Exploring Mars Together: Commercial Services Studies

Presentation to the Mars Exploration Program Analysis Group
November 7, 2024

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Alignments

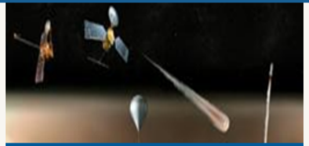
Strategically Supports the Draft MEP 2024-2044 Plan

MEP

Major Initiatives for MEP Future Plan 2024 – 2044

INITIATIVE 1

Expand Opportunities to Explore Mars through Competed, Lower-cost, More Frequent Flight Opportunities



INITIATIVE 2

Strengthen and Broaden Infrastructure at Mars to Enable a Diverse Set of Missions and New Opportunities for Partnerships

INITIATIVE 3

Invest in Key Technologies to Enable Expanded Access to, and Scientific Understanding of, Mars

INITIATIVE 4

Enable Participation in Mars Exploration for All Communities

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AGENCY

MULTIPLE M2M OBJECTIVES

RT-2:	Industry Collaboration
RT-9:	Commerce & Space Development
MI-2	Communications Infrastructure
TH-5 & -6:	Transportation Systems
TH-12:	Cargo Mass

\+ multiple M2M science-enabling and applied-science objectives enabled by low-cost commercial services

Sustainable Human-Robotic Presence in the Martian System

- Advances 2 Near-term Activities in the MEP Future Plan that can be accomplished within the current budget climate, provides key information to validate the future potential low-cost Mars mission framework
  - ***Explore opportunities for commercial services to address infrastructure needs***
  - ***Award study contracts to industry to define better potential public-private partnerships***

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What do we mean by Commercial Services?

- Government commits to buying services at regular intervals at a fixed price
  - Company owns and operates the assets
- Often done in two phases
  - A subsidized public private partnership phase to buy-down risks, develop & demonstrate technologies and to allow companies to assess market
  - Firm Fixed Price Contracted Service Phase
- Ex: Commercial Cargo, Commercial Comm, CLPS

Why are Commercial Services Potentially Attractive?

- Commercial services work best when the technologies are mature -- therefore leveraging technology investments from other efforts
- Streamlining of costs over multiple missions
- Potential for cost sharing with different customers

COMMERCIAL CARGO FLIGHTS
ABOVE: DRAGON, BELOW: CYGNUS

Introduction

- **The past decade has seen extraordinary growth in commercial capabilities for low-cost spacecraft from efforts in LEO constellations, GEO, CLPS, DOD, etc.**
    - CubeSats
    - SmallSats
    - Miniaturized instruments and avionics
    - New launch vehicles and rideshare opportunities
- **The result has been a transformation in the economics of Earth-orbiting space missions**

    . . . and more recently we see the beginnings of new commercial opportunities for low-cost lunar missions
- **We seek to capitalize on these advances and understand how they can be applied to Mars; however, we also need to be mindful of unique challenges of Mars relative to Earth-orbit and lunar mission applications**

Some Tied to Large Distance of Mars	Some Tied to Unique Martian Environment
• Flight times	• Atmosphere
• Telecommunications & Navigation	• Dust
• Transportation & Propulsion	• Thermal
• Power	• Radiation

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Findings from Key Interfaces with Industry Informing Study RFP

OCT 2022	**MEP Industry Day: >100 attendees in person and online**
NOV 2022 – July 2024	**15 Site Visits**

Finding 1: Significant Leverage

- Commercial capabilities are currently focused on Earth and Moon due to market demand

  YET

- US Industry has many existing and emerging capabilities that could be leveraged for Mars exploration with small deltas in designs/costs to existing systems designed for Earth and Moon

Finding 2: Strong interest from industry:

- to support MEP potential service areas
  (All but one company expressed strong desire to study and continue to discuss future service model with NASA)

- to study with MEP how Mars future exploration could fit into their business models

MEP
High-level Objectives & Guiding Principles

Richard M. ("Rick") Davis and Steve Matousek Study Co-leads

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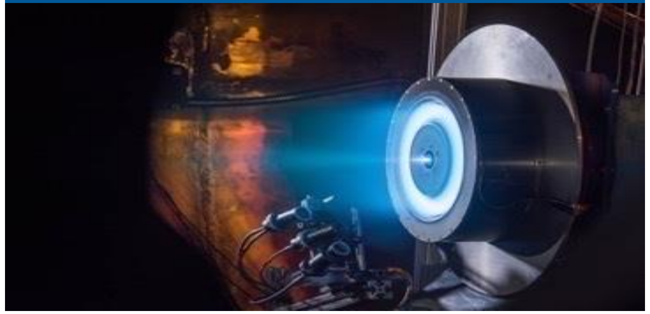
Intent of Industry Study RFP	
	1. Buy down costs and risk for both industry and government 2. Build a better understanding of potential costs for services 3. Understand industry need for a private-public partnership phase

