SAPPHO: Spectroscopic Analysis of Phobos Plus HD Orbital survey

Dakota Richline (Solo)

Department of Aerospace, Physics, and Space Sciences, Florida Tech

AEE 4806: Space Mission Engineering

Dr. Paula do Vale Pereira

SAPPHO: Spectroscopic Analysis of Phobos Plus HD Orbital survey

Mission Concept

The Decadal Strategy had a number of interesting questions, and those involving interplanetary science stood out to me. I originally wanted my mission to test a VASIMR in space for the first time—e.g. a resurrection of the cancelled ISS-VASIMR mission—but it seemed inappropriate for most of the proposed questions. I chose question Q3.4: "WHAT PROCESSES YIELDED MARS, VENUS, AND MERCURY AND THEIR VARIED INITIAL STATES?" (Origins, pp 167)

Most of the sub-questions would make for a very interesting scientific mission to improve Humanity's understanding of Mars and its origin:

1. How similar is Mars's chemical composition to that of its satellites?
2. What events could have created the surface features of Phobos and Deimos?
3. What is the background radiation on the surface of Phobos and Deimos as compared to Mars, and what isotopes does it originate from?
4. Is there any matter orbiting the Martian satellites?
5. Why do Phobos and Deimos resemble asteroids more than other planetary moons?
6. Do Mars's satellites have an internal structure similar to Mars's metal core and rocky crust?
7. Could Phobos and Deimos contain ice underneath their regolith?
8. Do Mars's satellites have any seismic activity?

I decided to answer questions 1, 3, and 8 with a Phobos lander mission; little is known about Mars's strange asteroid-like moons and a reconnaissance mission would be very enlightening. I chose Phobos for some of its mysterious properties (irregular shape/size, very fast orbit, and unknown composition), and to visit a body for the first time while developing a novel method of landing akin to docking with an asteroid.

Hypothesis: Performing an orbital survey of Phobos and studying its composition using lander-mounted mass and gamma spectrometers will greatly improve understanding of how Mars's moons were formed, as well as techniques for asteroid surface operations.

Mission Objective: Perform an impulsive (no aerobraking) Mars transfer and Phobos rendezvous, take RADAR and visual scans of the surface, land on Phobos, and study the composition of its unique regolith.

Success Criteria: Successful rendezvous and orbital survey, successful landing, and deployment of scientific instruments on the surface

Mission Architecture and Design Drivers

The main scientific objectives for Sappho are imaging Phobos and analyzing the composition of its regolith. Therefore, the main scientific payloads are visual and radar sensors as well as the mass spectrometer and its supporting equipment. Secondary payloads include sensors such as a seismometer and collaborative rideshare instruments, taking advantage of the relatively large 500 kg mass budget. There must be a system to collect regolith samples and transfer them to the mass spectrometer, using a method similar to Curiosity's SAL analysis lab. A gamma spectrometer/scintillator will be used to very precisely (relative to a Geiger tube) measure Phobos's surface radioactivity compared to Mars and determine the unstable isotopes present by counting gamma decays and their intensity via the photoelectric effect. A linear actuator will push the scintillation probe firmly against the regolith.

The mission originally included an orbiter and lander, but an orbiter cannot work: Phobos's SOI (7.2 km) is smaller than its radius (11 km), making orbit impossible. It also may not fit into the 500 kg mass budget. Further, the orbital period would be in the tens of seconds at most based on a gravitational parameter $\mu = 0.7127\,\mathrm{km}^3/\mathrm{s}^2$ [[1]] and Osirus-REx's 6.5 km orbit, presenting many challenges for solar power and communications.

To visit Phobos from Earth, there are several requisite orbits in three spheres of influence: Mars Transfer Orbit (MTO) in Earth's SOI; correction burns in the Sun's SOI; Mars capture orbit; and the elliptical Hohmann orbit with a periapsis kick to rendezvous with Phobos. Because Phobos is tidally locked, Sappho must land on the far side to have solar power and a line of sight to Earth, and Earth must not be occluded by the Sun. Apsidal rotation does not affect the capture or Phobos orbit, but J_2 effects will cause nodal rotation in both the capture and Phobos orbits; once Sappho is in rendezvous it will precess at the same rate as Phobos. I couldn't find a plot of nodal rotation vs altitude and inclination for Mars, but Sappho should be able to take advantage of the difference in nodal rotation rates to align its orbital plane with that of Phobos prior to rendezvous.

Based on Patched Conics and a Hohmann transfer from Mars capture to Phobos rendezvous, Sappho's service module must have a Δv of at least 3.2 km/s: 1.9 km/s for the capture orbit and 0.9 km/s for the Phobos transfer and rendezvous, with 0.4 km/s margin for correction burns. Main propulsion is provided by Orion's European Service Module using an AJ10 engine, modified from the ATV ISS resupply vehicle. It requires slight modification: replace its 360 kg of life support supplies with propellant. Removing all life support equipment would further improve the Δv budget, but this was neglected since the exact mass is unknown. With the 500 kg lander, Sappho has a Δv budget of 3200 m/s and can be launched by an expendable Falcon Heavy (maximum 16.8 tons to Mars transfer).

