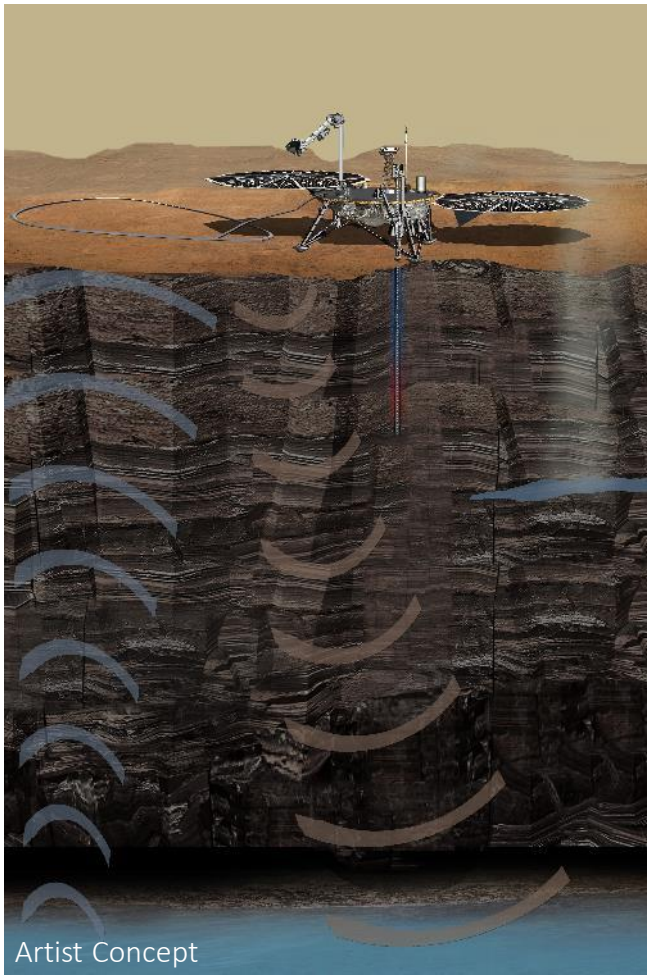
Key Assumptions:
- Solar arrays can be grown, or additional arrays can be added to the lander
- Solar arrays can be articulated with sufficient ground clearance
- New aeroshell and entry system design
- Warm electronics box is no more than 0.2 m3 in volume

Instrument List for Lander Concept 3A

Instrument	Qty.	CBE Mass
LIDAR (Phoenix)	1	6.0 kg
Meteorological station (MET-MPL)	1	3.0 kg
Sonic Anemometer (Mars Acoustic Anemometer)	1	1.5 kg
Dust Particle Analyzer (LADEE: LDEX)	1	3.6 kg
TLS- single channel	1	1.0 kg
VIS Camera	1	0.5 kg
Thermal Imager (mini-TES)	1	3.2 kg

Mars Ice and Climate Evolution (ICE-SAG)
Concept 3B: Subsurface Lander with static TEM

Architecture 3B



Lander Type: InSight/Phoenix
Location: 60°N
Power Type: Solar
Mission Duration: Full Mars Year
Primary Science: Subsurface sounding using static Ground Penetrating Radar (GPR) + Transient Electromagnetic (TEM), atmospheric monitoring.

Key Assumptions:

- Solar arrays can be grown, or additional arrays can be added.
- Solar arrays can be articulated with sufficient ground clearance
- New aeroshell and entry system
- Warm electronics box is no more than 0.2 m3 in volume

Instrument List for Lander Concept 3B

Instrument	Qty.	CBE Mass
LIDAR (Phoenix)	1	6.0 kg
Meteorological station (MET-MPL)	1	3.0 kg
Sonic Anemometer (Mars Acoustic Anemometer)	1	1.5 kg
Dust Particle Analyzer (LADEE: LDEX)	1	3.6 kg
none	1	0.0 kg
TLS- single channel	1	1.0 kg
VIS Camera	1	0.5 kg
Thermal Imager (mini-TES)	1	3.2 kg