DELIVERY/HOSTING

DRM 1: SMALL PAYLOAD(S)
DRM 2: LARGE PAYLOAD(S)

TRANSPORTATION INFRASTRUCTURE



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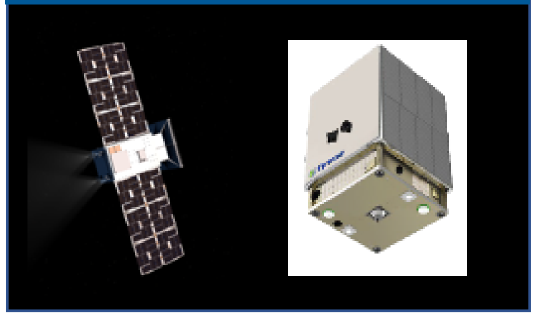
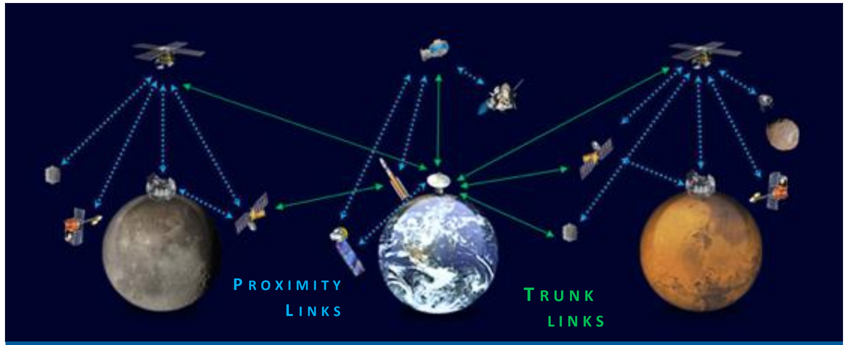
PAYLOAD SERVICES



ENABLE HIGH-PRIORITY MEP NEEDS:

CONTINUITY & COVERAGE

DRM 3: HIGH-RES IMAGING



MORE DATA, MORE DISCOVERY

DRM 4: COMM RELAY/PNT

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GUIDING PRINCIPLES

1 LEVERAGED CAPABILITIES	Leverage innovative, existing or soon-to-be-existing, commercial space systems (particularly those being developed for NASA's Moon-to-Mars initiatives) to accelerate Martian exploration
2 LAUNCH OPPORTUNITIES	Enable one or more missions per Mars launch opportunity, in profitable partnerships with US industry
3 LOWER COSTS / RISKS	Substantially lower costs, while maintaining acceptable risk
4 INDUSTRY LEADERSHIP	Empower leadership of U.S. industry in deep space
5 SUSTAINABILITY	Build toward a sustainable human-robotic presence at Mars

STUDY RESULTS INFORM MEP FUTURE PLANS:

Frequent, Lower-cost Mars Missions for High-priority Science & Support for US Commercial Leadership in Deep Space

- Provide expertise gained from Mars missions over the past 50+ years
- Benefit from industry economies of scale and other practices
- Potentially establish a regular cadence of lower-cost Mars missions, including initially facilitating connections with other potential customers in universities and other space agencies for a wider customer base, and thus a more sustained market for Mars services
- Help define a service model structure that works for both NASA and industry, including potential public-private partnership (PPP) phases etc.