[1] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2009GL041829

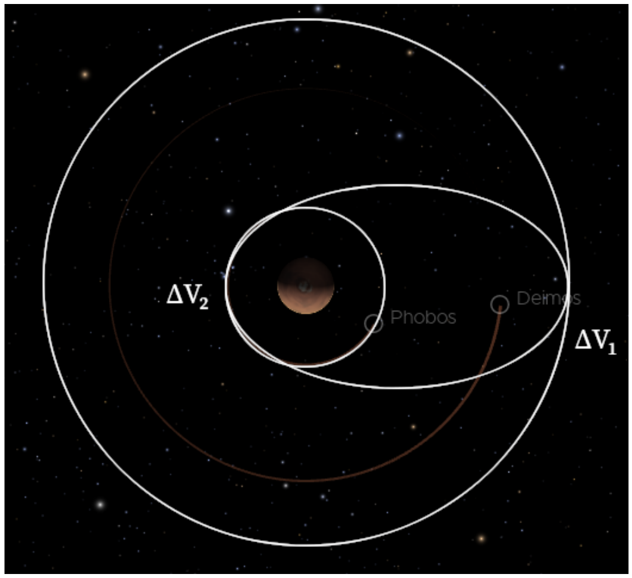


Figure 1. Diagram of capture orbit and Hohmann transfer

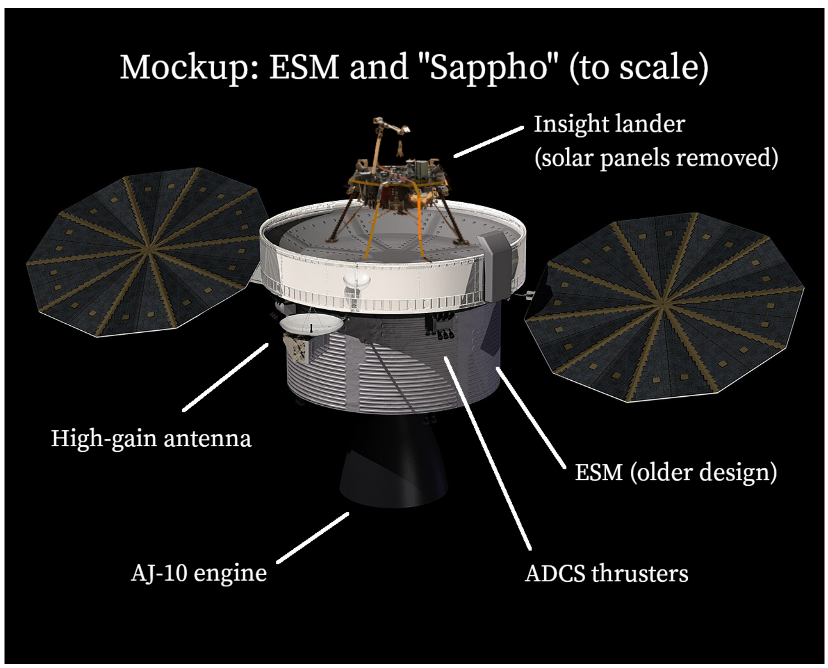


Figure 2. Mockup of Sappho and ESM to demonstrate their scale

Communication with Earth will use NASA's DSN on the X-band using a dual-gimbal (Az-El rotor) antenna. X-band is reserved for interplanetary satellites and has heritage in other Martian spacecraft; bandwidth should not be an issue because Sappho's total data budget (6 GB) is derived from the size of Curiosity's photo archive[2] divided by the time spanned by said archive. Several Martian satellites such as the Mars Reconnaissance Orbiter have a UHF to X-band relay, but they likely cannot be used. Phobos's orbit of 9376 km is much higher than MRO's $\approx 300\,\text{km}$ orbit, and the lander will point zenith rather than nadir towards the satellites; line of sight to Mars will be blocked by Phobos. UHF also has significant doppler shift at 400 km above Earth ($\approx 5\,\text{kHz}$), which could make UHF impractical at $\approx$ 9000 km even if Sappho had line of sight to the relays. The DSN can maintain a connection regardless of Earth's rotation, which is vital for high-gain communication systems with a very narrow emission pattern; gimbling the antenna will allow it to track Earth passes from its perspective.

