



National Aeronautics and
Space Administration

Mars Sample Return Capability Development: Mars Ascent Vehicle and Mars On-Orbit Rendezvous

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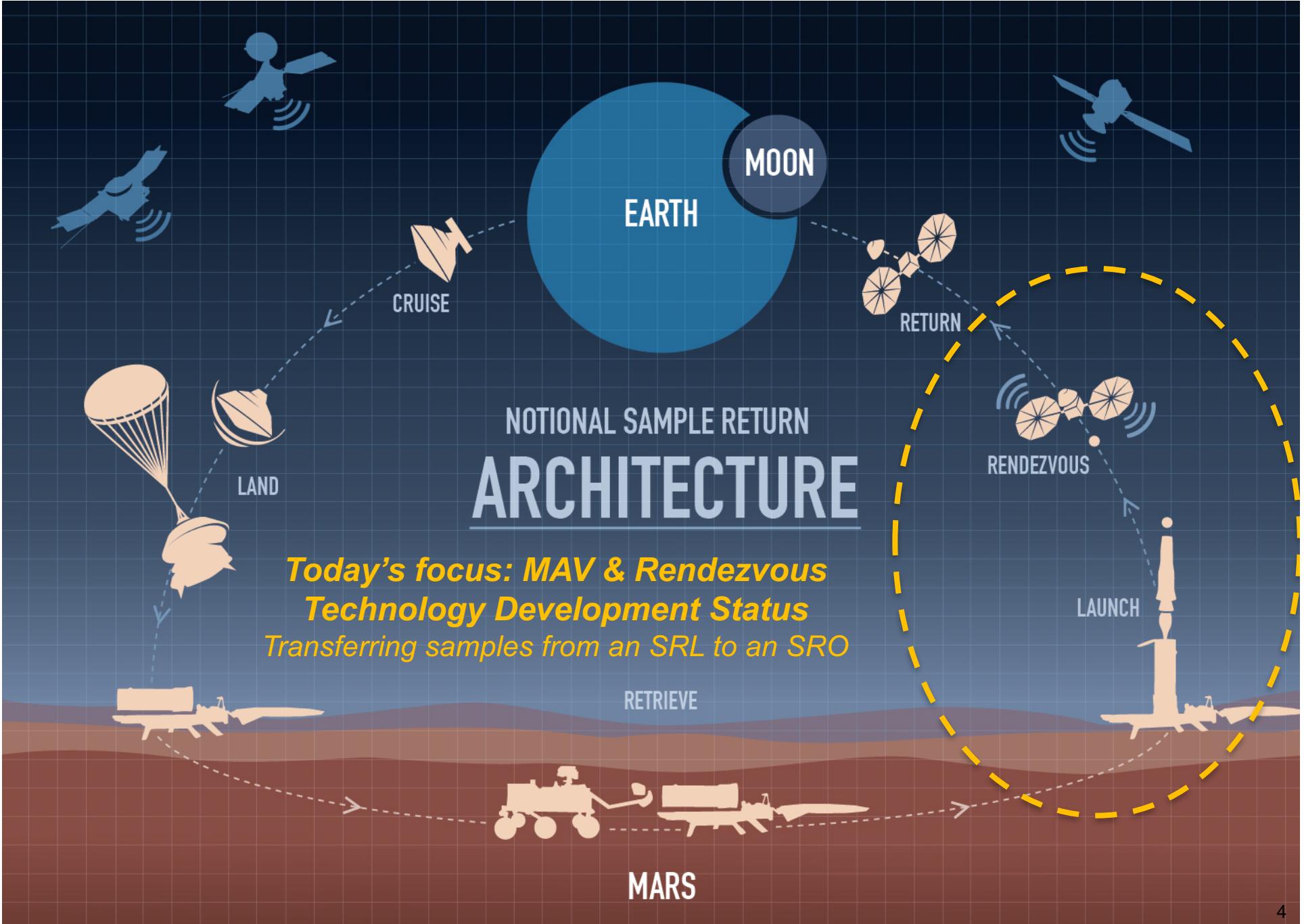
Predecisional information, for planning and discussion only

Executive Summary

- Mars Ascent Vehicle and Rendezvous are key capabilities that would be needed for Mars Sample Return
 - A Sample Retrieval Lander's MAV would launch an Orbiting Sample (containing collected samples) into stable Mars orbit
 - A Sample Return Orbiter would perform on-orbit Rendezvous w/ OS for Earth return
- Focused technology developments have advanced the maturity of the MAV and Rendezvous capabilities
- Future developments would establish readiness for SRL/SRO launch as early as 2026

Outline

- Notional MSR Campaign Overview
- Capability Development Status
 - Mars Ascent Vehicle
 - Orbiting Sample
 - Fundamental interface between an SRL and an SRO
 - Mars On-orbit Rendezvous concept
- Summary