Award Summary & Study Framework

Steve Matousek Study Co-lead and Contract Technical Manager (CTM)

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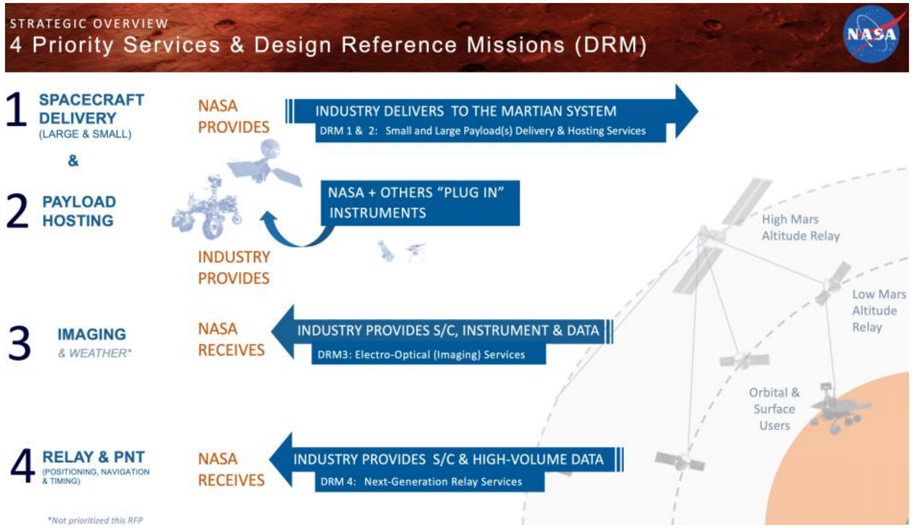
Award Summary

DRM 1	Firefly Aerospace	Impulse Space	Lockheed Martin
DRM 2	Astrobotic	Blue Origin	United Launch Alliance
DRM 3	Albedo	Astrobotic	Redwire
DRM 4	Blue Origin	Lockheed Martin	SpaceX

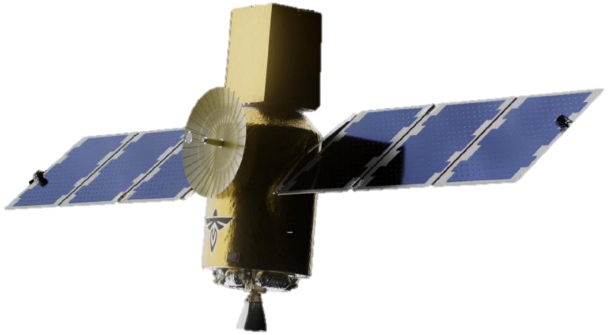


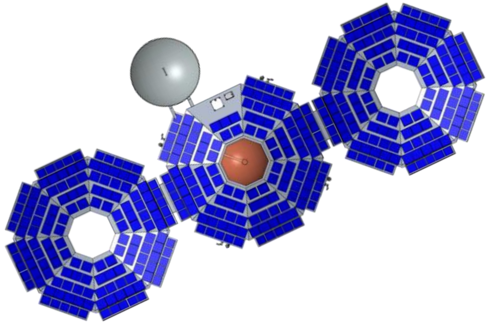
Completed Three Studies per DRM

- Provides higher level of confidence with DRM estimates
- Increased diversity across the US space industry
- Some ability to cross-correlate study results

Key Findings Planned to be Shared Publicly

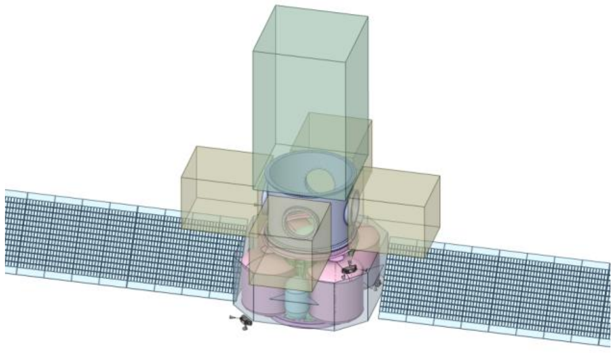
Mars Small Delivery & Hosting Concepts – DRM 1 (Delivery & Hosting; 20 kg Payload(s); Multiple Ports)