Code (Next Page)

[2] Public domain photo archive:
https://academictorrents.com/details/9d00cae359b90a2647c6b0971325219dad8d05c7

Sappho Part 1 Code: Mars Transfer and Phobos Rendezvous

Patched Conics and Capture

```
md""" # Sappho Part 1 Code: Mars Transfer and Phobos Rendezvous
# Patched Conics and Capture"""
```

```
(1.32712e11, 0.7127, 398600, 42828, 9376, 1.0659e16, 6.4171e23, 1.496e8, 2.279e8, 6378, 3
```

```
# Define variables
μ_sun, μ_phobos, μ_earth, μ_mars, a_phobos, m_phobos, m_mars, R_E, R_M, r_E, r_M,
r_park₁ = 132712e6, 0.7127, 398600, 42828, 9376, 1.0659e16, 6.4171e23, 149.6e6,
227.9e6, 6378, 3396, 150
```

```
SOI_phobos = 7.247173535045903
```

```
SOI_phobos = a_phobos * (m_phobos/m_mars)^(2/5)
```

NOTE: SOI is less than radius (11 km), therefore orbit is impossible

```
md"""NOTE: SOI is less than radius (11 km), therefore orbit is impossible"""
```

```
ΔV_budget = 3197.145197514107
```

```
ΔV_budget = 319 * 9.81 * log((13500+500)/(13500 + 500 - 8960))
# https://en.wikipedia.org/wiki/European_Service_Module
```

NOTE: slightly modified ESM without life support

```
md"""NOTE: slightly modified ESM without life support"""
```

Departure

```
md""" ## Departure"""
```

```
V_E = 29.78443048750875
```

```
V_E = sqrt(μ_sun/R_E)
```

```
a_transfer = 1.8875e8
```

```
a_transfer = (R_E + R_M)/2
```

T_transfer = 258.8281293883917

```
T_transfer = π*sqrt(a_transfer^3/μ_sun) / (3600*24) # [day]
```

V_Ev = 32.72788818661612

```
V_Ev = sqrt(μ_sun*(2/R_E - 1/a_transfer))
```

V∞₁ = 2.9434576991073698

```
V∞₁ = V_Ev - V_E
```

V_circ₁ = 7.814092974850494

```
V_circ₁ = sqrt(μ_earth / (r_E + r_park₁))
```

V_pE = 11.436085049773377

```
V_pE = sqrt(V∞₁^2 + 2μ_earth / (r_E + r_park₁))
```

ΔV_D = 3.6219920749228827

```
ΔV_D = V_pE - V_circ₁
```

Arrival

```
md"""## Arrival"""
```

V_A = 24.13142311168881

```
V_A = sqrt(μ_sun/R_M)
```

V_Av = 21.48351063061769

```
V_Av = sqrt(μ_sun * (2/R_M - 1/a_transfer))
```

V∞₂ = 2.6479124810711205

```
V∞₂ = V_A - V_Av
```

r_p_optimal = 32348.501173026252

```
# Circular capture orbit: e=0
r_p_optimal = 2μ_mars/V∞₂
```

V_pM = 3.107949965569481

```
V_pM = sqrt(V∞₂^2 + 2μ_mars/r_p_optimal)
```

V_cM = 1.1506329738607182

```
V_cM = sqrt(μ_mars/r_p_optimal)
```

ΔV_A = -1.9573169917087627

```
ΔV_A = V_cM - V_pM # Retrograde
```

ΣΔV = 5.579309066631645

```
ΣΔV = abs(ΔV_D) + abs(ΔV_A)
```

Phobos Rendezvuos

```
md""" # Phobos Rendezvuos"""
```

```
0.9033576177478388
```

```
let μ_mars = 42828, r₁ = r_p_optimal, r₂ = a_phobos
    v_c₁ = sqrt(μ_mars/r_p_optimal)
    a_e = (r₁ + r₂)/2
    v_e_a = sqrt(μ_mars * (2/r_p_optimal - 1/a_e))
    ΔV₁ = v_e_a - v_c₁ # -0.379 km/s Retrograde

    v_e_p = sqrt(μ_mars * (2/r₂ - 1/a_e))
    v_c₂ = sqrt(μ_mars/r₂)
    ΔV₂ = v_c₂ - v_e_p # -0.524 km/s Retrograde

    ΣΔV = abs(ΔV₁ + ΔV₂) # 0.903 km/s Total
end
```

Requirements and CONOPS (Next Page)

ID	REQ Short Name	Mission Requirements	Rationale	Verification
MIS_REQ_01	Visible Images	Before landing, Sappho shall successfully capture 10 visible spectrum images evenly spaced around Phobos (36 degree spacing)	A map of Phobos is useful scientific data, and will help choosing a landing site	Analysis, Test
MIS_REQ_02	RADAR Images	Before landing, Sappho shall construct a topographic map of Phobos's equator	Topographic images are also useful data and will help ensure the landing site is appropriate	Analysis
MIS_REQ_03	Attitude Control	3-axis attitude control on orbit shall be maintained automatically and in absence of a magnetic field	Communication times are too long for manual operation. Neither Mars nor Phobos have a magnetic field	Analysis, Test
MIS_REQ_04	Lifetime	Sappho shall operate for at least 180 Sols upon Mars capture; 444 days total	Based on the similarly experimental Pathfinder/Sojourner mission + margin for J2 plane alignment	Analysis, Test
MIS_REQ_05	Communications/Data budget	Sappho shall maintain communication with Earth and transmit a maximum of 6 gigabytes of data over its lifetime via the DSN or a Martian relay satellite	Based on Pathfinder (287 MB/ 3 month) and Curiosity (50 GB / 9 year = 500 MB / 30 sol)	Analysis
MIS_REQ_06	Lander	Sappho shall land on the zenith (Sun-facing) side of Phobos to perform surface operations	Directly observation from the surface will provide more insight into Phobos's formation than an orbital survey	Inspection, Test
MIS_REQ_07	<Removed>	Empty requirement to maintain numbering scheme		
MIS_REQ_08	Orbit Profile	Sappho shall insert itself into Martian orbit, than transfer to Phobos	The spacecraft will enter Mars's sphere of influence first, which is much larger than that of Phobos	Analysis
MIS_REQ_09	Payload integration	Sappho shall comply with the payload mounting requirements of its launch vehicle	Vibration and shock loads during launch could destroy a improperly mounted spacecraft	Inspection, analysis
MIS_REQ_10	Lander Science	The lander shall include a microscope, mass spectrometer, and electrical/thermal conductivity probe to study Phobos's regolith	Studying the regolith will improve understanding of the origin of Phobos and Deimos	Analysis, Test