Note: For option 3B, the GPR and TEM are not included here, but are included in the total cost and mass rollup

Lander Estimated Changes:

- Power: Add additional solar arrays = + 25 kg
- Thermal: No change
- Mechanical: Add solar array gimbals = + 18 kg
- Propulsion: Add additional H/W to accommodate added mass = + 9 kg
- Total estimated mass upper = + 52 kg

Note: Mechanical carried 15 kg for solar array gimbals, but this is within the error bounds of an architecture study

Planetary Protection for Static Lander Concepts

Lander Concept Option 1A and 1B: Static lander concept at 82-degree latitude with RPS power, surviving for one full Martian year

- Assumptions:
  - The landing site is close enough to the pole for temperatures to be too cold to support persistent water in the case of a non-nominal impact
- Challenges:
  - An analysis demonstrating that a region/pool of persistent water cannot be created in the case of a non-nominal impact may be required
    - If not possible to demonstrate that a region/pool of persistent water cannot be created, or the NASA Planetary Protection Officer does not accept the analysis then the hardware that would reach the Martian surface must be enclosed in a bio-barrier and undergo a four-order-of-magnitude microbial reduction process

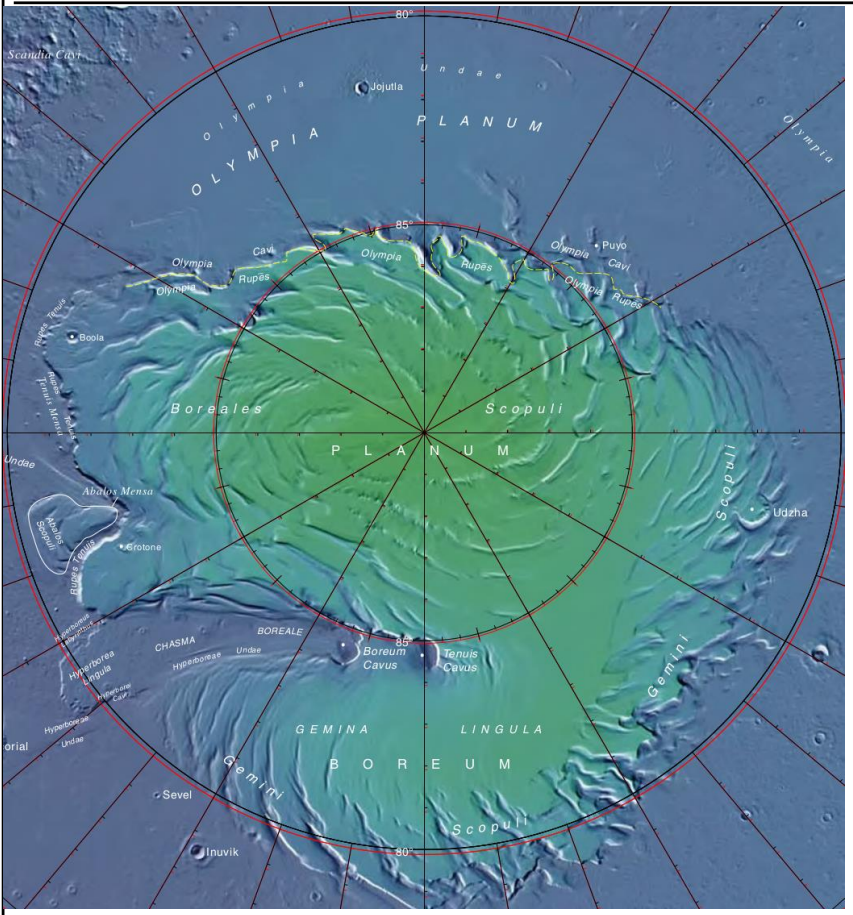
Lander Concept Option 2: Solar-powered static lander concept at 82-degree latitude with drill, operating just through the Martian summer

