EXPLORE MOON to MARS

Lunar Escape – Crew Risk Reduction

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Introduction

Lunar Escape – Crew Risk Reduction Project

Study aimed towards assessing and analyzing the current risks, current and possible mitigations, and effectiveness of those mitigations in a lunar mission scenario for 2024. Mitigation solutions considered include pre-deploying a low-mass, low-cost, high mission impact contingency ascent vehicle to the lunar surface prior to crew arrival at the lunar South Pole.

Breakdown:

A.) Systems-level understanding of crewed lunar missions (executed, planned, proposed, cancelled) and the timeline of a 2024 human lunar return.

B.) Systems-level hazards, risks, contingencies, and aborts analyses on possible lunar lander architectures.

C.) Pre-Phase A conceptual mission and spacecraft design within 2024 lunar mission requirements and constraints.

D.) Future Work and Questions

Background

Crewed Lunar Lander Missions of the Space Race

The Apollo Program's Lunar Module (LM) consisted of a two-stage lunar lander with **single-engine** for each stage of the lander.

- The takeoff and ascent mission phases carried high risks within the Apollo lunar missions, as the ascent propulsion system was a single point of failure for the ascent mission phase.
- If the LM ascent stage was considered unsafe or unable to take off into orbit, the crew would have been stranded on the lunar surface. Failure of the LM propulsion system due to lunar environment or low technology readiness could have resulted in loss of crew.

The Soviet N1/L3 Program's Lunniy Korabl (LK) consisted of a single-stage lunar lander with **primary and reserve main engines** for the lander.

- Failure of the LK primary propulsion system could have been mitigated with the reserve engine. Additionally, a reserve LK was pre-deployed to the lunar surface to mitigate possible loss of crew.

Why was this risk acceptable for the Apollo program?

High reliability, **simplistic** system design

Integrated testing on previous Apollo missions

Apollo Mission Background

Primary Mission Events

Command-Service Module (CSM) placed the Lunar Module (LM) into a low equatorial parking orbit. LM separates and the descent stage performs burns to descend onto the lunar surface. Anytime abort capability besides “dead man’s zone” during descent. Crew surface stay spanned one to three days. Ascent stage launches from descent stage, and enters lunar orbit. Ascent stage rendezvouses with CSM. Ascent stage jettisons post-crew transfer.

Notable Systems

System	Ascent Stage	Descent Stage
Propulsion	Single-engine	Single-engine
Electrical Power	Batteries	Batteries
Environmental Control and Life Support	Pressurized cabin to support 2 crew members	-
Attitude and Orbit Control	Reaction Control System Thrusters	-
Return Vehicle Interface	Docking Port allowing intravehicular transfer into CSM	-

N1/L3 Program Background

Primary Mission Events

Lunniy Orbitaly Korabl (LOK) and Blok D stage placed the Lunniy Korabl (LK) into a low equatorial parking orbit. LK and Blok D separate, and Blok D performs deorbit burns. Blok D jettisons, and LK performs descent and landing. Crew surface stay spans one day. LK launches from landing structure, and enters lunar orbit. LK rendezvouses with LOK. LK jettisoned post-crew transfer.

Notable Systems

Contingency lander pre-deployed to lunar surface.

System	Descent-Ascent Stage (LK)
Propulsion	Primary and reserve engine
Electrical Power	Batteries
Environmental Control and Life Support	Pressurized cabin to support 1 crew member
Attitude and Orbit Control	Reaction Control System Thrusters
Return Vehicle Interface	Docking Mechanism required extravehicular transfer to LOK

Current Challenge

We’re going forward to the Moon in 2024!

Programmatically, the 2024 human lunar return has tighter constraints than the Apollo Program – limited time, resources, and money.

What are some possible risks to 2024 lunar lander architectures?

- Propellant management risk based on low technology readiness level (TRL) of long-duration lunar cryogenic systems.
- Damage to ascent main propulsion system (MPS) from lunar environment or other factors.

What are possible mitigations to these risks?

