National Aeronautics and
Space Administration

NASA's Moon to Mars Architecture Workshop

How: NRHO - The Artemis Orbit

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WHEN WILL WE ACHIEVE LUNAR OBJECTIVES?

Multi-decadal campaign

Support annual cadence of crewed missions

Development of permanent infrastructure

Expansion of economic sphere to the Moon

WHO DOES THIS APPROACH INCLUDE?

NASA

U.S Government

Industry

International Partners

Academia

Public

WHAT FOUNDATIONAL CAPABILITIES ARE NEEDED

Long-duration microgravity systems

Partial gravity destination platforms

Low Earth Orbit assets and infrastructure

WHERE SHOULD SYSTEMS BE?

Ensure access to the Lunar South Pole

Capability for non-polar expeditions

HOW WILL WE GET THERE AND RETURN?

Lunar Microgravity staging in NRHO

Earth ⟷ NRHO ⟷ Lunar surface

Surface Mobility

WHY EXPLORE?

- SCIENCE -

Understand the universe
Direct observations

- INSPIRATION -

“Artemis Generation”
Overcome challenges
Succeed with hard work

- NATIONAL POSTURE -

Enrich lives on Earth
Technology development
International partnerships

Artemis Architecture Design Factors

Base Architecture Assumption:	Artemis includes independent lunar orbit arrival of elements, different architecture from both Apollo and Constellation
Crew/Cargo Vehicle Access:	Orion must perform both entry and exit to lunar orbit; cargo must have efficient access to enable cis-lunar delivery
Lunar Surface Access:	South Pole destination is significantly higher delta-V and access driver than equatorial locations on the Lander element
Orbit Maintenance:	Sustainable long duration station-keeping cost and staging aggregates over time; must be capable of supporting Mars forward elements
Rendezvous, Prox Ops, Docking (RPOD):	Dynamics of some cis-lunar orbits significantly different from Low Earth and Low Lunar experience base
Earth & Lunar Communication:	Critical crew operations require high availability and reliability
Space Environment:	Long duration vehicles depend on solar power and stable thermal environments; must avoid long eclipses or commodity driven services

Artemis Architecture must be achievable for all Design Factors

NRHO: Near Rectilinear Halo Orbit

Video File Provided Separately

Halo Orbits can be thought of as resulting from an interaction between the gravitational pull of the two planetary bodies and the Coriolis and centrifugal force on a spacecraft.

Halo orbits exist in any 3-body system, e.g., an Earth-Moon-orbiting satellite system. Continuous "families" of both northern and southern halo orbits exist at each Lagrange point.

The **Gateway Orbit** is from one of the **southern** families of halo orbits and has a synodic resonance (revs to months) of **9:2**, the lowest altitude NRHO with useful resonance and an orbit period of **6.5 days**.

Design note: with larger orbits, you have the Earth influencing the orbit making it less stable. So, you're trying to thread the needle with design.