- Assumptions:
  - The landing site is close enough to the pole for temperatures to be too cold to support persistent water caused by a drilling operation
- Challenges:
  - An analysis demonstrating that a region/pool of persistent water cannot be created during drilling may be required
    - If not possible to demonstrate that a region/pool of persistent water cannot be created, or the NASA Planetary Protection Officer does not accept the analysis then the hardware that would penetrate the Martian surface must be enclosed in a bio-barrier and undergo a four-order-of-magnitude microbial reduction process

Lander Concept Option 3: Solar-powered static lander concept at 60-degree latitude surviving for one full year

- 3A: with an AXEL rover
- 3B: without an AXEL rover but with GPR + TEM on lander
- Assumptions:
  - Lander has onboard RHUs
- Challenges:
  - Project should perform an analysis demonstrating that a region/pool of persistent water cannot be created in the case of a non-nominal impact
    - It is probably ***not*** possible to demonstrate that a region/pool of persistent water cannot be created, so the hardware that would reach the Martian surface must be enclosed in a bio-barrier and undergo a four-order-of-magnitude microbial reduction process

Static Lander Concept
EDL Mission Design Constraints



-EDL trajectory targeting to a high latitude region above 70deg N puts an additional constraint for Mars arrival conditions and B-plane crossing

- Below is a parametric look at Central angle as a function of V∞ (hyperbolic velocity) which must be used in selecting the Earth-Mars launch arrival pair for a direct transfer

Vinf	Central Angle	EDL Time
2 km/s	12.6 deg	392.4 sec
3 km/s	13.25 deg	399 sec
4 km/s	14.05 deg	410.6 sec
5 km/s	14.95 deg	417 sec
6 km/s	15.98 deg	424.3 sec

Entry Mass: 607 kg

Option 1: Static lander at 82-degree latitude with radioisotope power, surviving for one full Martian year

- 1A: MMRTG

According to MEL the dry mass of the lander is ~470 kg which is ~100 kg higher than InSight. A significant mechanical redesign of the leg structure and propellant tanks would be required. The MMRTG overall volume would have to be checked against the available area on the deck of the landing platform. The InSight/PHX heritage is not consistent with the inherent assumptions.

Static Lander Concept EDL Options Considered

Option 1: Static lander at 82-degree latitude with radioisotope power, surviving for

- 1B: SMRTG
- This option is within the heritage of the InSight lander. The lander mass is ~360 kg which is consistent with the InSight MEL.

- Radar Consideration for 1A/1B Options:
  - Both options are required to land on ice. The PHX/InSight Honewell FM-4 radar due to a long wavelength is not currently configured to do so. A significant flight test campaign is required . Another solution is to used the Italian radar build for Schiaparelli lander.
- Terrain Considerations for 1A/1B Options:
  - The region above 82deg N is poorly characterized. The InSight lander slope constraint is < 5 deg. The MOLA elevation at 82deg-85deg N is ~-2.0 km MOLA which could be problematic for this lander. Site alteration on ice from the pulsed engines could be another issue.

Option 2: Solar-powered static lander at 82-degree latitude with drill, operating just through the Martian summer

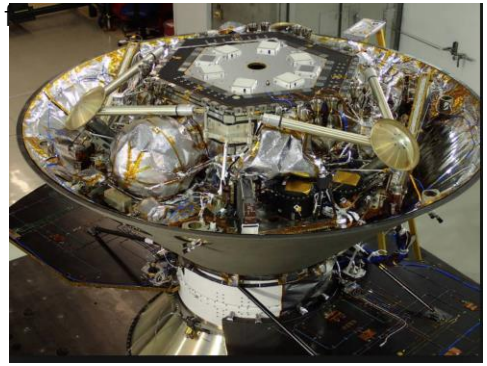
- All of the considerations outlined in Option 1 are applicable for this architecture as well. (see p.4)