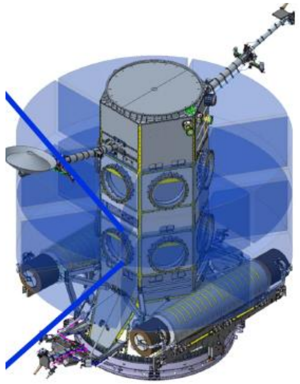


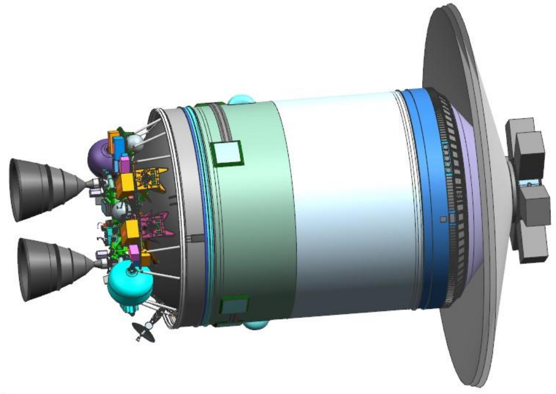


Firefly	Impulse	Lockheed Martin
• Modify Elytra OTV to deliver >175 kg payload to Mars orbit	• Aerobraking with enhanced space tug (Mira V2)	• Aeroassist Smallsat
• Elytra "Red" based on in-space propulsion tug to provide Mars orbit insertion • Can deliver up to 300 kg payload, depending on opportunity • Proposed alternative option with Alpha LV, Elytra kick stage, and microsat w/ 20 kg of payload to low Mars orbit	• Adaptation of Mira space vehicle (demo launched in 2023) • ESPA Grande form factor • Uses nitrous oxide/ethane fuel for 1.8 km/s of delta-v • Aerobrake from 2-sol orbit	• Builds on Curio™ smallsat Janus and LTB architecture • Aeroassist works in any Mars launch opportunity • Aeroassist technology enables more rapid launch to operations timeline • Up to 30 kg of payload • Draws on LM's extensive lander and aeroassist capabilities

Mars Large Delivery Concepts – DRM 2 (Delivery and Hosting; 1250 kg Payload(s); Multiple Ports)

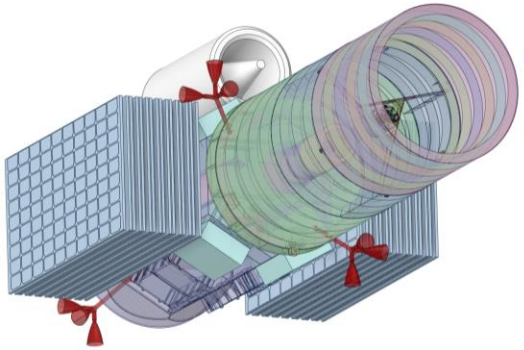


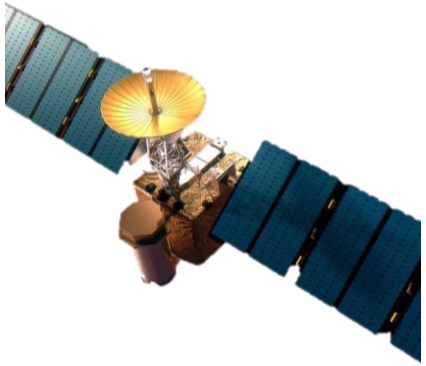




Astrobotic	Blue Origin	ULA
• Adapt Griffin-1500 lunar lander with minimal modifications for propulsive delivery to Mars orbit	• Blue Ring hybrid tug already in development for multiple cislunar applications	• Adapt and utilize Centaur for Earth departure, cruise, and MOI at Mars
• Mirrors current lunar delivery model • Peregrine lander launched in Jan. 2024, Griffin lander to launch in late 2025 • CLPS experience leveraged for ideas on commercial service model and payload ICD • Direct orbit insertion with large Delta-V • Provided draft payload user's guide	• Large SEP/Chem propulsion system for high Delta-V applications • Combo of SEP cruise and spiral with high-thrust capture leads to ~2.5 year delivery • Modular performance enhancements in propulsion, power, communications • Up to 2kW on-orbit power, 30 kbps X-band DTE @ 1.5 AU, maneuvering, onboard storage and compute	• Modifications include propulsion for MOI and utilize low boil-off Lox/H2 cryogenics for power generation • Fuel cells for power needs during cruise, would need deployable solar arrays for continued on-orbit hosting • Improved thermal isolation, thermal shields, radiators, and active cryo coolers • Compatible with Vulcan LV, may need aerobraking

Mars Imaging Concepts – DRM 3 (Resolve 1 Meter Surface Object)