ID	REQ Short Name	Mission Requirements	Rationale	Verification	Parent REQ ID
L2_REQ_01	Launch Mass	Sappho shall have a total launch mass of 15,000 kg or less	With a 500 kg payload, ESM has 3200 km/s of delta-v	Inspection	MIS_REQ_09
L2_REQ_02	Lander Mass	The Sappho lander shall have a mass of 500 kg or less	See Launch Mass rationale	Inspection	MIS_REQ_09
L2_REQ_03	Launch Vehicle	Sappho shall launch on a vehicle capable of 15 tons to MTO	Likely Falcon Heavy, unless future launchers become available	Inspection	MIS_REQ_08
L2_REQ_04	Volume	Sappho's launch volume shall be less than or equal to 4 m x 4 m x 5 m	Based on ESM and 1 m max lander height, and 4.6x11 m Falcon 9 fairing	Inspection	MIS_REQ_09
L2_REQ_05	Visible Camera	Sappho shall capture color images of at least 600 – 700 nm	Typical asteroids reflect light at the red end of the visible spectrum (approximately 700 nm)	Test	MIS_REQ_01

ID	REQ Short Name	Mission Requirements	Rationale	Verification	Parent REQ ID
L2_REQ_06	Attitude Maintenance	The Sappho orbiter shall point its instruments nadir during surveying operations	Instruments must be pointed at Phobos to capture images	Test	MIS_REQ_01 MIS_REQ_02
L2_REQ_07	Downlink	Sappho shall downlink up to 33 MB of data once per Sol	33 MB daily equals 6 GB over the mission's lifetime. Downlink once daily to stay within a communications time slot	Test	MIS_REQ_05
L2_REQ_08	Uplink	Sappho shall receive commands from the ground station at a data rate of at least 300 bit/s	Based on low-bandwidth packet radio and the minimum of 500 bit/s for typical Mars communication	Test, Analysis	MIS_REQ_05
L2_REQ_09	RADAR Frequency	RADAR images of Phobos shall be illuminated by a signal in the Ku band	The Ku-band is used for highly detailed mapping, and interference is unlikely near Mars	Inspection	MIS_REQ_02
L2_REQ_10	Delta-v budget	Sappho's propulsion system shall have a delta-v budget of at least 3000 m/s	1.9 km/s for capture, and 0.9 km/s for Phobos transfer with additional margin	Analysis	MIS_REQ_08
L2_REQ_11	Scientific instruments	Sappho shall support secondary experiments beyond the survey and spectroscopy	This expensive mission should take full advantage of extra room in technical budgets	Analysis, Test	MIS_REQ_10
L2_REQ_12	Power Source	Sappho shall meet its power requirements using solar panels during all mission phases	Solar power is the only source of electricity	Analysis, Test	MIS_REQ_08

ID	REQ Short Name	Mission Requirements	Rationale	Verification	Parent REQ ID
COMM_REQ_01	Frequency	All communication shall take place on the x-band	X-Band is used by the DSN, as well as the Perseverance and Curiosity rovers	Analysis	L2_REQ_07/08
COMM_REQ_02	Error Correction	Reed-Solomon error correction shall be applied to all communications	The DSN uses Reed-Solomon to determine which data packets contain errors	Analysis	L2_REQ_07/08
COMM_REQ_03	Data Error Probability	Total data errors shall not exceed 50 kB of the 6 GB data budget	Ideally an upper limit on the amount of corrupt data/images. Based on Curiosity's average 100 kB per image, and equal to Beavercube's 1e-5 error rate	Analysis, Test	MIS_REQ_05
COMM_REQ_04	Comms Interfaces	The communication subsystem shall interface with the scientific instruments	C&DH must be able to send and receive telemetry and scientific data	Analysis	L2_REQ_07/08
COMM_REQ_05	Comms Attitude	Sappho shall point its antenna towards Earth during downlink and uplink opportunities	High-gain antennas have a narrow emission pattern and must be pointed precisely	Analysis, Test	L2_REQ_07/08
COMM_REQ_06	Transmit Power	The communication subsystem shall have a transmit power of at least 10 W on X-band	Based on Martian satellites with 5-10 W of transmit power	Analysis, Test	L2_REQ_07/08
COMM_REQ_07	Antenna Rotor	The high gain antenna shall have an Az-El rotor capable of tracking Earth	The antenna must have line-of-sight to successfully transmit/receive	Inspection, Test	L2_REQ_07/08