- Aeroshell/Lander size considerations:
  - Note that any change in aeroshell size from 2.65 m to 3 m would break the InSight EDL heritage.The lander redesign should be costed as a "new development" unit.
- Option 3: Solar-powered static lander at 60-degree latitude surviving for one full year
  - The 60deg latitude constraint relaxes the site altitude limits (i.e. < -2.5 km MOLA) and FM-4 radar consideration described in Option 1 (see p.4). The EDL concept is more in line with Phoenix landing architecture (i.e. PHX landed at 68 deg N).

3A: with an AXEL rover

- The placement of the rover on the deck of the InSight/PHX lander does not allow to preserve the build to print EDL architecture. Due to the volume constraints inside the aeroshell this concept requires an increase in lander/aeroshell size. See Option 2 (p.5). Another engineering limitation is that the rover would require a deployable ramp which would require an upper deck redesign.

- The picture below illustrates how compact the folded configuration is



Source: NASA/JPL/Caltech

3B: without an AXEL rover with TEM

- The extra solar arrays required for this option would may require a larger aeroshell and entry system redesign.

Pre-decisional. For planning and discussion only.

Static Lander Concept
Thermal Design Considerations

Utilize state-of-the-art for insulation of warm electronics box (WEB) on Mars

- 2-inch thick CO_2 insulation layer
- 30% better performance can theoretically be achieved with an Aerogel design, but based on experience, it is difficult to implement and achieve this level

	Foam Insulation	Fibrous Insulation	Aerogel	CO_2 Gas Gap
Heritage	Good	Good	Good	Good
Launched Density	10 to 50 Kg/m^3	7 to 30 Kg/m^3	15 Kg/m^3	0 Kg/m^3
Thermal Conductivity*	0.02 W/m-K	0.012 W/m-K	0.006 W/m-K	0.009 W/mK
Cost/Ease of Installation	Good	Moderate	Poor	Excellent

* Approximate Thermal Conductivity at -80 C, 8 torr CO_2

Ref. Matthew Redmond, JPL, "Review and Comparison of Thermal Insulation for Mars Surface Missions", 2016 Spacecraft Thermal Control Workshop, El Segundo, California.

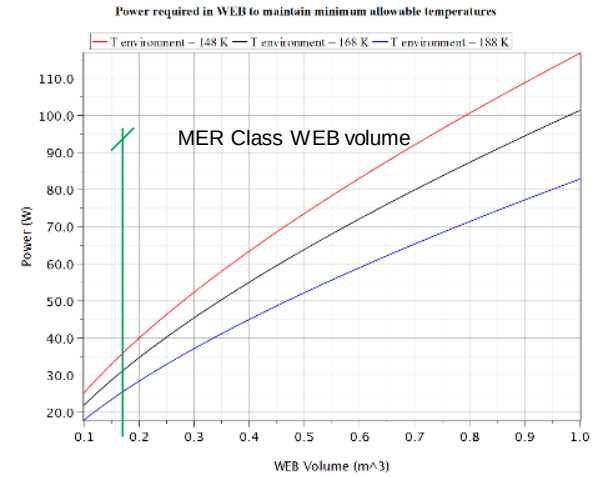


Figure 1. The power required internal to the WEB to maintain equipment temperatures above -20 C per Sol in Winter. The temperatures represent different latitudes (e.g., 148 K corresponds to about 85 deg North). Power will be reduced if wind temperatures are higher than local environment temperature.