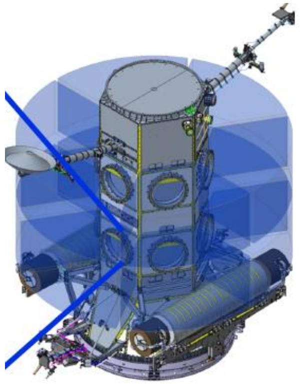


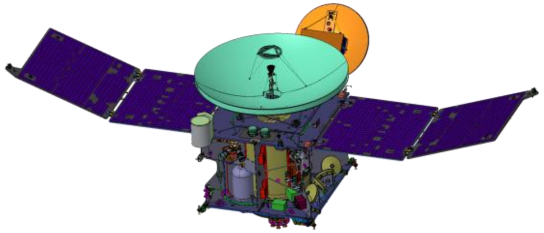


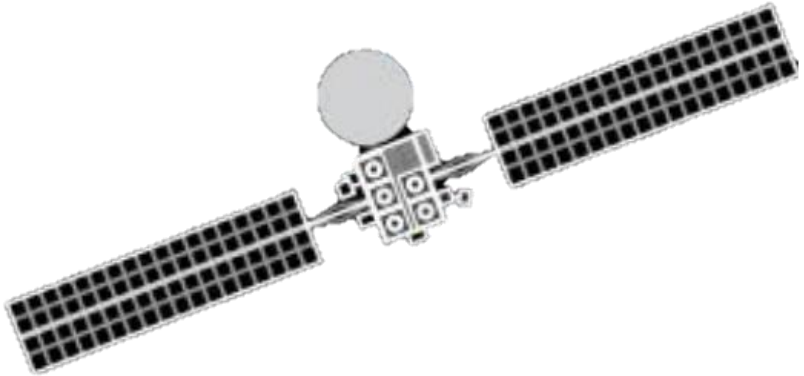
Albedo	Astrobotic	Redwire
• Ultra-high resolution with innovative, low-cost approach	• Custom-built platform with camera expertise from Malin and ASU	• RedScope concept with framing camera on Belgium smallsat bus
• Leveraging current design for commercial VLEO imaging slated to launch early 2025 • Ultra-high resolution from 300 km • Very low-cost spacecraft due to high commonality with VLEO product • Onboard processing and delivery via DSN or Mars relay network	• Camera best if hosted on Griffin DRM 2 bus • 50 cm aperture, 0.3 m/pix, 1-2m resolution • Highly integrated Space COTS detector • “Simplified HiRise” • 4.8 km swath, 6-band color across full FOV • 700 kg, 1330 W. ESPA interface	• Heritage P200 Bus and Argus imager with custom optics • Affordable and commercially available hardware • Framing camera to achieve image quality comparable to HiRise

Mars Next-Generation Relay Services – DRM 4 (≥4 Mb/s @ 1.5 AU)

Note: All solutions are integrated with each company's delivery capabilities







Blue Origin	Lockheed Martin	SpaceX
• Blue Ring tug configured with high performance relay payload	• Leverages LM's MAVEN spacecraft design	• "Marslink" constellation derived from Starlink designs
• Delivered and hosted via Blue Ring (DRM 2) • Various orbits considered (LMO, high circular, inclined, areostationary) • Ka/Ka DTE deployable mesh HGA; delivers 4 Mb/s @ 1.5 AU • X-band proximity links; broad beam for full hemisphere and narrow beam for steerable, high data-rate	• Has propulsion system to perform MOI and transfer to communications orbit (does not need DRM 2) • End-to-end scheduling, data relay service • X and Ka high data rate DTE • Looks to other Mars users (landed and orbiting) like a DSN Station	• Multiple SpaceX satellites placed in Mars orbit to provide full visibility and interoperability for ground and orbital assets • Optical links between relay satellites and with customer satellites • Exceeds requested capability, extra ability for global imaging and monitoring

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A Few Initial Study Observations

- There are a significant number of companies interested, even beyond the study participants
- The studies pointed out a synergy between DRM2 large payload delivery/hosting and DRM4 comm/nav
- Studies also indicate that potential imaging services benefit from larger volume data return
- Continued dialog important to ensure future science needs match payload hosting and data return services (interfaces, protocols, …)

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Near Term

NOV 2024	MEPAG Presentation
DEC 2024	MEP US Industry update
DEC/JAN ‘24/’25	Commercial services studies public info
1st half CY 2025	Potential commercial services science/industry workshop
CY 2025	Continue discussions with US Industry, Science Community, Stakeholders

BACKUPS

Definitions (DRAFT)