- Increasing active thermal control reliability in the lunar environment.
- Increasing passive thermal control reliability in the lunar environment.
- Architecture margins that allow for higher propellant reserves to mitigate potential boil-off losses.
- Increased micrometeoroids and orbital debris shielding for ascent MPS.
- **Pre-deployed contingency ascent vehicle.**

Payload Definition

Initial evaluation assumes unpressurized ascent vehicle is a lower mass and lower cost over a pressurized ascent vehicle.

To determine the lowest mass, lowest cost payload transiting to Near Rectilinear Halo Orbit (NRHO), the following assumptions were made:

- 2 crew members are donned in Exploration Extravehicular Mobility Unit (xEMU) suits and tethered to consumables stored in an unpressurized vehicle.
- Maximum 72-hour time of flight from takeoff to docking with Orion/Gateway.

For a surface abort, the contingency ascent vehicle payload is determined as crew, minimal function operating/supporting hardware, and consumables.

Gross Consumables Mass: 301.2 kg
Gross Equipment Mass (including astronauts): 416.5 kg
Total payload mass for 72 hour operation is approximately 717.7 kg

Hardware	**Mass (kg)**
Vehicle Systems to Support EVA Suit	51.1
EVA Suit Systems	177.4
Maximum Absorption Garments	0.5
Drink Bags	0.5
Clothing	5.9
Astronauts	181.1
Total	**416.5**

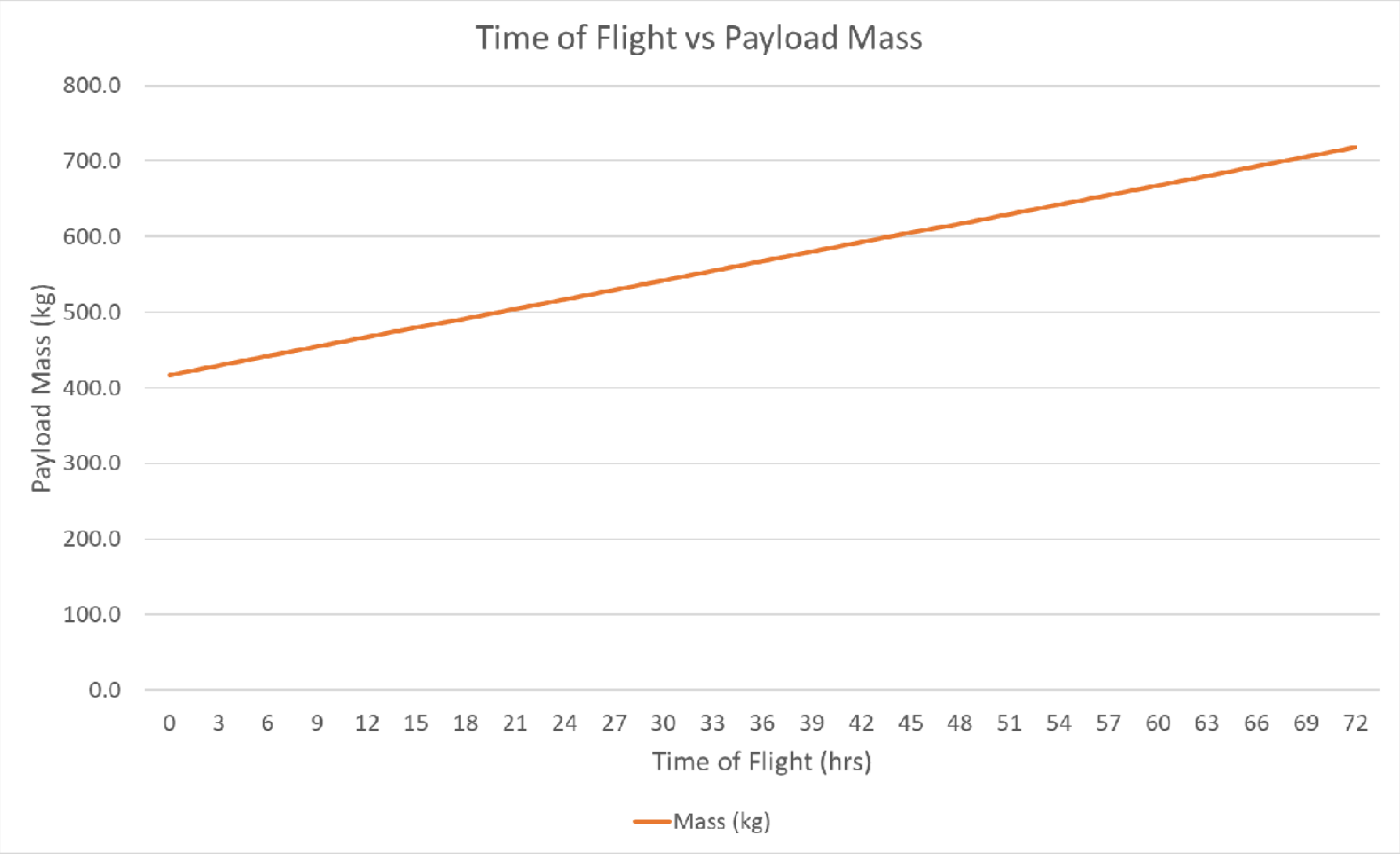
Identified Consumables	**Mass (kg)**
300 W-h battery, 108 kg battery	108
O2	36
H2O, Cooling	106.6
H2O, Potable	32.6
Food	18
Total	**301.2**