ADCS

ID	REQ Short Name	Mission Requirements	Rationale	Verification	Parent REQ ID
ADCS_REQ_1	Pointing Accuracy	The ADCS system shall achieve a pointing accuracy of 20 arcseconds	Based on Cassini pointing accuracy of 0.1 mrad (20 arcsec)	Analysis, Test	L2_REQ_06
ADCS_REQ_2	Attitude Determination	Sappho shall determine its attitude using sensor fusion across multiple redundant sensors that do not require a magnetic field	The lack of a magnetic field necessitates alternative attitude determination methods; sensor fusion helps increase pointing accuracy	Inspection	L2_REQ_06
ADCS_REQ_3	Stabilization	Sappho shall autonomously maintain 3-axis stabilization at all times	Slewing the spacecraft requires active control and passive methods such as magnets are not feasible	Analysis	L2_REQ_06
ADCS_REQ_4	Torque Types	ADCS shall generate external torques using thrusters	Reaction wheels would likely blow the mass budget and are likely unnecessary	Analysis	MIS_REQ_06
ADCS_REQ_5	Slew Rate	Sappho shall slew between any two attitudes in 10 minutes or less	Assuming 100 slews in 7 Sols, and 50% sunlit time. Approximately 1.2 slews per hour to complete the orbital survey in the first week.	Analysis, Test	MIS_REQ_01/02
ADCS_REQ_6	Landing	Sappho shall perform an autonomous landing on Phobos	Round-trip communication makes manual control impossible	Analysis, Test	MIS_REQ_06

EPS

ID	REQ Short Name	Mission Requirements	Rationale	Verification	Parent REQ ID
EPS_REQ_01	Solar Power	Sappho shall have solar panels that can function on orbit and on Phobos's surface	The spacecraft requires electrical power during both the orbiter and lander mission phases	Analysis, Test	L2_REQ_12
EPS_REQ_02	Solar Panels	Sappho's lander shall use conformal (non-deployable) solar panels on its surface. The service module shall use its ATV-derived solar panels	"The best part is no part," and deployable panels can fail to deploy or get damaged during imaging or landing. ESM comes with its own electrical system	Analysis, Test	L2_REQ_12
EPS_REQ_03	Solar Power Output	Sappho shall have a power output of at least 200 W in Sunlight	Based on 40% Insight lander output due to conformal panels' limited surface area	Analysis, Test	L2_REQ_12
EPS_REQ_04	Battery Power Output	Sappho shall have a power output of 150 W from batteries in Mars's shadow	Equivalent to 60% of battery capacity over 0.16 Sols of darkness	Test	L2_REQ_12
EPS_REQ_05	Energy Storage	Sappho shall store 1 kWh of energy in batteries	Based on Insight and Phoenix landers	Inspection	L2_REQ_12
EPS_REQ_06	Launch/Initial Power	The entire system shall be powered down until it is separated from the launch vehicle	Requirement of launch vehicle provider	Inspection	MIS_REQ_09