Public Private Partnership (PPP) – a joint effort between NASA and one or more industry or other private-sector partners in which resources, technical capabilities, and risks are shared to develop mutually beneficial products and services, often in less time at lower cost than otherwise possible; typically enabled at NASA by a Space Act Agreement (SAA) executed under NASA's Other Transactional Authority (OTA), which is designed to allow the advancement of capabilities that, once developed, can be later procured through traditional contracts

	Traditional	PPPs
Contract Type	Cost plus	Fixed cost or cost-sharing
Provides Funds	USG	Shared
Controls the development of the product	USG	Varies by type
Holds the risk	USG	Shared
Owns final product	USG	Partner

- **Service Model** – A procurement method by which the government purchases a service (e.g., payload hosting, delivery, etc.) and the service provider manages process and risk and executes the entirety of the mission.
  - Types: typically utilizes a firm fixed price contract (FFPC)
- **Design Reference Mission (DRM)** – Establishes an operational context by providing:
  - descriptions of the environment and situations in which solution concepts are expected to operate;
  - an operational narrative of expected behavior, including a sequence of operational activities and interactions between systems in an environment; and,
  - sample measures for establishing goals for mission success.

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Differences from a Traditional RFP (with insights from COTS) (DRAFT)

- No "one size fits all" or "business as usual" – successful PPPs develop a model specific to the effort
- NASA uses funded Space Act Agreements (SAA) to pursue the development of PPPs

  SAA: Fixed-price milestones enacted under NASA's Other Transactional Authority (OTA)

    - OTA enables the development of capabilities (that can later be procured through traditional contracts)
    - NASA sets the schedule and nature of pre-negotiated, funded performance milestones that motivate the industry partner's capability/cost/schedule performance
    - Funded milestones are the sole measurement of progress and incremental payments

  - Flexibility to adjust payments and schedule according to development milestones (technical, business or programmatic)
  - Avoids NASA owning the company's intellectual property
  - Aims to conclude the development phase with a demonstration flight, as applicable

- NASA writes requirements at highest possible level to reduce costs and accelerate schedules
  - **Tells the company what NASA wants (goals/objectives, capabilities, functions, outcomes), not how to do it**
  - **Gives industry partners the flexibility to operate using their own profit-motivated, streamlined industrial processes and to innovate** (rather than to meet stringent requirements)
  - Spurs NASA to focus on collaborative relationships with partners for insight, rather than providing oversight
  - Data deliverables are only for milestones and requirements compliance, thus also saving NASA management overhead

ADVANTAGES:

Short-term: Drive innovation toward a systemic capability in less time and at lower cost

Long-term: Save future mission costs with affordable, available services – enables more frequent low-cost missions

Overall: *Knowledge sharing for innovation, low-cost suppliers, economic growth, returns to other NASA deep-space missions etc.*

DRM 1 – Smaller Payload(s) Delivery and Hosting Services

Carry and deliver MEP-provided payloads, including possible deployed cubesats, and operate in Mars orbit. Any excess capacity is owned by the operator.

DRAFT MARKET MODEL FOR STUDY PURPOSE:

Every other Mars launch opportunity (~ every 52 months, alternating with DRM 2 opportunities), provide, deliver, and operate a bus/platform that hosts MEP-provided payload(s) in low-Mars polar orbit.

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DRM1

BUS/PLATFORM & PAYLOAD	
BUS/PLATFORM CAPABILITIES	• Provide mechanical, electrical, and data standard interfaces to hosted science payload and UHF proximity-link communications. Ability to deploy 2 or more CubeSats
P/L MASS	• Not to Exceed (NTE) 20 kg total (e.g., hosted instrument(s) and/or 2 or more deployable cubesats)
P/L MECHANICAL INTERFACE	• Sufficiently robust to minimize or eliminate launch load analyses, much like the CubeSat PPOD standard
P/L POWER	• < 100 W peak total to all payloads • Bus/platform provides 5W P/L keep-alive and checkout power during cruise
P/L SHIELDING	• P/Ls self-shield from interplanetary/Mars environment • Bus/platform provides full reset signal over the data interface so P/Ls can reset to guard against permanent latchup due to events like Single Event Upset (SEU) from solar flares
P/L POINTING	• No additional requirement; P/L utilizes available bus/platform pointing capabilities for accuracy, stability, and jitter
DELIVERY/OPERATIONS	
LIFETIME	• Cruise + 1 Mars year in orbit
LAUNCH C_3	• Assume a C_3 = 15 km^2/sec^2. • Note this allows for launch periods for most Mars opportunities in the 2030s for chemical propulsion systems. • SEP systems may be able to assume a much lower C_3 depending upon spacecraft performance and lifetime.
DELIVERY ORBIT	BASELINE: Similar to Mars Reconnaissance Orbiter - Sun-synchronous - Low Mars polar orbit (~300km)
CON OPS	• ≥ 8hr/day nadir-oriented observations for hosted payload
TELECOMMUNICATIONS	
DIRECT-TO- EARTH (DTE) COMMUNICATIONS	BASELINE: Bus/platform shall communicate with Earth via Direct-To-Earth (DTE)/Direct-From-Earth (DFE) links with the Deep Space Network (DSN)
HOSTING MEP-PROVIDED RELAY PAYLOAD	OPTION 1: Within the aggregate 20-kg P/L constraint, accommodate a CCSDS-compliant Proximity-1 UHF relay payload to offer low-gain data relay services to other landed/orbiting user spacecraft from Low Mars Orbit. OPTION 2: Support bi-directional data rates of ≥ 10 Mb/s with a 30-cm/15-W (RF power) X-band telecom capability