NOTIONAL SAMPLE RETURN ARCHITECTURE

***Today's focus: MAV & Rendezvous
Technology Development Status***

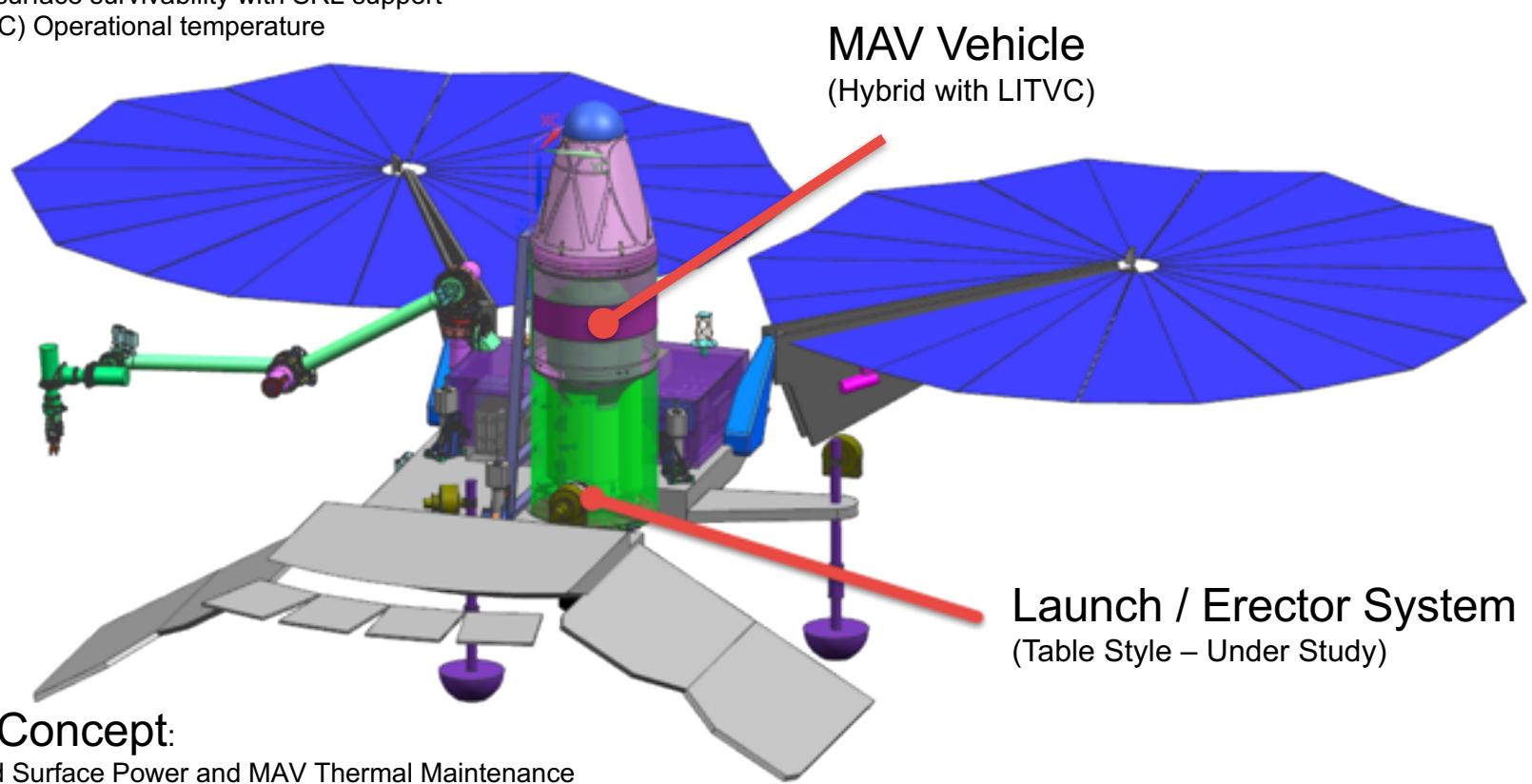
Transferring samples from an SRL to an SRO

MAV Technology Development

MAV Concept Overview

Driving MAV Requirements:

- ~300-400 km, “due east” circular orbit
- 12 kg Orbital Sample Canister Payload
- Launch from potential M2020 Landing Sites
- 9 months surface survivability with SRL support
- Cold (-20°C) Operational temperature

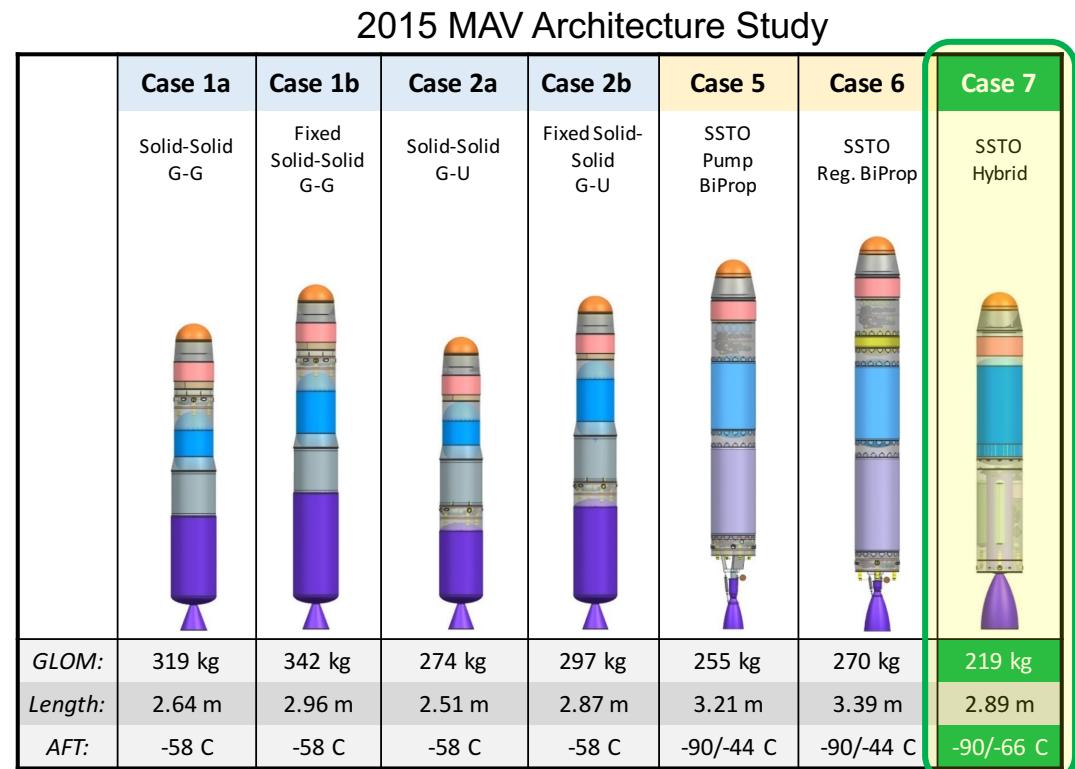


Lander Concept:

- Cruise and Surface Power and MAV Thermal Maintenance
- Launch Tube with Thermal Insulation to Minimize Energy Costs
- MAV Navigation Initialization
- Erector and Initial Launch Stability