The Artemis Orbit

Vehicles in NRHO are under the influence of both Earth & Lunar gravity

Video File Provided Separately

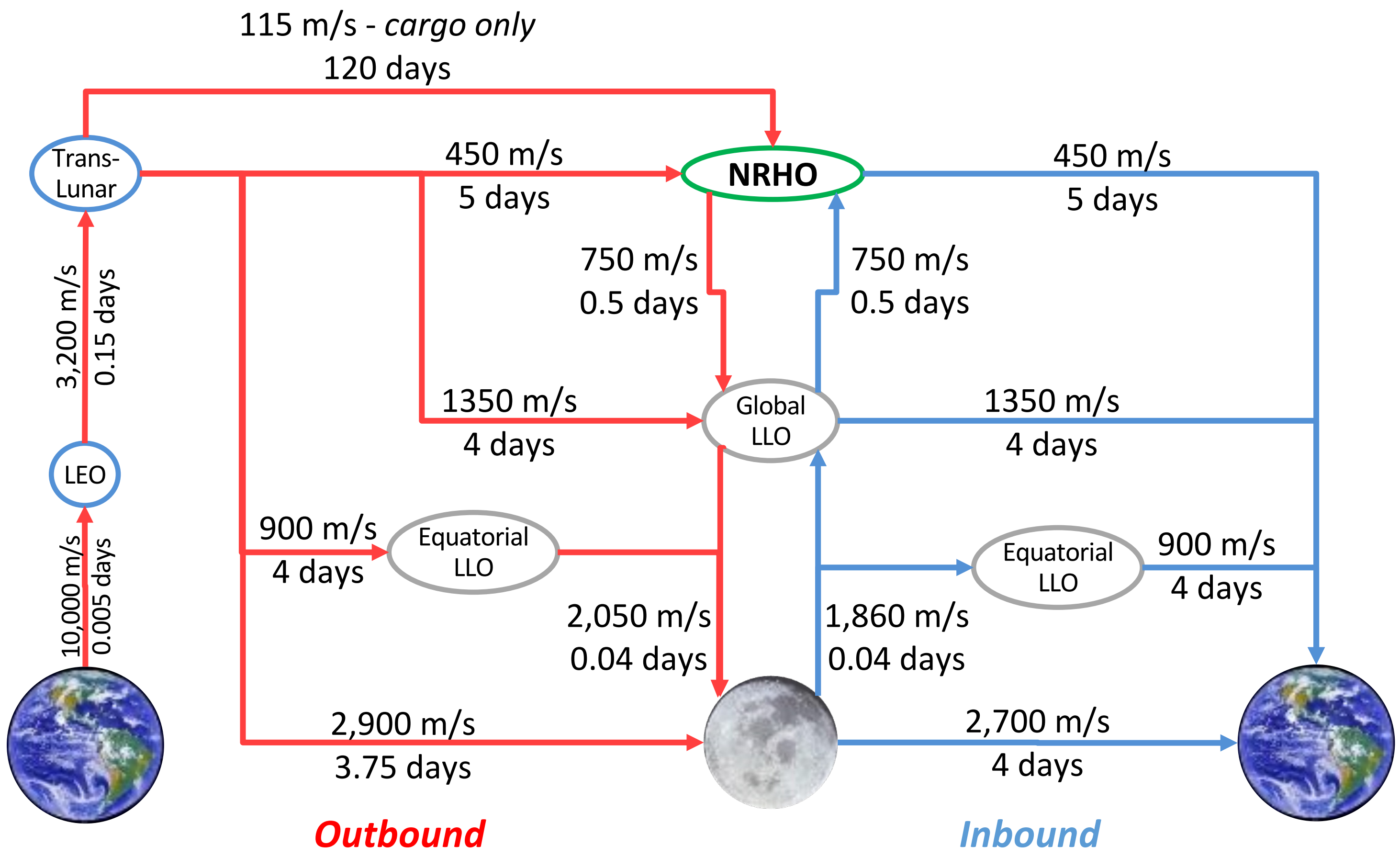
From the vehicle's perspective, the orbit always faces the Earth

While the Moon and the vehicle go "around" the Earth…

…Lunar gravity pulls the vehicle "up and down"

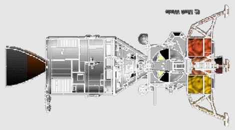
Cis-Lunar Architecture Performance Share

Approximate Translation Delta-V Cost



Apollo

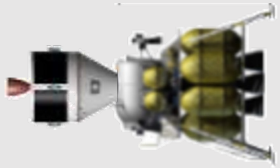
LLO-LOI + TEI*:
2800 m/sec



Descent: **2470 m/sec**
Ascent: **2220 m/sec**

Constellation
(CEV/Altair)

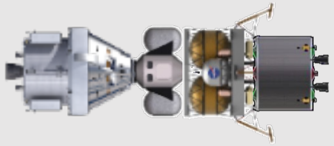
LLO-TEI* w/
Global Access:
1492 m/sec
(spec value)