Payload Definition (cont’d)

Tethered operations of the xEMU allows consumables to scale linearly with time of flight.

% total mass	Identified Consumables	Mass (kg/hr)
36%	300 W-h battery, 108 kg battery	1.50
12%	O2 (crew)	0.50
35%	H2O, Cooling (crew)	1.48
11%	H2O, Potable (crew)	0.45
6%	Food (crew)	0.25
	Total	**4.18**

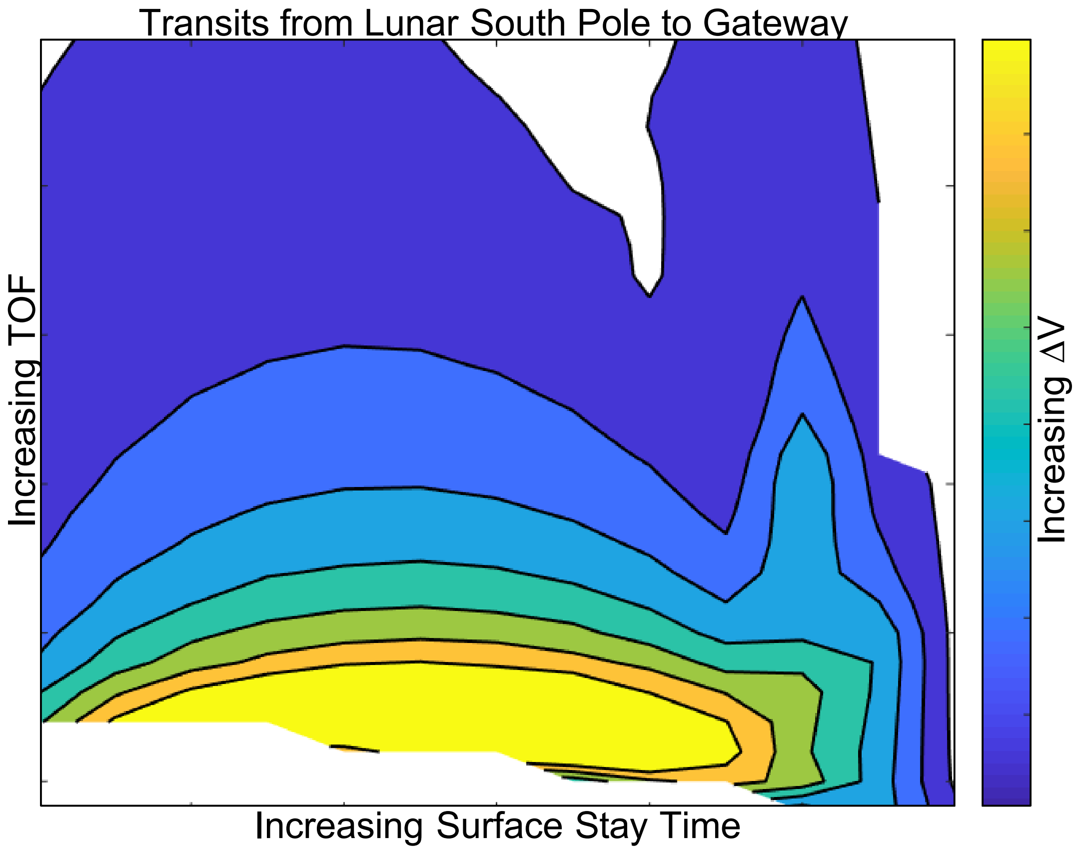
xEMU suit power and thermal control requirements significantly factor into overall consumable mass requirements.