Mars Ascent Vehicle 2015 Case Studies

- JPL/MSFC/LaRC carried out trade study in FY15 of MAV implementation options
 - Solid-Solid two-stage
 - Liquid bi-prop SSTO
 - Hybrid SSTO
- Based on propulsion performance and thermal accommodation, Hybrid SSTO option selected as current focus

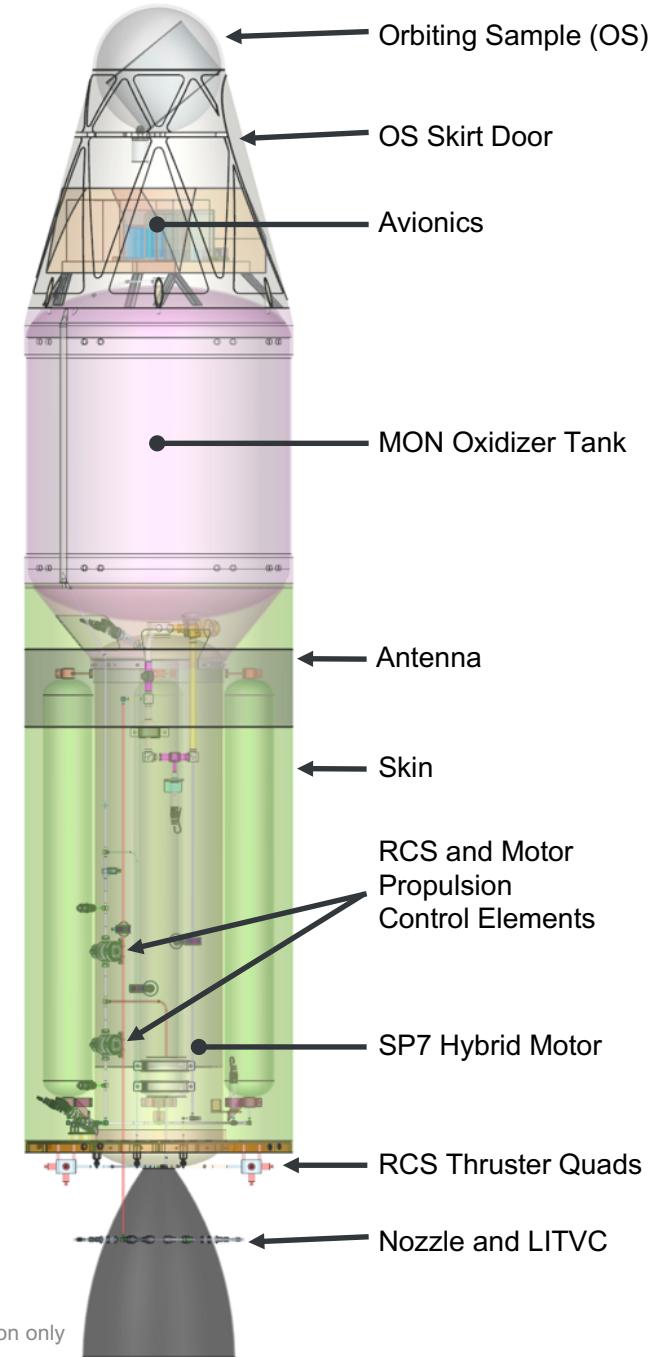


Broad study of MAV architectures has led to the current Hybrid SSTO approach

MAV Reference Design

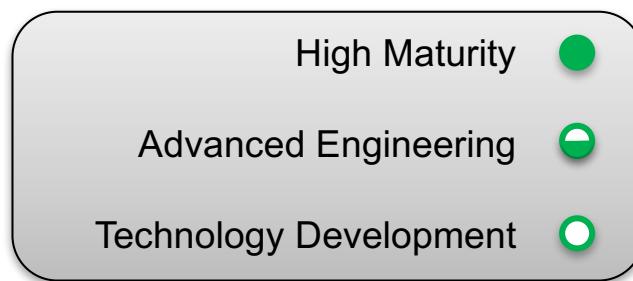
- Continued Study from 2015...
 - Added Subsystem Maturity and Fidelity
 - Validated Single-Stage-To-Orbit Design
 - Target Orbit 350 km @ 18° Inclination
 - 12 kg OS Capability (31-Tubes)
 - Length: 2.4 m x Diameter: 0.57 m
 - GLOM Range: 290-305 kg (w/ 50% margin)
 - Varies with launch uncertainties
 - Mass Fractions
 - Propulsion Dry Mass : 10%
 - Non-propulsion Dry Mass : 12%
 - Oxidizer Mass: 63%
 - Fuel Core Mass: 14%
 - Helium Mass: <1%

GLOM	Gross Liftoff Mass
LITVC	Liquid Injection Thrust Vector Control
OS	Orbiting Sample
RCS	Reaction Control System
TPS	Thermal Protection System