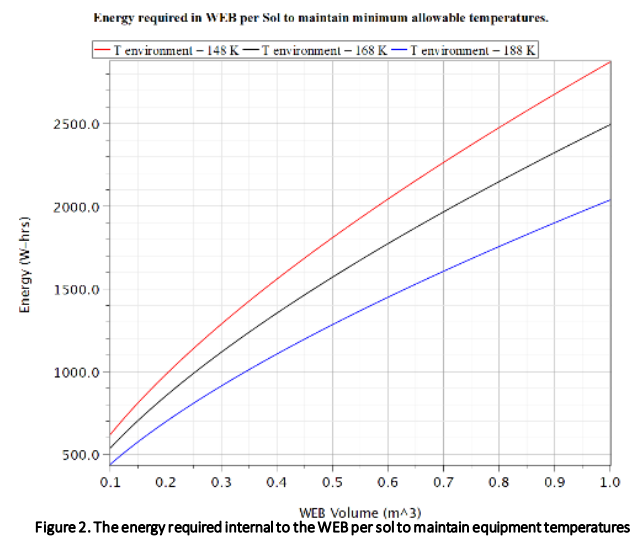


Figure 2. The energy required internal to the WEB per sol to maintain equipment temperatures above -20 C per sol in Winter. The temperatures represent the average at different latitudes (e.g., 148 K = ~85 N, 168 K = ~45 N, 188 K = ~35 N). Power will be reduced if wind temperatures are higher than local environment temperature.

Pre-decisional. For planning and discussion only.

Static Lander Concept Thermal Considerations

Static Lander Concept Option 1

Mission

- Phoenix-like lander at 82° North landing on Mars
- Operation for one full Martian year

Challenges

- Minimize active heating in attempt to preclude nuclear-based heating
- If RHUs are required: manage the resulting heat load during cruise phase
- If RTGs are used: manage the resulting heat load during cruise phase and shield the local ground which is targeted for science from heating effects

- If RHUs are utilized for heating (approximate number of RHUs required can be estimated as the average power dissipation internal to the WEB subtracted from the value on this graph), Phoenix-based thermal control system can be used during Cruise phase, which consists of heat pipes that transport heat to be radiated to heat shield

- If RTG is utilized, a thermal shield would be required to preclude its heating effects on local ground which is baselined for science
  - Based on engineering judgement, a lightweight, hemispherical thermal shield around a 0.224 m L x 0.4096 m dia. SMRTG-2 would have a mass of ~ 0.3 kg. But this does not include structural support mass, which would dominate
  - Analysis of the RTG shield on local ground temperatures is beyond the scope of this session

- If RTGs are utilized, waste heat is too large for a passive system during Cruise and an actively pumped fluid system would be required
  - This would result in ~ 67 kg upper
    - 45 kg for pumped loop system
    - 22 kg for Cruise stage radiators, assuming MMRTG at 2 kW waste heat
  - 15 W of continuous power for pump required during Cruise
  - 15 W of continuous power for pump required during Surface if RTG waste heat is reclaimed for survival heating, in which case no additional heater power is needed

Static Lander Concept Thermal Considerations

Static Lander Concept Option 2

- Mission
  - Same as Option 1, except 90 sol mission from Ls 30° to Ls 120°
  - Solar powered rather than RPS
  - Drilling at 82° N
- Challenges
  - Similar to Option 1 because the driving, worst-case cold scenario has an environment nearly as cold as Option 1 (Ls 30° is just as cold as Winter) per customer provided environment profile:

Static Lander Concept Option 3

- Mission
  - Phoenix-like lander with small Axel rover at 60 ° North landing on Mars
  - Year-round operation for Lander
  - Summer operation for Axel rover
- Challenges
  - Minimize active heating in attempt to preclude nuclear-based heating
  - If RHUs are required: manage the resulting heat load during cruise phase
  - If RTGs are used: manage the resulting heat load during cruise phase and shield the local ground which is targeted for science from heating effects

- Assuming a 40 W peak Axel internal dissipation, a radiator area of 0.13 m^2 is required. This radiator can likely be accommodated as part of Axel's cylindrical body.
- Survival power internal to Axel for cold case is 19 W
  - To reduce this survival power, a heat switch can be implemented that would reduce survival power by 1/10th