LLO LOI w/
Global Access and
Descent: **3160 m/sec**
Ascent: **1877 m/sec**

Artemis
(Notional)

NRHO-LOI + TEI:
1,000 m/sec
(as-built)

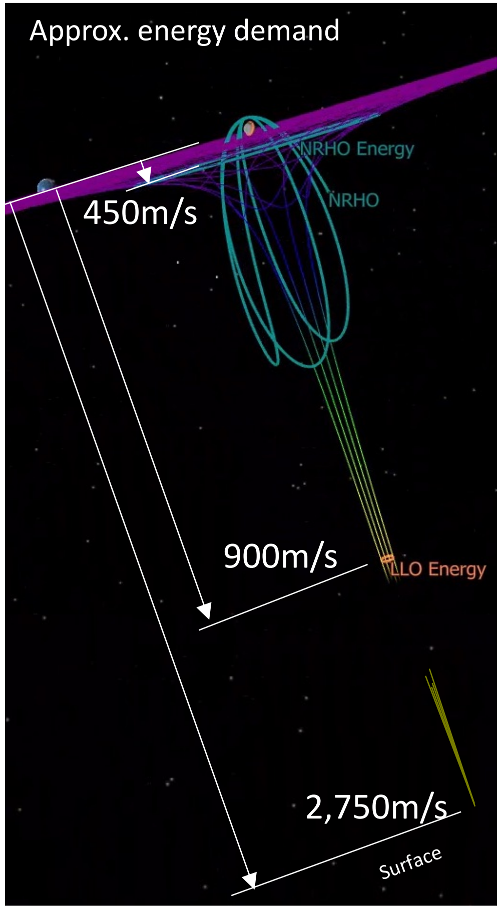


Transfer: ~**750 m/s**
Descent: ~**2,050 m/s**
Ascent: ~**2,610 m/s**

**Total performance values exclusive of attitude control, contingency, or other decrements to availability*

Lunar Orbit Energy States

Video File Provided Separately



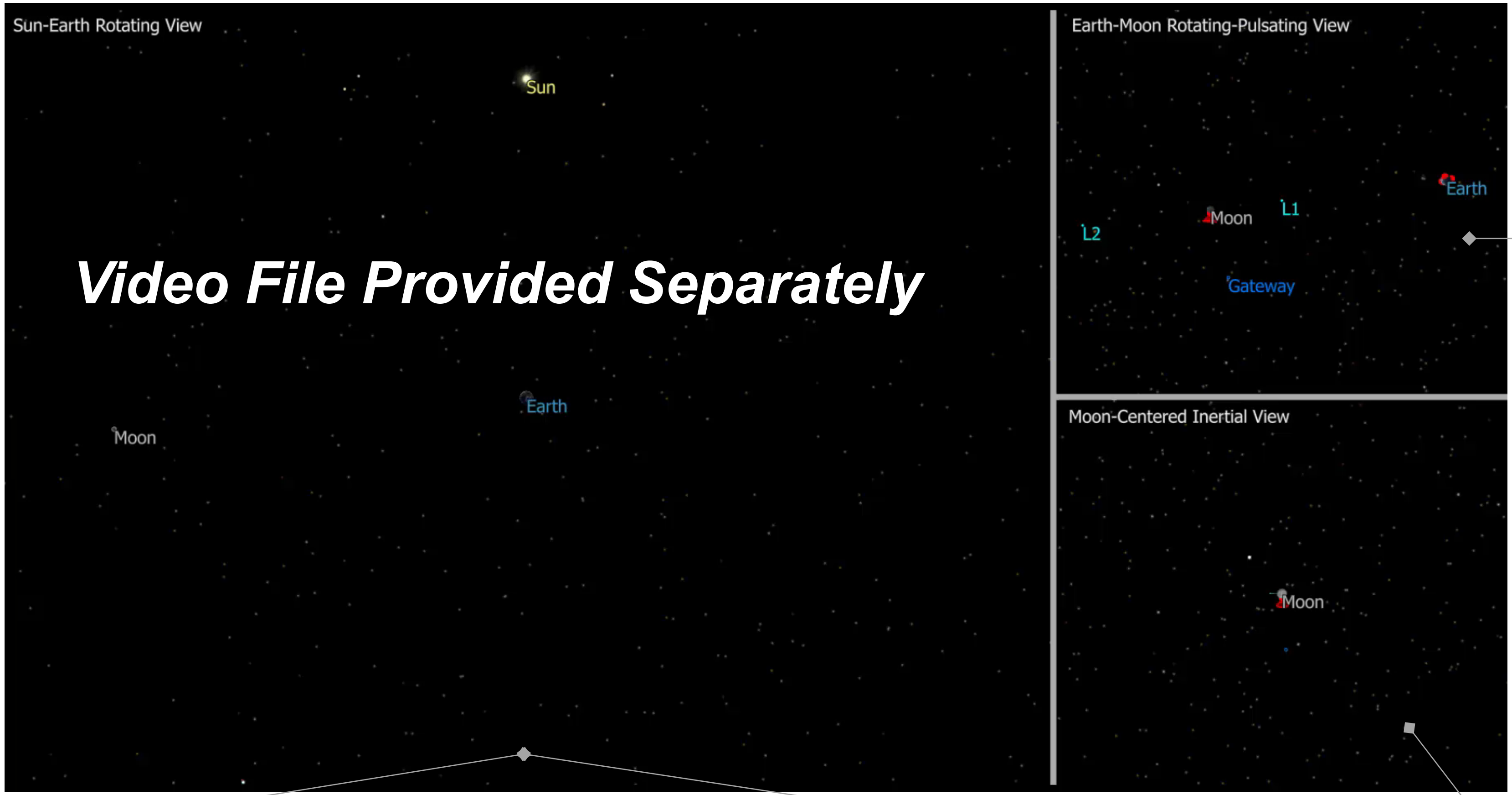
NRHO is balanced on the *edge* of the lunar gravity well

Minimal orbit maintenance cost to stay in NRHO over time

Low Lunar Orbit (LLO) is *deep* in the gravity well

NRHO insertion and departure is ~*half* delta-V of LLO

Comm/Power/Thermal Performance



Earth facing orbit provides *continuous* **Earth comm** for long duration mission capability

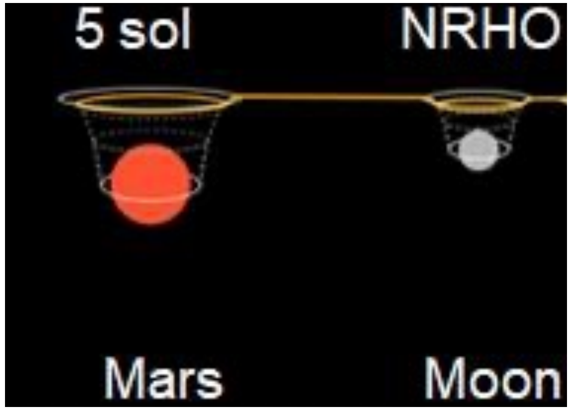
NRHO resonance places apolune below Sun/Earth shadow, *avoiding long eclipses*

This resonance ensures vehicle *near continuous* **power** and *stable* deep space **thermal environment**