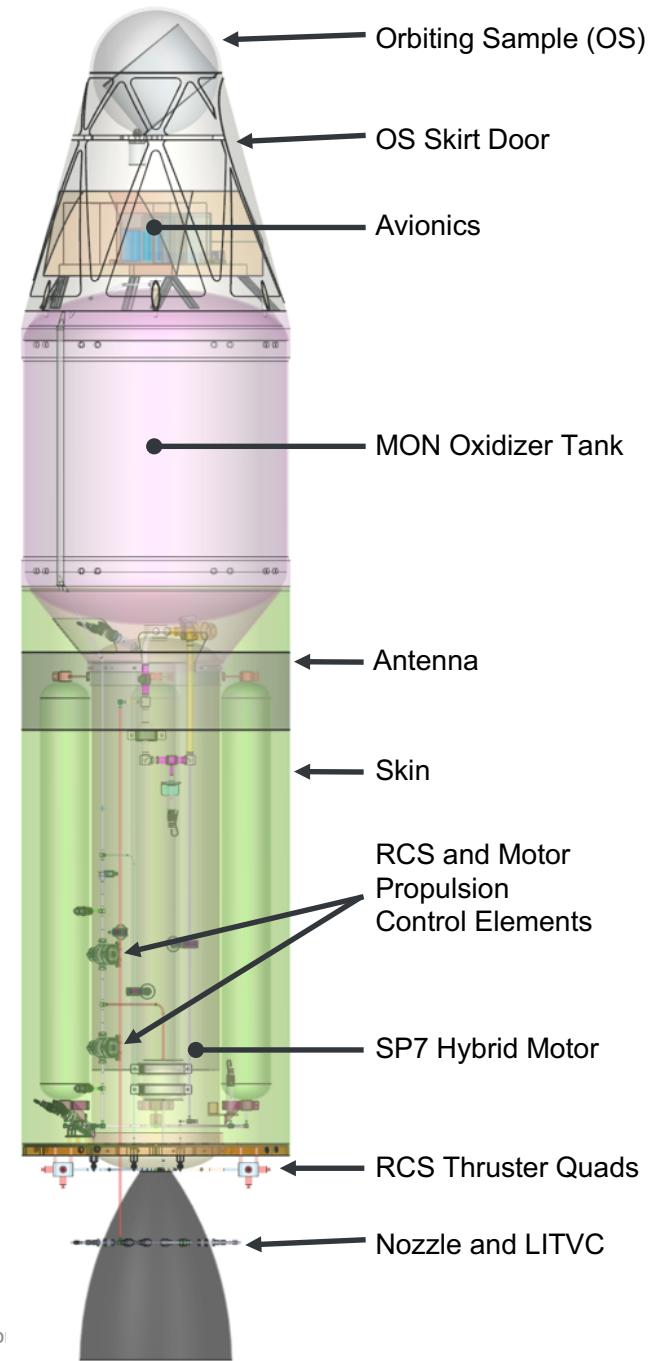


Hybrid MAV Technical Maturity

Subsystem	Maturity
OS	Significant Early Work and Prototyping Completed
Nose & Structure	Standard Flight Engineering
Avionics	Standard Engineering, Based on Europa Lander
Prop Tanks	Standard Flight Tank Engineering
Prop Components	Valves and Regulators are Long Lead Developments
Hybrid Motor	Technology Development Underway
RCS Components	Standard Engineering
LITVC	Technology Development Underway

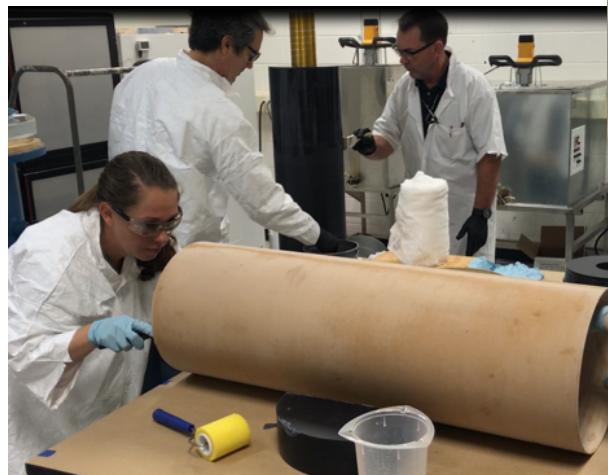


GLOM Gross Liftoff Mass
LITVC Liquid Injection Thrust Vector Control
OS Orbiting Sample
RCS Reaction Control System
TPS Thermal Protection System



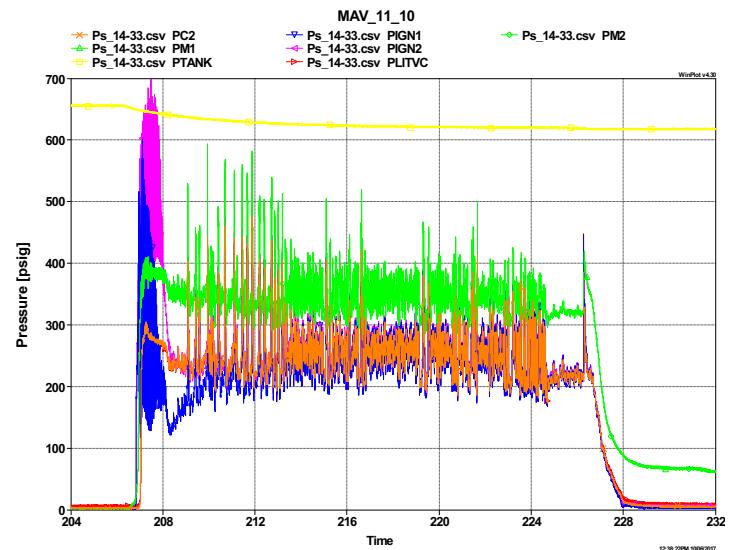
MSFC SP7 Fuel Grain Work

- MSFC has developed a robust and repeatable fuel grain manufacturing technique
 - Started making grain in many segments
 - Now capable of full-scale monolithic grains