Trajectory Analyses

The Artemis Lunar 2024 Mission places Orion, Gateway, and the Human Landing System into a Near Rectilinear Halo Orbit (NRHO) around the Moon. NRHO chosen due to orbit stability, low perilune radius, and long-term feasibility; results in multiple trajectory options for a lunar abort.

Due to the eccentricity of the NRHO, the ΔV required to transit from Low Lunar Orbit (LLO) to Gateway/Orion's position in NRHO offers a wide range of time of flight solutions.



As the elapsed surface stay time increases, the time of flight varies due to the position of Gateway/Orion in NRHO.

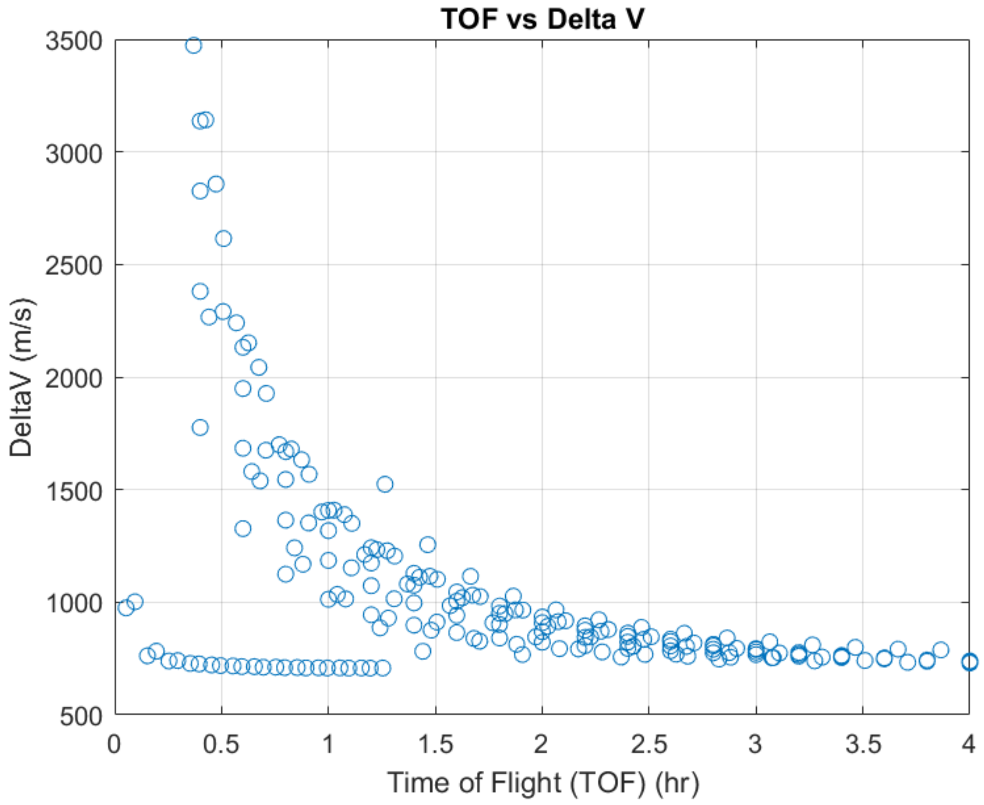
As the time of flight increases, the ΔV decreases, feeding into a trade between the impact of ΔV and payload mass on the ascent vehicle propellant mass.