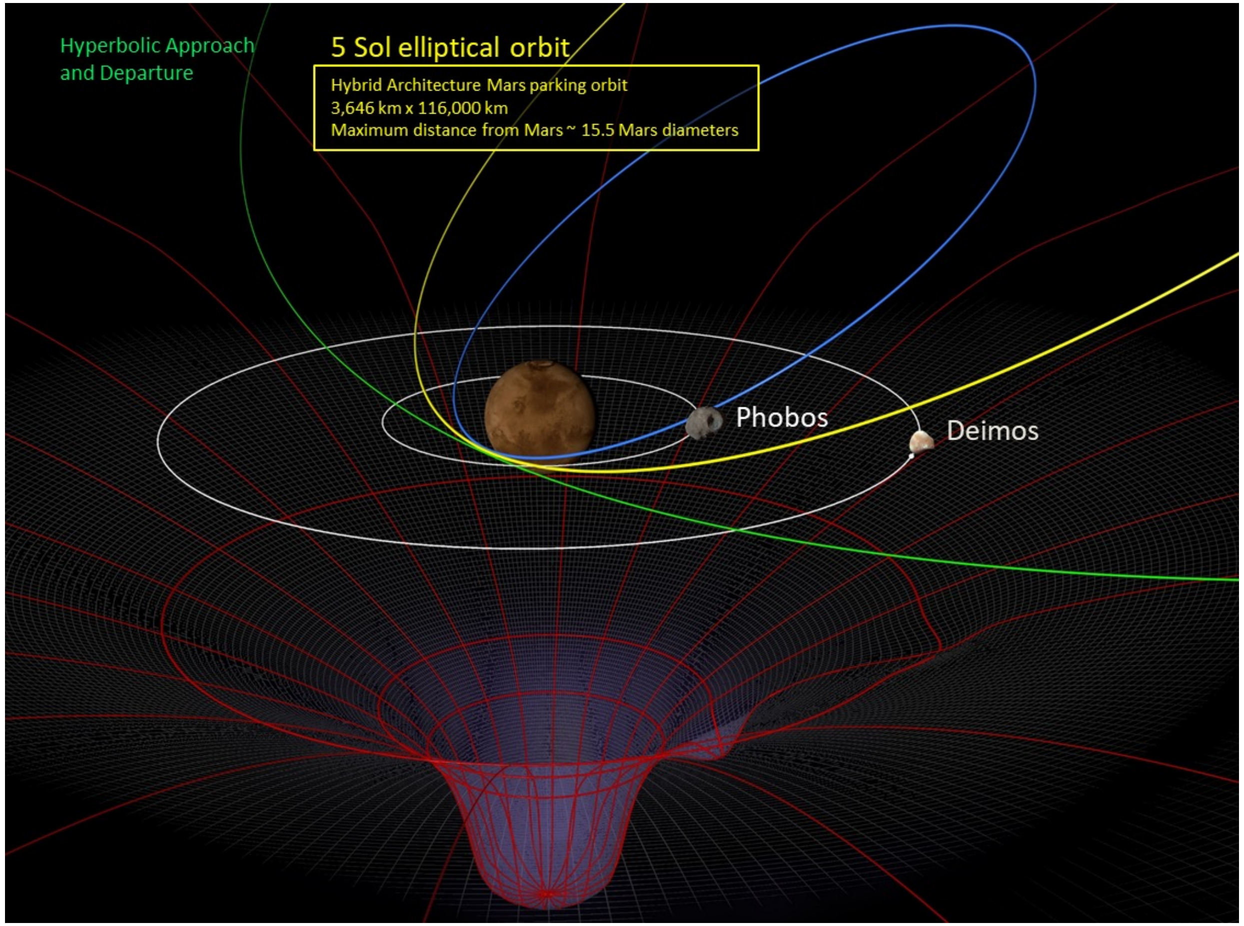
South Pole surface comm *lengthy* visibility during long apolune passes; *short* dropout during fast perilune pass

Design Trade: Mars Extensibility

Comparable Gravity Well Placement



	Mars (5-Sol Orbit)	Gateway (NRHO)
Typical Orbit Parameters	250 km x 110,000 km	1000 km x 70,000 km
Orbital Period	5 days	7 days
Total Descent Delta-v	~800 m/s	~2,700 m/s
Total Ascent Delta-v	~2,500 (stage 1) + 2,700 (stage 2)	~2,700 m/s
Time for Descent	2.5 days	0.5 days
Time for Ascent/Rendezvous	3 days	0.5 – 4 days