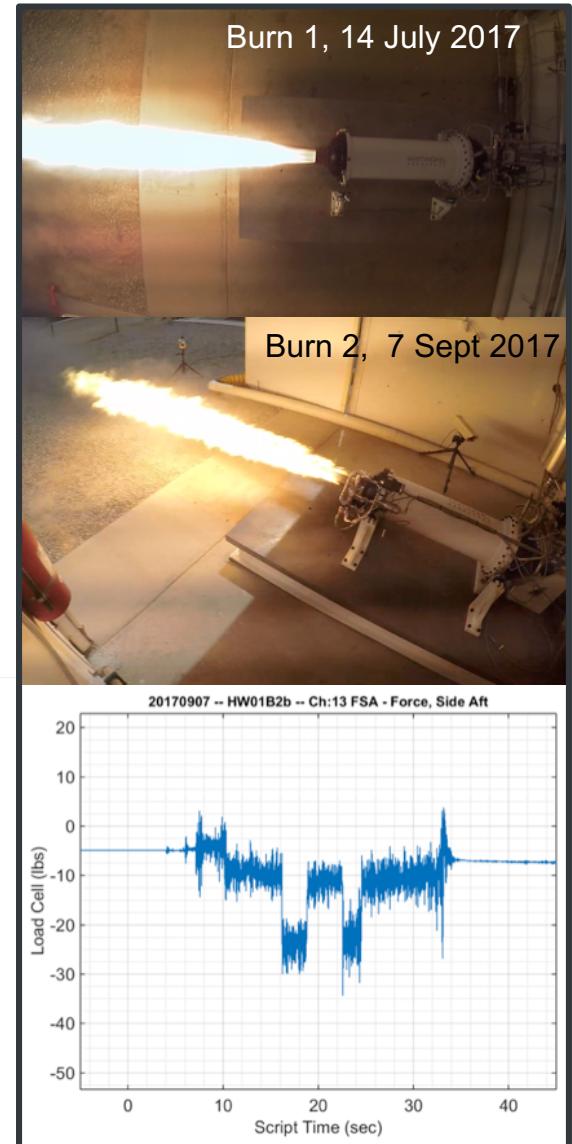
MAV Testing Progress - SPG

- Complete
Oct 5 & 13, 2017
 - ✓ Motor 1: Verify ignition of desired propellant combination at scale.
 - ✓ Motor 2: Extend burn duration (>20 s) and work on stability
- November 2017 (in progress)
 - Motor 3: Burn fuel grain to completion, restart at similar conditions to 2nd burn on MAV, extend burn durations, reduce insulation mass
- December 2017
 - Motor 4: LITVC demonstration
 - Motor 5: Burn fuel grain to completion, extend burn durations
- January 2018
 - Motor 6: Full duration burn with a restart (motor inspection between burn 1 and 2)
 - Motor 7: Full duration burn with a restart (no outside intervention)



MAV Testing Progress – Whittinghill

- ✓ **Heavy Weight Motor 1 (two burns):**
 - Smooth and rapid ignition
 - Establish SP-7 regression rate at full scale
 - Demonstrate smooth combustion
 - Demonstrate high c^* efficiency
 - Obtain initial LITVC data
- Complete**
- November 2017 (in progress)**
 - **Heavy Weight Motor 2:**
 - Burn motor on peak O/F
 - Increase burn time (~60 sec)
 - Demonstrate high c^* efficiency with minimal system impact
 - Investigate alternate injector patterns for more benign fuel impingement effects
 - Continue acquiring LITVC data
 - Flight Type Motor 3:**
 - Investigate lower injector ΔP for (flight) He conservation
 - One burn, near full duration
 - Continued LITVC
 - Flight Type Motor 4:**
 - Full impulse for MAV mission
 - C^* efficiency > 0.95
 - High Fuel utilization
 - Remote re-start, 2 burns on a MAV mission profile.
 - Continued LITVC
- December 2017**
- January 2018**



MAV Technology Development Status



WHITTINGHILL
A E R O S P A C E

MAV Heavyweight Motor #1
Burn 2, with Liquid InjectionTVC Events
Duration 21.5 seconds
September 7, 2017

OS Concept

Orbiting Sample (OS) Concept Overview

- The OS provides a container to securely hold and protect the M2020 Sample Tubes (nominally 31) for return to Earth
 - Mars atmospheric samples are also contained in the OS and returned to Earth
- Orbital Sample (OS) interfaces directly with both SRL/MAV and SRO elements of MSR
- The OS with Sample Tubes must withstand environments imposed by SRL, SRO, EEV



Current OS
Reference Design



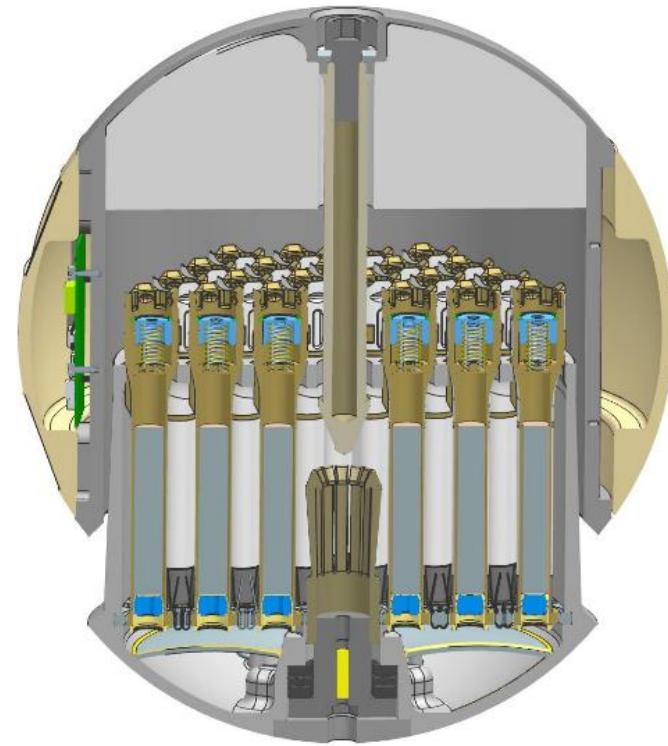
Mars 2020 Sample Tube
Assembly



Engineering OS ready for
impact testing

OS Architecture and Design Approach

- OS Concept
 - 31 tube slots, central rod for load support
 - 2 air sample tanks with manual valves
 - Assembled at Mars with aluminum foam to provide tube preload for EEV landing
- Surface
 - Sandblasted gold meets thermal, albedo, & specular reflectance requirements
- Mass & diameter
 - Mass \leq 12 kg
 - Diameter \leq 28 cm



Rendezvous Concept

Rendezvous Concept Overview

Phase 1: Initial Acquisition and Orbit Matching

Sensor: NAC (MAC backup)