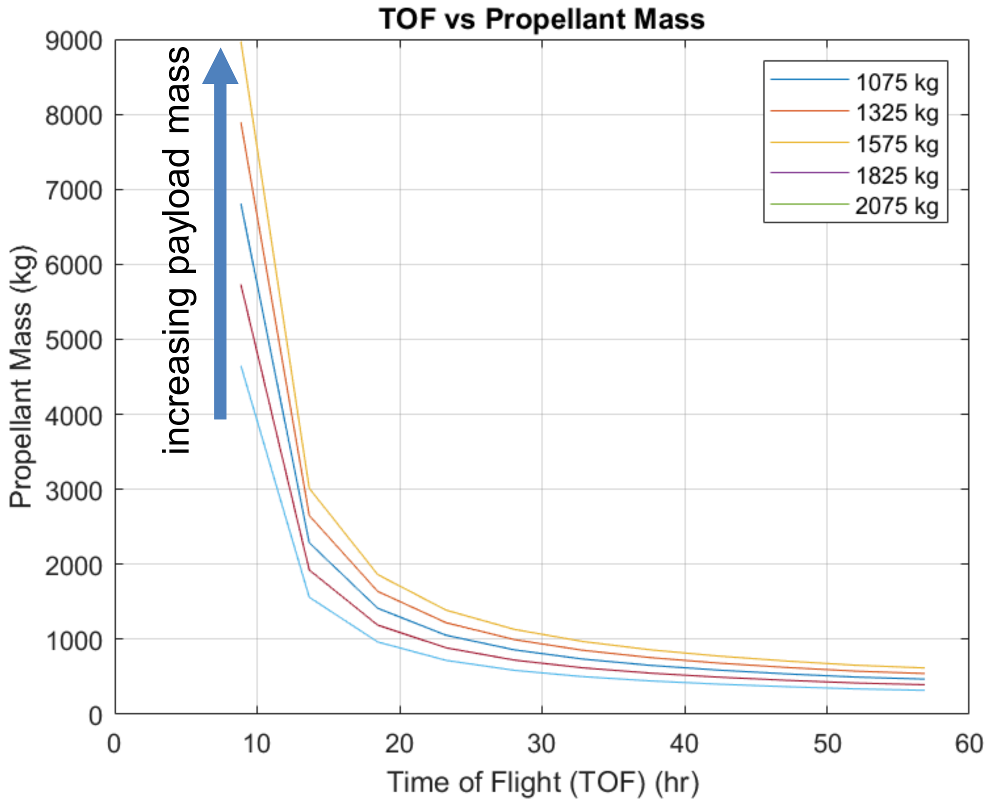
Trajectory Analyses (cont'd)

Typically as the time of flight increases, the ΔV decreases. Payload mass increases linearly due to the consumables mass required to sustain the crew.

The propellant mass calculations were based off worst case ΔV for the time of flight.

As a result, propellant mass decreases significantly as delta V decreases – but increases marginally as propellant mass increases.





Feasibility Study based on Propellant Mass Fraction (PMF)