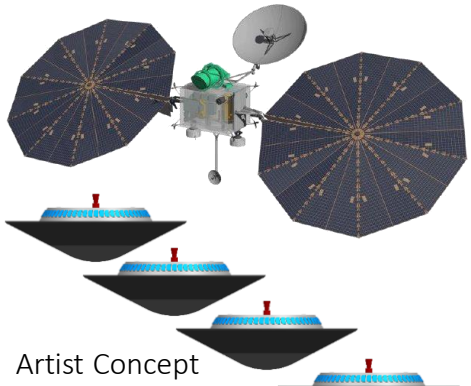
Pre-decisional. For planning and discussion only.

ORBITER WITH DEPLOYABLE LANDERS CONCEPT

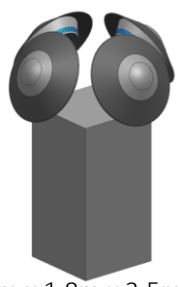
Science Objectives for Orbiter with Landers Concept

- Monitor atmospheric conditions from orbit with a few (2-6) "ground-truth" data points provided by landers that would connect larger-scale dynamics to conditions at the surface (and within the Boundary Layer).
  - Conditions to be monitored by the orbiter include:
    - Winds, temperature and pressure profiles, atmospheric aerosol profiles (water ice and dust), and atmospheric water vapor profiles
    - Clouds, dust events, and general circulation
  - Conditions to be monitored at the surface include
    - Surface pressure, temperature, absolute humidity
- Characterize atmospheric patterns, through diurnal and seasonal cycles.
- Observation timeframe one Martian year.

Mars Ice and Climate Evolution (ICE-SAG) Orbiter with Lander Concept



Artist Concept



1.8m x 1.8m x 3.5m bus

Orbiter Features:

Architecture: Electric Powered Orbiter
Propulsion: Solar Electric Propulsion
LV: TBD based upon New Frontiers
Target: Low Mars Orbit
Mission Duration: 1 Mars Year
Cost Target: New Frontiers

Lander Features:

Lander Payload Mass: 150kg(all landers)
LV: Piggyback on orbiter
Target: Equator
Mission Duration Target: 90 to 688 sols
Mission Class: D

Instruments

Payload Element	CBE Mass (kg)	Power (W)
Thermal IR Sounder	9	16.1
Weather Imager	1.04	4.6
Sub-mm Sounder*	20	18
Infrared Limb Imager*	10	15
Deployable Lander (4)	140	60
TOTAL	180	

Instrument Assumptions:

- Orbiter has four instruments – Thermal IR Sounder, Weather Imager, Sub-mm Sounder, Infrared Limb Imager
- 4 deployable landers with costing schedule.
- *The sub-mm sounder and infrared limb imager are currently not available and would need to be developed.
- Did not build in price for any mechanical gimbals or pointing devices.

Launch Vehicle		Orbiter		S/C P/L + Landers		Impact Lander		Landed Payload	
Constraint	Launch Vehicle	Constraint	Orbiter S/C	Constraint	Entry S/C	Constraint	Entry S/C	Constraint	Entry S/C
MEV Wet Mass (kg)	2500	MEV Orbiter P/L Mass	600	MEV Entry Mass (kg)	500	MEV Landed Mass (kg)	50	MEV P/L Mass (kg)	12
MEV Wet Mass (kg)	2134	CBE Orbiter P/L Mass	234	CBE Entry Mass (kg)	152	CBE Landed Mass (kg)	38	CBE P/L Mass (kg)	6
Margin (%)	15 %	Margin (%)	61 %	Margin (%)	70 %	Margin (%)	24 %	Margin (%)	50 %