Distance: 3,300 km → 10 km

Time: < 1 month

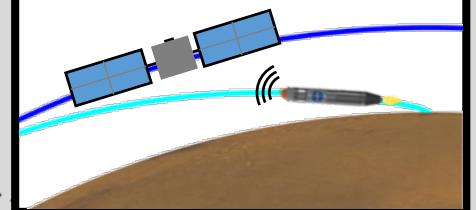
Maneuvers: SEP

Ground-In-The-Loop

Observe Only

NAC

Phase 0: Launch



~30 km

Low Mars Orbit

*not to scale

Phase 2: Inspection and Approach

Sensor: NAC + MAC

Distance: 10 km → 100 m

Time: ~2 weeks

Maneuvers: SEP

Ground-In-The-Loop

1 km

10 km

MAC

Predecisional information for planning and discussion only

Phase 3: Terminal

Sensor: MAC → WAC

Distance: 100 m → 0 m

Time: ~1 hour

Maneuvers: RCS

Autonomous



OS Capture

WACs

100 m

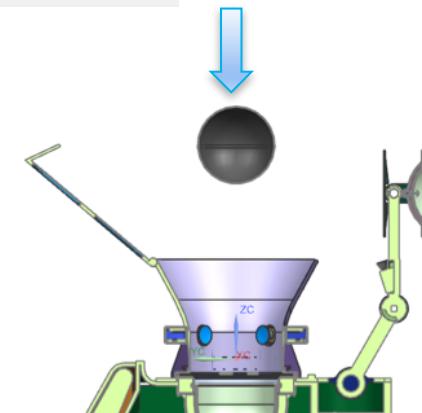
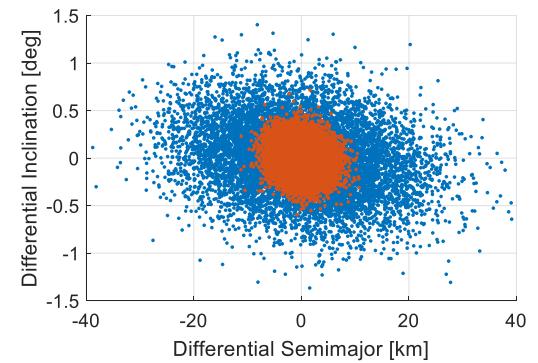
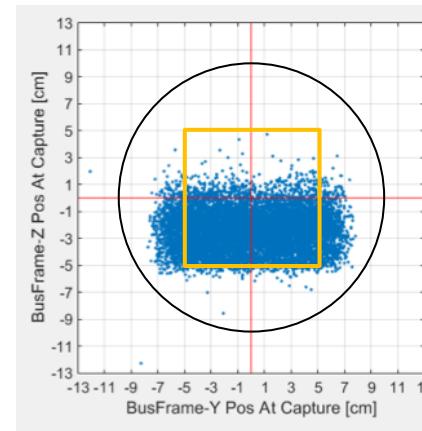
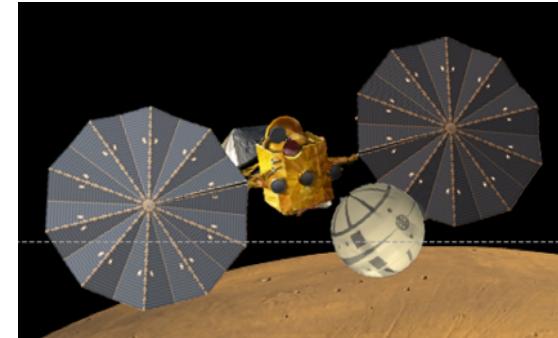
Rendezvous Concepts: MSR vs Earth-Orbit (e.g., ISS)

	Long Range (>10 km)	Medium Range (10 km - 100 m)	Short Range (<100 m)	
MSR Harder than ISS	Significant MAV Delivery Errors			Increases propellant required
	OS harder to image than ISS (smaller, farther from sun)			Long range optical detection required
	No GPS Available			
	No Ground Tracking			
	Target is passive			Increased autonomy required
		Round Trip Light Time ≈ Minutes		
MSR Easier than ISS	Orbit matching is allowed to take weeks			Reduces propellant and autonomy requirements
	Target shape is simple (sphere)			Complicated LIDAR/image processing not needed
	Target surface properties known and can be tailored to rendezvous		Relative Attitude does not need to be controlled	
			Unconstrained approach vector	
			Abort options are less constrained	Safer and more straightforward rendezvous strategy

- Many commercial and international partners have experience with rendezvous at the ISS
- The main new challenges for a potential MSR:
 - Long range acquisition of the OS (this is done by GPS and ground sensing for ISS)
 - Completely autonomous terminal phase (round trip light time too high for human-in-the-loop)
- However, many aspects are easier:
 - Because the OS is a sphere, its attitude is not relevant for rendezvous
 - Because the OS is small, there are no “keep-out corridors” complicating the approach and abort vectors