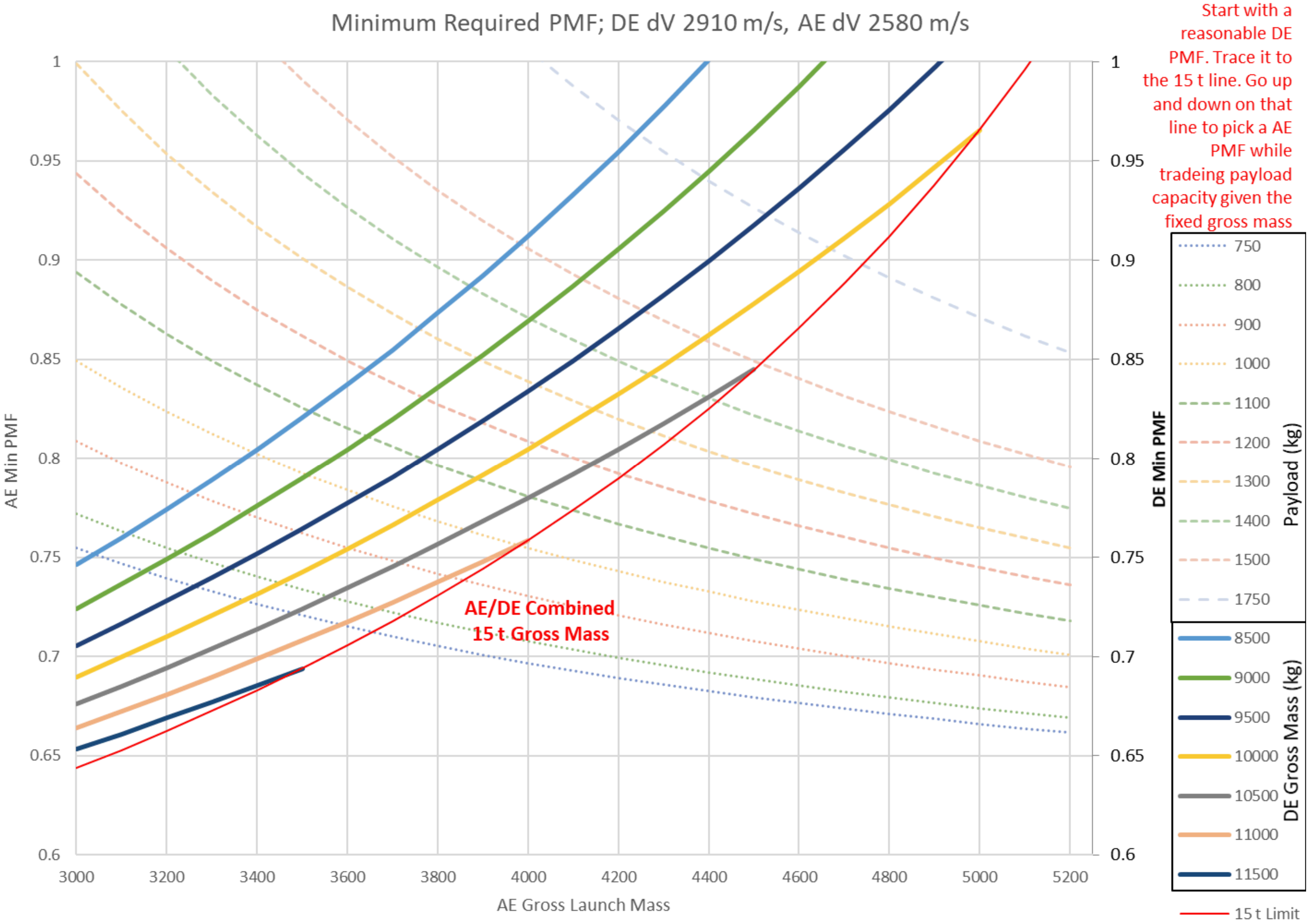
Current commercial launch vehicles have assumed maximum capability of delivering 15 t to trans-lunar injection (TLI).

As a descent vehicle is required to pre-deploy a contingency ascent vehicle on the lunar surface, a study trading possible ascent and descent vehicle PMFs was conducted to determine vehicle performance and sizing.

Initial feasibility studies supported the idea of a two-stage lander with a descent element (DE) delivering our contingency ascent element (AE) to the lunar South Pole.

Currently assumed performance		
Element	PMF	Mass (t)
AE	0.8	4.5
DE	0.85	10.5

$$PMF = \frac{m_{propellant}}{m_{gross} - m_{payload}}.$$



Future Work

What's next?

- Performing a parametric vehicle design derived from the Pre-Phase A design studies.
- Performing a cost assessment on the preliminary vehicle design.
- Assessing contingency vehicle feasibility from a programmatic standpoint.
- Exploring possibility of long-term program and mission use such as a lunar hopper.
- Performing a systems requirements vs vehicle mass impact tradeoff on the primary ascent vehicle vs a lower requirement vehicle and a contingency ascent vehicle.

Questions?