Lander Concept Thermal and Energy Assumptions

Thermal Assumptions

Survival Power Estimates

Assuming 1" CO2 gap insulation

Latitude	Power (W)	Energy (Wh)
0N	1.5	36
47N	4.5	108
60N	6	144

Driving Thermal Case

Assuming 3" CO2 gap insulation

Latitude	Power (W)	Energy (Wh)
0N	0.75	18

Assumptions

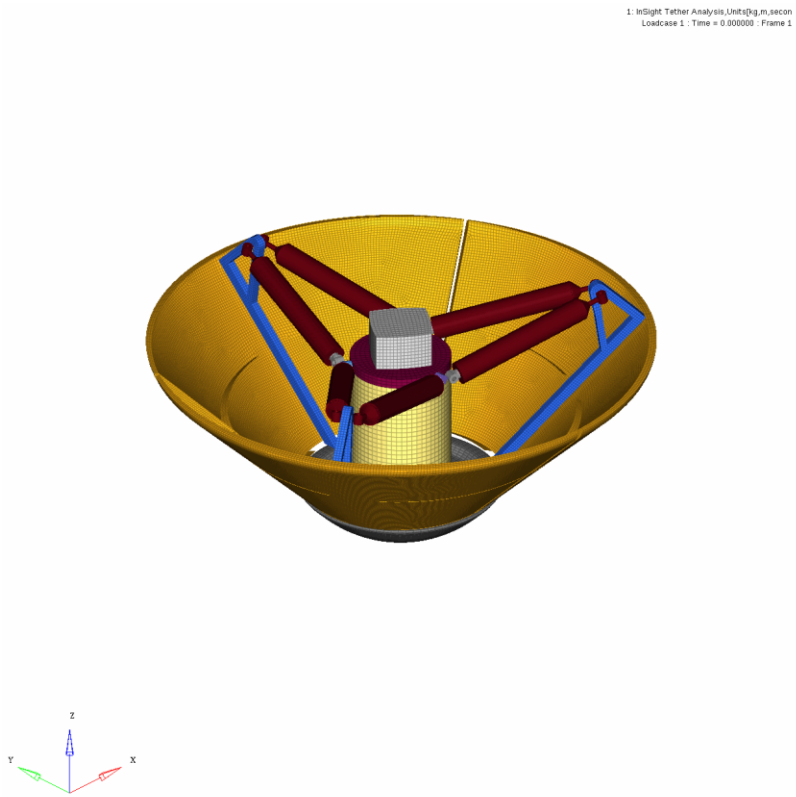
- 7 Sols of Autonomy for MET station
- 60% Depth of Discharge Batteries
- ZTJ Triple Junction Solar Cells, 29.5% Efficiency
- Min Active Area assumes 1 sol charging equals 2 days of science.
- See "Generated Energy chart" for additional assumptions