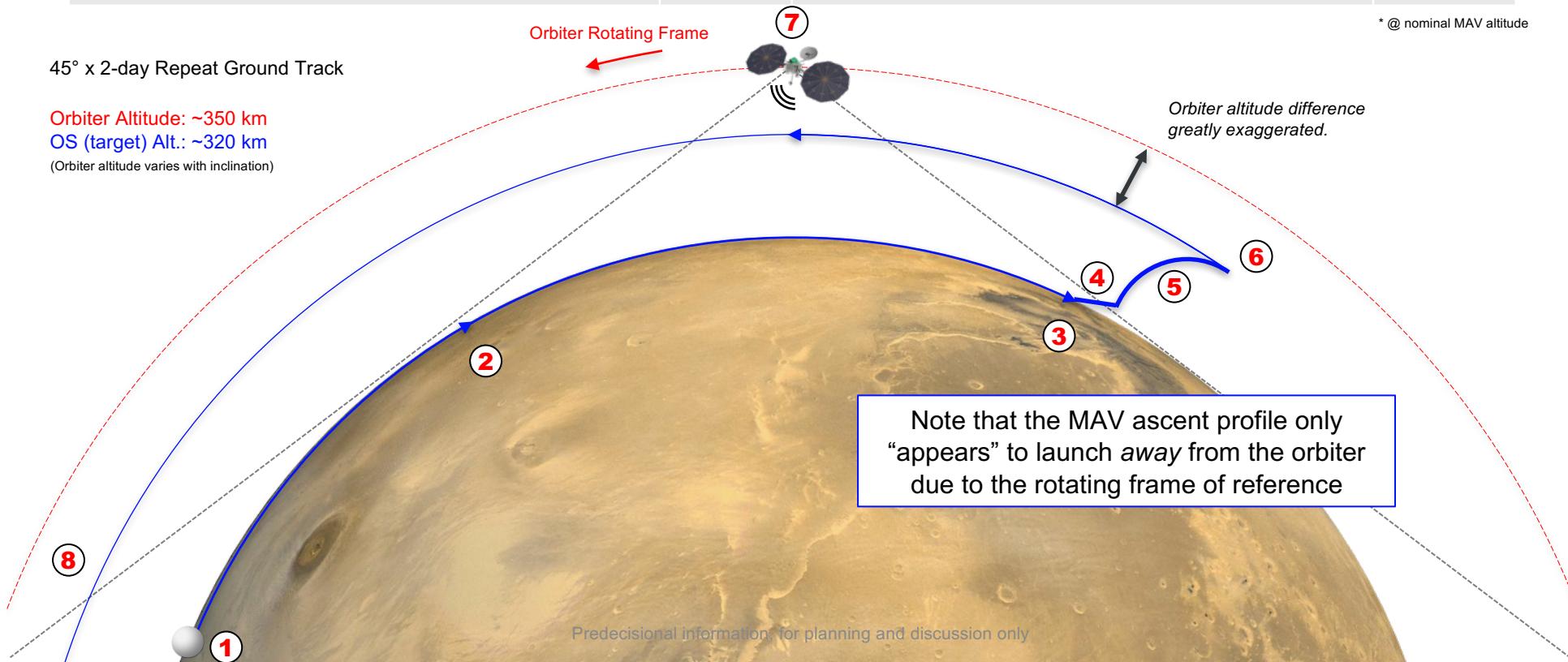
Driving Rendezvous Requirements

- OS:
 - Diffuse Sphere
 - Diameter = 28cm
 - Albedo: ≥ 0.3
- MAV Orbit:
 - Low Mars Orbit, circular
 - Unconstrained beta angle
 - Inclination: $\pm 1^\circ$ (3σ)
 - Semimajor axis: ± 32 km (3σ)
- Capture Vector (3σ):
 - Position: ± 10 cm
 - Velocity: 5 ± 1 cm/s
 - Direction: $\pm 5^\circ$
- System Considerations:
 - Remain fail-safe until terminal phase
 - Single-Fault Tolerance

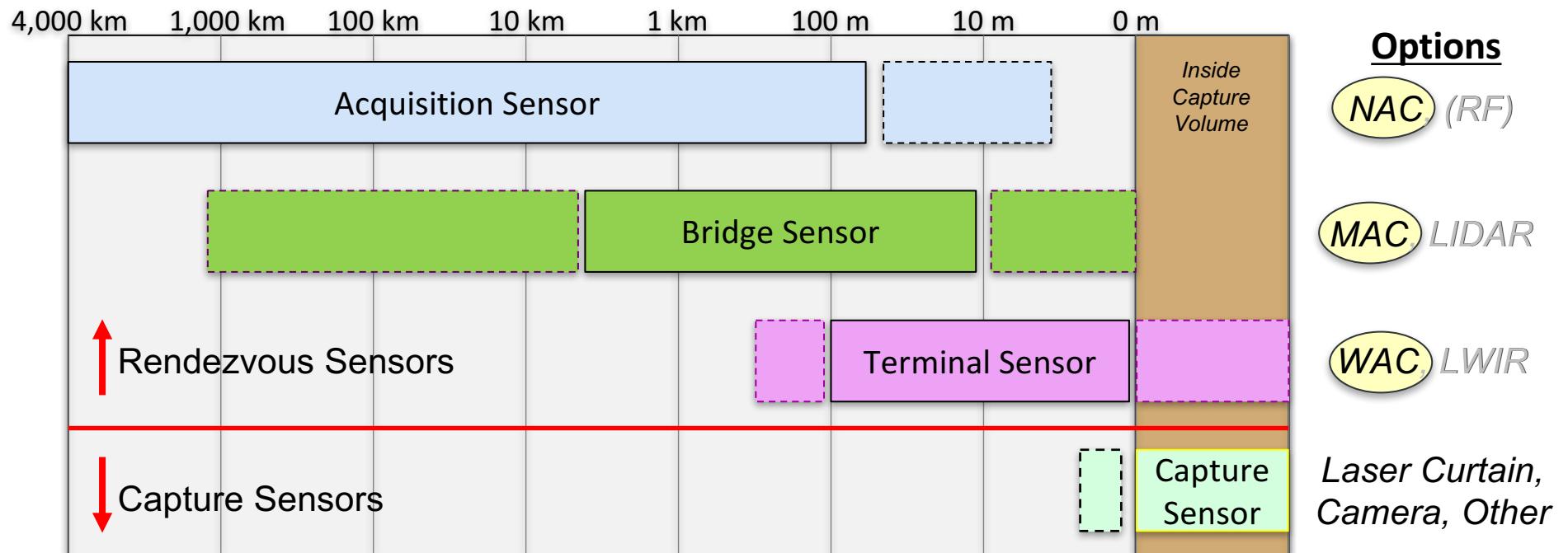


Notional MAV Launch Sequence

Event	Time	Event	Time
① MAV Ready for Launch	L-2d	⑤ Ascent Coast Phase	L+15m
② MAV-Orbiter In-View (Go / No Go)	L-20m	⑥ 2nd Burn / OS Separation	L+16m
③ MAV Launch	L-0	⑦ OS Passes under Orbiter	L+15h*
④ Ascent 1st Burn	L+2m	⑧ OS Occulted by Mars	L+39h*