DRM 2 – Larger Payload(s) Delivery and Hosting Services

Carry and deliver to Mars orbit one or more separable spacecraft, and optionally provide services for one or more hosted payloads, for an aggregate customer mass (combined mass of separable spacecraft and optional hosted payload[s]) of 1250 kg.

DRAFT MARKET MODEL FOR STUDY PURPOSE:

Every other Mars launch opportunity (~ every 52 months, alternating with DRM 1 opportunities), carry and deliver, one or more separable MEP-provided spacecraft and optionally hosted payloads to low-Mars polar orbit.

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DRM2

PAYLOAD(S)	
BUS/PLATFORM CAPABILITIES	Provide mechanical, electrical, and data standard interfaces to delivered spacecraft; see also supportable configurations below
P/L MASS	NTE 1250 kg (see supportable configurations)
P/L MECHANICAL INTERFACE	Sufficiently robust to minimize or eliminate launch load analyses
P/L POWER	Bus/platform provides keep-alive and checkout power during cruise
P/L SHIELDING	• P/Ls self-shield from interplanetary/Mars environment. • Bus/platform provides full reset signal over the data interface so P/Ls can reset to guard against permanent latchup due to events like Single Event Upset (SEU) from solar flares.
DELIVERY SYSTEM	
MODULAR APPROACH	• Ability to scale the system based on different needs at different opportunities (e.g., modular rings with multiple ports) • Service Provider owns excess capacity
INTERFACE	Utilize ESPA-like standard interfaces (15”/24” separation ring, etc.)
SUPPORTABLE CONFIGURATIONS	1. Single large spacecraft up to 1250 kg 2. Medium spacecraft 500-1000 kg + secondary spacecraft (up to 1250 kg total) 3. Multiple spacecraft 5 – 450 kg each, totaling up to 1250 kg Option: Additional hosted payloads, within overall 1250 kg total mass constrain 4. Multiple ports with ESPA, ESPA-Grande, or similar mass/volume specifications
SERVICES & OPERATIONS	
FULL SERVICE	Baseline: • Deliver spacecraft - includes integration, launch, cruise, and orbital delivery • Provide DTE during cruise Option: • After delivery, host and operate one or more NASA-provided P/L(s) on orbit (this is part of the 1250 kg total mass); • Provide relay services (see DRM 4)
LIFETIME	Baseline: Cruise through delivery to orbit(s) Option: + 1 Mars year in orbit for hosted payload(s)
CRUISE SERVICES	Maintenance and checkout power levels including periodic telemetry for each hosted platform through separation
LAUNCH C_3	Assume a C_3 = 15 km^2/sec^2. Note this allows for launch periods for most Mars opportunities in the 2030s for chemical propulsion systems. SEP systems may be able to assume a much lower C_3 depending upon spacecraft performance and lifetime.
DELIVERY ORBIT	Baseline: Similar to Mars Reconnaissance Orbiter - Sun-synchronous - Low Mars polar orbit (~300km) Option: Delivery to multiple orbits, especially en route to final orbit.
MISSION ARCHITECTURE	Open - (SEP vs. Chemical vs. hybrid, direct MOI vs. aerobrake, etc.)

Design Reference Mission (DRM) 3 – Electro-Optical (Imaging) Services

Provide sensor and orbital spacecraft platform(s) for imaging services at Mars. Imaging would be used in support of observational science investigations, landing site selection and hazard assessment, change detection, and monitoring and planning for surface assets.