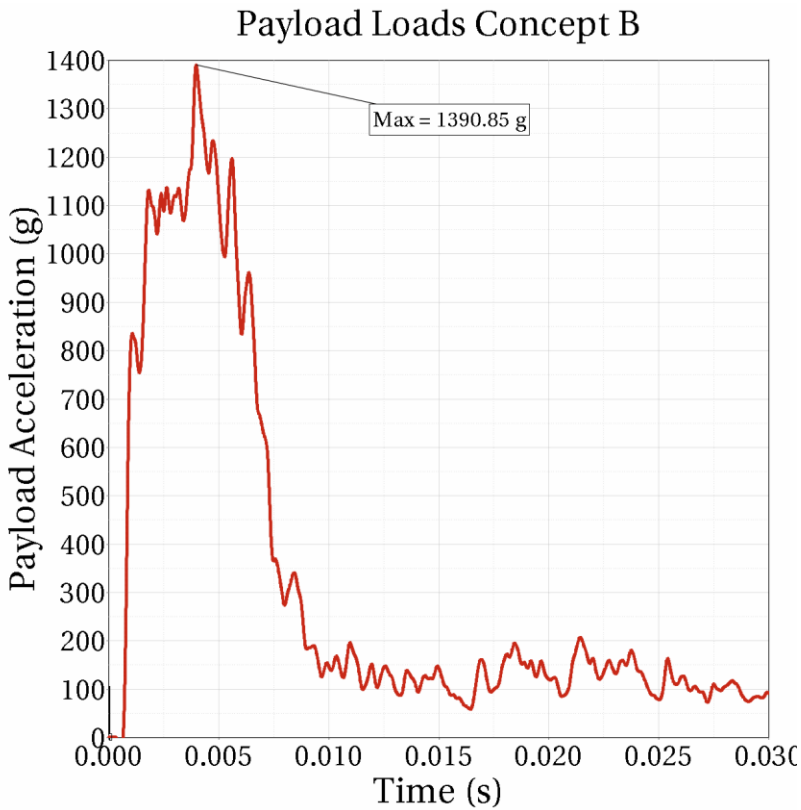
Impact Lander @ 0°N 3" CO2

Parameter	Value	Unit
Worst Case Mode	70.38	Wh
Days of Autonomy	7.00	Sols
Energy Storage Requirement	**492.67**	**Wh**
Battery Energy Density	260.00	Wh/kg
Battery Depth of Discharge	60%	
Battery Storage Requirement	821.12	Wh
CBE Battery Mass	**3.16**	**kg**
Assumed Daily Energy Harvest	350.00	Wh/Sol/m2
Min Required Active Area (ZTJ)	**0.40**	**m2**
Area need to charge 7 sols of automation in 1 sol of insolation	1.41	m2
Specific Power	1074.00	W/kg
Solar Panel Area to Mass Ratio	1.91	m2/kg
Min CBE Solar Panel Mass	**0.21**	**kg**

At first order analysis the instrument payload fits constraints for mass and power. Cost and volume will require further analysis and validation.

LS-Dyna Impact Analysis on Payload for Impact Lander Concept





Preliminary results from LS-Dyna indicate that the payload may experience an impact pulse of ~1390 g for 0.01s. Since this analysis, several design iterations have taken place to reduce mass and increase drag area to reduce the impact load to values less than 1000 g. Further analysis need to be conducted to ensure that the payload and components, especially batteries, can withstand a maximum accelerations of 1000g for 0.01s.

Payload impact mitigation techniques

Technique	Description	Examples	Risks
Encapsulation	• Space around circuitry filled with "potting" material • Provides structural support and damping	• Soft elastomers, hard plastics, epoxies, foams e.g., Dow Sylgard-184 Silicone, E&C Stycast-2651 epoxy • Transmit 0.03 – 14% of incident strain	• Careful choice of thermo-mechanical properties required • Difficult to rework components
Underfill	• Flowed beneath chips to fill area surrounding solder • Reduces failure under bending loads	• Filled epoxy composites e.g., Loctite 3568	• Most underfill materials prevent rework
Load path management	• Design of the supporting structure to minimize shock / vibration propagation – e.g, material choice, damping etc	• Design casing to limit bending of electronics boards • Orient electronics to limit shear forces acting on solder	• Upfront design work required

Optimal solution likely combines these techniques, further research to understanding off gassing implications.

Orbiter with Lander Concept Key Findings

How many landers can fit and stay within NF cost cap?

- At a first order level, 4 deployable landers meet the constraints for volume and mass.

How long can the landers survive on surface?

- The lander life is latitude dependent. Assuming the landers were at 0° latitude the landers could conceivably survive the one Martian year, with at least 0.4m^2 of active solar panel area. For higher latitudes such as 42° in order to survive the active solar panel area needs to be >3m^2.

Can the payload survive impact loads?

- At a first order level it appears the electronics would survive the impact, stresses, and strains caused by the initial impact. There are current electronics used by military that can withstand >>1000g.

Can we fit within the cost cap for this mission concept?

- Yes but the desired payload would need further refinement. Possible de-scope of instruments and number of landers should be considered.