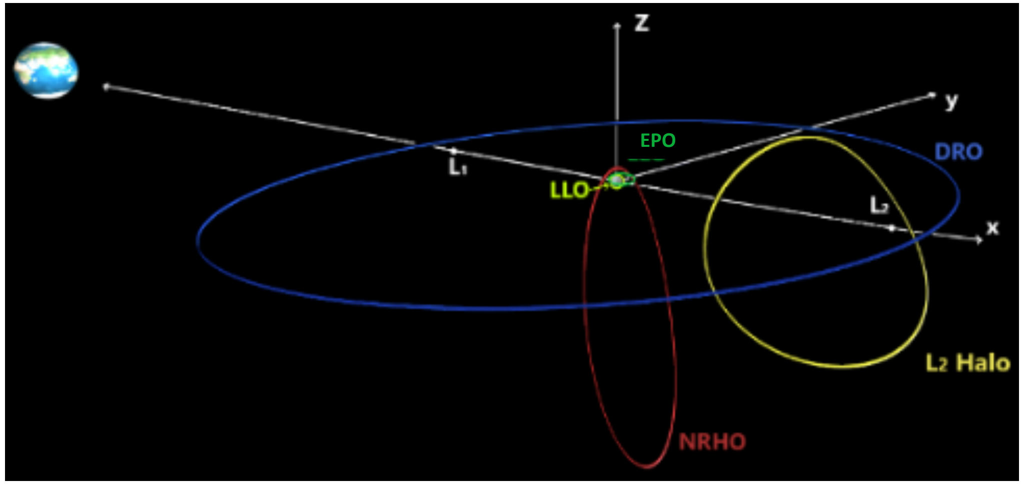


Design Trade: Conclusion

Cis-Lunar Orbits		Crew Vehicle Access (ΔV to/from Earth)	Lunar Access (ΔV to/from Surface)	Gateway Orbit Features					
				Gateway Access ΔV	Orbit Maintenance	RPOD	Comm Cutouts	Power/Thermal	Mars Forward
Low Lunar Orbit (LLO)	Equatorial	High	Infeasible/Short	High	Low/Moderate	Circular Orbit	Moderate	Most Challenging	Minimal
	Polar	Highest Shorter Earth return	Low/Short Duration						
Elliptical Polar Orbit (EPO) with Coplanar Line of Apsides (CoLA)		Moderate/High	Moderate Short Duration	Moderate/High	Moderate	Challenging	Moderate	Challenging	Minimal
Near Rectilinear Halo Orbit (NRHO)		Moderate	Moderate Medium Duration	Moderate	Minimal	Near Linear Dynamics	None	Deep Space Equivalent	Extensible
Earth-Moon L2 Halo		Low/Moderate Longer Earth return	Moderate Long Duration	Low/Moderate	Minimal	Near Linear Dynamics	None	Deep Space Equivalent	Partial Ext.
Distant Retrograde Orbit (DRO)		Low/Moderate' Longer Earth Return	High Longest Duration	Low/Moderate	N/A	Near Linear Dynamics	Infrequent	Deep Space Equivalent	Minimal

Table normalized to NRHO for comparison:

Better		NRHO		Worse



Multiple studies and trades indicate NRHO is the best option for a sustainable lunar architecture and preparation for Mars

Summary

- **NASA has studied numerous staging orbits to support Artemis and future missions beyond the Moon**
- **NRHO is a highly stable orbit that with repeatable Earth-Moon access & ideal environmental characteristics**
- **Near-Rectilinear Halo Orbit provides a balanced approach to support the multiple objectives and goals of the architecture.**

Access the white paper with this QR code or at www.nasa.gov/MoonToMarsArchitecture