Propulsion

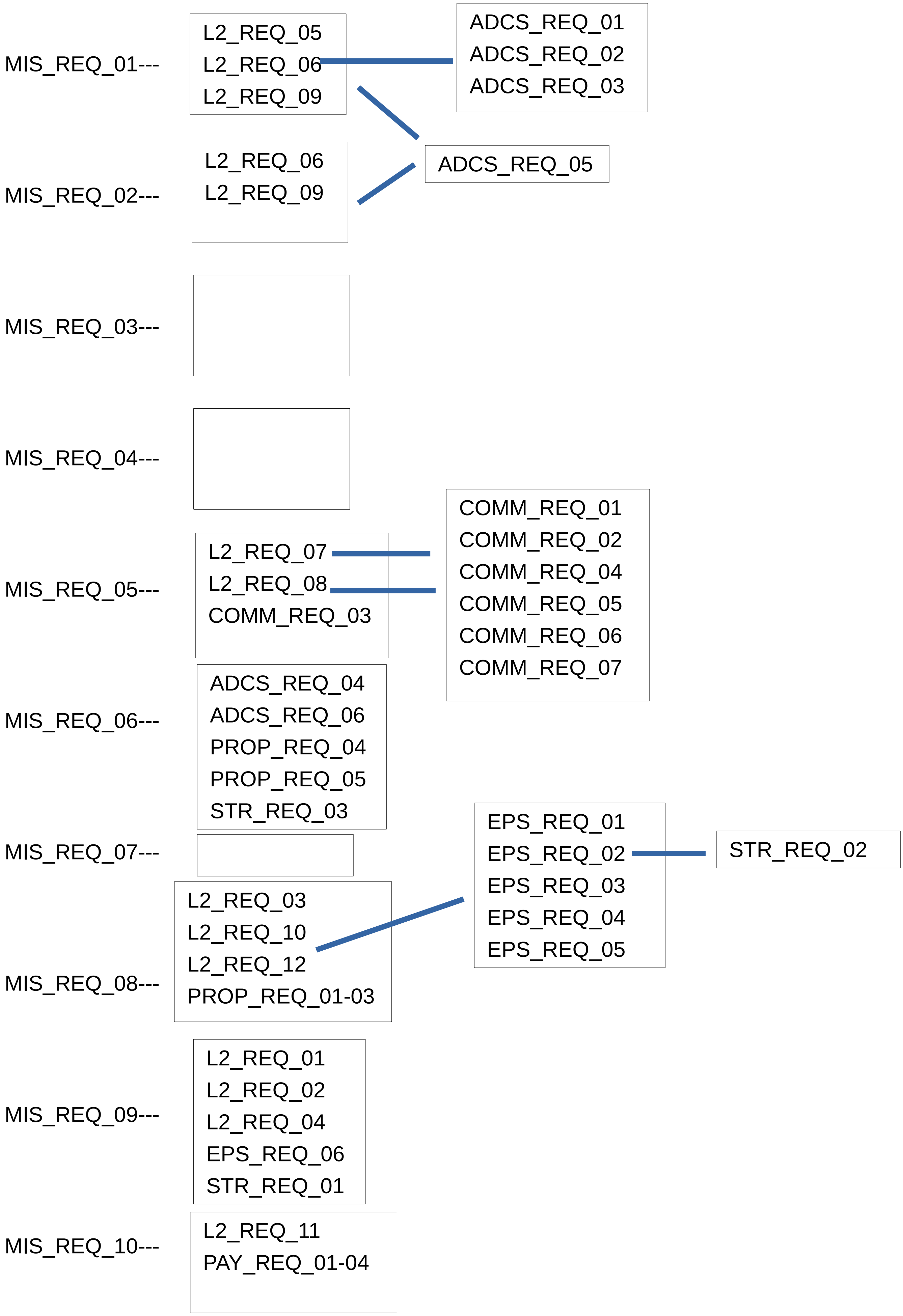
ID	REQ Short Name	Mission Requirements	Rationale	Verification	Parent REQ ID
PROP_REQ_01	Capture	The service module shall perform orbital capture and rendezvous with Phobos	Sappho needs a large delta-v budget for capture that cannot be provided by the lander	Analysis	MIS_REQ_08
PROP_REQ_02	Secondary thrusters	The lander shall have its own secondary propulsion system for maneuvering and landing	“Landing” on Phobos is effectively a rendezvous with station keeping and docking	Analysis	MIS_REQ_08
PROP_REQ_03	ESM	The European Service Module shall be used for Sappho’s propulsion until jettison	The ESM has a perfect delta-v budget and is designed for deep space	Analysis	MIS_REQ_08
PROP_REQ_04	SM Jettison	The service module shall separate from the lander following Phobos rendezvous	The service module is no longer required and is not capable of landing	Testing, Analysis	MIS_REQ_06
PROP_REQ_05	Lander Thrusters	The Sappho lander shall have sufficient thrusters to land with redundancy in case of failure	Sappho is completely dependent on thrusters for landing and attitude control, and failure should not compromise the mission	Analysis, Test	MIS_REQ_06