Imaging platform(s) are assumed be delivered to operational orbit and provide imaging services for one Mars year. Total coverage is determined by the assumed data return rate over the life of the mission.

DRAFT MARKET MODEL FOR THE STUDY RFP:

Provide sensors + spacecraft platform; assume MEP funding for 1 Mars Year (~2 Earth Years) of on-orbit imaging services, with option for extended services through 2044.

DRM3

IMAGING SYSTEM	
RESOLUTION	High-resolution, targetable passive (VIS/NIR) or active (RF) imaging with ≤ 0.5 m image resolution at Mars surface from either modality
ADDITIONAL SERVICES	Option: Combine imaging with atmospheric sounding services
ASSUMPTION	Launched and delivered to operational orbit via separate service or government asset.
ORBIT	
ORBIT	Similar to Mars Reconnaissance Orbiter - Sun-synchronous - Low Mars polar orbit (~300km)
TELECOMMUNICATIONS	
PROVIDED RELAY	Baseline: None, use a Direct-to-Earth (DTE) link to the DSN Option: Use the Next-Gen Mars Relay Network (MRN, see below option End-to-End Data Return Description)
END-TO-END DATA RETURN	Baseline: A capability with lower data volume return similar to the current Mars Reconnaissance Orbiter is representative of a minimum viable service (scaling of 1/R2 for other Earth-Mars distances) returned via Direct-to-Earth. Option: 0.5 Tb/day imaging data products at an Earth-Mars distance of 1.5 AU through the Next-Gen Mars Relay Network. The Next-Gen MRN could offer high-rate proximity link telecom services via directional X-band proximity links with rates of ≥ 10 Mb/s for orbital users equipped with an approximately 30-cm/15-W (RF power) X-band telecom capability (for example)

Design Reference Mission (DRM) 4 – Next-Generation Relay Services

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Provide communications relay services between Mars and Earth for surface and orbital assets.

DRAFT MARKET MODEL:

Provide high-volume data relay from Mars to Earth; assume MEP funding for relay services for 2 Mars Years (~4 Earth Years) with option for sustained long-term services through 2044. Any excess capacity is owned by the service provider

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DRM4

ANTICIPATED FUTURE USERS

- **One or more fixed or mobile surface users with small to medium data-return needs in low-to-mid latitudes.**
- **Orbiting science missions with small to moderate data return**
  - **Imaging orbiting mission could require highest data return) in polar to mid-latitude orbits.**
  - **Other non-NASA customers are encouraged**
- **Several users require data relay services at any given time.**
- **Special low data latency and critical-event coverage for single, infrequent events.**

SERVICE CHARACTERISTICS

SERVICE PROVISION	• Flexibility to provide communications and navigation services to a wide range of small, medium, and large orbital and surface missions over multiple Mars years preferred • Service could be provided during or after other services such as payload hosting/delivery.
MARS ORBIT	BASELINE: Any orbit that provides high-volume end-to-end data return, low latency, and long-life reliable service OPTION: Increased relay coverage and contact time with surface and orbital users, via a high-altitude orbit (e.g., 5,000 to 10,000 km) - Load-sharing capability across other high-altitude relay orbiters
DIRECT-TO-EARTH (DTE)	DATA RATE: High-performance DTE link capable of supporting ≥4 Mb/s data rate (with a goal of 10 Mb/s) to a DSN 34m antenna at an Earth-Mars distance of 1.5 AU (and scaling as $1/R^2$ for other Earth-Mars distances) STANDARDS: Utilize NASA Deep Space Network (DSN). DSN standard CCSDS protocols required BAND: Ka band for compatibility with future DSN
PROXIMITY RELAY - STANDARD	• Directional proximity links at X-band (forward and return, options for be S-, Ku, or K-band could be explored instead of X-band) supporting data rates of ≥ 10 Mb/s to minimize user telecom subsystem mass/power • Capability to acquire range, Doppler, and timing observables on the proximity link in support of in situ Position, Navigation, and Timing (PNT) services Note: other service support frequency and antenna options possible
PROXIMITY RELAY - LEGACY	• Legacy UHF link capability compatible with current Mars Relay Network • UHF omnidirectional that does not require pointing or high power from users • If from higher altitude orbit, lower data rates are acceptable due to larger slant range