Rendezvous Sensor Domains

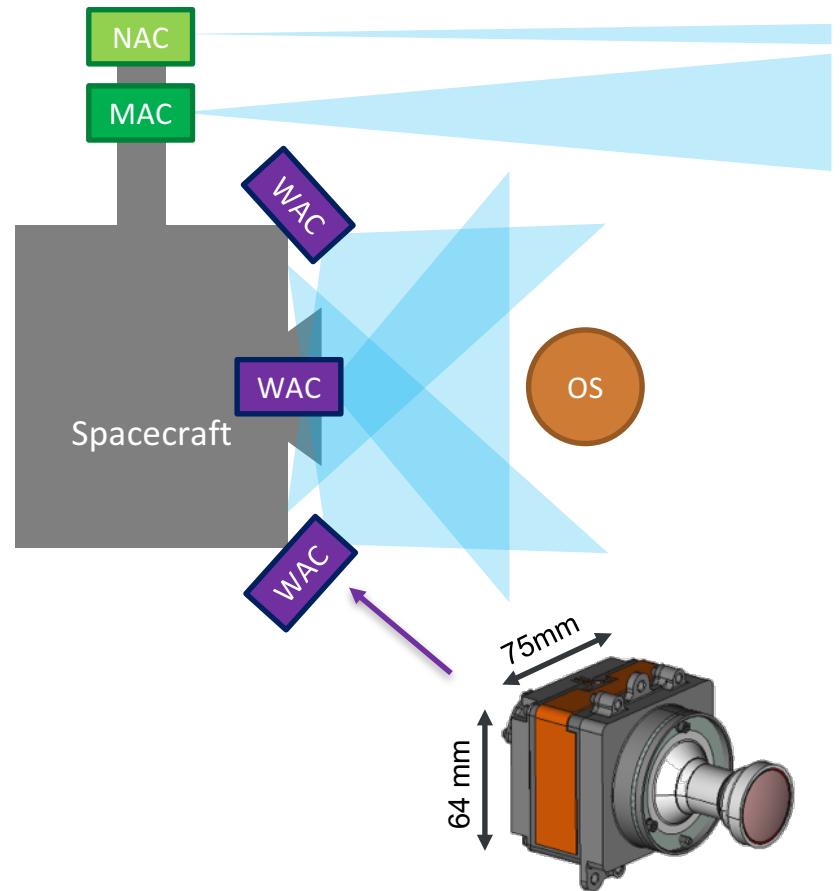


Sensor	Max Range	Min Range	FOV	Aperture	Detector	Accuracy	Phase Angle
NAC Narrow Angle Camera	>3,500 km	10 – 50 m	5° – 8°	5 – 10 cm	Existing	<35 µrad	< 90°
MAC Medium Angle Camera	>1,000 km	1 – 10 m	10° – 60°	3 – 5 cm	Existing	<500 µrad	< 90°
LIDAR	1 – 10 km	1 – 10 m	~20°	~5 cm	Existing	~3 mrad Range: ~10 cm	All
WAC Wide Angle Camera	100 m – 1 km	0 – 1 m	60° – 120°	1 – 5 cm	Existing	~1 mrad	< 90°
LWIR Long Wave Infrared	200 m – 2 km	0 – 1 m	60° – 120°	2 – 5 cm	Existing	~3 mrad	All

Predecisional information, for planning and discussion only

Reference Sensor Suite

- **Narrow Angle Camera**
 - Provides initial detection of OS at max. range (~3,500 km)
- **Medium Angle Camera**
 - Maintains visual lock during approach, provides relative navigation information
 - Can detect OS at long range (>1,000 km) in case NAC fails
- **Wide Angle Cameras**
 - Stereoscopic view of the OS at terminal approach, and covers a wide swatch of sky to provide situational awareness



Example Hardware:

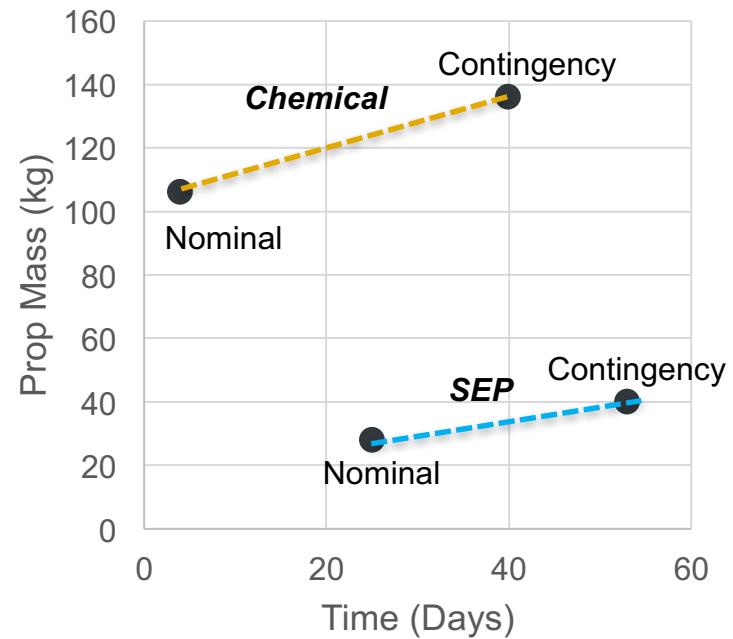
- WAC = M2020 EECAM Build-to-Print
- NAC and MAC use EECAM detector and electronics, but with larger optics
- All 5 cameras: ~10kg, 15W

SEP vs Chemical Orbit Matching

		3 σ Values Nominal Ops			3 σ Values Contingency Ops		
Propulsion Option	Isp [sec]	Time [days]	Delta V [m/s]	Propellant [kg]	Time [days]	Delta V [m/s]	Propellant [kg]
Chemical	230	4	78	106	40	100	136
SEP	2600	25	233	28	53	341	40

(Contingency scenario corresponds to failure to detect OS prior to first occultation, requiring 10-day limb-scanning period)

- Both Chemical and SEP propulsion options can meet MSR orbit matching needs for OS Rendezvous
 - Note: SEP case corresponds to high-acceleration SEP configuration, consistent with a fast-return MSR orbiter optimized for speed
- Key trade is between time-to-complete vs. propellant mass
 - SEP takes longer, but has a significantly lower propellant cost than Chemical



Conclusion

- Extensive MAV trade studies have established a Hybrid Propulsion, Single-Stage-to-Orbit MAV reference design for potential MSR
 - JPL/MSFC team working with industry partners to fully mature MAV technology to TRL 6 by 2022
- The Orbiting Sample (OS) – the physical interface between MAV and SRO – has a mature conceptual design
 - Fully incorporates M2020 sample tube design
- The SRO-OS Rendezvous function is well understood
 - Simple passive-imaging sensor suite is fully capable of supporting OS detection, approach, and terminal rendezvous phases

Key MSR technologies are on track to support SRL/SRO launch as early as 2026



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MARS SAMPLE RETURN