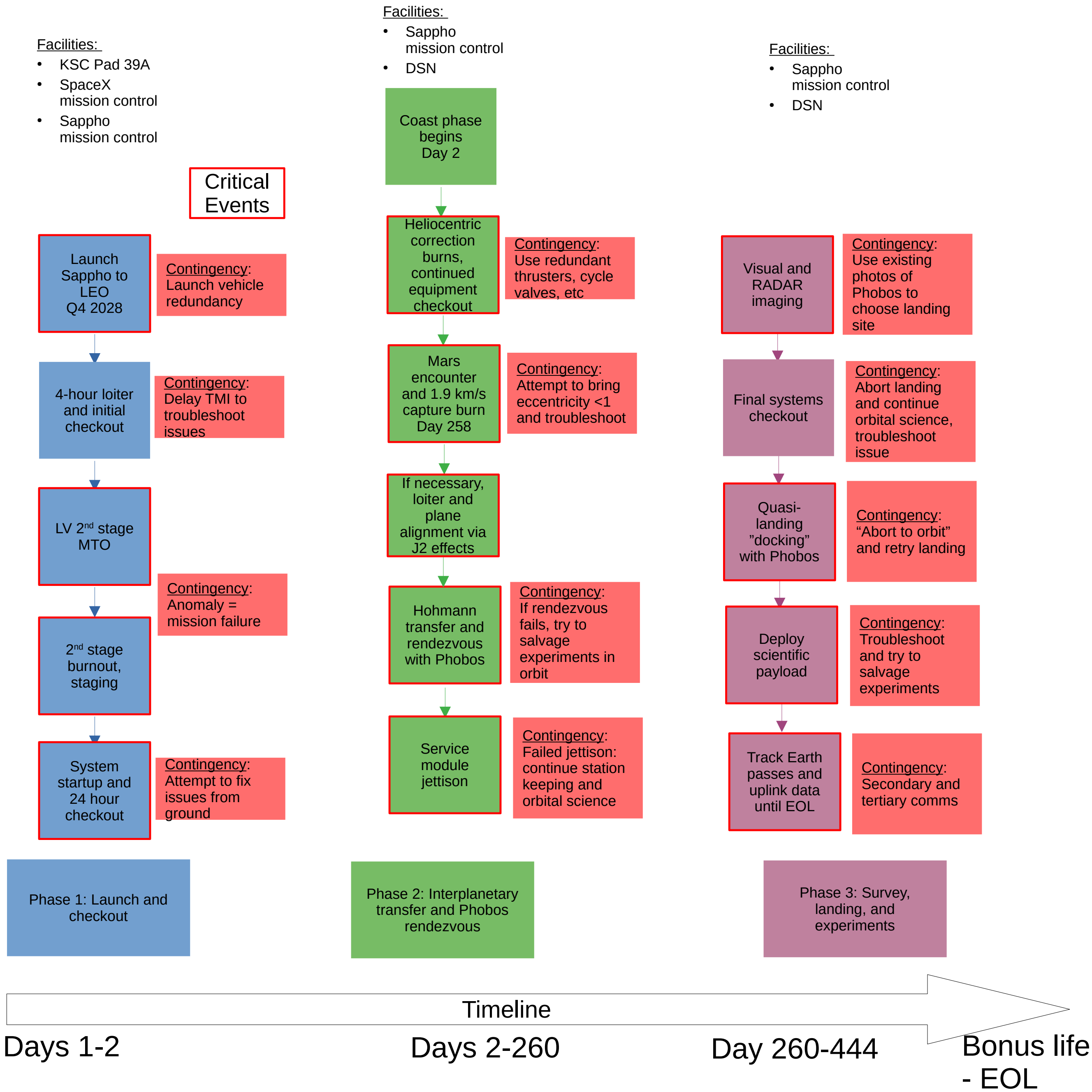
Payload

ID	REQ Short Name	Mission Requirements	Rationale	Verification	Parent REQ ID
PAY_REQ_01	Spectrometers	Sappho shall have gamma and mass spectrometers on the lander stage	Main scientific objective	Inspection	MIS_REQ_10
PAY_REQ_02	Regolith transfer	A mechanism shall be developed to transfer regolith to the mass spectrometer	The spectrometer will not be against the surface and therefore needs to transport regolith upwards	Analysis, Test	MIS_REQ_10
PAY_REQ_03	Scintillator actuator	A linear actuator shall lower the scintillation probe against the regolith surface	Scintillators are held against radioactive material; it does not need to be transferred	Analysis, Test	MIS_REQ_10
PAY_REQ_04	Rideshare	Sappho shall have interior space and common power/data buses for low-bandwidth collaborative payloads	Collaborative experiments will likely fit in the mass budget and hopefully improve the scientific value of Sappho	Inspection	MIS_REQ_10

Structure

ID	REQ Short Name	Mission Requirements	Rationale	Verification	Parent REQ ID
STR_REQ_01	Structure Volume	Sappho's structure shall fit within the volume budget	Size is limited by ESM's diameter and the LV fairing	Inspection	MIS_REQ_09
STR_REQ_02	Rigidity	The structure shall be rigid, i.e. no deployable parts	Reduced points of failure, and Sappho has a very large volume budget compared to similar landers	Inspection	EPS_REQ_02
STR_REQ_03	Aspect Ratio	The structure shall have a wide footprint with low center of mass for landing stability	The lander tipping over is a major risk, and a wider aspect ratio provides more solar area	Analysis, Inspection	MIS_REQ_06


MIS_REQ_01---
L2_REQ_05
L2_REQ_06
L2_REQ_09
ADCS_REQ_01
ADCS_REQ_02
ADCS_REQ_03
MIS_REQ_02---
L2_REQ_06
L2_REQ_09
ADCS_REQ_05
MIS_REQ_03---
MIS_REQ_04---
COMM_REQ_01
COMM_REQ_02
COMM_REQ_04
COMM_REQ_05
COMM_REQ_06
COMM_REQ_07
MIS_REQ_05---
L2_REQ_07
L2_REQ_08
COMM_REQ_03
MIS_REQ_06---
ADCS_REQ_04
ADCS_REQ_06
PROP_REQ_04
PROP_REQ_05
STR_REQ_03
EPS_REQ_01
EPS_REQ_02
EPS_REQ_03
EPS_REQ_04
EPS_REQ_05
STR_REQ_02
MIS_REQ_07---
L2_REQ_03
L2_REQ_10
L2_REQ_12
PROP_REQ_01-03
MIS_REQ_08---
MIS_REQ_09---
L2_REQ_01
L2_REQ_02
L2_REQ_04
EPS_REQ_06
STR_REQ_01
MIS_REQ_10---
L2_REQ_11
PAY_REQ_01-04


Facilities:
KSC Pad 39A
SpaceX mission control
Sappho mission control
Critical Events
Launch Sappho to LEO Q4 2028
Contingency: Launch vehicle redundancy
4-hour loiter and initial checkout
Contingency: Delay TMI to troubleshoot issues
LV 2nd stage MTO
Contingency: Anomaly = mission failure
2nd stage burnout, staging
System startup and 24 hour checkout
Contingency: Attempt to fix issues from ground
Phase 1: Launch and checkout
Facilities:
Sappho mission control
DSN
Coast phase begins Day 2
Heliocentric correction burns, continued equipment checkout
Contingency: Use redundant thrusters, cycle valves, etc
Mars encounter and 1.9 km/s capture burn Day 258
Contingency: Attempt to bring eccentricity <1 and troubleshoot
If necessary, loiter and plane alignment via J2 effects
Hohmann transfer and rendezvous with Phobos
Contingency: If rendezvous fails, try to salvage experiments in orbit
Service module jettison
Contingency: Failed jettison: continue station keeping and orbital science
Phase 2: Interplanetary transfer and Phobos rendezvous
Facilities:
Sappho mission control
DSN
Visual and RADAR imaging
Contingency: Use existing photos of Phobos to choose landing site
Final systems checkout
Contingency: Abort landing and continue orbital science, troubleshoot issue
Quasi-landing "docking" with Phobos
Contingency: "Abort to orbit" and retry landing
Deploy scientific payload
Contingency: Troubleshoot and try to salvage experiments
Track Earth passes and uplink data until EOL
Contingency: Secondary and tertiary comms
Phase 3: Survey, landing, and experiments
Timeline
Days 1-2
Days 2-260
Day 260-444
Bonus life - EOL

Risk Assessment

Subsystem	Mission phase	Risk	Severity	Liklihood
Mission	Pre-launch	Cost overrun or delay that leads to missed transfer window	High	Medium
Communication	Pre-launch	Delayed/denied spectrum license or DSN timeslot unavailable	High	Medium
Mission	Launch	Launch vehicle failure or MTO insertion failure	High	Low
Mission	Loiter - Capture	System checkout failure	High	Low
Propulsion ADCS	Coast - Capture	Thruster/attitude control failure	Medium	Low
EPS	Coast-EOL	Solar cell or other electrical failure	High	Medium
Propulsion	Capture - Rendezvous	SM failure	High	Medium
Payload	Orbital survey	Orbital survey failure	High	Medium
Propulsion	Landing	SM jettison failure	High	Low
Payload	Post-landing	Scientific instrument failure	Medium	Medium
Communication	Coast - EOL	Communication failure	High	Low

Table 1

Risks pre-mitigation

Liklihood			
High			
Medium		Scientific instrument failure	Delay - missed transfer window Denied spectrum/DSN time Solar/EPS failure SM failure Orbital survey failure
Low		Thruster/avionics failure	Launcher/MTO failure Checkout failure SM jettison failure Communication failure
Severity	Low	Medium	High

Table 2

RYG chart pre-mitigation

Possible mitigations:

1. Insurance and sufficient funding, store Sappho until the next transfer window
2. Request DSN time and begin spectrum licensing as early as possible
3. Launch insurance and thorough integration inspections
4. Extensive pre-flight testing, design C&DH to have the maximum possible level of remote control of spacecraft systems
5. Redundant attitude thrusters and avionics
6. Build two redundant EPS systems that split power requirements; a single failure can only reduce the power budget by half
7. Use the existing ESM, which has flight heritage and is designed for deep space

8. Choose a landing site based on pre-existing imagery of Phobos

9. Very unlikely; remain in Mars orbit and attempt to salvage the mission

10. Design experiments to be passive and have as few moving parts as possible

11. Use redundant communication systems and two redundant antenna rotors

Subsystem	Mission phase	Risk	Severity	Liklihood
Mission	Pre-launch	Cost overrun or delay that leads to missed transfer window	Medium	Medium
Communication	Pre-launch	Delayed/denied spectrum license or DSN timeslot unavailable	High	Low
Mission	Launch	Launch vehicle failure or MTO insertion failure	High	Low
Mission	Loiter - Capture	System checkout failure	Medium	Low
Propulsion ADCS	Coast - Capture	Thruster/attitude control failure	Low	Low
EPS	Coast-EOL	Solar cell or other electrical failure	Medium	Medium
Propulsion	Capture - Rendezvous	SM failure	High	Low
Payload	Orbital survey	Orbital survey failure	Low	Medium
Propulsion	Landing	SM jettison failure	High	Low
Payload	Post-landing	Scientific instrument failure	Medium	Medium
Communication	Coast - EOL	Communication failure	Low	Low

Table 3

Risks post-mitigation

Liklihood			
High			
Medium	Orbital survey failure	Delay - missed transfer window Solar/EPS failure Scientific instrument failure	
Low	Thruster/avionics failure Communication failure	Checkout failure	Denied spectrum/DSN time Launcher/MTO failure SM failure SM jettison failure
Severity	Low	Medium	High

Table 4